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CANADA
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GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

Summary Report, 1921, Part E

IRON-BEARING ROCKS OF BELCHER ISLANDS, HUDSON BAY

BY

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OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1922

No. 1944

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CHAPTER I

INTRODUCTION

Purpose and Character of the Report

This report presents information obtained from an examination of a Precambrian "iron-formation" occurring on Belcher islands, Hudson bay. The field work was done during the summer of 1921 in an interval of about four weeks, too short a period of time to permit of investigating more than the eastern part of the islands. The first part of the report contains an account of the general geology of the islands together with a detailed description of the iron-formation and has been prepared for readers familiar with the principles of geology. The concluding section of the report reals with the possible economic value of the iron-bearing horizon and is written in the hope that the discussion may be serviceable to readers interested in iron ore occurrences but perhaps unversed in geology.

Location and Area

Belcher islands lie off the eastern coast of Hudson bay, 70 miles due north of cape Jones, which marks the division between Hudson bay and James bay. Their southern extremity is 55 miles west-northwest of the mouth of Great Whale river, the nearest locality on the mainland. The island group is 70 miles long, north and south, and about 45 miles broad, but much of the area is occupied by water. The chief islands are separated by broad seaways and are either narrow, or where broader, are deeply penetrated by bays and inlets. A large part of the main island of the group is occupied by a lake reputed to be 40 miles long.

Transportation

Belcher islands may be reached in winter over the ice or in summer by boat. The Hudson's Bay Company and Revillon Frères maintain power-driven vessels on James bay. These boats make one or more trips a year from Moose Factory north along the east coast of Hudson bay, but normally these vessels are not available for transportation to the islands. Small sailing craft may be hired or purchased from these fur-trading companies, but it is questionable if crews to man them could be procured on James or Hudson bay. At present, 1921, two small decked-in power boats belonging to the Belcher's Islands Iron Mines, Limited, are the only other available craft known to the writer. Boats of size and sea-going qualities sufficient for the trip to the islands can be taken with little trouble to James bay from the Canadian Government railway crossing of the Pagwachuan branch of Albany river. Advantage should be taken of highwater conditions in the spring of the year; when there is for a short time ample water from the railway to the bay for the transport, without portages, of small cruising power boats. From the mouth of Albany river, the usual route is across James bay via Charlton island and northerly along the east coast to the north end of Long island, north of cape Jones. From there a course about

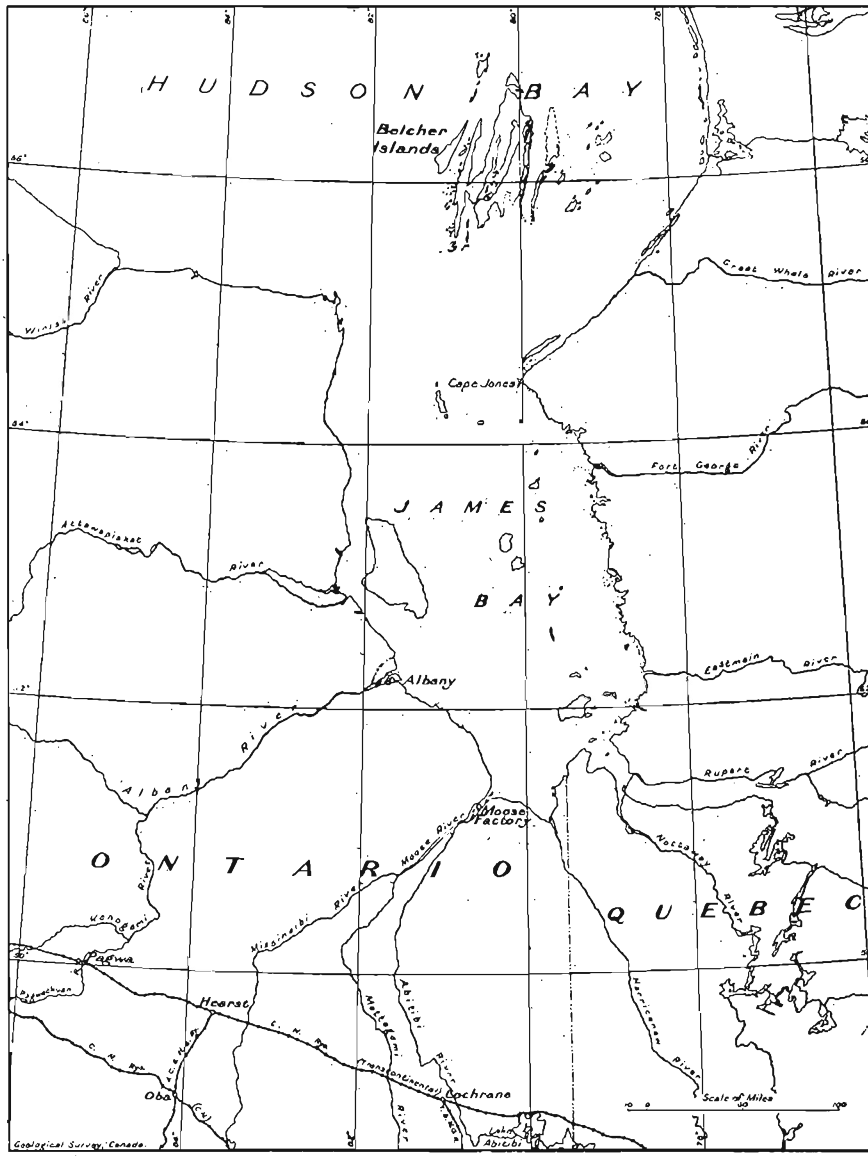

Figure 1. Index map showing location of Belcher islands, Hudson bay.

20 degrees west of true north will reach the southeast part of the islands. The period of navigation for small craft varies from season to season. As a general rule, about the middle of June is reasonably early for starting from Albany river. The return trip may be made in October or a little later.

Navigation to and from Belcher islands by large ocean-going vessels should not be attended with any great difficulty if the uncharted region north and northeast of the islands is avoided. The approach in other directions is free of islands or shoals. At many places on the islands secure harbours for the largest vessels are available and, should mining operations ever be carried out, docking facilities reasonably close to the mines could be provided without much difficulty. On the other hand a careful charting of the seaways seems to be a preliminary and imperative necessity, since in several of the sounds isolated reefs were noted barely awash at low tide, and the clusters of small islands bordering the main group suggest that shoal reefs may be present there also.

Previous Accounts

Belcher islands have long been known to form the southernmost group of a chain of islands lying off the east coast of Hudson bay and extending northwards for several hundred miles. Though inhabited by Eskimos, who each winter cross the ice to trade at the Hudson's Bay Company's posts, and although about the middle of the last century an official of this company visited the islands, yet in spite of these facts the position, extent, and general character of Belcher islands were until recently conjectural. Modern maps represented them as formless clusters of dots. In 1914, 1915, and 1916 the islands were visited by R. J. Flaherty, then engaged in exploratory work on behalf of Sir William Mackenzie, and in 1918 Flaherty published a map and an account of the islands in which he drew attention to the possible value of the iron-bearing strata.[1]

E. S. Moore, in 1916, visited the islands in the interests of Sir William Mackenzie and later published several accounts dealing with the general geology and the nature and possible economic value of the iron-formation.[2] Mr. Moore has described the islands as being formed of a thick assemblage of sedimentary strata, intruded by diabase sills, resting on a mass of basalt and diabase and capped by flows of basalt. He named the sedimentary group the Belcher series and concluded that it is of Precambrian age. It was found to be folded into long, broad, pitching anticlines and synclines. The uppermost member of the sedimentary series, which he named the Keepalloo (Kipalu) formation, was determined to be an iron-formation, with a variable thickness of several hundred feet, that everywhere lies immediately beneath the basalt flows. This iron-formation "consists of jasper, chert, hematite, magnetite, siderite, and green granules regarded as the iron silicate, greenalite" and Moore suggested that "algæ and iron bacteria have been responsible for the precipitation of colloidal silica, hematite, and iron silicate in . . . granular form, in some places as a direct precipitate . . . in others as a replacement of . . . calcite granules by the iron compounds."

Regarding the possible economic importance of the iron-formation, he wrote that "the wide distribution of the iron-formation and its location on hillsides and on the flanks of synclines combine to produce conditions so favourable for the concentration of ore-bodies that it is surprising that important bodies do not occur . . . The greater part of the formation is, however, very lean siliceous material . . . [and] while there are bands of low-grade ore in the iron-formation the great bulk . . . is lean and siliceous . . . [and]

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[1]Flaherty, R. J., "The Belcher Islands of Hudson Bay; Their Discovery and Exploration," Geog. Review, vol. 5, No. 6, pp. 433-458, 1918.

[2]Moore, E. S., "The Iron-formation on Belcher Islands, Hudson Bay, with Special Reference to Its Origin and Its Associated Algal Limestone," Jour. of Geol., vol. 26, pp. 412-438, 1918.

"Iron-formation on Belcher Islands, Hudson Bay, with Special Reference to Its Origin and Its Associated Algal Limestone," Bull. of the Geol. Soc. of Am., vol. 29, p. 90 (abstract only), 1918.

"Iron Deposits on the Belcher Islands, Hudson Bay," Monthly Bull. of the Can. Min. Inst., No. 82, Feb., 1919, pp. 196-206, 1919.

"Ore Deposits of Arctic Canada," Eng. and Min. Jour., vol. 110, pp. 396-400, 1920.

along the strike these bands of ore finger out into the jasper." Mr. Moore has distinctly stated that considering the character of the iron-formation and the climatic conditions and geographical position of the islands, the iron-formation is not of present economic value.

Other parties than those represented by Messrs. Flaherty and Moore became interested in the possibilities of the iron-formation. Expeditions were sent to the region, and the staking of claims commenced in the year 1916. As a result of these operations, twenty-two claims have been located and leases for them granted under the provisions of the regulations governing iron-ore locations in territories subject to the direct jurisdiction of the Federal Government. Twenty of the claims are of square outline, each enclosing approximately 160 acres. Two claims are each less than 25 acres in extent. These claims are controlled by the Belcher's Islands Iron Mines, Limited, Toronto. This company has twice sent engineers to the islands to report on the value of their claims. One of these, Mr. Dwight E. Woodbridge, has expressed the view that "extensive areas were found in the formation where there had been sufficient concentration of ore to present faces up to 25 feet in thickness of an average iron content of better than 52 per cent natural iron. . . But not enough commercial ore was disclosed by my examination to permit a recommendation that the development of mines, the construction of ships, docks, and a railway were warranted without further and considerable definite knowledge . . . [although] it was reasonably safe to assume the actual presence of commercial ore in mineable thicknesses up to a tonnage not far from a million tons."[1] Mr. Woodbridge has stated as his opinion that the existence of commercial tonnages of iron ore depended on, firstly, whether structural and other conditions were such as to permit of ore-bodies forming if the necessary solvents could act, and, secondly, whether the iron-bearing rocks now covered by diabase sheets were ever "exposed to atmospheric action for a sufficient period to permit . . . concentration to proceed adequately to make ore." He gave reasons for his belief, firstly, that structural conditions were such as to favour the concentration of the iron in ore-bodies, and, secondly, that the overlying lavas were much younger than the iron-formation and, therefore, that the iron-bearing strata had remained uncovered for a long period during which conditions favoured concentration of the iron content.

General Character of Belcher Islands

The general outline and size of the Belcher group are indicated in Figure 2. This sketch, compiled by members of the various private expeditions sent to the islands, is sufficiently accurate for general purposes, although it is erroneous in many respects both as regards major and minor features. Shapes and relative dimensions are all subject to revision. Many smaller islands and other minor features are not indicated and, on the other hand, major features shown in the sketch may be non-existent or wrongly located.

From the east side of Belcher islands, a number of islands are visible, some quite small, others several miles in length, and it is reported that if a course is followed eastward from the northern part of the islands to the mainland, land is in sight at all times. A number of small islands lie along the south and west sides of the Belcher group, but to seaward beyond these, both to the south and west, is open water free of islands. Northward, at varying intervals, groups of islands extend for several hundred miles.

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[1]Woodbridge, D. E., "Iron-ore Deposits on Belcher Islands," Eng. and Min. Jour., vol. 112, pp. 251-254, 1921.

The islands of the Belcher group are in general elongated north and south. Their outline and relief are, in the main, directly dependent upon the geological structure and character of the strata. The measures lie in broad folds that strike north and south. Erosion has been most vigorous along the arches of these folds, where it has removed a once continuous cover of basaltic sheets and produced long depressions that form long arms of the sea or valleys. One of these is partly occupied by the 40-mile long lake on Flaherty island. The limbs of the folds, still capped by the basalt sheets, form long, steep-sided ridges. The

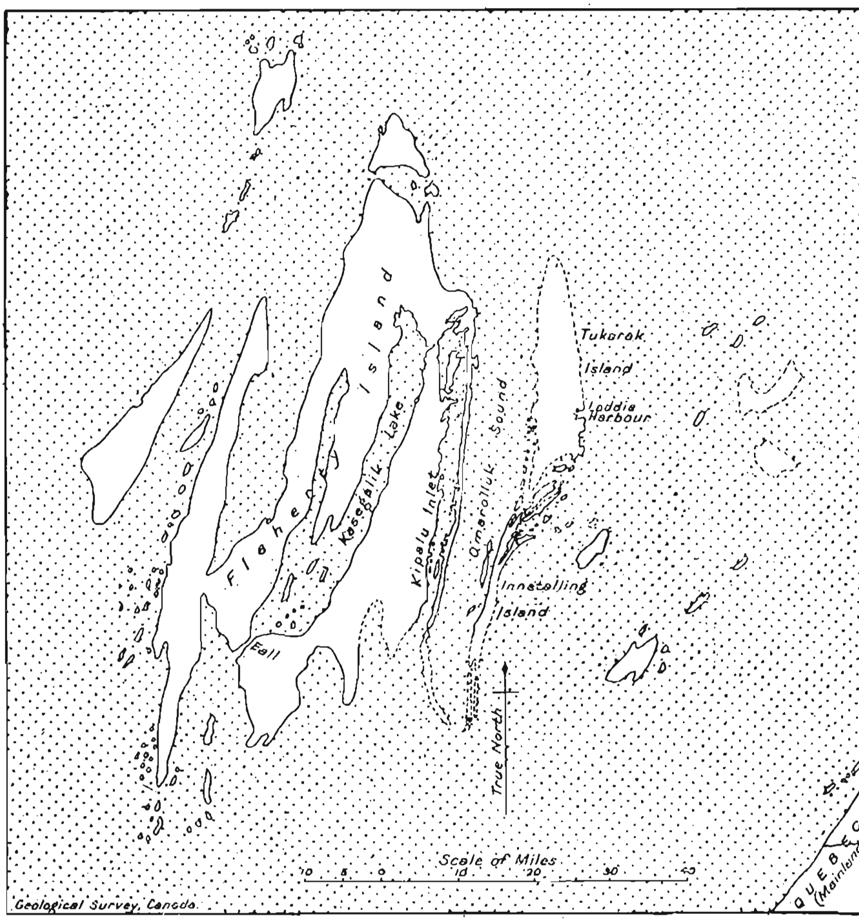

Figure 2. Sketch map of Belcher islands, Hudson bay.

synclinal portions, still preserving the capping of diabase, either underlie sounds or form steep-sided, broken uplands. There is a general southerly dip of the strata which has resulted in a gradual decline from north to south in the heights of the elevated portions which probably nowhere reach 400 feet above sea-level and in general are less than 300 feet high.

The main low-lying areas are variable in character, because of variations in the geological structure and the character of the bedrock, the local presence of diabase sills, and, along the anticlinal axes, the existence of large bodies of diabase. Thus the valleys show nearly level areas where the strata underneath are approximately horizontal; or long, rolling ridges corresponding to gentle folds in the measures; or occasional abruptly rising hills due to structural features or to the presence of a protective covering of locally developed sills of diabase; and, lastly, broader, more irregular ridges formed of diabase masses occurring along the anticlinal axes. Occasional comparatively narrow valleys cross the main ridges and join one major low-lying area with another. These cross-valleys are prominent local features which may be in part due to glacial action.

The main upland areas formed of the capping diabase sheets rise steeply, and in places precipitously. On top their surface is in general level but broken by step-like rises and drops from the surface of one sheet to another. They are almost bare of soil. Talus material occurs along the steeper slopes; the lower part of these slopes, the sides of the minor ridges and hills, and the floors of the depressions are mostly largely mantled with moss-covered sandy deposits. The islands are bare of trees. Alders grow only in open clumps of small, stunted individuals and the plant life in general is sub-arctic in character.

The physical features of the main islands lying east of Omarolluk sound (Figure 2) follow a simple general plan. These islands are traversed from north to south by an anticlinal axis whose course is marked by a low-lying area. In the south the continuation of the anticlinal axis is marked by a channel between two long, slender islands tipped by islets. Each island is composed of sheets of diabase dipping away from the intervening channel and rising steeply from the sea to a comparatively level top whose general elevation increases northward. This same structure is continued northward on Innetalling island, but there the anticlinal portion soon emerges from the sea and forms a long valley a half mile or less broad, but widening at the north end. The floor of the valley where it is narrow is heavily drift covered. Northward where the valley broadens, its character is more variable and at the north end of the island it is partly occupied by abruptly rising rocky ridges. The continuous, bounding diabase ridges are only from a quarter of a mile to somewhat over one mile wide.

The above general structure continues northward into Tukarak island, but there the western diabase wall is confined to a line of fringing islands which extend northward for a few miles only. On the east side, the comparatively narrow diabase ridge continues, so far as known, for the whole length of the island, but is broken through by several cross-depressions, two of which are bays of the sea. West of the eastern diabase ridge rises a second but lower line of broken ridges bounded on the west by a rolling area in part swampy and only a few feet above sea-level. Still farther west, in the south of the island, a long, broad ridge marks the position of a large body of diabase disposed along the anticlinal axis. The western side of this ridge slopes gradually seaward to the low shores which are there bordered by the already-mentioned line of islands that represent the partly submerged, northern part of the west diabase ridge.

Omarolluk sound, lying west of the above-described island group, is presumably a synclinal area doubtless floored by the diabase sheets which reappear on the west side and there form a peninsula about 40 miles long and for the most part less than half a mile wide. This peninsula, a part of Flaherty island, is continued southward by a long, narrow, low island which trends to the east of south so as partly to cut off Omarolluk sound on the south.

The above-mentioned peninsula and the island continuing it to the south separate Omarolluk sound from Kipalu inlet, lying to the west. Kipalu inlet lies along an anticlinal axis; it is about 50 miles long by 2 to 3 miles broad, open at the south end but closed at the north by a narrow strip of land forming part of the northeast coast of Flaherty island. On both sides rise steep-sided ridges that gradually increase in elevation from south to north. These ridges are formed of diabase sheets that dip away on either side from the water, with here and there small promontories and islands of the underlying strata. The ridges are broken, are crossed at infrequent intervals by low, narrow valleys, and at the north end nearly coalesce so as almost to encircle the inlet. Towards the north, the diabase ridges are bordered by more continuous low-lying areas and there, towards the centre of the inlet, ridges of diabase rise as islands along the axial portions.

The ridge bordering Kipalu inlet on the west marks the position of a syncline, and the diabase sheets composing this upland are for the most part approximately flat lying. The summit of the ridge is broken by minor depressions, though tending to be flat. The width varies from half a mile or less to 5 or 6 miles in the north, where it forms part of the northeast coast of Flaherty island.

West of this synclinal ridge lies the valley of Kasegalik lake. The lake stands about 25 feet above sea-level and is reputed to be 40 miles long and in places 5 to 10 miles broad. The valley in which it lies continues northward beyond the head of the lake to a bay on the north shore of Flaherty island. This general valley marks an anticline. Its eastern side is formed by the steeply rising edges of the diabase ridges separating the lake from Kipalu inlet. On the west, the country, as viewed from a distance, rises in a series of long, broad ridges which perhaps occupy the western part of Flaherty island.

CHAPTER II

GENERAL GEOLOGY

General Statement

The strata of the eastern part of Belcher islands are a series of little altered sedimentary rocks capped by sheet-like bodies of diabase; in places, appearing to rest on a basic igneous mass and at various horizons they are cut by sills and dykes of diabase. All these rocks are presumably Precambrian. The sediments are undoubtedly of the same age as those forming the islands which intermittently fringe the east coast of Hudson bay from cape Jones north to Portland promontory, a distance in a straight line of 300 miles. These sediments may be equivalent to the Animikie of the Lake Superior region.

The strata are disposed in broad, parallel folds running north and south. In the east an anticlinal axis extends through the line of islands that commences in the north with Tukarak, a relatively large island, and ends with the small islands 65 miles to the south. Omarolluk sound, which separates this group of islands from Flaherty island, the main island to the west, marks a synclinal axis. Kipalu inlet, west of this, lies along an anticlinal axis whose eastern limb forms a long, narrow peninsula and the long island south of it which, combined, divide the inlet from Omarolluk sound. The ridge bordering Kipalu inlet on the west is part of a synclinal form and the basin of Kasegalik lake, still farther west, marks the position of a succeeding anticline. Very little information regarding the western part of the islands is available, but what is known confirms the assumption that the same general structures and measures continue over that district.

Stratigraphical Section

A geological section across the east limb of the anticline on Tukarak island was carefully measured along a general line about 6 miles long extending westerly from a point south of Laddie harbour. The measurements commenced at the top of the sedimentary series, continued to its base, and were made by running a stadia traverse and carefully observing variations in angle of dip. The strata are for the most part well exposed along the line of section and in general dip eastward at angles which, commencing in the east, diminish from 35 degrees to 12 degrees and then, towards the west, increase to 25 degrees. Structural complexities encountered on the line of section, and the constantly varying angle of dip, detract from the value to be attached to the calculated thickness, but it is confidently believed that the thicknesses assigned to the different horizons are relatively correct and that the total calculated thickness is not far from the actual thickness. E. S. Moore[1] measured a section, presumably in the same general vicinity, and found the sediments to be 9,079 feet thick. The total found by the writer is less than this, as is indicated in the following summary statement in which the horizons are arranged in descending order.

	Feet
Diabase sheets	
1. Iron-formation	365
2. Quartzites with zones of siliceous limestone	1,747
3. Shales and slates, mainly red	723
4. Limestones, variously coloured	2,686
5. Quartzites, with subordinate amounts of limestone and shale	1,646
6. Slates and sandy or tuffaceous beds, etc.	705
Diabase mass	
Total sediments	7,872

[1]Moore, E. S., "The Iron-formation on Belcher Islands," Jour. of Geol., vol. 26, pp. 412-438. 1918.

The division of the sedimentary series into six members is arbitrary save in the case of the iron-formation, which alone is sharply divided from the underlying strata. Each of the other members grades upwards into the succeeding division by interbedding or by gradual changes in lithological characters. No evidence was found anywhere of a break in the sequence; all the strata appear to belong to one continuous series, for which Moore has proposed the name Belcher series.

Description of Strata

LOWER DIABASE

The lowest member of the general geological section is a mass of diabase prominently displayed towards the west side of Tukarak island. It outcrops there with in places a width of over a mile and extends from the south shore of the islands for perhaps 10 miles northward. This igneous assemblage occurs along the axis of the major anticline of this part of the islands. It is flanked on both sides by the Belcher series which, because of the northward pitch of the fold, passes over and around the northern termination of the igneous body. Southward from Tukarak island, the main fold pitches in the opposite direction, i.e., to the south, and the basic, igneous group is not represented in that direction.

Along the course of the next major anticlinal to the west, towards the head of Kipalu inlet, there is a large island which is chiefly occupied by diabasic rocks bordered on the east side by lower members of the Belcher series. The igneous mass and the sediments thus appear to possess the same mutual relations as on Tukarak island, but in both places the exposures near the contact are poor and it, therefore, may not be affirmed that the igneous rock is older than the overlying sediments. Moore found the same difficulty in attempting to decide upon the relative age of this igneous mass.[1]

The diabase mass on Tukarak island, so far as seen, is composed of rather fine-grained rocks, not sheared nor otherwise materially altered. They do not, apparently, possess ellipsoidal structures nor is there clear evidence of a sheeted form. Approaching the horizon arbitrarily chosen as the top of this member, the rock becomes somewhat finer in grain, and at several exposures is amygdaloidal. The diabase on the large island in Kipalu inlet is coarser grained and is characterized by small irregular areas and streaks that are paler, more coarsely crystalline, and more largely formed of feldspar. Prominent partings in the rock mass divide it into layers 10, 15, and more feet in thickness, and seem to conform in attitude with the structure of the bordering sediments. North of this island, a smaller mass of similar rock occurs along the course of the same anticlinal axis and in this case the sheeted appearance is even more prominent and regular, and certain zones are characterized by well-developed ellipsoidal structure such as is commonly supposed to be characteristic of flows.

DIVISION No. 6

On Tukarak island, near the line of section, the strata immediately succeeding the diabase mass are very poorly exposed and the lowest division, No. 6 of the measured section, outcrops at only three horizons in a total thickness of 705 feet. The lowest horizon is just above the base of the sedimentary series and is composed of dark, dull reddish, well-bedded argillites and impure limestones. The argillites are faintly banded. They are interleaved with the limestone and also occur within it as thin, discontinuous layers and fragment-like,

[1] Op. cit., p. 418.

small bodies arranged parallel with one another. The limestone shows, generally, a greenish tinge irregularly developed, is of medium grain, semi-crystalline, and carries numerous round quartz grains.

About 160 feet higher in the series are exposures of diabase grading into amygdaloidal diabase and overlain by a dark grey, faintly greenish, fine-grained, compact rock of very uniform character, though faintly showing a banding marked by variations in shades of colour. At the outcrop of the third and uppermost horizon the beds are dark red argillites banded in various tones. These lie 180 feet below the base of the next succeeding division, No. 5.

Division No. 5

Division No. 5 has a thickness of 1,646 feet and is fairly well exposed along the line of section. The stratum chosen as the base of this division is a purplish red limestone, finely crystalline and traversed by layers and streaks of deeper red, dense argillite. About 10 feet of the limestone is exposed. It is succeeded upwards after a short, exposureless interval, by compact, purple or red argillites, which are interbedded with other rocks. As the series is ascended, the argillites gradually decrease in volume until they are represented by only occasional zones 5 or 10 feet thick.

The greater part of the strata in this 1,600-foot interval are quartzitic. They vary rapidly in texture from bed to bed and alternate with very fine-grained beds which are presumably composed largely of quartz but in many cases have a general resemblance to argillites. The coarser types occasionally hold quartz grains as large as an eighth of an inch across. The beds are a dark greenish grey on fresh surfaces changing to pale grey or pale yellowish on weathered faces. The distinctly sandy types are mainly of small, close-set, glassy quartz grains and the individual beds mostly lack signs of bedding. The finer-grained, almost dense varieties in some cases are massive also, but in other instances they show regularly alternating lines and thin layers of different shades of green and grey. Occasional beds of pale grey, rusty-weathering carbonate occur with the quartzitic measures in the lower part of the division. These are much more abundant in the upper 500 feet, where also the siliceous beds are as a rule paler than below, in some cases pinkish or cream coloured, and in some instances carrying a considerable amount of carbonate.

The carbonate beds occur most abundantly in the upper part of the division and vary in colour from very pale grey to dark grey. They seem to range from nearly pure carbonate to highly siliceous phases. All are very fine grained, usually almost dense. The purer varieties are finely crystalline and on weathered surfaces have a pronounced yellow or deep cream colour. For the most part the carbonate rocks effervesce feebly and are presumably magnesian and in part, perhaps, iron-rich. On weathered surfaces some of them show very fine, regular banding, whereas others are very rough, deeply and irregularly recessed, apparently because of the presence of thin, discontinuous layers of less resistant materials.

Division No. 4

The carbonate beds in the upper part of Division No. 5 mark a transition to the strata of Division No. 4, which through a thickness of 2,686 feet are largely carbonates. The lower beds of the division weather brownish yellow and very pale yellow; but fresh surfaces vary from pale to dark grey and appear dense or very fine grained. Occasional layers are pink, white faintly tinged pink, or nearly pure white on fresh surfaces. There are some shaly beds towards the base of the division, whose weathered surfaces are frequently a deeper brown and yellow. The individual carbonate beds vary from 1 to 10 feet in thickness and often are banded. The varying shades and tints change from layer to layer, though successive zones are largely of one general colour. Such beds continue through a thickness of 950 feet, though near the top there appear a few beds of pink carbonate and several thinly banded grey and greenish zones, with streaks, dashes, and lines of nearly black chert marking the bedding planes in several layers. These beds, nearly 1,000 feet thick, have been referred to as carbonates rather than limestones, since the brownish weathering so characteristic of most of them and the further fact that most if not all these rocks do not effervesce very freely in cold acid, indicate they are not pure limestones but, possibly, magnesium-iron-carbonates.

Many layers in the 950 feet of strata above described, especially in the upper part, contain forms to which Moore has directed attention and which he regarded as being due to algæ.[1] These bodies tend to show elliptical cross-sections which in the simpler forms exposed by weathering are marked by an outer, relatively broad, raised zone of closely crowded, concentric but discontinuous dark lines. The central part of the form is usually depressed and frequently free of any prominent signs of structure. On fresh fractures, the structure is no longer represented by concentric lines but by a difference in colour or texture of the whole form. Commonly the material of the form and of the containing rock is carbonate. Occasionally the form is represented by dark chert and then the concentric onion-like structure of the whole is clearly apparent. These bodies are usually close-set, but not touching one another. Their outlines are spheroidal but irregular. In some cases two or more individuals are enclosed by an outer mesh to produce one composite form. In individual beds there is a tendency for the forms to be of one general size and this in different beds ranges from an inch or less to above a foot in diameter. A tendency for the forms to be abundant in one bed and absent from a succeeding bed is characteristic.

Overlying the above measures occurs nearly 1,000 feet of purplish and pinkish weathering limestone, presumably magnesian, pale and dark pink on fresh surfaces. The limestone is finely crystalline and is traversed by thin bands and fragmentary layers of deeper red colour, very dense, apparently argillaceous. This argillaceous material stands out in relief on weathered surfaces and frequently is so disposed as to give an irregular, mesh-like structure.

The remaining overlying 600 feet of Division No. 4 consists of limestones, presumably magnesian, white to dark grey when fresh, but generally weathering in varying tints of yellow to brown. Occasional zones are deep red on the surface and pale pink where unweathered. The rocks are banded, the bands varying in width from almost paper thin up to several inches or even feet. The alternating layers differ in colour and texture and owing to their varying powers of resistance, alternate layers are frequently recessed. In places the banding is very regular, in others the more resistant layers are fragmentary or so irregular in shape and distribution as to form a mesh-like structure.

The strata of Division No. 4 occupy much of Tukarak island and form a wide band extending northward, probably through the whole length of the island. They form the islands between Tukarak and Innetalling islands and are present on the north shore of Innetalling island, but owing to the southward pitch of the anticline that brings them to the surface, they disappear southward on this island beneath the succeeding formations. The strata of this division are broadly exposed on the large island in the north part of Kipalu inlet, already referred to as situated on the course of the next major anticline to the west. Equivalent strata are exposed on the west side of Kasegalik lake; they extend

[1] Op. cit., pp. 420-429.

northward for a considerable but unknown distance and here again outcrop along the course of a major anticline.

Division No. 3

Overlying the calcareous rocks of Division No. 4 are 723 feet of slates with irregular streaks and small lenses of pale weathering limestone distributed through a few feet at the base. The bulk of the strata are red slates with narrow, pale grey layers, in places closely spaced, in others widely separated. The red slates are in part rich in carbonate. Towards the top, the red strata are interbanded with green or with zones of dark grey which themselves in some cases are finely and regularly banded. The upper part of the division consists of dull greenish and reddish slates with thin interbeds of yellowish weathering quartzitic sandstones.

This slaty division extends southward along the east limb of the anticline on Tukarak island, and occurs on islands to the south and on the north shore of Innetalling island, where by reason of the southward pitch of the anticline the horizon disappears beneath succeeding members of the geological series. The red slates with the underlying and overlying divisions doubtless continue northward on the west limb of the anticline and apparently partly occupy a series of islands that fringe the west shore of Tukarak island.

The red slates outcrop on the east limb of the next main anticline to the west in Kipalu inlet. There they are confined mainly to a limited area on the mainland, since for most of their extent they lie beneath the sea. The same horizon is presumably again repeated on the anticline of the valley of Kasegalik lake, but that district is heavily drift covered and void of exposures in the parts where the strata might be expected to occur.

Division No. 2

The strata of Division No. 2, for a thickness of 500 feet above the interbanded red and green slates, are largely quartzites and dull greenish slates. The quartzites vary from pale coloured rocks which are fine, even-grained aggregates of rounded quartz grains, to dark coloured, nearly black varieties in which the minute quartz grains are scattered irregularly through an argillaceous base or in which the quartz is aggregated in thin layers that alternate with equally thin argillaceous layers.

Above this lower horizon the strata for a thickness of over 700 feet consist of two thick zones of siliceous limestone separated by a relatively narrow zone of quartzites. The calcareous rocks mostly weather with a yellow or brownish tinge, sometimes faint, sometimes very deep. Rarely the rocks are pinkish. On fresh surfaces the strata vary from white to dark grey. In composition they range from nearly pure, finely crystalline carbonates, to quartzites with an abundant carbonate matrix. The finer-grained varieties frequently present a narrow banding due to variations from layer to layer in the proportions of the siliceous matter.

Above this calcareous horizon, the rest of the division for a thickness of 450 feet to the base of the iron-formation consists of quartzites with occasional thin layers of very siliceous limestones. The quartzites on fresh surfaces vary in colour from nearly white to dark grey. On weathered surfaces they are mostly yellow or pink, apparently as the result of the decomposition of a carbonate which is invariably present, though usually in very small amounts. Some zones are darker and finer grained than the bulk of the strata, but, save for the carbonate, the rocks seem almost entirely composed of minute, rounded, close-set clastic quartz grains. Slight variations in the size of the grains characterize different layers. In general the rocks are massive and the individual zones structureless, but at various horizons bedding is very apparent, especially in the case of the darker-coloured varieties.

The above-described quartzitic division with its interbedded carbonate zone, everywhere directly underlies the iron-formation. The upper, nearly pure quartzitic member always has much the same general character and thickness, but the number and thicknesses of the calcareous bands in the lower part of the division appear to vary from place to place, although remaining fairly constant over considerable areas.

This division outcrops on the east side of Tukarak island, striking north and south, and doubtless also occurs on the west side of the island on the west limb of the anticline. The strata of this horizon extend southward into Innetalling island, outcropping in the central valley southward to where this valley narrows and becomes floored with drift. On both sides of Kipalu inlet, on the opposing limbs of the next anticline to the west, the quartzitic horizon is exposed at intervals on projecting points, and on islands, and in the north it outcrops nearly continuously for 8 miles. In all probability the quartzite occurs along the next anticline to the west, in Kasegalik Lake valley, but the parts of this district seen, and in which the quartzite might be expected to occur, are drift covered without rock outcrops.

Division No. 1 "Iron-formation"

The "iron-formation," or "Keepalloo" formation as Moore named it, abruptly succeeds the underlying quartzite. The strata of the two divisions are not interbedded, nor are any gradational or intermediate forms present. The iron-formation along the general line of section has a thickness of 365 feet, is a bedded formation, and at certain horizons at least, carries some undoubted clastic material. It varies in thickness somewhat from district to district and is variable in its general characters, though the order of succession is, in its broad outlines, everywhere much the same. A full description of the iron-formation and its distribution is given in the succeeding chapters.

Effusives

The top of the iron-formation wherever seen is followed by a thick sill of diabase. Above this sill in most places is a layer a few feet thick of black, carbonaceous shales, that is presumably a part of the iron-formation separated from the main body by the intervening sill. Above occur sheets of diabase, presumably flows, which form the uppermost strata exposed on the islands. These effusives, so far as seen, are of dark, fine-grained diabase or basalt, not amygdaloidal but generally with an ellipsoidal structure for the most part so well developed that vertical faces of the basalt usually appear as if composed of closely set, spheroidal forms of widely varying sizes. In various instances, however, the lower part of a sheet here and there lacks the ellipsoidal structure. In such cases, in vertical sections, the non-ellipsoidal portion was seen to extend from the base upwards to varying heights and to merge laterally and vertically into the ellipsoidal mass. The basalt, presumably of effusive origin, apparently occurs in a series of flows of varying thickness, in some places resting directly on one another, in other places parted by thin layers of dark shale or limestone. In one section at least twelve sheets of basalt are present in a thickness of 200 feet. These basalt sheets form the summit of the stratigraphical column and their upper limit is an erosion surface representing an unknown, destroyed thickness. Their original volume may have been much greater than the greatest thickness seen, namely 200 feet.

The effusives and the immediately underlying sill now outcrop over much of the eastern part of the islands. They occur along the east side of Tukarak island and on a series of narrow islands fringing the west shore. They continue southward as narrow ridges on both sides of Innetalling island and form all the islands south of this. The effusives occupy the greater part of the long peninsula and the long island south of it that separate Omarolluk sound from Kipalu inlet. The same rocks form nearly the whole of the ridge separating Kipalu inlet from the valley of Kasegalik lake and extending northward to the northeast shore of Flaherty island. How extensively the basalt may be developed over the western part of the islands is unknown, but since diabase is reported to form the southern shores of that part of the island group, it is probable that the effusives are largely developed, though northward it is probable that the underlying strata outcrop.

INTRUSIVES

As already stated the main part of the iron-formation is, so far as known, everywhere directly succeeded by a sheet-like body of diabase. This is variable in thickness, perhaps ranging between 50 feet and 100 feet. The rock is a normal, olivine-free diabase, of medium, even grain save at its upper and lower surfaces where it is fine grained. The sheet is characterized by partings giving a columnar structure. Ellipsoidal, vesicular, and flow structures were nowhere seen. The lower contact in general conforms to the bedding planes of the underlying iron-formation, but in detail this apparent conformity is found to be fictitious. The contact plane locally rises and falls. In places it sinks 20 feet or more in an horizontal distance of 100 feet and occasionally the plane of contact truncates the dark slaty rocks of the underlying iron-formation. In several instances tongue-like projections of the sheet were seen following bedding planes in the iron-formation, splitting off layers several hundred yards long and a few feet thick.

At its top, this universal sheet is either followed by a few feet of dark, argillaceous shales separating the diabase from the overlying ellipsoidal basalt, or else the effusive basalt rests directly on the diabase sheet. The overlying thin, shaly parting though not continuous is very persistent and—as along the east side of Kipalu inlet—may be seen to extend for miles with scarcely a break.

The crosscutting character of the lower boundary of the diabase sheet, its columnar habit, and the lack of vesicular, ellipsoidal, or other structures characteristic of surface flows indicate that the rock mass is a sill which has intruded the strata at or just beneath the base of the basalt flows. Other diabase sills, but none comparable with this in extent, occur in the iron-formation and underlying members of the Belcher series. Thick sills measuring 50 feet or more, as well as much thinner ones, were seen in the iron-formation on Tukarak and Innetalling islands. Examples of sills in lower members of the Belcher series were seen on Tukarak island, along the shores of Kipalu inlet, and at the head of Kasegalik lake.

The sills which occur below the top of the iron-formation, unlike the uppermost sill, appear at different horizons in different sections and none were seen more than a few miles long while most of them extend for only a few hundred yards. Some are, as mentioned, 50 feet thick, or more; others are less than 15 feet thick. Each sill tends to occur at a constant horizon throughout its length, but possibly, as noted in various instances, the sills may in most cases pass from one horizon to another either very gradually or in a series of small, abrupt, step-like jumps. Local complexities in the structure of the containing strata, such as abrupt reversals in the direction of the dip, small corrugations, etc., were noted in various places in the immediate vicinity of the sills, and perhaps some casual connexion exists between these structural features and the intrusion of the sills.

Besides the sills there are less regular-shaped bodies of diabase. On the west side of Kipalu inlet for example there is in the iron-formation, close to the water's edge, a vertical body of diabase that outcrops at intervals for several hundred yards. In part its boundaries are quite irregular, the mass thinning and thickening and sending out tongue-like extensions along the strike. It is possible this mass is located along a fault plane, for the bordering rocks are in part locally disturbed.

As already stated, it is not impossible that the large bodies of diabase situated on the anticlinal axes that respectively traverse Tukarak island and Kipalu inlet, are intrusives. If they are, they may be of the same general age as the widely occurring sills.

Geological Structure

The geological structure of the eastern part of Belcher islands is that of a series of broad folds trending approximately north and south, whose positions are indicated by the major physical features of the island group. In the east an anticlinal axis passes from north to south through Tukarak, Innetalling, and the islands beyond. On Tukarak island the anticline plunges to the north. To the south of Tukarak island it plunges gently southward so that gradually all but the effusive rocks sink below sea-level. In the south, the axial part of the fold is represented only by a long, narrow seaway between two slender islands of effusive rocks which dip gently away from the intervening channel.

Omarolluk sound, bounding the above islands on the west, is presumably a synclinal basin. Its western limb appears on the long peninsula of the east side of Flaherty island and the long island continuing this peninsula southward. Towards the south, the islands bounding Omarolluk sound converge and thus seem to indicate that the main synclinal form plunges northward.

West of the Omarolluk Sound syncline, an anticline traverses Kipalu inlet. This anticlinal axis from a point near the head of the inlet plunges—like that south of Tukarak island—gently southward; northward, the plunge is in the opposite direction, is more marked, and the effusive rocks at the top of the stratigraphical column close in and almost encircle the head of the inlet.

A third major anticline traverses Kasegalik Lake valley, the synclinal form between this and the Kipalu Inlet anticline being represented by the intervening ridge of effusives. The general structure of the western anticline and of the western part of the islands is unknown but in all probability, is the same as in the east, and possibly ends with a syncline traversing the outermost main island.

The strata of the major folds are affected everywhere by minor folds of the nature of open domes and basins elongated parallel to the courses of the main folds. Locally the strata exhibit still smaller folds, in some cases descending in size to open corrugations measuring a few feet or yards from crest to crest.

The measures appear to be singularly free from faulting. A major fault or zone of faulting may follow the axis of the anticline of Kipalu inlet, for the space at the head of the inlet now occupied either by drift or water seems almost too limited to permit the strata to bend round from the east and west limb of the anticline without rupture. Some evidence of an east-west fault is afforded by exposures in the narrow valley which extends westward from near the head of Kipalu inlet to a bay on Kasegalik lake. At this locality, along the north side of the largely drift-covered valley floor, are several exposures of corrugated and highly disturbed strata. These may mark a fault zone, but if they do, the net differential movement must be small, judging from the relative positions of the strata north and south of this limited zone of disturbance. As already stated, local irregularities—in some instances very pronounced in character—occur near some of the diabase intrusions. These irregularities do not extend far from the igneous body.

Consequent upon the geological structures affecting the strata, the various horizons outcrop in bands running north and south and gradually sinking in both directions beneath sea-level. Along their courses the bands locally rise and fall through the operation of the minor folds. For the same reason the outcrops of the bands that traverse relatively level districts may follow curving courses or be repeated in closed forms to one side of the main band. In general, the strata in the axial areas have comparatively low angles of dip, whereas on the limbs of the folds high angles of dip up to vertical are common.

Correlation

The upper part of the Belcher series, as has been pointed out by Moore,[1] is almost certainly the equivalent of the upper part of a group of strata that occur at intervals on the islands bordering the east coast of Hudson bay from cape Jones north to Portland promontory and in places, as around Richmond gulf, outcrop on the mainland itself. The strata in question have been named by Leith,[2] the Nastapoka group. To an underlying series, the same author has given the name Richmond group[3] since he supposed the lower group was unconformable beneath the upper. Low[4] has given many details regarding these groups of strata which he believed formed one conformable assemblage whose middle member is that which Leith called Nastapoka. In the following table are given in descending order, condensed statements of various sections as measured by Low, together with two sections measured by the present writer, one on Long island, and one on Belcher islands. In the table, the sections are arranged in order from north to south:

No. 1, north end of Long island, north of cape Jones on east coast Hudson bay.
No. 2, Manitounik islands, 55 miles northeast of Long island.
No. 3, Little Whale river, 85 miles north of Manitounik section.
No. 4, Richmond gulf, south shore of, 12 miles north of Little Whale river.
No. 5, Richmond gulf, south shore of, east of above.
No. 6, Belanger island, opposite Richmond gulf.
No. 7, Belcher islands.

Thicknesses in Feet

Locality No.	1	2	3	4	5	6	7
Iron-formation	340	82	....	....	....	255	365
Quartzites, etc	60	778	118	145	239	294	1,147
Slates	....	....	....	....	....	....	723
Limestones	150	....	334	168	230	70	2,686
Quartzites (mainly)	....	....	150	....	....	....	1,646
Slates, etc	....	....	....	....	....	....	705
Limestones	....	....	210	....	....	....	....
(Unconformity)							
Arkose	....	....	175	....	....	....	....

[1]Op. cit., p. 415.

[2]Leith, C. K., "An Algonkian Basin in Hudson Bay—A Comparison with the Lake Superior Basin," Econ. Geol., vol. 5, pp. 227-246, 1910.

[3]"*Richmond Group*". Since a division of the Ordovician has long been known by this name, it is here suggested that the Precambrian formation in question might be renamed, the Richmond Gulf group.

[4]Low, A. P., "Report on an Exploration of the East Coast of Hudson Bay, etc., etc.," Geol. Surv., Can., Pub. No. 778, 1902.

"Report on the Geology and Physical Character of the Nastapoka Islands, Hudson Bay," Geol. Surv., Can., Pub. No. 819, 1903.

In the case of Section No. 3, at Little Whale river, the arkose at the base belongs to Leith's Richmond group which, according to Low, is 2,000 feet or more thick in some sections on Richmond gulf. The overlying strata of section 3 and their equivalents in the other sections, together with the iron-formation, constitute the Nastapoka group. The variations from section to section, in the thicknesses of the different members, are in part due to the fact that, except in the case of section No. 7, the lowermost members are not accessible for measurement and the same condition holds with respect to the uppermost members of some of the sections. There is, however, a real variation in thickness from place to place and, in the case of the section on Belcher islands, the members below the iron-formation are much thicker than elsewhere. The validity of the correlation of at least the upper part of the Belcher series with the Nastapoka group rests on the general similarity of the rock succession, on the geological structure which indicates that the strata have all passed through a common history since their formation, and on the lithological characters of the individual members. The equivalence of the lower part of the Belcher series with the lower part of the Nastapoka group as developed at Little Whale river (section No. 3) is open to doubt. It may be that the lower 5,000 feet of strata on Belcher islands represent some part of the time interval indicated by the unconformity at the base of the Nastapoka series, or it may even be that sedimentation in the Belcher Islands district was continuous from Richmond Gulf group time into and through Nastapoka time.

As regards the correlation of the Nastapoka series and, therefore, also of the Belcher series, with the formations of the Lake Superior region, it does not yet seem possible to add anything of value to the statement of Leith, namely, . . . "while, therefore, a satisfactory correlation, in the nature of the case, is impossible, one familiar with Lake Superior geology is tempted to regard the Nastapoka series as of Animikean age."[1]

[1]Op. cit., p. 245.

CHAPTER III

THE IRON-FORMATION

The iron-formation is the uppermost sedimentary member of the Belcher series and everywhere rests on a thick quartzite member from which it is sharply divided. Upwards it is bounded by a series of basaltic flows, but for convenience the upper limit is taken as being marked by the base of a thick diabase sill intruded along, or very close to, the contact of the basaltic flows and the underlying iron-formation. The sediments and overlying flows lie in a series of parallel long folds the arches of which have been partly eroded. The iron-formation, once continuous over the whole district, is now confined to certain areas where it is largely concealed by the overlying volcanic rocks. It appears at the surface only along the edges of these areas in long, narrow bands outcropping on the sides or at the foot of steep slopes surmounted by the diabase sill and the basaltic rocks.

The position, extent, and attitude of the various bands of the iron-formation are detailed in Chapter IV. The outcropping bands form four areas, which in order from west to east may be named: (1) the Kasegalik Lake area, (2) the Kipalu Inlet area, (3) the Innetalling Island area, and (4) the Tukarak Island area.

Stratigraphical Succession and Character

KASEGALIK LAKE AREA

The Kasegalik Lake area is situated in the northeast part of Flaherty island. It includes the southern part, 5 miles long, of a band of the iron-formation that outcrops along or close to the east shore of the lake; a second band 2 miles long that outcrops 1½ miles to the east along the west shore of the head of Kipalu inlet; and finally a third band-like area extending east and west along the sides of a cross valley and connecting the first-mentioned two bands. These several band-like outcrops occur, respectively, along the west and east sides and across the middle of the flat synclinal form lying between the anticlines of Kipalu inlet and Kasegalik lake.

In this area the whole thickness of the iron-formation is nowhere exposed. The lower part on the Kipalu Inlet side lies below sea-level, and on the Kasegalik Lake side, it is everywhere drift covered. The greatest exposed thickness is 220 feet. This represents, presumably, not more than the upper two-thirds of the formation, for in the other areas the total thickness ranges from 320 feet to more than 400 feet. The strata are divisible into two members and the division is so clearly indicated at many places, and is so persistent as to justify assuming that it marks a natural plane of division occurring throughout the area at a single definite horizon, although, from place to place, the overlying strata vary somewhat in thickness. For convenience in describing the strata, the measures below and above this dividing plane will be referred to, respectively, as the Lower Division and the Upper Division.

Lower Division

The Lower Division, on the Kipalu Inlet side, is exposed to a depth of 100 feet below its summit; on the Kasegalik Lake side only the upper 50 feet anywhere outcrop. The lowermost 50 feet of strata from the lowest exposed beds up to an horizon 50 feet below the summit of the Lower Division are fine-grained, in part dense rocks that break readily along slate-like partings spaced parallel to the bedding at intervals of several inches or less. The strata for the most part weather dark, dull red or brownish red. On fresh fractures they are a pronounced red, brownish red, or purplish red, with interbedded dark grey and black layers forming zones 1 to 7 feet thick. At the top and bottom of the dark-coloured zones, the dark grey or black and the red strata are thinly interbedded and, usually, if not always, each of the dark-coloured layers grades quickly upwards into the succeeding reddish layer.

The individual dark layers vary in thickness from several inches to much less. They are for the most part unbanded and very dense, but some show distinct bedding indicated by lines and very narrow bands of black and different shades of grey. Many of the dark grey layers weather brownish, but the black beds do not change colour on weathering. Cold acid causes no perceptible effervescence, but frequently the beds on weathered surfaces are minutely pitted along narrow zones, presumably because of the removal of a carbonate. The rocks resist a knife or are scratched with difficulty. The harder varieties have a splintery or semi-conchoidal fracture. One specimen examined in thin section under the microscope was found to be composed of very fine-grained material so turbid as to appear dark grey by transmitted light and in part, at least, seemingly aggregated in faintly indicated oval areas varying widely in size but averaging about 0·25 mm. in diameter. In addition there appear minute, wisp-like black opaque streaks, perhaps of magnetite, arranged roughly parallel with one another and with the longer axes of the vaguely discernible oval areas, giving a foliated or bedded appearance which is further emphasized by variations from band to band in the density of the turbidity of the general section. The material composing the ovoid bodies is exceedingly fine grained and not determinable, but was judged to be largely silica and carbonate.

An example of the softer varieties of the dark rocks, examined in thin section, appeared as a very finely granular mass of a somewhat turbid carbonate. The carbonate varies somewhat in coarseness from layer to layer and is abundantly accompanied by minute shreds of a green—in part yellowish-green—mineral, these shreds being more plentiful in occasional very thin layers than elsewhere. A very few minute, perhaps clastic, grains of quartz are also present. The green mineral may possibly be an iron-bearing compound analogous to greenalite in composition. The carbonate is presumably ferruginous also, a sample of the rock assaying 13·2 per cent metallic iron.

The more abundant red rocks form layers, some of which are unbanded, but most of which show a very distinct banding due to minute variations in texture and colour in bands varying in width from several inches to a small fraction of an inch. The adjoining layers grade into one another. Some of the red layers are dense, moderately soft, and look argillaceous, but most have a granular aspect, though so fine that the individual grains are not discernible even with the aid of a powerful lens. None of the more normal red rocks of this part of the section in the Kasegalik Lake area were examined in thin section, but it is presumed that they are of the same general nature as examples from the Lower Division in other areas. These proved to be composed largely of very fine-grained silica or carbonate usually masked by a great abundance of dust-like red and black matter presumably hematite (perhaps hydrous) and magnetite.

In both the red, and the dark grey and black strata are occasional distinctive layers up to an inch in thickness that pinch and swell along the strike or end to reappear, after a short interval, along the same horizon. In some instances, instead of distinct layers, a series of flattened lenticular bodies up to

3 inches in length occur in narrow zones. The material of these irregular layers and lenticular bodies is dark red or purple, has a finely granular texture though the individual grains are not discernible to the unaided eye, and seems responsible for the momentary brisk effervescence frequently producible by applying acid to unweathered surfaces. With a lens, minute red, grey, and black granules are visible. In some instances relatively large cleavage faces up to an eighth of an inch in breadth of a red carbonate may be seen enclosing the minute rounded forms. On weathered surfaces the material is frequently minutely pitted, due, seemingly, to the removal of very finely divided carbonate. Material apparently similar to that of the distinct layers also occurs disseminated through zones sometimes so thin as to appear as lines rather than bands. In the case of the dark strata, this finely divided matter is in places sufficiently abundant to give a reddish tint to the rock.

A thin section of one of these purple layers occurring in the dark grey beds proved to be an aggregate of turbid, reddish stained, rounded grains of carbonate averaging about 0·5 mm. in diameter, accompanied by opaque, red hematite grains of similar outline and size and a few grains of magnetite. The rock is a ferruginous carbonate containing by chemical analysis 12·8 per cent metallic iron. A thin section of one of the very similar-looking layers in the red strata appeared under the microscope as a rather even, fine-grained aggregate of clear carbonate in irregularly oval grains averaging 1 mm. in diameter, of turbid and reddish-stained carbonate, of opaque red material presumably hematite, and of magnetite. Large formless grains of carbonate also compose irregular bands, which are apparently of secondary origin, since they reveal remnants of the rounded outlines of the normal grains. The very abundant hematite also seems to be secondary; it occurs as films surrounding the magnetite grains, and all gradations are present from nearly pure carbonate grains with only a few specks of red to grains completely opaque red. Possibly the carbonate was originally ferruginous, but has since been partly transformed to non-ferruginous carbonate, and the iron oxide has been set free.

In the red and dark grey strata are occasional thin layers, in some instances several inches thick, of very dark, faintly greenish, cherty-looking material having a semi-conchoidal fracture and in a general way resembling some of the harder, dark layers. To the unaided eye, the material appears dense, but with a lens very minute granules are visible, some reddish, others greyish or black and not so clearly distinguishable as the red forms. Minute grains of grey-brown carbonate occur here and there in irregular aggregates. Under the microscope, the rock appears composed of an exceedingly fine-grained, almost cryptocrystalline, colourless base presumably of silica, crowded with very small, ovoid bodies, averaging 0·5 mm. in diameter. A few of these bodies are of magnetite or of a green mineral, perhaps greenalite. Most of them are of silica so fine grained as to appear almost dense, and they vary from such as are clear and colourless, save for a turbid, yellowish margin, to others wholly yellowish or faintly greenish, somewhat turbid looking, and appearing red stained in reflected light. Many green, shred or lath-like bodies are present, perhaps of greenalite, and many similarly shaped individuals are opaque and are red in reflected light. Carbonate is present in single formless grains and aggregates of the same and seems younger than the other constituents and probably is of secondary origin.

On the Kipalu Inlet side strata such as form the lower 50 feet of the section continue upwards, but in a thickness of about 10 feet their general character gradually changes to that of a second phase 40 feet thick that continues to the summit of the Lower Division. On the Kasegalik Lake side this second phase is 50 feet thick and no lower strata are there exposed. In the upper phase the strata are more massive and lack the easy, slate-like parting. The bulk of the measures are conspicuously banded, have a finely granular texture, and are very ferruginous, containing much magnetite as well as hematite, and assaying at various horizons for thicknesses of 10 to 15 feet, 35 per cent to 45 per cent metallic iron. The general colour is red, in places very dark because of the abundance of magnetite. Black or faintly greenish black zones several feet in thickness occur at diffierent horizons in different sections. The true black layers are largely composed of finely granular and crystalline magnetite which gives the rock a faint sheen. The faintly green beds are poorer in magnetite. The assemblage is also characterized by a great abundance of the cherty-looking material previously described as occurring very sparingly in the underlying beds. In places this cherty-looking rock occupies as much as 20 per cent of the section.

The general colour of the upper phase of the Lower Division is, as stated, a deep red verging on purple. Beds up to several inches in thickness have a uniform colour, but these alternate with others as thick which are characterized by dark, very narrow streaks spaced at varying intervals or so grouped as to resemble a single, nearly black layer. Examined with a lens, the red layers are seen to be formed of close-set, minute grains mostly red, but in many cases black and then composed of magnetite. The same structure holds in the case of the dark-coloured streaks and bands, but in them the black magnetite grains predominate.

Other beds which occur with those just described are purple, more compact, less granular in appearance, have an irregular fracture in some cases verging on conchoidal in character, and possess a slightly vitreous lustre. Such rocks, when closely examined with a lens, are seen also to be composed of red, grey, and black grains. Other beds, which form layers in some cases several feet thick, are very dark and faintly lustrous from the great abundance of magnetite which in some examples occurs very largely in minute octahedra. Occasional thin layers are of a brighter red than the average, are very fine grained, and have an argillaceous appearance. Some layers are very dark, slightly greenish, carry abundant grains of magnetite, but lack the reddish and grey grains.

The finely granular, banded red and purple beds when examined in thin section under the microscope present evidence of having once been composed of minute bodies closely set in a matrix. In every instance two general types of bodies are indicated, one hereafter referred to as being granules, tending to have rounded or elliptical outlines and the other to have elongated, lath-like or more irregular shred-like shapes.

The granules in some thin sections are predominantly of silica, in some cases microcrystalline, in other slides cryptocrystalline. In some cases, these granules are irregular mixtures of finely granular silica and minute specks of a brilliantly polarizing mineral which, possibly, is calcite. In one instance the colourless granules were almost wholly calcite. The colourless granules contain in varying proportions in different sections, and in different bands in a single section, opaque, dust-like material. In some cases, this mineral is red by reflected light and considered to be hematite; in other cases it is black by reflected light and either dull or with a metallic lustre, and is presumably magnetite.

In every section may be observed what appear to be all gradations from a clear, colourless granule to a perfectly opaque one, either red, dull black, or black with a metallic lustre. This phenomenon apparently indicates that the granules have been subjected to a process of replacement by iron oxide.

The elongated, frequently shred-like forms are in part composed of a green mineral whose colour varies from grass green through yellowish green to greenish yellow or brown, one tint of colour being usually characteristic of each section, as though the variations in colour might be of secondary origin. The mineral also forms rounded or plate-like individuals. These show no pleochroism or absorption of colour, but the elongated forms usually do, though frequently only faintly so. No decided cleavage is apparent, but the elongated individuals in some cases vaguely show a parting or appear as though bent. Between crossed nicols the mineral in some cases shows low interference colours, in other cases colours of a high order. The mineral is presumably greenalite or some analogous ferrous silicate. In many cases it forms a small part of the otherwise colourless granules and in such instances seems present as minute specks or as a mere film.

In different thin sections, as in the case of the rounded granules, all gradations may be observed from a homogeneous individual of the green mineral to one that is perfectly opaque and either red or black by reflected light. Presumably the green mineral also has been subjected to a process of replacement by iron oxides.

In some instances the unaltered and variously replaced granules and individuals of green mineral are set in a colourless ground of silica, either finely granular or showing radiating and sheaf-like structures. In most cases the ground is composed of magnetite or of magnetite and hematite. The hematite when sparingly present is irregularly disposed; when abundant it occurs in minute, elongated patches. In the base of iron oxide are also clearly visible, by reason of a difference in texture, etc., rounded or oval bodies of magnetite and more irregular forms of lustreless black, iron oxide, presumably representing replacements of the green mineral. Much of this formless ground may represent replaced granules, but some part, at least, is a replacement of the matrix in which the granules once were set.

Banding is indicated in all thin sections by variations in proportions of the different constituents, by, in nearly every case, a parallelism of the elongated green forms, and, less generally, by a parallelism of the longer axes of the colourless granules. The granules show much variation in size not only from section to section but within individual sections. Occasional individuals are four or more times larger than the next average size, and in each section many are considerably smaller than the average. This average size varies from section to section between 1 mm. and 3 mm. in diameter. The outlines of the forms are variable, but in general tend to be round or elliptical and are never angular.

An example of the red, dense, argillaceous-looking rock which forms occasional thin beds, when examined in thin section, proved to be solidly opaque, and composed chiefly of hematite, but with considerable magnetite in dust-like particles and small grains. The hematite has a streaked look and appears as though it might be in small aggregates, some oval in outline, but the bulk quite irregular in shape.

The more compact, less distinctly granular beds that have a faintly vitreous lustre were found when examined microscopically to have a colourless base of silica. In one instance this appeared as a fine-grained mosaic of quartz in part distinctly arranged in granular layers about rather widely spaced granules. These are small, of rather even size, and tend to be elliptical in outline. A majority of them show some magnetite and many are solid magnetite or magnetite with a partial narrow rim of hematite. Others contain near their centre a minute grain or two of quartz, or a small centrally disposed area of comparatively coarse, quartz mosaic. Gradations occur to forms in which magnetite composes only a border or partial border around a quartz mosaic, and some granules are almost entirely of silica either comparatively coarse or so dense as to appear structureless. In some granules there are a few shreds of a grass green or a yellowish, micaceous looking mineral and some granules are almost entirely of such material.

Another example of one of these dark bands still denser and more siliceous looking than the preceding, when examined in thin section, was found to consist largely of silica varying in grain from microcrystalline to very finely granular, the different textures being so disposed as to faintly indicate the presence of small close-set granules for the most part oval in outline. Through the section abundant magnetite occurs in formless, small grains and dust-like particles lacking any special structural features. The green mineral is also abundantly present in small shapeless grains and larger aggregates of the same. Calcite is common in small and larger grains and aggregates of the same and some of the individuals have rhombohedral outlines.

Examples of dark, nearly black rock varieties so rich in magnetite as to have a distinct lustre, in thin section appeared composed in about equal amounts of magnetite and the undetermined green mineral which presents elongated forms seldom ragged, lying parallel to one another. The magnetite for the most part is in formless aggregates of apparently both irregular and crystalline grains, the latter presenting rectangular boundaries to the adjoining areas of green mineral. A small amount of carbonate is present and a few granules of cryptocrystalline silica.

In a thin section of another example the rock proved to have the same general mineralogical composition, but the individuals of the green mineral do not show any common orientation and the relative proportions of magnetite and the green mineral vary from place to place in the thin section. A thin section of a magnetite-rich, dark variety having a faint purplish tinge was found to be composed of a continuous matrix of magnetite with small vague areas and stainings of hematite. This matrix holds isolated granules and what appeared like remnants of granules of the green mineral; also dull black, opaque, shred-like patches which are presumably magnetite pseudomorphs after the green mineral. A thin section of a nearly black, faintly greenish type not so rich in magnetite as commonly was the case, proved to be largely composed of the green mineral holding much magnetite in formless grains and small granular aggregates, and a few elliptical granules of calcite.

In the upper part of the Lower Division and occurring upwards in increasing amount are irregular layers and thin zones of dense, dark, faintly greenish, or reddish, or reddish mottled green, chert-like looking material such as has been described as occurring at wide intervals in the lower beds. In the uppermost horizons, this chert-like material is very abundant; in places it composes 20 per cent of the section. The material has a semi-vitreous lustre, a semi-conchoidal fracture, and, unless it is very closely examined, appears dense and structureless. Examined with a lens, it may be seen to be composed of minute granules, mainly red but with many of grey and black shades. In some instances the individual grains are close set, in others more widely dispersed through a dense matrix. A thin section of a purple mottled type, under the microscope was seen to be composed predominantly of very fine-grained silica. The silica varies slightly in grain from one small area to another, making it apparent that the rock is essentially composed of close-set granules of such material. Opaque, dust-like material, in places black, in others red, frequently outlines the granules or occurs in varying amounts within the granules. In some instances small granules or elongated forms were seen to be composed solely of the opaque matter which undoubtedly is both magnetite and hematite. A small amount of the usual green mineral is present in very small individuals and larger shreds. Some turbid carbonate also occurs in aggregates of irregular outlines.

In the zone extending downwards for some 30 feet from the top of the Lower Horizon, this "cherty" material, though always conspicuous, varies in amount from section to section. The locally decreased amounts may in part be compensated by an increase in material intermediate in character between the chert-like matter and the normal ferruginous strata, but this point was not determined. The boundaries of the "cherty" layers appear sharp, but close inspection shows that at top and bottom they grade into the adjacent strata. Along the strike a layer may be continuous for many yards or only for a few feet. Frequently the layers are not continuous, but consist of a series of elongated lens-shaped bodies appearing along a definite horizon or within a narrow zone. In various instances a relatively thick layer may be seen to give way to a number of separate irregular bodies lying in material like the normal strata, but so disposed as to appear like remnants of a former extension of the solid layer. The boundaries of the smaller masses of chert-like material appear in sections as smooth curves, but the masses are frequently embayed and of fantastic outlines. In some instances centrally disposed portions of the masses are of the same composition as the surrounding strata. It is noticeable where this chert-like material is most abundant that the partings marking the bedding in the enclosing ferruginous strata are arched, hummocked, curved, and otherwise confusedly irregular in their mode of development.

Upper Division

The strata of the Upper Division of the iron-formation are well exposed in many places along Kipalu inlet. The upper portions are also exposed on the sides of the cross valley and the bay on Kasegalik lake. On the slopes facing Kasegalik lake to the north and south of the bay, the strata are not so well exposed, but outcrops are sufficiently numerous to show that the Upper Division everywhere possesses the same general characters and is divisible into three members.

The lowest member abruptly succeeds the ferruginous strata at the top of the Lower Division, and has a thickness of 50 feet. At the base, for several feet in thickness, the beds are very dark green and dense of grain. The lowermost layers have close-set, slate-like partings whose surfaces have a faint sheen due to a multitude of minute, shining specks which, under a lens, appear tabular. These beds are moderately soft. The succeeding layers are harder, break with an irregular fracture, and the abundant, glistening, minute scale-like material is no longer oriented parallel to the bedding planes. A thin section of the lower, softer strata showed a bedded rock mainly formed of a very fine-grained, turbid, greenish aggregate carrying innumerable small clastic grains of quartz and feldspar. Different layers vary in the proportions of the clastic material, and some thin layers are clear green, with larger clastic grains and with the green mineral in distinct grains of a grass-green colour. But by far the greater part of the section appeared as a fine-grained, confused, greenish aggregate with many slender, apparently cleaved, green, pleochroic individuals resembling the ordinary green mineral and so arranged as to give a distinctly foliated appearance. Possibly much of the turbid base is a carbonate and many minute clastic grains may enter into its composition. No iron oxides were detected. The upper compact beds, in thin section, resemble the above, but the abundant clastic grains are much larger and are distinctly composed of quartz and orthoclase and plagioclase feldspar. A few grains of magnetite were visible and it is probable that much of the dust-like matter causing the turbidity of the green matrix is magnetite.

Upwards in the rock section the massive dark strata revert to the more slaty form and gradually assume a dark reddish or reddish-purple colour. The minute, shining, scale-like particles are always abundant and, apparently, according as these scales are or are not oriented parallel to one another, the rocks have or have not a slate-like parting. Still higher the rocks assume a pronounced reddish colour with thin, coloured layers marking the bedding. Towards the top, the beds again become a dark, faintly greenish grey; they vary from shaly to slaty to compact, are mostly quite soft, very dense, and look not unlike true argillaceous strata.

The middle member of the Upper Division seems to have a thickness of between 25 and 30 feet, but decreasing rapidly at the north end of the exposures on Kipalu inlet and perhaps there disappearing altogether. On the shore of Kasegalik lake, towards the south end of the outcrops, the strata also seemed to become thinner. This member on the whole weathers greyish with yellowish and brownish tinges and the strata lack regular bedding and are blocky in character.

The lowest part of the member is a compact, dark grey nearly black rock, very fine grained to chert-like in texture. The coarser parts have a granular look, are rough to the touch, and with the aid of a lens may be seen to be composed of rounded forms, mostly dark grey but in some cases red. In thin section, the rock appeared as a mosaic of minute quartz grains of fairly uniform size with close-set, rounded, elliptical and irregularly shaped bodies perhaps averaging 6 mm. in diameter. These bodies are composed in varying proportions of quartz grains like those of the general base, magnetite and the usual green mineral with a small amount of carbonate. In some instances these bodies or granules are distinguishable only through the presence of a narrow rim of the green mineral, with or without magnetite. In other cases these two minerals in varying proportions lie between some or most of the grains of quartz within the granule, and examples show gradations from granules such as these to others composed almost solely of magnetite or, more commonly, of the green mineral with varying amounts of magnetite. On the other hand, there are areas in which the outline of the granule is only partly indicated. The general appearance is that of a rock once formed of close-set granules, of whose original characters perhaps only their shapes are preserved and even these in many cases only partly. A thin section of the lower beds from another locality resembles the above in various ways, but the amount of the green mineral and magnetite is considerably less, and the quartz grains of the granules are much larger than those of the base.

The strata of the middle member above its lowermost layers are finely granular and blackish grey or, in some places, pinkish. Some portions carry much pinkish carbonate in minute grains and granular aggregates. The rock frequently holds much magnetite in minute grains and narrow streaks; lenticular-like layers are dark greyish black due to the local abundance of finely disseminated magnetite. On close inspection, the rock is seen to be composed of close-set pale and dark greenish, black and red grains. The rocks weather a dirty brown, are rough to the touch, and vary considerably in grain in apparently an irregular fashion. Such rocks compose the bulk of this member. In thin sections these are on the whole similar to the rocks just described, but in one instance the abundant magnetite occurs wholly in small polygonal crystal forms, disseminated and grouped in large and small aggregates. In another instance, the green mineral is frequently bounded by hematite, or stained reddish, and the relations so expressed appear to indicate that the hematite was derived from the green mineral. This conception, seemingly, is substantiated in the case of another thin section in which the granules are clearly indicated by the difference in grain of the quartz mosaic composing respectively the granules and the base and are further differentiated by the presence of abundant magnetite and hematite, in some instances the whole granule being iron oxide. No green mineral is present, but the magnetite and hematite are arranged with respect to one another as the magnetite and green mineral are in other sections.

Towards the top of the middle member, the grain of the rocks becomes more variable. Fine-grained, irregular bands or layers occur with others that are much coarser and that in one instance proved to be composed of large granules averaging 8 mm. in diameter. The granules are stained yellowish, composed of coarsely granular quartz, and lie in a relatively fine-grained quartz mosaic.

In the strata of the middle member are occasional layers from a mere film to several inches thick, most of which weather a deep ochreous yellow or brown to depths as great as half an inch, where the weathering abruptly ceases. Such layers are dark greenish grey on fresh surfaces. In general appearance they resemble the main rock body, but in thin section they appear as a structureless, even-grained, granular mass of carbonate, green mineral, and quartz perhaps of clastic origin. Some of these thin layers are dark green and appear dense; when closely examined, however, the material may be seen to be composed of close-set, pale greenish granules separated from one another by very thin, imperfect black rims. In thin section, the rock seemed composed of close-set, uniformly large granules of exceedingly fine-grained silica with varying amounts of a green mineral in minute specks so small as to be almost dust-like. Some of the granules contain scarcely any of the green substance, some are largely composed of it, and others are intermediate in this respect. There are also a few rhombs, some large, of calcite that appear to have developed without regard to the structure of the rock. The matrix in which the granules lie is a quartz mosaic slightly coarser than that of the granules and present in only small amounts, many of the granules touching one another. Other thin layers are compact, dark grey, faintly purplish, siliceous looking, and dense. In thin section one of these proved to be an exceedingly fine-grained aggregate of turbid carbonate and green mineral.

In the upper 3 feet of the middle member occur dark, faintly greenish interbeds which are in part thinly shaly, in part slaty, in part hard massive but argillaceous-like strata. These interbeds are 1 to 3 inches thick. The intervening beds expand and contract in thickness along the strike.

The highest member of the Upper Division appears to vary in thickness between 30 and 60 feet, but for the most part is about 40 feet thick and it may be that everywhere this is approximately the true thickness. It is formed mainly of dark, slaty strata, either faintly green or very dark grey, and for the most part weathers reddish or brownish. The measures are in part thinly bedded, rather soft, in part more compact, and in part, hard, brittle, inclining to be massive. The higher beds show a marked narrow banding in varying shades of dark grey. They are fairly hard and dense, but with indications of a granular texture. Characteristically the brownish or red weathering extends inwards for one-eighth to one-quarter of an inch, ending abruptly along even planes. In thin section one such variety appeared as a dense turbid mass with narrow, opaque, black zones and streaks. Much of the matter is exceedingly fine-grained carbonate but the remainder is too fine grained for closer identification.

In this upper dark member there is usually present one—perhaps in some places several—layers of structureless material such as composes the middle member. A layer from 3 feet to 7 feet in thickness is continuous in the area fronting on the shore of Kipalu inlet and may be the equivalent of layers of the same character seen on the Kasegalik Lake side.

At one place, on the south side of the bay in Kasegalik lake, a 6-inch bed of dense, grey limestone occurs high up on the uppermost member and may be seen to persist along the strike for 100 yards.

KIPALU INLET AREA

On the east side of Kipalu inlet, the iron-formation forms a narrow band that extends nearly due south from the north end of the tidal basin at the head of the inlet, to where the formation sinks below sea-level. Over the whole distance the band maintains a nearly uniform width of about 350 feet and lies on the west slope of the diabase capped ridge beneath which the iron-formation dips. The boundaries of the band for the greater part of the distance are closely defined by outcrops of the overlying dark diabase and of the underlying pale quartzite, but, on the whole, the iron-formation itself is poorly exposed. The total thickness of the formation appears to vary from 320 feet to 360 feet or perhaps even a greater amount.

Southern Section

Towards the south of the 10-mile stretch, the general section seems to be somewhat as follows, though as it is based on correlations of partial sections and isolated outcrops distributed over a length of several miles, the results are subject to revision.

The lowest outcropping strata occur about 40 feet above the base of the formation. They consist of thinly-bedded, red, slaty, dense rocks with dark greyish layers, and closely resemble the already described, lowest exposed rocks on the west side of the inlet. Such beds extend upwards for 26 feet to an horizon 66 feet above the base of the formation. The next 26 feet is composed of a bank of granular rock such as forms the middle member of the Upper Division in the Kasegalik Lake area. In this 26-foot bank, seams and lenses of red, dense, cherty-like material are largely developed. The material is not true chert, but is composed of minute granules set in a dense base and in major characters corresponds with the chert-like matter so largely developed in the upper part of the Lower Division to the west.

From the top of this bank for 160 feet, up to an horizon 252 feet above the base, the strata so far as they are exposed are mainly red but are accompanied by thin, dark grey beds mostly confined to zones of varying thicknesses. All the strata possess slate-like partings. They are very largely dense rocks, banded in different tints, and with layers of different degrees of fineness. The coarser layers have a granular aspect, but the individual grains cannot be detected even with the aid of a lens. A thin section of one of the coarser varieties consists of a base of opaque, dense, red, hematitic material minutely flecked and streaked black. Small oval areas of what appear to be turbid carbonate occur through this base, lying with their longer axes parallel and more numerous in certain minute bands than elsewhere. The arrangement of the granules gives a banded structure which is further emphasized by minute bands holding abundant minute clastic grains of quartz, orthoclase, microcline, and plagioclase feldspar. An occasional oval area of carbonate occurs in these narrow bands rich in clastic material and the clastic grains occur throughout the section. A thin section of a second example of these rocks when examined microscopically showed the same dense, opaque, red base, but the clastic grains are only sparingly present and the carbonate is more abundant.

In these predominantly red beds, in some places if not everywhere, are two horizons, one 185 feet and the other 205 feet above the base of the formation, at which for thicknesses of 10 feet to 20 feet, the strata are highly ferruginous and in general appearance are quite similar to, and apparently almost identical with, the ferruginous strata at the summit of the Lower Division in the Kasegalik Lake area. As in that area the ferruginous beds are interleaved with many thin, irregular layers analogous to the chert-like layers of the western area. Some of the ferruginous beds, for a thickness of several feet, are more purely hematite than is usual and are soft, and friable enough to soil the hands.

The abundant, irregular layers referred to in the above are bright red and in part are comparatively coarse, being composed of rounded and shapeless forms which are red, grey, and black and in some instances an eighth of an inch in length. A thin section of this type showed variously shaped granules of widely varying sizes crowded together, the interspaces being occupied by a finely granular quartz mosaic. Some of the granules are wholly of very finely granular silica, others are similar but have a partial or complete rim of red or black, and frequent examples show all gradations between forms such as these and others wholly stained red, or composed almost entirely of magnetite with a thin border and small, irregular, internal areas of hematite.

The predominantly reddish, fine-grained strata with the several ferruginous zones and, low down, the bank of grey, granular rock, extend upwards from the base of the formation for a thickness of 252 feet. Except that they lack a ferruginous member at the top, these strata correspond in position and characters to the Lower Division of the formation in the Kasegalik area, whose nearest outcrops are 4 miles to the west. They are succeeded upwards by a group of strata corresponding to the Upper Division of the Kasegalik Lake area and, like it, composed of three members. These three members, however, seem to be variable in thickness and in places have a combined thickness of not more than 70 feet.

The lowest of the three is about 25 feet thick in most localities, but in places is, perhaps, much thinner. It is composed of dark, shaly and slaty beds, dark greenish on fresh, unweathered surfaces.

The middle member at one place is 21 feet thick and presumably is everywhere of about this thickness. It is of poorly bedded, irregularly banded, "blocky" strata such as compose the equivalent horizon in the Kasegalik Lake area. The rocks weather yellowish, brownish, and reddish, and are granular and rough to the touch. Fresh surfaces vary from light to dark grey to almost black. Some irregular layers are very largely composed of magnetite, others are red and hematitic. One specimen, in thin section, was found to consist of a mosaic of granular quartz varying in grain irregularly from spot to spot and holding areas of magnetite, irregular in outline, in part frayed or wisp-like. A red staining was slightly developed. No features were noticed indicative of the former presence of the usual granules. A second specimen showed a rock composed of large granules crowded together in a quartz mosaic. The granules were of finer grained silica with varying proportions of magnetite, which in many instances merely outlined the individual granules.

The uppermost member in some places at least is 24 feet thick and is composed of dark, greyish and black, slate-like strata with, in the lower part, some red-weathering layers. The beds for a few feet at the top are very dark, in part thinly banded in different shades of grey, and are hard, splintery, dense, almost chert-like. Other beds are softer, unbanded, and nearly black; they effervesce freely with acid and weather brownish in a sharply defined shallow outer zone. Some of these softer rocks carry small ellipsoidal bodies up to one-half inch in length of dark, dense, chert-like material. In thin section an example of the harder, banded type appeared as an exceedingly fine-grained rock composed mainly of silica but with much carbonate for the most part assembled in small irregular areas. The amount of carbonate varies in such a manner as to cause a marked banding. Occasional small vague areas of the silica seem distinguished by texture from the neighbouring matter, but there was no certain indication of the former presence of granules.

The softer, unbanded rocks as represented by one thin section appeared as a fine-grained, almost dense, turbid mass with tiny frayed and wisp-like areas of black. Both in ordinary light and with crossed nicols, the section seemed to be largely formed of very small, oval aggregates presumably of finely divided silica and carbonate.

Northern Section

Towards the north end of the 10-mile Kipalu Inlet band of iron-formation after a long, for the most part, very imperfectly exposed interval, outcrops become more numerous, but only a partial, imperfect section can be reconstructed. The total thickness of the strata is about 320 feet. The greater part is of red, banded, slaty strata with, as in the south, a band of the grey, compact, blocky rocks in the lower part, but perhaps not everywhere at the same horizon. The upper part, as before, is composed of dark grey and black beds with, in places at least, a layer of the grey, granular rock, thus repeating the threefold division of the Upper Division.

The outcrops of the lower part of the formation consist of relatively soft, almost dense, reddish, in part argillaceous-looking banded strata with some layers less dense almost granular in appearance. In one locality, at horizons between 40 and 85 feet above the base of the formation, are exposures of such beds that weather dark purplish. They are accompanied by thin, nearly black interbeds very dense on fresh surfaces but weathering yellowish and reddish. In these strata are irregular layers 1 to 2 inches thick and still more irregular layers that swell in places to a thickness of 1 foot, of bright red colour and possessing a splintery or semi-conchoidal fracture. The rock in these layers consists of a bright red, dense matrix crowded with elongated, irregular, darker coloured forms varying from minute specks up to others 0·03 inches in length. These forms have mostly minutely wavy irregular outlines and lie with their longer axes parallel with one another. In thin section this rock appeared to be mainly of matter, bright red in reflected light, containing small irregular areas of magnetite and innumerable, elongated, mostly wisp-like areas of colourless, very fine-grained silica. Most of the red material is opaque, but in part was seen to be a red staining on silica.

The thicker layers of the above-described material in many places have a central part that includes irregular bodies of a darker, duller red colour formed chiefly of close-set, grey and black granules of uniform size. In thin section such a rock was seen to be composed of vaguely indicated, comparatively large granules of very fine silica stained reddish and closely packed together in a coarser quartz matrix. A few of the forms are outlined with magnetite. This more definitely granular material also forms homogeneous layers and layers which along the strike grade into the more brilliantly red rock. The relations are such as to suggest that the brighter red variety has been derived from the more normal granule-bearing type.

The banded red strata with the numerous irregular red layers, are succeeded at 85 feet above the base of the formation by a 15-foot bank of the blocky, irregularly banded, granular rock type. It is grey and greenish in colour, weathers reddish and yellowish, and varies irregularly in grain and composition. Many thin, irregular layers of the red "cherty-looking" material are also present. A relatively coarse rock crowded with magnetite octahedra occurs in irregular streaks and bands up to 1 foot in breadth; it has irregular curving boundaries and in many parts holds irregular fragment-like masses of the more normal strata, as if the coarser phases were in some way replacing the finer. In thin sections the coarser type appears as composed of large granules, stained reddish and formed of very fine silica with varying amounts of dust-like or more definitely granular magnetite. The magnetite in some cases is uniformly distributed through the granules or is aggregated towards the centres or about the borders; and there are all gradations to granules of solid magnetite. The matrix is a comparatively coarse mosaic of quartz. Much calcite is present, partly in sharp rhombs, partly in large irregular areas, in both cases appearing to have replaced the other rock constituents.

Upwards in the formation, red strata predominate for over 100 feet. At one or more horizons in this interval the beds are highly ferruginous and resemble those occurring at the summit of the Lower Division in the Kasegalik Lake area. At some horizons in these red strata occur zones of very dark, nearly black rocks in part thinly banded and interleaved with pale films and thin layers of pale grey, fine-grained carbonate. The dark beds have an outer ochreous brown or yellow weathered zone. An example of one of these rocks in thin section was found to be composed of innumerable small, clastic grains of quartz, orthoclase, microcline, and plagioclase lying in a very finely granular base of turbid carbonate and still finer particles of the quartz and feldspars. Large, formless areas of carbonate that appear to be secondary were present. A few small grains and shreds of a pleochroic green mineral were noted. The total thickness of the Lower Division is estimated to be 260 feet, much of which is only poorly exposed or not at all as in the case of the uppermost part.

The Upper Division perhaps not over 60 feet thick is as usual composed chiefly of dark strata, and there is evidence of the existence of a band of the grey, granular, blocky rocks.

INNETALLING ISLAND AREA

At the north end of Innetalling island, 20 miles south of the south end of Kipalu Inlet area, there is a narrow valley which extends southward through the middle of the island. This valley broadens out at its north end and is in part occupied by a bay of the sea at whose head is a tidal lake. The iron-formation outcrops on either side of the valley in two narrow bands, 2 miles apart in the north but converging southward as the valley narrows, so that 3½ miles to the south they are only a quarter of a mile apart. These two bands, representing the opposing limbs of an anticline, outcrop at the foot of, and for varying heights on, the slopes of diabase-capped ridges. Only the upper parts of the iron-formation are exposed in the western band, the lower parts being drift covered or beneath water-level. Even the upper parts are much concealed by drift. In the eastern band, owing to minor folds, the formation rises and falls, so that in places the base lies above sea-level, in other places the top descends beneath the water. Considerable sections are drift covered, but in general the upper parts are well exposed. The total thickness of the formation apparently is at least 450 feet and may be slightly greater. As in the Kasegalik Lake area, the strata are divisible into two groups the lower of which is terminated by a ferruginous horizon, and these groups respectively correspond in general characters to the Lower Division and Upper Division of the before-mentioned western area.

Lower Division

The lowermost beds of the iron-formation are exposed only along the eastern band and at only two localities. They abruptly succeed the underlying pale-coloured quartzites. The quartzite and iron-formation are not interbedded, nor are there any signs of gradation of one type into the other. The lower beds for a thickness of 25 feet are mainly dark purplish red, hard, and fine grained. They vary from dense to finely granular in general appearance, but the individual grains are not distinguishable. The rocks are banded, the banding being expressed by variations in colour and in grain and by the presence of dark greenish-grey layers. The bands in part are thin, varying from the thickness of a film only up to one-half inch; in part they are broad, and include zones several feet in thickness largely of dark grey to black strata. Adjoining layers grade into one another. In thin sections, one example banded red and purple was seen to consist of minute bands all very fine grained, some nearly colourless, others largely opaque and red by reflected light as though largely of hematite. Magnetite in detached minute grains and dust-like forms is about equally abundant throughout. Very small, angular clastic grains of quartz and feldspar (orthoclase, microcline, and plagioclase) occur in all layers but are most abundant in the clear portions, and in the case of some minute layers largely constitute them. The base of the clearer layers is cryptocrystalline. It possibly is silica and apparently the same material occurs throughout. Some layers contain 50 per cent of very finely granular carbonate; other layers are characterized by very small formless grains of a pleochroic green mineral; and some layers, as already stated, are largely opaque red by reflected light. Possibly this opaque mineral is not pure hematite but a dust-like aggregation in the dense base. Calcite in small rhombs occurs in all the layers.

In some localities at least, at an horizon about 30 feet above the base of the iron-formation, there is a 4-foot bed of the granular, unbanded, blocky rock type, of a dark red colour and comparatively coarsely grained. Examined with a lens the rock may be seen to consist of irregular red bodies apparently set in a grey matrix. In a thin section, a part was found to be composed of large granules most of which are partly or wholly turbid and, where turbid, red stained. These are closely set in a fine-grained quartz mosaic and are composed of granular silica, largely very fine grained but in many instances with a coarser-grained central part. Large rhombs of carbonate lie indifferently in both the granules and the matrix, and there are small patches of a strongly pleochroic mineral arranged in radial and sheaf-like aggregates.

A part of the section contains only angular remnants of the granules and of such portions of carbonate rhombs as lie within or project into the granules. The rest of this part of the section is a granular aggregate or mosaic of quartz varying irregularly in grain but always relatively coarse. This part of the section seems undoubtedly to have once possessed the granules of the normal rock and represents vaguely outlined areas that are macroscopically visible in hand specimens. These areas have a cherty appearance, their borders are frayed, and they appear to merge into the normal rock.

In this zone and in the adjoining strata, are thin layers and detached lenses of bright red material, cherty-looking but in reality composed of minute granules in a dense siliceous matrix such as has already been described in other areas. Above this zone, the strata for several feet are dark purple. They have a splintery fracture and are almost dense in grain, but give indications of a granular texture and exhibit many minute grains with a metallic lustre. In thin section the rock appears as a fine-grained aggregate of colourless and opaque grains. The opaque ones are mainly red by reflected light, but many are of magnetite. Occasional larger grains are distinctly oval in outline and the whole appears as a close-set aggregate of granules barely averaging 0·5 mm. in diameter. The colourless granules are largely exceedingly dense and, presumably, composed of silica. In many instances minute green shreds and scales, and dust-like and larger grains of red or black iron oxide are also present. The green mineral also forms elongated individuals. The bulk of the iron oxides gives indications of occurring in rounded areas corresponding in size and outline to the colourless granules, but possibly the iron oxides in part represent what may have been the matrix in which the granules lay.

Upwards the strata become more thinly bedded and in the horizons between 50 feet and 60 feet above the base they are banded in different shades of dark purple and brighter red. The red layers are relatively soft and fine grained and are themselves banded. In thin section, this type was found to be prominently banded, opaque layers alternating with others that appear on the whole to be transparent but are actually heavily charged with dust-like opaque material that gives a dark purplish cast to the whole in reflected light. The relatively transparent bands seemed to be formed of minute, irregular, elongated bodies lying with their longer axes parallel. These bodies or aggregates are possibly exceedingly fine-grained silica. They carry countless minute forms possibly of the green mineral. Occasional larger, clear, oval bodies of the same material characterize some layers. The opaque layers by reflected light seem composed largely of hematite, but with abundant magnetite, the two minerals being in minute, irregular, frayed aggregates with their longer axes parallel to one another and to the banding, thus producing a pattern like that exhibited by the relatively clear bands.

In this zone are thin, bright red, irregular layers of the so-called cherty rock composed of minute ellipsoidal and sharply-rectangular bodies, some 0·03 inches in length, set in a dark, dense base. In thin section, the rock was seen to be composed of rounded, ovoid, and irregular forms of widely varying sizes set in a clear colourless matrix of silica, the silica being both granular and in radiating and sheaf-like aggregates. Most of the granules are opaque or nearly so and in reflected light appear wholly red or red with a partial or complete rim of magnetite and small, irregular spots of magnetite. A few smaller granules are wholly of magnetite. Other examples show all gradations from wholly opaque granules to nearly wholly colourless transparent granules composed of fine-grained silica stained red. Carbonate is present in a few small grains in the matrix and, also, in several areas, as assemblages of larger, plate-like forms that lie indifferently in the matrix and in the granules. In some instances, the carbonate is charged with slender, green rods.

In the red cherty-looking rock are occasional streaks, small lenticular patches, and as noted in one instance, thin layers, of very dense, hard, dark reddish, banded material. This in thin section closely resembles the banded, dense, red types forming the main rock mass. The two rock types, that is, the bright red, somewhat cherty-looking material which occurs in thin discontinuous layers and the ordinary banded measures, apparently grade into one another along their mutual boundaries. In detail these boundaries are minutely irregular with individual granules projecting from one type of rock into the other, and the whole boundary is a series of embayments and finger-like projections of one rock in the other. The individual brightly coloured, relatively coarse layers may extend for yards but always end. The number of such layers, in the general zone, varies from place to place, and individually they range in thickness from ½ to 6 inches.

Still higher in the section, in the zone between 60 and 70 feet above the base, the strata are banded. They are chiefly purple and red, but with some zones of black and with layers of the bright red, granular material with the semi-conchoidal fracture and slightly vitreous aspect. The black layers are very dense; in part they have a shale-like parting, in part they are more massive, very dark grey and dense, though a lens reveals minute, red bodies. The rock has a banded appearance due to the arrangement along parallel planes of lenticular black bodies 0·05 to 0·03 inches long. These show shining faces, and effervesce in acid. This dark rock in thin section was found to be composed of a matrix of magnetite holding close-set, colourless grains often ovoid in outline, mainly of carbonate, but which in one band-like area were of microcrystalline silica. In another band-like area, the magnetite was in great excess. The rounded grains of carbonate in part extinguish simultaneously over large areas as though each grain were part of a larger body.

The associated red strata are banded in shades of dark purple. The alternating bands vary in width from a mere film up to one-quarter of an inch and in part have a striped appearance due to the presence of dark streaks rich in iron oxide. The alternate bands vary in texture from dense to minutely granular and are composed of red granules for the most part just distinguishable with a lens, set in a darker matrix. The rock also carries small glistening faces of carbonate. A specimen of a coarser variety was seen in thin section to be composed largely of iron oxide and transparent granules averaging about 1 mm. in diameter. The granules are of very finely granular silica, mostly red stained, and holding variable amounts of dust-like iron oxide. In parts of the section, the iron oxide, chiefly magnetite, is so abundant that it appears like a matrix holding the colourless grains. In other places, the magnetite grains are more widely spaced and have the size and shape of the granules. A slight amount of green mineral is present in some of the granules.

The red, finely granular, slightly vitreous-looking material present in these red and black-zoned strata forms highly irregular lenses and strips. Some are several feet long, brilliant red, and composed of minute ellipsoidal and occasional sharply rectangular, red granules varying in size up to 0·03 inches and closely set in a dark, dense base that contains carbonate. The borders of some of these layers are banded red and faintly reddish, almost black. The layers have wavy outlines, individual layers swelling, thinning, and terminating. The dark parts seem to be of the same materials as the lighter coloured parts but are much richer in iron oxide. A sample of a red part of one layer examined in thin section was found to be composed of granules, set in a colourless matrix of silica, that in part exhibits radiating and sheaf-like forms. The granules are mainly elliptical and vary greatly in size; most are opaque and wholly red in reflected light or with dust-like grains and aggregates either distributed through the granules or forming a partial rim. Some granules, red stained, are transparent and composed of exceedingly fine-grained silica. Individuals are present affording all gradations between granules wholly dense and others wholly clear save for included dust-like matter. Carbonate occurs in various areas, in rhombs and irregular grains developed without regard to the general structure. One exceptionally large granule was composed of about one hundred small granules set in a granular carbonate matrix.

Red-weathering strata, in part dark grey or black where unweathered and in general resembling the measures of the lower 70 feet, extend upwards in the section. Their total thickness is certainly 125 feet and may be as much as 175 feet, if, as is probable, the iron-formation everywhere in this rather limited area in the north part of Innetalling island has a uniform total thickness of 450 feet. Unfortunately in the few places where the whole iron-formation lies above sea-level and the position of the base is clearly indicated, the middle part of the formation is concealed and it is not possible directly to determine the thickness of the lower member. The highly ferruginous zone at the top of the Lower Horizon is exposed in various parts of the northern sections 180 feet below the top of the formation; it is 200 feet below the top in the southern sections. Assuming that the total thickness of the iron-formation remains constant at about 450 feet and that the top of the ferruginous zone marks everywhere an equivalent horizon, then, as displayed along the outcrop of the western band in the north, the lower, fine-grained, chiefly red strata have a thickness of 175 feet and extend upwards to an horizon 90 feet below the top of the Lower Division. They are there succeeded by a 15-foot zone of strata banded purple and dark reddish, nearly black, which are finely granular and rich in iron oxides. This zone resembles the upper ferruginous horizon, but has a lower content of iron. Above this zone for a thickness of 50 feet, the strata as shown in several sections in the northern part of the western band are chiefly red with layers and zones of dark grey. The red beds are in part ferruginous with occasional beds of a high iron content. These measures in character are intermediate between the overlying ferruginous zone and the denser, less ferruginous beds of the lower part of the formation.

Towards the north end of the west band, a well-defined ferruginous zone commences at an horizon assumed to be about 240 feet above the base and extends upwards for 27 feet to the top of the Lower Division. The strata in this zone are markedly banded and this appearance is emphasized by the presence of much of the red, somewhat cherty-looking material in flattened lenses arranged as though they were portions of disrupted or partly replaced, thin, irregular layers that swelled and pinched in thicknesses from one foot to less than an inch. In places such material is more abundant than in others. On the whole it is estimated to occupy at least 10 per cent of the total volume. The associated ferruginous strata are in part black, being a fine-grained aggregate of minute granules of magnetite and red-coloured material. The individual layers are mainly massive and unbanded. Some are so rich in magnetite that the granules are no longer apparent. Layers are present exhibiting characters ranging from those of the dark, magnetite-rich beds to others which are red, low in magnetite, and very clearly exhibit the granular texture. Zones are present, also, which include layers of very dense, almost argillaceous-looking material, other dark greenish layers, and still others finely granular in texture approximating in character the "blocky" type.

The highly ferruginous zone at the top of the Lower Division is traceable southward along the western band for about 4 miles until it sinks below the waters of the tidal lake, and it is visible at intervals along the course of the eastern band. In places the relations holding between the ferruginous strata and the interrupted, thin, red, irregular, somewhat chert-like layers, seem to indicate that these layers at one time were continuous, but since have been partly replaced. At one exposure what appears originally to have been a 6-inch layer of the red rock is now represented by larger and smaller bodies of various shapes, but so disposed as to clearly define what seems to have been the two bounding planes of a uniformly thick and presumably solid layer. The fragment-like remains of this once continuous layer are now embedded in finely granular ferruginous rock minutely streaked and lined in black. This lining is parallel to the bedding in the main body of the rock, but in the fragmentary layer it conforms to the curving, irregular outlines of the fragments, and where the granular ferruginous matter crosses the band in narrow strip-like areas the lining is parallel to the sides of these strips. Depending on the direction of the strips, it may even follow planes at right angles to the normal bedding planes. Considering that the ferruginous country rock is composed so largely of granules and that these presumably received their outlines when the rocks first formed, it seems probable that the replacement of the red, somewhat vitreous layers, if such a replacement has happened, took place while the strata were still forming and prior to their final consolidation.

Upper Division

Wherever the top of the ferruginous member at the summit of the Lower Division is exposed it is sharply terminated and is succeeded by dark, slaty beds, in part hard and splintery. A few feet up, these become reddish and in some places at least, at an horizon 35 feet above the base there is a zone containing many irregular layers of the red, somewhat chert-like rock and a few beds of the grey, granular, irregularly bedded type.

The slaty strata are succeeded upwards by a band of the grey, granular rock variety. The base of this band was nowhere seen, but its summit is visible in many places at an horizon 90 to 95 feet above the base of the Upper Division. The greatest exposed thickness of this band is 35 feet. The rock composing it is dark grey and varies in grain. The individual grains, when large enough to be distinguished by the aid of a lens, are reddish, grey or black. Occasionally they are rounded, but most seem irregular of outline. Small grains of carbonate are present, the amount varying from spot to spot. There are some very dark irregular streaks and areas due to the abundance of finely granular magnetite. At some localities the mass holds many partings of nearly black, dense, slaty material. In some exposures the whole bank is interleaved with irregular, discontinuous layers, lenses, and streaks of the brilliant red, chert-like material. This red material is composed of small red granules, many with a dark centre of magnetite, closely set in a paler matrix. In thin section, the large, close-set granules were seen to be composed of very finely but distinctly crystalline silica, stained reddish, and, in some cases, with groups of small magnetite grains generally centrally disposed. The granules are turbid, varying in this respect from faintly turbid to almost opaque. The turbidity is apparently the cause of the red colour. The sparsely developed matrix is a rather coarse quartz mosaic.

The relations of this red material to the normal rock are intricate. In general the red layers are sharply outlined, but in places their boundaries are embayed and narrow projections of the red seem at their extremities to be represented by small detached masses, the outermost of which in size are only minute grains. One layer of the red material several inches thick was observed into which the grey, granular rock projected as a narrow, straight, vein-like body an eighth of an inch wide; towards the middle of the red layer this vein expanded into a body of irregular outline, one-half inch in diameter and with numerous red granules throughout. In some parts of the rock mass, the red material instead of forming numerous definite layers is represented only by small, irregular bodies not systematically arranged. The phenomena thus referred to seem to indicate that the red material has suffered replacement by the grey.

The bank of grey, granular rock is succeeded upwards by a zone varying in thickness, in different sections, between 5 feet and 10 feet and consisting of dark, dense strata, in part slaty-like, in part hard and splintery. These beds characteristically weather a dark brown in a sharply defined outer zone. At one locality this weathered zone holds many layers, etc., of the red, somewhat chert-like material and beds of the dark strata are crowded with minute octahedra and specks of magnetite.

The dark horizon is succeeded upwards by 30 feet of the grey, granular rock type not distinctly bedded and holding numerous streaks of rusty and dark brown weathering matter. The main rock is a very dark grey, with a sheen due to the great quantity of minute specks of magnetite. These lie in a finely granular, crystalline ground free from carbonate. The strata are hard, massive, and not distinctly bedded, but parting in irregular layers. An example of this rock in thin section appears as a granular mass of magnetite and quartz. The quartz occurs in interlocking grains, varying in size but perhaps averaging 1 mm. The magnetite is less abundant and the individual grains mostly possess clean-cut crystal boundaries. In addition to these constituents there are large and small felted aggregates of a green mineral in thin plates.

At the locality that shows abundant red, cherty-looking material in the underlying slaty zone, this blocky layer carries much of the same cherty-looking matter and the upper part of the bank has interbedded leaves and thin layers of dark strata resembling that of the next overlying horizon.

The grey granular bank just described is overlain by 20 feet of dense, dark strata. In several localities, the uppermost beds are unbanded and contain a carbonate. They have an outer, weathered, deep brown to almost black zone, whereas the fresh interior is a deep chocolate brown, very fine grained, and full of minute, brightly shining flakes irregularly disposed. Below this layer the strata are of purple, compact rock, in part almost dense, in part with a suggestion of granularity. They are ferruginous and in some cases display tiny specks of magnetite and minute red granules. A specimen of the upper dark beds, in thin section shows specks and small grains, some with crystal boundaries, of magnetite uniformly scattered through a turbid base apparently very largely formed of finely granular carbonate carrying innumerable thin plates of a green mineral. Individuals of this green mineral, according to the direction in which they are cut, appear either as ragged films or acicular forms.

These fine-grained beds are overlain by a band of the grey, granular rock type that forms the uppermost horizon of the iron-formation. It varies in thickness from 25 feet in the north to 50 feet in the south. The rock weathers reddish, but is dark greenish grey on fresh surfaces and is streaked, parted, and recessed by rusty-weathering material which in places perhaps equal in volume the more normal strata. Much of the rock weathers with a pitted surface due to the presence of grains and small aggregates, up to 0·25 inches or more in diameter, of this same rusty-weathering matter. The latter occurs in long strips, in places in bands or highly irregular, elongated lenticular bodies.

The normal rock on fresh surfaces is almost black, flecked with white, and possesses an irregular, semi-conchoidal fracture. With the aid of a lens it is possible to distinguish innumerable pale coloured, faintly greenish granules set in a darker matrix. In thin section the rock appears composed of very fine-grained but distinctly granular silica arranged in a coarse net-work whose meshes are oval, and irregular areas of comparatively coarse, slightly reddish, quartz mosaic containing a few shreds or wisps of green mineral. No iron oxide is visible. Presumably the oval and irregular areas represent large granules. A number of rhombs of calcite with pronounced zonal structure have developed without respect to the general structure of the rock.

The markedly rusty-weathering material, so abundant in the strata, is, on fresh surfaces, pale grey, crystalline, of medium grain, and has a faint vitreous lustre. In thin section it appears as a finely granular, interlocking aggregate of carbonate with occasional small grains of quartz and countless needle-like forms of a mineral resembling sillimanite.

At one locality where, as already noted, the underlying strata are somewhat abnormal and contain much of the red, somewhat chert-like material, the uppermost horizon also shows a development somewhat out of the ordinary. The lower part consists of irregular massive layers of rusty-weathering, very dark greyish rock minutely flecked with white. It is very dense, almost cherty, in appearance and bears grains and irregular aggregates up to one-half inch in diameter of clove-brown, finely crystalline carbonate. In thin section, this rock variety appears composed chiefly of silica, in part very finely granular, in part in small irregular areas, relatively coarse grained. Possibly the finer-grained matter represents large granules whose boundaries are not distinguishable. A small amount of turbid carbonate is present partly in irregular, partly in crystal forms.

The upper part of this stratum is in part of rock like that of the lower part, and in part is denser, duller-looking, and lacks the areas of carbonate.

TUKARAK ISLAND AREA

On Tukarak island the eastern band of the iron-formation is for the most part drift covered, but at two localities outcrops are more numerous and it is evident that the general expression of the formation is different from that of the already described areas.

At one locality, one mile south of Laddie harbour, the formation is 365 feet thick. The lower part, 245 feet thick, is only partly exposed and so far as seen is composed of very fine-grained strata, chiefly banded purple and dark grey or black. Towards the base there are more thinly banded measures of red, green, and dark grey colours and with zones in which are numerous irregular layers of the red, somewhat chert-like material.

These banded rocks are succeeded upwards by about 15 feet of dense, black, slate-like strata with a thin, outer, brown-weathered zone. Above this for 30 feet in the rock section, the dark, dense rocks are interbedded with ferruginous layers which upwards increase in thickness and frequency and finally for a thickness of 10 feet between horizons 290 feet and 300 feet above the base of the formation, the strata are all ferruginous. Above this, through an interval of 65 feet to the top of the iron-formation, the strata are wholly concealed.

The ferruginous rocks are banded dark red, purple, and nearly black. Individual layers are finely granular, not unlike a fine, even-grained sandstone; they are compact, unbanded, and have a sheen due to abundant, minute, scaly particles of brilliant lustre. The variations in colour are largely due to the variations from layer to layer in the amount present of finely granular magnetite. In thin section the rock is seen to be an even-grained aggregate chiefly of clear grains of quartz, orthoclase, microcline, and plagioclase feldspar, and of shapeless aggregates of hematite and magnetite which with a green mineral act as a matrix in which the colourless grains lie embedded. The grains of quartz and feldspar apparently are of clastic origin and are rounded or irregularly rectangular of outline. Most of them have narrow borders of the green mineral which seems to be penetrating the quartz and feldspar grains and in some cases follows cracks across them. A complete series of examples exist, from clear grains having the narrowest of green rims to others composed nearly entirely of the green mineral. It seems reasonably certain that the green mineral has partly replaced the quartz and feldspar.

Six miles north of the above-described locality or 4 miles north of Laddie harbour, the iron-formation is partly exposed and has a thickness of 370 feet. The lowermost strata for a thickness of 35 feet are concealed. Above this for 70 feet to an horizon 105 feet above the base of the formation, the strata possess a marked banding. To near the top of the 70-foot interval the measures occur in thin beds and layers an inch or less thick and variously coloured black, grey, dark and light reddish purple, and green. The strata are all fine grained and slate-like. One variety in thin layers of an eighth of an inch and less is chiefly dark greenish, but partly black and pale grey. The different layers are not continuous, many of them being very short, lens-like. The whole is very fine grained and hard. In thin section the rock is seen to be composed of close-set grains of quartz, orthoclase, microcline, and plagioclase; abundant carbonate in minute grains and larger irregular forms appears to be replacing the quartz and feldspar. In addition there is considerable magnetite and a small amount of green mineral. The rock is banded, the banding being made evident by the concentration of the magnetite along narow zones. The rock is essentially a clastic.

Above these fine-grained banded strata, for a thickness of 10 feet up to an horizon 115 feet above the base of the formation, the strata are almost dense and purple. They include ferruginous layers and also many irregular layers of dark coloured, somewhat cherty-looking material. Above this zone, through a thickness of 15 feet up to the 130-foot horizon, the rock is chiefly of the bright red, chert-like matter which forms irregular layers and lenticular masses as thick as 6 inches. These occur in bright red, dense yet faintly granular, slaty beds containing much hematite.

Upwards in the section for 75 feet to the 205-foot horizon, the strata are very fine grained, banded in various shades of purple, with thin films and bands of grey finely granular material. Along their parting planes the rocks mostly exhibit a faint sheen due to abundant, brightly reflecting, presumably scaly forms.

The reddish, purple and grey-banded strata are overlain by dense, compact, black strata carrying, irregularly arranged, minute scaly forms and weathering to form an outer brown zone. Upwards for nearly 50 feet the strata are poorly exposed, but in this interval there is one exposure of beds of black, faintly purple-tinged rocks which are very dense and moderately soft. They are grey lined in thin zones and have slate-like partings possessing a faint sheen from the abundance of minute scaly forms.

Between horizons 250 feet and 305 feet above the base of the formation, the measures are banded in reddish, purplish, and purplish-grey shades. In the lower part of this 55-foot interval the alternate bands are very narrow and some of these are largely of finely granular, grey material, presumably of clastic grains, forming short overlapping layers. Upwards the grey bands decrease in amount, the rocks gradually assume a more prominent granular appearance, and towards the top many layers are highly ferruginous.

The succeeding strata for a thickness of 35 feet to an horizon 340 feet above the base, so far as they are exposed, are highly ferruginous and largely dark reddish. They have irregular fractures, feel rough, and look minutely granular. Fresh surfaces have a faint sheen. Examined with a lens the rocks have the appearance of a fine, even-grained sandstone. Some of the beds are less ferruginous than others, are banded in lighter colours, and are denser and more argillaceous in general appearance. All the layers or bands vary in thickness along the strike.

A thin section of one of the coarser phases shows the rock to be an aggregate of rounded and irregular grains of quartz, orthoclase, microcline, and plagioclase feldspar, specks and irregular grains of iron oxide, and aggregates of green mineral. The iron oxide appears as a matrix holding the colourless quartz and feldspar individuals, but though the iron oxide in part may play the part of a host, yet by reflected light this material appears in part as rounded aggregates corresponding in shape and size to the colourless grains. There are also examples which show a complete gradation from quartz or feldspar grains encircled with a very narrow rim of hematite to other grain-like forms either solely of hematite or with a small, remnant-like core of quartz or feldspar. Apparently the iron oxide has in part replaced the clastic grains. Magnetite occurs as grains bordered by hematite, but most of the dark oxide occurs dust-like as small specks and small formless grains irregularly distributed through the hematite. The green mineral forms individuals in shape and size like those of quartz and feldspar, but occurs partly in irregular aggregates, and these together with the more regularly outlined forms are either a felted mass or an assemblage of bladed forms.

Above the exposures of ferruginous strata, the rocks are concealed for a thickness of 20 feet up to an horizon 360 feet above the base or 10 feet below the top of the formation, where a thickness of 5 feet of the grey granular type is exposed. Upwards the strata are concealed to the top of the formation. The grey variety in thin section is seen to consist of faintly yellowish, in part turbid granules lying in a clear, quartz mosaic. The clearer granules are composed of finely granular silica, in many cases with a relatively coarse-grained central part. The turbid granules in part owe their turbidity to dust-like magnetite, but mainly to turbid carbonate which in the aggregate is very abundant. The carbonate grains for the most part are small rhombs with an occasional one much larger than usual. Some of the granules are wholly carbonate and the same mineral also occurs in the matrix. A few shreds of green mineral are present.

Origin

CONDITIONS OF DEPOSITION

The iron-formation, as the previous descriptions indicate, is a bedded formation, varying in thickness, so far as known, between 300 feet and 450 feet and exhibiting no evidence of having been subjected to either contact or regional metamorphism. A large part of the formation is composed of dense, red, somewhat slate-like strata made up of very finely granular quartz and carbonate. These constituents are in varying proportions in different beds and bands and are accompanied by a small amount of minute clastic grains of quartz and feldspar. The red colour is due to dust-like hematite frequently so abundant as to obscure the other rock constituents. These dense red types in places grade into finely granular, red, purple, and black, richly ferruginous rocks which in addition to hematite and magnetite are largely composed of finely granular quartz that in part forms the matrix of the rocks and in part forms distinct rounded aggregates or granules. A third rock type is dark grey or black, usually slate-like, banded, and dense. This type commonly carries considerable fine-grained, detrital quartz and feldspar and is composed of ferruginous carbonate and finely divided quartz in various proportions. A fourth rock type, unlike the preceding varieties, is not distinctly bedded nor banded, is grey of colour, finely granular, and composed chiefly of very fine-grained quartz that occurs in minute granules and as a matrix around these forms. A fifth rock type is highly ferruginous, bedded and banded, resembles fine, even-grained sandstones, and is chiefly composed of minute clastic quartz and feldspar grains lying in a base of granular hematite and magnetite. A sixth rock type is greenish, purple or red, possesses a slightly vitreous lustre and a semi-conchoidal fracture. It superficially resembles chert or jasper, but is composed of minute granules, largely of quartz, set in a dense, siliceous matrix. These jaspery and chert-like rocks do not form homogeneous zones, but occur as irregular discontinuous layers in the ferruginous horizons and, in places, in zones of the compact, grey, granule-bearing type.

A striking feature of the formation is its banded or bedded character. The individual bands vary from mere films to essentially homogeneous zones 20 or more feet thick, but the great bulk of the layers range in thickness from a small fraction of an inch to several inches. The individual layers differ from one another in colour and texture and these differences seem to correspond to a still wider range in mineral and, presumably, ultimate composition. Some sixty thin sections were examined under the microscope and the results of this examination seem to indicate that only by a minute examination of the strata layer by layer, could a proper conception be obtained of the number, kinds, and relative proportions of the different rock varieties present. Independent of the exact mineralogical characters of the individual layers, one important general feature was plainly evident by macroscopic examination in the field, namely, that each individual layer usually grades into one or both of the bounding layers.

In some cases this passage is gradual through a considerable proportion of the thickness of the layers, whereas in other instances the change is almost abrupt.

An analogous feature on a larger scale is also characteristic of the lower part of the formation where throughout the several hundred feet of strata composing what has been termed the Lower Division, the general character varies from zone to zone. Successive zones merge into one another as a result of the interbedding of different rock varieties and of slow changes in the lithological characters of the individual layers accompanied by gradual changes in the relative proportions of the numbers and sizes of the various rock varieties. In the Upper Division, on the other hand, the strata of each zone are lithologically distinct. The rocks of one zone do not grade into those of adjoining zones. Their contacts are abrupt, though in some instances at the junction of the zones the contrasting rocks are interbedded.

The zonal distribution of the strata is indicated in the folowing tabular statement. In the case of the zones described in this table as being composed of "red and grey, dense" rocks, the red and the grey measures, respectively, form distinct zones which in general grade into one another by interbedding.

Lithological units	Thickness in feet			
	1	2	3	4
Grey, granule-bearing	....	....	25 to 50	....
Dark, dense	40	24	20	....
Grey, granule-bearing	25	21	30	....
Dark, dense	....	....	5	....
Grey, granule-bearing	....	....	45	....
Dark and red, dense	50	25	50	....
Ferruginous, granule-bearing	50	....	30	....
Red and grey, dense	50	45	50	....
Ferruginous, granule-bearing	....	10	15	....
Red and grey, dense	....	15	130	....
Ferruginous, granule-bearing	....	10	....	25
Red and grey, dense	....	80	....	....
Grey, granule-bearing	....	26	10	....
Red and grey, dense	....	66	30	105

Locality No. 1. Kasegalik Lake area; lower strata not exposed.
Locality No. 2. Kipalu Inlet area, south end.
Locality No. 3. Innetalling Island area.
Locality No. 4. Tukarak Island area, northern section; lower part only.

Microscopic examination indicates in unmistakable fashion that all the strata have been subjected to processes of alteration, but these processes seem to have consisted in the main of the replacement of one mineral by another without completely obliterating the original rock textures and structures. The rocks examined are with scarcely an exception, either fine-grained, banded, but otherwise formless aggregates frequently carrying clastic grains, or else they present definite evidence of having been composed of minute granules lying in a distinct matrix. Several thin sections showed that siliceous rocks of the granule-bearing type had been partly transformed into a finely granular quartz aggregate bearing only remnants of the granules. Other thin sections showed carbonate to have replaced original constituents and to have partly destroyed the original textures and structures; but this destruction was never complete. It does not seem probable that many, if any, of the carbonate-rich layers originated in this fashion, for the secondary carbonate always appeared to be mineralogically distinct from the more abundant rock-forming variety. Single thin sections and suites of thin sections afforded examples of long series that seemed to indicate all stages in the replacement of one mineral by another, but no examples were observed of the transformation of rock varieties bearing clastic grains into dense, structureless rocks or into granule-bearing types. Neither, except partly in two instances, were granule-bearing strata observed to graduate into structureless rocks. The absence of any such examples is considered ample proof that no wholesale transformation of the strata has taken place and that the present textures and structures are original. The fact that different rock varieties form definite zones traceable for long distances and in some cases of remarkably uniform thicknesses, is also evidence that on the whole the present rock structures and textures are original.

The iron-formation is indicated to be of sedimentary origin by the bedded nature of the whole formation, the zonal grouping of beds of allied lithological characters, the uniform manner in which individual zones extend for miles along the strike, the banded character of most of the zones and the accompanying variations in mineralogical and textural features from layer to layer, the natures of the apparently original textures and structures exhibited by the different rock varieties and by the presence of clastic grains of quartz and various kinds of feldspar. Except the clastic quartz and feldspar grains, no material of clearly detrital origin was noted, but it seems possible that some of the fine-grained beds may hold finely comminuted argillaceous matter. No tuffaceous material was anywhere recognized nor was there any indication of the former existence of any such materials. All observed characters agree in indicating that except for the relatively unimportant clastic matter, the iron-formation is of the nature of a precipitate produced under changing conditions. The nature and source of the original solutions and of the agents of precipitation, whether organic or inorganic, are not directly indicated.

Some of the general conditions governing the manner of deposition of the iron-formation may be deduced by considering the nature of the preceding and succeeding formations. Underlying the iron-formation is a very thick assemblage of impure limestones, fine-grained mostly calcareous sandstones, and mud rocks. They give evidence of having formed in standing water, and it is reasonable to believe that the basin was at least sufficiently extensive to include the areas of similar strata distributed at intervals for a length of 300 miles along the east coast of Hudson bay. The waters of this basin may have been fresh, but no evidence supporting such a conception was collected; it seems more probable that the waters were marine.

The formation immediately underlying the iron-formation is essentially a clean, even, and fine-grained quartz sand with a variable amount of carbonate that in part forms relatively wide bands in the quartzite. The contact of the quartzite with the overlying iron-formation is sharp. There is no evidence of an unconformity, no interbedding of the two classes of materials, and absolutely no signs of any grading of one into the other. The nature of the contact and the character of the two formations seem to indicate that deposition of the quartz sand was succeeded by a considerable interval of non-deposition during which the sand was reworked, shifted, and spread out by tidal or other currents. Deposition of materials may have proceeded continuously in other parts of the basin, but in this area in order to explain the abrupt succession of two such unlike formations, it seems necessary either to postulate an intervening period of non-deposition or to suppose that the precipitation of the thick iron-formation (300 to 450 feet) was abruptly commenced and was so rapidly accomplished that only a very small amount of clastic material was included in it. It seems probable that the area was continuously submerged while the iron-formation was being deposited, for the overlying basalts have a prominent ellipsoidal structure such as is not inconsistent with a belief that these flows were submarine. Furthermore, the strata of the iron-formation nowhere afforded any evidence of even a temporary emergence during their deposition. Interleaved with the basalt flows are thin, discontinuous layers of black, carbonaceous, shale-like strata, in all probability truly argillaceous. Their presence corroborates the general conception that the iron-formation was deposited in a basin, probably marine, during an interval when little or no coarsely clastic material was laid down, but when some argillaceous matter may have been deposited along with the iron-formation. The interval was apparently closed by the outpouring of basaltic flows accompanied by the deposition of dark muds.

The available direct evidence as given above seems to justify the conclusion that the iron-formation is primarily a sediment precipitated in an extensive marine basin, that precipitation was accomplished in some unknown way and that it took place under changing conditions. These conclusions are in part based on observations which indicate that certain rock textures and structures are original features which have been preserved despite the fact that various mineralogical substitutions may since have taken place. The nature of these mineralogical changes and their probable date are matters of prime importance in connexion not only with a discussion of the mode of origin of the iron-formation, but also in connexion with any discussion of the possible existence of iron ore deposits of economic importance.

PARAGNEISSES

The mineralogical constancy of the individual lithological zones composing the iron-formation is striking and significant. The iron-formation was examined over a considerable length of outcrop in four separate areas and in a single partial section in a fifth area. These areas are distributed within a district 40 miles long by 20 miles broad. Except in the northeast part of this area of 800 square miles, the iron-formation is clearly divisible into an Upper and Lower division each of which wherever developed has the same distinctive features. Furthermore, lithological units no thicker than 5 to 25 feet may be traced along the outcrops for upwards of 10 miles. In the northeastern part of the district it did not seem possible to divide the strata into two horizons respectively equivalent to those found elsewhere, but the strata of this area are divisible into a number of horizons, some only a few feet thick, traceable along the strike and possessing characters and thicknesses as uniform as the subdivisions of a normal sedimentary formation. Therefore, however greatly the strata may have been changed, the iron-formation is stratigraphically similar to more normal sedimentary groups. Even the highly ferruginous beds which might be assumed to be largely secondary, occur in each area at definite continuous horizons. Such a condition indicates that the present lithological characters are essentially original. Any mineralogical changes that may have taken place must have been almost contemporaneous with the first laying down of the beds, or else, if they occurred long afterwards, they must have been accomplished by agents operating with almost uniform effect through each lithologically distinct zone.

The clastic grains of quartz and feldspar are the only constituents that unquestionably are original. The uniform, clear, undecayed condition of the feldspar grains indicates that they are the product of a mechanical disintegration of an earlier rock. But it is not clear whether the granules of the granule-bearing rock types were at one time all composed of greenalite or some allied ferruginous compound, or whether some were of iron oxide, or of silica, or of carbonate, or of mixtures of various minerals. The thin sections alone give no certain indication of the original mineralogical composition of the granule-bearing rocks. There is, however, a considerable body of evidence indicating that the iron oxides are at least partly replacements both of the granules and of the matrix and of larger irregular forms of what once was a green mineral.

The non-clastic beds of the formation are composed of silica, carbonates, hematite, magnetite, and a green mineral or minerals thought to be in part, at least, greenalite. These minerals were observed to occur in so many combinations and proportions as to render it probable that there are layers composed of any one or of any two, three, four, or all five of these constituents in various proportions.

The very fine-grained strata so prevalent in the Lower Division were found in the few specimens microscopically examined to be exceedingly fine grained and composed chiefly of carbonate or perhaps, in some instances, carbonate and silica. Dark dense strata of the Upper Division are in some instances largely of finely granular carbonate that in some cases forms the matrix in which lie clastic quartz and feldspar grains. The carbonate in such and related examples has every appearance of being an original constituent. It is indicated to be ferruginous by its turbid appearance, the associated dust-like or very finely granular hematite or magnetite, or both, and by the characteristic yellowish and brownish, limonitic outer weathered zones of some of these rocks. Secondary carbonate was observed as vein-like aggregates or crystals in many thin sections.

The silica was observed to occur in three general ways. First, as fine-grained aggregates partly or wholly forming spherical, elliptical, and more irregular minute bodies or "granules." Second, as finely granular aggregates partly or wholly forming a matrix holding such granules. Third, rarely as granular aggregates holding only fragments and mere traces of granules as though the rock were undergoing a process of recrystallization. Though many layers were observed which bore a casual resemblance to dark chert or brilliant jasper, no undoubted example of chert or jasper was found. The chert-like and jasper-like layers invariably displayed perfectly preserved granules of varied composition in, apparently, unaltered siliceous matrices. In a number of examples the rocks consisted essentially of granules of silica in a granular matrix of the same material. In many thin sections granules composed almost entirely of silica were accompanied by others formed of greenalite, others of iron oxides, and yet others composed of any two or all three of these main constituents in various proportions. Phenomena to be referred to later seem to indicate with a reasonable degree of certainty that much if not all the iron oxide is secondary. The debatable point is whether all or nearly all the granules were once composed of a single mineral, greenalite or quartz, or whether some granules were originally of greenalite and others of quartz.

The granule-bearing rocks occur now with three main habits and form definite zones alternating with dense strata. In the Upper Division the granule-bearing strata form grey, nearly massive zones from a few feet up to 50 or more feet thick. These rocks are mainly composed of quartz and are relatively poor in greenalite and iron oxide. In the Lower Division similar rocks in different localities form one or two zones. A second general type of the granule-bearing rocks occurs in the Lower Division. It is highly ferruginous and occurs in groups of definite beds of varying textures and mineralogical composition. A third general type occurs in thin discontinuous layers. It is highly siliceous and usually red and jasper-like or grey and chert-like, but the resemblance to jasper or chert is only superficial. These discontinuous layers in some cases accompany the granule-bearing strata of the Upper Division and always occur with these rocks where developed in the Lower Division. The tabular statement on page 40 indicates the positions of the observed zones of the granule-bearing rocks in the generalized sections representing the various areas examined.

If the granule-bearing zones in the Upper Horizon were once composed of granules of greenalite lying in a quartz matrix, it is remarkable that now, wherever the strata are exposed in the areas examined, the granules are essentially of quartz. The area examined is considerable, consisting as it does of three outcrops of the iron-formation, each 10 miles or more long, and with the two most distant outcrops 35 miles apart. Eminent authorities have shown that lithologically essentially similar rocks in the Mesabi district, Minnesota, have developed from rocks whose granules once were solely or mainly composed of greenalite. Therefore, lacking evidence to the contrary, the analogous strata on Belcher islands also presumably once contained granules only of greenalite. In the Mesabi district the alteration of the greenalite rocks to the more purely siliceous rocks has been shown to be due to ordinary processes of weathering and circulating surface waters. The same general agents may have produced analogous changes in the rocks of Belcher islands, but there is some evidence that indicates that other transforming processes were also active.

In describing the strata frequent reference was made to thin, discontinuous layers of rocks that superficially resemble chert and jasper. These rocks are in part bright red like jasper, in part of duller green and purple tones. and have a slightly vitreous lustre and splintery or semi-conchoidal fractures. Unlike jasper or chert, they are composed of granules lying in a fine-grained siliceous matrix. Thin layers of these occur occasionally in the dense strata of the Lower Division and are very abundant in the ferruginous zones, in some places representing 20 per cent of the rock volume. Similar layers also occur in some districts with the grey, granule-bearing zones of the Upper Division. In the detailed description of the strata it has been stated that in places these layers give evidence of having been partly replaced by the rocks in which they occur. Examples have been cited of layers which for an interval are represented by irregular bodies with curving outlines, so disposed as to indicate very clearly the former boundaries of the layers. An example was described where the enclosing strata, being lined and streaked parallel to the bedding, retains this structure where it lies between the fragments of the once continuous layer. The lining and streaking tend, however, to be parallel to the irregularly curving outlines of the fragments of the layer, and in places is parallel to planes at right angles to the bedding. The detached portions of the once continuous layers are not products of contemporary erosion, for they still lie in their original position, and their outlines are frequently highly irregular with curving tongue-like projections and deep embayments sometimes enlarging inwardly. All the observed facts indicate that these layers were unstable products of deposition subject as soon as formed to partial—perhaps in many cases complete—re-absorption of replacement.

Since the somewhat jasper-like and chert-like layers in all probability were absorbed or replaced as the strata were forming, it is not unlikely that other members, also, of the rock assemblage were subjected to transformations during, or immediately following, their deposition. Thus, even assuming that the granules of these rocks were originally largely or solely greenalite, it does not seem necessary to suppose that all or any alteration of such granules took place after the final consolidation of the iron-formation. It is concluded that the grey granule-bearing strata that form the prominent, continuous zones in the Upper Division and are uniformly deficient in greenalite and low in iron oxides, may have received their present mineral composition prior to the final consolidation of the iron-formation.

The mode of occurrence of greenalite has been partly referred to in the preceding discussion. The mineral occurs forming the whole of granules and also in shred-like forms in siliceous granules. It occurs, too, in irregular forms through the matrix and is abundant in many of the dense, non-granule-bearing rock varieties. In many cases the greenalite appears as though partly altered to or replaced by hematite or magnetite. In many cases individual areas of iron oxide have outlines precisely similar to those of aggregates and films of greenalite, as they occur in granules or in the matrix of the granule-bearing and dense rock varieties. Without doubt the greenalite has been replaced in a varying degree by iron oxides.

In many of the dense rocks, a green mineral is very abundant and is supposed to be greenalite. Possibly this mineral has been wrongly identified; it may be a hornblende. It occurs in matted masses, frequently with much carbonate. It also, in some rocks, forms coarser, granular bands enclosing clastic grains, or occurs in ragged grains and more regular plate-like individuals. Beds of these dense rocks rich in the green mineral may be recognized in places in the ferruginous zones of the Lower Division, interbedded with the granule-bearing rock types. In such interbedded layers, the green mineral appears to have been largely replaced by magnetite, still preserving the characteristic outlines of the individual aggregates of the green mineral.

The iron oxides almost invariably appear to be secondary. In some cases they are undoubtedly a direct product of weathering, as in the case of the outer, brownish, presumably limonitic, weathered zones of many of the carbonate-rich layers. But the hematite that gives the red colour to the bulk of the strata of the Lower Division does not seem to be a product of weathering confined to a shallow zone; instead, it seems to be an integral part of the rock which developed as each layer formed, or relatively soon thereafter. In the dense rocks, the hematite is for the most part dust-like. In some cases it is so abundant that thin sections of the rock are opaque. No evidence was observed that indicated whether such hematitic matter was originally deposited as such, or has been derived from ferruginous carbonate, or perhaps from original limonite.

In the coarser, granule-bearing rocks and in the dark grey, dense-grained types, magnetite is usually as abundant as hematite and often greatly preponderates. Some dark, granular beds are very largely magnetite. In the denser rocks the magnetite is disseminated dust-like, or as small, irregular grains, or as minute octahedra sometimes grouped in small aggregates. In the coarser, granule-bearing rocks, the magnetite may occur only as thin partial rims about or in irregular aggregates within the granules. Examples are common showing all gradations from forms such as these to others solidly composed of magnetite. Examples of what appear to be various stages in the replacement of greenalite and of the siliceous matrix in which the granules lie, are common. Hematite also shows the same phenomena. The relation of the hematite to the magnetite does not seem to be clearly indicated. It is not apparent, for instance, why in an outcrop of the ferruginous zone, some layers should be rich in both hematite and magnetite whereas other layers with a high magnetite content should hold little or no hematite. The view is held by most writers who have dealt with the subject, that in strata such as compose the iron-formation, the magnetite content is not original but has been derived from previously existing hematite or limonite or other iron-bearing minerals. Assuming this view to be correct and considering the frequent intimate association of the magnetite with hematite, and that both minerals hold the same relations to the other rock constituents, it seems necessary to conclude that the magnetite was mainly or solely derived from hematite. The hematite may have been derived from limonite in whole or in part, but in either case most if not all of the iron oxide appears to be secondary in nature, to have replaced other minerals. There is no available direct proof that the iron oxide did not develop long after the laying down and general consolidation of the iron-formation, but certain considerations indicate this could not have happened and that the iron oxide developed at a very early date.

The iron-formation is overlain by basaltic flows with thin, discontinuous shale partings. Sills of diabase, mineralogically similar to the basalt, intrude the iron-formation and underlying strata. These sills are not older than the flows. They may be of about the same age or considerably younger. In any case the iron-formation appears to have been sealed below a series of volcanic flows which, apparently, were submarine, and formed immediately after the deposition of the iron-formation. So long as the iron-formation remained buried beneath the overlying basaltic cover, which may have been augmented by considerable thicknesses of younger formations since entirely removed, it is scarcely possible that any notable formation of iron oxides could have taken place. If any limonite or hematite had formed previously it is conceivable that during the volcanic period some or much of it might change to magnetite. Such a change might also take place while the iron-formation remained covered or as long as any part of the ferruginous portions were deeply buried. There is no evidence of the strata having been affected by more than one general period of igneous activity. There is evidence of only one period of dynamic stress, namely, that interval when the strata were thrown into the broad, open folds now so clearly revealed. Subsequently erosion uncovered the iron-formation along the axes of the major anticlines. Since then no recognized process capable of producing magnetite has been operative at or near the surface. It seems, therefore, that the magnetite so abundantly developed must have formed while the strata were deeply buried, or still earlier.

The hematite so abundantly associated with the magnetite might be conceived as being secondary after magnetite, to have formed from it by the action of normal weathering agencies and surface waters after the strata were exposed by erosion. Some small portion may have been produced in this fashion, but it is improbable that the great bulk could have so formed. At present the iron-formation outcrops as narrow bands on the slopes or at the foot of basalt-capped ridges beneath which the measures dip. The exposed width of the iron-formation is rarely more than 150 yards, and this narrow outcrop very nearly expresses the width of the catchment basin for surface water, some portion of which might find its way underground along the strata of the iron-formation. At present, therefore, the amount of water that finds its way underground is insignificant, and the rocks at the surface—save for an oxidized film and the thin limonitic outer zone of some of the carbonate beds—are unweathered. Past climatic conditions may have been more conducive to surface weathering, but there is nothing to indicate that the present land forms are descendants of others that would have afforded larger water sheds to supply surface waters to the outcrops of the iron-formation. It is almost certain that the iron-formation was never exposed except as a narrow selvage along basalt-capped slopes. It thus seems that the conditions always were such that only a very insignificant amount of surface water was available to find its way underground through the iron-formation. It also seems fairly certain that, even granting a large supply of surface water, the underground circulation would not be vigorous, for the iron-formation everywhere dips downwards under an impervious cover consisting of a diabase sill overlain by basaltic flows interleaved with thin, discontinuous beds of shale. Furthermore, the rocks of the iron-formation are not now, and give no indication of ever having been, permeable to water except along parting planes.

Thus various independent lines of reasoning unite in indicating that the present content of iron oxides is not a product of superficial changes that took place after the iron-formation was uncovered by erosion, but, instead, resulted from processes in action at the time of deposition of the beds or shortly thereafter.

The foregoing account is mainly directed to offering explanations of various secondary characters of the strata. It does not seem that any facts were observed that definitely indicate what was the ultimate source of the non-clastic content of the iron-formation, how it was transported, or how its deposition was brought about. It may be, as Leith has suggested,[1] "that the essential requisite for the deposition of the iron-formation . . . was the event of great masses of basic lavas carrying excess of iron salts, contributing the iron salts in unusual amounts to the shallow waters, which disposed of them as best they could while handling the ordinary fragmental and chemical sediments." On the other hand Grout and Broderick,[2] in discussing the origin of the iron-formation of the Mesabi district make statements that seem equally applicable to the iron-formation of Belcher islands. These authors state that in the strata "there are hundreds of alternations. . . . Rhythmic sedimentation is in some cases due to a rhythmic supply of different materials. . . . If the material had been derived from volcanic sources . . . it seems improbable that these supplies would alternate as many times as the sediments indicate. It is unlikely that there were so many successive flows. Volcanic rhythms should produce alternations on a large scale. Furthermore, climatic rhythms are also larger features. The detailed alternation of beds from $\frac{1}{16}$-inch to 6 inches thick is more likely attributable to seasonal or other occasional changes in conditions. These changes would affect a chemically depositing sediment only if in shallow water." As regards the nature of the solutions contributing the materials to these shallow waters, these same authors write: "The solution of silica may have been facilitated by the presence of alkalies; that of iron would be more likely in the presence of acids. If carbonate minerals were more abundant (as in some other ranges) an alkaline bi-carbonate solution might be suggested as the most probable combined solvent. This kind of solution is known to have had an igneous origin in some places."

[1] Leith, C. K., "An Algonkian Basin in Hudson Bay, etc.," Econ. Geol., vol. 5, p. 243, 1910.

[2] Grout, F. F., and Broderick, T. M., "The Magnetite Deposits of the Eastern Mesabi Range, Minnesota," Minn. Geol. Surv., Bull. No. 17, pp. 40-47, 1919.

CHAPTER IV

ECONOMIC GEOLOGY

Iron-Formation Occurrences

The most westerly investigated outcrops of the iron-formation on Belcher islands occur on Flaherty island (Figure 3) in a band that is probably nowhere more than 500 yards wide. This band runs southerly from the northeast shore of the island to and along the east side of Kasegalik lake. Only the south end of this band was examined, but iron-formation has been reported to occur on the northeast coast, and distant views from near the head of Kasegalik lake unmistakably indicated that the strata continue northward along a nearly straight course probably to the reported outcrops on the northeast shore. The length of this band is 16 miles or more.

The northern part, so far as known, is largely drift covered, but in the last 7 miles to the south, commencing about opposite the head of Kasegalik lake, outcrops are not so rare. Finally, along the sides of a narrow easterly-intruding bay and for a mile south of this, the strata are comparatively well exposed. Along the east side of the lake the land rises quickly, in places precipitously, for about 200 feet to the edge of an upland. This upland is in part fairly level, in part much broken, and extends easterly to the shores of Kipalu inlet, or in the north to the northeast coast of Flaherty island. It is composed of the volcanic rocks, from beneath which on the west side the iron-formation outcrops along the slopes facing Kasegalik lake and along the sides of the valley that runs northward from the head of the lake. On the east side of the upland the strata reappear on the west shore of Kipalu inlet. The strata are nearly flat-lying, but on the whole slope gently to the east on the Kasegalik Lake slopes. The general structure is clearly expressed along the shores of the narrow, easterly-extending bay of the lake already referred to and along the low valley which extends east from the head of this bay to the shores of Kipalu inlet. In this stretch of about 2 miles the iron-formation is continuously exposed along the lower slopes up to the foot of cliffs of the overlying volcanics. At the west entrance, the contact of the iron-formation with the cover of volcanic rocks lies about 220 feet above sea-level. Eastward it sinks to as low an elevation as 60 feet and then rises to a height of 180 feet on the slopes facing Kipalu inlet. Along this line of section the beds, therefore, lie in a very shallow trough and doubtless this is the general structure of the whole of the upland area that lies between the valley of Kasegalik lake and Kipalu inlet and extends southward for some 60 miles from the northeast coast of Flaherty island to the entrance of Kipalu inlet. But minor undulations affecting the strata and a general southerly slope of the whole, cause the iron-formation to sink below lake level a short distance south of the above-mentioned narrow bay. It is not known whether farther south the iron-formation again rises above the lake level. For several miles at least, the volcanics outcrop along the shore and 20 miles to the south they were seen again rising directly from the water-level. If anywhere in this interval the iron-formation does come to the surface the probabilities are that only the upper part rises above the water-level and does not remain long exposed.

On the east side of the trough, that is along the western side of Kipalu inlet, the iron-formation outcrops at intervals for 35 miles to near the south entrance to the inlet. In places only the upper beds of the iron-formation

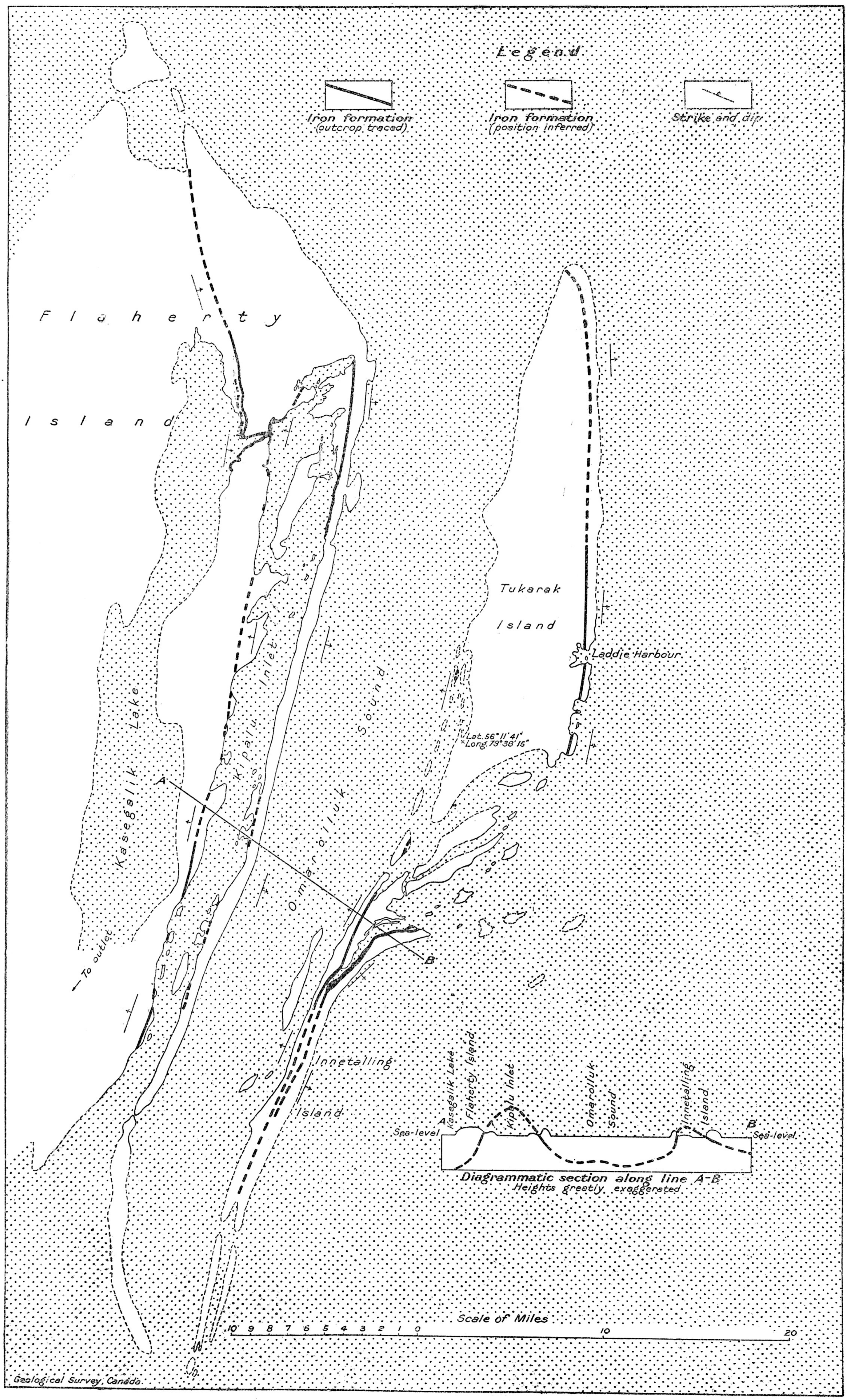

Figure 3. Eastern part of Belcher islands, Hudson bay, showing surface distribution of iron-formation.

rise above sea-level for distances of a few hundred yards, but at several places the whole formation may lie above sea-level though it is almost wholly covered by drift. At one locality in the south the strata dip at an angle of 70 degrees. Northward the beds are less steeply inclined and near the head of the inlet where exposed for the last time on the west shore, they dip gently westward.

The iron-formation undoubtedly underlies all of the ridge of volcanics between Kasegalik Lake valley and Kipalu inlet. In places this ridge is only half a mile wide, but in the north it is perhaps 10 miles broad. This ridge is estimated to occupy 125 square miles and consists of volcanic rocks resting on and concealing the iron-formation which, as already explained, is only intermittently exposed along the eastern and western sides. These volcanic rocks are in places at least 200 feet thick and in some localities are presumably much thicker.

Nowhere along the edges of this area is the full thickness of the iron-formation known to be exposed. Either the lower part lies below sea- or lake-level or it is concealed by drift. In the north, the upper part is well exposed along the east shore of Kipalu inlet, along the sides of the short depression that runs west from the inlet to Kasegalik lake, and for short distances north and south along the lake. In all, the upper part of the formation is clearly exposed over a length of outcrop of about 5 miles and everywhere has the same general expression. The upper 120 feet to 150 feet consists of three members of which the upper and lower give no indication whatever of grading into or carrying iron ore-bodies. The middle member, about 25 feet thick, is a finely granular rock type such as in the Mesabi iron range is believed to have been in places altered into iron ores. It is essentially what is called taconite or ferruginous chert. It is everywhere a greyish, highly siliceous rock and is not now high in iron whatever its original composition may have been.

At an horizon 120 feet to 150 feet below the summit of the formation lies a ferruginous zone at least 40 or 50 feet thick. On the Kasegalik Lake side this is the lowest stratum exposed, the remaining lower part of the formation being either drift-covered or below lake-level. On the Kipalu Inlet side, about 60 feet of strata appear from beneath the ferruginous zone. These lower beds are fine grained and give no indication of grading into iron ore. The ferruginous zone is exposed at intervals along Kipalu inlet for 2,400 yards. It lies below sea-level along the depression leading west to the bay on Kasegalik lake, but reappears on the south side of this bay and is exposed at intervals for 2,500 yards. It does not outcrop on the north side of the bay, being beneath lake-level or else drift covered. North of the mouth of the bay, it outcrops at wide intervals over a length of about 2 miles. Wherever it appears, the ferruginous zone has the same general character. It is composed of distinct beds, some black and largely of magnetite, others of varying shades of red and purple that carry both magnetite and hematite in various proportions and amounts. Some of the layers are very fine grained, but most are distinctly granular and resemble types such as yield ore-bodies in the Mesabi district. Interleaved with these measures are thin, discontinuous, irregular layers with a very low iron content and so abundant that in faces 15 to 20 feet thick, these form one-fifth of the total volume.

Four samples of different thicknesses of the ferruginous zone were taken and submitted to the Mines Branch for analysis. The results obtained are given in the following table. Analysis No. 1 is of a sample representing a thickness of 2 feet of black, magnetite-rich beds at the top of the ferruginous zone. Analysis No. 2 is of a sample from a thickness of 11 feet immediately below the black, 2-foot layer, both being from exposures on the shores of

Kipalu inlet, on mining location No. 13. Analysis No. 3 represents a thickness of 12 feet of the strata on the same mining location, commencing 6 feet below the top of the zone and extending downwards. Analysis No. 4 represents a thickness of 15 feet of the strata on mining location No. 20, Kasegalik lake, 20 feet below the top of the zone and extending downwards.

	1	2	3	4
Fe_2O_3	41·41	42·30	43·50	45·10
FeO	29·92	19·74	11·12	4·95
Metallic iron	52·26	44·96	39·10	35·42
SiO_2	23·96	32·52	38·60	46·48
CaO	0·36	0·40	0·64	0·34
MgO	1·00	1·54	1·61	1·37
Mn	0·64	0·64	0·34	0·24
TiO_2	0·04	0·10	0·08	0·08
S	0·104	0·048	0·012	0·012
P	0·093	0·072	0·060	0·039

The material represented by analysis No. 1 is exceptional since it occurs only sporadically at the top of the ferruginous zone. The beds represented by the remaining three analyses are not commercial iron ore, for not only is the iron content low, ranging from 35 per cent to 45 per cent, but silica is very high, varying between 46 per cent and 32 per cent. It would be possible to improve the grade by removing the more highly siliceous layers by hand-picking, but though this in the case of the 11 feet of strata represented by analysis No. 2 might increase the iron content from about 45 per cent to 54 per cent, it would not reduce the silica content by more than 12 per cent, from 32·5 per cent to 20 per cent. It is questionable if it would be possible to remove the siliceous layers except at a prohibitive cost. These layers are discontinuous, vary in thickness from a fraction of an inch up to 6 inches, are tightly welded to the enclosing strata, and in places constitute as much as one-fifth of the total volume.

This ferruginous zone, however it may have formed, now appears as a continuous layer. Its ferruginous character is not accidental, but is due to the peculiar mineralogical and textural characters of the strata. These characters are not shared by the bulk of the associated strata, which give no indications of passing into ore. Any ore deposits that may exist must, in all probability, occur in connexion with this ferruginous zone or with any similar zones that may occur in the underlying part, or in the overlying part, as in the case of the 25-foot grey layer already mentioned.

The next band of iron-formation to the east outcrops on the east side of Kipalu inlet, Flaherty island (Figure 3). Commencing on the shore of the tidal basin at the head of the inlet, the band runs slightly west of south for 10 miles before it again approaches the shore and passes below sea-level. The lower and upper boundaries of the band are closely defined in most places, and its width, depending on the inclination of the strata, varies between 80 yards and 160 yards. Between where it disappears below the sea at both ends, it ranges from 80 feet to 160 feet above sea and outcrops on the west face of a narrow ridge surmounted by volcanic rocks. The beds dip between 45 degrees and 55 degrees to the east. The total thickness varies from 320 feet to perhaps as much as 400 feet. Though the upper and lower boundaries of the band are mostly closely defined by outcrops of the overlying and underlying strata, the iron-formation itself is largely covered by a thin mantle of drift. In the north and the south exposures are more frequent than elsewhere and indicate that the formation has developed in much the same way as the band

4 miles to the west on the opposite side of Kipalu inlet. These two bands occur on the limbs of an arch or fold whose axis runs north and south along Kipalu inlet, and if no rupture has occurred along the central part of the fold they must curve towards one another and unite at the head of the tidal basin at the north end of the inlet. The projected course of the greater part of the western band and the extreme north end of the eastern band lie, however, in a low area without rock exposures and it is not possible to determine the precise nature of the geological structure.

In the band on the east side of the inlet, the iron-formation appears to be composed of two divisions, as in the western area. The upper division is about 70 feet thick, and is divided into three members of which the middle member is, as in the west, a grey, siliceous taconite. The lower division is about 250 feet thick and in it two ferruginous zones, 10 to 20 feet thick, occur at horizons between 170 and 215 feet above the base of the formation. These relatively iron-rich zones closely resemble the 40 to 50-foot zone found on the west shore of the inlet and in the Kasegalik Lake area. Lower down in the formation, in the lower 100 feet, there are thinner ferruginous zones and bands of the grey siliceous taconite. The whole formation is ferruginous, but only in the case of the thinner ferruginous zones in the lower 100 feet and the two thicker zones lying between 170 feet and 215 feet above the base of the formation where the strata have the general character of taconite, do the beds even approximate an iron ore. The rest of the strata are either dense rocks or lean, siliceous taconite. The different varieties of rocks appear to be grouped in zones each traceable over the whole 10-mile length of the band.

The eastern side of Kipalu inlet is a narrow peninsula chiefly of volcanic rocks sloping to the eastward. The peninsula continues southward for 30 miles beyond the southern termination of the above-mentioned 10-mile band of iron-formation. Along this 30-mile stretch the shoreline is nearly straight and the volcanics rise steeply from the water's edge except in three places where, in each case for several miles, westward projections of the land bring the iron-formation and underlying measures above sea-level. These three areas were not examined, but as seen in passing in a boat the impression was obtained that the iron-formation is very largely drift covered, except perhaps the uppermost part. The peninsula is continued southward for 12 to 15 miles by one or more low-lying islands of the volcanic rocks, but there is no reason for supposing that in this direction the iron-formation again appears above sea-level.

The volcanic rocks and the underlying iron-formation on the peninsula forming the east side of Kipalu inlet dip steeply to the east and pass under Omaralluk sound, a body of water 6 to 8 miles broad. On the east side of the sound, the volcanic rocks reappear, dipping to the west and rising in a narrow, discontinuous ridge on whose eastern slopes the underlying iron-formation is exposed. In the north this interrupted ridge of volcanic rocks is represented by a line of narrow islands paralleling Tukarak island and close to the southern part of its west coast; in the south it forms a ridge one-quarter to one-half mile wide along the western coast of Innetalling island; and farther south it forms a long, slender island and several smaller islands to the south. The extreme length of this partly submerged narrow ridge is above 40 miles and doubtless everywhere the westward-sloping volcanics are underlain by the iron-formation, but only on Innetalling island and on some of the small islands to the north, over a length of some 30 miles, does the iron-formation lie above sea-level. In the northern islands, the outcrops of the iron-formation are mainly limited to the upper part of the formation. On Innetalling island, except in the extreme north, the strata are almost wholly drift covered and were not examined. In the north part of the island, where the strata were examined over a length of 7 miles, the upper part of the formation is fairly well exposed, but the lower part is everywhere concealed. The strata in the north are vertical, but proceeding southward dip to the west at progressively lower angles to 45 degrees. Of the exposed part, the upper 200 feet consist of alternations of thick zones of lean, grey, siliceous taconite and thinner zones of dark dense strata. Beneath these beds and traceable for several miles in the north part is a ferruginous zone about 30 feet thick that is comparable in every way to the ferruginous zone of the Kasegalik area. A sample taken across a thickness of 24 feet of this zone was submitted to the Mines Branch for analysis and gave the following results:

Fe_2O_3	50·79
FeO	3·05
Metallic iron	37·80
SiO_2	42·12
CaO	0·50
MgO	1·44
Mn	0·35
TiO_2	0·08
S	0·04
P	0·032

A somewhat similar ferruginous zone, 15 feet thick, occurs lower in the formation, 280 feet below the top. This second horizon is exposed only in one limited area; elsewhere it and all lower beds are drift covered.

The band of iron-formation and overlying volcanics just referred to, occurs on the west limb of a long fold. The easternmost band of the iron-formation occurs on the east limb of this fold on the opposite, eastern side of a low-lying area that occupies the axial portion of the fold. This eastern band was examined only on the northern part of Innetalling island and the southern half of Tukarak island, but there is every reason to believe that it extends almost the full length of these two islands, a distance of about 60 miles, including a water-covered interval of 12 miles between the two islands. The iron-formation outcrops on the western slopes of a discontinuous ridge about half a mile wide that extends to the sea coast. The iron-formation dips eastward under the volcanic rocks at angles varying from place to place between 10 degrees and 35 degrees. On the southern part of Innetalling island only a narrow valley a few hundred yards wide separates this easternmost band of the iron-formation from the previously mentioned band of the western side of the island and in places the lower beds of the formation may extend across the valley. Along the sides of this valley outcrops are rare and, so far as known, none occurs in the bottom. Northward the valley widens and exposures are more frequent. In this direction the strata rise from the shores of a southward-extending bay and a tidal basin at its head. In places along this part of the band, the full thickness of the iron-formation of about 450 feet lies above sea-level. Owing, however, to minor folds in the strata, the iron-formation in places partly or wholly sinks below sea-level. At the north end of the island, the apparent thickness of the formation is increased by a sheet-like body of igneous rock. On Tukarak island, the iron-formation is poorly exposed and in places the drift-covering is thick. The boundaries with the overlying and underlying strata are usually closely indicated, but for stretches of a mile or more there is scarcely a single outcrop of the iron-formation.

On Innetalling island, at the north end, the iron-formation band was examined for a length of 8 miles. The lowermost and uppermost beds are well exposed in places, but the middle part of the strata is poorly exposed. The total thickness is about 450 feet; of this, the upper 200 feet corresponds with the strata of the band to the west and consists of heavy bands of grey siliceous taconite with thinner separating zones of dense dark strata. Below these is a thick ferruginous zone, the counterpart of that exposed in the nearby west band. Towards the base of the formation there is a thinner, less ferruginous, but otherwise similar, zone and one or more additional zones may occur higher up. The remaining strata, though in part red from the presence of comparatively abundant iron oxides, are dense and give no indication of grading into even low-grade iron ore.

On Tukarak island, the iron-formation was examined in two localities where it is locally partly exposed. One locality is about a mile south of Laddie harbour and the other 6 miles farther north. At both places the formation was found to be 370 feet thick and to present the same general succession. In the northern section a ferruginous zone commences about 25 feet below the top of the formation and extends downwards for a thickness of 40 feet. The counterpart of this zone, only partly exposed, occurs in the southern section and on the south shore of Laddie harbour. The rocks of this zone are unlike those of the ferruginous zones of the other districts. They are not taconites, but consist chiefly of iron oxides and minute, clastic grains of quartz and feldspar. Lower down in the strata of the northern section, at an horizon about 100 feet above the base, is a still lower-grade ferruginous zone of the more usual type. The two zones possibly extend continuously along at least the southern half of the band. The rest of the strata in the two areas where exposures are at all numerous, give no indication of grading into iron ore. The extent and character of the band on the north part of Innetalling island are quite unknown.

Iron-formation has been reported to occur on the large island west of Flaherty island where dark rocks of the upper part of the formation are said to rise from the water's edge. Possibly the iron-formation also occurs in the southern part of Flaherty island west of Kipalu inlet, for strata that underlie the iron-formation are known to outcrop west of the head of Kasegalik lake. The overlying volcanics outcrop east of this along the west side of Kipalu inlet and, therefore, somewhere between these two areas the intervening iron-formation must come to the surface unless it is drift covered or unless a fault occurs along the west margin of the volcanic-covered area. Since it is reported that dark rocks like the overlying volcanics form the southern part of Flaherty island the strata are probably not faulted and an undiscovered band of the iron-formation is probably developed in this extensive area.

General Considerations

Character and Distribution of the Iron-formation. The iron-formation on Belcher islands is of a type that in the Mesabi district of the Lake Superior region contains large bodies of high-grade iron ore. It has been established that these ore-bodies of the Mesabi range and those of the other Lake Superior iron ranges are secondary concentrations and did not exist when the enclosing strata of iron-formation were formed. Originally the iron-formation comprised rocks of unusual types that contained much iron in various mineral forms; but too low grade to constitute iron ore. Later in the history of these rocks, in certain localities, surface waters entered the strata, and by carrying away some constituents in solution and concentrating and redepositing others, brought about the formation of bodies of iron ore. One almost universal characteristic of this type of ore-bodies is that they extend to the surface of bedrock, although the bedrock may be covered by a considerable thickness of soil, sand, gravel, etc. This outcropping is a natural result of the ore-bodies having been caused by surface waters entering the rocks of the iron-formation and changing their composition.

Since the iron-formation of Belcher islands is of the same general type as those of the Lake Superior region it is to be expected that if any bodies of iron ore occur, they will be local exceptional developments outcropping at the bedrock surface of the iron-formation, though perhaps concealed by drift. It is conceivable, however, that the iron-formation on Belcher islands may contain beds that from the beginning were rich in iron and that some parts of such beds were sufficiently rich to constitute iron ore-bodies. Such types of iron ore deposits occur in other regions and it is characteristic of them that the iron-rich beds vary from place to place in quality and volume. Since the ferruginous beds and any local parts of them sufficiently rich to be considered iron ore were formed when the containing strata were being laid down, the positions of the ore-bodies in the enclosing rocks is in no way connected with the manner in which the beds now may be exposed. It is a matter of chance whether the part or parts of such a bed entitled to be considered an iron ore deposit appear in the outcropping portions of the containing iron-formation or lie concealed in some part of the formation back from its outcropping edge.

These two modes of occurrence of iron ore, (1) as local, exceptional bodies or concentrations formed within and later than the iron-formation and extending downwards from the present bedrock surface, and (2) as beds formed within and contemporaneously with the iron-formation and only by chance outcropping at the present bedrock surface, are the only known ways applicable to the iron-formation of Belcher islands. This formation varies in thickness between 300 feet and 450 feet and is formed of beds of rock that differ from one another in composition and appearance, but nearly all contain much iron in various mineral forms. No beds were seen of sufficient thickness and quality to be properly called iron ore, although some zones up to 50 feet thick would, in all probability, assay better than 30 per cent metallic iron. The beds composing the formation were deposited in a body of water and were laid down on one another in horizontal layers of varying thicknesses. In some cases they extend continuously over large areas, in other cases they are more limited in extent. After some hundreds of feet of such beds had accumulated, they were covered by flows of volcanic rock and into them in some places sheet-like bodies of similar rock were injected. One such sheet appears everywhere at the top of the iron-formation just below the volcanic flows. At some period the whole group of rocks was bent into a series of long, broad folds that trend north and south and are affected by minor folds or crumples. Perhaps other rocks were laid down on the volcanic flows, but if so they have been swept away from all that part of the rocks now lying above sea-level.

The strata eventually were raised above water-level. In the course of time the volcanic rocks were eroded in places along the crests of the long, north-south trending folds, and long valleys were thus formed revealing on their sides and floors the underlying iron-formation and the strata on which the iron-formation was laid down. At the present time, the resistant volcanic rocks stand up in pairs of ridges facing one another across the axis of the long folds; along the inner slopes, or at the foot of each ridge, the iron-formation outcrops in a narrow, partly drift-covered band. Away from these long valleys, that is, in the troughs of the folds, the volcanic rocks form a continuous sheet that rests on and conceals the iron-formation.

Principles for the Prospecting of Iron Ore Deposits. If iron ore-bodies developed in the iron-formation as they have done in the Lake Superior region, they will occur along the band-like outcrops of the formation. If some parts of some of the iron-formation beds have been iron ore from the beginning then some of these richer, ore-bearing parts may chance to be exposed along the same narrow, band-like outcrops. Prospecting for iron ore-bodies should be systematically planned on a comparatively large scale and should consist of stripping at intervals the whole width of the bands of the iron-formation and carefully measuring and classifying the strata of the cross-sections thus exposed. By comparing the thicknesses, succession, and kinds of rock found in any one cross-section with the same features as found in the nearest cross-sections, it can be determined whether intermediate lines of stripping are required. This method of prospecting is applicable because the iron-formation is certainly an orderly succession of groups of beds, each group having a general character which it maintains for long distances. Such work should precede any search for ore-bodies by diamond drilling at localities back from the outcropping edge of the iron-formation because, in the writer's opinion, the present available information does not yet give a clue to where ore-bodies are likely to occur if they occur at all. If, however, one or two drill holes were bored in the area between the heads of Kasegalik lake and Kipalu inlet, well back from the outcropping edge of the iron-formation, they would definitely indicate whether the ferruginous zones outcropping in this general district are, as in the Lake Superior region, the products of agents of change acting at the surface or whether, as the writer believes, they were always as they now are. The iron-formation can be examined on both sides of this volcanic-covered area and the greatest thickness of volcanic rocks to be bored through is probably not above 200 feet.

Until the manner of formation of these ferruginous zones has been determined and the variation of the iron-formation along its outcrop has been worked out, it would seem unwise to commence drilling for ore beneath the cover of volcanic rocks. If the ferruginous zones are original features and somewhere along their outcrop grade into iron ore, the systematic study of suitably placed cross-sections of the strata will indicate the manner in which these zones vary and the directions along which they grow richer or poorer in their iron content and thus give some clue to the position of areas in which iron ore-bodies may occur. Drilling operations planned according to such information would yield reasonably definite results and prove the presence or absence of commercial ore-bodies. If, on the other hand, the ferruginous zones represent conditions such as led to the formation of ore-bodies in the Lake Superior iron ranges, it is equally true that the outcropping edges of the iron-formation should be examined, for according to both theory and experience the enriched deposits should outcrop there. Long stretches of the formation, that are wholly or largely drift covered, should be tested, for if ore-bodies exist they should be less resistant to weathering than the other rocks and would tend to occur in recessed areas which naturally are likely to be drift covered. In places this covering must be as much as 50 feet thick, but in most parts it probably averages less than 10 feet.

Possibilities of Secondary Ore-concentration. Unless all competent authorities are at fault, the only manner in which secondary ore-bodies could grow in these rocks would be through the action of surface waters. This action could take place only if there was an adequate, long-continued supply of such waters, if the rocks were permeable, and if the general structures were such that the underground movement of the waters was active and localized so as to abstract certain impurities and concentrate the iron oxides. It is by no means evident that these necessary conditions now prevail on Belcher islands, or that they ever did prevail, except possibly at some period so remote that any ore-bodies then formed have since been destroyed.

At present the iron-formation outcrops in narrow bands but little wider than the thickness of the iron-formation—a few hundred yards at most. In every case the outcrops are on the sides or at the foot of ridges into which the strata dip and are overlain by volcanic rocks which form the upper part of the slopes and the tops of the ridges. The amount of surface water now available to produce any changes in the iron-formation is limited to that which falls on the outcrop or drains from the surmounting steep face of the overlying volcanics. This supply is trivial, and since the Glacial period it has produced practically no change. Not only is the supply of surface water very slight, but the rock structures are not favourable to a vigorous underground water movement. The overlying volcanics with their slate partings form an almost impervious capping that prevents the entry or exit of water and must give rise to a condition of stagnation so far as regards any water that may have entered the iron-formation by way of its narrow outcrop.

The present situation is unfavourable to the development of ore-bodies through the concentrating action of surface waters and it is probable that similar conditions prevailed for a long period in the past while the present land forms were developing. The stages through which the land forms passed are exemplified on Innetalling island where a valley has formed along the crest of one of the long folds in the strata. In the south this valley is only between one-quarter and half a mile in width. It is bounded by the steep faces of two parallel ridges whose tops are composed of the volcanic rocks. On the opposite slopes of the valley, the iron-formation outcrops from beneath the volcanic rocks. Northward on the island, the valley widens to several miles, but the iron-formation still outcrops as two narrow bands, one on each side of the valley at the foot of, or along the steep sides of the slopes of the bounding ridges of volcanic rocks. This single valley illustrates the various stages in the growth of all the other valleys or depressions along the sides of which the iron-formation at any stage outcropped. At very early dates in some localities the iron-formation may have outcropped so as to favour the development of ore-bodies by surface waters, but that stage has long since passed, and present conditions have so long prevailed that any ore-bodies that might have been formed in the earliest stages of development of the land forms would have been destroyed. As regards the formation of ore-bodies through the action of surface waters, three general types of structures exist on Belcher islands. The most common structure is exemplified along the eastern side of Kipalu inlet (Figure 3), where the iron-formation outcrops along the sides and foot of a steep ridge. The beds dip into the ridge at angles generally above 30 degrees and pass beneath a cover of volcanic rocks. In a distance of one mile or less down the dip the covering rocks and the underlying iron-formation pass below the sea. In a few places where the iron-formation outcrops near the top of the ridge, the cover may not be very thick, but in most places at least 100 feet of volcanic rocks, in places twice this amount, must overlie the iron-formation. In such circumstances it is difficult to conceive of any active circulation of water within the iron-formation.

A second general type of structure is developed on Innetalling island and so far as known only there. The iron-formation outcrops on the two sides of a long narrow valley. The beds slope in opposite directions away from the centre of the valley, the strata exposed being on the two sides of a fold and very close to its axis. In the southern part of the island, the general land-level sinks, and it may be that in some places the iron-formation forms the rock floor of the valley and thus is preserved on the very crown of the fold. In such a position, if anywhere, the surface waters should be capable of producing an ore-body, for along the arch of the fold the strata are likely to be fractured and permeable to water, and the long, narrow valley would afford a relatively large water supply. This valley, so far as known, is floored with drift. At its north end the rock floor cannot be much above sea-level and may be considerably below it. At the south end it lies below sea-level and it may be that throughout the entire length of the valley the iron-formation has been largely or wholly removed. If so the special opportunity for ore formation does not exist, since the conditions along the valley sides are only a repetition of the general case exemplified along the east side of Kipalu inlet.

The third and only remaining type of structure is that prevailing between Kipalu inlet and Kasegalik lake and not known to be developed elsewhere. In this district the strata have a basin-like structure, the reverse of that referred to as yielding the second type. On the west side of Kipalu inlet near its head, the exposed iron-formation dips gently to the west beneath a ridge of volcanic rocks, and reappears several miles farther west along the margin of Kasegalik lake where the beds slope to the east. The structure is not symmetrical. Northward from a valley that extends west from Kipalu inlet to a bay on Kasegalik lake, the strata form a shallow basin which widens northward and is tilted to the northeast; southward the basin is tilted southwesterly. Such a structure in conjunction with other conditions would be favourable to active underground water circulation and the development of ore-bodies. In this district, a zone rich in iron oxides and 40 to 50 feet thick, occurs at a constant horizon in the iron-formation, about 120 feet below the summit. This zone outcrops on both sides of the basin-shaped area and its existence might be taken as satisfactory evidence that surface waters influenced by the favourable general rock structure had favoured a partial concentration of the iron contents of the strata and that somewhere along the outcropping edges of the iron-formation, or perhaps down along this zone beneath the cover of volcanic rocks, bodies of high-grade iron ore may occur.

Several features, however, indicate that the iron-rich zone is an original feature of the strata. In the first place, this ferruginous zone is not exceptional. Essentially similar zones occur without definite relation to structure wherever the strata are well exposed. Wherever this rock type was observed below a certain marked level in the iron-formation, it was found to be comparatively rich in iron oxides. Secondly, there are above the level of the ferruginous zone usually one or more thick layers of rock essentially similar to that of the ferruginous zones, but always relatively barren of iron oxides. This constantly recurring contrast suggests again that the rocks do not owe their main features to changes produced by circulating waters originating at the surface.

Thirdly, the top of the iron-formation is everywhere largely composed of iron carbonate, and these rocks are relatively easily altered and, of all the strata of the iron-formation, show the greatest amount of weathering. At the surface they have a brownish coloured, decomposed, limonitic (iron oxide plus water) outer shell in place half an inch thick, whereas the other rocks are quite fresh. These iron carbonate rocks would be much altered if surface waters had freely circulated through them for a long period of time. But except for superficial weathering they are always fresh and unaltered. It is difficult to understand in these second and third cases why a lower zone should have been altered to a relatively highly ferruginous condition, whereas overlying zones of the same character or rich in the less stable carbonate should remain unchanged. The conditions suggest that circulating surface waters had little or nothing to do with the development of the iron-rich strata.

There is yet a fourth condition which does not seem to accord with the idea that the ferruginous zones owe their high iron content to the action of surface waters circulating underground. A large part of the iron oxides is, in these zones, in the form of magnetite. In places there are layers several feet thick mainly of this material. So far as known, surface waters could not form magnetite. Nor could this mineral have been produced from iron oxides formed by the action of surface waters, because no agencies capable of producing magnetite have acted since the strata have been accessible to surface waters. The presence of abundant magnetite is evidence, therefore, that much of the iron content of the ferruginous zones is not a product of the action of surface waters, and it would be strange if the other intimately associated iron oxides had been produced by surface waters which left the magnetite untouched. In other words, if surface waters have had any effect at all, they have merely changed some part of the magnetite to other iron oxides.

The writer is of the opinion that the zones relatively rich in iron were so from the beginning and that considering the extent of the iron-formation and how little of it has been examined, it is not impossible that somewhere one or more zones may grade into iron ore-bodies of commercial size and quality. If, however, these zones are secondary products, the results of the action of the surface waters, then it is evident that such activities have been widespread, and considering that for thicknesses of 50 feet the strata are of rocks that elsewhere have been replaced in part by high-grade iron ore, it is not unreasonable to suppose that somewhere high-grade ore-bodies may occur. In any case, it is certain that further prospecting should take the form of methodical examinations of cross-sections of the outcropping bands of the iron-formation, and this work—if the results obtained warrant the action—should be followed by drilling.

Summary and Conclusions

The iron-formation is known to occur in five bands, as follows, commencing with the most easterly.

(*a*) A band in the south part of Tukarak island extends probably for about 25 miles along the whole east side of this island. It reappears 12 miles to the south on the north coast of Innetalling island and extends south along the east side of this island for perhaps 18 miles. In the northern 5 miles of this stretch it is in places partly or wholly below sea-level. South of this, the formation lies below sea-level (Figure 3).

On Tukarak island, in two places the formation is 370 feet thick; on the northern part of Innetalling island it is 450 feet thick.

The strata for the most part are heavily drift covered, but are definitely known to outcrop in a band rarely more than 300 yards wide. The strata dip easterly at angles varying between 10 degrees and 30 degrees and pass beneath volcanic rocks that rise in a ridge which extends to the coast and is seldom more than a mile wide, usually considerably less.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them, is estimated to be 30 square miles.

(*b*) A band commences in the north on a small island close to the west shore of Tukarak island, and appears at intervals on some islands that extend in a line southward for 12 miles. It reappears on the north coast of Innetalling island and extends south along the west side of this island for perhaps 18 miles. South of this the formation lies below sea-level. On one of the small islands in the northern chain, the whole formation may for a short interval lie above sea-level; on the other small islands only the upper part of the formation anywhere rises above the sea. On the northern part of Innetalling island only the upper half is exposed; southward few outcrops occur.

The strata dip westward at varying angles and in places are vertical. They pass beneath volcanic rocks that rise in a ridge, seldom over half a mile wide, that extends to the coast.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 10 square miles.

(*c*) A band commences in the north on Flaherty island at the north end and on the east side of a tidal basin at the head of Kipalu inlet, extends south for 10 miles to where on the east shore of Kipalu inlet it sinks below the sea, to reappear three times for lengths of 1 to 2 miles in a further distance southward of 26 miles. South of this the formation lies below sea-level.

The strata dip to the eastward at from 30 degrees to 75 degrees. They pass beneath volcanic rocks that rise in a ridge seldom more than half a mile wide that extends to the coast.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 18 square miles.

(*d*) A band commences in the north on Flaherty island, on the west side of Kipalu inlet near its head, and for 35 miles southward occurs at intervals along the coast in stretches varying in length from a few hundred yards up to 6 miles. In some places a comparatively small part of the higher beds rises above sea-level, but in the northernmost stretch about the upper half of the formation rises above sea-level and in some of the longer stretches the whole formation is above sea-level, though almost completely drift covered. The formation doubtless extends northward towards the end of the band on the east side of the inlet, but in this direction lies beneath drift-covered flats or the waters of a tidal basin.

The strata dip westward at low angles in the north, at high angles in the south. They pass beneath volcanic rocks that rise in a ridge which extends to the shores of Kasegalik lake and to a valley extending north from this lake to the northwest shore of Flaherty island. In the south the distance across this area in places is only half a mile. Northward it increases to as much as 4 miles, and still farther north the width may be 6 or 8 miles.

The land area occupied by the iron-formation and by the volcanics with the iron-formation beneath them is estimated to be 100 square miles.

(*e*) A band commences on the northeast coast of Flaherty island and passes southerly along the east side of Kasegalik lake until, about 5 miles south of the head of the lake, it sinks below lake-level. The length of this band is about 16 miles. Whether it reappears to the south is unknown.

The strata dip easterly at, as far as known, low angles. In the south only the upper part of the formation is exposed, the lower part lying below lake-level or being drift covered. Northward the number of exposures decrease and beyond the head of the lake, for some distance at least, outcrops are rare. This band is the western edge of the above-mentioned 100-square-mile area.

In addition to the definitely known bands, the iron-formation is reported to occur on a large island lying west of Flaherty island and probably it outcrops on the southern part of the island west or south of the valley of Kasegalik lake. In the southeast, although the iron-formation nowhere outcrops, it undoubtedly is present there beneath a cover of volcanic rocks which project above sea-level and occupy a further estimated land area of 50 square miles.

The total estimated land area occupied by the iron-formation and by the volcanics overlying the iron-formation is 198 square miles; the total outcropping area of the iron-formation is not greater than 15 square miles.

The volcanic rocks overlying the iron-formation occur in sheet-like bodies. They form in each area practically continuous exposures and doubtless it would be possible to determine the approximate thickness of volcanics in any given locality. In places they are known to be 200 feet thick; it is reasonable to suppose that the maximum thickness is not greater than 400 feet or 500 feet and that the average thickness is less than 200 feet.

The total length of outcrop of the iron-formation, exclusive of the problematical areas in the south part of Flaherty island and on the island to the west, is estimated to be 110 miles, of which it is estimated only 10 miles all told are sufficiently well exposed to permit of unreservedly stating that iron ore beds are present or absent.

No iron ore deposits of commercial value under existing conditions were seen after traversing in all 40 miles of the various bands. Over most of this length it is certain that no iron ore-bodies occur in the upper one-quarter of the formation.

In each area examined on the several outcropping bands of iron-formation, highly ferruginous zones were found, and where the formation was fully exposed two or more such zones were always in evidence. With the exception of one horizon in the eastern band on Tukarak island, these zones everywhere have the same general characters. The positions of these zones in the iron-formation and their individual thicknesses vary from area to area, but in each area these characters are remarkably uniform.

In thickness the individual zones vary from 10 feet to 50 feet. Assays of samples representing thicknesses up to 24 feet and the examination of the material itself indicate that the zones are composed almost wholly of silica and iron oxides; the silica is largely in the form of quartz, the iron oxides in the form of magnetite and hematite, but a small proportion of the silica and iron oxides is combined as an iron silicate. Four representative samples gave the following results:

Silica	32·52	46·48	42·12	38·60
Iron oxides	62·04	50·05	53·84	54·62
Metallic iron	44·96	35·42	37·80	39·10

The individual zones consist of distinct beds, almost all alike in general characters but varying as regards their iron content. In general about 20 per cent of the volume consists of thin, discontinuous, highly siliceous, very lean layers. If by hand-picking these layers were removed, the metallic iron content could be raised to 50 per cent and more, but the silica content would still be 20 per cent or greater. The more purely siliceous layers are tightly welded to the other rocks and do not form zones that could be eliminated as one body, hence hand-picking would be a heavy charge against the ore produced.

The ferruginous zones represent groups of beds of rocks having many of the essential features of the rocks which yielded the iron ore-bodies of the Mesabi district, Minnesota. The associated strata are also ferruginous and might under some conditions yield an iron ore. The iron-formation has not been metamorphosed in such a fashion as to prevent the formation of ore-bodies in the way those of the Mesabi range originated.

The ferruginous zones approximate an iron ore and this may indicate that the processes which gave rise to ore-bodies on the Mesabi range also operated on Belcher islands. The failure to find ore-bodies on Belcher islands may be due to the heavy drift that covers the outcrops.

If ore-bodies of the Mesabi type are present, then by theory and experience they should occur outcropping at the bedrock surface of the bands of the iron-formation and not within the iron-formation wholly concealed by the cover of volcanic rocks.

It is considered to be improbable that the ferruginous character of these zones is due to causes such as operated in the Mesabi listrict. It seems rather that the ferruginous zones possessed their present characters when first formed or very soon thereafter. If this is so it is not impossible that somewhere they may grade into ore-bodies which, having formed when the rocks first developed, are not connected in origin with the present land surface and, therefore, may occur wholly concealed beneath the cover of volcanic rocks.

The above-mentioned two general modes of occurrence of iron ore deposits are the only known ones applicable in the case of the iron-formation on Belcher islands, and in either case it is not impossible that deposits of iron ore may occur.

Considering the, so far as known, only two possible ways in which iron ore deposits may occur on Belcher islands, the general conformity of the geological structures, the orderly fashion in which the strata of the iron-formation are grouped and succeed one another, and the regularity and constancy of the more ferruginous zones it is evident that prospecting should consist of methodical geological examinations of complete natural or artificially-bared cross-sections of the iron-formation made at intervals along the course of each outcropping band. Such cross-sections need be made only at wide intervals of say 1,000 yards or more, but would have to be supplemented by the examination of intermediate, partial cross-sections of particular horizons. In places, because of the thickness of the drift cover, diamond drilling instead of trenching or test-pitting might prove the most economical fashion of obtaining the desired information, but, in any case, drills should not be used to prospect for ore-bodies in localities back from the outcropping edge of the iron-formation until these edges have been systematically and fully examined. Until such an examination is made, the essential information requisite to ensure the success of any reasonably extensive drilling campaign will be lacking.

The annual Summary Report of the Geological Survey is issued in parts, referring to particular subjects or districts, and each designated by a letter of the alphabet. A review of the work of the Geological Survey for the year forms part of the Annual Report of the Department of Mines.

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