THE CAMBRO-ORDOVICIAN SEQUENCE IN THE SOUTHEASTERN PART OF THE CONCEPTION BAY AREA, EASTERN NEWFOUNDLAND

AVINASH CHANDRA NAUTIYAL

The Cambro-Ordovician Sequence in the Southeastern Part of the Conception Bay Area, Eastern Newfoundland

By

Avinash Chandra Nautiyal

A Thesis

Submitted in Partial fulfilment of the
requirements for the degree of
Master of Science in Geology

Memorial University of Newfoundland

August, 1966

Table of contents

Illustrations

Figure | Page

Plates

Number

Abstract

The Cambrian - Lower Ordovician rocks studied in this research program occur on Bell Island, Kellys Island, Little Bell Island and in the lower Manuels River valley in the southeastern part of the Conception Bay area, Eastern Newfoundland. They include the Wabana hematitic oolite deposits. The Cambro-Ordovician sequence of the abovementioned areas is composed of relatively unmetamorphosed fossiliferous shale and sandstone, with intercalated and interbedded beds of hematitic oolite. The ore and it's host rocks are considered to be primary, shallow-water, marine sediments; with the ore owing its existence to both physical and chemical processes.

Microfossils discovered in this research program have affinities with previously described European forms and are the first finds made in Newfoundland. Professor Van Ingen in 1914 suggested in an abstract entitled '<u>Cambrian and Ordovician faunas of southeastern Newfoundland</u>', that all the Cambrian and Ordovician faunas which occur in the Avalon Peninsula are related to the Welsh - French facies rather than to the interior North American - Northern Scottish facies, and the present study provides additional evidence in favour of his proposal.

In the stratigraphic division of the Lower Ordovician rocks of Bell Island, the writer has found it necessary to lower the status of the Wabana Group to formational level. In addition, three new formational names are proposed: Polls Head Formation, Townsquare Formation, and Airfield Formation, for stratal units of Bell Island Group. Finally, it is proposed that the Wabana Formation is conveniently divisible into Lower, Middle and Upper (Grebes Nest) Members.

Structurally, the mapped areas are uncomplex. Tilting, accompanied by minor faulting and local slumping, has effected the Cambro-Ordovician rocks. Broad folding of the strata in post-Ordovician time resulted in the development of a regional synclinal structure in southern Conception Bay.

Acknowledgements

The author is most grateful to Professor Dr. W.D. Brueckner for suggesting the problem, encouragement, help in numberless ways, and for all the facilities he made available in the Geology Department for preparation of this thesis. Financial assistance in the form of an N.R.C. Grant for the year 1965-66 was gratefully received under the aegis of Dr. Brueckner. Thanks are due to Mrs. W.D. Brueckner for translating French research papers on micropaleontology.

The author wishes to express his gratitude to Dr. R.D. Hughes for his guidance, constructive criticism, interest, and encouragement in the preparation of this thesis. The quality of this research work and writing of the manuscript was much enhanced by the discussions on several geological problems, supervision and assistance of Dr. Hughes, which are gratefully acknowledged.

The writer would like to thank Dr. V.S. Papezik of Memorial University for his assistance in identification of several minerals and the X-ray printing (diffraction pattern) of iron pyrites of the Lower Member of this report. The constructive criticisms of Dr. W.G. Smitheringale concerning the map of Bell Island, and suggestions of Professor H.D. Lilly on other problems are gratefully acknowledged.

Thanks are due to Dr. A.G. Rowell of the University of Nottingham, England, for checking identification of brachiopods from Kellys Island and Bell Island; Professor K.C. Caster of the University of Cincinnati, Cincinnati, Ohio, for suggesting probable affinities of disc-type medusoid? fossil impressions of Kellys and Bell Islands; Dr. A.G. Loomis, Loomis Laboratories, California, for chemical analyses of phosphatic nodules and coprolitic silty-shale samples.

For supplying subsurface core samples and other material, the help of Mr. Fred Bishop and Mr. W.K. Coughlan of DOSCO, Bell Island is gratefully acknowledged. The interest and cooperation of those residents of Bell Island who permitted me to examine stratal sections in basements of their houses, and the help of Mr. Fergus Joseph Power (boatman) are also gratefully acknowledged.

Thanks are due to Mr. J.M. Fleming and Mr. I. Harris of the Department of Mines, Government of Newfoundland, who made necessary arrangements in printing geological maps and parallel projections of this thesis.

The assistance of Dr. S.W. Breckon in the form of providing facilities, in the Department of Physics, Memorial University, for preparation of microfossil plates of this report is gratefully acknowledged.

Thanks are due to Mr. F. Thornhill and Mr. Albert Morgan for preparing the thin sections used in this study.

The writer is deeply indebted to Mrs. Eileen Hayes for her painstaking help in the typing of this typescript.

Miss Janet Marshall aided me greatly by her careful hand colouring of the maps of this thesis.

CHAPTER I

INTRODUCTION

Location

This thesis is concerned with four occurrences of Cambro-Ordovician sediments in the southeastern part of Conception Bay, Eastern Newfoundland (see Figs. 1 and 2), namely:

1) the lower Manuels River valley (Coordinates $47^{\circ}31'$N. to $47^{\circ}32'$N. and $52^{\circ}56.5'$W and $52^{\circ}57.5'$W.),

2) Little Bell Island (Coordinates $47^{\circ}33.5'$N. to $47^{\circ}34.5'$N. and $52^{\circ}58'$W. and $52^{\circ}59'$W.),

3) Kellys Island (Coordinates $47^{\circ}32'20''$N. to $47^{\circ}33'07''$N. and $53^{\circ}00'0''$W. and $53^{\circ}02'$W.), and

4) Bell Island (Coordinates $47^{\circ}35.6'$N. to $47^{\circ}39.5'$N. and $52^{\circ}54.7'$W. and $53^{\circ}02'$W.).

Together, these four occurrences cover an area of about 16.5 square miles.

Purpose of study

The objectives of this investigation were to study in detail the lithology, stratigraphy, and paleontology of the Cambro-Ordovician sequence within the region outlined above. Special emphases were to be given to micropaleontological investigations,

Fig.1 Index map showing Conception Bay(modified after Hayes)

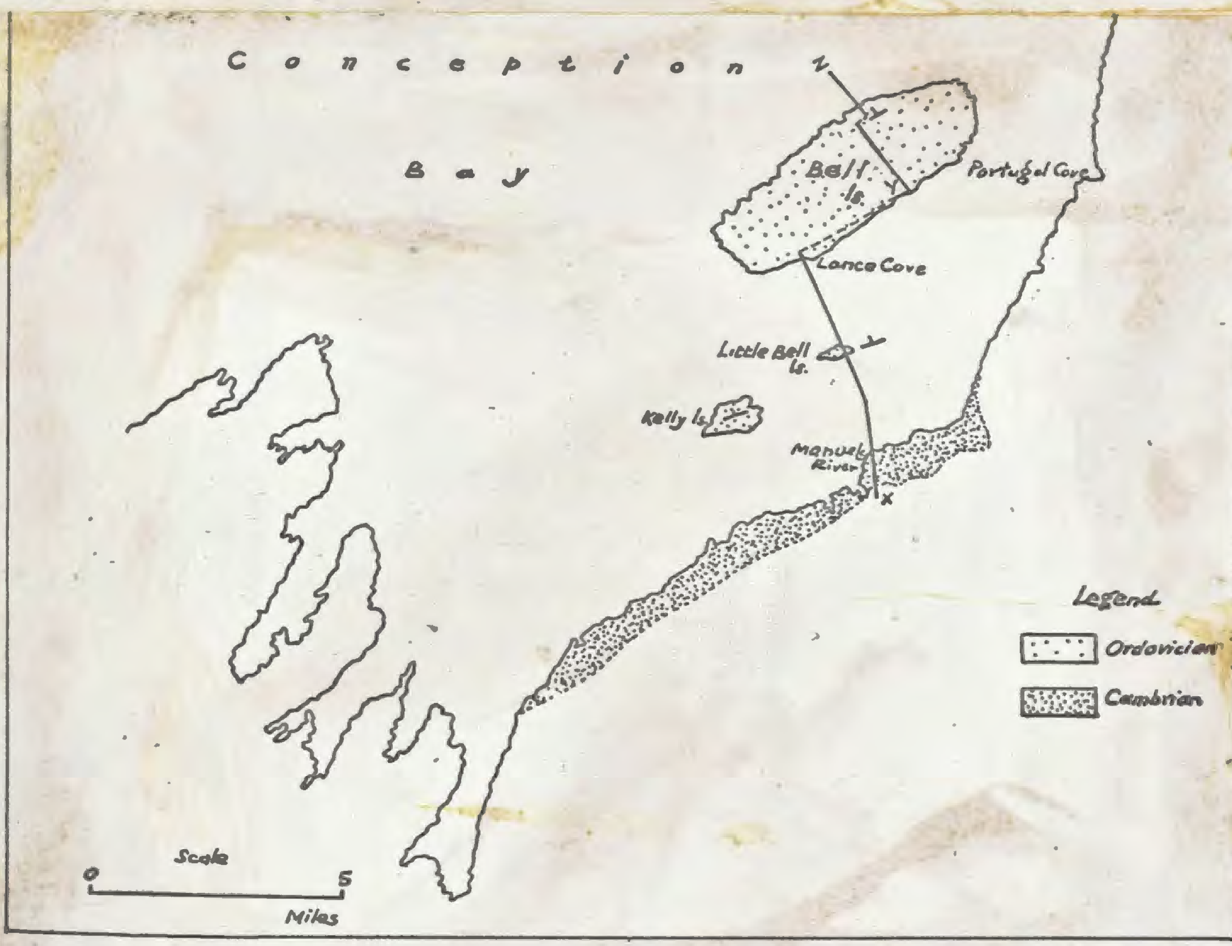


Fig.2 Map showing location of thesis area (modified after Hayes)

(See Fig.No.4,this Report)

and detailed geological maps and sections of the four separate areas were to be prepared.

Field work and accessibility

Geologic field work included in the present study was carried out during the summer months of 1965. Mapping was done on the following scales: 2.5 inches to 1 mile on Bell Island, 5 inches to 1 mile in the lower Manuels River valley, and 10 inches to 1 mile on Little Bell Island and Kellys Island.

The section in the lower Manuels River valley is exposed only on the steep banks of the valley which are accessible on foot, except at times when Manuels River is in flood, from the Conception Bay Highway (Fig. 3).

Little Bell Island and Kellys Island (see Fig. 6) can be reached by chartered boat either from Manuels Long Pond on the southeastern shore of Conception Bay or from Lance Cove on Bell Island. Of the four beaches of Little Bell Island the two narrower ones on the southern and northern sides are the best landing places. Kellys Island is accessible from all five of its beaches. Two small level areas situated on the southeast and the southwest corners of the Island provide the best camp sites. The writer mapped both Little Bell Island and Kellys Island during a period of 8 days in August 1965 from a tent camp erected at Kellys Island.

Fig.3 Showing Manuels River and Conception Bay. Part of Little Bell Island and Bell Island are also shown at distance. View N

Fig.5 Ice centers on the eastern part of the Avalon Peninsula(after W.F.Summers)

Fig.6 Bird's eye view of Little Bell Island (left) and Kellys Island (right) from Lance Cove, Bell Island. View S

Fig.7 showing of different fossil zones and stratigraphic units of Dr.Howell at left gorge, Manuels valley area. View N

Bell Island is served by a regular Car and Passenger Ferry from Portugal Cove on the eastern shore of Conception Bay. The Island has a well-developed road system from which every point, apart from the coastal cliffs, can be reached on foot with comparative ease. The coastal cliffs were investigated along their base, using a boat, as well as from the top using fixed ropes for security.

In all four areas the stratigraphic sections were studied and measured in detail, and all accessible exposed parts of the sequence were examined.

Areas concerned

An area of 0.18 of a square mile was studied in the lower Manuels River valley (see Figs. 2 and 4) where a section of about 1,000 feet of gently dipping, fossiliferous Cambrian rocks unconformably overlie the Precambrian Harbour Main group and Holyrood granite. A basal conglomerate measuring about 18 feet in thickness is exposed at Manuels River highway bridge. Fossiliferous Cambrian beds occupy the lowland which extends from Topsail Head beyond the western boundary of the map area on Conception Bay. The best, almost a continuous, section of beds is found in the lower part of Manuels River valley where rocks of Lower (?), Middle, and Upper Cambrian age are exposed. This section has been the object of detailed investigation by many of the leading students of the Cambrian since T.C. Weston's first discovery of fossils there in 1874.

In the summer of 1965 I collected shale samples from the different beds of the gorge section of lower Manuels River valley and in these discovered microplanktonic forms (Hystrichospheres), which are the first recorded find from the lower Paleozoic of Newfoundland.

The Paradoxides beds of the Cambrian section at lower Manuels River valley are of unusual interest, first, because of the detailed geological work that has been done on them by members of four geological expeditions from Princeton University especially by B.F. Howell in 1919; and, second, because a large percentage of the species of fossils occurring there are found also in contemporaneous beds of northwestern Europe.

Except for lower Manuels River valley area the sedimentary rocks of the Cambro-Ordovician sequence have been divided into Wabana Formation and Bell Island Group (see Fig. 32). The rocks of the latter group occur on Kellys Island, Little Bell Island, and are found in the northwestern part of Bell Island. About 700 feet of shale and sandstone of the group are exposed on Kellys Island, about 230 feet on Little Bell Island and some 1,500 feet on Bell Island. Although the base of the Bell Island group is unexposed, being covered by the waters of Conception Bay, nevertheless an estimated thickness of 4,000 feet for it has been given by A.O. Hayes. Little Bell Island and Kellys Island cover areas of 0.18 of a square mile and one square mile respectively and lie about 3 miles south of Bell Island.

Bell Island covers an area of about 16.5 square miles and in general consists of varying gray sandstones and shales, sandy shales, shaly sandstones with beds of red brown[1] hematitic oolite, greenish black sandstones and moderately to highly ferruginous sandstones and shales. The strata are present in the form of interbeds, intercalations, and broad lenticulations of varying thickness.

During the course of the fieldwork, it became apparent that it would be worthwhile to revise the rock-stratigraphic units proposed by Van Ingen in 1914 and by E.R. Rose in 1952. In this thesis the Wabana Group of Rose has been lowered to formational rank, but Bell Island Group has not been changed. I have subdivided Bell Island Group into three formations to which I have given the following new names, from oldest to youngest: Polls Head Formation, Townsquare Formation, and Airfield Formation. In addition I have proposed that the Wabana Formation is conveniently divisible into a Lower Member, a Middle Member, and an Upper (Grebes Nest) Member. These new rock-stratigraphic units are defined later in this report.

Previous work

J.B. Jukes in 1839 was the first geologist to note the presence of shales at Manuels, and he referred them to the

---

[1] Colour names given in this thesis are taken from the Rock-Colour Chart distributed by the Geological Society of America, 1963.

"Belle (sic) Isle" division of his "Upper Slate Formation". Alexander Murray in 1868-69 was the next geologist to work at Manuels. In his first published results of this investigation the beds at Manuels were mapped as belonging in the "Calciferous" division of the "Lower Silurian" (Ordovician) Quebec group (Logan, 1865, p. 15, pl. 1) but he did not succeed in finding any fossils in the Manuels River beds. In 1874 T.C. Weston found fossils in the Paradoxides beds in the valley of Manuels Brook identifying a species of "Microdiscus".

Dr. C.D. Walcott (1884) correlated the Paradoxides beds at Manuels with those at St. John, New Brunswick, and with "the lower part of the Menevian" of the European section.

Important field investigations were carried out during the summers of 1912, 1913, and 1914, by Professor Gilbert Van Ingen, Dr. A.O. Hayes, Dr. N.C. Dale, Dr. A.F. Buddington and B.F. Howell, all of who studied and mapped the rocks at Manuels and collected more than 3,000 fossils from the Paradoxides beds. Again in 1919 Howell examined the Paradoxides beds in the valley of Manuels River and collected about 7,000 fossils from them.

Perhaps next we should discuss the studies of these pioneer investigators in a little more detail. During the years 1842 and 1843, J.B. Jukes had made a general survey of the geology of Newfoundland and in his report (pp. 81-82) the following descriptions are found:

"On the southeast side of Kelly's Island a mass of gritstone in many beds, having a total thickness of thirty or forty feet, rises into the middle of the cliff... . In Little Bell Isle, as well as in Bell Isle itself, several bands of similar stone exist, but none of such thickness, nor in so favourable a situation for working, as in Kelly's Island."

In his report for 1868, Alexander Murray (p. 157) described a section from Manuels brook across Kellys Island, Little Bell Island, and the west end of Bell Island from Lance Cove northwards. A general geological survey of the Cambro-Ordovician of Conception Bay was made in the summer of 1912 by Professor Gilbert Van Ingen and Dr. A.O. Hayes, with the assistance of B.F. Howell of Department of Geology, Princeton University.

In 1945, Dr. D.M. Baird made a preliminary survey of Kellys Island and summarized his findings in an unpublished report entitled <u>Notes on the Geology of Kellys Island</u>.

In the Nineteenth Century anchors for sailing ships were made by Irish settlers by enclosing the heavy "red rock" of Bell Island in frames made from small fir trees but no one realized the significance of these weighty rocks until many years had passed. Finally late in the Century the economic significance of the iron ore was recognized and Bell Island property was acquired by Messrs. Butler of Topsail, Newfoundland, from whom it was purchased by the Nova Scotia Steel and Coal Company in 1893.

A description of the development of mining operations was given in 1909 by R.E. and A.B. Chambers; and in 1911 an article by Mr. Thomas Cantley reviewed the history of the mines, and described the ore beds and mining methods used in their exploration.

The following few lines have been taken from Mr. Cantley's paper:

"During the summer of 1895, when the mines on Bell Island were being opened and preparations made for large shipments of ore, Mr. Thomas Cantley gave the locality the Indian name "Wabana" which means 'The place where daylight first appears'." (26: p.5).

In his paper on the iron ores of Newfoundland (p. 751) Mr. James P. Howley gave an estimate of the approximate amount of ore stating:

"By the aid of the dip and strike of the strata, where accessible, it is possible to form a fair idea of the extent of the trough, and unless some unforeseen disturbance takes place, whereby the ore may be greatly diminished or thrown out altogether, and provided the bands maintain their thickness and stratified character throughout, the result arrived at reaches the enormous total of 3,635,343,360 tons, I shall not hazard an opinion as to the amount that may be recoverable."

On the other hand Mr. H. Kilburn Scott, M.I.M.M., of London, in 1909 (26: p. 7) estimated the tonnage of the ore on the property owned by Scotia Company to amount to about 652,500,000 tons, and total recoverable ore, deducting the waste in pillars, through faulting, and poor zones, at 395,525,000 tons.

Mr. Elwin (sic) E. Ellis and Mr. Edwin C. Eckel also have estimated the reserves of Wabana iron ore in an article entitled - The Steel Corporation Dissolution Suit, according to the Iron Age of October 16, 1913. Edwin E. Ellis, of Birmingham, Alabama, a former geologist, of the United States Geological Survey and Tennessee Coal, Iron, and Railroad Company, estimated the reserves at 3,250,000,000 tons allowing for workings 5 miles long.

"Edwin C. Eckel testified ... that in Newfoundland there were 3,500,000,000 tons of economically available ore within a radius of 5 miles of Bell Island." (26:p. 8).

The geology of Wabana ore, with reference to its origin, has been given by Dr. A.O. Hayes in 1911 in Memoir 78, of the Geological Survey of Canada, 1915, entitled Wabana Iron Ore of Newfoundland. Professor C.K. Leith and Dr. R. Beck grouped them with the Clinton ores as primary sediments.

Dr. G. Berg submitted his findings on Wabana ores in his manuscript report entitled Petrographical Studies on the Microstructure of the Wabana ores, Berlin, May 5th, 1923.

Dr. A.O. Hayes' further work on Cambro-Ordovician sequence was published in two papers: Further studies of the origin of the Wabana Iron Ore of Newfoundland and Structural Geology of the Conception Bay Region, and of the Wabana Iron Ore Deposits of Newfoundland, in Economic Geology Vol. XXIV, No. 7, November, 1929, and Vol. XXVI, No. 1, January - February, 1931.

In the summer of 1961 William M. Jordan, a graduate student of Columbia University, New York, measured in detail the stratigraphic sections of the cliffs of Bell, Little Bell, and Kellys Islands. His field notes were not made available to me until after I had completed my field work, and they have not been used in the preparation of this thesis.

Geomorphology and Quaternary geology

Drainage

In general, the areas are poorly drained owing to the fact that they are covered with a mantle of drift of varying thickness left by an ice sheet, or sheets, which advanced over the areas during the last glacial advance in late Pleistocene time. Another contributing factor is marshy land which retains meteoric waters, especially in the eastern and western part of Bell Island, significantly preventing the development of an efficient drainage system.

The only major drainage area is in lower Manuels River valley where the river contributes clastic material to the southern part of Conception Bay.

Relief

In general, the areas have low relief with an average altitude of 180 feet above sea level, and slope gently northward. The flat-topped surfaces of Little Bell, Kellys and Bell Islands have altitudes of about 75, 175 and 300 feet respectively. The lower Manuels River valley has a maximum altitude of about 100 feet ranging down to sea level.

The surface areas, especially on Bell Island, Kellys and Little Bell Islands, are interrupted by occasional ridges, hills and valleys. The ridges and hills are made up of resistant sandstone rocks, and the valleys are a reflection of underlying shales.

Glacial geology and geomorphology

Almost all the areas are covered by a fairly thick mantle of glacial drift. Good exposures of till are found along the top faces of cliff sections as high as the grass line; as well as in road cuts, artificial pits, and building excavations. This material is unsorted and is composed mainly of clay, sand, and boulders, ranging up to several feet across. Drift is found, especially well exposed, in a section at the mouth of Manuels River. The drift has a characteristic light grayish-brown colour, becomes a paler shade when dry but turns dark brown after a rainfall. In Manuels valley the drift material was found to range from 1 to 20 feet in thickness, 1 to 2 feet in thickness on Little Bell Island, 1 to 5 feet on Kellys Island, and to vary up to about 4 feet in thickness on Bell Island. Boulders, cobbles, and pebbles of Precambrian granite and rhyolite are common in these areas. Some of these show glacial striae.

Due to active wave erosion Kellys and Little Bell Islands have been cliffed on all sides and remain as erosional remnants of a series of formerly continuous gently-dipping sediments. On the southeastern corner of Kellys Island there occurs a cusped spit made up of boulders, cobbles, and pebbles constituted of varying types of sandstone derived from the nearby cliffs which border a lagoon. The surface of the Island is crossed by linear cuestas and hollows marking either underlying resistant sandstones or soft shales. These cuestas can be seen near the southern cliffs of the Island.

The surface of Little Bell Island is nearly flat except for the west-central part which reaches an altitude of up to 100 feet above sea level. As at Kellys Island the rocks have been cliffed on all sides of the Island, and also locally border a lagoon on its southeastern side. Little Bell Island is covered with a blanket of glacial drift from 1 to 2 feet deep through which sandstones crop out at several places. The blanket of glacial drift can best be observed along the cliff tops, where wave erosion has produced good sections from the upper limit of bedrock up to the grass line. Glacial erratics came mostly from Precambrian rocks occurring on the nearby mainland.

On Kellys Island a thick blanket of glacial drift (from 1 to 5 feet deep) covering the Island can be observed along the cliff tops especially at the northern corner. Wave erosion has resulted in a cliff section and a blanket of glacial drift can be observed along the edge of the cliff reaching from bedrock up to the grass line.

According to Stuart E. Jenness (30: pp. 174-175)

"... ice movement throughout the peninsula was from the higher central areas coastward. Because of the unusual configuration of the Avalon coast line, the ice masses commonly moved in opposing directions on either side of the long bays. This has certainly happened in Trinity and Conception bays and presumably also in Placentia and St. Mary's bays. It follows therefore that centers out of which the ice flowed on the Avalon peninsula lay along the spines of each of the four narrow peninsulas. W.F. Summers (1949, unpub. M.Sc. thesis, McGill Univeristy) has suggested the existence of three former centers." (see Fig. 5).

CHAPTER II

Geology of Lower Manuels River Valley, Little Bell Island, and Kellys Island

About three thousand feet of unmetamorphosed sedimentary rocks underlie Bell Island and dip about 9 degrees to the north-northeastward. The horizontal distance across these strata from the Cambrian conglomerate on lower Manuels River valley to the highest beds on Bell Island is about 8 miles, of which approximately 3 1/2 miles is beneath the waters of Conception Bay (see Fig. 2). Exposures of Bell Island group occur on Kellys and Little Bell Islands midway between Manuels River valley and Bell Island, and constitute a thick section of over 1,000 feet. Bell Island group sediments were deposited either as interbeds, intercalations, or broad lenticular beds of varying thickness and extent. Individual minor lenticular rock units characteristically thin out within distances of 10 to 100 feet, although some of them are more continuous laterally than others. Cross-bedding and ripple marks (interference and symmetrical type) are very common within the sandstones indicating that they were deposited in marine sea waters so shallow that wave effects were able to disturb the sea floor sediments. Sedimentary rock units varying in thickness up to 200 feet, composed of sandstone and shale layers, are exposed on cliff faces. The ore beds of Bell Island show features common to shallow water tidal deposits, and appear to have been deposited usually in thicker individual layers than those of contiguous rocks. The thicker beds of hematitic oolite, commonly accompanied with greenish black sandstones, are the most competent rock units found on Bell Island.

The oolitic iron ore and ferruginous sediments occur within four formations on Bell Island. These are given in stratigraphical order and described in Chapter III. The relationship of these formations is shown in accompanying tables in that chapter.

Lower Manuels River valley

The Avalon Peninsula, on which Manuels River is situated, is composed of a complex of Precambrian igneous and sedimentary rocks.

The oldest rocks among the Precambrian, described by Buddington as the Avondale volcanics, are overlain unconformably by the Cambro-Ordovician sequence at Manuels River southeast of Bell Island.

Outcrops of rhyolite are present south of Manuels River bridge. Holyrood granite and a Paleozoic basal conglomerate are found below the bridge and younger Cambrian beds follow in succession northwards downstream. The dip of thePaleozoic rocks is approximately 10 degrees northward. No major faults or thrusts were detected anywhere in the section of the valley.

The rhyolite (see Table 1) of the Harbour Main group constitutes the oldest (?) rocks of the section, and varies in colour and texture from place to place. The greenish-gray colour of the volcanic rocks of the eastern bank of the River gradually grade into chocolate brown towards the western bank. The rocks characteristically are composed of light brown phenocrysts of feldspars in an aphanitic matrix, are highly jointed in N.70°W., N.30°E., N.60°E., N.50°W., and N.75°E. directions, and probably are intruded by the Holyrood granite. Beginning at Manuels River bridge this granite is overlain by an 18 foot thick conglomerate bed composed of pebbles and cobbles derived from the adjacent Precambrian rocks and cemented with a silty and siliceous matrix. The conglomerate is coarsest at its base and overlain by a thin bed of pinkish blue limestone which is partly argillaceous, pyritiferous, and silicified.

Overlying the limestone is a shale which grades upwards into a hard grayish-red shale bed of about 2 feet in thickness. It is overlain, in turn, by a 6 inch bed of red and green shale which grades upwards into a 1 foot thick grayish-purple limestone which is nodular, pebbly, and pyritiferous in character and contains fragmentary fossils including trilobite exoskeletons. This is further overlain by olive-gray shale beds containing occasional black nodules as well as specimens of Paradoxides and microplanktonic (?) forms (see PlateVIII, Fig. 13) and having a total thickness of about 30 feet. A stratum of medium dark-gray shale measuring 6 inches in thickness and containing flattened black oval nodules overlies the fossiliferous shales. The next youngest strata are hard green shales which contain occasional manganiferous calcareous nodules. These beds measure 2.6 feet in thickness and grade upward into a unfossiliferous variegated manganiferous shales in which are found occasional flattened nodules.

Above these beds are found the lowermost beds of Howell's Paradoxides bennetti zone (see Fig. 7). This zone has a total thickness of about 230 feet and is made up of a medium dark gray to dark gray shales with thin olive shale interbeds. An angular-pebble sandstone bed, 2 inches in thickness, is intercalated with the shales and exhibits occasional disseminated pyrite crystals and anhedral grains. These shales of varying character are described in Table No. 1. This zone is highly fossiliferous and fossils collected from it have been listed in the same table. A Middle Cambrian age has been assigned to it by Howell, based on the contained trilobite fauna.

The next overlying beds are included in the Paradoxides hicksi zone by Howell. The beds are medium dark gray to dark gray shales with a rich Paradoxides fauna but devoid of hystrichospheres. The zone is about 35 feet thick and Middle Cambrian in age according to Howell. Overlying it is a 30 foot thick zone termed the Paradoxides davidis zone by Howell. It is mainly dark gray to grayish black shales, ranging from soft to hard, pyritiferous, and fossiliferous with trilobites, hystrichospheres, and brachiopod shells (Eoorthis bellicostata ? Walcott) in nodular beds (see Table No. 1). Fine grained sandy, micaceous, clay ironstone

Table No. 1

Upright Section of Cambrian Beds along lower Manuels River (see Map No. 1)

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
12	Orusia lenticularis zone Shale; dark gray, non-calcareous, fissile, soft, partly micaceous; Baltisphaeridium parvispinum Deflandre, B. microcladum Downie, Micrhystridium rhopalicum Sarjeant, M. parvispinum Deflandre, M. parincospicuum Deflandre	50
11	Agnostus pisiformis and Olenus zones Shale (70%); dark gray, non-calcareous, fissile, soft, papery, interbedded with sandstone (30%), dark gray, non-calcareous, fine-grained, micaceous	450
10	Paradoxides davidis zone Shale; medium dark gray to grayish black, non-calcareous, fissile, pyritiferous, hard but also occasionally soft, containing fine-grained sandy, micaceous clay ironstone lenticles and sometimes concretions common with lower surface, nodular, rich in brachiopods; Eoorthis bellicostata? Walcott, Micrhystridium parvispinum Deflandre, M. parincospicuum Deflandre, Paradoxides davidis Salter, Eodiscus sp..................................	30
9	Paradoxides hicksi zone Shale; medium dark gray to dark gray, non-calcareous, fissile, occasionally pyritiferous, soft and hard varieties; Paradoxides sp.	35
8	Paradoxides bennetti zone Shale; medium dark gray to dark gray with occasionally interbedded olive shales of 1/2 to 1 inch in thickness, occasionally calcareous at some places, highly fossiliferous zone, and fissile; Acadagnostus acadicus (Dawson), Bailiaspis sp., Bailiaspis howelli Hutchinson, Dikelocephalus (?) sp., Eodiscus punctatus (Salter), Corynerochus minor (Walcott), Andrarian globiceps jaculator (Howell), Paradoxides davidis Salter, Pardailhania cf. barthouxi (Mansuy), Peronopsis (Acadagnostus) matthewi (Hutchinson), Peronopsis cf. P. quadrata (Tullberg), Peronopsis (Acadagnostus) scutalis (Salter in Hicks), Protolenus (Bergeronia) elegans, Sao hirsuta Barrande, Syspacephalus laticeps Rasetti, Syspacephalus sp. Syspacephalus tardus Rasetti, Agnostus pisiformis Linnaeus	100

Unit No.		Thickness Feet
	Shale; dark gray to medium dark gray with occasional 1' thick beds of olive shale which at places contain black nodules, fossiliferous and occasionally pyritiferous. A 2" thick bed of brecceous pebbly sandstone occurs in between the shales	105
	Shale; medium dark gray to dark gray with occasional black nodules which sometimes contain manganese contents, fissile. These shales have thin lenses of limestone and gray sandstone, in some places interbedded with 1 to 1 1/2' thick olive-coloured shales consisting of black nodules and rare fragmentary trilobites; <u>Paradoxides</u> sp.?	25
7	Shale; red and green, unfossiliferous, manganiferous with occasional flattened nodules	10
	Shale; green, hard with occasional manganiferous calcareous nodules	2.6
	Shale; medium dark gray, non-calcareous, fissile, with more or less flattened oval nodules	0.6
	Shale; olive gray, non-calcareous, with occasional black nodules; <u>Paradoxides</u> sp., Microplankton?	30
6	Limestone; grayish purple, nodular and pebbly, pyritiferous, with occasional 3" thick pyrite veins; fragmentary fossils	1
5	Shale; red and green, partly calcareous, hard, partly fissile	0.6
	Shale; grayish red, non-calcareous, hard, partly fissile	2
	Olive shale; olive gray, non-calcareous, partly fissile.	
4	Limestone; pinkish blue, partly shaly, pyritiferous, partly silicified	?
3	Conglomerate; medium gray, non-calcareous, coarse grained with pebbles and cobbles and angular fragments of quartz, chalcedony and rhyolite	18
2	Plutonic rocks (Precambrian) Granite; grayish pink, leucocratic, medium to coarse grained, with phenocrysts of pink feldspar	?
1	Volcanic rocks (Harbour Main Group) (Precambrian) Rhyolite; chocolate brown, fine grained, porphyritic with phenocrysts of light gray sodic plagioclase and fragments of volcanic rocks, occasionally flow-banded	?

lenticles and occasional concretions are common in the shales. This zone is of Middle Cambrian age according to Howell.

The _Paradoxides_ _davidis_ zone is overlain by a 450 foot thick zone called _Agnostus_ _pisiformis_ _obesus_ and _Olenus_ fauna zone by Howell. It is made up mostly of soft dark-gray paper shales (about 70%) with interbedded dark-gray sandstones (about 30%). The zone is devoid of hystrichospheres, and is Upper Cambrian in age according to Howell.

The overlying youngest zone was called _Orusia_ _lenticularis_ by Howell (see Fig. 8) and is made up of soft dark gray shales containing hystrichospheres. It is of Upper Cambrian age according to Howell, and constitutes the uppermost zone of the gorge section at the valley.

Little Bell Island

On Little Bell Island are found about 230 feet of unmetamorphosed and almost undisturbed sediments which are best exposed in cliff faces and dip 9 degrees to the north-northeastward. These rocks form part of the Cambro-Ordovician sequence and occur on the eastern limb of the syncline which occupied part of Conception Bay (see Fig. 9). At the location of what is now Little Bell Island and Kellys Island a great thickness of sediments were deposited in an early Paleozoic ocean basin which later underwent depression by progressive subsidence.

Fig.8 Photograph shows exposure of Orusia lenticularis zone of Dr.Howell at left gorge, Manuels River area. View N

Fig.9 lower strata of the Polls Head Formation (alternating sandstones and shales) at southwestern coast, Little Bell Island. View N

Sedimentological and paleontological evidence from Little Bell Island sedimentary rocks indicate they are of shallow marine origin (see Fig. 10).

Table No. 2 shows the succession of the different types of sedimentary rocks exposed in the Island cliffs and on its surface.

The sedimentary beds of the section, mostly sandstones and shales, were measured on the northern, southern, eastern and western cliffs of the Island. The table also lists important microfossils discovered by the writer during the course of this investigation.

The sandstones normally are either light olive gray, light gray or medium gray in colour with well-sorted quartz grains. At some horizons the sandstone beds are partly quartzitic. They usually occur as interbeddings, intercalations, lenticulations and partings in the shales. At the southern cliff section are found slabby sandstones which could be used as excellent building stone.

The shales are light to dark gray, soft, partly silty and contain conspicuous amounts of mica flakes on bedding surfaces. Some shale beds are fossiliferous containing hystrichospheres.

Along the southern side of the Island the cliff is about 100 feet high whereas the northern end is only about 50 feet above sea level.

Table No. 2

Section studied in detail on Little Bell Island, (Locality 419 P to A; see Map No. 2), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
419, P	Sandstone; pale yellowish brown, non-calcareous, fine grained, massive, hard. This member constitutes the topmost part of the sequence at Little Bell Island	5
O	Sandstone (100%); light olive gray, non-calcareous, fine grained, massive, partly micaceous, highly jointed (produces loose slabs in the rock exposure in the cliff of the northwestern coast), with occasional intercalations of 8 inch thick grayish-olive sandstone beds	30
O'	Sandstone (100%); dark gray, non-calcareous, fine grained, micaceous	3
N	Shale (60%); dark gray, non-calcareous, soft, fissile, interbedded in upper part with sandstones (40%). The shale in contact with sandstones grades into silty shale	16.3
M	Sandstone (80%); light olive gray, non-calcareous, medium grained, jointed, the joint planes constitute a rhomb pattern, fossiliferous (with brachiopod shells); at the contact with shale the rock shows shale pebbles up to 1 inch long and 0.6 inch thick, interbedded with shale (20%); Lingulella ibicus Walcott	27.6
L', L	Shale (70%); medium dark gray, non-calcareous, soft and fissile; Baltisphaeridium brevispinsoum (Eisenack), B. microspinosum (Eisenack)?, Micrhystridium stellatum Deflandre, M. lejeunei Stockmans and Williere, Archaeohystrichosphaeridium, ?Cymatiosphaera sp. indet. Sandstone (30%); medium gray, non-calcareous, medium grained, micaceous, with very fine mica flakes; rock occurs in form of interbeddings, intercalations and lenticulations with shale	40

Unit No.		Thickness Feet
K	Sandstone (100%); very light gray, non-calcareous, micaceous, the joints contain secondary quartz veins up to 0.6 inch in thickness. This sandstone occurs in large slabs and is suitable for building construction	8.9
J	Sandstone (100%); medium gray, calcareous, medium grained, micaceous; with 6 inch thick coating of ferruginous matter	1
I	Sandstone; similar to H but intercalated with 1 inch thick sandstone, medium gray, soft and highly micaceous	17.5
H'	Shale (75%); medium gray, non-calcareous, highly micaceous, soft, fissile and papery, interbedded with sandstone; Leiofusa tumida Downie, Archaeohystrichosphaeridium, indeterminate form.	
H	Sandstone (25%); light gray, non-calcareous, fine grained, banded with very fine muscovite flakes, current bedded with interference and symmetrical ripple marks; the rock is partly iron stained with encrustations	11.3
G	Sandstone (100%); light gray, non-calcareous, medium grained, partly sorted, rarely pebbled. The pebbles range up to 1 inch long	7.3
E	Shale (60%); medium dark gray, non-calcareous, soft, fissile, interbedded with sandstones. Sandstone (40%); light gray, non-calcareous, fine grained, symmetrical ripple marks	7.5
F	Sandstone (100%); similar to D, but interbedded with 6 inch thick bed of sandstone; medium gray, non-calcareous, micaceous, asymmetrical ripple marks and load casts	18.9
D	Shale (65%); dark gray, non-calcareous, soft, papery, with worm borings and tubes, interbedded with sandstones; Veryhachium rhomboidium Downie. Sandstone (35%); light gray, non-calcareous, fine grained, micaceous, banded, occurs in form of interbeds, intercalations and lenticles, current bedded, symmetrical ripple marks (miniature), with occasional blue brachiopod shell fragments	11

Unit No.		Thickness Feet
C	Sandstone (100%); medium gray, calcareous, medium grained, micaceous with non-calcareous dusky brown ferruginous coating. This sandstone grades upward into non-calcareous type with pebbles (2 cms. long) which are ferruginous, silty and micaceous	6
B	Sandstone (50%); light gray, non-calcareous, fine grained, partly micaceous, current bedded, interbedded with shales, can be used as building stone. Shale (50%); light green, non-calcareous, micaceous and papery	10
A	Sandstone (50%); medium gray, non-calcareous, fine grained, partly micaceous, banded, current bedded with miniature interference ripple marks, occasionally occurs as scour-and-fill structures or balls in shales interbedded with shales. Shale (50%); dark gray, non-calcareous, soft and papery. These strata are present at the foot of cliff .... (see Pocket Fig. No. 16).	6

The lithological characters of the sandstones and shales, which range from non-calcareous to partly calcareous, are shown in Table No. 2.

Kellys Island

The various units of the sandstones and shales of the cliff section of Kellys Island were measured in detail especially along the eastern coast of the Island. On the Island are found sedimentary rocks measuring about 700 feet in thickness which have been divided into nine members in this report (see Map No. 3). Dr. Hayes (1911) has proposed that the rocks of Kellys Island are part of a Cambro-Ordovician sequence forming the eastern limb of a syncline occupying the southeastern part of Conception Bay.

The sandstones are similar to those of Little Bell Island. In general they are light to medium gray in colour, are made up of well-sorted quartz grains, and have a microcrystalline texture. The constituent grains vary from angular to rounded in shape and are well cemented. The sandstones occur in the form of either interbedded or intercalated lenticles, roll-up structures (see Fig. 11), or thin partings within enclosing shales. The more massive sandstone beds range in thickness up to 20 feet. Some light-gray sandstones of the southeastern and southern part of the Island could provide excellent building stone.

The shales range in colour from light gray to black and are soft. Some of the shale units are silty and sandy, and the

Fig.10 Symmetrical ripple marks in medium gray sandstone, northern coast, Little Bell Island. Top of picture north. View from above.

Fig.11 Photograph shows a sandstone bed with roll-up and rounded structure at northern coast, Kellys Island, View E

remainder contain conspicuous amounts of muscovite flakes on bedding surfaces. Owing to high percentages of mica, certain silty shales are finely fissile. Most of the shale beds are highly fossiliferous and contain species of Lingulella and hystrichospheres. Fossils are less common in the arenaceous shale beds than in the non-arenaceous ones. In the southern coast cliff section the thickness of the shale series, which contains some interbedded sandstones, is about 100 feet.

Some of the sandstones occur as lenses interbedded with shales (see Fig. 12) but the thick-bedded massive members are continuous, with only local thinning, over the whole Island. However, the thin-bedded sandstones are of more limited lateral extent. The details of the measured sections, especially for the eastern coast of the Island, are shown in Table No. 3. The sequence (see Fig. 13) shown in the table was measured along the shoreline from the southern end (near the southeastern beach), along the northern and eastern coasts of the Island, up to the top of Big Head Cove (see Map No. 3). The top beds of the sequence occur in the cliffs between Martin Cove and Big Head Cove, and along the base of the cliff at the beach on the southern shore. The sequence, except for the upper 70 feet, is exposed at low tide along the eastern side of the Island and is readily accessible, but along the southeastern, western and north-central coasts of the Island considerable small boat work and cliff climbing is necessary to gain access to the different horizons of the sections.

Fig.12 Showing a sandstone lenticle in dark gray papery shales, eastern coast, Kellys Island, View W

Fig.13 Part of studied section No.420 at southeastern and eastern coasts, Kellys Island. View W

As in Little Bell Island, the Kellys Island sediments also exhibit evidences of shallow water deposition (see Fig. 14).

Three sandstone beds (see Table 3, 420, S), with a composite thickness of approximately 8 feet through a total stratigraphic interval of about 32 feet, contain about 50% chamosite and are highly ferruginous.

The shales and some sandstones, especially at localities Nos. 420, R to 'a' along the eastern, southwestern and northeastern coasts, are highly ferruginous. At the latter two places iron content of the beds result in iron-stained groundwater springs.

Fig.14 Interference ripple marks in a gray sandstone bed, northwestern coast, Kellys Island. View SSW

Fig.15 Showing northeastern coast cliff section, at the base of which an organic (medusoid?) fossil impression was found in sandstone, Kellys Island. View NNE

Table No. 3

Section studied in detail on eastern coast of Kellys Island (Locality No. 420 k to A, see Map No. 3); from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
	Kelly's nine member:	
420, k	Sandstone (95%); medium dark gray, slightly calcareous, fine grained, partly banded owing to very fine mica flakes, massive, jointed, interbedded with shales. Shale (5%); medium gray, non-calcareous, soft, papery. These strata constitute the top of the sequence between Martin Cove and Big Head Cove, at Kellys Island	16
	Shale (50%); dark gray, non-calcareous, soft, interbedded with sandstones. Sandstone (50%); light gray, medium grained	50
	Sandstone (100%); medium gray, poorly calcareous, fine grained	4
	Kelly's eight member:	
j	Shaly sandstone (50%); dark gray, non-calcareous, micaceous, fissile, with brachiopod shells and worm tracks, interbedded with light gray sandstones (50%) which in their upper parts show current bedding, and interference and symmetrical ripple marks	20
i	Sandstone (100%); light gray, partly calcareous, medium grained, with very fine mica laminations	5
h	Shale (50%); dark gray, non-calcareous, soft, interbedded with sandstones. Sandstone (50%); light gray, partly calcareous, and medium grained	21
	Sandstone (90%); medium gray, non-calcareous, fine grained. Shale (10%); dark gray, soft, papery	4

Unit No.		Thickness Feet
g	Shale (60%); dark gray, very poorly calcareous, fissile, papery, interbedded with sandstones. Sandstone (40%); medium gray, non-calcareous	9
f	Sandstone (100%); medium light gray, non-calcareous, fine grained; with blue fragmentary brachiopod shells and occasional shale pebbles	20
e	Shale (80%); medium gray, non-calcareous, silty, interbedded with sandstones. Sandstone (20%); medium gray, non-calcareous, and fine grained	3.8
d	Sandstone, shaly sandstone and shale; Sandstone; dark gray, non-calcareous, fine grained, jointed; worm burrowed, with interference and symmetrical ripple marks, occurs interbedded with dark gray shaly sandstones and laminated dark gray shales	1.3
c	Sandstone (100%); dense black, non-calcareous, fine grained, occurs as lenticulation with 0.6 foot long shale pebbles and blue fragmentary brachiopod shells	1.6
b	Shale (60%); dark gray, non-calcareous, soft, occasional worm borings; *Leiofusa jurassica* Cookson and Eisenack?, *Veryhachium rhomboidium* Downie, *Baltisphaeridium brevispinosum* var. *nanum* Deflandre, *B. brevispinosum* var. *Wenlockensis* Downie, *B. microcladum* Downie, *Micrhystridium* sp., *M. stellatum* Deflandre, ? *Cymatiosphaera* sp. indet. Sandstone (40%); medium gray, non-calcareous, fine grained in alternating 1 foot thick beds; uppermost 1.6 feet thick horizon is very rich in blue fragmentary brachiopod shells	12.11
	Kelly's seven member:	
a	Sandstone (95%); medium gray with light greenish tinge, interbedded with shales. Shale (5%); medium gray, non-calcareous, silty, micaceous, with asymmetrical ripple marks and worm borings	11
	Kelly's six member:	
Z	Shale (60%); dark gray, non-calcareous, silty, micaceous, fissile, hard with worm borings, occurs interbedded with sandstones.	

Unit No.		Thickness Feet
	Sandstone (40%); medium gray, non-calcareous, fine grained, banded owing to layerings of blue fragmentary brachiopod shells	2.3
Y	Sandstone (100%); medium dark gray, calcareous, fine grained, banded owing to blue fragmentary brachiopod shell concentrations and very fine mica flakes layerings	3.1
X	Shale (60%); dark gray, non-calcareous, interbedded with sandstones. Sandstone (40%); medium dark gray, non-calcareous, medium grained	15.3
	Kelly's five member:	
W	Shale (100%); dark gray, non-calcareous, papery; <u>Veryhachium</u> cf. <u>formosum</u> Stockmans and Williere	6.8
V	Sandstone (100%); dense black, non-calcareous, fine grained with blue fragmentary brachiopod shells	1.6
U	Shale (70%); dark gray, occurs interbedded with sandstones. Sandstone (30%); occurs in medium gray, pale-greenish and ferruginous dark-brown colours, non-calcareous, fine grained, present in form of lenticulations and interbeds. Two disc type (medusoid ?) organic fossil impressions were discovered in sandstones which are medium dark gray, partly shaly, micaceous, symmetrically ripple marked and current bedded; the strata are up to 3 inches thick (see Fig. 15)...........................	48.6
	Sandstone (75%); partly calcareous, medium grained, occurs interbedded with dark gray shales (25%)	6.2
T	Shale (70%); dark gray, papery, interbedded with sandstones. Sandstone (30%); medium gray, non-calcareous, occasionally banded due to concentrations of very fine mica flakes, fine grained	37.9
S	Sandstone (70%); medium dark gray with greenish tinge (owing to chamosite), partly calcareous, and ferruginous, fine grained, current bedded, occur interbedded with dark gray shales (30%)	5.5

Unit No.		Thickness Feet
R'	Shale (60%); dark gray, non-calcareous, occur interbedded with medium dark gray sandstones. Sandstone (40%); symmetrically ripple marked, current bedded; with brachiopod shells; Lingulella ibicus Walcott	20.9
R	Sandstone (80%); medium dark gray with greenish tinge, the upper 1.6 feet are medium dark gray in colour, interbedded with dark gray shales (20%); Veryhachium sp., Baltisphaeridium sp., B. brevispinosum var. nanum Deflandre, B. brevispinosum var. wenlockensis Downie, Micrhystridium sp.	7.8
Q	Shale (50%); medium dark gray, non-calcareous, fissile, highly fossiliferous with several species of Lingulella and one unidentified trilobite pygidium, interbedded with sandstones (50%); light gray, non-calcareous, but 4 feet thick sandstone beds in uppermost part are medium dark gray with greenish tinge; Lingulella ibicus Walcott, L. fostermontensis (Butts), L. moosensis Walcott, L. concinna Matthew, L. waptaensis Walcott, L. rotunda Matthew	20
	Kelly's four member:	
P	Sandstone (100%); medium gray, non-calcareous, medium grained, micaceous	15.5
	Sandstone (50%); dark gray, non-calcareous, fine grained, partly lenticular grades up into sandstone similar to O; interbedded with dark gray shales (50%), occasional 0.6' thick sandstone concretions	7.8
	Kelly's three member:	
	Sandstone (85%); light olive gray, non-calcareous, fine-grained, occasionally show lenticulations in its lateral extension, interbedded with shales (15%); dark gray, non-calcareous, papery	8.3

Unit No.		Thickness Feet
O	Shale (70%); dark gray, non-calcareous, papery, with scour-and-fill structures of current-bedded sandstones. Sandstone (30%); medium dark gray, non-calcareous, medium grained	17.4
	Sandstone (100%); light gray, non-calcareous, fine grained, highly jointed	1.3
	Shale (60%); dark gray, non-calcareous, papery. Sandstone (40%); medium gray, non-calcareous, medium grained, micaceous	18.4
	Sandstone (90%); light olive gray, non-calcareous, fine grained, with shale (10%); dark gray, non-calcareous, papery	10.8
	Shale (80%); dark gray, non-calcareous, papery. Sandstone (20%); medium dark gray, non-calcareous, medium grained; in upper part occur as lenticles (3 to 4 inches long and upto 1 inch in thickness) in shale bodies	7.2
	Sandstone (100%); light olive gray, non-calcareous, fine grained	6.1
N	Sandstone (100%); light gray, partly calcareous, medium grained, micaceous, show rolled and rounded structures	1.6
M	Shale (75%); dark gray, non-calcareous, papery, interbedded with medium gray, fine grained sandstones (25%)	8
L	Sandstone (75%); medium light gray, non-calcareous, fine grained. Shale (25%); dark gray, non-calcareous, papery, occasionally show scour-and-fill sandstone structures up to 2 inches in length	5.9
K	Shale (80%); dark gray, non-calcareous, soft and papery, interbedded with sandstones; *Baltisphaeridium brevispinosum* var. *nanum* Deflandre, *B. brevispinosum* var. *Wenlockensis* Downie, *Micrhystridium stellatum* Deflandre.	

Unit No.		Thickness Feet
	Sandstone (20%); medium grained, non-calcareous, micaceous	14.3
J	Sandstone (100%); medium gray, non-calcareous, and medium grained	10.3
	Sandstone (100%); similar to 419 (O) of Little Bell Island	21.1
	Kelly's two member:	
H'	Sandstone (80%); medium dark gray, non-calcareous, medium grained, micaceous, interbedded with shales. Shale (20%); dark gray, non-calcareous, papery and fossiliferous; Lingulella chapa Walcott, L. ibicus Walcott, L. fostermontensis (Butts)	5.7
G	Sandstone (70%); medium light gray, non-calcareous, fine grained, micaceous, interbedded with 1.6 ft. thick sandstones having rolled and rounded structures. Shale (30%); dark gray, non-calcareous and soft	14.7
F	Sandstone (80%); medium grained, non-calcareous, fine grained, with roll-structure, rock is interbedded with shales. Shale (20%); dark gray, non-calcareous, soft; with 6 inch long sandstone concretions; Lingulella ibicus Walcott	10.3
E	Shale (60%); medium gray, non-calcareous, soft and fissile, occurs interbedded with sandstones. Sandstone (40%); medium gray, non-calcareous, medium grained, micaceous, up to 6 inches thick	4.1
D	Sandstone (95%); the lower 1.9 foot thick bed is medium gray, non-calcareous, medium grained, micaceous and banded, the upper 1.7 foot bed is light gray, poorly calcareous and is similar to 419 (O) of Little Bell Island. The sandstones are laminated with shale (5%); Veryhachium sp., V.? irregulare Jekhowsky, Baltisphaeridium sp., B. longispinosum (Eisenack)? B. brevispinosum var. wenlockensis Downie	3.7

Unit No.		Thickness Feet
C	Shale (80%); dark gray, non-calcareous, soft and papery, interbedded with sandstones; Lingulella fostermontensis (Butts). Sandstone (20%); medium gray, non-calcareous, micaceous, medium grained, occurs as lenticular and rounded structures	39.1
	Kelly's one member:	
B	Sandstone (95%); similar to 419 (0) of Little Bell Island, but occasionally shows its cherty nature and shale laminations (5%) of medium gray colour; Lingulella ibicus Walcott	27.9
A	Shale (80%); medium dark gray, non-calcareous, soft, fissile, with brachiopods (Lingulella), and worm trails; interbedded with sandstones; Veryhachium sp., Baltisphaeridium brevispinosum (Eisenack). Sandstone (20%); medium gray, non-calcareous, fine grained, micaceous. The strata are exposed in the lower part of the sequence and extend under the beach along southern shore of Island .... (see Pocket Fig. No. 16)	100

Petrography

Lower Manuels River valley

Precambrian Rocks

Precambrian basement rock most probably provided the main source for the Cambro-Ordovician sedimentary rock constituents and therefore it appears appropriate to include a note on the nature of the Harbour Main volcanics and Holyrood granite which flanked the Lower Paleozoic depositional basin.

Rhyolite (Sample No. A1)

The rhyolite belongs to Harbour Main group which mainly consists of volcanic rocks with minor amounts of interbedded sedimentary strata. This part of the group comprises flow-banded rhyolite including a chocolate brown variety (see Fig. 17), and is exposed in the lower Manuels River valley. In general these acidic flows are silicified, sericitized, and chloritized.

The rhyolite varies in colour, partly in texture, and composition. It is fine grained, dense, massive, and locally porphyritic with megascopic phenocrysts of light-gray sodic plagioclase feldspars accompanied by fragments of volcanic rocks. However, at some places it exhibits flow-banding in combination with the above features. Silica, in the rock is present mainly in the glass, and the microcrystalline aggregate of feldspars and quartz (rare) commonly constitute about 70 to 80 percent of the rock. The chocolate brown colour of the rhyolite results from hematitic constituents which occur commonly in finely disseminated specks. At some places the microcrystalline aggregates are concentrated in flow-bands.

Petrographic descriptions:

The fine-grained groundmass in an aggregate of feldspar laths, chlorite folia, and glass. The feldspar crystals are oriented in a semi-parallel alignement providing evidence of flowage. Greenish-yellow epidote, zoisite, magnetite and apatite (very rarely) are present in disseminated specks. At some places the rock shows amygdules of zoisite with characteristic radiating aggregates.

Feldspar phenocrysts (albite and orthoclase) show alteration into minute scales of sericite. Occasionally the feldspar phenocrysts show perthitic intergrowths and inclusions of zoisite and chlorite. The latter mineral is found mostly along the cleavage planes of the feldspars and often outlines zoned structure with a skeletal pattern of its arrangement (see Fig. 18). According to Dr. V.S. Papezik of Memorial University, it seems probable that part of the glassy material was trapped in the feldspar phenocrysts during crystallization and was later devitrified into chlorite.

The abundance of chlorite in the rock suggests that there was a hydrous environment at the time of crystallization

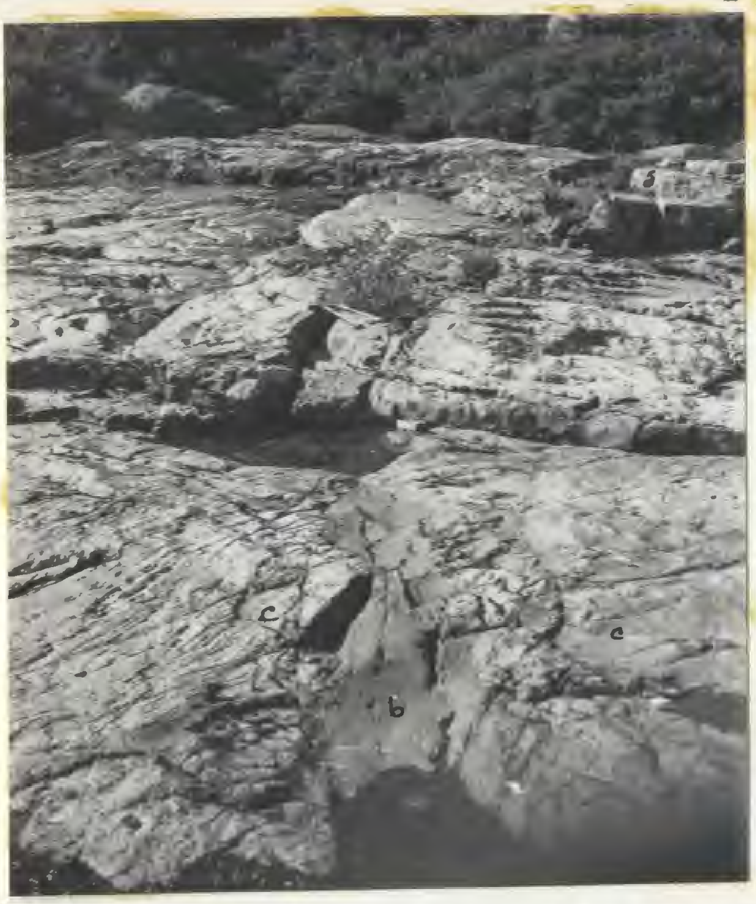


Fig.17 Photograph of rhyolite showing brown(b) and chocolate brown(c) modes. Outcrop located on south side(upstream) of Manuels bridge. View W

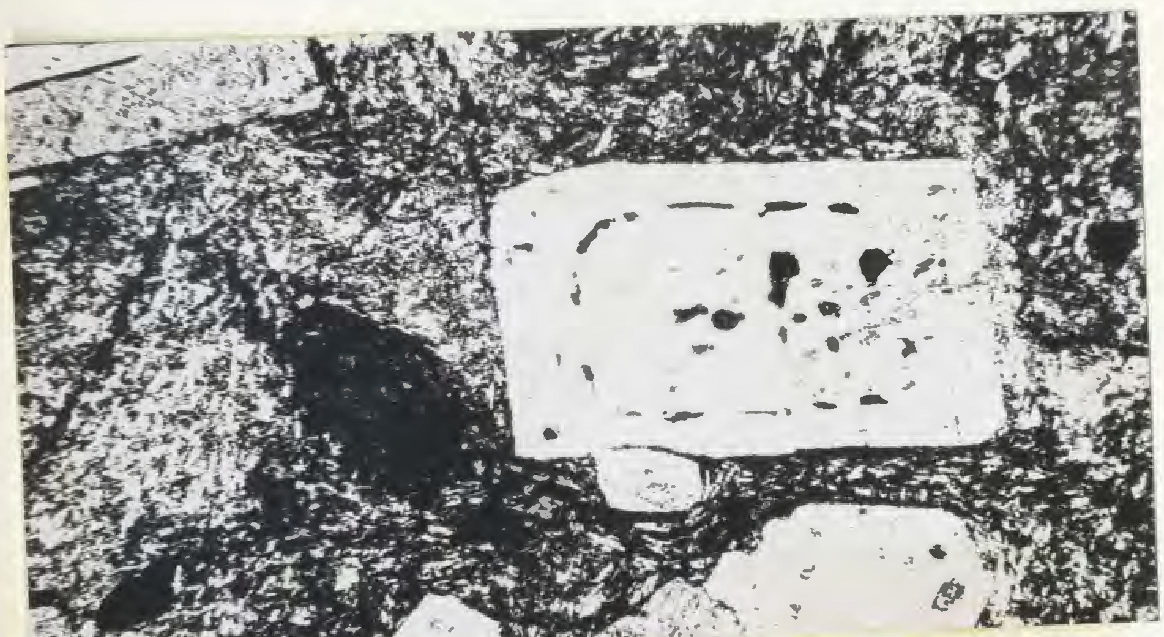


Fig.18 Photomicrograph of rhyolite showing phenocrysts of plagioclase feldspar with chlorite outlining, Sample No.1A, Manuels River valley. x266(approx.)

which might have speeded the transformation of several silicate minerals into chlorite with an accompanying decrease in viscosity of the lava favouring coarser crystallization of feldspar (phenocrysts).

Heavy mineral studies of rhyolite specimens yielded epidote (platy form), zoisite, chlorite with rutile inclusions, magnetite with occasional inclusions of apatite euhedra.

Granite (Sample No. 2 A)

The rhyolites of the Harbour Main group are intruded by the younger Holyrood granite immediately south of the bridge over Manuels River. The granite is grayish pink (leucocratic) in colour, medium to coarse grained and contains occasional phenocrysts of pink feldspar ranging up to 0.3 inch in length.

Petrographic characters:

The rock has inequigranular allotriomorphic texture with variable sizes of quartz, feldspar, and magnetite grains. The feldspars and quartz exhibit microperthitic (see Fig. 19) and micrographic intergrowths; and phenocrysts of feldspars occur in an equigranular groundmass made up of quartz, feldspar and chlorite. Some feldspars have been altered into sericite and partly chloritized. The feldspars (albite, oligoclase and orthoclase) and quartz are essential minerals of the rock and make up about 90% of the area of thin section whereas chlorite (alteration after biotite and feldspars), magnetite, zircon, muscovite constitute about 10% of it.

Potential sedimentary rock heavy minerals found in the Holyrood granite include euhedral zircon and rutite anhedra but rarely magnetite and epidote.

Conglomerate (Sample No. 3)

The rock is medium gray, coarse grained with quartz, chalcedony and rhyolite pebbles and cobbles. The matrix is medium to fine grained siltstone with siliceous minerals, while the coarser constituents are commonly angular. A thin section of a sample of the rock contained pebbles and cobbles of quartz, chalcedony, rhyolite, and feldspars (with perthite variety) well cemented with green coloured chlorite, muscovite (sericite) mica, quartz and siliceous cement. The heavy minerals are magnetite and zoisite.

The predominating greenish colour of ferruginous matrix points to reducing conditions of deposition either in a marine or in a lacustrine environment.

Limestone (Sample No. 11)

Paradoxides bennetti zone of Dr. Howell

Rock light brownish gray, very fine grained (massive) but with occasional recrystallized pink crystals of calcite, fragmentary tests of trilobites are found throughout the rock. This limestone occurs interbedded in shales.

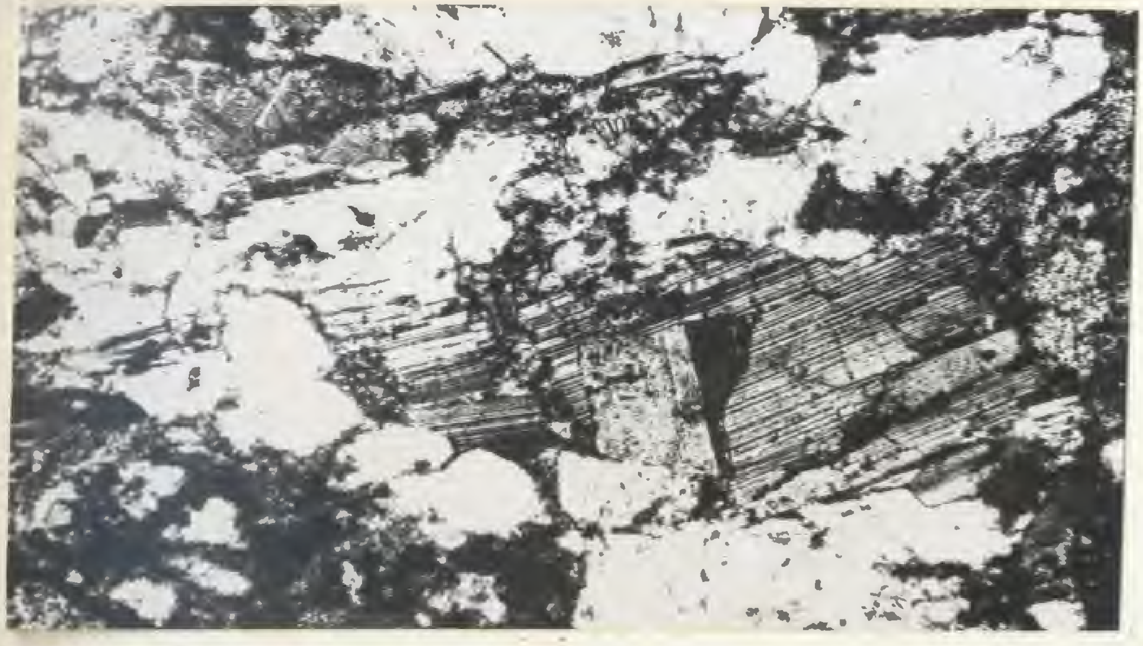


Fig.19 Photomicrograph of granite showing microperthite structure in plagioclase feldspar. Sample No.2A, Manuels River valley. X266(approx.)

Fig.20 Photomicrograph of limestone exhibiting trilobite test fragements. Sample No.11, Paradoxides benneti zone of Dr.Howell, Manuels River area. X266(approx.)

A thin section cut perpendicular to bedding planes (see Fig. 20) exhibits very fine-grained calcite constituting the groundmass which in most places is replaced by recrystallized calcite. Fragmentary tests of trilobites are found scattered throughout the groundmass.

Impure Limestone (Sample No. 7, Lower Cambrian)

Rock medium gray, very fine-grained, partly silicified with light gray to moderate red jasper (?) which contains prominent pyrite veinlets.

A thin section cut parallel to bedding exhibits a partly silicified shaly part which is mostly replaced by chlorite and calcite. Muscovite flakes and iron oxide stains are common in the groundmass. At the contact zone (shale and limestone) the groundmass is partly replaced by recrystallized calcite, and exhibits veinlets of pyrite up to 1/8 inch in width. Limestone adjacent to the contact is partly silicified and chloritized.

Manganiferous Bed

A chocolate brown, very fine grained, calcareous, partly cherty and baritic manganiferous stratum is found in the Manuels River valley intercalated with shale of Middle Cambrian age. In the field the bed shows more or less rectangular joint pattern. A hand specimen from this bed is crossed by thick, laminated chocolate-red bands and thin bands of green-edged pale-yellow colour. The boundaries between the different coloured layers are usually extremely sharp. A light gray cherty layer in the rock shows local chocolate-brown and light-gray lenticles of barite.

A thin section cut perpendicular to bedding shows alternating colour layers of chocolate-brown and light-gray (see Fig. 21). The former is made up of rhodochrosite (colourless rhombs) and some barite. These minerals frequently are stained with hematite and, in part, with chocolate-brown cobalt compounds. The light-gray layer is made up of rhodochrosite and barite minerals but devoid of hematite and cobalt stains. This layer also shows the lenticles made up of barite. Also present is a thin band of green-edged pale yellow material which suggests that enrichment of baritic solutions, probably with associated chromium solutions, occurred at the time of deposition. The intensely black material results from minute grains of manganese oxide found scattered throughout the rhodochrosite minerals. Extremely fine grains of quartz are occasionally found disseminated within the rhodochrosite. In short, microscopically, the ore is essentially an extremely fine-grained admixture of rhodochrosite and barite.

Recently a chemical analysis, by P.A. Mohr and R. Allen, 1965, of a sample from the manganese bed of the same locality indicate the following significant relationship of the trace elements:

"Manuels, Conception Bay (single samples)

	Co	Ni	Cr	V	Cu	Mo	Zr	Ba
Red	22	7	5	8	-	5	5	5,000
Dark brown	10	10	15	10	-	-	10	1,000
Green	10	32	12	-	-	5	10	1,000
Pale gray	5	5	12	8	10	5	5	220"

(76: p. 336).

The result indicates cobalt and nickel solutions were available and account for the staining of the described minerals of the rock at the time of deposition.

<u>Shale</u> (Sample No. 5, Lower (?) Cambrian)

Rock greenish gray, noncalcareous, partly fissile. A thin section cut parallel to bedding exhibits microcrystalline aggregates of silt-sized grains of feldspars (albite, orthoclase); quartz, magnetite, muscovite flakes, rarely epidote and zoisite are found in the cryptocrystalline matrix of chlorite and clay minerals. Most of the silicate minerals (feldspars and biotite) are either completely or partly altered into chlorite. At a few places muscovite flakes exhibit a more or less parallel orientation.

<u>Shale</u> (Sample No. 15, Upper Cambrian)
(<u>Orusia</u> <u>lenticularis</u> zone of Dr. Howell)

Rock dark gray, noncalcareous and fissile. A thin section cut perpendicular to the bedding exhibits minerals oriented on bedding plane surfaces, but locally silty fragments seem to have been randomly oriented during deposition of the rock. The minerals are stained with iron oxides. The occurrence of hystrichospheres is the characteristic paleontologic feature of the rock. In other characters this specimen is similar to shale sample No. 5 (Lower (?) Cambrian).

Clay ironstone (Sample No. 16)
(*Paradoxides hicksi* zone of Dr. Howell)

Rock medium dark-gray, intercalated with shales, non-calcareous, partly fissile. Pyrite crystals in the form of bands are arranged along the bedding planes.

A thin section cut perpendicular to the bedding plane exhibits microcrystalline aggregates of muscovite flakes and a partly silty fraction of feldspar and quartz in a very fine-grained (cryptocrystalline) matrix of clay minerals and secondary chlorite. Pyrite crystals are found disseminated throughout the matrix as well as concentrated in bands.

Little Bell Island

Sandstones

The sandstones of Little Bell Island comprise thick units of light to medium dark-gray, greenish-gray sandstones. These are comprised of subangular to rounded grains of quartz, ranging in size from 0.06 to 1 mm. in diameter, well sorted with minor amounts of feldspars, ferromagnesian minerals and accessory zircon, zoisite and magnetite. These grains occur in a minor argillaceous, chloritic and, very rarely, calcareous groundmass. Carbonate minerals are characteristically lacking. Only four samples (Nos.: 419, C, J, L and O) contained calcareous cement. In general, the quartz grains are loosely to tightly held together by the cementing material. Some sandstones showed banding owing to oriented mica (muscovite and biotite) flakes and occasional oriented fragmentary brachiopod shells. Only one sample (419, C) shows significant iron mineral contents (Fe_3O_4) in the groundmass. Chlorite constitutes the main cementing material in the groundmass of some of the sandstones (for instance sample Nos. 419: O, O", B, C, H).

The rocks in general show equigranular microcrystalline texture. Common accessory minerals are zircon, zoisite, magnetite and biotite (secondarily chloritised) in sample Nos. 419: B, C, H, J, L, O, O', P".

Microscopically the sandstones and shales show essentially the same minerals. Some of the more interesting rocks are described in detail in the following paragraphs:

Sandstone (No. 419, B)

A thin section cut perpendicular to the bedding exhibits mostly subangular, subrounded to rounded quartz grains, with diameters measuring about 0.07 mm., but rare feldspar (albite and orthoclase) grains. The constituents are cemented with sericite, minor chlorite and clay minerals, and locally with siliceous minerals. Muscovite flakes are scattered throughout the matrix and some are curved indicating that during compaction of the rock they underwent stress. The rock shows equigranular microcrystalline texture. Among the accessories the zircon (with its zoned variety also), zoisite, magnetite, biotite, and chlorite are common but leucoxene is rare. At places iron oxide staining was seen. Heavy mineral analysis yielded the same minerals as those listed above.

Sandstone No. 419, O (see Fig. 22)

A thin section cut perpendicular to the bedding plane shows that about 70% of the two dimensional sample are quartz grains of subangular to subrounded shape with diameters of about 0.10 mm. They are densely packed with chlorite (secondary after biotite) making up about 25% of the section. The matrix is partly calcareous and sericitic and has a microcrystalline equigranular texture. Magnetite, zircon and zoisite are present as minor minerals and constitute about 5% of the section.

Fig.21 Photomicrograph of a thin section of manganese bed showing rhodochrosite (colourless minerals) and a barite lenticle, Manuels River area. X70(approx.), under crossed nicols.

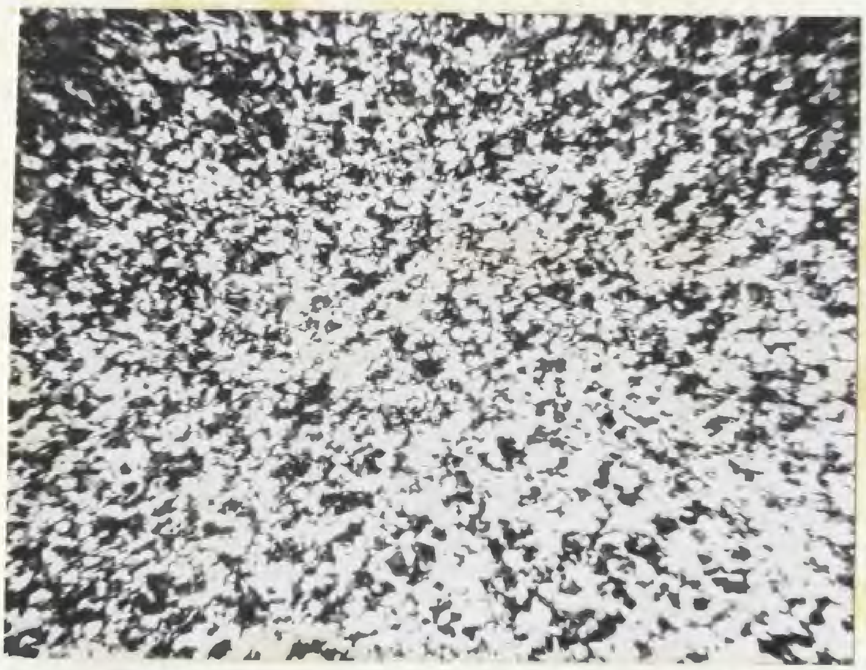


Fig.22 Photomicrograph of sandstone, showing densely packed and cemented quartz grains with chloritic and sericitic matter. Sample No.419,0,Polls Head Formation. X70(approx.), under crossed nicols.

Shales

The shales of the Island are dark gray, papery, soft and fissile with rich amounts of mica flakes, commonly with very fine-grained aggregates of comminuted quartz and carbonaceous material in a predominatly argillaceous groundmass. Some shales (see Table No. 2) are fossiliferous and yield microplanktonic fossils. Magnetite anhedra, biotite flakes and, very rarely, chlorite (secondary after biotite) are scattered throughout the groundmass. For example sample No. 419, L' (see Fig. 23) is a highly micaceous shale with some silt content.

Kellys Island

The lower part of the cliff section of the Island, comprising sandstones and shales, can be correlated lithologically, microscopically and on micropaleontological evidence with the sandstones and shales of Little Bell Island.

Sandstones

The microscopic character of most of the rocks of Kellys Island are similar to Little Bell Island but shales of the upper part of Kellys Island Formation yield rich faunas of inarticulate brachiopods (see Table No. 3), especially where there is an increase in silt content. One rock sample (No. 420, d) shows recrystallization of an original microcrystalline calcareous groundmass into very fine rhombs of calcite.

In addition to common accessories, such as zircon, zoisite, magnetite, and biotite (somewhat chloritised), leucoxene is found in sample Nos. 420: A,B,D,E,F,G,H,K,R',k,r,Y. Some of the sandstones, for instance 420,H, show peculiar habits of zircon including six-sided euhedra, both with and without zoning, and oval to rounded grains with inclusions.

Some sandstones are shaly (for instance 420: K,R' and d) with the sandy part making up about 60% and the shaly part about 35 - 40% presenting a banded appearance.

Banded sandstone (No. 420, H)

A thin section cut perpendicular to bedding shows quartz grains of subangular to subrounded shape with an approximate size of 0.08 mm., and these are closely held together with sericitic, chloritic, and siliceous cement. The rock shows equigranular microcrystalline texture. The muscovite flakes are oriented in one direction giving a banded appearance of the rock. Among the accessories large zircon crystals with various habits are very common while zoisite and magnetite crystals are rare.

Shaly sandstone (No. 420, R')
(see Fig. 23)

A thin section cut perpendicular to the bedding exhibits angular, subangular and subrounded quartz grains cemented with a micaceous shaly matrix. The grains in the micaceous shaly part are loosely cemented by argillaceous material, whereas in the other parts they are partly tightly interlocked and partly loosely cemented. In the silty shale part of the rock the mica (muscovite and biotite) flakes are oriented in one direction and this characteristic gives a banded structure to the rock. Zircon, zoisite, leucoxene, magnetite and chlorite are the accessory minerals.

Chamositic sandstone (No. 420, R)
(see Fig. 24)

A specimen thin section exhibits spherules and oolites of chamosite (about 50%) of 0.05 mm. in size with subangular to subrounded quartz grains (about 15%) with 0.01 - 0.10 mm. in size set

Fig.23 Photomicrograph of shaly sandstone showing shale bands in sandy part. Sample No.420,R', Polls Head Formation. X70(approx.), under crossed nicols.

Fig.24 Photomicrograph of chamositic sandstone showing sandy part in calcareous cement. Sample No.420,R,Polls Head Formation. X70(approx.), under crossed nicols.

in a calcareous groundmass with occasional recrystallized calcite rhombs. The accessory minerals (about 5%) include biotite, chlorite, magnetite, leucoxene and various iron oxides.

Shales

The shales of the lower part of the cliff section are more or less similar to Little Bell Island rocks but the middle and upper part of the formation exhibits an increase in silty content and occasional zircon needles are found in this type of shale, for instance in sample No. 420, G.

Silty shale No. 420, Q (see Fig. 25)

The constituent muscovite flakes and subrounded quartz grains range in size from 0.01 to 0.08 mm. and are cemented with an argillaceous and micaceous matrix. The mica flakes are oriented in one direction and are partly curved indicating stress effects obtained during compaction of the sediment. The shaly part constitutes about 80% and sandy about 20% of the rock. Zircon, zoisite, leucoxene, magnetite, are the accessory minerals. The rock is stained with iron oxides.

Modal Analysis

Point counter modal analyses were made by the writer of two Little Bell Island sandstones and one Kellys Island sandstone. These sandstone specimens contained unusually high amounts of chlorite. The results of the analyses are as follows:

LOCALITY		Little Bell Island		Kellys Island
Sample No.		419 O'	419 c	420 B
Percentage of different minerals	Quartz	46.5	61.8	52.9
	Chlorite	48.4	12.4	43.8
	Magnetite	2.73	-	1.8
	Zircon	1.3	0.4	0.4
	Zoisite	0.54	0.4	0.4
	Feldspar	0.2	-	-
	Hematite	-	6.02	-
	Muscovite	-	-	0.4
	Groundmass (sericitic and chloritic)	-	18.8	-
	Total	99.67	99.82	99.70

Sedimentary Structures

The more interesting sedimentary structures present in the lower Manuels River valley include cross-bedding in the sandstones, intercalations of sandstone and shale, and clay ironstone concretions of variable size, ranging from 1 inch up to 10 inches, in the shales.

On Little Bell Island macro- and micro-ripple marks (symmetrical and interference type) are visible at the base of nearly every sandstone bed. In most of the sandstones cross-bedding is marked. Worm tracks and trails are rare on the Island. In only one sandstone bed were seen roll-up and rounded structures and load cast features. The sandstones and shales of the Island provide evidence of shallow water origins.

The Kellys Island sedimentary rocks provide evidence, as do those of Little Bell Island, that they too are of shallow water origin. At the base of nearly every sandstone bed symmetrical and interference ripple marks and channeling features are common. Numerous channel fillings of sandstone on shale substrata are found especially along the eastern and western coasts of the Island. Cross-bedding commonly is present in the sandstone units despite their variation in other features. Small trilobite tracks and trails have been abundantly preserved in the dark gray silty shales of the southeastern and northwestern coasts of the Island but are very rarely found in light-gray sandstones. The latter sandstones, however, contain occasional giant trilobite tracks at some horizons. Load casts were seen in only a single light-gray sandstone member on the southwestern coast of the Island.

Structural geology

In the lower Manuels River valley a well marked unconformity occurs between the Paleozoic basal conglomerate and the underlying Holyrood granite. Four faults are present on the west side of the valley. Two are found about 800 feet from the river mouth and the other two a further 1,200 feet upstream. The attitudes of the faults are shown on Map No. 1. The true dip and strike of the third fault upstream from the mouth was not measurable. Shale beds adjacent to its fault plane have been locally crushed and crumpled.

In the valley walls at some places the shale beds are slickensided on their bedding planes. This slickensiding probably took place as gently tilted shale beds slid toward the north in a series of diminutive movements as a result of small scale gravity tectonics. These slickensided surfaces show hardening effects.

On Little Bell Island the sedimentary rocks dip gently at about 9 degrees north-northwestward and strike N.75°E. This regional structural attitude corresponds to that of the Kellys Island rocks, however, on Little Bell Island at two faulted areas the local dips abruptly change to 40 and 70 degrees.

Two normal faults occur in the northern cliff of Little Bell Island. The first, located at about the middle of the Island (see Fig. 26), has a throw of 12 feet and strikes northwestward with a dip of 40 degrees to the northeastward. The second fault

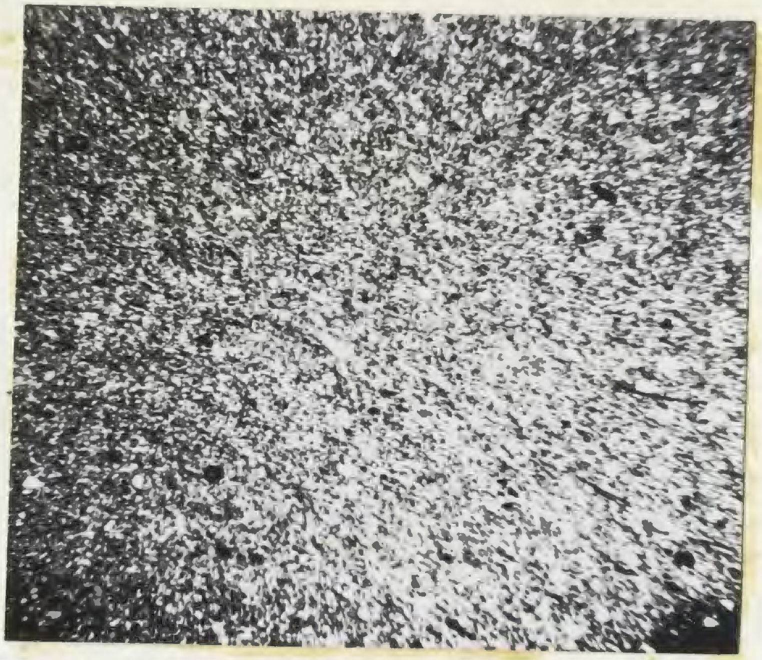


Fig.25 Photomicrograph of silty shale showing very fine quartz grains. Sample No.420,Q,Polls Head Formation. X70(approx.), under crossed nicols.

Fig.26 Picture shows a normal fault, with a throw of 12 feet, located at about middle of the northern cliff coast, Little Bell Island. View SSE

(see Fig. 27) is present near the eastern end of the northern cliff, strikes N.65°W., dips 70 degrees to the northeastward and is downthrown for 5 feet on the west.

Strata on Kellys Island strike about N.75°E., and dip about 9 degrees to the northward. The Island has two slightly elevated areas. These occur near the south-central cliff and on the northwestern coast of the Island. They form part of two prominent sandstone ridges. Two normal faults and one reverse fault were mapped on Kellys Island. The first can be seen at western end of the southern cliff face and has a throw of 11 feet. It strikes N.55°W. and dips 80 degrees to the northeastward. The other normal fault is found on the northwestern cliff of the Island and has a throw of 9 feet, strikes N.55°W. and dips 46 degrees to the northeastward. The reverse fault is present on the northwestern cliff of the Island also and strikes N.70°W., dips 55 degrees to the northeastward, and has a throw of 5 feet (see Fig. 28). Close to the fault planes the sandstones and shales have been highly sheared and some of the associated fractures infilled with secondary calcite veins.

A number of small displacements and minor slickensided structures on the bedding planes of the rocks were observed on Kellys Island.

At several places the light-gray sandstone facies of the Kellys Island sequence exhibit peculiar roll-up and rounded structures (see Fig. 29), and large sandstone structures of lenticular to spherical

Fig.27 Shows a normal fault with a throw of 5 feet near eastern coast of the northern cliff, Little Bell Island. View SSW

Fig.28 Normal fault with a throw of 5 feet at the northwestern cliff coast of Kellys Island. View SE

shape varying from one to six feet in diameter. Shales occupy the concavities and interstices of the sandstone roll-up structures, and shale bedding parallels the contorted bedding surfaces of these sandstone structures. Micaceous shaly laminations and very fine mica bandings are present inside the sandy structures. The roll-up sandstone structures are very prominent in the thicker beds, especially in the northeastern cliff, as contrasted with their less prominent development in the thin-layered beds.

D.M. Baird proposed three alternative theories for the origin of these roll-up sandstone structures but later he rejected all of them. Nevertheless these three suppositions are worth mentioning at this point. They are as follows:

1) Preconsolidation concretionary structures.
2) The sandy masses represent channel fillings.
3) Preconsolidation slumping.

Concerning their formation, Dr. Baird finally wrote that they may have been produced when:

"a sandy layer was slid down on top (of) a soft yielding mud, and that locally masses of the heavy sand would sink through the mud squeezing it up through between similar adjacent masses. This would account for the fact that the shaly layers are parallel to the outside of the sandstone masses, and that the structure becomes more prominent in the thicker parts of the beds. Weathering would remove the shaly facies first leaving exposed the bulging masses of sandstone." (4: p. 4).

In my opinion the abovementioned points numbered 1 and 2 are improbable explanations for these structures. That there may be some possibility for the acceptability of point No. 3 is evidenced by fine shale laminations which are parallel to the original beddings in these features. However taking into account the presence in several localities of slickenside structures (see Figs. 30 and 31) at the contacts between the roll-up sandstone and overlying and underlying shaly facies rules out a "preconsolidation concretionary structure" origin as mentioned in point No. 1. The writer has observed hook-shaped and several roll-up structures in sandstones which were undoubtedly results of slumping in the manner described by P.E. Potter and F.J. Pettijohn, 1963 (see Fig. 33). The writer believes that these structures are the result of preconsolidation slumping on the gently tilting slope of a depositional basin. This conclusion is also supported by several distorted specimens of brachiopod (Lingulella) valves found on the bedding planes. The direction of movement observed above and below the slumped planes was northwards.

D.M. Baird's third hypothesis about their origin could not explain the presence of slickensides (see Fig. 31) between the roll-up sandstones and shale beds. However Baird had assumed that the structures were formed while the strata were flat lying. On the contrary either tilting or deposition on a slope appear to have been present at the time the roll-up structures and slickensides were formed. The two most important factors in the origin of these structures are, in my opinion, the unconsolidated nature of the sediments and the declivitous environment in which they were forced to slump under the 'pull' of gravity.

Figure 33 shows a hypothetical origin for hook-shaped and roll-up structures in sandstones.

Fig. 29 Showing a sandstone bed (see arrow) with roll-up structure at the northern cliff near eastern coast, Kellys Island. View SE

Fig. 30 Photograph shows scour and fill of gray sandstone in shale(see overlying strata) and roll-up and rounded structures in gray sandstone(see underlying strata) at eastern coast, Kellys Island, View W

Fig. 31 Showing roll-up sandstone structure with slickenside surfaces at northern cliff near eastern coast, Kellys Island. Tape uncoiled for one foot for scale. View E

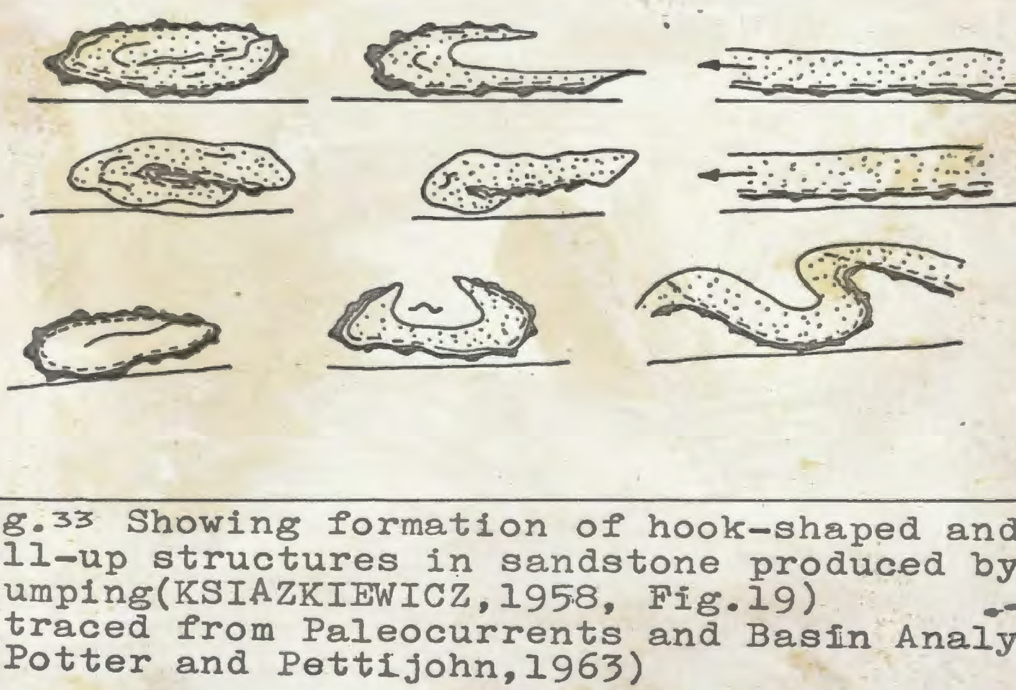


Fig. 33 Showing formation of hook-shaped and roll-up structures in sandstone produced by slumping(KSIAZKIEWICZ,1958, Fig.19)
(traced from Paleocurrents and Basin Analysis, Potter and Pettijohn,1963)

CHAPTER III

Geology of Bell Island

The writer's research on the geology of Bell Island understandably did not result in the solution of all problems therein occurring! Indeed, many remain unsolved and would in themselves each provide material sufficient for a M.Sc. thesis. As examples of these the following two scientific problems and one technical problem (the latter requiring only sufficient finances to resolve) are brought to the reader's attention.

Rich accumulations of micas (muscovite and biotite) and zircon in the sandstones of the Cambro-Ordovician sequence present a problem with reference to their origin. There appears to be no known source provenance in adjoining areas of Newfoundland for the supply of such detrital minerals.

A part of the sequence between Manuels River valley, Kellys Island and Bell Island (see Fig. 2) is under water and hence it will be difficult to locate the boundary between the Cambrian and Ordovician rocks until submarine cores become available. This is a technical rather than a scientific problem.

Concentrations of microplankton (hystrichospheres and chitionozoa) especially in chloritic and phosphatic nodules found in the Airfield Formation and in the Middle and Upper Members of the Wabana Formation provided a very interesting situation. The writer believes that there may be a significant relationship, between the chitin of the tests of microplankton and chloritic and phosphatic material, which might have favoured the concentration and preservation of these tests. However, this is an opinion and the real reasons for this relationship remains a problem still to be solved by further research. Tests also have been preserved where microorganisms were eaten by 'worms', and their indigestable hard parts became concentrated in 'worm' excreta which, on lithification, became microfossiliferous coprolites.

Further research studies may throw new light on the three above mentioned problems.

Ages inferred by previous workers in thesis area:

The sequences of rocks in lower Manuels River valley range from Precambrian to Cambrian in age. The younger shales are rich in trilobites which have been assigned a Cambrian age by Dr. Howell.

A.O. Hayes notes (29: p. 4) that Professor G. Van Ingen in his field work of 1912-13 reported Lingula howleyi, and Lingulella billingsi as being index fossils found in the strata of Kellys Island and Little Bell Island respectively, and rock units of both Islands were assigned an age of Lower Arenig by him. Professor Van Ingen suggested a Lower Arenig age for the Bell Island ferruginous sandstones and hematitic oolite, making up the newly proposed Polls Head Formation, owing to occurrences in the beds of the following index fossils: Obolus burrowsi, Sphaerobolus fimbriatus, Lingula murrayi, Lingulella billingsi, Lingulella bella. Based on the presence of boring and other algae, and Lingulobolus sp. cf. L. affinis (Lingula hawkei) in the Dominion ore bed, Van Ingen suggested that it is Armorican in age. The occurrence of index fossils including Orthoceras, Synhomalonotus chambersi, and Didymograptus nitidus in the gray shale of the Lower Member of the Wabana Formation suggested to Van Ingen that a Middle Arenig age could be assigned to it; whereas other index fossils including Westonia sp., Lingula sp., and Schizocrania hayesi sp. in his Phosphorite bed (J 2), Cruziana in sandstone and shale, and Lingula leseueri, Westonia, and Schizocrania striata in oolitic hematite beds resulted in Van Ingen assigning an Upper Arenig age for the upper part of Wabana Formation. In general these faunas imply a Lower Ordovician age for the Bell, Kellys and Little Bell Islands' sediments.

Sequence of geologic events in the thesis area

The geologic history of the Cambro-Ordovician sequence begins in earliest Cambrian time when most of the area, now the present Avalon Peninsula, was a highland and contributed clastic material to the sequence preserved in the southeastern part of Conception Bay, eastern Newfoundland. Subsidence of the area commenced in late Precambrian time and continued into Lower Ordovician time. Onlapping Cambrian sediments were deposited in the lower Manuels River valley area. The resulting rocks are mainly shales with minor manganiferous beds, limestones and sandstone intercalations, underlain by a basal conglomerate. The Cambrian shales are rich in pyrite which suggests that reducing conditions sometimes were prevalent in this part of the basin. These Cambrian rocks eventually were overlain by a thick blanket of Lower Ordovician sediments,deposited under marine shallow water conditions,which are now exposed on Kellys, Little Bell and Bell Islands. This sequence is summarized diagrammatically in Fig. No. 32.

The Lower Ordovician sediments are divided into the Bell Island Group and Wabana Formation. The occurrence of thin beds of hematitic oolite in the Polls Head and Townsquare Formations of the Bell Island Group is suggestive of oxidizing conditions as is evidenced also by the presence of hematitic strata, boring-algal fossils, and worm tubes in the ore beds of the Airfield and Wabana Formations, further suggesting that during Lower Ordovician time the sequence of this part of the basin possibly was subaerially exposed at intervals. The pebble beds overlying the Dominion and Scotia beds (see Fig. 32) contain hematitic oolite pebbles indicating that a short hiatus occurred.

Regarding rocks of Conception Bay, A.O. Hayes has written:

"Except for the glacial deposits, the youngest rocks remaining on the Avalon Peninsula are of Ordovician age; pre-Cambrian rocks are exposed over most of the region. The rocks have suffered repeatedly from compressive earth movements. The region forms part of the great Appalachian mountain system which was modified by at least four epochs of crustal shortening in Paleozoic time, and by folding and block faulting in Mesozoic time. Continued erosion of the surface by streams, ocean waves, and moving ice, has removed all rocks younger than Ordovician which may have existed, and therefore the history of later Paleozoic, Mesozoic and Cenozoic time has to be inferred from the records of rocks of these ages found elsewhere." (28: pp. 1, 2).

During the Pleistocene an ice sheet eroded a large amount of bedrock and deposited a thin blanket of drift disrupting the former drainage patterns and leaving, at the time of its final withdrawal, many small lakes present on Bell Island. A few of these lakes subsequently have been filled in by vegetable materials forming bogs. Drift blanket sections can be seen near cliff tops of Little Bell Island, Kellys Island and the southern part of Bell Island.

Stratigraphy

On Bell Island there occurs a thickness of about 1,500 feet of unmetamorphosed sediments which are divisible into two major rock units (see Fig. 32). The underlying unit called the Bell Island Group comprises a thickness of about 1,200 feet of sediments and is overlain by Wabana Formation (Wabana Group of Rose), a rock unit with a thickness of about 300 feet. A thin conglomerate bed, containing pebbles of hematitic oolite, occurs in disconformable contact with the underlying 'Dominion bed' which is the uppermost iron-ore bed of the Bell Island Group. The base of the conglomerate marks the division between the Bell Island Group and the Wabana Formation (see Fig. 32). Neither the base of the Bell Island Group nor the top of the Wabana Formation are exposed.

The Bell Island Group can be divided into three mappable stratigraphic units: Polls Head, Townsquare and Airfield Formations. The Wabana Formation similarly has three subdivisions called Lower, Middle and Upper (or Grebes Nest) Members. The Polls Head Formation is the basal unit and occurs in the southeastern part of the Island whereas the topmost Grebes Nest Member is located in the northwestern part of the Island (see Map No. 4).

The stratigraphy and petrology of the formations beginning with the oldest are described next (see Fig. 32).

Polls Head Formation (including zone 0 of Dr. Hayes)

Polls Head Formation comprises a thickness of about 400 feet of strata. The formation extends from the extreme southwestern part of the Island and trends along strike to Polls Head at the extreme eastern end of the Island.

Townsquare Formation (including zone 1 of Dr. Hayes)

This formation comprises strata reaching a thickness of about 600 feet and overlies the Polls Head Formation with a basal medium gray pebbly sandstone bed about 3 inches in thickness. The strata occur between The Bell and Ochre Cove on the northwestern coast and from there extend along strike to Eastern Head and Freshwater Cove.

Airfield Formation (zone 2 including the Dominion Bed of Dr. Hayes)

The total thickness of this formation is about 200 feet and outcrops of the formation extend from Gull Island South Head, on the northeastern coast, to their western limit at Ochre Cove, on the central northwestern coast of the Island. Greenish-black coloured sandstones alternating with hematitic oolite (dark reddish brown) containing Lingulobolus sp. (Lingula hawkei) and flattened spheroids of hematite are characteristic of the formation.

Lower Member (including zone 3 of Dr. Hayes)

The only exposed outcrop section I was able to find of this member was located about one-quarter mile east of Ochre Cove. At this locality only a 12 inch thick Pyrite bed, out of an approximate total thickness of 10 feet for the Lower Member, was visible. Three beds of Pyrite which vary laterally from 2 to 12 inches in thickness were at one time exposed in the open cut working but are now covered by rock waste. The Lower Member disconformably overlies a hematite bed belonging to the Airfield Formation. The disconformable relationship is marked by a basal pebble bed.

Middle Member (including zone 4 of Dr. Hayes)

Beds of this member measure about 200 feet in thickness. The ore beds with related sediments extend from a locality on the coast line about half way between Gull Island South Head and Grebes Nest Point, in the northwestern part of the Island, and extend along strike to Upper Grebes Nest Point at their western limit. The reader should note that there is a Grebes Nest Point and an Upper Grebes Nest Point on Bell Island.

Dark-gray paper shales with sandstone concretions (see Fig. 75), grayish-red hematitic oolites, and nearly perfectly globular spherules of hematite are characteristic of this member.

Grebes Nest Member (Upper Member) (including zone 5 of Dr. Hayes)

In the type area of this member, at Grebes Nest Point on the northern coast of the Island, a thickness of about 100 feet of rocks was measured by the writer. Dark gray shales with giant worm tubes and coprolites, grayish-red hematitic oolites, and ferruginous beds with phosphatic nodules (very light gray and light gray) are characteristic of this member.

Pocket Fig. No. 34 shows parallel projecting of the coast-line of Bell Island and Fig. No. 35 exhibits localities of studied sections and microfossil occurrences on Bell Island.

Detailed stratigraphy and petrography of sediments

Bell Island Group

Polls Head Formation

The Polls Head Formation comprises light to dark gray sandstones, medium to dark gray shales, medium gray shaly sandstones, and a ferruginous band (zone O of Dr. Hayes), measuring about 5 feet in thickness, containing a pebbly sandstone. This ferruginous rock unit occurs in the extreme southern part of Bell Island, and is exposed from a short distance west of Lance Cove to the extreme southwestern shore near Clapper Rock. The beds of Polls Head Formation have a total thickness of about 400 feet. As a result of the intersection of bedding planes with topographic irregularities they have broadly undulating outcrop traces across the Island. Strata seen in the southern cliff are folded and faulted in eastern, western and central parts of the Island (see Map No. 4 and Figs. 38, 39, 40).

In Bell Island the best exposures of the lower part of the sedimentary rocks of Bell Island Group are found east and west of Lance Cove in the face of the southern cliff. The southern cliff sections have varying thicknesses of rocks from place to place but the maximum thickness lies in the eastern (near The Beach) and central parts of this cliff section. The beds exhibit several unique sedimentary structures (see Figs. 36, 37) in this area.

Fig. 36 Photograph showing cross-bedding in sandstones (see arrows) at Pulpit Head, Polls Head Formation, southern coast, Bell Island. View SW

Fig. 37 Showing folded sandstone balls (owing to slumping) in dark gray papery shales (see arrow), Polls Head Formation, southern coast, Bell Island. View NNW

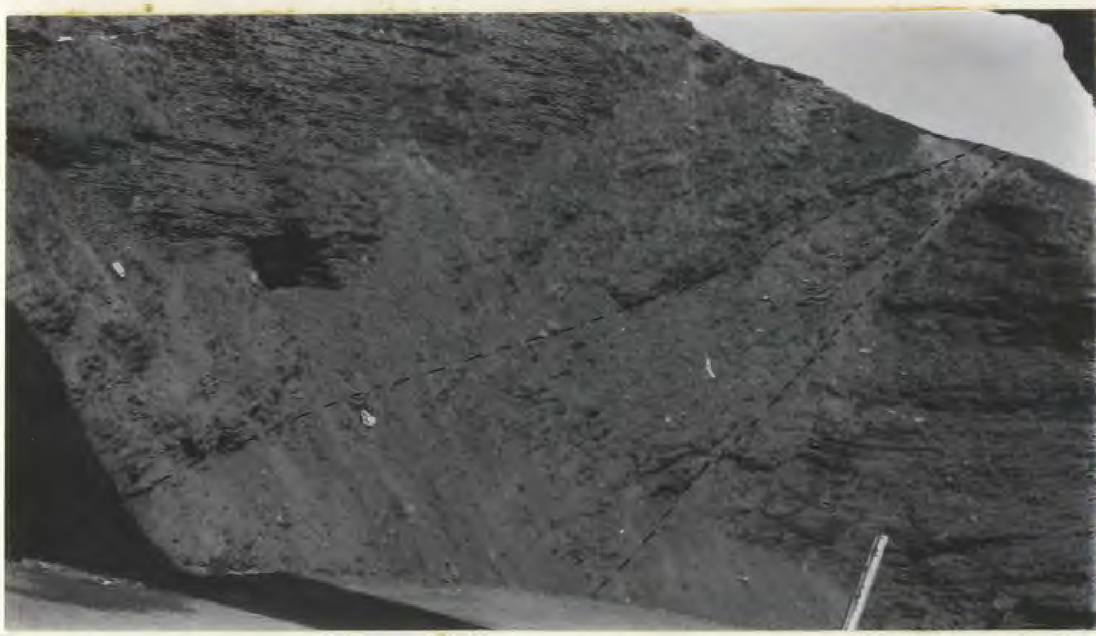


Fig.38 Photograph shows two fault planes (badly weathered) at the Old Dam, Polls Head Formation, south central cliff, Bell Island, View SE

Fig.39 Drag folds in an anticline with faulted western limb, Polls Head Formation. Structure at west of Chimney Cove, western end, southern cliff, Bell Island. View NE

Between the top of zone 0 and the base of the 'Lower bed' (zone 1) of Dr. Hayes, about 200 feet of strata of the Polls Head Formation, consisting of sandstones, shales and shaly sandstones, occur. Part of these were exposed on the surface from the western coast near Clapper Rock to Long Harry Point on the eastern coast of the Island.

The southern cliff section was studied in detail at two localities. The first was at The Beach, Bell Island (see Locality 243, Table 6), and the second at Chimney Cove (see Locality 436, Table 4). In addition every care was given to the study of the nature and character of the sedimentary rocks occurring in the accessible exposures in the same cliff face; and along it less detailed studies of three additional measured typical sections were made (see Table Nos. 4, 7, 8).

The Polls Head Formation, especially in its lower part (see The Beach section, Locality 243, and section at Polls Head, Locality 402, A to M), displays a remarkable succession of cyclical marine deposits (see Figs. 41, 42).

Fig.40 Showing asymmetrical anticlinal fold, Polls Head Formation, at west of Lance Cove beach, south central cliff, Bell Island. View ENE

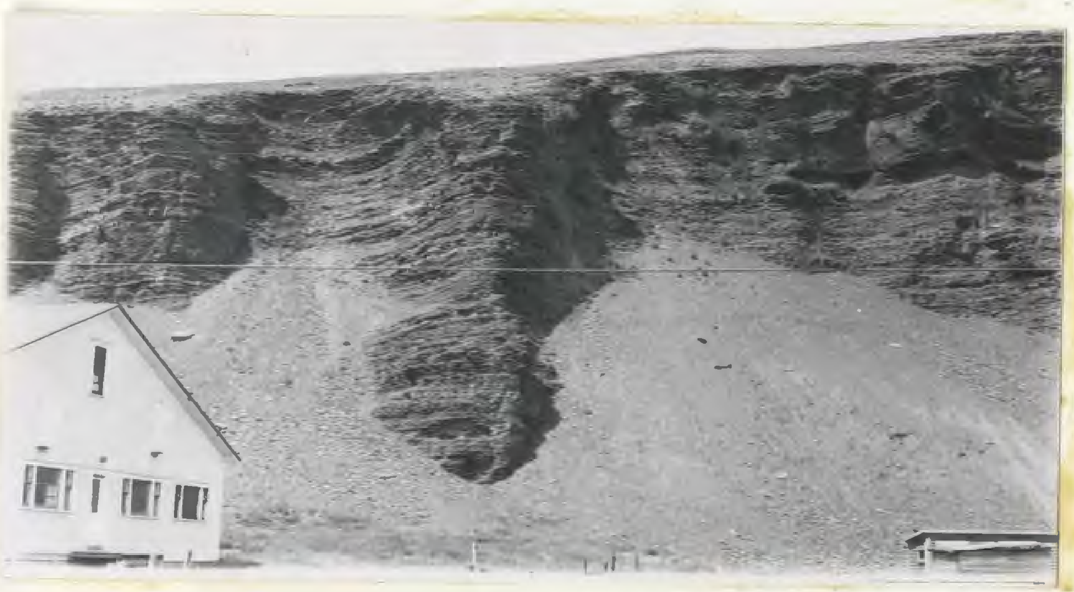


Fig.41 Showing upper part of the studied section No.243, Polls Formation, at The Beach, southern coast, Bell Island. View NE

Table No. 4

Section studied in detail immediately east of Lance Cove Beach (Locality 432), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
432, 1	Shale (55%); medium to dark gray, non-calcareous, soft, fissile, rarely papery, interbedded with sandstones. Sandstone (45%); light to medium dark gray, fine to medium grained, slightly calcareous. Both strata with poor worm trails	60
2	Shale (50%); dark gray, non-calcareous, soft, fissile with worm borings. Sandstone (50%); medium gray, non-calcareous, fine grained. Shales present as intercalations, lenses.....	40
3	Shale (60%); dark gray, non-calcareous, soft, fissile, highly worm bored, interbedded with sandstones. Sandstone (40%); light, medium and dark gray, slightly calcareous, fine grained, partly banded. Some sandstone strata are similar to underlying sandstones..	25
4	Sandstone (70%); light to medium gray, non-calcareous, fine grained, occasionally banded and interbedded with dark gray papery shales. Shale (30%); same as underlying shales. Both the strata are highly worm bored, worm tubes up to 5 inches in length and 0.5 inch across	40
5	Shale (90%); dark gray, non-calcareous, soft, fissile, papery, with occasional worm borings. Sandstone (100%); medium gray, non-calcareous, fine-grained, massive, shales present as intercalations, lenses, with occasional shale pebbles up to 1 inch in diameter	35
	These strata constitute the bottom most part of the Bell Island sediments.	

Table No. 5

Section studied in detail at Chimney Cove (Locality 436), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
436, 1	Shale (55%); medium to dark gray, non-calcareous, soft, fissile, interbedded with sandstnes. Sandstone (45%); light to medium dark gray, medium to fine grained	20
2	Shale (50%); dark gray, non-calcareous, soft, fissile. Sandstone (50%); medium gray, non-calcareous, fine grained, interbedded with shales	20
3	Shale (70%); dark gray, non-calcareous and soft, interbedded with sandstones (30%); medium gray, fine grained. A three inch thick sandstone bed is medium dark gray, and is composed of blue fragmentary brachiopod shells	15
4	Sandstone (70%); light to medium gray, non-calcareous, fine grained, interbedded with dark gray shales, occasionally with trilobite tracks. A three foot thick sandstone stratum, medium light gray, exhibits bands of mica flakes. Shale (30%); dark gray, non-calcareous, soft, fissile, papery	15

Table No. 6

Section studied in detail at The Beach (Locality 243), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata covered with alluvium and drift.	
243, j, k, l,	Sandstone (50%); medium dark gray, non-calcareous, fine grained, interbedded with shales and with lenticles of shaly sandstones. These strata lie on top of the beach section	18
	Sandstone; yellowish gray, non-calcareous, medium grained with fragmentary brachiopod shells (i)	0.6
	Sandstone; light olive gray, non-calcareous, interbedded with dark gray shales and medium gray shaly sandstones ..	20
g, h	Sandstone (35%); light olive gray, non-calcareous, fine grained, laminated and interbedded with dark gray shales (35%) and light gray shaly sandstones (30%). Up to 6 feet from the base the sandstone is medium dark gray, gritty with shale pebbles and blue fragmentary brachiopod shells	18
f	Shaly sandstone (60%); light gray green, non-calcareous, fine grained, soft, laminated and interbedded with dark gray shales (40%)	4
d, e	Shaly sandstone (50%); dark gray, non-calcareous, fine grained, laminated and interbedded with dark gray shales (50%), papery and soft	3
c, b	Sandstone (70%); yellowish gray, non-calcareous, medium grained, banded, laminated and interbedded with shales similar to underlying strata. Both strata are highly worm bored	3
	Sandstone (100%); dark brown, non-calcareous, fine grained and ferruginous	0.1
a	Sandstone (60%); light olive gray, non-calcareous and fine grained, interbedded with dark gray shales (40%) ...	18

Unit No.		Thickness Feet
Z	Sandstone (80%); light olive gray, non-calcareous, fine grained, micaceous, banded, ripple marked, current bedded, interbedded and laminated with shales (20%)	10
Y	Sandstone (70%); dark brown, non-calcareous, laminated and interbedded with shales (30%) similar to underlying strata	10.6
X'	Sandstone (70%); dark brown, non-calcareous, fine grained and ferruginous, laminated and interbedded with dark gray shales (30%)	9
X	Sandstone (90%); dark brown, non-calcareous, fine grained, ferruginous at the joint planes owing to fillings of ferruginous matter, heavy, laminated by dark gray shales (10%) and brown sandstone lenticles	0.1
	Shale (50%); dark gray, non-calcareous, micaceous and soft with interbedded and lenticular sandstones (50%) ..	10
W	Sandstone (100%); light olive gray, non-calcareous, fine grained, grades downward into an olive gray variety	1
	Sandstone; olive gray, non-calcareous and fine grained. Shale; dark gray, non-calcareous, micaceous and soft......	3
	Sandstone (100%); olive gray, non-calcareous and fine grained	0.5
U, T	Shale (60%); dark gray, non-calcareous, micaceous, soft, papery with lenticular sandstone. Sandstone (40%); olive gray, non-calcareous, fine grained, with blue fragmentary brachiopod shells	2
	Sandstone; light gray, non-calcareous, fine grained, banded. Shale; dark gray, non-calcareous, soft, fissile, interbedded with sandstones	11.5
R	Sandstone; light brownish gray, non-calcareous, medium grained, slightly loose with occasional shale pebbles ..	0.1
	Sandstone; light gray, non-calcareous, fine grained and banded, interbedded with dark gray shales	7.6

Unit No.		Thickness Feet
O	Sandstone; medium dark gray, non-calcareous, massive, fine grained	2
N	Sandstone (70%); light gray, non-calcareous, fine grained, banded with ripple marks, current beds, flute casts, laminated and interbedded with dark gray shales having trilobite tracks	3
	Shales; dark gray, non-calcareous and soft, interbedded with medium grained sandstones which are highly micaceous	8
	Shale; dark gray, non-calcareous, fissile and papery, interbedded with sandstones. Sandstone; medium gray, partly calcareous, fine grained and occasionally worm bored	10
L	Sandstone; medium light gray, partly calcareous and fine grained, interbedded with shales, dark gray, non-calcareous and soft	20.6
	Sandstone (100%); same as sandstone J but with occasional shale pebbles	13.6
J	Sandstone (100%); light gray, non-calcareous, fine grained, banded and current bedded	2
I	Sandstone (60%); medium gray, non-calcareous, fine grained, ripple marked, laminated and interbedded with dark gray shales	4.6
H	Sandstone (50%); medium light gray, partly calcareous, fine grained. Shale (50%); dark gray, non-calcareous, soft and fissile .	3.6
G	Sandstone (100%); medium gray, calcareous, fine grained, ripple marked with pebbles up to 1 inch in length	0.1
F	Shale (60%); dark gray, non-calcareous, micaceous, fissile and papery. Sandstone (40%); medium gray, partly calcareous, fine grained	4.6
E	Sandstone (50%); similar to B but devoid of shale pebbles. Shale (50%); dark gray, non-calcareous, soft and fissile .	4.3

Unit No.		Thickness Feet
D	Sandstone (40%); medium gray, partly calcareous and fine grained.	
C	Shale (60%); dark gray, non-calcareous, fissile and papery	7.3
B	Sandstone (100%); medium light gray, partly calcareous, fine grained, banded with calcite veins and shale pebbles which contain Micrhystridium stellatum Deflandre	2
A	Shale (60%); dark gray, non-calcareous, micaceous, fissile, papery, occasionally worm bored, interbedded with sandstones. Sandstone (40%); medium gray, partly calcareous, fine grained, worm bored	3

Table No. 7

Section studied in detail from Pulpit Head to Polls Head (Locality 402, M to A), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
402, M	Sandstone (50%); medium gray, non-calcareous, fine grained, occasionally micaceous and banded .... Shale (50%); dark gray, non-calcareous, soft, fissile, interbedded with sandstones	110
	Sandstone (100%); medium gray, non-calcareous, fine grained	5
L	Sandstone (60%); medium gray, non-calcareous and fine grained with interbedded dark gray shales. Shale (40%); dark gray, non-calcareous, soft with worm borings	43
J	Sandstone (50%); medium gray, non-calcareous, medium to fine grained, interbedded with dark gray shales (50%) which occasionally exhibit cone-in-cone structures and worm burrows	40
I	Sandstone (60%); medium gray, non-calcareous, fine grained, interbedded with dark gray shales (40%). Both strata are highly worm bored and occasionally exhibit coprolites	26.9
H	Sandstone (100%); light to olive gray, calcareous, medium to fine grained, highly current bedded, with a 3.6 inch thick ferruginous band, occasionally pebbly (shale pebbles up to 1 inch in length)	6.9
	Sandstone; medium gray, non-calcareous, fine grained, interbedded with shales. Shale; dark gray, non-calcareous and soft	7.6
G	Sandstone (95%); light gray, non-calcareous, fine grained, with dark gray shale (5%) laminations	3.3
F	Shale (80%); dark gray, non-calcareous, soft, interbedded with sandstones (20%); medium gray and fine grained	1

Unit No.		Thickness Feet
E	Sandstone (60%); medium gray, non-calcareous, fine grained, interbedded with soft dark gray shales (40%) ...	2.6
	Shale (100%); dark gray, non-calcareous, soft, papery with intercalations of 1/4 inch thick medium gray sandstones	0.1
	Sandstone (90%); dark gray, non-calcareous, fine grained, interbedded with dark gray shales (10%)	0.6
D	Shale (50%); dark gray, non-calcareous, soft. Sandstone (50%); dark gray, non-calcareous, fine grained, interbedded with shales	3.9
	Shale (100%); dark gray, non-calcareous, soft, papery and fissile	1.1
	Shale; dark gray, non-calcareous, soft and fissile, interbedded with light gray, fine grained sandstones ...	1
	Sandstone (100%); medium gray, non-calcareous, fine grained, finely laminated with medium gray shales	0.2
	Shale (100%); medium gray, non-calcareous, fine grained and banded	0.2
	Sandstone (100%); light gray, non-calcareous, fine grained and banded. Top 1.6 inches thick part is composed of shale pebbles	1.8
	Sandstone (100%); light gray, non-calcareous, fine grained, banded	1.9
	Sandstone (50%); light gray, non-calcareous, fine grained, banded, occurs as intercalated and with lenticles in shale but at top 2.6 inches thick strata are pebbly. Shale (50%); dark gray, non-calcareous, soft and fissile .	1.3
C	Shale (100%); dark gray, non-calcareous, soft, papery and fissile	1.3
	Sandstone (100%); medium gray, non-calcareous, fine grained and banded	1
B	Shale (100%); dark gray, non-calcareous, soft, papery, fissile, with small worm borings, interbedded at the base by 4 inches thick sandstone; medium gray, pebbly and occasionally lenticular	1.3

Unit No.		Thickness Feet
A	Sandstone (100%); medium gray, non-calcareous, fine grained, banded and current bedded	1

Table No. 8

From top to bottom, the general sequence of 200 feet thick sediments (above Zone O of Dr. Hayes) is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
1	Sandstone (35%); light medium to dark gray, non-calcareous, and fine grained. Shaly sandstone (35%); medium gray and non-calcareous. Shale (30%); dark gray, non-calcareous, with occasional cone-in-cone structure. These strata are highly ferruginous with iron seeps. They are composed of gray, gritty sandstone lenticles, passes upward in to Lower iron ore bed of Dr. Hayes through 4' thick light gray massive sandstone and 3 inch thick light gray pebbly sandstone bed	100
2	Shaly sandstone (80%); medium to dark gray, non-calcareous to slightly calcareous, fine grained with blue fragmentary brachiopod shells, inter-bedded with sandstones. Sandstone (20%); medium to dark gray, non-calcareous, and fine grained	30
3	Shale (50%); similar to underlying strata. Shaly sandstone (30%); medium gray, non-calcareous with worm borings. Sandstone (20%); medium gray, non-calcareous, fine grained, banded and massive. These strata exhibit worm borings, trilobite burrows and tracks	20
4	Shale (70%); dark gray, non-calcareous, papery, fissile with worm borings. Sandstone (30%); light, medium to dark gray, non-calcareous to slightly calcareous, fine grained, well sorted. Light gray variety is banded whereas the dark gray usually with blue fragmentary brachiopod shells. Sandstones in the shale occur as inter-beds, intercalations and lenticles	50
478' 5	Ferruginous sandstone and hematitic oolite; this is zone O of Dr. Hayes. A highly ferruginous, partly pebbly sandstone, interbedded with hematitic oolite, medium gray sandstones and dark gray shales	5

Detail Petrography (thin sections)

Fig. No. 43, Magnification x 280 (approx.), Locality and Slide No. 243, A.

Sandstone. A thin section (see Fig. 43) cut perpendicular to bedding shows a fine-grained sandstone to be present consisting of quartz grains (about 70%) ranging from subangular to rounded in shape. Their grain size ranges from 0.01 to 0.10 mm., and they are loosely held together with calcitic, and partly sericitic, cement constituting the groundmass (about 25%). In general this matrix shows an equigranular microcrystalline texture. Biotite flakes and glauconite grains (subrounded) are the more common accessories while magnetite, zircon, sphene and albite are rare minerals (about 5%).

Fig. No. 44, Magnification x 280 (approx.), Locality and Slide No. 243, L.

Shaly sandstone. The figure is a thin section cut perpendicular to bedding. In it is seen quartz grains (about 70%) which are subangular, subrounded and partly rounded in shape; range in size from 0.01 to 0.12 mm., and are loosely held together with an argillaceous cement (about 25%). The rock exhibits occasional bands of silty shale. Magnetite, glauconite, zircon, zoisite and hornblende are the accessory minerals (about 5%). In general the rock has a microcrystalline texture.

Fig. 42 Showing lower part of the studied section No. 243 at the Beach, Polls Head Formation, southern coast, Bell Island. View NE

Fig. 43 Photomicrograph of sandstone, shows quartz grains with sericite and calcite cement. Locality and Slide No. 243, A, Polls Head Formation. X280 (approx.), under crossed nicols.

Fig. No. 45, Magnification x 70 (approx.), Locality and Slide No. 402, T.

Fossiliferous sandstone. A thin section cut perpendicular to the bedding shows abundant quartz grains (about 70%). These are rounded to subrounded in shape and range in size from 0.05 to 0.55 mm. They are loosely held together with calcite cement (about 15%). Fragmentary brachiopod shells (about 10%) are approximately oriented in one direction. The thin section contains a few fragments of rhyolite and in general shows a microcrystalline texture. Magnetite, leucoxene, biotite and zoisite constitute the accessories.

Fig. No. 46, Magnification x 70 (approx.), Locality and Slide No. 478'.

Ferruginous sandstone with oolites. A thin section cut perpendicular to bedding exhibits highly ferruginous oolitic sandstone in contact with ferruginous sandstone. The latter part shows fairly well-sorted, equigranular quartz grains of subangular, subrounded to rounded shapes with an average size of 0.10 mm. They are held together with ferruginous, and partly chloritic, cement. However the oolitic part shows dense ferruginous cementing material between the quartz grains and the oolites. Hematitic oolites with a range in size from 0.34 to 0.62 mm., are made up of alternating layers of chamosite and hematite. Some chamosite spherules were observed which occasionally showed crystallized hematite. Both the oolites and the spherules have nuclei of either quartz or muscovite grains or brachiopod shell fragments. Figure 47 shows a magnified oolite with alternating layers of hematite and chamosite surrounding a quartz nucleus.

Fig.44 Photomicrograph. Showing quartz grains with argillaceous cement. Locality and Slide No.243,L, Polls Head Formation.X280(approx.), under crossed nicols.

Fig.45, Photomicrograph of sandstone, showing quartz grains, a few fragment of rhyolite and brachiopod shell fragments. Locality and Slide No.402,T, Polls Head Formation. X70(approx.), under crossed nicols.

Fig. 46 Photomicrograph. Picture shows hematitic oolites with quartz grains and ferruginous cement. Locality and Slide No. 478', Polls Head Formation. X70(approx.), under polarized light .

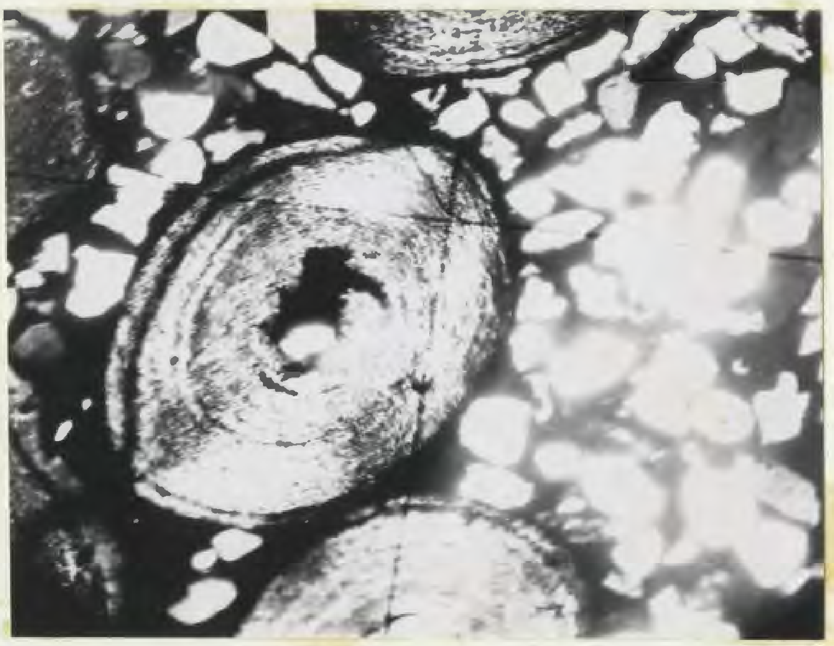


Fig. 47 Photomicrograph shows alternating layers of hematite and chamosite in hematitic oolites. A quartz nucleus in the center of a oolite. Locality and Slide No. 478', Polls Head Formation, X280(approx.), under polarized light.

Townsquare Formation

This formation comprises about 600 feet of sedimentary rocks separated from the underlying Polls Head Formation by a thin but well marked bed of pebbly sandstone, followed upwards by an ore bed (zone 1, Lower bed of Dr. Hayes) of about 25 feet in thickness. This formation is in part exposed in shallow tramway cuts of the Dominion Iron and Steel Company near Kents Bridge. Additional outcrops and sections are present along abandoned tramways of the former Nova Scotia Steel and Coal Company and also can be clearly traced in intermittent outcrops from Eastern Head on the northeastern coast to Big Head and The Bell of the western end of the Island (see Fig. 32 and Map No. 4). This formation contains bands of hematitic oolite.

Four outcrop sections have been chosen to illustrate the stratigraphy of the Townsquare Formation. Two are from the east-central part, the third from the western end, and the fourth from the northern coast of the Island (see Fig. 48). The latter section represents a complete sequence of the formation. The rocks of the lower 70 feet of the fromation range from non-calcareous to poorly calcareous, however rocks of the remaining upper part of it are entirely non-calcareous. In several of its primary features this formation exhibits evidence of shallow water deposition (see Figs. 49 to 52).

Fig.48 Photograph shows very light gray sandstone strata with shale partings at Freshwater Cove, Townsquare Formation, northern coast, Bell Island. View NW

Fig.49 Shows cross-bedding and deposits of blue brachiopod shells along the foreset beds, Townsquare Formation. This structure occurs near The Bell, western coast, Bell Island. View SE

Fig.50 Photograph of symmetrical fossil ripple marks in greenish black sandstone and hematitic oolite strata, Middle Member,near at Grebes Nest Point, northern coast,Bell Island. View NW

Fig.51 Worm borings in very light gray sandstone strata near United Church, Townsquare Formation,Bell Island.

Table No. 9

Studied outcrop section on Martins Road (Locality 217), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
217, D	Sandstone (100%); grayish olive green, non-calcareous, medium grained and gritty, compact and hard	2
C	Sandstone (100%); olive gray, non-calcareous, medium grained and ferruginous	0.1
B	Sandstone (100%); grayish olive green, non-calcareous, gritty and ferruginous	1
A	Sandstone (100%); olive gray, non-calcareous, medium grained, ferruginous and occasionally pebbly, with 2 to 3 inches thick intercalated porous variety (No. AA)	3
A'	Sandstone with hematitic oolite and iron ore; greenish black, non-calcareous, medium grained, heavy poorly fossiliferous, with white specks (phosphatic ?).	2

Table No. 10

Studied outcrop section on Ore Conveyor road (Locality 83), from top to bottom, the sequence is as follows:

Unit No.			Thickness Feet
		Overlying strata, covered with alluvium.	
83	F	Sandstone (60%); greenish black, non-calcareous, medium grained, fossiliferous (brachiopod shells), interbedded with dark gray shales (40%)	0.10
		Iron ore bed; dark brown, massive with brachiopod shells	1
	E	Sandstone; greenish black, partly calcareous, medium grained and gritty, fossiliferous, grades upward into medium grained variety	0.3
	D	Sandstone; dark greenish gray, calcareous, medium grained, with mud cracks	0.4
	C	Sandstone; dark greenish gray, non-calcareous, fine grained and current bedded	0.6
	B	Sandstone; dark greenish gray with light shade, non-calcareous, fine grained	0.6
	A	Sandstone; dark greenish gray, non-calcareous, fine grained, current bedded	0.4

Table No. 11

Section studied in detail at Bell Cove (Locality 455 to 448), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
	Sandstone (80%); light to medium gray, non-calcareous, medium to fine grained, banded, symmetrically ripple marked with interbeds and partings of dark gray shales. These strata constitute the top part of Big Head	45
	Sandstone (50%); medium gray, non-calcareous and fine grained, interbedded with dark gray shales. Shale (50%); dark gray, non-calcareous, soft and fossiliferous	6
	Sandstone (80%); medium gray, non-calcareous, fine grained, occasionally medium grained, micaceous, with interbeds and laminations of dark gray shales (20%)	22
455	Sandstone (50%); medium gray with greenish tinge, non-calcareous and fine grained, interbedded with shales. Shale (50%); dark gray, non-calcareous and papery; Baltisphaeridium brevispinosum var. nanum Deflandre ..	5
454	Sandstone (75%); greenish black, non-calcareous, fine grained with hematitic oolite lenticles and bands (25%) up to 1 ft. thick	15
1	Sandstone (70%); medium gray with greenish tinge, non-calcareous, fine grained, interbedded with shales. Shale (30%); dark gray, non-calcareous, and papery	10
2	Sandstone (50%); medium gray, non-calcareous, fine grained, interbedded with shales. Shale (50%); dark gray, non-calcareous and papery	15
453	Sandstone (100%); greenish gray, partly calcareous with occasional ferruginous contents, medium grained and gritty	25

Unit No.		Thickness Feet
452	Shale (60%); dark gray, non-calcareous and papery, interbedded with sandstones. Sandstone (40%); brownish gray, non-calcareous, gritty and pebbly (shale pebbles)	15
3	Sandstone (100%); greenish and brownish black, banded, fine grained, occasionally gritty	0.4
4	Sandstone (60%); light gray, non-calcareous, fine grained, interbedded with dark gray shales (40%)	10
5	Sandstone (90%); light olive gray to brownish gray, non-calcareous, gritty, pebbly (shale pebbles), with intercalated dark gray shales (10%)	8
6	Sandstone (60%); light grgy, medium to fine grained, and current bedded. Shale (40%); interbedded with sandstones	12
451	Sandstone (100%); greenish and brownish black, banded, the former variety partly calcareous, gritty and the latter non-calcareous, fine grained	10
450	Sandstone (100%); medium light gray, non-calcareous, medium grained, porous, micaceous, highly current bedded with medium light gray shale pebbles up to 3.5 cms. in length with blue fragmentary brachiopod shells and *Linguloblus* sp...........................	0.8
	Sandstone (100%); light gray, non-calcareous, and fine grained	2.6
7	Sandstone (50%); light gray, non-calcareous, fine grained, interbedded with dark gray shales (50%)	1
8	Sandstone (100%); medium light gray, non-calcareous, medium grained and micaceous	0.8
9	Sandstone (70%); greenish gray, non-calcareous, partly gritty, interbedded with shales. Shale (30%); dark gray, non-calcareous and papery	7.6
449	Sandstone (100%); medium gray, non-calcareous, medium grained with dark gray shale pebbles and blue fragmentary brachiopod shells	5

Unit No.		Thickness Feet
10	Shale (60%); dark gray, non-calcareous, papery, worm bored. Sandstone (40%); medium to medium light gray, calcareous, medium grained, partly gritty, occasionally micaceous, with blue fragmentary brachiopod shells	17.6
488	Sandstone (80%); medium light gray, non-calcareous, medium grained, partly gritty, with blue fragmentary brachiopod shells and shale pebbles, interbedded with shale. Shale (20%); dark gray, non-calcareous, papery	2.6
11	Shale (60%); dark gray, non-calcareous, papery and worm bored, interbedded with sandstones. Sandstone (40%); light gray, non-calcareous, fine grained, this unit lies at the base of Bell Cove.......	6

Table No. 12

Section studied in detail from Freshwater Cove to base of Eastern Head (Locality Nos. 313 to 402, N), northern coast of Bell Island, from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium and drift.	
312	Shale (60%); dark gray, non-calcareous, silty, interbedded with medium dark gray sandstones (40%) .... These strata form upper part of the Townsquare Formation.	70
309	Sandstone; medium dark gray, non-calcareous, and fine grained, interbedded with dark gray shales	1
	Shale (80%); dark gray, non-calcareous, rarely worm bored, interbedded with medium gray, fine grained sandstones (20%)	10
	Sandstone (90%); medium dark gray, non-calcareous, fine grained with brown sandstone bands, interbedded with dark gray shales (10%), partly silty in lower part	35
	Sandstone (95%); light green, non-calcareous, lower 2.6 feet is partly gritty but above 0.6 foot is green and gritty which grades up into a medium dark gray variety with shale laminations (5%)	9
	Sandstone (70%); dark gray, non-calcareous, fine grained, interbedded with dark gray shales (30%)	10
	Sandstone (60%); very light gray, non-calcareous, and medium grained, interbedded with dark gray shales (40%)	3
	Sandstone (100%); very light gray, non-calcareous, medium grained and massive	10
	Sandstone (100%); light gray with light greenish tinge, non-calcareous, banded and graded	1
	Sandstone (50%); medium gray, non-calcareous, fine grained, interbedded with dark gray shales (50%)	0.1

Unit No.		Thickness Feet
Y'	Sandstone; medium to medium dark gray, non-calcareous and medium grained	0.5
Y	Sandstone; light gray, non-calcareous, medium grained ..	2
X	Sandstone (90%); medium gray, non-calcareous, medium grained, partly banded, current bedded, with a half inch thick ferruginous band and intercalations of dark gray shale (10%)	2
W	Sandstone; greenish black, non-calcareous, medium to fine grained, graded and current bedded	1
U	Sandstone; dark gray, non-calcareous, fine grained, grades up to medium grained variety with dark gray fossiliferous shale laminations (V); <u>Conochitina</u> sp., <u>Veryhachium</u> <u>trispinosum</u> (Eisenack)?, <u>V.</u> <u>rhomboidium</u> Downie, <u>Baltisphaeridium</u> sp., <u>B.</u> <u>brevispinosum</u> var. <u>wenlockensis</u> Downie, <u>B.</u> <u>longispinosum</u> (Eisenack), <u>Micrhystridium</u> sp., Indeterminate spp..	3
T	Sandstone; dark gray, non-calcareous, fine grained, grades up into very fine grained shaly sandstone	0.6
S	Sandstone; dark gray, non-calcareous and fine grained ..	1.6
R	Shaly sandstone; medium gray, non-calcareous, fine grained, interbedded with dark gray shales	1
P	Sandstone (100%); medium light gray, non-calcareous, and medium grained	1.6
N	Sandstone (90%); medium light gray, non-calcareous, medium grained, micaceous, symetrically ripple marked, partly banded, pebbly (up to 2.5 inches long shale pebbles), with intercalations of shale (10%) of medium dark gray colour, micaceous, silty. A disc type of (medusoid?) impression was found in the sandstone unit	2
K	Shale (80%); dark gray, non-calcareous with lenticles and interbeds of sandstone of medium light gray colour, medium grained (20%)............................	5

Unit No.		Thickness Feet
J	Sandstone (100%); medium light gray, non-calcareous, medium grained	0.4
I	Sandstone (50%); light gray, non-calcareous, medium grained with interbeddings of dark gray papery shales (50%)	0.1
H	Sandstone (100%); medium dark gray, non-calcareous, medium grained, micaceous with trilobite burrows	2.6
G	Sandstone (90%); medium gray, non-calcareous and fine grained with non-calcareous, dark gray shale laminations (10%)	6
F	Shale; medium dark gray, non-calcareous, micaceous and partly silty	4
E	Sandstone (100%); medium gray, non-calcareous, fine grained, partly banded and occasionally laminated by shales	3
D	Shale (100%); dark gray, non-calcareous and fissile	0.5
309, B	Shaly sandstone (90%); medium gray, non-calcareous, fine grained, thin quartz veins occur in the fractures, with medium gray shale laminations (10%) ..	1.6
301, A	Sandstone (95%); medium dark gray, non-calcareous, fine grained, partly banded, current bedded, laminated by dark gray shales (5%)	2
	Sandstone (100%); light greenish, non-calcareous, fine grained, micaceous and finely bedded	0.6
	Sandstone; very light gray, non-calcareous and medium grained, interbedded with dark gray shales	10
301, L M	Sandstone (50%); medium to medium light gray, calcareous and medium grained, mud cracked, interbedded with non-calcareous dark gray shales; _Hoegisphaera_ sp., _Veryhachium_ sp., _Baltisphaeridium_ sp., _B. brevispinosum_ (Eisenack)........................	10

Unit No.		Thickness Feet
	Sandstone (100%); white to very light gray, non-calcareous, medium grained, hard and massive	12
	Sandstone; very light gray, non-calcareous, medium grained, interbedded with dark gray shales	1.5
	Sandstone; medium gray, non-calcareous, medium grained and banded, interbedded with dark gray shales	2
	Sandstone; very light gray, non-calcareous, medium grained, interbedded with dark gray shales	8
J	Sandstone (70%); medium gray, non-calcareous, medium grained, banded, laminated and interbedded with dark gray shales (30%)	4
I	Sandstone; very light gray, non-calcareous, and medium grained, interbedded with dark gray shales	12
F	Sandstone (40%); medium gray, non-calcareous and fine grained.	
G	Shale (30%); dark gray, non-calcareous and fissile. Shaly sandstone (30%); medium gray, non-calcareous and banded. These strata occur interbedded	8
E	Sandstone; very light gray, non-calcareous and medium grained, interbedded with dark gray shales	12
B	Shaly sandstone (35%); medium gray, non-calcareous and fine grained.	
C	Shale (35%); dark gray, non-calcareous and fissile, fossiliferous; Lagenochitina baltica Eisenack, Veryhachium sp.	
D	Sandstone (30%); medium gray, non-calcareous and fine grained. These strata occur interbedded	8
A	Sandstone (98%); very light gray, non-calcareous, medium grained, hard and massive with light gray shale laminations (2%). Sandstone exhibits rhomb joint patterns	12
	Shaly sandstone (35%); medium gray, non-calcareous, fine grained, banded. Shale (35%); dark gray, non-calcareous and fissile. Sandstone (30%); medium gray, non-calcareous, fine grained and symmetrically ripple marked. These strata occur interbedded	6

Unit No.		Thickness Feet
402	Sandstone (95%); very light gray, non-calcareous, medium to fine grained, highly current bedded, laminated by silty shales (5%) of light green colour, micaceous. The sandstone exhibits occasional shells of Lingulobolus sp.	60
	Sandstone (90%); medium gray, non-calcareous and fine grained, interbedded with non-calcareous dark gray shales (10%)	20
	Sandstone (100%); medium gray, non-calcareous and fine grained	5
	Sandstone (70%); dark gray, non-calcareous, fine grained, interbedded and laminated with dark gray shales	35
	Sandstone (100%); greenish black, non-calcareous and fine grained, and grades up into a medium grained variety	1.6 –
	Hematitic oolite ore (100%); red brown, non-calcareous, oolitic and rhombic	1.6 – 2
	Sandstone (100%); greenish black, non-calcareous and fine grained	1
	Sandstone (100%); medium gray, non-calcareous and fine grained	5
	Sandstone (100%); brown, with greenish tinge, non-calcareous and gritty	10
	Sandstone (100%); greenish black, non-calcareous and fine grained	15
	Shale (60%); medium gray, non-calcareous, interbedded with sandstones. Sandstone (40%); medium gray, non-calcareous and fine grained	20
	Sandstone; greenish black to medium gray, non-calcareous and fine grained	3
	Hematitic oolite ore (100%); red brown, non-calcareous, oolitic and rhombic	1 to 3

Unit No.		Thickness Feet
	Sandstone (100%); greenish black to medium gray, non-calcareous and fine grained	5
	Hematitic oolite ore; red brown, non-calcareous, oolitic and rhombic	0.8
	Sandstone (100%); brown with greenish tinge, non-calcareous, gritty	8
	Sandstone (100%); greenish black, non-calcareous, and fine grained	7
	Sandstone (80%); medium gray to greenish black, non-calcareous, fine grained, interbedded with shales. Shale (20%); dark gray, non-calcareous, and highly worm bored	8
	Sandstone (70%); grayish green, non-calcareous, gritty, interbedded with shales. Shale (30%); dark gray, non-calcareous	6
	Sandstone; medium gray, non-calcareous, medium grained, with blue fragmentary brachiopod shells, interbedded with dark gray shales. These strata occur at the base of Lighthouse	15
420, W	Sandstone (100%); medium gray, calcareous, medium grained, and occasionally gritty	0.10
	Sandstone; light greenish gray, non-calcareous and medium grained, interbedded with dark gray shales	0.60
	Sandstone (100%); light greenish gray, non-calcareous, medium grained with dark gray shale pebbles up to 1 inch in length	1.3
V	Sandstone (100%); medium gray, non-calcareous, medium grained with blue fragmentary brachiopod shells	0.80
	Sandstone (80%); medium grained, non-calcareous, fine grained, interbedded with non-calcareous dark gray shales (20%)	1
	Sandstone; light greenish gray, non-calcareous, medium grained, with very fine laminations of dark gray shales.	1.6

Unit No.		Thickness Feet
U	Sandstone (80%); medium gray, non-calcareous, fine grained, interbedded with dark gray shales (20%)	6
S T	Sandstone (95%); light greenish gray, non-calcareous, fine grained with intercalations of dark gray shale. Top 5 foot part of the sandstone is medium grained	18
R	Shale (60%); dark gray, non-calcareous, interbedded with medium gray, fine grained sandstones (40%). Their top 1.60 foot thick part is medium grained with fragmentary brachiopod shells	5
Q	Sandstone (90%); medium gray, non-calcareous, fine grained, with laminations of dark gray shales	1.6
P	Shale (95%); light olive gray, non-calcareous, soft with intercalations and lenticles of sandstone (5%) of medium gray colour. Strata are highly worm bored with trilobite burrows	1.3
O	Sandstone (50%); light gray, non-calcareous, fine grained, partly banded, interbedded with shales. Shale (50%); dark gray, non-calcareous, fissile, moderately worm bored	9
	Sandstone (80%); medium gray, calcareous, medium grained, partly gritty, and pebbly with blue fragmentary brachiopod shells. Shale (20%); dark gray, non-calcareous, fissile, interbedded with sandstones	7.6
	Sandstone (65%); medium gray, non-calcareous and fine grained, interbedded with shales. Shale (35%); dark gray, non-calcareous and highly worm bored	5.6
	Sandstone (50%); medium gray, non-calareous, fine grained, interbedded with shales. Shale (50%); dark gray, non-calcareous, highly worm bored	10.3
N	Sandstone (50%); light to medium gray, non-calcareous, fine grained, interbedded with shales. Shale (50%); dark gray to light greenish, non-calcareous, soft, fissile	1

Petrography

Fig. No. 53, Magnification x 70 (approx.), Locality and Slide No. 447'.

Calcareous sandstone. The quartz grains (about 80%) are subangular, subrounded and rounded in shape, range in size from 0.05 to 0.50 mm., and are loosely held together with a calcareous and micaceous (biotite and sericite) cement. Occasional bands of calcite are present. The rock has medium-size grains of quartz and in general exhibits a microcrystalline texture. Some of the oolites are composed of phosphatised material with nuclei, and contain occasional inclusions of leucoxene and zircon. The oolites range in size from 0.12 to 0.50 mm., and are unevenly distributed. Fragmentary brachiopod shells are found in the groundmass. Biotite (about 15%) and leucoxene are the most common accessory minerals. Zircon, magnetite, and light brown chert grains are present but rare.

Fig. No. 54, Magnification x 70 (approx.), Locality and Slide No. 451.

Banded sandstone. A section cut perpendicular to bedding shows fairly good size sorting of quartz grains of subrounded, rounded to subangular shapes. The grains are loosely held together with sericitic and chloritic cement. The groundmass contains some phosphatised oolites with alternating layers of phosphate and chlorite.

Fig.52 Showing giant 'worm'tracks in gray sandstone bed, near Grattons Cove, Townsquare Formation, Bell Island. View SW

Fig.53 Photomicrograph. Showing phosphatized oolites and fragmentary brachiopod shells. Locality and Slide No.447', Townsquare Formation. X70(approx.), under polarized light.

Figure 54 shows graded bedding of very fine (silt grade) and fine grained (sand grade) quartz. Minor amounts of the sandy part were enclosed in the former during deposition. The size of quartz grains in the finer part ranges from 0.04 to 0.35 mm., and in coarser part from 0.05 to 0.50 mm. In general the quartz grains constitute about 80% of the rock whereas the groundmass makes up about 15 to 20% of the rock.

Fig. No. 55, Magnification x 70 (approx.), Locality and Slide No. 452.

Pebbly sandstone. The rock is more or less similar to that of Locality 447' but differs by having a predominance of brachiopod shell fragments. Figure 55 is a photo of a thin section which, cut perpendicular to bedding, shows silty shale pebbles and a few brachiopod shell fragments in the groundmass.

Fig. No. 56, Magnification x 70 (approx.), Locality and Slide No. 83, A.

Sandstone. A thin section cut perpendicular to the bedding shows unsorted quartz grains (about 75%) of angular, subangular, subrounded to rounded in shape with a range of size from 0.02 to 0.15 mm. which are loosely held together with chloritic, sericitic and siliceous cements forming the groundmass (about 20%). The groundmass locally shows recrystallized, very fine grained quartz, and, very rarely, chlorite spherules with silica and magnetite

Fig.54 Photomicrograph. Showing very fine and fine grains of quartz.Locality and Slide No.451 Townsquare Formation.X70(approx.),under crossed nicols.

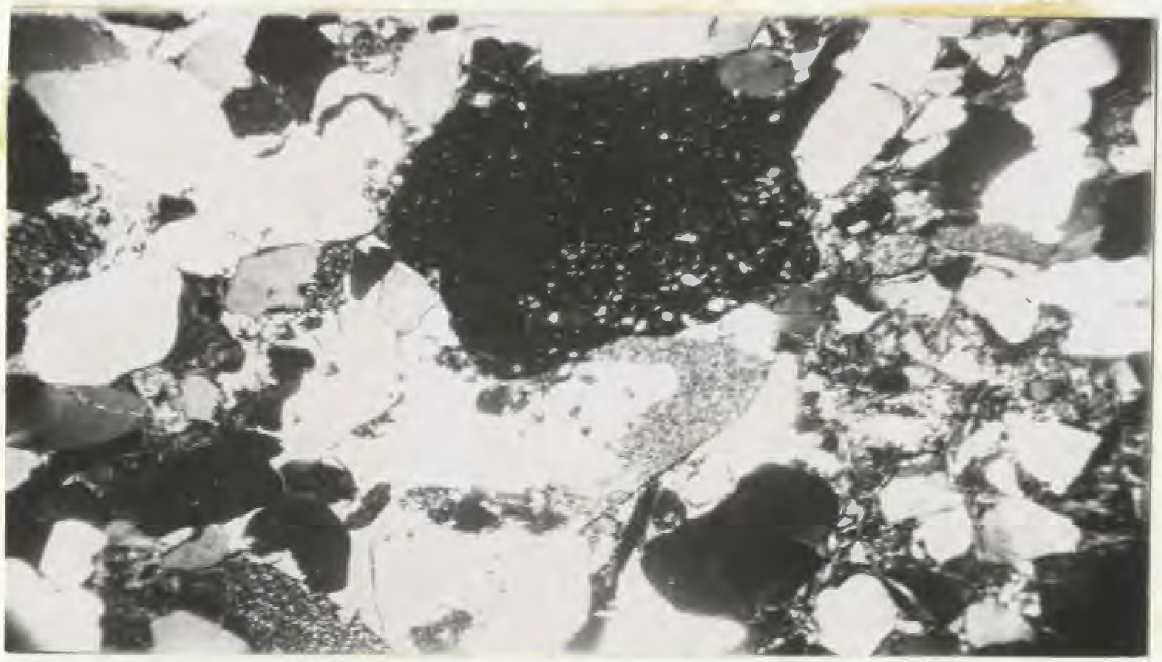


Fig.55 Photomicrograph of sandstone shows silty shale fragments.Locality and Slide No.452, Townsquare Formation.X70(approx.),under crossed nicols.

inclusions. The brachiopod shell fragments and muscovite flakes are oriented in one direction (not seen in the figure). Magnetite and muscovite are the common accessories (about 5%) but zircon although present is rare.

Fig. No. 57, Magnification x 70 (approx.), Locality and Slide No. 83, D.

Sandstone. Figure 57 is photomicrograph of a thin section cut perpendicular to bedding and it shows quartz grains (about 80%) of subrounded to rounded shapes with a range in size from 0.05 to 0.25 mm. The grains are well sorted, loosely held together with iron oxide, chlorite and siliceous cements (about 20%). A few oolites are unevenly scattered throughout the groundmass. They are made up of alternating layers of phosphate and chamosite around nuclei of quartz, magnetite, and leucoxene. They range in size from 0.15 to 0.40 mm.

Fig. No. 58, Magnification x 70 (approx.), Locality and Slide No. 217, AA.

Sandstone. A thin section (Fig. 58) cut parallel to bedding exhibits moderately sorted quartz grains (about 85%) with subrounded to rounded shapes and with a range in size from 0.05 to 0.75 mm. The grains are loosely held together with chlorite and iron oxide cement (about 15%) which locally exhibits siliceous contents in which are set magnetite grains. A few chamosite oolites

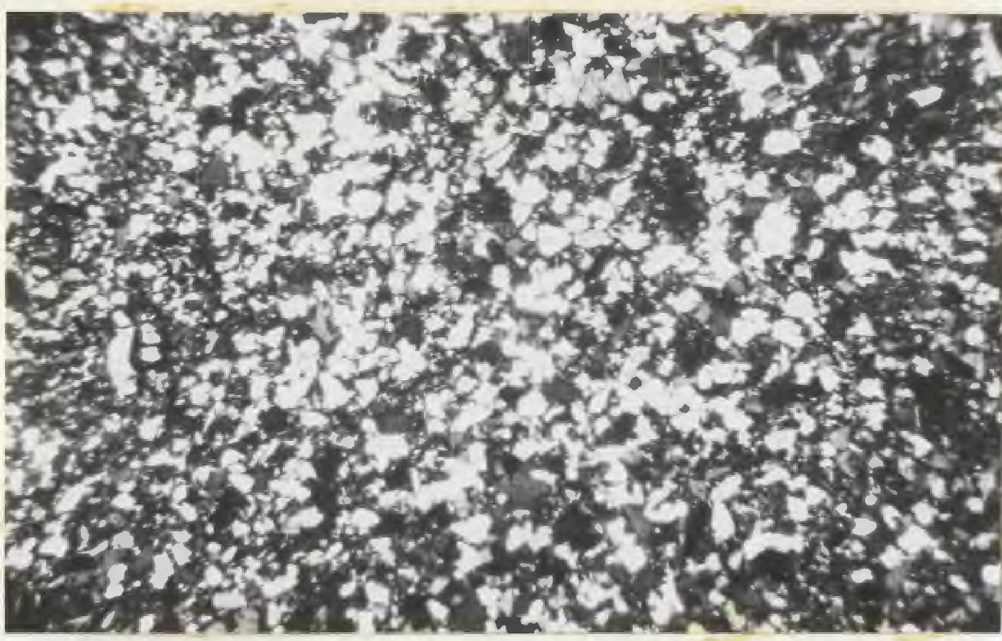


Fig.56 Photomicrograph. Showing unsorted quartz grains in sandstone. Locality and Slide No.83 A, Townsquare Formation.X70(approx.),under crossed nicols.

Fig.57 Photomicrograph shows two chamositic and phosphatic oolites in sandstone. Locality and Slide No.83,D,Townsquare Formation. X70(approx.), under crossed nicols

(of 0.20 to 0.40 mm. in size) show alteration to limonite surrounding the magnetite nuclei. A few of the oolites exhibit exterior rims of limonite. Recrystallized quartz grains occasionally are found in the groundmass. Magnetite and muscovite flakes are the accessory minerals.

Fig. No. 59, Magnification x 70 (approx.), Locality and Slide No. 217, A'.

Hematitic oolite. A thin section (see Fig. 59) cut perpendicular to bedding shows oolites (about 80%) made up of alternating layers of hematite and chamosite. Other oolites exhibit chamosite and siderite layers with nuclei of either magnetite, quartz or crystallized hematite. Occasionally hematite predominates in the oolites with poorly developed chamosite layers. The oolites (0.15 to 0.56 mm. in size) are loosely held together with calcareous, partly chloritic, and siliceous cement (about 10%). The calcareous cement was found to be impregnated locally with hematite deposits. The quartz grains (about 10%) are subrounded to rounded in shape, have an average size of about 0.35 mm., and occur scattered throughout the groundmass.

Fig. No. 60, Magnification x 70 (approx.), Locality and Slide No. 217, B.

Gritty sandstone. In Figure 60 can be seen a thin section of gritty sandstone cut perpendicular to the bedding. The quartz grains (about 70%) are subrounded to rounded in shape with a range

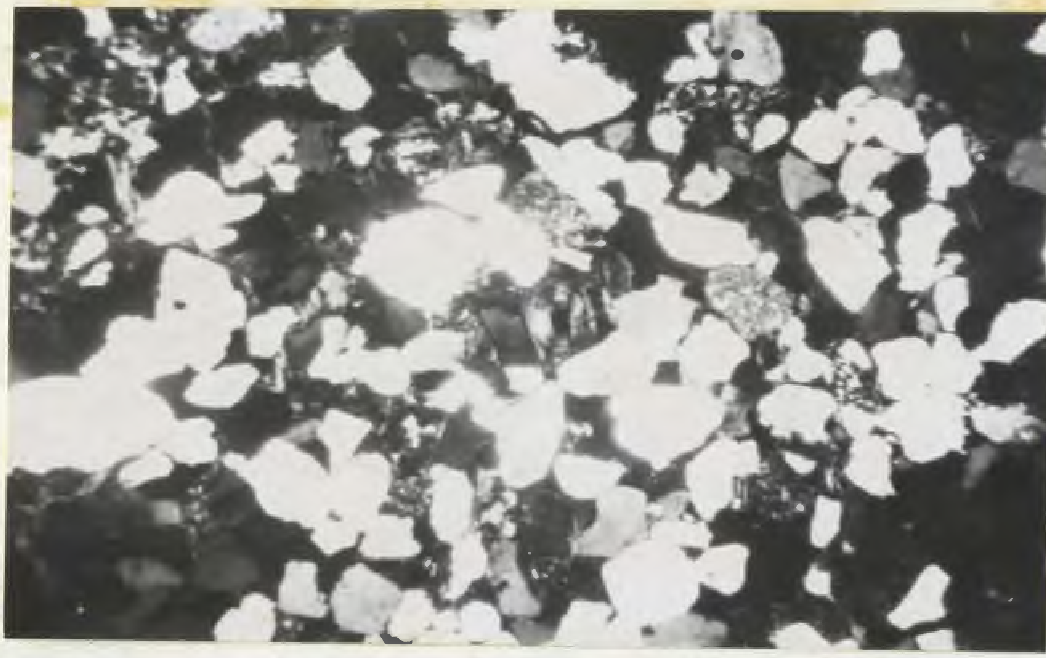


Fig.58 Photomicrograph of sandstone showing oolites of chamosite and limonite(see arrows).Locality and Slide No.217 AA,Townsquare Formation. X70(approx.),under crossed nicols.

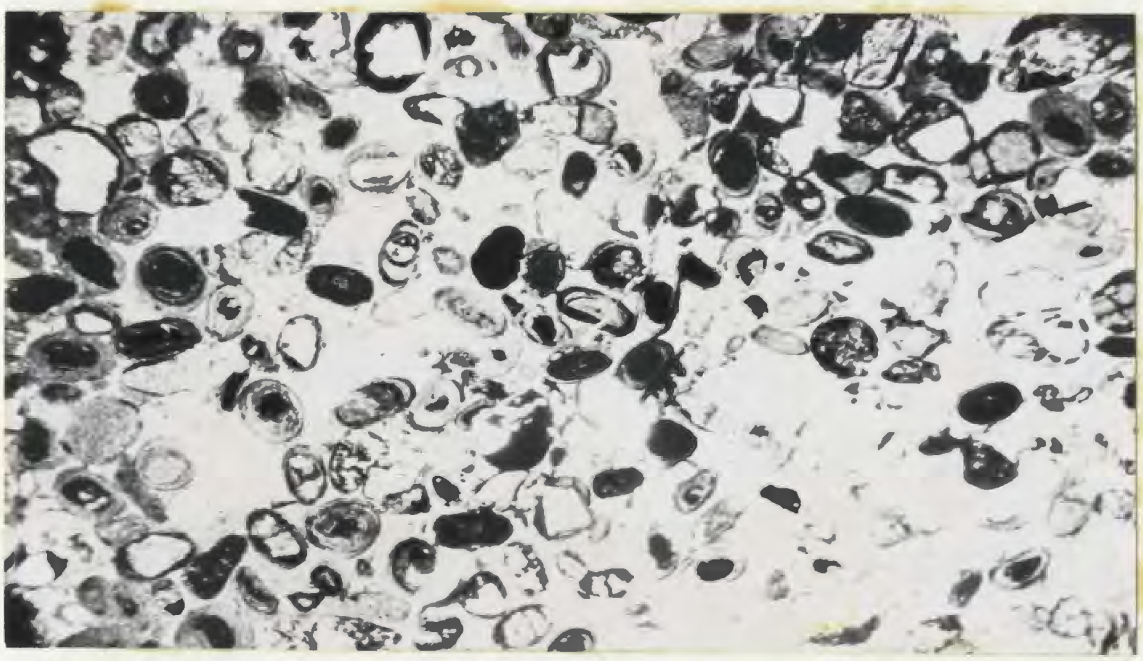


Fig.59 Photomicrograph of hematitic oolites.Locality and Slide No.217,A',Townsquare Formation. X70(approx.),under polarized light.

in size from 0.04 to 0.75 mm., and are unevenly distributed throughout the groundmass. They are loosely held together with iron oxide, magnetite and siliceous cement (about 30%) which also forms the groundmass. The rock is devoid of oolites or spheroids. Magnetite, sparse biotite and muscovite flakes constitute the accessory minerals.

Airfield Formation

The total thickness of this formation is about 200 feet. The lowest hematitic oolite bed in it lies about 600 feet above the basal ore bed (zone 1 of Dr. Hayes) of Townsquare Formation, and the whole Airfield Formation comprises a series of bands of hematitic oolite alternating with cross-bedded, fine-grained, greenish-black sandstones and dark-gray shales. The upper 30 to 40 feet of the formation is composed mainly of hematitic oolites in thick beds with interbedded ferruginous sandstone and shale partings. Two cliff sections are well exposed. The first is located immediately southwest of the Airfield and the second is found at the Ruins, on the northern coast of the Island near Gull Island South Head.

The top of the Dominion bed (of Dr. Hayes) trends about 3 3/4 miles along strike from Gull Island South Head, on the northern coast, extending to a western limit at Ochre Cove (see Fig. 61), on the northwestern coast of the Island. The writer collected specimens, from a bore hole in the mine workings east of 9-57 E Hdy., of hematitic oolite and sandstone (greenish black) at a depth of about 1,189 feet below sea level located about 3 miles north and west from Gull Island South Head, and these rocks were found to continue unchanged in general character from those collected at surface outcrops. As in the surface sandstone outcrops, trilobite tracks also are common in the subterranean greenish black sandstones. The Dominion bed, although originally about 20 feet in thickness in the open cut working some 1,500 feet east of

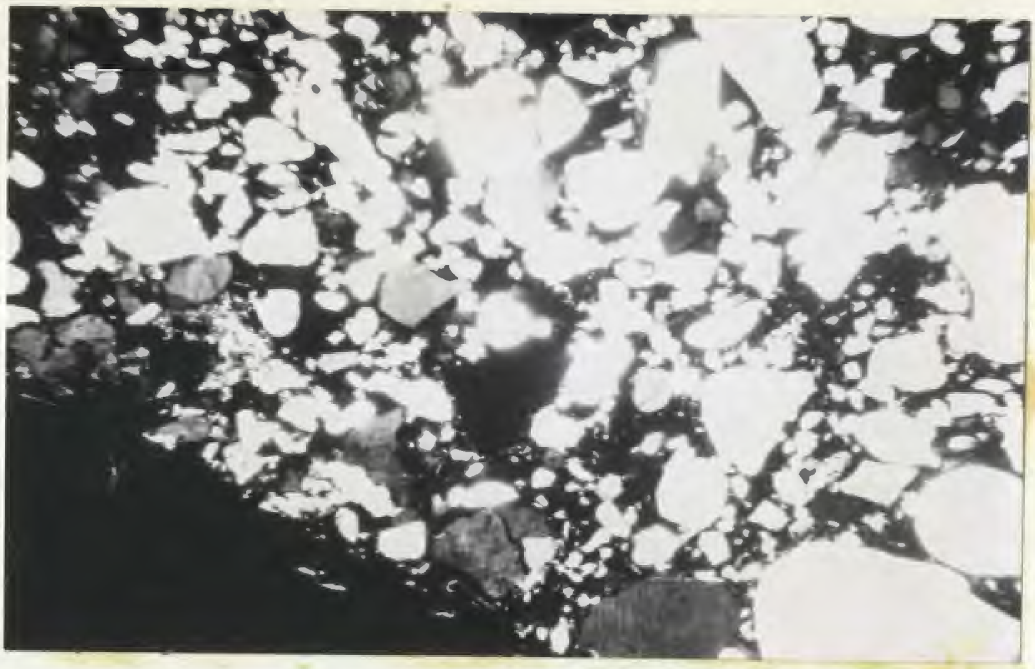


Fig. 60 Photomicrograph of unsorted gritty sandstone. Locality and Slide No. 217, B, Townsquare Formation. X70(approx.), under crossed nicols.

Fig. 61 Photograph shows two normal faults in hematitic oolite and greenish black sandstone strata, Ochre Cove, Airfield Formation, northern coast, Bell Island. View SSE

Ochre Cove, now has been nearly worked out at that place. However the typical fossil brachiopod genus <u>Lingulobolus</u> is found to occur commonly in the hematitic oolite and greenish-black sandstone outcrops left unmined in the open cut. Since the Dominion ore bed locally has been nearly completely removed in the process of mining by DOSCO, it is now impossible to measure the Airfield Formation as a continuous unit.

Near Gull Island South Head and south of the Ruins on the northeast coast of the Island, a section (Locality 344) of about 125 feet in thickness was studied in detail by the writer. This exposure includes most of the Formation. In this section 19 hematitic oolite beds of varying thicknesses were found. They are highly jointed with a rhombic pattern (see Fig. 62) and commonly exhibit cross-bedding (see Fig. 63).

Fig.62 Rhombohedral joint pattern in hematitic oolite, Airfield Formation, eastern coast, Bell Island. View NW

Fig.63 Photograph shows cross-bedding in hematitic oolite strata, west of Gull Island South Head, Airfield Formation, Bell Island. View E

Table No. 13

Section studied in detail immediately north and south of Ruins (Locality Nos. 345, and 344), northern coast of Bell Island, from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata;covered with alluvium.	
345,A	Shaly sandstone; light greenish gray, non-calcareous, fine grained; Conochitina sp., Urochitina sp., Indeterminate spp., Veryhachium rhomboidium Downie, V.? irregulare, Baltisphaeridium sp., B. brevispinosum (Eisenack), Micrhystridium stellatum Deflandre	1.6
	This unit lies on the surface; immediately northwest of Ruins, northern coast, Bell Island.	
B	Chamosite ore; dark reddish brown, calcareous, oolitic, nodular with fragmentary brachiopod shells, worm tracks, trilobite tracks and burrows; Veryhachium sp., V. trispinosum (Eisenack), V. rhomboidium Downie, Baltisphaeridium sp., B. longispinosum (Eisenack), Multiplicisphaeridium sp., Micrhystridium stellatum Deflandre, Indeterminate spp.	1.6
C	Hematitic oolite ore; dark reddish brown, calcareous, oolitic, rhombic, highly jointed in rhombic pattern, holding Lingulobolus sp.	3
D	Sandstone (90%); medium dark gray, non-calcareous, partly silty, micaceous, with abundant worm burrows and tracks. The burrows are filled with dark gray sandy material. Sandstones are interbedded with dark gray shales (10%); fossiliferous; Conochitina sp., Rhabdochitina magna Eisenack, Uruchitina sp., Ancyrochitina sp., Staurocephalites sp.?, Arabellites sp.? A. com is Eller, scolecodont jaws of maxilla, Veryhachium rhomboidium Downie, Micrhystridium stellatum Deflandre, Baltisphaeridium sp., Indeterminate spp.	3
	Sandstone; greenish black, non-calcareous, fine grained, interbedded with hematitic oolites and dark gray shales ..	13
	Hematitic oolite; dark reddish brown, calcareous and oolitic	10
	Sandstone (100%); greenish black, non-calcareous, and fine grained	1.6

Unit No.		Thickness Feet
	Sandstone; greenish black, non-calcareous, fine grained, interbedded with hematitic oolite and shales	1
	Hematitic oolite; dark reddish brown, calcareous and oolitic	0.5
	Sandstone; greenish black, non-calcareous, fine grained, interbedded with hematitic oolite and dark gray shales ..	2
	Hematitic oolite; dark reddish brown, calcareous and oolitic	0.6
344,a	Sandstone (60%); greenish black, non-calcareous, fine grained with worm borings. Bores are filled with hematitic matter. Sandstones interlaminated with light green micaceous shale. Occasionally sandstones are interbedded with hematitic oolites (20%) and shales (20%)	2
Y Z	Shaly sandstone (40%); greenish gray to light green, non-calcareous, fine grained, banded and interbedded with hematitic oolite. Hematitic oolite (40%); non-calcareous, about 5 foot thick strata show pebbly nature. Shale (20%); medium dark gray, interbedded with shaly sandstones	7.6
W X	Sandstone (45%); medium dark gray, non-calcareous, fine grained, micaceous, interbedded with medium dark gray shales (45%) and hematitic oolite (10%) of dark reddish brown colour	2
	Sandstone (100%); dark greenish gray, non-calcareous and medium grained	0.6
	Hematitic oolite ore (100%); dark reddish brown, calcareous, oolitic	1
V	Sandstone (50%); dark greenish gray, non-calcareous, medium grained, interbedded with shales. Shale (50%); medium dark gray, non-calcareous, silty, fossiliferous; *Lagenochitina baltica* Eisenack, *Lagenochitina* cf. *spherocephala* (?) Eisenack, *Conochitina* sp., *Conochitina dactylus* Collinson and Schwalb, *Urochitina* sp., Indeterminate sp., *Veryhachium* sp., *V. rhomboidium* Downie, *Micrhystridium* sp.?, *Baltisphaeridium longispinosum* (Eisenack), *B. brevispinosum* (Eisenack)?	6

Unit No.		Thickness Feet
U	Sandstone (50%); medium dark gray, non-calcareous, fine grained, interbedded with hematitic oolite	1.6
	Sandstone; medium gray, partly calcareous, fine grained, interbedded with medium dark gray shales	2.6
T	Hematitic oolite (60%); dark reddish brown, calcareous with sandy shales (40%)	1
	Shale (75%); medium dark gray, partly calcareous, grades up into hematitic oolite	2
S	Sandstone (80%); dark greenish gray, non-calcareous, medium grained, micaceous, interbedded with medium dark gray shales	2
	Shale; medium dark gray, non-calcareous, micaceous with coprolites and trilobite tracks. Occasionally interbedded with medium gray sandstones	9
	Hematitic oolite; dark reddish brown, calcareous and oolitic	0.3
R	Shale; medium dark gray, non-calcareous, silty, interbedded with medium gray sandstones	4.1
	Hematitic oolites; dark reddish brown, calcareous and oolitic	0.3
	Shale; medium dark gray, non-calcareous, silty, interbedded with medium dark gray sandstones	0.6
P	Hematitic oolites; dark reddish brown, calcareous and oolitic with fragmentary brachiopod shells	0.2
O	Silty shale; medium dark gray, non-calcareous, micaceous, fissile, with coprolites, trilobite tracks and burrows, worm burrows, with abundant hystrichospheres and chitinozoa (?); Veryhachium sp., V. rhomboidium Downie V. (Hystrichosphaeridium) lairdi (Defl.) Dff., Micrhystridium stellatum Deflandre, Hystrichospaeridium lucidum Deunff, Baltisphaeridium longispinosum (Eisenack)	2

Unit No.		Thickness Feet
N	Hematitic oolite; dark reddish brown, calcareous and oolitic, intercalated with sandstone and shale lenticles (25%)	2
M	Shale (50%); medium dark gray, non-calcareous, silty, interbedded with medium dark gray sandstones	0.6
L	Sandstone (100%); dark greenish gray, partly calcareous, fine grained, micaceous	2
K'	Shale (90%); medium dark gray, non-calcareous, silty and micaceous, interbedded with medium gray sandstones (10%)	3.6
K	Sandstone with hematitic oolites; medium dark gray, non-calcareous, fine grained, ferruginous, banded in upper part, interbedded with 3 inch thick brown hematitic oolite bed. The sandstone is partly current bedded and worm bored	1
J	Sandstone with hematitic oolite; reddish brown, highly ferruginous with mica laminations and fragmentary brachiopod shells	0.5
I	Sandstone (80%); medium dark gray, partly calcareous, fine grained, with worm tubes and miniature interference ripple marks, interbedded with dark gray shales (20%)	2.10
H	Hematitic oolite; dark reddish brown, calcareous, oolitic. The unit varies in thickness laterally in the form of lenticles. At some places lenticles show a thickness of up to 8 inch with intercalation of 1.6 inch thick medium dark gray pebbly sandstones	0.2
	Shale (80%); dark gray, non-calcareous, soft and fissile interbedded with sandstones. Sandstone (20%); medium gray, partly calcareous, fine grained	6
G	Sandstone (100%); greenish gray, partly calcareous, fine grained and massive	2.4
F	Shale (70%); medium gray, non-calcareous, micaceous, soft, papery and fissile; interbedded with sandstones. Sandstone (30%); medium dark gray, partly calcareous, medium grained	4

Unit No.		Thickness Feet
E	Sandstone (80%); medium gray, partly calcareous with interlaminated medium dark gray shales. Sandstones contain worm borings	1
D	Shale (75%); medium dark gray, non-calcareous, silty, micaceous, fissile and hard with sandstone lenticles (25%) having brachiopod shells. These strata contain worm burrows; *Hoegisphaera* sp., *Rhabdochitina magna* Eisenack, Indeterminate spp., *Veryhachium* sp., *V. rhomboidium* Downie, *Leiofusa jurassica* Cookson and Eisenack?, *Poikilofusa* sp., *Baltisphaeridium* sp., *Micrhystridium* sp., *M. stellatum* Deflandre, *Multiplicisphaeridium* sp.	2
C	Sandstone (80%); medium dark gray, partly calcareous, fine grained, banded, ripple marked with rare brachiopod shells, trilobite burrows, interbedded with medium gray shales	2.6
B	Shale (50%); medium gray, non-calcareous, micaceous, soft, papery and fissile, interbedded with sandstones; *Rhabdochitina magna* Eisenack, *Veryhachium* sp., *V. rhomboidium* Downie, *V. trispinosum* (Eisenack)? *Leiofusa jurassica* Cookson and Eisenack?, *Baltisphaeridium* sp., *B. longispinosum* (Eisenack), *Micrhystridium stellatum* Deflandre, *Multiplicisphaeridium* sp., Indeterminate spp.	
B'	Sandstone (50%); medium dark gray, partly calcareous, medium grained. These strata contain worm burrows and trilobite burrows	9
A	Sandstone (90%); greenish gray, partly calcareous, fine grained, massive with interlaminated shales. Shale (10%); medium gray, non-calcareous and micaceous. These strata are present at the foot of cliff	5

Table No. 14

Section studied in detail at a place between Grebes Nest Point and Gull Island South Head (Locality No. 347), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
347,Q	Shale (100%); dark gray, non-calcareous, soft, micaceous, and silty	4
P	Shale (100%); dark gray, non-calcareous, micaceous, soft and papery with cone-in-cone structure	18
O	Shale (100%); dark gray, non-calcareous and fine grained ..	10
N	Shale (90%); dark gray, non-calcareous, soft, micaceous, silty, fissile with lenticles and concretions (up to 1.06 ft. in diameter) of dark gray sandstones (10%)	5.6
M	Sandstone (60%); medium dark gray, non-calcareous, fine grained, banded, with pyrite contents, laminated and interbedded with dark gray shales (40%)	5
K	Sandstone(65%); medium dark gray, non-calcareous, fine grained, banded, interbedded with shales.	
L	Shale (35%); medium gray, non-calcareous, soft and fissile .	15
J' J"	Shale (70%); dark gray, non-calcareous, soft, interbedded with sandstones (10%); light gray, fine grained, banded with two beds of pyrite spheroids (20%), the sandstone contains graptolites in lower 3 inches and upper 7 inches thick beds	15
J	Shale (50%); and sandstone (50%); medium dark gray, both rock types are mixed with pyrite spheroids and blue fragmentary brachiopod shells	1
	Sandstone (100%); dark gray, non-calcareous, fine grained with pyrite spheroids and abundant dark gray shale and sandstone pebbles	0.7
I'	Sandstone (100%); greenish black, non-calcareous, fine grained, with hard pyrite pebbles up to half inch in length, and pyrite spheroids	1.3

Unit No.		Thickness Feet
	Sandstone (100%); greenish black, non-calcareous and fine grained	1.9
	Hematitic oolite; grayish red, non-calcareous, oolitic, occasionally laminated by shales	3.6
	Hematitic oolite (100%); dark reddish brown, non-calcareous, oolitic with occasional shale laminations	3.9
H	Shale (80%); dark gray, non-calcareous, fissile, with very thin lenticles of greenish black sandstone (20%) ...	1.3
G	Hematitic oolite (60%); grayish red, non-calcareous, oolitic, hard, interbedded with dark gray shales (40%). Hematitic oolite is occasionally current bedded with fragmentary brachiopod shells	3
F	Hematitic oolite; dark reddish brown, calcareous, hard with greenish black sandstone pebbles	0.2
E	Sandstone; greenish black, non-calcareous, fine grained, interbedded with dark gray shales	0.6
D	Sandstone (50%); greenish black, non-calcareous, fine grained, interbedded with shales. Shale (50%); dark gray, non-calcareous, fissile and micaceous, fossiliferous; Veryhachium sp., V. rhomboidium Downie, V. trispinosum (Eisenack), Micrhystridium stellatum Deflandre, Multiplicisphaeridium sp., Baltisphaeridium sp., B. longispinosum (Eisenack), Indeterminate spp.	0.10
C	Hematitic oolite (100%); dark reddish brown, non-calcareous, massive, hard, rarely oolitic, mostly present in the groundmass	2.6
B	Sandstone and hematitic oolite; brownish gray, calcareous, fine grained, both strata are mixed and jointed	0.1
A	Sandstone (100%); dark gray, non-calcareous, fine grained. This unit is present at the foot of cliff and dips down into the ocean	0.1

Petrography

Fig. No. 64, Magnification x 280 (approx.), Locality and Slide No. 344, O.

Fossiliferous silty shale. In this slide a coprolite has been cut parallel to the bedding and exhibits hystrichosphere and broken chitinozoa (?) tests (2.95% by point count) distributed throughout the groundmass. These microfossils are too small to be seen in Figure 64. In addition random distributions of fine grains of clastic quartz (3.95%) and mica flakes (muscovite, biotite and chlorite, 1.63%) were seen in it. The remainder of the section shows an "argillaceous groundmass" (91.45%) containing a number of different kinds of mineralogical and chemical constituents in a more or less homogenous mixture, including quartz, cryptocrystalline silica, micas, clay minerals, iron oxides, and phosphate. The photomicograph shows varying sizes of quartz grains in which larger grains are present probably as the result of the disruption of originally even bedding by the activity of 'worms'.

Fig. No. 65, Magnification x 70 (approx.), Locality and Slide No. 345, B.

Chamosite rock (ore). A thin section cut perpendicular to bedding exhibits chamositic oolites, spherules and nodules cemented mainly with a chamosite matrix, but occasionally with hematite also forming part of the cement. The groundmass locally is replaced by siderite. The spherules have nuclei of brachiopod shell fragments

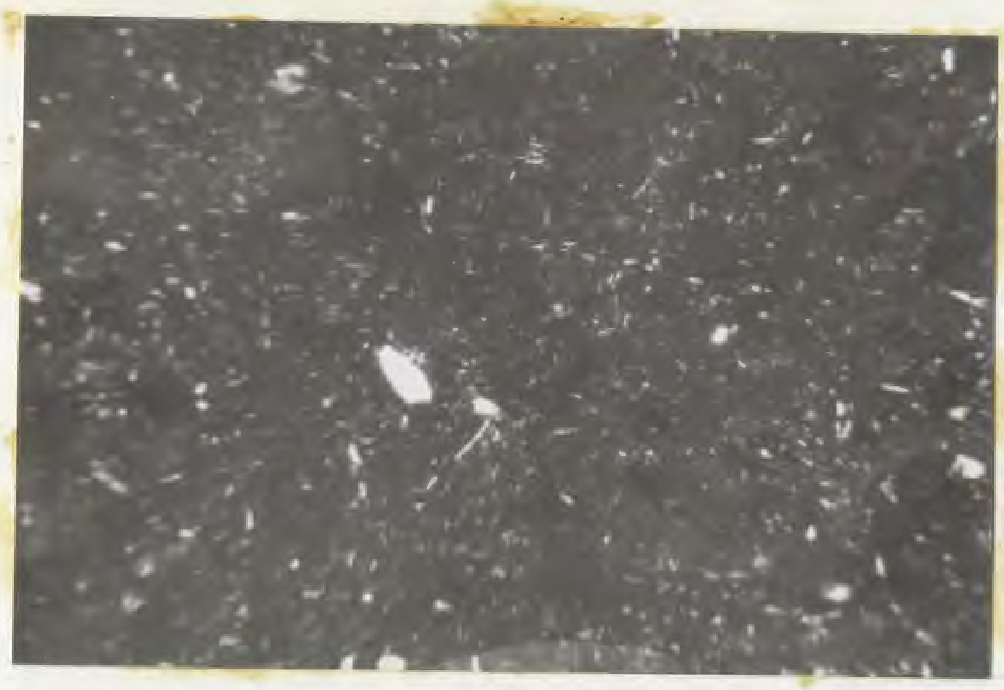


Fig. 64 Photomicrograph. Showing quartz grains(silt grade) in shale. Locality and Slide No. 344,O, Airfield Formation. X280(approx.),under crossed nicols.

Fig. 65 Photomicrograph of chamosite rock(ore), showing chamositic oolites and nodules. Locality and Slide No. 345,B, Airfield Formation. X70(approx.),under polarized light.

and are oriented in one direction on bedding planes. A few of the oolites occurring in the alternating layers of chamosite and hematite have quartz nuclei. Occasionally the nodules contain angular quartz fragments. Rare quartz grains (subrounded in shape), leucoxene and magnetite grains make up the accessory minerals. The chamosite nodules contain hystrichospheres (Veryhachium sp., Micrhystridium stellatum Deflandre) but are not present in this photomicrograph.

Figure No. 66, Magnification x 70 (approx.), Locality and Slide No. 345'D.

Sandstone. Figure 66 shows a thin section, cut perpendicular to bedding, in which is seen fine quartz grains, rounded to subrounded in shape, and of about 0.14 mm. in diameter. They are well sorted and held together with chloritic, sericitic and siliceous cement. Locally the quartz has been recrystallized. There are a few spherules (from 0.15 to 0.24 mm. in size) of chamosite and limonite, and also oolites made up of alternating layers of the same two minerals. These structures contain nuclei of either quartz or magnetite. The brachiopod shell fragments in the rock are oriented in a single direction. Magnetite, leucoxene and zircon are present as accessory minerals.

Fig. No. 67, Magnification x 70 (approx.), Locality and Slide No. 345, D.

Shale. A thin section cut perpendicular to bedding shows mica flakes and quartz grains set in a ferruginous and clayey

Fig.66 Photomicrograph. Sandstone showing well sorted quartz grains. Locality and Slide No.345',D, Airfield Formation.X70(approx.), under crossed nicols.

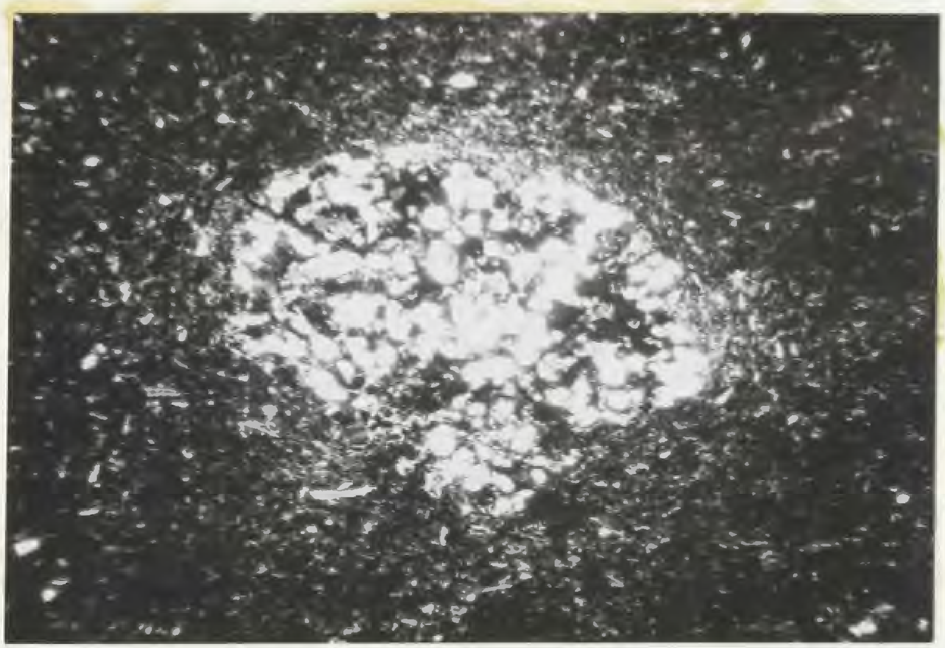


Fig.67 Photomicrograph. A worm bore in shale filled with clastic quartz grains. Locality and Slide No.345,D,Airfield Formation.X70(approx.),under polarized light.

groundmass containing fragmentary brachiopod shells. The rock is shot with worm tubes (see Fig. 67) which range in cross-section between 2.0 and 9.0 mms. The borings were filled with clastic quartz grains (subrounded to rounded) of about 0.16 mm. in size which are now loosely held together with sericitic and chloritic cement. The chloritic groundmass of the rock contains hystrichospheres (Micrhystridium stellatum Deflandre) not seen in the figure. Leucoxene, magnetite, zircon, and siderite (replacing chlorite) are the accessory minerals.

Fig. No. 68, Magnification x 70 (approx.), Locality and Slide No. 454.

Greenish-black sandstone. A thin section cut perpendicular to the bedding (Fig. 68) shows quartz grains of subrounded to rounded shapes, about 0.17 mm. in diameter and cemented with a chamosite groundmass. They are moderately well sorted with a rim of hematite. The spherules of hematite and oolites, made up of alternating layers of chamosite and hematite, are scattered throughout the groundmass. This rock type grades into another kind which exhibits quartz grains cemented with magnetite and chamosite. Fragmentary brachiopod shells are common in the rock. Locally siderite is found replacing chamosite in the groundmass. Zircon and leucoxene are the common accessory minerals.

Fig. No. 69, Magnification x 70 (approx.), Locality and Slide No. Subterranean 1189.

Hematitic oolite with interbedded calcareous shale (from deep mine workings). A thin section cut perpendicular to the bedding planes (Fig. 69) exhibits alternating bands of hematite spheroids and highly micaceous calcareous shale. The spheroids, and rarely the oolites (of hematite and chamosite layers), are oval, having been more or less compressed owing to compaction. The rock exhibits local micro-crossbedding. The spheroids, with a range of size from 0.06 to 0.20 mm., contain nuclei of quartz, chamosite and calcite, and are loosely cemented with a calcareous groundmass. Some spheroids are composed of chamosite. The muscovite mica flakes in the chloritic shaly part are oriented along the bedding plane similar to spheroids. Magnetite and leucoxene are the accessory minerals.

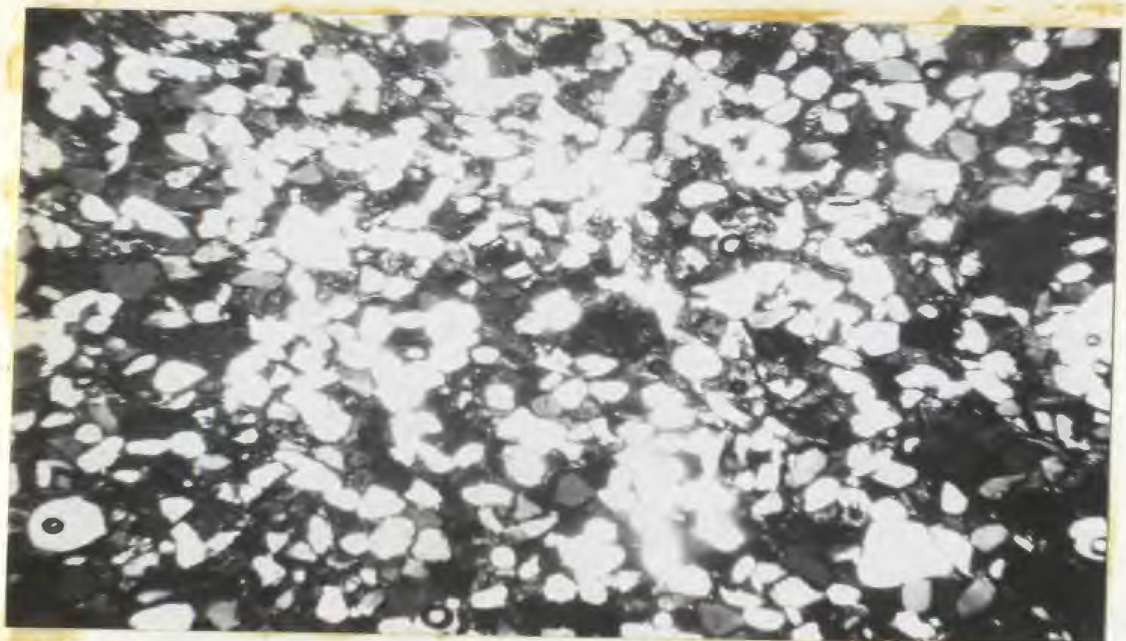


Fig.68 Photomicrograph of sandstone showing quartz grains of subrounded to rounded in shape, Locality and Slide No.454, Airfield Formation. X70 (approx.), under crossed nicols.

Fig.69 Photomicrograph. Oval and flattened hematitic oolites, Locality and Slide No.Subterranean, Airfield Formation. X70(approx.),under crossed nicols.
Note:lineation of oolites between arrows.

Wabana Formation

Lower Member

About 1/4 mile east of Ochre Cove a very thin outcrop section of the Lower Member (10 feet thick) was measured by the writer in December, 1965. However, since then the mining company has dumped waste rock on this outcrop completely burying it.

A contained graptolite fauna which is present in the member is indicative of a change in marine environment from that in which the underlying Dominion bed and other hematitic oolite beds of the Airfield Formation were deposited. Living graptolites are believed normally to have been creatures which lived in open oceans and not in the shallow parts of the seas. When they are found preserved in black (graptolitic) shales it is assumed that these are deep water marine facies. This change from oxidizing conditions typical of hematite deposition could occur only if a major subsidence of the ocean floor had taken place. Additional evidence for a significant subsidence is provided by the presence of an overlying stratum of spheroidal primary iron sulphide minerals (Pyrite bed), containing abundant pyritized graptolites, undoubtedly deposited under reducing conditions. This section of the Pyrite bed contains no traces of iron oxides. Thus geochemical evidence indicates that the subsidence of the shallow water hematite deposits took place at the close of the deposition of topmost members of the Airfield Formation.

The spheroidal pyrite occurs in three bands, which vary laterally in thickness with the thickest reaching a maximum of one foot at a stratigraphic level about 9 feet above the highest hematitic oolite bed of the Airfield Formation.

In lateral extent the pyrite beds thicken, thin and pinch out within short distances but the main Pyrite bed itself is very prominent and persistent.

Several sedimentary structures were recognizable at an exposure located directly above the Dominion bed in the east working face of the same open cut located about 1/4 mile east of Ochre Cove. At this locality the absolute thickness of the beds above the iron ore horizon could be measured, giving the following succession:

Shale bed	(Blue graptolites with partial pyritization)	
Pyrite bed with local shale partings		6"
Shale bed		3 1/2"
*************** Conglomerate *************************		
Conglomerate		85"
Iron ore (Dominion bed)		

Petrography

Fig. No. 70, Magnification x 70 (approx.), Locality and Slide No. Py. B.; I.

The rock seen in this slide is dark gray to black in colour, non-calcareous, fine grained and highly fossiliferous. The contained pyritized graptolites, pyrite spheroids, and pyrite nodules are cemented by a siliceous and shaly groundmass.

A section cut perpendicular to bedding (see Fig. 70) exhibits rectangular, rounded, and elongate oval masses (spheroids) of pyrite unevenly distributed and cemented with a siliceous shaly groundmass. In some parts the pyrite spheroids and nodules contain angular to subangular brown brachiopod shell fragments and quartz grains which indicate that during sedimentation both types of constituents were transported into the deeper ocean waters and deposited on the sea floor where some later were replaced secondarily by pyrite. The pyrite spheroids and nodules are loosely held together with an extremely fine-grained, siliceous, shaly groundmass suggesting that an original siliceous mud was present and that in a later stage the pyrite constituents were cemented with it. Occasional spheroids contain recrystallized quartz grains.

The groundmass in general is siliceous and shaly with recrystallized quartz grains. Mica flakes (muscovite and biotite) are abundant. Accessory minerals include magnetite and zoisite.

Orientations of the brachiopod and graptolite fragments suggest agitated waters were present at the sea floor-ocean interface at the time of their deposition, and that they were swept together either by wave or current action.

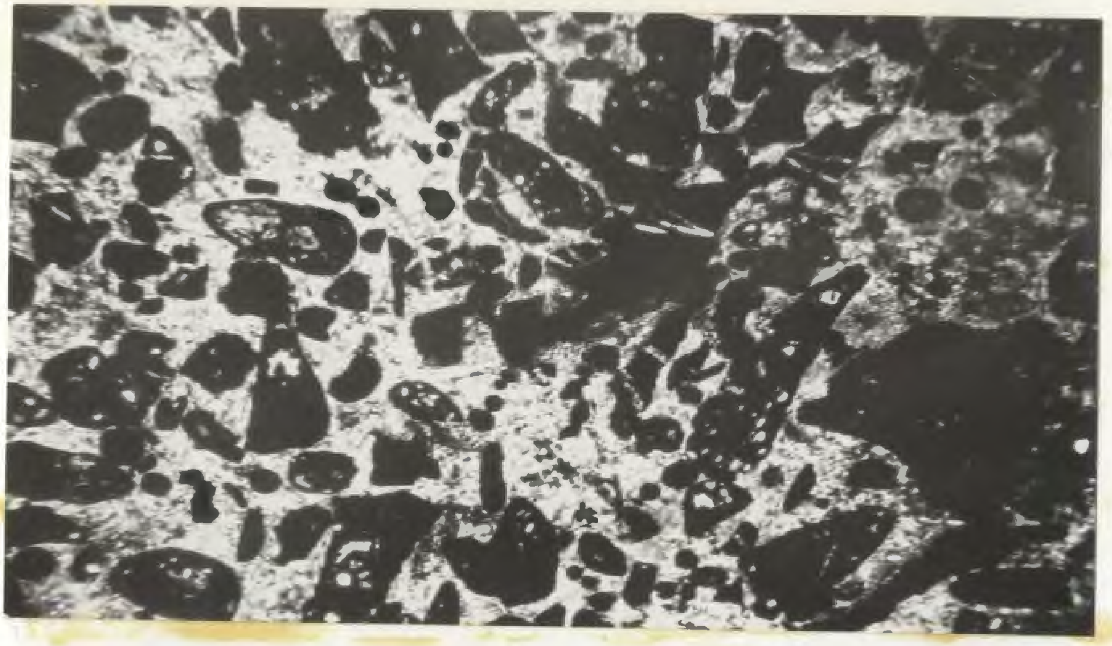


Fig.70 Photomicrograph of pyritized shale showing pyrite spheroids, nodules and pyritized graptolite fragments, Locality and Slide No. Py.B.I., Lower Member. X70(approx.), under polarized light.

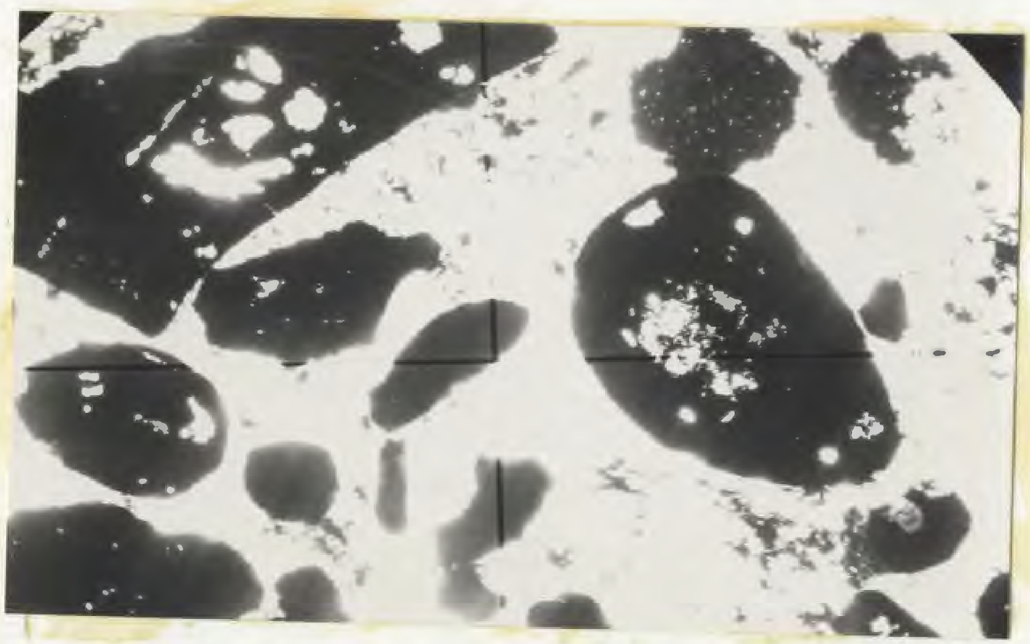


Fig.71 Photomicrograph. Pyrite spheroids and nodules with quartz fragments in pyritized shale, Locality and Slide No.Py.B.I., Lower Member. X280(approx.), under polarized light.

Middle Member

The Middle Member of Wabana Formation crops out intermittently for about three miles from a locality between Gull Island South Head and Grebes Nest Point, on the northern coast of the Island, to Ochre Cove at its western limit.

This member has a total sedimentary thickness of about 200 feet. It comprises a lower sequence of sandstones with shale partings containing several hematitic oolite beds, and an upper 15 foot sequence mainly made up of hematitic oolite beds which alternate with dark gray shales.

Two sections which are described in detail cover a major part of the stratigraphy of the member. The first section was studied at map stations Nos. 347 and 359 and the second immediately southwest of Gravel Head (Locality No. 378) on the northern coast of the Island.

The hematitic oolite bed (Scotia bed of Dr. Hayes) is cross-bedded indicating that in this area shallow water conditions probably were present during most of the time of its deposition (see Figs. 72 to 75). The greenish-gray sandstones, seen at station No. 345, show symmetrical and interference ripple marks, worm borings, coprolites, and rain prints, all of which are indicative of a shallow water origin (see Figs. 72 to 74).

The topmost hematitic oolite bed is overlain by a 3 inch thick pebble bed of which the upper surface marks the upper contact of the Middle Member.

The occurrence of sandstone concretions (ranging up to 3 feet in diameter) in shales is one of the characteristic features of this member (see Fig. 75).

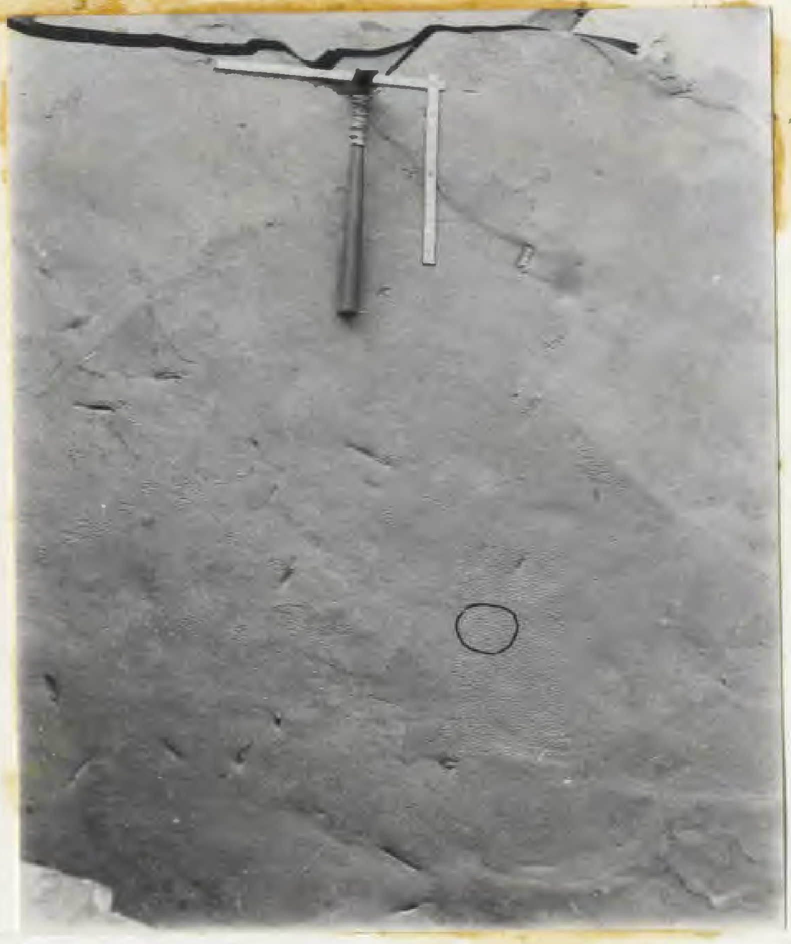


Fig.72 Photograph shows rain prints in sandstone, Middle Member, northern coast, Bell Island.
Note: the rain drop impressions are extremely fine and as can seen particularly well in the encircled area.

Fig.73 Worm borings in micaceous sandstone, Middle Member, northern coast, Bell Island.

Fig.74 Showing interference ripple marks in micaceous sandstone of the Middle Member, northern coast, Bell Island.

Fig.75 Photograph shows sandstone concretions with calcite veins in dark gray papery shales, Middle Member, open mine working, northern coast, Bell Island.

Table No. 15

Section studied in detail at a place southeast of Grebes Nest Point (Locality No. 359), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
359	Pebble bed; brown, fine grained sandstone with shale pebbles	0.3
	Hematitic oolite (ore) (100%); grayish brown, oolitic, cross-bedded	7
359,A	Sandstone (100%); greenish black, non-calcareous, interbedded with dark gray shales and grayish green sandstones	3.9
	Shale (80%); dark gray, fissile, non-calcareous, interbedded with greenish black sandstones (20%)	0.3
	Sandstone (80%); greenish black, non-calcareous, laminated in upper part by 10 inches thick dark gray shales (20%)	1.3
	Hematitic oolite (70%); grayish brown, oolitic, interbedded with greenish black sandstone (30%)	1.3
	Sandstone (100%); greenish black, non-calcareous and fine grained	1.3
B C	Sandstone (60%); dark greenish gray, non-calcareous, fine grained, banded, current bedded, interbedded with dark gray shales (40%)	3.9
D' D	Sandstone (50%); light gray, calcareous, fine grained, banded, current bedded, beds with giant worm tubes. Shale (50%); medium gray, non-calcareous, fissile, interbedded with sandstones	3.2
E	Sandstone; light gray, calcareous, fine grained, banded, occasionally with dark gray shale pebbles up to half inch in length, interbedded and laminated with dark gray shales which contain worm borings and tubes	7.6

Table No. 16

Section studied in detail at a place immediately southwest of Gravel Head (Locality No. 378), from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
378,M	Sandstone; greenish black, non-calcareous, fine grained, jointed. In between the joint planes occur fillings of hematitic solutions	2.6
L	Sandstone; medium gray, non-calcareous, fine grained, mixed with dark gray micaceous shales. Sandstone unit occasionally occurs as lenticular intercalations in shales	6.3
K	Hematitic oolite with siliceous rock; very dusky red, the siliceous rock (greenish black) and hematitic oolites are mixed. The hematitic oolite beds occasionally show dark gray shale intercalations and light gray phosphatic nodules (containing hystrichospheres) up to 1 inch in length occur on bedding planes	4.9
J	Hematitic oolite; very dusky red, non-calcareous, very finely oolitic and with occasional hematitic spheroids .	3.9
	Sandstone (100%); dark gray, non-calcareous and fine grained	0.10
	Shale (85%); dark gray, non-calcareous, soft, papery with intercalations and lenticles of medium dark gray sandstone (15%)	4.5
I	Sandstone; dark gray, non-calcareous and fine grained	1
	Shale; dark gray, non-calcareous, soft and papery	1.9
	Sandstone; medium gray, non-calcareous, fine grained, with some phosphatic pebbles	1.9
	Shale; dark gray, non-calcareous, fissile and micaceous ..	11
	Sandstone; medium gray, non-calcareous, fine grained, interbedded with dark gray shales	5

Unit No.		Thickness Feet
	Shale; dark gray, non-calcareous, silty, with worm burrows	2
	Sandstone; medium gray, non-calcareous, fine grained, interbedded with dark gray shales having giant worm tubes	7
	Shale; dark gray, non-calcareous, silty and sandy with worm burrows	5
H	Sandstone (80%); medium gray, non-calcareous, fine grained, occasionally shows quartz lenticles, banded, current bedded, interbedded with dark gray shales (20%) having giant worm tubes. These strata are interbedded with a half inch thick pebble bed	3.9
G	Shale (100%); dark gray, non-calcareous, silty and sandy, micaceous with worm burrows	0.5
	Pebble bed; dark gray sandstone bed with dark gray shale pebbles	0.2
F	Shale (100%); dark gray, non-calcareous, fissile and micaceous	0.5
E	Pebble bed; dark gray pebbly sandstone bed, partly calcareous, fine grained, with medium dark gray to dark gray shale pebbles up to 1 inch in length and very hard	1.6
D	Sandstone (100%); medium gray, non-calcareous, medium to fine grained	0.6
C	Hematitic oolite ore (100%); very dusky red, non-calcareous. This was the main ore bed which has been mined by DOSCO	5.6
B	Shale (70%); dark gray, non-calcareous, interbedded in lower 2 feet by 3 to 4 inches thick, non-calcareous hematitic oolite (30%), the shale occurs mixed with the hematitic oolite	8
A	Sandstone (60%); greenish gray, non-calcareous, medium grained, banded, interbedded with dark gray shales (40%) having giant worm tubes upto 8 inches long and 1 inch in diameter present mostly along the bedding planes. These strata are present at the foot of cliff	7

Petrography

Fig. No. 76, Magnification x 70 (approx.), Locality and Slide No. 347, I'.

Pyritiferous sandstone. A thin section cut perpendicular to bedding shows quartz grains (about 40%), medium to fine grained, moderately sorted, subrounded to rounded in shape with a range of size from 0.05 to 0.11 mm. Pyrite spheroids and nodules (about 60%) of 0.07 to 0.18 mm. in size are abundant and along with fragmentary brachiopod shells are oriented parallel to the bedding planes. Locally the quartz grains and pyrite spheroids appear together in pyrite pebbles of about 0.95 mm. in size. A thin film of silica (chalcedonic ?) forms the outer rim of some of the pebbles. The quartz grains, pyrite spheroids and pyrite pebbles are tightly held together with a sericite and siliceous matrix. The quartz grains in the rock exhibit graded distribution.

Fig. No. 77, Magnification x 70 (approx.), Locality and Slide No. 347, J.

Shaly sandstone. Figure 77 is a thin section cut perpendicular to bedding exhibiting unsorted quartz grains which vary in size from 0.05 to 0.72 mm. The pyrite contents are similar to rock No. 347, I' but they show poorly developed orientation, are unevenly distributed throughout the groundmass, and along with quartz grains are cemented with a pyritic and siliceous matrix.

Locally the sandstone is impregnated with silty shale. In general the rock contains a sandy part (about 40%), a shaly part (about 40%), and pyrite contents (about 20%).

Fig.76 Photomicrograph. Showing pyrite spheroids and pyritized brachiopod shell fragments, Locality and Slide No.347,I', Middle Member, X70(approx.), under polarized light.

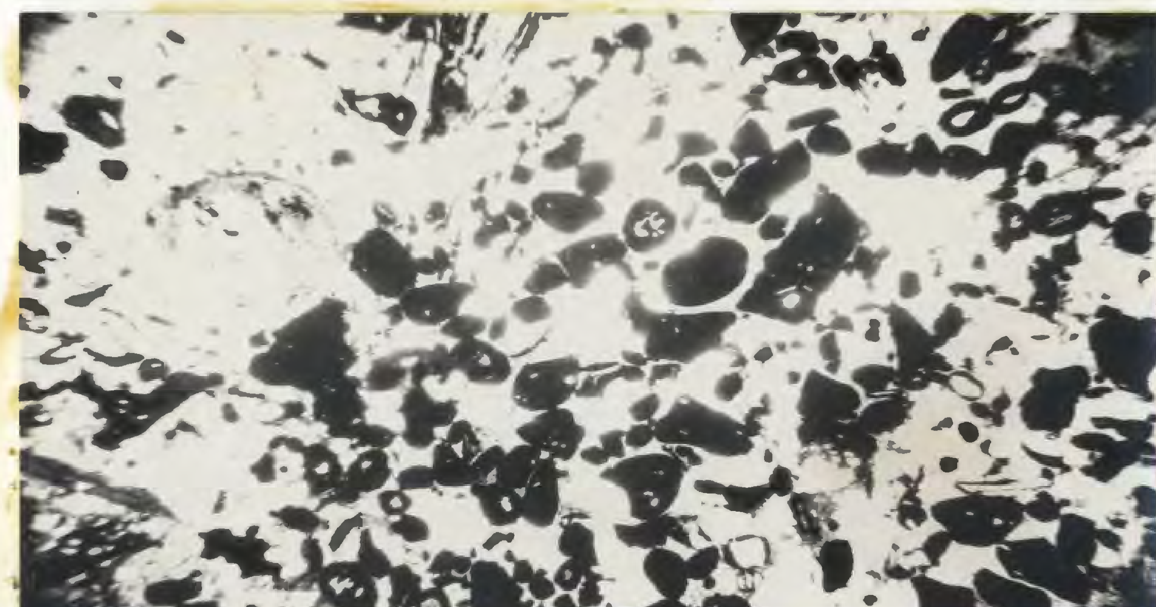


Fig.77 Photomicrograph of shaly sandstone exhibiting pyrite spheroids, brachiopod shell fragments and shale inclusions, Locality and Slide No.347,J, Middle Member. X70(approx.), under polarized light.

Fig. No. 78, Magnification x 70 (approx.), Locality and Slide No. 347, C.

Sandy hematitic oolite. This thin section, cut perpendicular to the bedding, is seen to exhibit oolitic and massive hematite which constitutes the groundmass and forms about 80% part of the rock. The oolites are made up of alternating layers of hematite and limonite (not shown in this photomicrograph). The quartz grains (about 20%) are subrounded to subangular in shape. Subrounded chamosite grains with crystallized hematite are also present in the groundmass.

Fig. No. 79, Magnification x 70 (approx.), Locality and Slide No. 378, c.

Hematitic oolite with shale intercalations. Figure 79 is a thin section cut perpendicular to the bedding. It contains spherules and oolites of hematite, ranging in size from 0.16 to 0.42 mm., in a groundmass of microcrystalline chamosite. The oolites are composed of alternating layers of hematite and chamosite which variously have nuclei of chamosite, quartz and magnetite. Their long axes are oriented in one direction in the rock slice and they are loosely held together in the groundmass. In this thin-section of shale can be seen a worm boring which has been filled with hematitic oolite. Highly micaceous silty shale (about 5%) is present in the form of intercalations. The hematitic part constitutes about 95% of the rock. A few fragments of quartz occur in the groundmass. This specimen is from the principal ore bed mined by DOSCO.

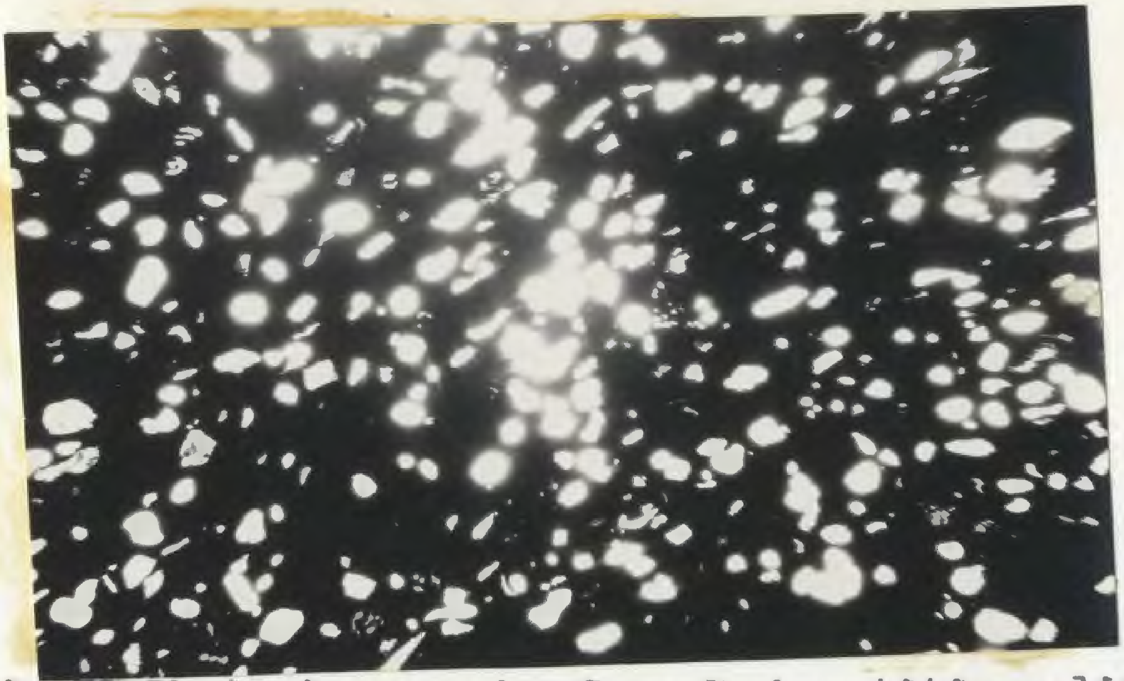


Fig. 78 Photomicrograph of sandy hematitic oolite showing clastic quartz grains in a massive groundmass of hematite, Locality and Slide No. 347,C, Middle Member. X70(approx.), under polarized light.

Fig. 79 Photomicrograph. A worm bore in shale filled with hematitic oolites, Locality and Slide No. 378,C, Middle Member. X70(approx.), under polarized light.

Fig. No. 80, Magnification x 70 (approx.), Locality and Slide No. 378, E.

Pebbly sandstone. In a thin section, cut perpendicular to bedding, fairly well sorted quartz grains of subangular to subrounded shape, with a range in size from 0.01 to 0.14 mm., are closely held together with sericitic, chamositic and calcareous cement which also forms the groundmass. Included silty shale pebbles are oriented in one direction in the groundmass and contain occasional hystrichospheres (Baltisphaeridium microcladum Downie), but these microfossils are not shown in this photomicrograph. The pebbles are highly ferruginous and some of them contain chamosite spherules and oolites. Some spherules are distributed randomly in the groundmass. Their diameters range from 0.24 to 0.32 mm.

Fig. No. 81, Magnification x 70 (approx.), Locality and Slide No. 378, K.

Hematitic oolite with phosphatic nodules. Figure 81 is a photomicrograph of a thin section of a phosphatic nodule cut parallel to the bedding. In it can be seen an uneven distribution of hematitic oolites and hematite spherules with quartz and chamosite nuclei. The size of the oolites and spherules range from 0.08 to 0.28 mm. A phosphatic groundmass contains very fine flakes of muscovite, clay particles and silica, recrystallized hematite, quartz grains (subrounded to subangular), leucoxene, magnetite and chamosite. The groundmass yielded several species of hystrichospheres (not seen in the Figure) after chemical maceration of the phosphatic nodules.

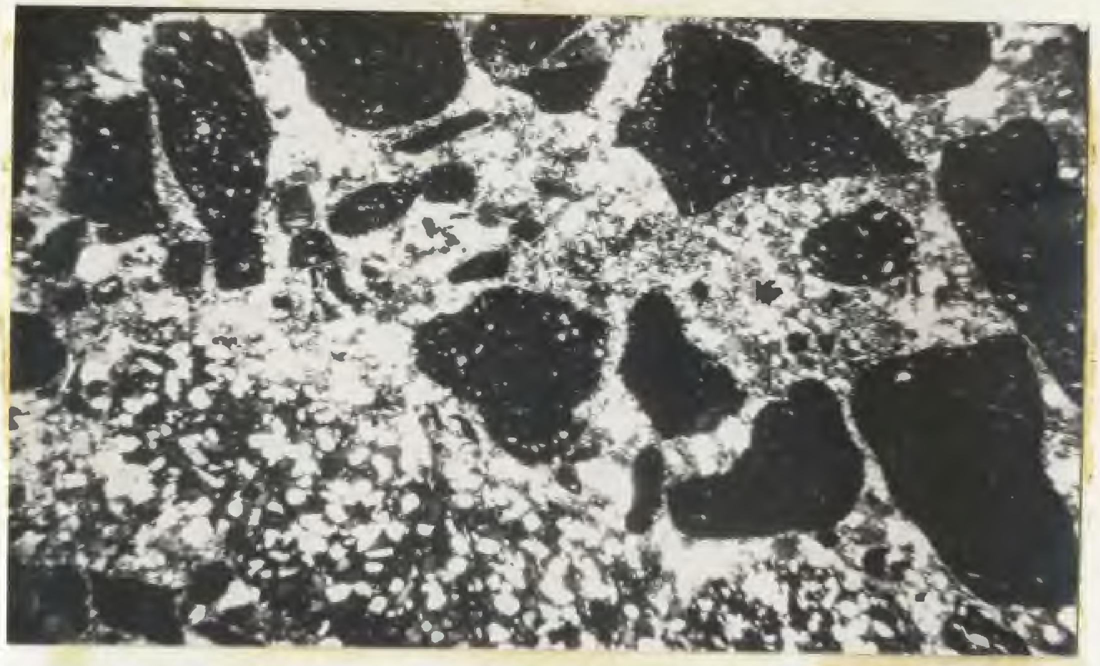


Fig.80 Photomicrograph of pebbly sandstone. Shale pebbles and fragments in sandstone, Locality and Slide No.378,E,Middle Member,X70(approx.), under crossed nicols.

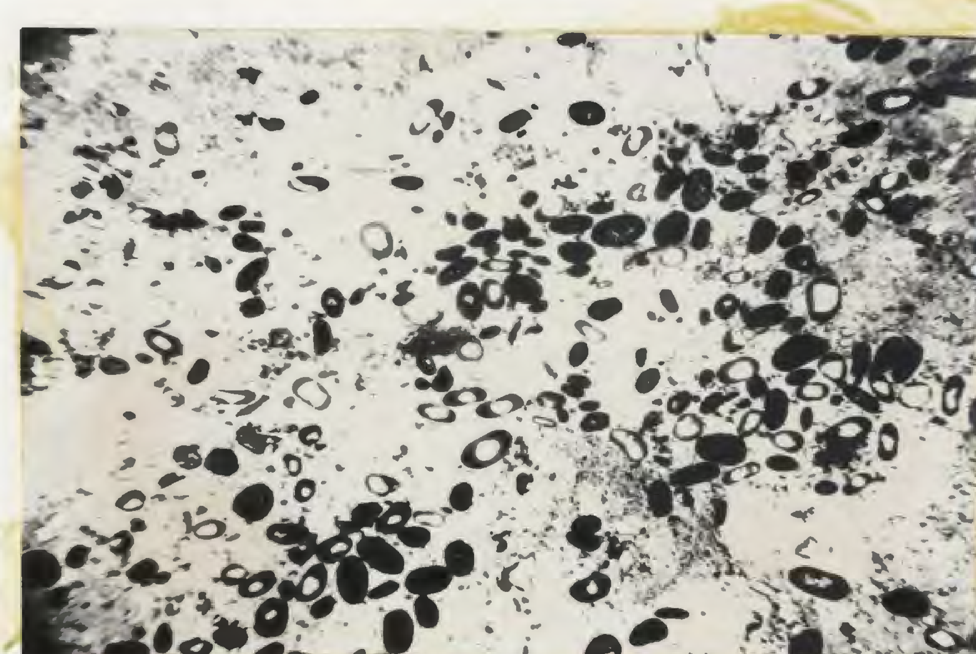


Fig.81 Photomicrograph. Showing uneven distribution of hematitic oolites in phosphatic groundmass, Locality and Slide No.378,K,Middle Member. X70(approx.), under polarized light.

A modal two-dimensional analysis of the nodules (by point counter) exhibits the following percentage of different constituents:

Constituents	Percentage
Phosphatic material	71.6
Quartz	8.7
Hematite	8.5
Oolitic and spherulitic hematite	7.4
Magnetite	2.02
Hystrichospheres	1.40
Total	99.62

Fig. No. 82, Magnification x 70 (approx.), Locality and Slide No. 460, S.

Sandstone. A thin section (Fig. 82) cut perpendicular to bedding exhibits quartz grains, of subrounded to rounded shape with a range of size from 0.01 to 0.12 mm., closely held together with sericitic and siliceous cement. The rock is highly micaceous (biotite almost completely altered to chlorite), well sorted and exhibits occasional very fine bands of shale. Magnetite, zircon and leucoxene constitute the accessories.

Upper Member (Grebes Nest Member)

The stratigraphic thickness of Grebes Nest Member, which is the youngest member of Wabana Formation, is about 100 feet. The lowest bed of the member is separated from the top of the Middle Member by an unconformity at the base of a 3 inch pebble bed. Sandstones and shales, measuring about 40 feet in thickness, overlie the pebble bed and, in combination with an additional 50 feet of overlying hematitic oolite beds, sandstones and shales, constitute the Member (see Fig. 32). In the Upper Member occur a series of oolitic hematite beds separated by sandstone and shale partings, and containing chamosite and siderite with small amounts of hematitic oolite.

A well-exposed cliff section of the Member occurs at Grebes Nest Point, on the northern coast of the Island, where details of the primary sedimentary features of the Member can be studied (see Fig. 83). The cliff section at Locality 362 is described below.

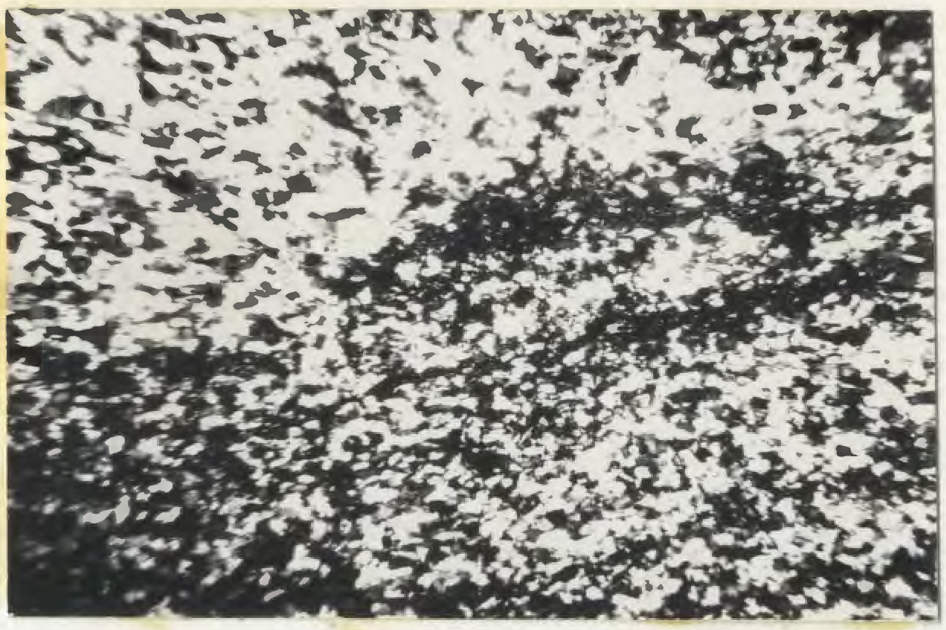


Fig.82 Photomicrograph. Fine grained sandstone with shale bands, Locality and Slide No.460,S, Middle Member. X70(approx.), under crossed nicols.

Fig.83 Photograph shows studied section No.362 at Grebes Nest Point, Grebes Nest Member, northern coast, Bell Island, View W

Table No. 17

Section studied in detail at Grebes Nest Point (Locality No. 362) northern coast of Bell Island, from top to bottom, the sequence is as follows:

Unit No.		Thickness Feet
	Overlying strata, covered with alluvium.	
362,c	Shale; dark gray, non-calcareous, silty, micaceous, papery, fissile. This unit occurs at top of cliff section	0.2
	Sandstone (95%); medium dark gray, non-calcareous, fine grained, with micaceous shale laminations (5%)	0.6
b	Shaly (50%) and siliceous rock (50%); dark gray shaly rock mixed with greenish black siliceous rock show light gray phosphatic nodules with large worm burrows up to 1 foot in length and 2 inches in diameter	1
a'	Siliceous rock with hematitic oolite; mixed rock, grayish red with greenish tinge and non-calcareous	0.8
a	Shaly siderite rock; very dusky red, partly calcareous and fine grained	0.1
Z	Siliceous shaly rock with phosphatic nodules; brownish and greenish black with brown stains, slightly calcareous, rarely oolitic, nodules with brachiopod shells and microfossils; *Angochitina flasce* Collinson and Schwalb, operculum of *Desmochitina*?, *Veryhachium trispinosum* (Eisenack), *V. rhomboidium* Downie, *Baltisphaeridium* sp., *B. longispinosum* (Eisenack), *Micrhystridium stellatum* Deflandre, *Multiplicisphaeridium* sp., Indeterminate spp.	2.8
X	Hematitic oolite; grayish brown, non-calcareous, oolitic and rhombic	0.1
V W X	Chamosite rock (ore); greenish black with brown stains, poorly calcareous, fine grained and partly oolitic	2.4
	Slate; dark gray, non-calcareous and very hard	0.6
	Chamositic and shaly rock; mixed rock, dark greenish gray, fine grained with fragmentary brachiopod shells	0.4
	Slate; dark gray, non-calcareous and very hard	0.6

Unit No.		Thickness Feet
U	Chamositic shaly rock; mixed rock, dark greenish gray, non-calcareous, fine grained, with fragmentary brachiopod shells and shale pebbles	0.3
	Slate and siliceous rock; dark gray, non-calcareous, micaceous, very hard with worm burrows	3.2
T	Hematitic oolite; grayish red, rhombic and oolitic	0.6
	Hematitic oolite mixed with siliceous rock; grayish red with greenish tinge and non-calcareous	0.4
	Hematitic oolite; grayish red, rhombic and oolitic	0.7
	Siliceous rock; dark greenish gray with slaty shale	0.1
	Hematitic oolite (ore); grayish red, rhombic and oolitic	2
	Slate with siliceous rock; dark gray, non-calcareous, micaceous, with occasional greenish black siliceous pebbles	1.2
S	Slate with siliceous rock; dark gray, non-calcareous, micaceous, very hard, with worm burrows	4.3
	Hematitic oolite; grayish red, non-calcareous, oolitic and rhombic	0.3
	Siliceous rock; greenish black, non-calcareous, and fine grained with worm burrows and ripple marks	0.2
Q	Siliceous rock with hematitic oolite; mixed rocks, grayish red with greenish tinge, non-calcareous	2.1
	Hematitic oolite; grayish red, rhombic and oolitic	0.3
	Siliceous rock and hematitic oolite; mixed rock, grayish red with greenish tinge, and non-calcareous	0.6
	Siliceous rock (parting); dark greenish gray, with very fine grained sandy and slaty shale	0.1
	Hematitic oolite; grayish red, non-calcareous, rhombic and oolitic	1.1
	Siliceous rock; greenish black, non-calcareous, and fine grained	0.1

Unit No.		Thickness Feet
P	Hematitic oolite (ore); grayish red, non-calcareous, rhombic and oolitic, occasionally occurs with dark gray shale partings	2
	Hematitic oolite; grayish red, rhombic and oolitic	0.2
	Siliceous rock; dark greenish gray, partings of slaty shale	1.6
	Siliceous rock; dark greenish gray, with very fine grained sandy and slaty shale	0.1
	Hematitic oolite; grayish red, rhombic and oolitic	0.4
	Siliceous rock; dark greenish gray with slaty shale	0.1
	Hematitic oolite; grayish red, rhombic and oolitic	0.2
	Siliceous rock; dark greenish gray with very fine grained sandy and slaty shale	0.3
	Hematitic oolite; grayish red, rhombic and oolitic	0.6
O"	Siliceous rock; dark greenish gray, partings of slaty shale	0.6
O	Hematitic oolite; grayish red, rhombic, oolitic	0.3
N	Siliceous rock with oolitic hematite; both rock types occur as mixed, grayish red with greenish tinge and non-calcareous	1
M	Slate; dark gray, non-calcareous, micaceous, hard, jointed in three directions, with worm borings, occasionally shows medium dark gray sandstone lenticles	0.7
L	Siliceous rock with hematitic oolite; both rock types are mixed, grayish red with greenish tinge, and non-calcareous	0.9
	Shale (100%); dark gray, non-calcareous and fissile	0.3
K	Hematitic oolite (ore); grayish red, non-calcareous, soft, platy and oolitic, with abundant brachiopod fragments	2.6
J	Siliceous rock; non-calcareous, fine grained with brown ferruginous matter	4.4

Unit No.		Thickness Feet
I	Siliceous rock (50%); greenish black, non-calcareous, very fine grained; with two beds (interbedded) of dark gray shales (50%), each a half foot in thickness, silty and hard	2
H	Hematitic oolite ore (100%); grayish red, non-calcareous, oolitic, rhombic with occasional dark gray shale pebbles .	4
G	Shale and siliceous rock; dark gray, non-calcareous, mixed with green siliceous rock. These strata occur at base of the cliff at Grebes Nest Point	2
F	Shale (80%); dark gray, non-calcareous, papery, interbedded with sandstones. Sandstone (20%); greenish gray, non-calcareous, fine grained. The shale beds show giant worm burrows up to 6 inches long, and coprolites. A shale pebble bed of 6 inches thick is present between the beds	6.6
E	Sandstone (90%); greenish gray to medium gray, non-calcareous, fine grained with dark gray micaceous shale laminations, having minute worm burrows	6.6
D	Shale (60%); dark gray, non-calcareous, soft, papery, with coprolites and giant worm burrows up to 10 inches long and 1.6 inches in diameter, shale occurs interbedded with sandstones. Sandstone (40%); greenish gray, non-calcareous, fine grained, banded, current bedded	18.9
C	Sandstone (90%); greenish black, non-calcareous, fine grained, interbedded with 3 inch thick rhombic and hematitic oolite (10%)	10
B	Hematitic oolite (ore); grayish red, non-calcareous, pebbly (up to half inch long shale pebbles)	1
A	Siliceous rock; greenish black, non-calcareous, fine grained. These strata are present at the foot of cliff adjoining Grebes Nest Point.	1.6

Petrography

Fig. No. 84, Magnification x 70 (approx.), Locality and Slide No. 362, B.

Hematitic oolite (ore). A thin section cut perpendicular to bedding shows hematitic oolite and hematite spherules of 0.16 to 0.26 mm. in size cemented with a chamosite matrix. The oolites and spherules contain nuclei of either chamosite or quartz. The oolites (0.16 to 0.24 mm. in size) are made up of alternating layers of chamosite and hematite and their long axes are oriented in one direction. Brachiopod shell fragments and medium to coarse grained, subrounded to rounded quartz grains, about 2 cms. in size, are unevenly distributed in the groundmass.

Fig. No. 85, Magnification x 70 (approx.), Locality and Slide No. 362, L.

Hematitic oolite and siliceous rock. The figure shows a thin section, cut perpendicular to bedding, in which can be seen oolitic hematite and chamosite spherules cemented with a sideritic matrix. Several oolites have exterior borders made up of siderite which was also found completely replacing the chamosite of the spherules and occasionally of the oolites. Some quartz grains present in the groundmass are rounded to subrounded in shape.

Fig. No. 86, Magnification x 70 (approx.), Locality and Slide No. 362, O".

Slaty shale. Figure 86 is a thin section cut perpendicular to bedding. In general the rock is highly micaceous slaty shale with a

Fig.84 Photomicrograph. Showing hematitic oolites with nuclei of quartz, Locality and Slide No. 362,B, Grebes Nest Member. X70(approx.), under polarized light.

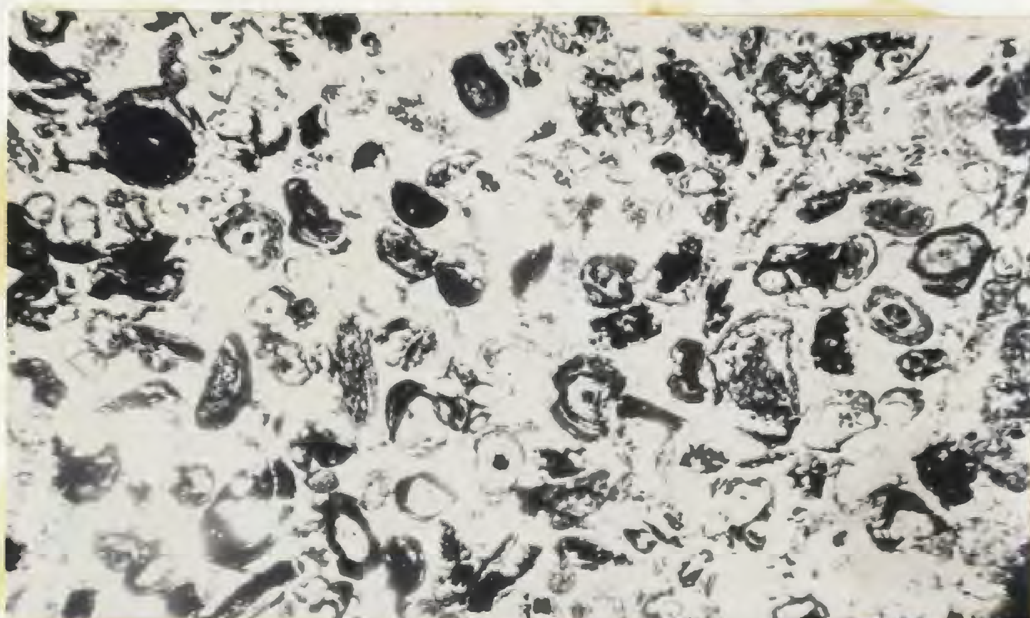


Fig.85 Photomicrograph. Hematitic oolites and chamosite spherules in siderite groundmass, Locality and Slide No.362,L, Grebes Nest Member. X70(approx.), under crossed nicols.

chloritic, siliceous, and calcareous groundmass. Mica flakes in it are oriented in one direction as are the subrounded to rounded quartz grains (0.01 mm. in size). This microfacies grades into hematitic oolite and chamosite spherules (0.20 mm. in size) which are loosely held together with sideritic cement. Locally the siderite was found replacing spherules. The oolites, with an average diameter of 0.22 mm., are made up of alternating layers of chamosite and hematite with either magnetite, quartz or chamosite nuclei. The chamosite is partly replaced with a sideritic groundmass. The oolites and spherules are oval probably as a result of flattening.

Fig. No. 87, Magnification x 70 (approx.), Locality and Slide No. 362, Q.

Sandstone (siliceous rock). A thin section, cut perpendicular to bedding, show very fine grains of quartz of subrounded to rounded shape, ranging up to 0.11 mm. in size, loosely held together with a matrix of shale and chamosite. The rock also contains brown shale fragments, fragmentary brachiopod shells, and accessory minerals including magnetite, and zircon.

Fig. No. 88, Magnification x 70 (approx.), Locality and Slide No. 362, W.

Chamosite rock (ore). A thin section cut perpendicular to bedding shows chamosite spheroids and oolites ranging up to 0.36 mm. in size which are loosely held together by a mixture of siderite and

Fig.86 Photomicrograph of slaty shale showing bands of shale and hematitic oolites, Locality and Slide No.362,O'',Grebes Nest Member. X70(approx.), under polarized light.

Fig.87 Photomicrograph. Fine grains of quartz with shale fragments, Locality and Slide No.362,Q, Grebes Nest Member.X70(approx.), under crossed nicols.

chamosite which forms the groundmass. The spheroids and oolites are either rounded, oval, or more or less flattened in shape possibly owing to the weight of the overlying sedimentary column on the unlithified structures sometime after deposition. The spheroids are rimmed externally with a thin film of hematite part of which is intermixed with the siderite in the groundmass. Either siderite, chamosite, or leucoxene form the nuclei of the spheroids.

Fig. No. 89, Magnification x 70 (approx.), Locality and Slide No. 362, Z.

Siliceous shaly rock with phosphate nodules. A thin section cut perpendicular to bedding shows phosphate nodules cemented with a shaly groundmass. The latter is ferruginous and phosphatic with subrounded quartz grains close to 0.10 mm. in size. The nodules are silty, and contain muscovite lamina and fine recrystallized quartz grains. The nodules have yielded several species of hystrichospheres (not seen in Fig. 89) including Micrhystridium stellatum Deflandre, Veryhachium rhomboidum, Baltisphaeridium sp. There are concentrations of magnetite and hematite grains throughout the groundmass.

Fig. No. 90, Magnification x 70 (approx.), Locality and Slide No. 362, b.

Shaly and siliceous rock. A thin section perpendicular to bedding exhibits unsorted quartz grains of subrounded to rounded shape, with a range of size from 0.01 to 0.14 mm., loosely held together with

Fig.88 Photomicrograph of chamosite rock(ore) showing chamosite spheroids and oolites in chamosite groundmass, Locality and Slide No.362,W, Grebes Nest Member. X70(approx.), under crossed nicols.

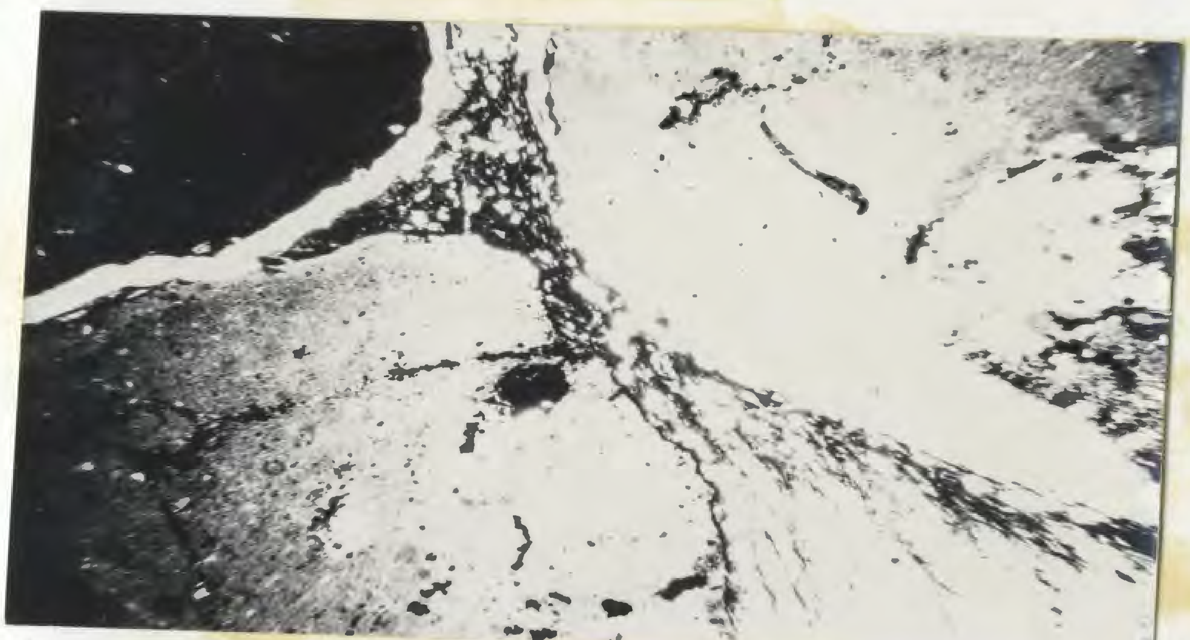


Fig.89 Photomicrograph. Showing parts of three phosphatic nodules in silty shale, Locality and Slide No.362,Z, Grebes Nest Member. X70(approx.), under polarized light.

a shaly and chloritic groundmass. Locally the groundmass may be either impregnated with phosphatic material or replaced by it, and where the latter condition obtains only traces of the original groundmass can be seen. A few brachiopod shell fragments are present in the rock. Zircon is common as an accessory mineral but magnetite and limonite are rare.

Origin of the ore

Hematitic oolite beds occur in all formal rock units found on Bell Island except for the Lower Member of the Wabana Formation. The ferruginous beds of the lowermost Polls Head Formation, part of which is exposed on Kellys and Little Bell Islands, have no economic importance. The Townsquare Formation, which overlies the Polls Head Formation, is similarly unimportant economically. The Airfield Formation, and the Middle and Upper Members of the Wabana Formation have fairly high iron contents, and the hematitic oolite beds of these formations are economically productive. The ferruginous beds have gross stratigraphic relationships similar to enclosing sandstone and shale layers. All three types of beds thicken and thin probably owing to the depositional and erosional activity of currents and waves as recorded by abundant ripple-marks and cross-bedding features.

Since the hematite beds contain marine fossils, such as brachiopods, trilobites, worm tubes and algae, which are known to have lived in the littoral zone, it is probable that the ore beds were deposited under shallow marine conditions.

Previous work with writer's observations

Dr. A.O. Hayes came to the conclusion that the ore-bearing formations are of Lower Ordovician age. Since the faunas found on Bell Island have a closer relationship with European faunas, than with North American ones, Hayes made his correlation with the European Arenig and Llandeilo of Wales and, less exactly, with the Beekmantown, Chazy, and Black River of the Appalachian Province.

In his detailed remarks Dr. Hayes suggested

"... that the iron ore occurs as a primary bedded deposit, and that the iron content was present in the sediments at the time that the series was laid down. It is probable that the spherules were formed out of the extremely fine grained, unconsolidated, ferruginous sediments of the sea bottom, in water sufficiently shallow to allow of a certain amount of agitation owing to the action of the surface waves." (26: p. 67).

The absence of detrital quartz grains in the ore beds of the Middle Member of Wabana Formation indicates that it may have been deposited some distance from the shore line. The Upper Member also exhibits the same phenomenon. Cross-bedding and ripple-marked features have indicated its deposition occurred under shallow water conditions. The presence of thin lamellae of hematitic oolites, and earthy hematite arranged in alternating layers in the spherules, indicate that they were formed before the final consolidation of the ore beds took place.

The important iron-bearing minerals occurring in most of the ore beds are chamosite, hematite and siderite. The siderite in general is a secondary replacement after original chamosite and hematite. Alternating concentric layers of chamosite and hematite in the oolites and spherules indicate that probably most of the hematite was formed contemporaneously with chamosite.

A conglomerate bed with pebbles of hematitic oolite and chamosite occurs in a matrix of dark gray shale directly overlying the top of the Airfield Formation suggesting that the oolitic iron ore was formed before the lithification of the iron ore beds took place.

Dr. A.O. Hayes has suggested that

"... it seems probable that the iron was derived by long continued weathering of earlier crystalline and sedimentary rocks, the solution of their iron content by mineral and vegetable acids and subsequent transportation of the iron salts by streams into the sea.

The Precambrian sedimentary and crystalline rocks contain much iron and these have furnished the iron of the Cambrian and Ordovician rocks underlying the Wabana ore." (26: p. 71).

The shale beds of the west bank of lower Manuels River valley, of the western end of the south coast of Kellys Island, and of the western coast of Bell Island are highly ferruginous as is evidenced by iron-stained groundwater seepages.

Regarding precipitation of the iron Dr. Hayes has mentioned that

"since W. Spring... has shown that ferric hydroxide will become dehydrated in salt water and form ferric oxide, the view may be taken that some of the iron may have been precipitated as ferric hydrate and formed the ferric oxide directly. If so, both the silicates and oxide have formed together in a most intricate fashion to build alternate layers in the spherules. It appears probable that a considerable proportion of the iron was precipitated primarily as ferrous aluminous silicates similar to chamosite and thuringite, and while a small amount of hematite appears to have been formed about tubules of boring algae, apparently secondary to the chamosite, most of the hematite may be of contemporaneous origin with the silicates. The siderite was the last iron-bearing mineral to form and it frequently replaces chamosite, hematite and quartz. It may have been produced by the aid of decomposing organic matter acting on chamosite and hematite during a period of shallow water conditions such as prevailed during the formation of the top of the Dominion bed, zone 2, and of much of zone 5." (26: pp. 73, 74).

In the Dominion bed of Dr. Hayes and in the hematitic oolite beds of the Middle Member of Wabana Formation are found occasional fossil algae which are covered exteriorly with either a thin layer, or film, of crystalline hematite suggesting, especially that at these places, the biochemical activity of these organisms might have aided in the oxidation of iron phosphate producing hematite.

In some ore beds the siderite associated with chamosite and hematite is always found as a replacement of the two latter minerals. In this connection Dr. Hayes has mentioned that:

"... during the deposition of the ferruginous beds, it seems probable that a variety of iron salts were in solutions in the sea water, and the ammonium carbonate resulting from the decomposition of organic matter, where entombed by overlying sediments, may have decomposed these iron salts, with the formation of the corresponding ammonium salts and the precipitation of the iron carbonate, siderite." (26: p. 81).

Iron ore deposits of the world

In this section are summarized selected iron ore deposits from other parts of the world which Hayes (1915) considered to have more or less the same character and age as those found on Bell Island.

Dr. Hayes has mentioned that:

"M.Y. Williams has correlated an occurrence at Arisaig, Nova Scotia, with the Wabana ore and refers it to the Upper Cambrian." (26: p. 83).

In the present study I contacted Nova Scotia Department of Mines in order to try to obtain either drill cores or surface samples of the rocks associated with iron ores of Arisaig in order to make a comparative study with those of Bell Island. However, these could not be made available to me.

Professor C.H. Smyth (26: pp. 83, 84) has considered such hematitic deposits as analogous to modern lake and bog iron ores and concluded that these deposits in the most part were precipitated as limonite with minor associated marls.

Dr. Hayes has written about the important work done by J.J. Rutledge and Professor C.K. Leith as follows:

"J.J. Rutledge ... concludes that by far the greater part of the iron of the Clinton ores is due to replacement and concentration of the iron, but thinks that the intimately associated oxides and silicates of the spherules and the iron present as the carbonate in isomorphous mixtures with calcium carbonate may be due to original deposition." (26: p. 84).

"Professor C.K. Leith ... groups together the flax seed ores of the Clinton and other beds of the Appalachians and Wisconsin, the ores of the Torbrook and Nictaux areas of Nova Scotia, the Wabana ores of Newfoundland, and a recently discovered deposit in Missouri. He considers them to be sedimentary ores derived by weathering processes and deposited in the ocean as iron oxide rather than as ferrous salts, and that they have undergone no further concentration, being mined essentially in the condition in which they were deposited." (26: p. 84).

<u>Origin of nodules and oolites in the ore beds</u>

A large number of hystrichospheres and some chitinozoa, along with some hematitic oolites, have been found in chloritic nodules (Airfield Formation) and phosphatic nodules (Middle and Upper Members), and in chamosite nodules which occur in the ore beds of Wabana Formation. This association throws important light on the concentrations of these microorganisms and oolites found in the nodules and pebbles. The abovementioned formations were marine in origin as clearly demonstrated by the presence of large numbers of brachiopod shells, trilobite tracks, and microplanktonic fossils.

The presence of fossil hystrichospheres concentrated in chloritic, phosphatic, and chamositic nodules and pebbles presents an interesting problem with reference to their origin. Dr. Deunff, in his paper on <u>Microorganismes Planctoniques du Primaire armoricain</u>, I-Ordovicien du Veryhach (Presqu'île du Crozon) (1). stated that

"Il n'est cependant pas téméraire de penser aujourd'hui, qu'un état colloïdal soit à l'origine du processus de consolidation des nodules. La conservation d'un microbios requiert, en effet, des phénomènes rapides de préservation; or ces conditions semblent nécessaires dans le cas présent, lequel nous révèle que des Hystrichosphères, organismes du microplancton fossile, êtres apparemment frêles et délicats, ont souvent pu nous parvenir sous un aspect d'une déroutante fraîcheur. Il est vraisemblable qu'un tel processus a présidé à l'édification de beaucoup de structures noduleuses (silex inclus). Mais les modalités de formations de ce stade initial colloïdal ne nous apparaissent pas toujours avec netteté." (13: pp. 6, 7).

The writer has observed that certain delicate processes of hystrichospheres were found well preserved in the phosphatic and chloritic nodules of the Middle (Slide and Locality No. 378, K) and Upper (Slide and Locality No. 362, Z) Members of the Wabana Formation which indicates that preservation of these hystrichospheres occurred in the nodules before abrasion and comminution of their fragile spines could have taken place. It may be possible that the phenomenon of thixotropy in these unlithified nodules and shaly sediments, in part, might have helped in the preservation of their delicate structures. Professor Boswell (1961) has proposed that:

"The concept of thixotropy offers the only satisfactory explanation yet advanced to account for the preservation of delicate plant and animal tissues as fossil replacements or impressions." (77: p. 126).

Dr. Deunff further has stated, in his abovementioned paper that:

"Peut-on imaginer que des macroorganismes dont les tests tombaient sur le fond marin livraient un apport de sels phospho-calcaires suffisant pour faire floculer un volume restreint de sédiments dans lequel se trouvèrent brusquement inclus les microorganismes évoluant dans cette zone en voie de consolidation. Ou bien dans un milieu marin peu profond et agité, des fragments organiques ou minéraux, arrivaient-ils à s'agglomérer par déplacement en une masse sphéroïdale compacte ét dense?

La présence très fréquente de Trilobites, Lamellibranches, Oolithes au centre des nodules dans les schistes considérés viendrait à l'appui de l'une et l'autre de ces suggestions. (Certains nodules quaternaires -coll. I.G. de Rennes- montrent cette même disposition, il s'agit en l'occurence de valves de Lamellibranches enrobées dans une vase bien consolidée)." (13: p. 7).

Regarding the phenomenon of flocculation, Professor Boswell (1961) writes that:

"When the particles that have been shaken up with a liquid are so finely divided that they settle only very slowly and the suspension becomes more or less permanent, the stability of the system is due to the fact that they are electrically charged with respect to the adjoining liquid. The potential difference between particle and liquid tends to prevent the flocculation of the particles into aggregates which would settle more rapidly. If the potential difference is reduced, the stability is affected. This may be brought about by the addition of a substance which conducts electricity, i.e. an electrolyte: for example, a salt solution such as sea-water flocculates the suspensate brought down in a muddy stream." (77: p. 9).

These hypotheses might be used to explain, in part, situations that we have found to occur in Bell Island sediments. The iron ore beds of the Airfield and Wabana Formations are highly fossiliferous containing abundant brachiopod shells. These shells probably contributed sufficient phospho-calcareous salts to have caused flocculation to occur at loci within the sediment. During this preconsolidation stage, the sediment, having rich phosphatic, siliceous, and partly chamositic and calcareous contents with microorganisms (hystrichospheres and some chitinozoa) evolving in it, was in a process of lithification under marine shoal water conditions. These environmental conditions were very favourable for the preservation of the microorganisms in contrast to the shoreward oxidizing environment in which hematitic oolites, spherules and nodules were forming. The same hypotheses hold true with regard to the chloritic nodules of Airfield Formation (see Fig. 91) in which occur large numbers of hystrichospheres and chitinozoa tests (Slide and Locality No. 345, B). The chitin of these microorganisms appear to have been highly resistant to the action of solvents (acids) and bacteria (?) (6: p. 277) present in Lower Ordovician times, and chitinous tests were present in large numbers.

Concerning the formation of the oolites of the Veryhach area, France, Dr. Deunff has mentioned that:

> "Il est permis de penser que leur origine in situ a eu lieu dans les conditions ordinaires de formation, c'est-à-dire sur le fond d'une mer relativement agitée, peu profonde et soumise à des courants variables. Ces Oolithes résultant d'une accumulation concentrique de produits minéraux autour de fragments variés furent ensuite irrégulièrement réparties sur un fond sablo-vaseux." (13: p. 7).

It is possible that similar conditions to these obtained on Bell Island and, if so, Dr. Deunff's hypothesis may explain in part petrogenesis of Ordovician oolites found in Newfoundland. Agitation under variable ocean currents of various proto-nuclei, including brachiopod shell fragments and quartz grains present on the sea floor and concentrical accumulation of minerals around them might have helped to some extent in the formation of some of the oolites and also some chloritic nodules. The formation of hematitic oolites, containing angular quartz grains and abundant hystrichospheres, found in the chloritic and phosphatic nodules of the Airfield Formation (Slide and Locality No. 345, B) and in the Middle Member (Slide and Locality No. 378, K) and Upper Member (Slide and Locality No. 362, Z) of the Wabana Formation possibly could be explained, in the terms of last-mentioned hypothesis.

Fig.90 Photomicrograph. Unsorted quartz grains in shaly and chloritic groundmass, Locality and Slide No.362,b, Grebes Nest Member. X70(approx.), under crossed nicols.

Fig.91 Photomicrograph. Showing part of a chlorite nodule(see arrow) which had yielded several species of hystrichospheres and some chitinozoa, Airfield Formation. X70(approx.), under crossed nicols.

Presence of coprolites (?)

Several silty-shale coprolite-like structures (Slide and Locality No. 344 , O) found in the silty shale beds of studied section No. 344, immediately south of the Ruins on the northern coast of the Island, have yielded large number of hystrichospheres and some chitinozoa test fragments. These 'coprolitic' structures were found ranging in size up to 1 inch in diameter and 1.5 inches in length, and in various shapes from spherical, ovoid to elongate. These silty shale beds were also shot with worm borings and tubes, and trilobite burrows. Thin sections of four selected coprolite-like structures were examined and found to be siliceous. In them several species of hystrichospheres and some chitinozoa test fragments were found to be well preserved in contrast to the matrix in which they are rare. A thin section of a worm-bored non-coprolitic silty shale (Slide and Locality No. 345,D) also was examined. The burrows at the latter locality were filled with chlorite containing isolated angular quartz fragments and small phosphatic nodules. In this chlorite filling were found well-preserved hystrichospheres as contrasted with poorly preserved ones in the surrounding silty shale. In the writer's opinion these relationships provide good evidence to indicate that worms probably played an important role in the concentration of microplanktonic tests.

Dr. Deunff has also reported an abundance of hystrichospheres in 'pseudo-nodules', which resemble true coprolites, in the Ordovician of Veryhach, France (13: p. 8).

Environment of fossilization

The writer has come to the conclusion that for the Ordovician of the Conception Bay area combined siliceous, phosphatic, calcareous and chloritic environments of burial were exceptionally favourable for the preservation of hystrichospheres and chitinozoa tests. This is supported by the work of Dr. Loomis who has made chemical analyses of coprolitic silty shales and phosphatic nodules from these beds for the Department of Geology, Memorial University. Furthermore chemical macerations and thin section studies both of nodules and coprolite-like structures have provided further evidence in favour of this hypothesis.

In his paper Dr. Deunff suggested, concerning the preservation of these microplanktons that:

> "Ce milieu chloriteux possède donc une valeur réelle dans la conservation des composés organiques chitinoïdes. Les nodules les plus verdâtres, c'est-à-dire les plus chloriteux, se révélant les plus riches." (13: p. 9).

In the same manner, as mentioned above, the chloritic nodules of the Airfield Formation (Slide and Locality No. 345, B) have yielded large numbers of hystrichospheres and fewer chitinozoa tests whereas the oolitic matrix of the rock does not contain them.

Pyrite beds

(Lower Member of the Wabana Formation)

The Lower Member of the Wabana Formation and the underlying Airfield Formation are separated by a well-marked disconformity. The Pyrite beds in the Lower Member alternate with dark gray shale partings. The latter beds of the Lower Member contain a rich graptolitic fauna and also fossil brachiopods, hystrichospheres and chitinozoa.

Origin of the Pyrite bed is problematic. Only graptolites and brachiopods are found in the Pyrite bed. However, the presence of chitinozoa and hystrichospheres, which are considered to be restricted to the littoral zone during their life cycle, in the dark gray papery shale beds immediately overlying the Pyrite beds indicate that this upper part of the basin was shallow.

Previous work

Many geologists, biochemists and biologists have done detailed research work on the origin of pyrite which occurs in different forms in sediments. Their published works present important contributions on this subject and the most interesting of them are summarized next.

In his published report on the origin of Pyrite beds of Bell Island, Dr. A.O. Hayes has written that:

> "... the fact that the iron sulphide is present in the form of FeS_2 raises the question as to whether it was deposited as this higher sulphide or as ferrous sulphide, FeS_2 and free sulphur, the higher sulphide forming by subsequent diagenetic process. In either case the evidence indicates that the essential constituents were present in the original sediment and the Pyrite occurs as a primary bedded deposit." (26: p. 90).

Theoretical chemical reactions that might occur in muddy waters are given by Murray and Irvine (26: p. 89) as follows:

1) $RSo_4 + 2C = 2Co_2 + RS$, where R is either an earthy alkaline metal or an alkali,

2) $RS + 2Co_2 + H_2O = H_2S + RCo_3Co_2$

3) $RS + RCo_3Co_2 + H_2O = 2RCo_3 + H_2S$.

The reaction of hydrosulphuric acid with ferric oxide (Fe_2O_3) of the surface layer of the blue mud is given as follows:

4) $Fe_2O_3 + 3H_2S = 2FeS + S + 3H_2O$.

N. Androussow (26: p. 7) has pointed out that formation of ferrous sulphide in the bottom deposits of the Black Sea at depths of 300 to 717 fathoms results from the biochemical activity of _Bacterium hydrosulfuricumponticum._

Dr. Bruno Doss (26: pp. 90, 91) has reported the formation of iron sulphide in Recent bottom deposits of the Black Sea and in the Miocene sandy clays of Samara through the activity of iron bacteria (_Gullionella ferruginea_ of _Ehrenberg_).

In reference to the mode of formation of the pyrite beds of Wabana, Dr. A.O. Hayes has written:

"the Black Sea communicates with the Mediterranean through the narrow strait of Bosphorus through which two currents flow in opposite directions, the surface water being carried into the Sea of Marmora while the deeper water moves toward the Black Sea. The upper current, flowing toward the Sea of Marmora, consists of brackish water, while the lower carries salt water from the Mediterranean into the Black Sea. Since the salt water currents do not reach the surface, marine planktonic organisms cannot be freely carried into the Black Sea. Somewhat similar conditions, but with the access of surface currents of water, may have obtained in the Ordovician sea when the graptolitic pyrite beds of the Wabana deposits were formed. In such an enclosed sea, uplift would cause shallow water conditions suitable for the growth of algae and the formation of the hematite - chamosite - siderite deposits. Subsidence would bring about the deeper water necessary for the production of the iron sulphide such as is found in zone 3." (26: pp. 91, 92).

An interesting occurrence of pyritic nodules and crystals, and pyrite casts of marine organisms in Tertiary marine clays exposed along the coast of south central Victoria at Torquay, Point Addis, and Curlewis, has been reported by A.B. Edwards and G. Baker (1951). In their paper (79) they have suggested that the development of pyritic nodules in these clays occurred under reducing conditions. Their association with fossils indicates their localization by dead organisms possibly in a marine environment.

L.G. Love (1958) has reported the formation of syngenetic pyrite owing to the activity of microfossils, Pyritosphaera and Pyritella (monotypic genera), which were fossilized and preserved in the pyrite. Numerous small granules of pyrite were found in certain beds of the Scottish Lower Carboniferous Oil Shale Group. Love writes in his paper that:

"It is suggested that during their lifetime they generated hydrogen sulphide as a by-product of the anaerobic decomposition of sulphur compounds, the gas continually passing outwards into the adjacent mud or water. Reaction with iron in this immediately surrounding medium would precipitate iron sulphide on the organism, probably in the form of a slime of hydrotroilite, later to become crystallized as pyrite (Emery & Rittenberg, 1952)." (82: p. 434).

L.G. Love and D.O. Zimmerman (1961) have suggested (34) a syngenetic origin for the first generation pyrite of the Lower

Proterozoic Mount Isa Shale of Australia. Its origin was connected with the activity of micro-organisms either at the time of deposition of the enclosing sediment or during the earliest period of diagenesis before complete lithification to shale. This pyrite was deposited in the micro-organisms owing to their secretion of hydrogen sulphide which reacted with iron contents present in the environment.

L.G. Love (1962) has further suggested (35) that the formation of pyrite in Lower Jurassic and Carboniferous argillaceous rocks of Britain took place as a result of microfossils (e.g. Pyritosphaera barbaria, Pyritella polygonalis). He considered that these forms probably were saprophytic and produced hydrogen sulphide as a by-product of metabolic activity. Later the hydrogen sulphide eventually reacted with ferrous contents producing a precipitation of iron sulphide.

Steinike (1963) and Vallentyne (1962) have expressed (86) different opinions regarding origin of the pyrite spheres or grains in sediments. They reported examples where these were believed to have originated by simple inorganic precipitation.

J. Kanwisher (1962) in his paper (81) 'Sulfur chemistry in marine muds' has discussed the formation of iron sulphide in anaerobic marine muds. He considered shallow marine sediments as being typically anaerobic. Sulfate reduction in anaerobic marine muds is followed by accumulation of hydrogen sulphide gas owing to activity of Desulfovibrio bacteria. If ferrous iron is chemically available to this gas there will result a formation of insoluble black FeS.

In his paper (78) on '<u>Experimental studies of the sedimentary iron sulfides</u>', R.A. Berner (1962) has described the formation of crystallized tetragonal FeS in the Mystic River, Boston, Massachusetts. Hydrogen sulphide is formed by sulfate-reducing bacteria. Reaction of hydrogen sulphide with either metallic iron or goethite results in the formation of crystallized tetragonal FeS in this area.

S.A. Tyler and E.S. Barghoorn (1963) in their paper (84) on '<u>Ambient pyrite grains in Precambrian cherts</u>' have suggested that the origin of pyrite and organic matter in the pyrite-chert facies of the basal Gunflint formation, Ontario, and the Biwabik iron formations, Minnesota, is the result of reducing, or euxinic, environments which existed on a regional scale at the time the sediments were deposited.

L.G. Love and J.W. Murray (1963) have reported (83) on the formation of pyrite found within organic cells and organic tests. Such pyrite occurs in the Recent sediments of Christchurch Harbour, Hampshire, England, and forms in the reducing zone according to them.

In his paper (85) on '<u>Syngenesis of sulfide ores: an evaluation of biochemical aspects</u>', K.L. Temple (1964) has come to the conclusion that syngenetic theories of sulphide ore formation, which involve microbial sulfate-reduction as the source of sulphide, are not adequate. He writes that:

"The conditions required for sulfate-reduction can not be specified simply but are satisfied by various combinations of circumstances that result in oxygen depletion in a wide variety of physical environments. Metals entering such environments, whether absorbed or not, are converted to metal sulfides. Sulfate-reduction does not explain the origin of the metal moiety." (85: p. 1473).

S. Honjo, A.G. Fisher, and R. Garrison (1965) have given examples where pyrite has been formed as microscopic spheroidal aggregates (framboids) within radiolarian tests occurring in fine-grained limestone (80). This limestone of Late Jurassic Oberalm beds, of the northern Austrian Alps, contain abundant radiolaria and other microplanktonic fossils. The framboids occur lodged in the lower part of the fossil sphere, which suggests that the pyrite was precipitated within the fossil and eventually sank to its base during early diagenesis probably in an alkaline reducing environment.

The writer's independent observations

Stratigraphic sequences and thin sections of the Pyrite bed indicate that in general pyritization was complete although it still is possible to discern in it original organic structures. A pyritized graptolite sample was powdered in a crucible and a sample X-rayed. It gave a pattern comparable with the standard iron pyrite pattern (see Fig. 92).

Calcium phosphate may occur in small amounts coating the graptolites with a light brown film. A small sample of a graptolite was ground up into a powder to which concentrated nitric acid later was added. On addition of a few drops of ammonium molybdate a yellow precipitate was formed indicating the presence of a phosphate.

The bulk of the shale partings associated with the Pyrite bed, however, is made up of clay minerals. The individual clay minerals were not identified in the present study.

Age of Pyrite beds

Three hypotheses concerning the time of pyritization of the Pyrite bed and several important conclusions concerning the most probable one will be discussed next.

Epigenetic deposits

The Pyrite bed is marked off from an underlying shale band by a sharp break in sedimentation. Pyrite crystals are absent in the lower few inches of the shale where it first appears abruptly above the basal conglomerate which marks the base of the Lower Member. At first a similar sharp break at the top of the Pyrite bed was thought to occur, but closer inspection revealed a gradation was present upwards from pyritization to non-pyritization. The change takes place stratigraphically quite suddenly and two inches above the top of the Pyrite bed little trace of pyrite can be found in overlying strata.

As a rule the percentage of pyrite increases downwards toward the bottom of the bed. The Pyrite bed is a relatively impermeable unit compared to the shale beds above and below it as a result of diagenesis and pyritic interstitial cementation. There are, however, several objections to the hypothesis that it is an epigenetic deposit. Firstly, variations in amount of pyrite parallel the sedimentary features. Of course, the possibility exists that these sedimentary bands could have favoured pyritization to take place more easily on account of their horizontal similarity but vertical difference in composition. Secondly, the base of the Pyrite bed appears as a sharp discontinuity and no gradational change downward in pyritization is observable. Here again it is possible that the impermeable, although porous, shale acted as a barrier to pyrite solutions, but if this was so one would expect a much denser layer of pyrite at the base as the solutions came up against the impermeable shale horizon. Thirdly, the fact that a gradation from pyrite to non-pyrite takes place vertically in the shale near the top of the bed again suggests that the pyritization was not epigenetic because otherwise why is there not a similar gradation at the bottom of the bed? Most of the pyritized material in the shale above the Pyrite bed takes the form of pyritized spheroids.

<u>Pyritization of the sediment previous to its deposition</u> (reworked constituents)

Let us next consider the hypothesis that after pyritization of the constituents had taken place they were transported by waters in which there was strong current activity and deposited having travelled an unknown distance.

The fact that the graptolites found in the Pyrite bed are much fragmented is an indication that prior to their deposition they probably underwent sufficient tumbling to break them into fragments consisting of only a few thecae. This evidence suggests that the graptolites may have been fragmented, completely pyritized and, perhaps, again broken during transportation. It is possible that the uneven fractured margins were smoothed to a certain extent by abrasion during saltation.

Syngenetic deposits

Pebbles found in the Pyrite bed and also in the subsurface core samples invariably show a thin coating of pyrite around the margins. These coatings are relatively easy to flake off. The coatings were observed to completely cover the pebbles strongly suggesting that the pebbles probably were not pyritized prior to transportation but instead obtained their coating after deposition. This does not necessarily preclude the possibility of a pyrite coating which had been acquired elsewhere, later being lost during transportation.

The abovementioned example of pyrite coating around the margins of the pebbles would appear to be an indication that pyritization might have taken place during deposition.

In conclusion, there would appear to be a strong case for syngenetic pyritization of the Pyrite bed in preference to the other suggested hypotheses, although this does not mean I exclude either epigenesis or reworking of pyrite constituents or both processes from having taken place. Indeed, it is quite possible that more than one process was involved during the deposition of the Pyrite bed under discussion.

Fig.92 X-Ray diffraction pattern of iron pyrites

Structural geology

Secondary (diastrophic) structures

On the Avalon Peninsula exposed bed rock is either Precambrian, Cambrian, or Lower Ordovician in age. Both folds and faults are common in these rocks, however, faults appear to be more prominent in the Lower Ordovician units.

Faults

About thirty faults (see Map No. 4) were mapped on Bell Island and these exhibit a variety of strike and dips. Marked parallelisms can be detected in the directions of two main sets of faults. The first strike N.20°E. and the second N.60°W. Their throws ranged from 1 to 15 feet.

The ore beds of the northwestern coast of the Island are cut by four prominent faults (see Map No. 4). The fault planes are associated with profound brecciation of the adjacent rocks, slickensides, and the deposition of secondary crystalline calcite in veins.

Underground mining at Bell Island has revealed two major fault systems offsetting the iron ore beds. The first trends north-northeasterly and the second northwesterly. In the underground mine several faults examined by the writer had their planes filled with either secondary quartz veins or calcite veins.

Joints

The rhombohedral joint pattern displayed by the Wabana hematitic oolite beds and, to a less degree, by the Ordovician sandstone are strikingly apparent. This pattern in the hematitic oolite beds of Bell Island caused the ore to break naturally into angular smooth-sided rhombs. The jointing directions parallel the northeastern and southwestern fault directions. Some joints are filled with either secondary calcite, siderite, or quartz.

Primary structures

(see Plate 1, Figs. 1 to 5)

General

Many of the sedimentary rock sequences of Bell Island, Kellys Island, Little Bell Island and Manuels River area contain evidence of deposition under shallow water conditions. In the basal beds of most sandstone units symmetrical ripple marks, interference ripple marks, channelling, and cross-bedding features are very common. Other primary structures, including flute casts, load casts, mud intrusions, rain imprints, primary current lineations, graded bedding, and mud cracks are found in some of the sandstones. In addition, trilobite tracks and burrows, worm tracks and borings, and coprolites are common in some of the sandstones and shales. Cone-in-cone structures are present in some shale and shaly sandstones of both the Polls Head Formation and the Airfield Formation. Fossilized boring-algae are common in the iron ore rocks of the Airfield Formation, and in the Middle and Upper Members of the Wabana Formation.

Ripple marks and cross-bedding

These structures are common in the Lower Ordovician rocks of Bell, Little Bell and Kellys Islands. Ripple marks are rare in some sandstones, probably because these are gradational upward into silt-stones and shales in which ripple marks are unlikely to be formed. The cross-bedding in the medium-grained to gritty sandstones of Townsquare Formation exhibit almost totally unsorted mineral grains. Small-scale cross-laminations, on the contrary, are quite common in most sandstone beds, particularly in the Polls Head Formation. A freshly broken surface of sandstone generally does not show cross-laminations, but differential etching and colour banding of laminae after weathering render the structures readily visible.

Graded bedding

Fine-grained sandstones exhibit graded bedding. In almost all cases surfaces of the sandstone beds have sharp contacts with overlying dark gray shales. Possibly the source area provided mainly moderately-sorted sediments. Although grading may not be megascopically discernible, it is sometimes visible in thin sections.

Primary current lineation

Faint streaks on some bedding surfaces, more or less parallel to the current direction, are referred to primary current lineation. These linear structures are mostly the result of current action. They were clearly seen on bedding surfaces of Polls Head sandstone unit, and appear as small warps, creases, and grooves that are most conspicuous when sunlight strikes the surface at a low angle throwing shadows.

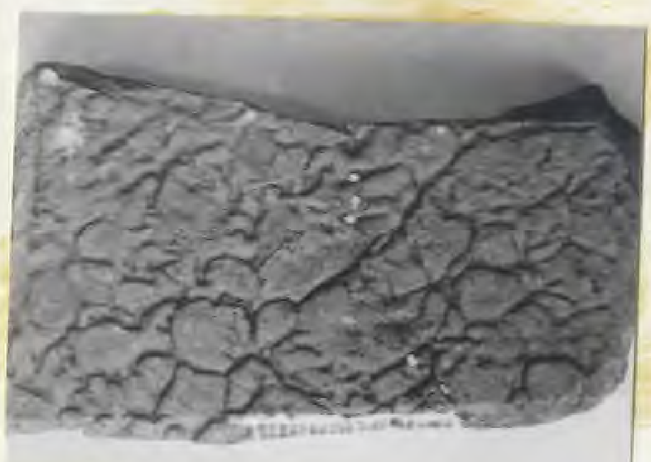
EXPLANATION OF PLATE I

Fig. 1. Flute cast. Current moved from top to bottom of picture.
Fig. 2. Symmetrical ripple marks with mud cracks.
Fig. 3. Cone-in-cone structure in dark gray shale, Locality: Old Dam, southern coast, Bell Island.
Fig. 4. Primary current lineation in sandstone, current direction shown in the figure.
Fig. 5. Load casts in sandstone, Locality: Grattons Cove, Bell Island.

1

2

4



NAUTIYAL, Lower Ordovician sedimentary structures, Bell Is.

Sedimentary structures in and contiguous to the Pyrite beds, (Lower Member of the Wabana Formation)

Some structures recognized and studied in the Pyrite bed and in the underlying and overlying shale beds were: cross-bedding, graded bedding, ripple marks, burrows and borings and mud intrusions. Detailed notes on these follow:

Cross-bedding

Cross-bedding is well developed within the Pyrite bed. Argillaceous bands make the cross-bedding more noticeable. Locally the top set beds appear to be truncated by the basal plane of the overlying shale horizon. More rarely the Pyrite bed was observed to be subdivided by thin shaly lenses of only limited lateral extent. In such cases basal pyrite sections exhibit a tendency toward lack of cross-bedding features which are replaced by coarse graded bedding features.

Graded bedding

Graded bedding is present under sedimentary conditions similar to those mentioned above, and it also occurs in some sections of the Pyrite bed to the exclusion of cross-bedding. Pebbles occurring at the base of the Pyrite bed are generally in the order of 1 to 2 cms., range from rounded to angular, and possess very thin coatings of pyrite. Throughout the graded bed sections pyritic spheroids are very abundant.

Ripple marks

Ripple marks occur frequently in the basal part of the Pyrite bed and near the top. Most wave lengths range from 1.5 to 2 inches. In addition, symmetrical micro-ripple marks are fairly abundant (0.2 inches approximately in wave length).

Burrows and borings

Burrows and borings are visible at the bottom of the shale horizon underlying the Pyrite bed. These, however, give little or no indication of depth of deposition, and merely indicate that an aerobic environment suitable to an abundant fauna was present. The presence of Lingulid Brachiopods in the shale horizon indicates that the environment was marine at this time.

Mud intrusions

The base of the Pyrite bed is marked by rounded flow-type structures which in places appear to partially intrude the shale. This suggests that underlying muds were unconsolidated during deposition of the Pyrite bed. This conclusion is substantiated by the angular constituents and folded nature of the conglomerate at the base of the Pyrite bed.

The conclusions drawn from the above observations and postulations are as follows:

Evidence of graded bedding suggests a depositional area present which was subjected to strong current action. A high-energy environment is even more strongly indicated by the manner in which the top-set beds have been truncated. The graded bedding varies laterally and corresponds to local variations in the thickness of the Pyrite bed which, in turn, indicates that the bed was deposited over a region of low but significant topographic relief. Ripple marks appear to be of an asymmetrical type and are very frequent at the top of the Pyrite bed. However, current directions suggested by their orientation are in directions opposite to those indicated by cross-bedding. Menard has reported symmetrical ripples in Globigerina ooze at a depth of 4,500 feet, but Pettijohn has pointed out that ripple-marked sands generally can be ascribed to very shallow water conditions. As the original small organic fragments and quartz grains forming the Pyrite bed must have behaved in a similar way to sand, then it follows that the ripple-marks seen at the top of the Pyrite bed probably indicate fairly shallow water conditions. This conclusion has been supported by the occurrence of several hystrichospheres (microplanktons) in shale beds immediately overlying the Pyrite beds.

Source of sediments

One of the main sources of most of the sandstones of the Cambro-Ordovician sequence was a Precambrian terrain (rhyolites and Holyrood granites) which now is located on the Avalon Peninsula. As has been mentioned earlier certain accessory minerals found in the sandstones including zircon, zoisite and leucoxene are also common as primary minerals in the Precambrian rocks (especially in granites). However, the enrichment of zircon and micas (muscovite and biotite flakes)present in the sandstones indicate a distant source because mica-rich Precambrian and Cambrian rocks are not found in the areas neighbouring Conception Bay.

Chemistry

Detailed chemical analyses of the iron ores of Bell Island were made by Dr. Hayes. A summary of his main conclusions follow. Chemical analysis of a sandy shale sample taken from the cliff at the Slipper pier of the Nova Scotia Steel and Coal Company, southeastern coast of the Island, by Hayes, has shown that the rock contains considerable amounts of iron and alumina, but is devoid of lime. In another analysis of a sandstone from an outcrop, located between the Dam and Martins Road, showed a low content of iron alumina and an absence of lime. The rocks of the northwestern coast of Bell Island contain low percentages of calcareous contents. Very light gray sandstones of the Townsquare Formation rarely contain brachiopod shells whereas the iron ore beds of the Airfield Formation, especially near the northwestern coast, are fairly rich in brachiopod shells. According to Dr. Hayes the brachiopod shells contain between 60 and 70 percent calcium phosphate (26: p. 65). This indicates that the calcareous and phosphatic contents of these rocks were derived from these brachiopod shells.

In general Dr. Hayes has mentioned that:

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

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

(26: p. 66).

Analyses by earlier workers indicate that the main iron ore bed of the Airfield Formation contains about 60% hematite whereas the Middle and Upper Members of the Wabana Formation include about 50% to 55% hematite. The iron ore beds of the latter formation differ from the former by an increase in siderite and a decrease in hematite and quartz contents.

Two samples (silty shale and phosphatic nodules) were chemically analysed by Dr. A.G. Loomis (1966) in Loomis Laboratories, California, for the determination of percentages of SiO_2, Fe_2O_3, FeO, P_2O_5 and CaO, and gave the following results:

Text sample No. 344, O, Airfield Formation. Coprolitic silty shale		Text sample No. 378, K, Middle Member. Phosphatic nodules of hematitic oolite bed	
SiO_2	21.35%	SiO_2	10.95%
Fe_2O_3	2.03%	Fe_2O_3	14.38%
FeO	9.10%	FeO	6.24%
P_2O_5	20.50%	P_2O_5	25.25%
CaO	25.46%	CaO	32.34%
Total Fe_2O_3	= 12.14%	Fe_2O_3	= 21.31%

Both samples yielded large number of hystrichospheres. Presence of large percentages of P_2O_5, CaO, SiO_2 and hydrous iron, in the samples, apparently provided a very favourable environmental condition for the preservation of microorganisms.

Economic geology

Iron ore

Iron ores of the Bell Island Group and Wabana Formation are very important from an economic point of view. The Wabana ore is one of the higher grade iron occurrences in Canada, averaging 49.5% iron at the mine head, northern coast of the Island. The ore was supplied up to recent years to Canadian, European and American markets. It is this 'Clinton type' iron formation of Lower Ordovician age which provided the economic support for most of the population of Bell Island. There are numerous significant beds but five of them are the most important; and economic production has been concentrated on the ore beds of the Airfield Formation and on the Middle and Upper Members of the Wabana Formation (the Lower, Middle and Upper beds of DOSCO). At the beginning of present year (1966) the iron ore bed of the Airfield Formation was being worked.

The area underlain by ore beds is about 70 square miles. The ore beds, in common with the other sedimentary rock units, dip gently northwesterly and pass under the floor of Conception Bay.

Surface open pit mining, concluding with the removal of the Dominion ore bed of the Airfield Formation, was completed in 1965. Up to the present time (July, 1966) the mines of Bell Island have produced more than 70,000,000 tons of ore although their annual production figures fluctuated greatly.

Constructional materials

Ridges of sandstone pass through the heart of Bell Island and provide excellent building stones for the inhabitants. Several churches on Bell Island have been made from these sandstones. The Roman Catholic Cathedral of St. John the Baptist was constructed mainly from the greenish-gray Lower Ordovician sandstones of Kellys Island.

CHAPTER IV

Paleontology

In this part of thesis the paleontology of the Cambro-Ordovician sequence will be discussed.

Several dark-blue fragmentary brachiopod shells belonging to the genus Lingula and species of Lingulella were found in sandstones on Kellys and Little Bell Islands. These fossil remains are common in outcrops along the southern, eastern and northern coasts of Kellys Island. A single faint impression of a pygidium of a trilobite (see Plate 5, Fig. 4) was found near the eastern coast of Kellys Island. Worm borings and tubes are common in the shales and sandstones of both Islands. Numerous tracks and trails of trilobites were found in the sandstones and dark gray papery shales (see Plate 4, Figs. 1, 2, 4, 5) of Kellys Island. A single specimen of an unidentified microfossil (see Plate 5, Fig. 6) was collected on the southern coast of Kellys Island. A disc-type medusoid (?) fossil impression was discovered in medium-gray, micaceous, shaly sandstone in Martins Cove, Kellys Island.

Abundant trilobite exoskeleton parts, hystrichospheres, and brachiopod shell impressions were collected from lower Manuels River valley.

Several specimens of hystrichospheres were discovered in shale samples from Kellys and Little Bell Islands.

Bell Island sediments yield varied kinds of macro- and microfossils which are listed below:

Coprolites and trace fossils are common both in Wabana Formation and Bell Island Group. A few lamellibranch shell impressions were collected from a sandstone bed of the Middle Member. Two species of cephalopods were found in shales and sandstone strata of Middle and Upper Members. Brachiopods are common in Bell Island rocks. One trilobite pygidium was found in a silty shale bed of the Middle Member. Pyrite and dark gray shale strata of the Lower Member yielded several specimens of graptolites. One disc type (medusa ?) fossil impression was discovered in a sandstone bed in Freshwater Cove, northeastern coast of Bell Island.

Abundant microfossils including hystrichospheres, chitinozoa, and scolecodonts were discovered in Bell Island shale and silty-shale strata, and are the first reported finds of these forms on the Island of Newfoundland.

The paleontology of lower Manuels River valley, Little Bell Island, Kellys Island and Bell Island have been described as follows:

Macropaleontology

Lower Manuels River valley

Systematic paleontological descriptions of selected species of Cambrian trilobites found in the shale beds of the *Paradoxides bennetti*, and the *P. davidis* zones of Dr. B.F. Howell are given next. These Cambrian shale beds vary from olive, through light gray, to dark gray in colour. The shales are non-calcareous, fissile, and soft. Complete and also fragmentary trilobite forms are found well preserved on the bedding planes.

Summary of systematic position of described species

Phylum - Arthropoda

Subphylum - Trilobitomorpha

Class - Trilobita

Order, AGNOSTIDA Kobayashi, 1935

Suborder, AGNOSTINI Jaeckel, 1909

Family, PERONOPSIDAE Westergard, 1936

Subfamily, ARCHAEAGNOSTINAE Kobayashi, 1939

Genus, Acadagnostus Kobayashi, 1939

Order, POLYMERA Jaeckel, 1909

Suborder, MESONACIDA Swinnerton, 1915

Family, CONOCORYPHIDAE Angelin, 1878

Genus, Bailiaspis Resser, 1939

Family, PARADOXIDAE Emmerich, 1839

Subfamily, PARADOXINAE Howell, 1933

Genus, Paradoxides Brongniart, 1822

Order, PTYCHOPARIIDA Swinnerton, 1915

Suborder, PTYCHOPARIINA Richter, 1933

Subfamily, DIKELOCEPHALACEA Miller, 1884

Family, DIKELOCEPHALIDAE Miller, 1889

Genus, Dikelocephalus

Order, AGNOSTIDA Koyabashi, 1935

Suborder, EODISCIDI Koyabashi, 1939

Family, EODISCIDAE Raymond, 1913

Genus, Eodiscus Matthew, 1895

Order, OPISTHOPARIA Beecher

Family, ORYCTOCEPHALIDAE Beecher

Genus, Corynexochus Angelin, 1854

Order, POLYMERA Jaeckel, 1909

Suborder, MESONACIDA Swinnerton, 1915

Family, PTYCHOPARIDAE Matthew, 1887

Genus, Ptychoparia Corda, 1847

Order, AGNOSTIDA Koyabashi, 1935

Suborder, AGNOSTINI Jaeckel, 1909

Family, PERONOPSIDAE Westergard, 1936

Subfamily, PERONOPSINAE

Genus, Peronopsis Corda, 1847

Order, OPISTHOPARIDA

Superfamily, PTYCHOPARIOIDAE

Genus, Syspacephalus Resser, 1939

Family, SAOINAE (HUPÉ, 1953)

Genus, Sao Barrande, 1846

Description of species

Genus, Acadagnostus Kobayashi, 1939

Acadagnostus acadicus (Dawson)

(see Plate 2, Fig. 13)

Material: A small cephalon from the Paradoxides bennetti zone of Dr. B.F. Howell. Its dimensions are: length 1.84 mm.; width 1.71 mm.; length of glabella 1.18 mm. (Collection No. AC, MFI).

<u>Description</u>: This small cephalon was found in medium dark-gray shale, natural convexity retained. Cranidium small, subquadrate, with rounded anterior corners, convex; length and width about equal. Glabella short, more or less subconical, tapering forward, bluntly rounded in front, strongly convex, elevated above cheeks, bounded by broad shallow dorsal furrow, bilobed, divided by a broad shallow furrow transverse to axis. The glabella is distinctly arched backward. Cheeks broad, gently convex, highest near glabella, sloping evenly outward into shallow marginal furrow, united in front of glabella. Border flat, broadest in front of glabella, becoming narrower posteriorly. No ornamentation.

<u>Age</u>: Middle Cambrian.

Genus, Bailiaspis Resser, 1936

<u>Bailiaspis</u> sp.

(see Plate 2, Figs. 7, 8)

<u>Material</u>: A small cephalon from the <u>Paradoxides</u> <u>bennetti</u> zone of Dr. Howell. Its dimensions are: length, 1.78 mm.; width at posterior border, 2.31 mm.; length of glabella, 1.32 mm.; width of glabella, 0.66 mm. (Collection No. AC,MF 2, 3, 4).

<u>Description</u>: Cranidium semicircular, gently convex. Glabella more or less conical, longer than broad. Occipital furrow deep, curved backward near dorsal furrow. Glabella unfurrowed. Brim rather narrow, depressed; border not prominently raised, narrow at sides but thickening in front of glabella. Fixed cheeks gently convex. Facial suture not well shown, but it apparently cuts across the border on to the fixed

cheeks. No ornamentation.

Age: Middle Cambrian

Bailiaspis howelli Hutchinson

(see Plate 2, Fig. 3)

Material: A small cephalon. Its dimensions are: length, 1.55 mm.; width, 2.44 mm.; length of glabella, 1.25 mm.; width of glabella, 0.75 mm. (Collection No. AC, MF5).

Description: Cranidium evenly semielliptical, moderately convex. Dorsal furrows broad, shallow. Glabella elevated, strongly convex, tapering forward, rounded in front, showing a slight keel, unfurrowed. Occipital furrow narrow, bent back at edges, broader and shallower near axis. Occipital ring broad, widening backward at midline, bearing a node. Fixed cheeks wide, horizontal to slightly downsloping near dorsal furrow, sloping fairly sharply to marginal furrow. Brim in front of glabella short, gently downsloping to broad, shallow marginal furrow, border flat to slightly raised, slightly thickened backward in front of glabella, so that marginal furrow is straight to slightly concave across front of cranidium. Surface smooth.

Age: Middle Cambrian.

Dikelocephalus Owen, 1852

Dikelocephalus (?) sp.

Material: A moderately sized cephalon from the Paradoxides bennetti zone of Dr. Howell. Its dimensions are: length, 1.4 cm.; width 1.4 cm.; length of glabella, 0.7 cm.; width of glabella, 0.7 cm. (Collection No. AC, MF6).

Description: General form comprising a broad ellipse, moderately convex, cephalon transverse, genal angles extended into small spines: cranidium roughly subquadrangular in outline with narrow fixed cheeks. Glabella subquadrangular in outline, and narrowing slightly towards its broadly rounded front, posterior furrow strong and extending across the glabella; second furrow indicated by a pair of short side furrows, a third furrow is indicated.

Age: Middle Cambrian.

Genus, Eodiscus Hartt in Walcott, 1884

Eodiscus punctatus (Salter)

(see Plate 2, Fig. 5)

Material: A small pygidium from Paradoxides bennetti zone of Dr. Howell. Its dimensions are: length of pygidium, 2.17 mm.; width of pygidium at anterior end, 3.1 mm. (Collection No. AC, MF2).

Description: Pygidium semicircular in outline, rounded posteriorly. Axis prominent, strongly elevated, broad in front, narrowing backward. Eight furrows cross axis, dividing it into nine lobes. Axis bounded by shallow dorsal furrow. Pleural lobes broad, strongly convex, joined behind axis.

Age: Middle Cambrian.

Genus, Corynexochus Angelin, 1854

Corynexochus minor (Walcott)

(see Plate 2, Fig. 11, 12)

Material: A small cephalon from the Paradoxides bennetti zone of Dr. Howell. Its dimensions are: length, 0.627 mm.; width about 1.15 mm.;

length of glabella, 0.627 mm. (Collection No. AC, MF7).

Description: Form elongate-oval, convex. Head longitudinally semicircular, convex. Glabella expanding from the base to twice the width in front, marked by four pairs of short, faint glabellar furrows, occipital furrow deep, occipital ring strong. The broad, deep dorsal furrows unite with the posterior furrows to separate the strongly convex subtriangular fixed cheeks; eye lobe short, narrow, and defined by a groove from the cheek, the groove extends forward to the dorsal furrow. Free cheeks narrow, marginal rim round; posterior angle pointed, but not known to be extended into a spine.

Age: Middle Cambrian.

Genus, Andrarina Raymond, 1937

Andrarina globiceps jaculator (Howell)

Material: Several small to moderate sized cranidia were found preserved in shales of *Paradoxides bennetti* zone of Dr. Howell. The dimensions of a single measured specimen of cranidium are: length, 0.8 cm.; width, 1 cm.; length of glabella, 0.5 cm. (Collection No. AC, MF 8).

Description: Cranidium moderately convex, the glabella only a little more convex than the rest of the cephalon. The front of cephalon is slightly curving. The brim is flat and broad, and is separated from the rest of the cephalon by a broad, shallow furrow. The fixed cheeks moderately convex, join broadly in front of the glabella. The fixed cheek is almost twice as wide at its posterior end as it is opposite the palpebral lobe. A facial ridge runs from near the front of the glabella outward and slightly backward, in a gentle curve, to the anterior end of palpebral lobe. The neck ring is of medium size, and is prolonged backward into a small spine. The glabella tapers slightly toward the front, where it is rounded. It has four pairs of short, shallow, indistinct furrows which run obliquely backward. Surface smooth.

Genus, Paradoxides Brongniart, 1822

Paradoxides davidis Salter

Material: Several partly preserved cephalons and one fairly well preserved moderate-sized cranidium was found in the Paradoxides davidis zone of Dr. Howell. The dimensions of one cranidium are: length, 1.5 cms.; breadth, about 2 cm.; length of glabella, 1.7 cms.; (Collection No. AC, MF 9).

Description: Cephalon parabolic in outline, the genal spines are not exposed in the specimen. Glabella reaching forwards to the marginal furrow, rounded in front, expanded forwards, with the maximum width about one and a half times the width of the neck ring, the posterior part of glabella is crossed by two complete glabellar furrows as well as the neck-furrow. The free cheek is fairly wide. The margin of the head, broad and convex on the free cheek, narrows in front of the glabella.

Age: Middle Cambrian.

Genus, Pardailhania Thoral, 1947

Pardailhania cf. barthouxi (Mansuy)

(see Plate 2, Fig. 14)

Material: A moderate sized cephalon was found in the shale bed of Paradoxides bennetti fauna of Dr. Howell. The dimensions are: length 0.8 cm.; breadth about 1 cm.; length of glabella 0.55 cm.; breadth of glabella, 0.4 cm. (Collection No. AC, MF 10).

Description: Cephalon roughly semicircular in outline, with median length about half the breadth. The glabella moderately convex. Glabellar outline almost a trapezium, its sides converging forward gradually to the frontal lobe. Smooth, unfurrowed glabella. In front of the preglabellar furrow lies a broad, slightly convex, preglabellar field, equal to about one-quarter of the glabellar length; in front of this the anterior border rises steeply, in outline convex longitudinally, and thickening medially. Occipital furrow moderately deep and transversely straight, occipital ring not exposed in the specimen.

Age: Middle Cambrian.

Genus, Peronopsis Hawle and Corda, 1847

Peronopsis (Acadagnostus) matthewi (Hutchinson)

(see Plate 2, Fig. 9)

Material: A small cephalon was found preserved in medium dark-gray shale of Paradoxides bennetti fauna zone of Dr. Howell. Its measurement: length, about 2.8 mm.; width about 3.3 mm.; length of glabella 1.98 mm.; width of glabella at posterior end 1.05 mm. (Collection No. AC MF 11, 12).

Description: Cephalon subrounded, length about equal to width, cephalon evenly, gently convex from side to side and from front to back; glabella about two thirds length of cephalon, moderately raised, subcylindrical, rounded anteriorly, divided into two lobes by a transverse furrow which is shallow. Anterior lobe short, wider than long, posterior lobe bearing a small, central node. Cheeks subequal in width throughout, downsloping, smooth. The posterolateral corners of the specimen are not exposed.

Age: Middle Cambrian.

Peronopsis cf. P. quadrata (Tullberg)

(see Plate 1, lower Fig. 9)

Material: One small pygidium found from the same shale sample from which Peronopsis (Acadagnostus) matthewi was recovered. Its measurements are: length, 2.54 mm.; width, 2.9 mm.; length of the axis, 1.98 mm. (Collection No. AC, MF 12).

Description: Pygidium more or less semi-elliptical in outline, axis broad, tongue-shaped, not reaching rim, bearing a prominent elongated tubercle in anterior part; lateral lobes gently down sloping, confluent behind axis, rim broad, flat, the posterolateral corners are not well exposed.

Age: Middle Cambrian.

Peronopsis (Acadagnostus) scutalis (Salter in Hicks)

(see Plate 2, Figs. 1, 4)

Material: A small cephalon recovered from the same shale sample from which Peronopsis (Acadagnostus) matthewi was found. Its measurements are: width, 3.3 mm.; length of glabella 1.89 mm.; width of glabella at posterior end 1.32 mm. (Collection No. AC, MF 13).

Description: Cephalon subrounded in outline, gently convex from side to side, glabella moderately raised, subcylindrical, rounded anteriorly, divided into two lobes by a prominent shallow and wide transverse furrow. Anterior lobe short, wider than long. Cheeks subequal in width throughout, downsloping, smooth. The posterolateral corners of the specimen are not exposed.

Pygidium (Fig. 4) hemispherical in outline and with narrow, pointed axes, the two pleurae do not join at the posterior end of the axes. Both pleurae and axes are sharply convex without somites.

Age: Middle Cambrian.

Genus, Protolenus Matthew, 1892

Protolenus (Bergeronia) elegans? Vogdes, 1893

Material: A small cephalon preserved in shale sample of Paradoxides bennetti fauna zone of Dr. Howell. The measurements are: length, 4.62 mm.; width, 5.61 mm.; length of glabella, 3.3 mm.; width of glabella at posterior end, 2.31 mm. (Collection No. AC, MF 14).

Description: Cephalon more or less hemispherical in outline. Glabella cylindro-conical, marked by three pairs of furrows, the posterior ones are longer than the anterior ones. Fixed cheeks broad and gently sloping towards the outer margin.

Age: Middle Cambrian.

Sao Barrande, 1846

Sao hirsuta Barrande, 1846

(see Plate 2, Fig. 10)

Material: A complete form was found in the dark gray shale of Paradoxides bennetti fauna zone of Dr. Howell. Its measurements are: cephalon, length, 0.495 mm.; width, 0.87 mm.; length of glabella, 0.33 mm.; width, 0.165 mm.; length of thorax and pygidium, 0.23 mm.; width of thorax, 0.82 mm. (Collection No. AC, MF 2).

Description: Test rounded in outline, cephalon hemispherical in shape, with convex glabella which is more or less expanded toward the anterior, three pairs of very indistinct transverse oblique glabellar furrows, fixed cheeks convex, thorax has six segments with rounded extremities, pygidium is very small is fused with the thorax so it is difficult to mark the pygidial characters.

Age: Middle Cambrian.

Genus, Syspacephalus Resser, 1936

Syspacephalus laticeps Rasetti

(see Plate 2, Figs. 2, 6)

Material: A small cephalon was found in dark gray shales of Paradoxides bennetti zone of Dr. Howell. The measurements are: length, 2.44 mm.; length of glabella 1.65 mm.; width of glabella at posterior end 1.24 mm. (Collection No. AC, MF 13).

Description: Cephalon hemispherical in outline, glabella slightly tapered, straight sided, truncated in front, most elevated posteriorly.

Four glabellar furrows indistinct. Occipital furrow deep at the sides; occipital ring expanded mesially, a part of which is broken in the sample so absence of node. Brim and fixed cheeks convex, fixed cheeks on the average downsloping. Rim of the species is not exposed. Fixed cheeks almost as wide as the glabella. Ocular ridges present extending from the front edge of each eye (not visible) to glabella. Surface smooth.

Age: Middle Cambrian.

Genus, Syspacephalus sp.

(see Plate 2, Fig. 15)

Material: Two nearly complete forms (with parts of cephalon, thorax and pygidium) were found in dark gray shale of Paradoxides bennetti zone of Dr. Howell. The species of Syspacephalus could not be determined since diagnostic portions of the cephala were lacking. Their measurements are: Moderately large specimen, length of cephalon, 5.11 mm.; length of thorax, 5.11 mm.; width of thorax, 6.09 mm. Small specimen: length of thorax, 4.95 mm.; width of throax, 4.95 mm.; length of pygidium, 0.66 mm.; width of pygidium, 2.42 mm. (Collection No. AC, MF 14).

Description: The features in the cephala are not clear. The thorax consists of 13 segments, and the small pygidium of two segments which appear to be fused to the thoracic segments. There are two prominent axial nodes on the fourth and fifth lobes of the axial region of the specimens.

Age: Middle Cambrian.

Syspacephalus tardus Rasetti

Material: A moderate sized cephalon from medium dark-gray shale of Paradoxides bennetti zone of Dr. Howell. Its measurements are: length, 0.7 cm.; width, 0.75 cm.; length of glabella, 0.5 cm.; width of glabella at posterior end, 0.35 cm. (Collection No. AC, MF 13).

Description: Cephalon more or less hemispherical in outline, glabella of average convexity, slightly tapered, rounded in front. Glabellar furrows indistinct. Occipital ring not greatly expanded, bearing a node. Brim convex, downsloping. Marginal furrow and rim are not exposed. Fixed cheeks convex, slightly downsloping. Ocular ridges faint. Surface of the test smooth.

Age: Middle Cambrian.

Genus, Agnostus Brongniart, 1822

Agnostus pisiformis (Linnaeus)

Material: A small cephalon found in the dark gray sandstone of the Paradoxides bennetti zone of Dr. Howell. Its measurements are: length, 3.79 mm.; width, 4.45 mm.; length of glabella, 2.64 mm; width of glabella at posterior end, 1.48 mm. (Collection No. AC, MF 15).

Description: Cephalon hemispherical in outline, cranidium small, moderately convex, surrounded by a narrow, convex margin. Glabella bilobed, tapering, the front part evenly rounded, front lobe separated by a straight furrow of median width and depth. The glabella is surrounded by a deep, narrow furrow, which is continued forward in front of the front lobe, so that it joins with the marginal furrow and separates

EXPLANATION OF PLATE 2

(Figs. 1 to 13 are x 50, Figs. 14, 15 are 3/4 of natural size)

Figs. 1, 4. Peronopsis (Acadagnostus) scutalis (Salter in Hicks). Showing cephalon and pygidium.
Figs. 2, 6. Syspacephalus laticeps Rasetti. Showing two cephalons.
Fig. 3. Bailiaspis howelli Hutchinson. Showing cephalon.
Fig. 5. Eodiscus punctatus (Salter). Showing pygidium.
Figs. 7, 8. Bailiaspis sp. Showing cephalon.
Fig. 9. Peronopsis (Acadagnostus) matthewi (Hutchinson) upper figure showing cephalon. The lower figure, Peronopsis cf. P. quadrata (Tullberg). Showing cephalon.
Fig. 10. Sao hirsuta Barrande, 1846. Showing complete form.
Figs. 11, 12. Corynexochus minor (Walcott). Showing two cephalons.
Fig. 13. Acadagnostus acadicus (Dawson). Showing cephalon.
Fig. 14. Pardailhania cf. barthouxi (Mansuy). Showing cephalon.
Fig. 15. Syspacephalus sp. Showing 2 complete forms except cephalon which is partly destroyed.

PLATE 2

Cambrian trilobites

the two cheeks. The front lobe is of moderate convexity, approximately the same as the cheeks. The posterior lobe is approximately twice as long as wide. The cheeks are wider than glabella and moderately convex, of approximately equal width throughout, and are separated by a furrow in front of the glabella.

Age: Middle Cambrian.

Phylum, BRACHIOPODA
Class, ARTICULATA
Order, ORTHIDA
Suborder, ORTHACEA
Genus, Eoorthis Walcott

Eoorthis bellicostata? Walcott

Material: Several complete shells were found preserved in clay ironstone beds of the *Paradoxides bennetti* zone of Dr. Howell. The specimens vary in size. Measurements of a selected pedicle valve yielded the following dimensions: pedicle valve, 6 mms. in length and 4 mms. in height, the length of the hinge line is 4 mms. (Collection No. AC, MF 16).

Description: The specimens have a uniform, regular and delicate sharp radiating surface costae, which are beautifully preserved in the fine grained clay ironstone. Other features of the shell are not visible. This form corresponds to Walcott's species (63: pp. 505, 506), Plate 13, Fig. 8

Kellys Island

Brachiopoda

In this part of Chapter IV brachiopods are identified and classified according to internal and external morphologic features.

Shales in the basal part of the Bell Island Group are mostly very soft, dark-gray in colour, and occasionally finely fissile. They contain abundant brachiopod valves (for instance, Sample Nos. AC, K I, 420, C' and A') which, however, are poorly preserved owing to their delicate nature and the later compression they have undergone. The crushing effects acting on valves of single species of brachiopods result in distortions which lead to secondarily-shaped valves, laboratory examination of which may give the impression that several brachiopod species, rather than one, are present. According to Dr. A.J. Rowell (personal communication), several pseudo-species could well be produced by variously directed crushing of a single species. Some valves are laterally crushed producing a median crest.

There is a vertical lithological change in the Bell Island Group and it becomes silty upward as the result of the addition of fine quartz grains. Thin sections show that these rocks are composed of silt-sized (0.01 to 0.08 mm.) detrital quartz grains (about 10%) with muscovite flakes and minor amounts of zircon, magnetite, leucoxene and unidentified clay minerals. These lighter silty shales (Sample No. AC, K I, 420, Q) have yielded species of brachiopods (Lingulella). The shales of the still younger part of the sequence are more sandy and sometimes grade into shaly sandstones. This upper part, in contrast to the lower and middle sections, apparently was either unfavourable as a habitat for living brachiopods or unfavourable for the preservation of their valves. Owing to one of these situations few valves of brachiopods are found (Sample Nos. AC, K I, 421, F', H' and 420, R') in it.

Apparently the lower and middle parts of the section were deposited on a gently dipping slope under marine conditions which permitted the growth of Lingulella in abundance. Primary sedimentary features of this outcrop section suggests that the species of Lingulella lived in very shallow water.

Some of the collected species are as follows: Lingulella chapa Walcott, L. ibicus Walcott, L. fostermontensis (Butts), L. moosensis Walcott, L. concinna Matthew, L. waptaensis Walcott, and Lingulepsis rotunda Matthew. Specimens of these species have been checked by Dr. A.J. Rowell and according to him the latter four species cannot be confirmed unless topotype material were available for comparison.

Systematic description

Phylum, BRACHIOPODA

Class, INARTICULATA

Order, LINGULIDA

Superfamily, LINGULACEA

Genus, Lingulella Salter

Lingulella chapa Walcott

(see Plate 3, Figs. 11, 12)

Description: Specimens collected by me resemble Walcott's holotype, Cambrian Geology and Paleontology, Vol. 57, Pt. II, 1913, Plate 50, Fig. 4. Ventral valve with vascular canal (not visible in valve but fold is present), umbo acute. The surface has fine concentric growth lines. Length of shell 1.1 cms., width 0.7 cm.

Collection Nos. AC, K I, 420, H'.

Lingulella ibicus Walcott

(see Plate 3, Figs. 5, 6, 7)

Description: Several dorsal and ventral valves of the species were found, the figures (see Plate 3, Figs. 5, 6, 7) are of dorsal valves which resemble Walcott's holotype, illustrated in Cambrian Geology and Paleontology, Vol. 67, Pt. 4, 1924, Fig. 8, Plate 108. However, the valves collected by me are elongate and broader anteriorly. Shell thin with very fine concentric striae and lines of growth. Length of dorsal valve, 0.8 cm., width, 0.5 cm. A few shells of this species have also been collected from Little Bell Island (e.g. Sample No. AC, LB I, 419, M).

Collection Nos. AC, K I, 420, B, F, Q, 12, H, R'.

Lingulella fostermontensis (Butts)

(see Plate 3, Figs. 8,13 to 15)

Description: The pedicle valves are subpentagonal to elongate oval in outline, and longer than wide with the greatest width at about the middle. Valves nearly equal in length. Lateral margins more or less subparallel, but anterolateral extremities rounded; anterior margin moderately rounded. Surface with concentric undulations crossed by fine concentric lines. Colour of the shells dark brown. Length of a selected medium-sized shell, 1 cm., width, 0.7 cm.

Collection Nos. AC, K I, 420, Q, H', C'.

Lingulella moosensis Walcott

(see Plate 3, Fig. 4)

Description: The outline and characters of the ventral valve resemble those of Lingulella moosensis, of Fig. 3, a species erected by Walcott and described in Cambrian Geology and Paleontology, Vol. 57, Pt. II, No. 7, 1912, p. 232.

The valve (see Fig. 4, Plate 3) is elongate and acuminate in outline and its surface is marked by fine concentric lines with strong lines of growth at regular intervals. Only the exterior part of the ventral valve is exposed.

Length of ventral valve, 0.4 cm., width 0.3 cm.

Collection Nos. AC, K I, 420, Q.

Lingulella concinna Matthew

(see Plate 3, Fig. 9)

Description: The valves seem to be quite thin towards the lateral and front margins. The beak is blunt and the lateral margins give the ventral valve an ovate form. Surface of valve covered with very fine concentric ridges. Length of shell 0.7 to 1 cm., width 0.7 to 0.9 cm.

Collection Nos. AC, K I, 420, Q.

Lingulella waptaensis Walcott

(see Plate 3, Fig. 10)

Description: Elongately rounded form, the ventral valve resembles Walcott's species described in Cambrian Geology and Paleontology, Vol. 67, Pt. 4, 1924, Plate 122, Fig. 7. The valve shows concentric growth ridges with fine concentric growth lines. Length of shell 0.5 to 0.6 cm., width 0.4 cm.

Collection Nos. AC, K I, 420, Q.

Genus, Lingulepsis

Lingulepsis rotunda Matthew

(see Plate 3, Figs. 1, 2,3)

Description: Minute valve, ventral valves indistinct acuminate, ovate and bluntly pointed, marked by undulating ridges of growth. The surface of ventral valve provide growth ridges with minute tuberculation. Valves dark gray in colour. Length of a valve 0.5 cm., width 0.3 cm.

Collection Nos. AC, K I, 420, Q.

Kellys Island and Bell Island

Coprolites and trace fossils

Nodular-shaped coprolites were found in shales on Bell Island. Station No. 344, O, immediately south of the 'Ruins' on the northern coast of the Island is a particularly rich locality for this type of fossil.

Abundant trilobite tracks and trails were collected from the rocks of Bell Island and Kellys Island, and three types were identified by the writer. The behavior and living habits of Lower Ordovician trilobites are reflected in various trackways and markings called "trace fossils". These traces indicate that in life these organisms were able to travel either directly ahead or obliquely to right or left, occasionally losing contact with the bottom as they planed upwards or sideways into water currents. They probably also channelled into the muds constructing 'nests'. Some sidewise motion is implied by laterally successive similar arrays of paired tracks such as would be made by dragging a set of approximately equal-sized appendages across a muddy surface. The size and depth of tracks and trails made by trilobites indicate that movements of their appendages often were made while the animal was pushing its way through a soft sandy or muddy surface either in search of food or while browsing on sea floor algal mats. The identified tracks and trails are listed below.

Genus, CRUZIANA d'Orbigny, 1842

Cruziana dispar Linnarsson

Cruzana dispar ?

(see Plate 4, Fig. 2)

The tracks of this form species show simple or double grooves. On the sides they exhibit furrowed striations. The grooves appear to be made by oscillations of walking legs and at the same time the walking and grazing traces are often formed by the action of two simultaneous powerful terminal and lateral claws. Often these are bordered by two lateral grooves marking the trailing tips of the creatures genal spines. The width of Cruziana dispar ? approximates 3.5 cms. The form genus Cruziana ranges from Cambrian to Devonian in age. Locality of this specimen: Lower Ordovician of Kellys Island.

Cruziana semiplicata

(see Plate 4, Figs. 4, 5)

These types of tracks occur in the form of more or less shallow pocket-like pits which apparently were either shoveled or scratched by the walking legs of the trilobites. The cross ribs formed in this way were obliquely placed, more regularly distributed and set at a more acute angle than in Rusophycus. In Figure 4 the clearly incised lateral grooves mark the position of this creature's genal spine trace. This species ranges from Cambrian to Lower Ordovician in age. In width they measure 1.3 cms. on Kellys Island and approximately 3.5 cms. for those found on Bell Island.

Cruziana rugosa

(see Plate 4, Fig. 1)

The tracks made by this species are typical of the Ordovician.

EXPLANATION OF PLATE 3

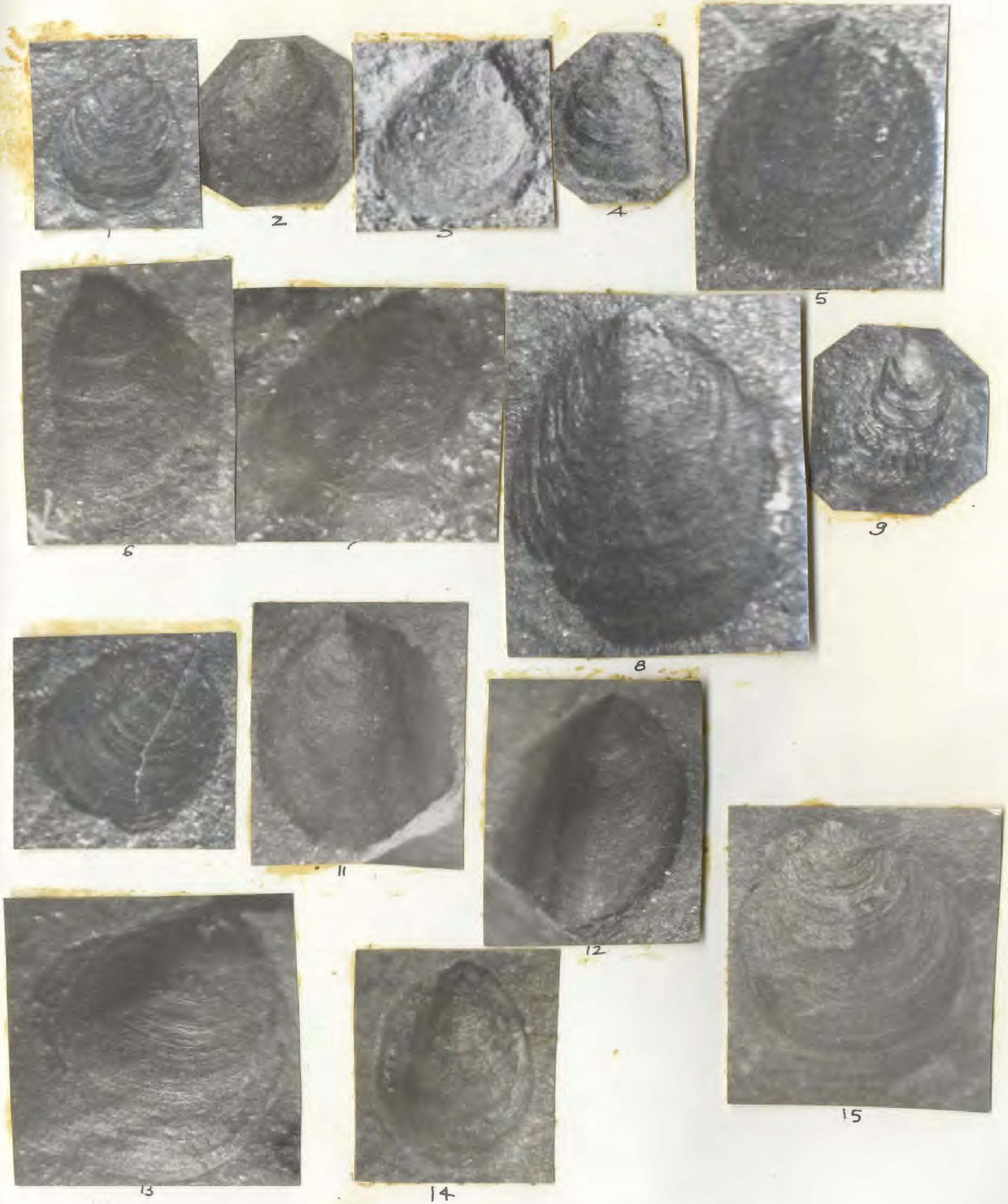
Magnification: Figures 1, 6, 7, 11, 12 = x 24; 2 - 5, 8 - 10 = x 32; 13 - 15 = x 16.

Figs. 1, 2, 3. _Lingulepsis_ _rotunda_ Matthew, ventral valves.
Fig. 4. _Lingulella_ _moosensis_ Walcott, ventral valve.
Figs. 5, 6, 7. _L._ _ibicus_ Walcott, dorsal valves.
Figs. 8, 13, 14, 15. _L._ _fostermontensis_ (Butts), ventral valves.
Fig. 9. _L._ _concinna_ Matthew, ventral valve.
Fig. 10. _L._ _waptaensis_ Walcott, ventral valve.
Figs. 11, 12. _L._ _chapa_ Walcott, ventral valves.

EXPLANATION OF PLATE 4

Fig. 1. _Cruziana rugosa_, Locality Sandstone, Airfield Formation, Bell Island.
Note: This is a natural mud cast collected on Bell Island.
Fig. 2. _Cruziana_ _dispar_? in sandstone, Locality Kellys Island. Cast.
Figs. 3, 6. Worm tubes in dark gray shale and sandstone, Polls Head Formation, Bell Island.
Fig. 4. _Cruziana_ _semiplicata_ in shaly sandstone, Locality Bell Island. Cast.
Fig. 5. _Cruziana_ _semiplicata_ in dark gray shale, Locality Kellys Island. Cast.

PLATE 3



NAUTIYAL, Lower Ordovician Brachiopods, Kellys Island.

PLATE 4

Cambro-Ordovician 'trace fossils' & worm borings

The cross grooves are very sharp where the endopodite part of the limb of creature swept forward and backward marking the mud floor with these scratches. Seileicher suggests that occasionally the pre-epipodite part of the limb might have also taken part in their formation. In width this species generally measures about 10 cms. Locality: Lower Ordovician of Bell Island.

Trilobite resting traces

According to Seileicher even when trilobites were 'resting' they made burrows (molds) which were later infilled resulting in the formation of Ruhespuren, or resting traces. Striations are often seen on the sides of the traces made by "claws" of the animal.

(Medusoid ?) fossil impressions

Two disc type fossil impressions (medusoid ?) were discovered on Kellys Island and Bell Island. These are shown in Fig. No. 93, A,B. These forms are being studied by the writer, and a paleontological note for publication is being prepared on them.

Fig.93,A. Photograph exhibits a disc type(medusoid?) fossil impression in sandstone of Polls Head Formation, Martins Cove, Kellys Island.

Fig.93,B Showing major part of a medusoid? fossil impression in sandstone of Townsquare Formation near Freshwater Cove, northern coast, Bell Island.

Bell Island

Systematic paleontology

Phylum, MOLLUSCA

Class, PELECYPODA

Subclass, PRIONODESMACEA

Order, DYSODONTA

Suborder, MYTILACEA

Whiteavesia Ulrich, 1893

Whiteavesia sp.

(see Plate 5. Fig. 5)

The shell is thin, obliquely elongate and convex in basal outline. It is inequilateral, the anterior end is small but the posterior large. The hinge part of the shell is not exposed. Length, 4 cms. and width about 2.5 cms. Locality: This specimen was found in a sandstone bed of Middle Member, northern coast, Bell Island.

Phylum, CEPHALOPODA

Subclass, NAUTILOIDEA Agassiz, 1847

Order, ELLESMEROCERIDA Flower in Flower and Kummel, 1950

Family, PROTOCYCLOCERATIDAE Kobayashi, 1935

Genus, Protocycloceras Hyatt in Zittel, 1900

Protocycloceras sp.

(see Plate 5, Fig. 1)

The specimen includes a single strongly annulate orthocone, circular in cross-section. The annulations and sutures are transverse and straight. The siphuncular segments are tubular. The specimen can be compared with the Lower Ordovician species of Protocycloceras mentioned in Treatise on Invertebrate Paleontology (K), Mollusca 3, Fig. 86 (1 a), page k 151. Locality: Silty shale bed of Middle Member, northwestern coast, Bell Island.

Subclass, ENDOCERATOIDEA Teichert, 1933

Order, ENDOCERIDA Teichert, 1933

Family, PROTEROCAMEROCERATIDAE Kobayashi, 1937

Genus, Kirkoceras Ulrich and Foerste, 1936

Kirkoceras sp.

(see Plate 5, Fig. 2)

The collected specimen is not complete. It is large, with a siphuncle which is circular to compressed in cross section, rapidly enlarging in earlier stages, and tapering adaperturally. The surface of siphuncle is oblique to the septa. This specimen can be compared with the Lower Ordovician species of Kirkoceras mentioned in the Treatise on Invertebrate Paleontology (K), Mollusca 3, Fig. 2, page k 171. Locality: Sandstone bed of Upper Member at Grebes Nest Point, Bell Island.

Brachiopoda

No identifiable brachiopods were recorded within the Pyrite bed of the Lower Member of the Wabana Formation. Directly beneath the pyrite bed specimens of Lingulobolus affinis (Lingula hawkei of Dr. Hayes) were collected and these were of some significance in interpretation of the paleogeography. Agar (1: pp. 38, 39) states that modern forms of Lingula are confined to tropical or subtropical seas and depths of less than 40 meters. They inhabit many different kinds of littoral sediments, but especially favour argillaceous types. They are tolerant of a wide variety of environmental conditions ranging from marine to brackish water.

One specimen of linguloid brachial valve was collected from the non-pyritized graptolite shale of the Lower Member of Wabana Formation. Several specimens of Eoorthis sp. (see Plate 6, Fig. 2) were obtained from the sandstones of Freshwater Cove, northeastern coast of Bell Island.

Systematic paleontology

Phylum, BRACHIOPODA

Class, ARTICULATA

Order, ORTHIDA

Genus, Eoorthis Walcott

Eoorthis sp.

(see Plate 6, Fig. 2)

The valves exhibit the characters of Eoorthis. Incomplete shells were found in a sandstone bed (No. 301, D) which contained several specimens with uniform, regular and delicate sharp radiating surface costae. The hinge line is straight. Total length, about 2.5 cms., width about 2 cms. Locality: Freshwater Cove.

EXPLANATION OF PLATE 5

Fig. 1. _Protocycloceras_ sp. Hyatt in Zittel, Locality shale, Bell Island.

Fig. 2. _Kirkoceras_ sp. Ulrich and Foerste, Locality Sandstone, Grebes Nest.Member, Bell Island.

Fig. 3. _Pygidium_ of _Niobe_ (_Niobella_) _homfrayi_ Salter, natural size, shales, Bell Island.

Fig. 4. Pygidium of a trilobite, Locality Kellys Island, Lower Ordovician, x 64.

Fig. 5. _Whiteavesia_ Ulrich, sandstone, Bell Island.

Fig. 6. Unidentified microfossil, Locality Kellys Island, Lower Ordovician, x 64.

EXPLANATION OF PLATE 6

Fig. 1. Linguloid brachial valve (crushed), x 16

Fig. 2. _Eoorthis_ sp., Locality Freshwater Cove, Bell Island, x 64.

Figs. 3, 4, 5. _Lingulobolus_ sp. cf. _L._ _affinis_ (Billings), x 16

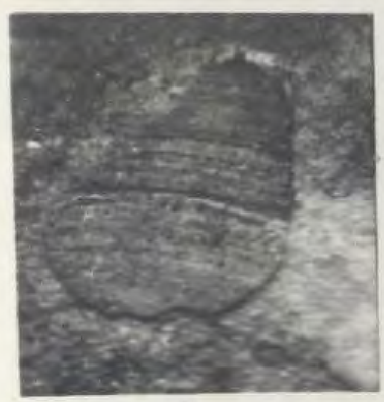
1

2

3

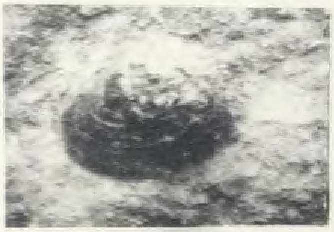
4

5



6

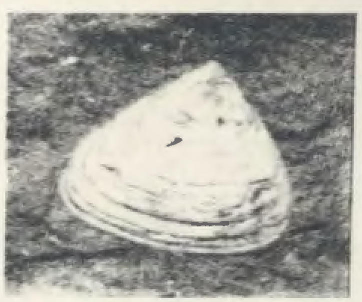
Lower Ordovician fossils, Bell Island & Kellys Island



1

2

3



4

5

Lower Ordovician brachiopods, Bell Island

Linguloid brachial valve

(see Plate 6, Fig. 1)

This is a linguloid brachial valve which has been crushed longitudinally (i.e. shortened). More or less rounded in outline, surface of the valve with concentric growth lines and very fine striae radiating towards anterior and lateral margins. Both length and width of shell 0.4 cm.

Lingulobolus sp. cf. L. affinis (Billings)

(see Plate 6, Figs. 3, 4, 5)

This species has been called Lingula hawkei by Dr. Hayes but according to Dr. A.J. Rowell of Nottingham University (personnel communication) it should be referred to Lingulobolus and may be compared with L. affinis (Billings).

Figs. 4, 5, length 3.5 cms., width, 2.6 cms. Collection No. AC, Bl, 2.

Fig. 3, length and width of shell 2.7 cms. Collection No. AC, BI, 1.

A trilobite pygidium specimen was found obliquely oriented in silty shales of the Middle Member of Wabana Formation.

Systematic paleontology

Phylum, ARTHROPODA

Class, TRILOBITA Walch, 1771

Order, PTYCHOPARIIDA Swinnerton, 1915

Suborder, PTYCHOPARIINA Richter, 1933

Superfamily, ASAPHACEA Burmeister, 1843

Family, ASAPHIDAE Burmeister, 1843

Subfamily, NIOBINAE Jaanusson, nov.

Genus, Niobe Angelin, 1851

Niobe (Niobella) homfrayi Salter

(see Plate 5, Fig. 3)

Description: The general shape of the pygidium is best described as semi-elliptical, possessing a margin approximately 4 mms. wide. The axial region is outlined by deep furrows which vary in depth from anterior to posterior resulting in the posterior axial region being set at a slightly higher relief than the anterior.

The axial furrows taper posteriorly in the form of a slightly concave curve, and terminate bluntly on the inner edge of the margin.

The axial region contains 6 distinct rings which are more prominent towards the anterior end; in addition, 2 or 3 more faint rings may be seen towards the posterior margin.

The pleural furrows descend to the margin in asymmetrical curves and possess 6 distinct ribs with intervening furrows. The ribs terminate at the inner edge of the margin. The furrows deepen towards the margin which appears to be flat. Locality: open cut working, northern coast, Bell Island.

Graptolites

Reasonably well preserved non-pyritized graptolites, found in the shale directly above the Pyrite bed, appear to belong to a single morpho-species. Those occurring at the base of the shale are, in part, pyritized. For a distance of about one inch above the Pyrite bed the graptolites were unique in that they have a blue colour on fresh exposure which is due possibly to a small proportion of copper present in the iron sulphide. At this horizon well-preserved branching forms were collected, and from the specimens studied a range for the initial angle of divergence was 100 to 130 degrees. The stipes tended to be quite short (in the order of 1.5 cms.) as compared to the forms found in the dark gray shales. The number of thecae varied from 10 per 10 mms. to 10 per 7 mms. The apertural margins of the thecae are as a rule only slightly concave and in general the thecae are 3 to 4 times as long as they are wide. The angle of inclination of apertural margins range between 20 and 30 degrees. The sicula of this form was long and thin and generally found to measure about 1 mm. in length.

Graptolites found in the Pyrite bed itself were completely pyritized and those in the shale directly above were either partially or completely non-pyritized.

Pyritized forms

Pyritized forms from Bell Island appear to be larger than the non-pyritized forms found in the shales. The pyritized thecae are preserved in some specimens in the form of cylinders broadening towards the aperture, but in other forms they have a somewhat cone shape. The aperture in some of the forms was elliptical rather than circular. In general the interthecal angles of the pyritized forms ranged from 14 to 30 degrees.

Spjeldnaes has suggested that pyritized graptolites from the Upper Tremadocian of the Oslo region in Norway underwent, in the process of fossilization, a certain amount of swelling and distortion. He envisaged dead graptolites becoming filled with an iron sulphide gel which eventually solidified but, where the quantity of gel was sparse, only partial pyritization took place. He also suggested that the gel would become swollen owing to differential osmotic pressure.

Non-pyritized forms

Measurements of the interthecal angles of the non-pyritized graptolites gave readings varying from 18 to 69 degrees. This variation may be owing to the following causes. First of all, it may be possible, assuming that the two types are the same species, that the difference in modes of fossilization accounted for the variation in the thecal angles. Second, it may be possible that the pyritized forms represent a single species and the non-pyritized forms more than one species, which would explain why some measured thecal angles of the non-pyritized graptolites are found to coincide with those recorded for the pyritized forms. The third possibility, which could account for a wide variation in interthecal angles, is that during compression in the case of the non-pyritized types the thecae would be overlapped at angles bearing little relation to those of the original living animal. It is not proven which of the three possibilities is the most probable explanation. In short, the interthecal angles are of little use as a criterion for identifying the species present.

A note on the orientation of Graptolites

The graptolites were found oriented roughly along an E.-W. direction which also provides evidence for local current directions in that part of the basin. There are very strong suggestions that preferential orientation has occurred in the case of non-pyritized graptolites found above the Pyrite bed. On the other hand, in the case of the pyritized forms, similar trends were discernable although locally there appeared to be a more or less random distribution. In the case of the specimens which did show some preferred orientation it was possible to relate this to the sedimentational picture. This has been illustrated in a very general diagram given overleaf.

Six species of graptolites were identified by the writer from the pyritized and non-pyritized graptolite beds as follows: Monograptus sp., Didymograptus nitidus, Didymograptus cf. nitidus (Ruedemann), Didymogratus nicholsoni Elles and Wood, Didymograptus nicholsoni var. planus Elles and Wood, Phyllograptus angustifolius ? Hall.

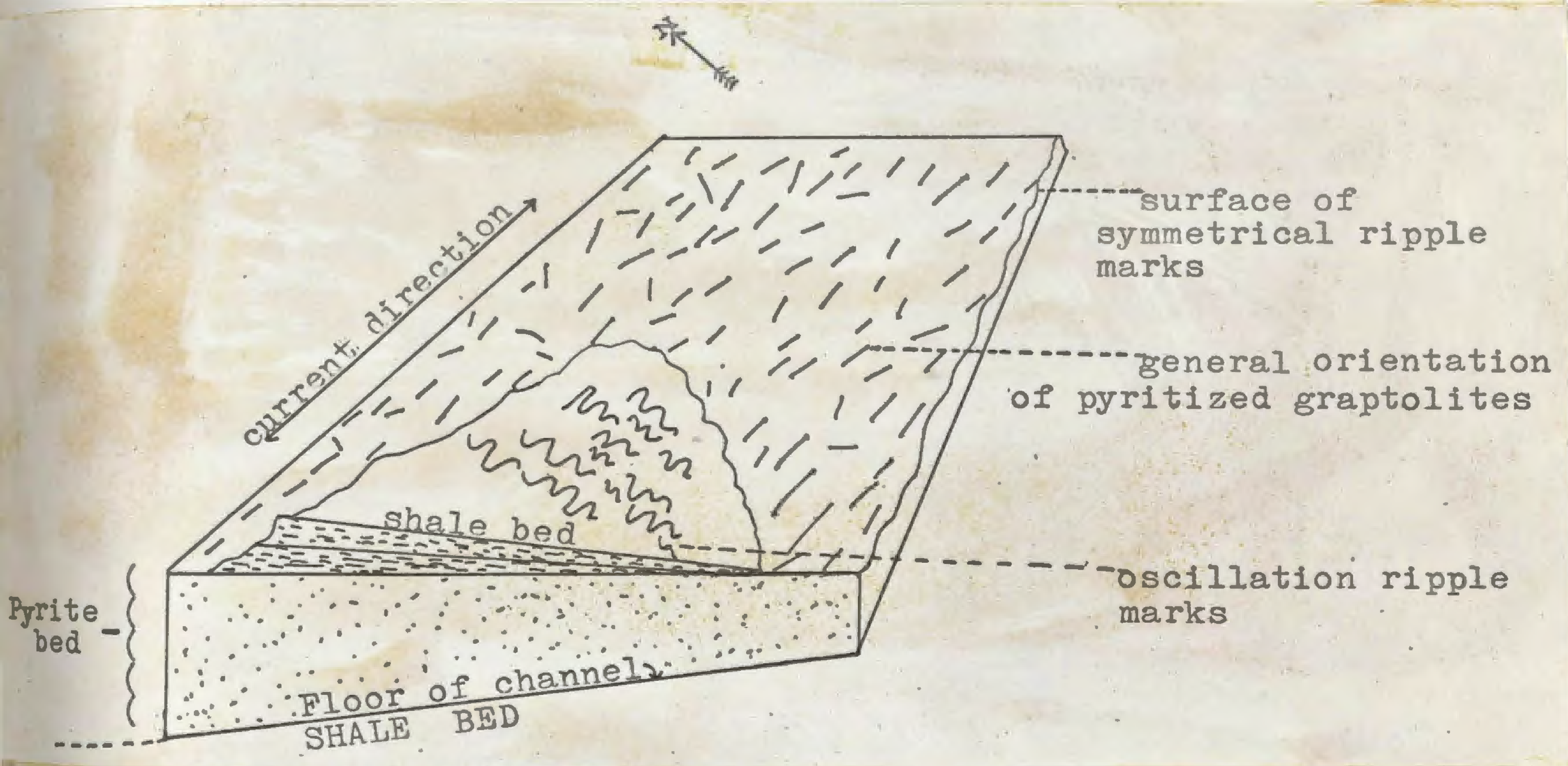

current direction
surface of symmetrical ripple marks
general orientation of pyritized graptolites
shale bed
oscillation ripple marks
Pyrite bed
Floor of channel
SHALE BED

Figure 94

Systematic paleontology

Phylum, HEMICHORDATA

Subphylum, STOMOCHORDA Dawydoff, 1948

Class, GRAPTOLITHINA Bronn, 1846

Order, GRAPTOLOIDEA Lapworth, 1875

Family, MONOGRAPTIDAE Lapworth, 1873

Genus, Monograptus Geinitz, 1852 emend, of authors.

<u>Monograptus</u>

(see Plate 7, Fig. 6)

<u>Description</u>: Rhabdosome is simple, straight to slightly curved, thecae straight but appreciably overlapping.

Genus, Didymograptus

<u>Didymograptus</u> <u>nitidus</u> (Hall)

(see Plate 7, Fig. 1)

<u>Description</u>: This is a horizontal form in which stipes become straight after initial flexing at their proximal end. Siculae were not observed in the specimens collected. Thecae are arranged about 12 per centimeter and individually are very slightly curved to nearly straight. The thecae diverge from the axis at about 40 degrees and are about 1.5 mm. long, and 0.4 mm. wide at the aperture. Thecae are in contact for about two-thirds of their length.

Didymograptus nicholsoni

(see Plate 7, Fig. 2)

escription: The stipes are about 2.5 cms. in length, uniformly lender, diverging from the sicula at an angle of 130 degrees. Thecae umber about 12 per centimeter, with interthecal angles of about 22 derees. Apertural margin is normal, and straight.

Ruedemann has discussed this species as follows:

"black shale beds on Bell Island, Conception Bay, Nfld., are ensely covered on the bedding planes with a single species of graptolite, hich is identical with Didymograptus nicholsoni, a form of large range nd wide distribution in Great Britain. The Newfoundland form does not iffer sufficiently to be recognized as a variety, but in its general utline, that is the angle of divergence of its branches, approaches he variety planus." (45: p. 388).

Didymograptus nicholsoni var. planus Elles and Wood

(see Plate 7, Figs. 3, 5)

escription: These specimens are characterized by their rigid horizontal tipes and can be compared with the species described by Elles and Wood.

Genus, Phyllograptus

Phyllograptus angustifolius ? Hall

(see Plate 7, Fig. 4)

escription: The rhabdosome is provided with elongate, semi-elliptical ranches of nearly equal width throughout their length. The length of he specimen is about 1.1 cms., the width is 0.4 cms. The thecae are n contact throughout and about 13 in number per centimeter. They are irected obliquely upward and are straight. The specimen collected was roken and incomplete.

EXPLANATION OF PLATE 7

Fig. 1. Didymograptus nitidus (Hall).
Fig. 2. Didymograptus nicholsoni.
Figs. 3, 5. Didymograptus nicholsoni var. planus Elles and Wood
Fig. 4. Phyllograptus angustifolius ? Hall.
Fig. 6. Monograptus sp.

1

2

3

4

5

6

NAUTIYAL, Lower Ordovician Graptolites, Bell Island.

Micropaleontology

In the present study over 150 rock samples (shales, silty shales, phosphatic nodules) of the Cambro-Ordovician sequence were chemically macerated in a search for microfossils. More than 45 stratal units yielded large numbers of hystrichospheres, chitinozoa, scolecodonts, and some "Problematica" microfossils. A summary list of the microfossiliferous zones in the Cambro-Ordovician is given below:

Lower Manuels River valley: Four zones containing hystrichospheres.
Little Bell Island: Four zones containing hystrichospheres.
Kellys Island: Seven zones containing hystrichospheres.
Bell Island: Thirty zones containing combinations of hystrichospheres, chitinozoa, scolecodonts, and microscopic Problematica.

The technique used to isolate chemically-resistent microfossils in the present research programme is given below:

1. The sample was crushed to pea size and treated with dilute hydrochloric acid (10 - 20%) in order to remove any calcareous contents, and then washed with distilled water.
2. A small part (about 5 grams) of this sample was placed in a polyethylene beaker and digested with 20 cc. of hydrofluoric acid (60 - 100%) for either 12 to 20 hours or until completely disintegrated.

3) The digested sample was centrifuged, decanted, washed, and recentrifuged. This process was repeated several times (5 or 6) until the supernatant water was clear.

4) Next the sample was oxidized with concentrated nitric acid for 20 to 30 minutes, and then washed with distilled water (5 or 6 times).

5) This washed sample was treated with a base (either KoH or NH_4OH may be used) to eliminate humic acids. This step was repeated several times until no odor of the base remained, and then the supernatant water was decanted.

6) The residue was mixed with either a mixture (heavy liquid) of potassium iodide, zinc chloride, cadmium iodide and water, or zinc chloride solution, both having a specific gravity of 2.2.

7) The remaining mixture (sample + heavy liquid) was centrifuged for either a half hour or until the organic residue floated above the heavy liquid in the form of a thin film.

8) This floating separate was decanted into a glass beaker (400 cc) containing 10 to 20 cc of either hydrochloric acid (10%) or acetic acid (10%) and was filled with distilled water. The residue was allowed to stand overnight.

9) A passage of 12 to 14 hours allowed the residue to settle to the base of the beaker, and the supernatant liquid was either decanted or siphoned off.

10) This residue was centrifuged and washed several times (5 or 6) with distilled water to remove any remaining acid content.

11) Finally the water in the centrifuge tube was decanted, and the residue mounted in glycerine jelly on a glass slide for microscopic examination.

As mentioned above, two types of heavy liquids were employed in Step 6 of this microfossil floatation method. A heavy liquid containing a mixture of potassium iodide, zinc chloride, cadmium iodide, and water was found most successful. Preparation of this mixture is as follows:

Potassium iodide, zinc chloride and cadmium iodide were taken in 2:1:1 ratio or 415 gms. : 215 gms.: 230 gms. This mixture was boiled with 150 cc of distilled water until the solution attained a specific gravity of 2.2. If necessary, some distilled water was added to gain the abovementioned specific gravity.

Hystrichospheres

General comments:

In general the tests of hystrichospheres, which are presumed to be the remains of unicellular microorganisms, are composed of organic substances. The test surfaces may be smooth, punctate or perforate, granular or smooth, and occur in several shapes including polygonal, spherical, ellipsoidal, discoidal or, sometimes, elongate. The test encloses a central body and either may or may not have outgrowths. If outgrowths are present in a hystrichosphere fossil, they may be in the form of spines (or processes), flanges, or raised ridges. The spines may or may not have openings.

Well-preserved hystrichosphere tests are transparent, often yellow in colour, and extremely resistant to the effects of chemicals. Their exact composition is still unknown but some micropaleontologists are of the opinion that they are composed of 'cutin' (an organic compound).

Hystrichosphaers, hystrichospheres, or hystrichosphaerids are names which have been derived from the generic name Hystrichosphaera applied to micro-organisms belonging to the Family Hystrichosphaeridae. These generic and family names were proposed by Wetzel (1933) for acanthaceous microfossils which he described from the Cretaceous of Germany. It is interesting to note that their spheroid nature and smooth casing was first described by J.W. Dawson (1871) from Paleozoic deposits of eastern North America.

Eisenack, in 1938, added the smooth-cased forms to Family Hystrichosphaeridae, Wetzel, 1933, and erected the new Order Hystrichosphaerides to include both smooth and acanthaceous forms. Under this order he added a new Family, Leiofusidae, consisting of fusiform and oval forms. In general the name "hystrichospheres" is used most commonly for all the forms belonging to Order Hystrichosphaeridea.

The taxonomic position of hystrichospheres is still unknown. In 1963, C. Downie, W.A. Evitt, and W.A.S. Sarjeant proposed that the genera of uncertain affinity which were formerly classed as hystrichospheres be termed "acritarchs", and that the Acritarcha be treated as a group <u>incertae</u> <u>sedis</u>. Furthermorethey have pointed out that nomenclatural treatment should fit with the "International Code of Botanical Nomenclature". Following are the reasons they put forward in favour of the use of this Code:

" i. According to the consensus of modern biological interpretation, dinoflagellates are algae (Braarud, in litt.).

ii. The concept of a third kingdom, the Protista, including all unicellular organisms, has gained little acceptance and it is unlikely that a third nomenclatural Code will be brought into being.

iii. For nomenclatural purposes, the algae generally have been and should continue to be treated under the Botanical Code.

iv. Therefore, the fossil dinoflagellates, as fossil algae, are most satisfactorily treated under the Botanical Code, regardless of how one chooses to evaluate further the affinities of the algae.

v. The precise affinities of the acritarchs to algae, protozoans, protists, true plants, and true animals and the interrelationship of these groups themselves are in varying degrees uncertain, speculative, and controversial.

vi. From purely practical considerations, acritarchs and other miscellaneous planktonic microfossils of organic composition and uncertain affinity (so long as they are not demonstrably animals <u>sensu</u> <u>stricto</u>) should be dealt with under the same code as the dinoflagellates."
(12: p. 4).

Frank L. Staplin, Jasonius and Stanley A.J. Pocock, 1965 in their paper on 'Evaluation of some Acritarchous Hystrichosphere Genera' have reviewed the morphology and nomenclature of leiospheres along with simple hystrichospheres. In this paper they have grouped the hystrichosphere genera, with some modifications, according to the system which was proposed by Downie, Evitt, and Sarjeant.

In the present study the taxonomy, nomenclature and systematics proposed by C. Downie and W.A.S. Sarjeant in their paper 'On the interpretation and status of some hystrichosphere genera' (18: pp. 83 - 96) in 1963 have been followed as closely as possible. However, since even the experts disagree about the systematics of this group, the writer found that he could not follow Downie and Sarjeant's classification strictly without introducing taxonomic ambiguities.

Lower Manuels River valley

Description of Hystrichospheres

Group, ACRITARCHA Evitt 1963

Order, HYSTRICHOSPHAERIDEA Eisenack 1938

Family, HYSTRICHOSPHAERIDAE

Genus, Baltisphaeridium Eisenack, 1958

Genus, Micrhystridium Deflandre 1936

Genus, Baltisphaeridium Eisenack, 1958

Baltisphaeridium parvispinum Deflandre

(see Plate 8, Fig. 1)

escription: Test oval and brown in colour, long diameter 40 μ and hort diameter 26μ, test covered with several spines, curved, tapering, heir tip is pointed and closed, the base is broad and embedded, size 4μ. Collection No. AC, MHY). Found in Orusia lenticularis shale of Upper ambrian age.

Baltisphaeridium microcladum Downie

(see Plate 8, Figs. 2, 6, 8)

escription: Test slightly ellipsoidal and dark brown to black in colour, heir size varies, the long diameter of test ranges from 30 μ to 38 μ and hort diameter ranges from 24 μ to 28 μ, test smooth, spines moderately ong and numerous, narrow and slightly tapering. Forking only at the ips bifurcate, branches very short and thin. Spines length 2 μ and ranches 1 μ. Found in Orusia lenticularis shale of Upper Cambrian age.

Genus, Micrhystridium Deflandre 1936

<u>Micrhystridium parvispinum</u> Deflandre

(see Plate 8, Figs. 3, 5, 12)

escription: Test more or less globose and dark brown in colour, long iameter 20 μ and short diameter 18 μ without the spines. Spines 2 μ n size, top broad (Collection No. MHY).

Found in the *Orusia lenticularis* shale of Upper Cambrian age nd in the *Paradoxides davidis* zone of Middle Cambrian age.

<u>Micrhystridium parinconspicuum</u> Deflandre

(see Plate 8, Figs. 10, 11)

escription: Test oval and light brown in colour, long diameter 20 μ nd short diameter 16 μ without the spines. Spines are 2 μ in size, traight, shorter than the radius of test tapering with broad base erging into test, tips closed. (Collection No. MHY).

Found in *Orusia lenticularis* shale of Upper Cambrian age and aradoxides *davidis* zone of Middle Cambrian age.

<u>Micrhystridium rhopalicum</u> Sarjeant

(see Plate 8, Figs. 4, 7, 9)

escription: Test slightly oval rather than spherical and dark brown in colour, long diameter of test 20 μ and short diameter 17 μ, the spines number about 20, they taper slightly from the base but expand (knob-shaped) at the tip, size is 4 μ. (Collection No. MHY).

Found in *Orusia lenticularis* zone of Upper Cambrian age.

Microplankton (unidentified)

(see Plate 8, Fig. 13)

__Description__: Test more or less oval, nearly transparent, long diameter 32 μ and short diameter 24 μ, its surface does not show any spines.

Found in the olive shale of Lower Cambrian age.

Summarizing the paleontological results of this investigation of the Lower Paleozoic rocks of lower Manuels River valley one can write that altogether eighteen species of trilobites were collected and identified. Forty specimens of hystrichospheres (exclusing broken specimens) were discovered in which two generic forms and five species were identified. A single specimen from the olive coloured shale of Lower (?) Cambrian age was unidentifiable but appears to be a microplanktonic ? fossil (see Plate 8, Fig. 13).

EXPLANATION OF PLATE 8

Hystrichospheres from the Cambrian shales of Lower Manuels River valley. All Figures x 600.

Fig. 1. Baltisphaeridium parvispinum Deflandre, from Orusia lenticularis zone of Dr. B.F. Howell.
Figs. 2, 6, 8. Baltisphaeridium microcladum Downie, from Orusia lenticularis zone of Dr. Howell.
Figs. 3, 5, 12. Micrhystridium parvispinum Deflandre, from Orusia lenticularis and Paradoxides davidis fauna zone of Dr. Howell.
Figs. 4, 7, 9. Micrhystridium rhopalicum Sarjeant, from Orusia lenticularis zone of Dr. Howell.
Figs. 10, 11. Micrhystridium parinconspicuum Deflandre, from Orusia lenticularis and Paradoxides davidis fauna zone of Dr. Howell.
Fig. 13. Unidentified microplankton?

NAUTIYAL, Cambrian hystrichospheres, Manuels River valley

Little Bell Island

Hystrichospheres

Systematic paleontology

Order, HYSTRICHOSPHAERIDEA Eisenack 1938

Family, LEIOFUSIDAE Eisenack 1938

Genus, Leiofusa Eisenack 1938

Leiofusa tumida Downie ?

(see Plate 9, Fig. 1)

Description: This specimen shows two long terminal processes and a more or less rounded central body. The specimen is partly folded from one side and gives a fusiform appearance. The test is hollow with smooth membrane. Terminal processes are broken. Length of the central body 36 μ. Sample No. 419, H.

Family, HYSTRICHOSPHAERIDAE O. Wetzel 1933, emend, Deflandre 1937

Genus, Veryhachium Deunff 1954

Veryhachium rhomboidium Downie

(see Plate 9, Fig. 2)

Description: Test rhomboidal with moderately thick wall, surface smooth, test size 28 μ; processes, four, arising at corners of the test, simple and long spines equal to the length of the test size. This specimen resembles Downie's (1959) species but test is slightly larger. Sample No. 419, D.

Genus, Baltisphaeridium Eisenack 1958

<u>Baltisphaeridium</u> <u>brevispinosum</u> (Eisenack)

(see Plate 9, Fig. 3)

<u>Description</u>: This species has a more or less spherical test, processes shorter than the radius with a size of 8 μ, less than 25 in number, (in optical section), merging with test at their bases, distal ends rounded, tips closed. Overall size of the specimen 34 μ. Sample No. 419, L'.

<u>Baltisphaeridium</u> cf. <u>brevispinosum</u> (Eisenack)

(see Plate 9, Figs. 4 - 7)

Diameter of the test ranges from 24 - 26 μ and length of spines about 12 μ. Sample No. 419, L'.

<u>Baltisphaeridium</u> <u>microspinosum</u> (Eisenack) ?

(see Plate 9, Fig. 8)

<u>Description</u>: The test of this specimen is spherical, light brown. Overall size 32 μ, size of process 2 μ, processes closely spaced. The specimen partly resembles the species described by Downie 1959 but is smaller in size. Sample No. 419, L'.

Genus, Micrhystridium Deflandre 1937

<u>Micrhystridium</u> <u>stellatum</u> Deflandre

(see Plate 9, Figs. 9 - 11)

<u>Description</u>: Test more or less globose, 14 - 17 μ without the spines, occasionally tending to be polygonal and bearing about a dozen simple

but strong spines whose length exceed the test radius; in specimens length of processes about 14 µ. Sample No. 419, L'.

Micrhystridium stellatum Deflandre 1945

(see Plate 9, Fig. 12)

Description: This specimen resembles 'Forma 3' of Wall and Downie 1963. Test subpolygonal with a size of 18 µ, spine bases are slightly enlarged (expanded), length of spine equal to test diameter, more or less flexuous and about 12 in number. Sample No. 419, L'.

Micrhystridium lejeunei Stockmans and Williere

(see Plate 9, Fig. 13)

Description: Test is globose with an ellipsoidal profile, ornamented with 15 - 20 processes, simple, tapered and curved, and their bases are conical, bifid and spread over the test. Length of test 16 µ and of processes 6 µ. This specimen resembles the holotype of Stockmans and Williere 1962. Sample No. 419, L'.

Genus, Archaeohystrichosphaeridium

(see Plate 10, Figs. 1 - 9)

Description: This genus was erected by Timofiev (1959) but no type species has yet been designated known to the writer. According to Downie and Sarjeant 1963, the genus is indistinguishable from Baltisphaeridium Eisenack and may be by intent a synonym of that genus.

In the identified specimens diameter of the vesicle ranges from 20 - 30 μ, thin, ornamented with simple and pointed spines. Only one specimen (Fig. 9) shows blunt spines. Size of spines ranges from 4 - 12 μ. Colour of the test is brownish yellow. Sample Nos. 419, H' (Fig. 3, 9), 419, L' (Figs. 1, 2, 4 to 8).

Family, PTEROSPERMOPSIDAE

Genus, Cymatiosphaera O. Wetzel 1933 emend. Deflandre 1954

? Cymatiosphaera sp. indet.

(see Plate 10. Fig. 10)

Description: One specimen is attributed to this genus. Shape is spherical. The test surface is divided into very numerous polygonal fields by very low membranes sustained by spines at their junction, these spines sometimes are bifurcated. The overall diameter is 40 μ and the spines measure 4 μ in height from the abovementioned junction. W.A.S. Sarjeant (1961) described two specimens from the Upper Jurassic strata of Yorkshire coast that resemble members of this genus but he mentioned that these cannot be attributed with any certainty to it. It is worth noting that certain Mesozoic pollen grains, for instance Lycopodiumsporites clavatoides Couper, have a similar ornamentation to Cymatiosphaera. Sample No. 419, L'.

Indeterminate

(see Plate 10, Fig. 11)

This form was recovered from the Sample No. 419, H', but is not determinable as to its systematic position.

EXPLANATION OF PLATE 9

Hystrichospheres from the Lower Ordovician of Little Bell Island.
All figures x 600.

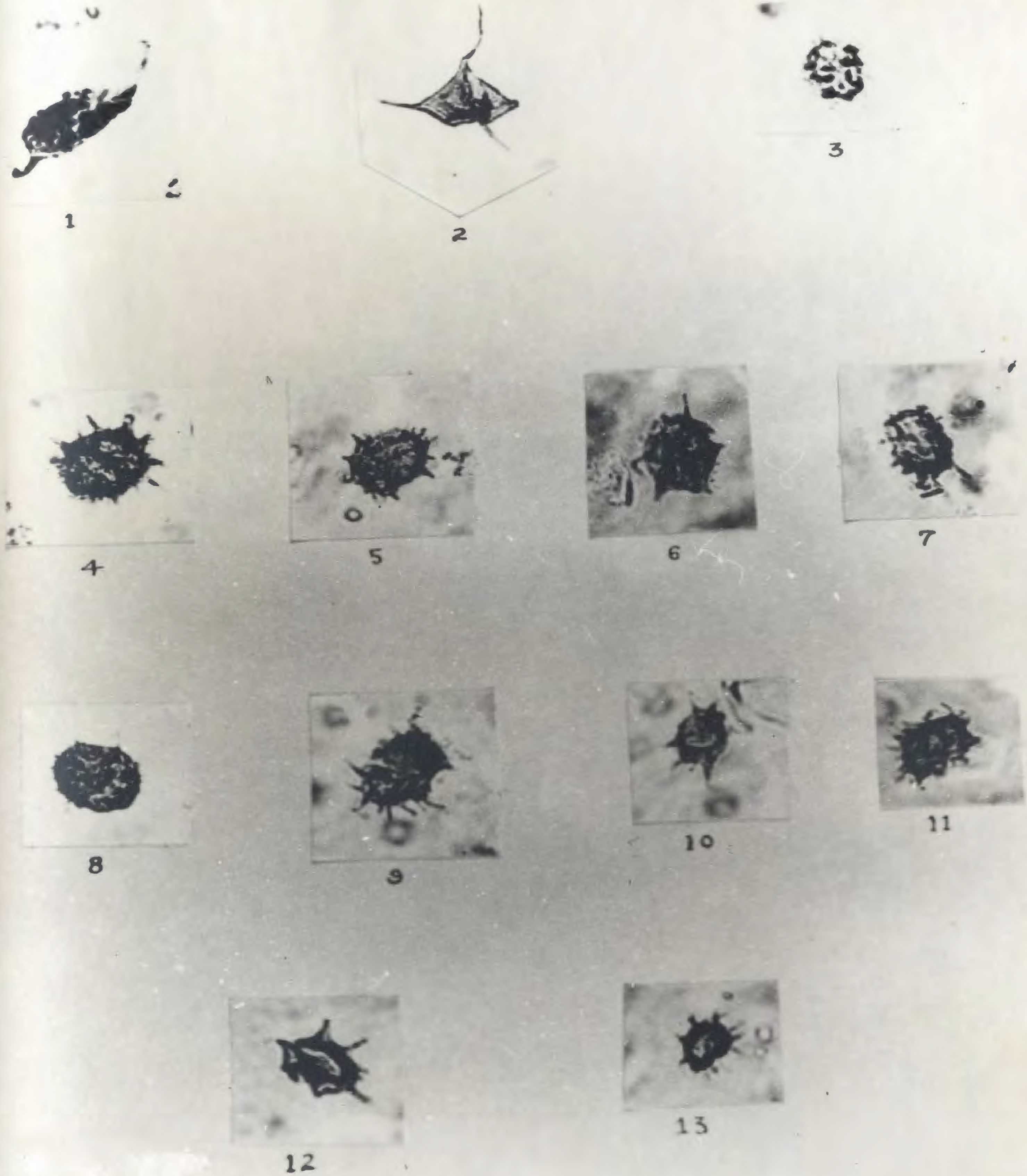
Fig. 1. Leiofusa tumida Downie?
Fig. 2. Veryhachium rhomboidium Downie.
Fig. 3. Baltisphaeridium brevispinosum (Eisenack).
Figs. 4 - 7. Baltisphaeridium cf. brevispinosum (Eisenack).
Fig. 8. Baltisphaeridium microspinosum (Eisenack)?
Figs. 9 - 11. Micrhystridium stellatum Deflandre.
Fig. 12. Micrhystridium stellatum Deflandre, Forma 3.
Fig. 13. Micrhystridium lejeunei Stockmans and Williere.

EXPLANATION OF PLATE 10

All figures x 750.

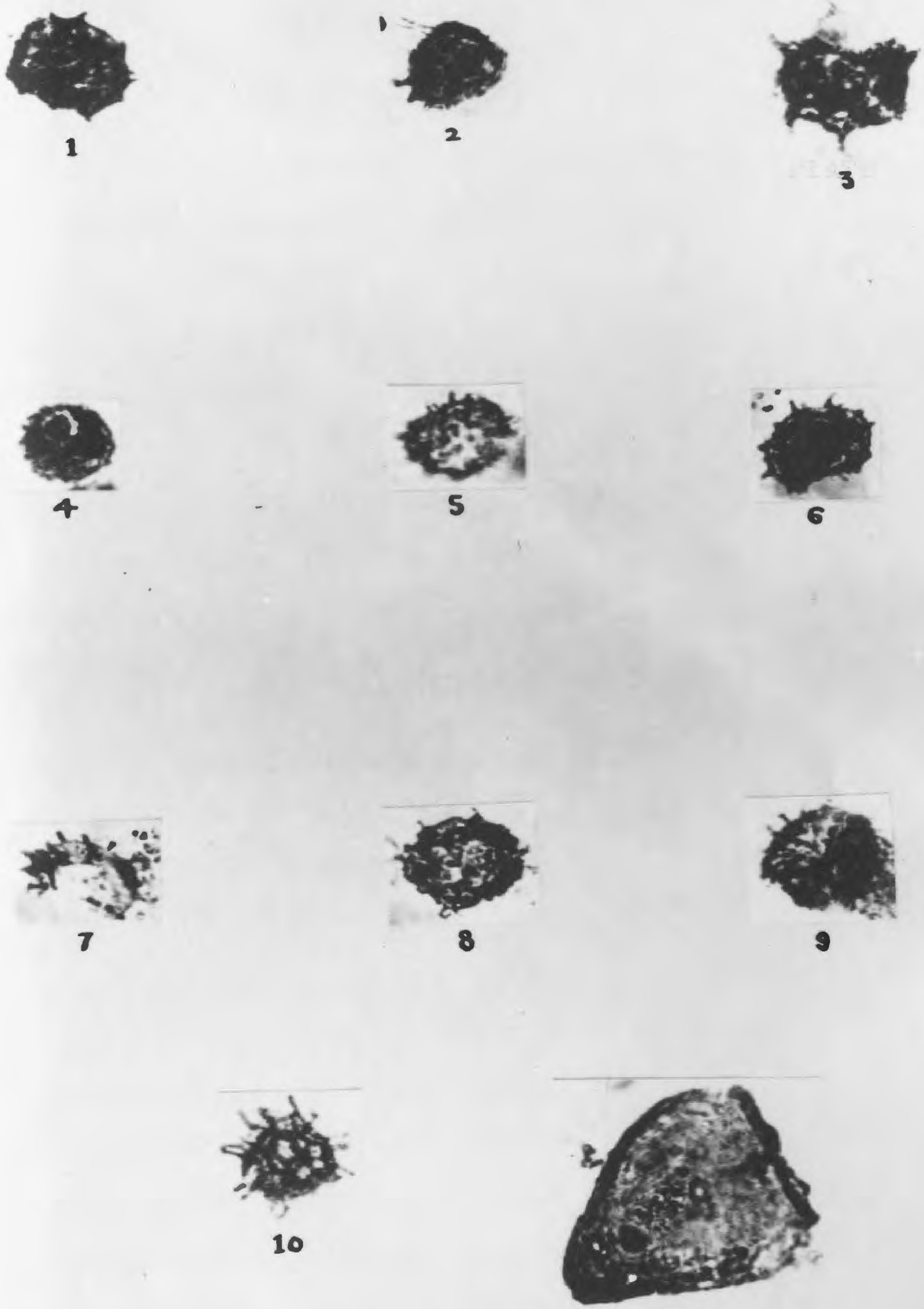
Figs. 1 - 9. Archaeohystrichosphaeridium
Fig. 10. ? cymatiosphaera sp. indet.
Fig. 11. Indeterminate.

PLATE 9



NAUTIYAL, Lower Ordovician hystrichospheres, Little Bell Island

PLATE 10



NAUTIYAL, Lower Ordovician hystrichospheres, Little Bell Island

Kellys Island

Hystrichospheres

Genus, Leiofusa Eisenack, 1938

Leiofusa jurassica Cookson and Eisenack ?

(see Plate 11, Fig. 1)

Description: The test of this species is fusiform, size of central body 40 x 20 μ, two spines of the specimen are broken and their narrow bases can be seen to gradually merge with the test.

This hystrichosphere is very rare in the Lower Ordovician samples examined and resembles the form described by Wall and Downie 1963 from the Permian of Britain but is slightly smaller in size. Sample No. 420, b.

Genus, Veryhachium Deunff 1954

Veryhachium sp.

(see Plate 11, Figs. 2, 4)

Description: The specimen (see Fig. 2) is poorly preserved and contains 7 broken processes. The test is rhomboidal with 3 apical processes visible but the fourth is broken completely. Three supplementary processes ornament the face. Their bases are slightly expanded and in length are less than the test size. Test size 38 μ, length of a process about 18 μ. Sample No. 420, A.

The specimen (see Fig. 3) is badly preserved and broken, test subglobular with a size of 36 μ, length of processes about 8 μ. Sample No. 420, R.

The specimen (see Fig. 4) has a more or less ellipsoidal test bearing 6 processes. Size of test 20 μ, and of one process 8 μ. Sample No. 421, D.

<u>Veryhachium</u> <u>rhomboidium</u> Downie

(see Plate 11, Fig. 5)

<u>Description</u>: Test rhomboidal, surface smooth, walls moderately thick, test size 30 microns, processes four arising from the corners of the test, simple, broken in the specimen.

This specimen resembles <u>V</u>. <u>rhomboidium</u> Downie 1959 but is slightly larger in test size. Sample No. 420, b.

<u>Veryhachium</u> ? <u>irregulare</u> Jekhowsky

(see Plate 11, Fig. 6)

<u>Description</u>: Test subglobular with extremely short, variable and conical spines. Size of test 28 μ, and spines range from 2 - 3 μ. This species resembles forma 1 of <u>V</u>.? <u>irregulare</u> Jekhowsky described by Wall and Downie 1963. Sample No. 421, D.

<u>Veryhachium</u> cf. <u>formosum</u> Stockmans and Willier 1960

(see Plate 11, Fig. 7)

Description: Test more or less tetrahedral and possesses 8 appendages (processes), 4 apical and 4 supplementary processes ornament the faces.

Their bases are expanded and in length are less than the test size. Test size 14 μ and of one process 10 μ. The specimen is partly broken. Sample No. 420, W.

Genus, Baltisphaeridium Eisenack 1958

Baltisphaeridium sp.

(see Plate 11, Figs. 9, 10)

Description: The specimen (see Fig. 9) is dark brown with a spherical test of 30 μ, fine granulate wall. Spines are sharply conical, solid and short (length 4) and about 50 in number. Sample No. 421, D.

The specimen (Fig. 10) is broken. Diameter of test 26 with 5 short spines, 6 μ long. Sample No. 420, R.

Baltisphaeridium longispinosum (Eisenack) ?

(see Plate 11, Fig. 11)

Description: The test and all 4 spines in the specimen are broken. Test spherical and brown with a size of 44 μ. Processes simple and smooth. Sample No. 421, D.

Baltisphaeridium brevispinosum (Eisenack)

(see Plate 11, Figs. 12, 13)

Description: Specimens resemble Fig. 3, Plate 9 of Little Bell Island. The test ranges in size from 24 - 26 μ and length of processes range from 6 - 8 μ and are less than 25 in number. Sample No. 420, A.

Baltisphaeridium brevispinosum var. nanum Deflandre

(see Plate 11, Figs. 14 - 23)

Description: This is a small variety of B. brevispinosum, and is one of the commonest and more variable forms found in Kellys Island shales. The test is more or less spherical to ellipsoidal, processes shorter than the radius and range in size from 1.2 - 4 μ, and are less than 20 in number. Tests range in size from 24 - 26 μ. Sample Nos. 420, R. (Fig. 15), K (Fig. 17, 20) b (Figs. 14, 16, 18, 19, 22, 23); 421, D (Fig. 21).

Baltisphaeridium brevispinosum var. wenlockensis Downie

(see Plate 12, Figs. 1 - 10)

Description: This variety also is one of the commonest and most variable in the Kellys Island shales. Specimens are more or less spherical to ellipsoidal in shape with a range of size from 24 to 30 μ. Processes are in length about one-fifth of the diameter of test and number about 20 in optical section. Their tips are sharply pointed to rounded. Sample Nos. 420, R. (Figs. 2, 3, 4, 6, 10), D (Fig. 9), b (Figs. 1, 5, 8), k (Fig. 7).

Baltisphaeridium triangulare Stockmans and Williere ?

(see Plate 12, Fig. 11)

Description: The specimen is triangular and rounded with convex borders, brownish yellow, test covered with small number of processes. Their extremities are fine but usually broken with narrow base but are widespread.

Diameter of test 26 μ and length of processes 12 μ. The specimen is partly broken. Sample No. 421, D.

<u>Baltisphaeridium</u> <u>microcladum</u> Downie

(see Plate 12, Fig. 12)

<u>Description</u>: This is a partly broken specimen, test slightly ellipsoidal, granular with a size of 28 μ, number of processes in broken specimen (optical section) about 10, their length about 30 percent of test diameter, processes narrow and slightly tapering, forking only at tips - bifurcate type, branches very short, thin and 1 to 2 μ long. Sample No. 420, b.

Genus, Micrhystridium Deflandre 1937

<u>Micrhystridium</u> sp.

(see Plate 12, Figs. 13 - 17)

<u>Description</u>: Test subpentagonal to subpolygonal with a range of size from 18 - 20 μ. In one specimen usually about 12 processes are present, length of a process 12 μ and their bases are enlarged. Sample Nos. 421, D (Figs. 13, 16); 420, b (Figs. 14, 15) R (Fig. 17).

<u>Micrhystridium</u> <u>stellatum</u> Deflandre

(see Plate 13, Figs. 1 - 9)

<u>Description</u>: Test more or less globose to polygonal, size 20 μ, usually one specimen bearing 8 to 12 spines, tapering, 12 - 16 μ long. Spines in the specimen (see Fig. 9) are equal to the test size,

tapering and can be compared with forma 1 (Plate 112) of Wall and Downie, 1963. Similarly Figure 48 can be compared with forma 4 (Plate 113). Sample Nos. 421, D (Figs. 1, 6, 7); 420, b (Figs. 2 to 5, 9), k (Fig. 8).

Genus, Cymatiosphaera O. Wetzel 1933 emend. Deflandre 1954

? Cymatiosphaera sp. indet.

(see Plate 13, Figs. 10-12)

Description: This is a broken and badly preserved specimen (Fig. 11) with brownish shades. Only two ridges (crests) of membranous substance, 10 - 11 microns high, are preserved. According to Deunff (1958), an absence of characteristic polygonal net on the surface of test, and the peripheral membranous formation similar to Membranilarnax, would put it rather close to the group described under the name of Membranilarnax (?) pirus.

The specimens seen in Figures 11 and 12 are badly preserved and broken specimens which appear to resemble each other but two polygonal areas are visible on the membranous surface of the former.

Figure 10 illustrates a partly broken specimen which resembles the specimen seen in Figure 10, Plate 10 of the Little Bell Island microflora. Body size about 30 μ and height of a spine about 8μ. Sample No. 420, b.

Genus, Archaeohystrichosphaeridium

(see Plate 11, Fig. 8)

The specimen resembles the form illustrated in Figure 8, Plate 8 of Little Bell Island. The test is thin walled with a size of 30 μ, processes are simple and broken. Sample No. 421, D.

EXPLANATION OF PLATE 11

Microplankton from the Lower Ordovician of Kellys Island.
All figures x 600.

Fig. 1. Leiofusa jurassica Cookson and Eisenack?
Figs. 2, 4. Veryhachium sp.
Fig. 5. Veryhachium rhomboidium Downie
Fig. 6. Veryhachium ? irregulare Jekhowsky
Fig. 7. Veryhachium cf. formosum Stockmans and Williere 1960
Fig. 8. Archaeohystrichosphaeridium.
Figs. 9, 10. Baltisphaeridium sp.
Fig. 11. Baltisphaeridium longispinosum (Eisenack)?
Figs. 12, 13. Baltisphaeridium brevispinosum (Eisenack)
Figs. 14 - 23. Baltisphaeridium brevispinosum var. nanum Deflandre.

EXPLANATION OF PLATE 12

All figures x 667

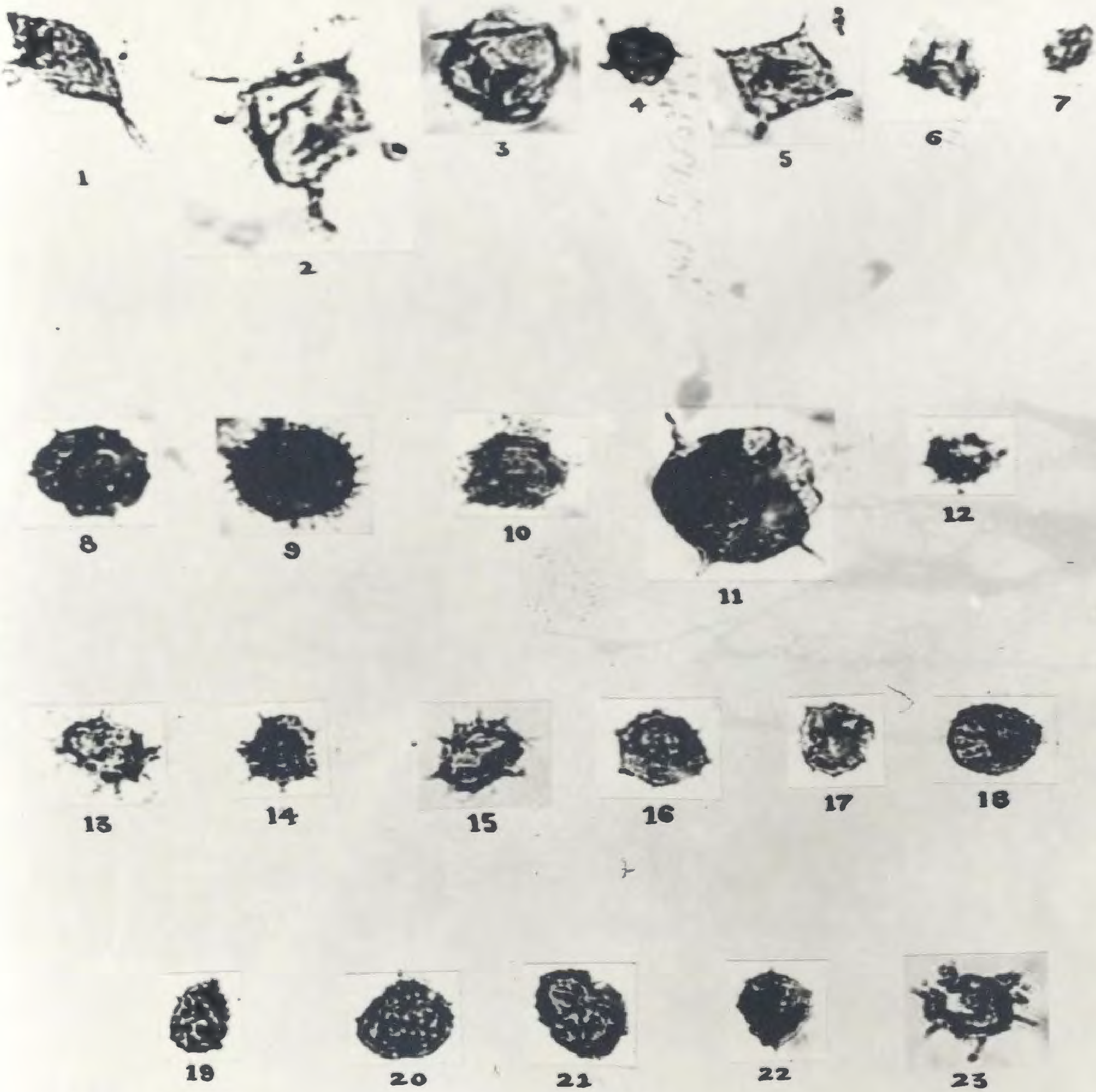
Figs. 1 - 10. Baltisphaeridium brevispinosum var. wenlockensis Downie.
Fig. 11. Baltisphaeridium triangulare Stockmans and Williere?
Fig. 12. Baltisphaeridium microcladum Downie
Figs. 13 - 17. Micrhystridium sp.

EXPLANATION OF PLATE 13

All figures x 540

Figs. 1 - 9. Micrhystridium stellatum Deflandre.
Figs. 10 - 12. ? cymatiosphaera sp. indet.

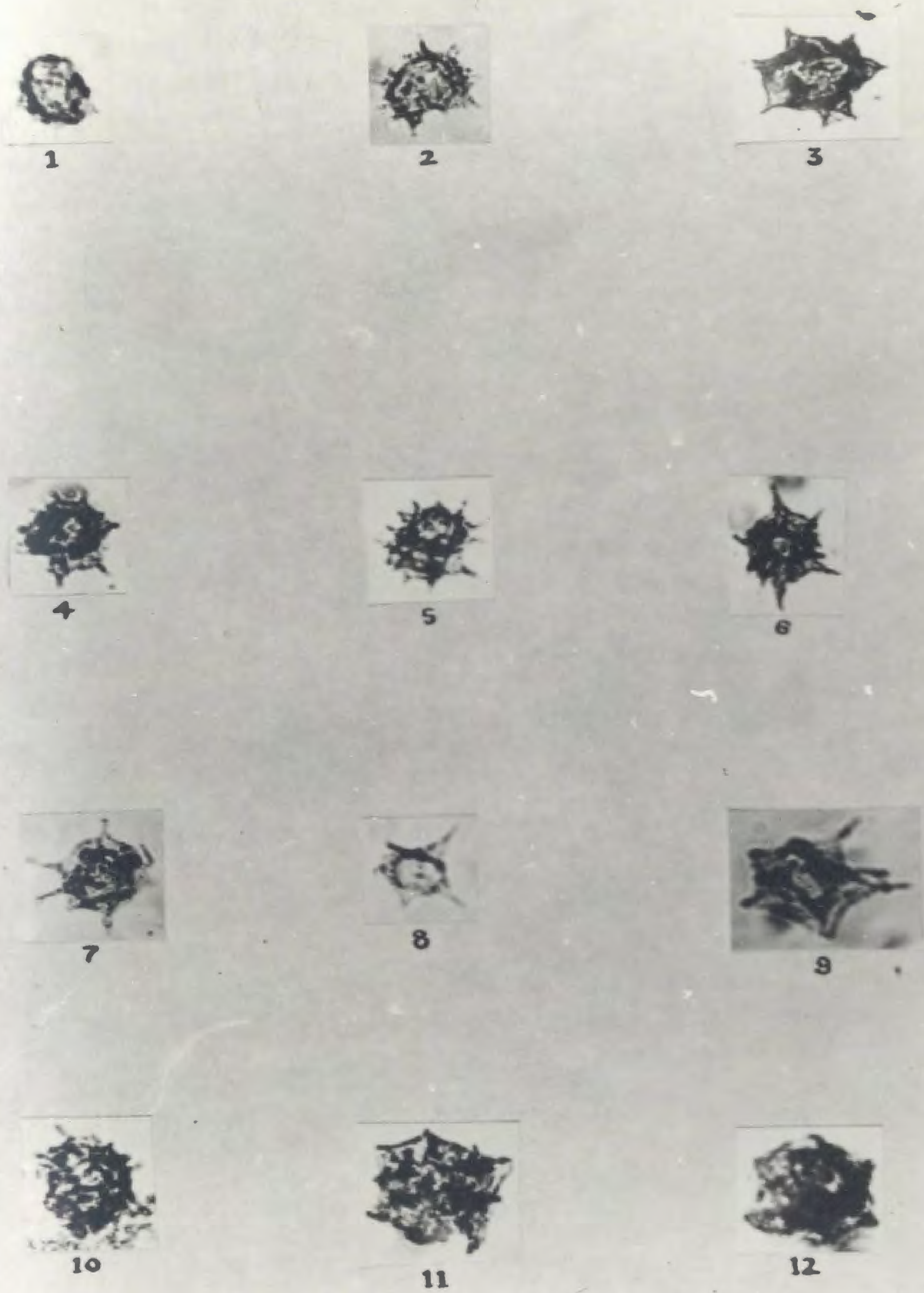
PLATE 11



NAUTIYAL, Lower Ordovician hystrichospheres, Kellys Island

PLATE 12

NAUTIYAL, Lower Ordovician hystrichospheres, Kellys Island



NAUTIYAL, Lower Ordovician hystrichospheres, Kellys Island

Table listing biostratigraphic zones of Bell Island formations.

	Biostratigraphic Zones	Hystrichospheres	Chitinozoa	Scolecodonts
Upper Member	362, Z	X	X	
Middle Member	Phosphatic nodules	X		
	354, A A	X	X	X
	460	X	X	
	347, D	X	X	
Lower Member	Py. Shales	X	X	
Airfield Formation	354, C	X	X	
	A	X	X	X
	345', O'	X		
	L'	X	X	
	G	X	X	X
	C	X	X	X
	395	X	X	
	345, D	X	X	X
	B	X	?	
	A	X	X	
	344, V	X	X	
	O	X	?	
	D	X	X	
	B	X	X	X
Town-square Formation	309	X		
	301, M	X	X	
	C	X	X	
Polls Head Formation	455	X		
	120	X	X	
	252	X	X	
	446	X	X	
	213	X		
	401	X		
	243	X		
	(Shale pebbles)			

Bell Island

Systematic paleontology

Order, HYSTRICHOSPHAERIDEA Eisenack, 1938

Genus, Baltisphaeridium Eisenack, 1958

Baltisphaeridium sp.

(see Plates 14 to 26)

The characters in general are more or less similar to the forms illustrated on page No.269 ; size of the tests range from 21 to 70 μ and spines measure about 10 μ.

Occurrence: Wabana Formation and Bell Island Group.

Baltisphaeridium brevispinosum (Eisenack)

(see Plates 15, 18)

For description, see page No.261 . Size of tests about 22 μ, spines measure about 12 μ.

Occurrence: Airfield Formation and Townsquare Formation.

Baltisphaeridium brevispinosum var. *nanum* Deflandre

(see Plate 15)

For description, see page No.270

Occurrence: Townsquare Formation.

B. brevispinosum var. *wenlockensis* Downie

(see Plate 15)

For description, see page No.270

Occurrence: Townsquare Formation.

B. longispinosum (Eisenack)

(see Plates 14, 15, 18, 19, 20, 21, 22)

This species has more or less a spherical test with processes longer than the radius and usually less than twenty-five in number. Size of the tests range from 25 - 30 μ. Spines are broken in most of the collected specimens from Lower Ordovician of Bell Island. According to Eisenack (1939), this species is characteristic of the Ordovician. This species is one of the most common in Lower Ordovician shales and silty shales of Bell Island.

Occurrence: Upper and Middle Members, Airfield Formation, Townsquare Formation, and Polls Head Formation.

Baltisphaeridium trifurcatum (Eisenack)

(see Plate 25, Fig. 16)

This species may be compared to that discussed and illustrated in Figure 3, Plate IV of '*The Microfossils of the Upper Carodocian*

Phosphate Deposits of Montgomeryshire, North Wales', by Professor H.P. Lewis, 1940.

Processes are broken in Figure 16 except one which shows trifurcation. The processes have expanded bases. Test measures about 25 μ in diameter and one process is about 7 μ in length. This specimen was found in phosphatic nodules of hematitic oolite bed of the Middle Member. It is interesting to note that Professor Lewis has described similar specimens from the Upper Carodocian phosphate-band at Pen-y-garnedd, Montgomeryshire, North Wales.

Genus, Micrhystridium Deflandre, 1936

Micrhystridium sp.

(see Plates 17, 18, 21)

For description, see page No. 271

Occurrence: Airfield Formation.

Micrhystridium stellatum Deflandre

(see Plates 14 to 26)

For characters, see page No. 271. This is one of the most common species discovered in the shale, silty shale and phosphatic nodules of Bell Island.

Occurrence: Wabana Formation and Bell Island Group.

Genus, Multiplicisphaeridium (Staplin)

Multiplicisphaeridium sp.

(see Plates 15, 16, 18, 19, 21, 22, 23, 24, 26)

Subspherical and spherical shapes of vesicles of this species are very common in Bell Island rocks. Processes are separate, proximally slender but distally they are expanded or modified, with closed tips. One vesicle usually contains only one kind of process. Wall of the vesicle is smooth; and there is no differentiation between wall of the vesicle and processes. Spines open in vesicle interior at their connections. Size of vesicle ranges from 18 to 20 μ and sometimes more, spines are about 3 μ in length.

Occurrence: Upper, Middle and Lower Members, common in Airfield Formation, Townsquare Formation.

Genus, Veryhachium Deunff

Veryhachium sp.

(see Plates 14 to 26)

For characters, see page No. 267. This is also a very common species in Lower Ordovician rocks of Bell Island.

Occurrence: Wabana Formation and Bell Island Group.

V. rhomboidium Downie

(see Plates 14 to 26)

Characters are more or less similar to page No. 268. This is one of the most common species in Bell Island rocks.

Occurrence: Wabana Formation and Bell Island Group.

Veryhachium ? irregulara Jekhowsky

(see Plate 18, Fig. 12)

The test of this species is subgbbular, possessing about 6 - 7 extremely short spines which are conical. Size of the test 24 μ and spines measure from 2 - 3 μ.

Occurrence: Airfield Formation.

Veryhachium trispinosum (Eisenack)

(see Plates 14, 15, 18, 19, 20, 22 to 26)

This is a variable species. Shape triangular, sides of the vesicle more or less straight. Measurement of a specimen: size from one side of tip of appendage (process) to tip of opposing appendage is about 25 μ. Size of another specimen: the tests range from 18 - 19 μ, spines are about 18 μ in length. No internal structures present.

Occurrence: Upper and Middle Members, Bell Island Group.

Veryhachium trisulcum Deunff

(see Plates 14,23,25,26)

This species differs from V. trispinosum (Eisenack) in having a well marked inflated test. Size of the test of a specimen 12 μ and spines are about 12 μ in length.

Occurrence: Upper Member, Airfield Formation and Polls Head Formation.

Veryhachium (Hystrichosphaeridium) lairdi (Defl.) Dff.

(see Plate 16, Fig. 4)

This species may be compared with the form illustrated in Plate VIII, Fig. 76 of 'Microorganismes Plactoniques du Primaire armoricain' I.-Ordovicien du Veryhach (Presqúile du Crozon)' by Jean Deunff, 1959, size of test 25 μ and overall size about 45 μ.

Occurrence: Airfield Formation.

? Veryhachium macroceros Deunff

(see Plate 14, Fig. 3)

The processes of this species are broken (see Fig. 3). This form may be compared with Deunff's (1959) form illustrated in Plate III, Fig. 37. Form illustrated in this report is smaller than Dr. Deunff's species. Size of the test measures (longer diameter) 40 μ.

Occurrence: Polls Head Formation.

Genus, Hystrichosphaeridium Defl.

Hystrichosphaeridium lucidum (Deunff) ?

(see Plate 16, Fig. 13)

This species may be compared with form illustrated in Plate IX, Fig. 82, by Dr. Deunff (1959). Species illustrated in Plate 16, Fig. 13 of this thesis exhibits broken processes.

Occurrence: Airfield Formation.

Family, LEIOFUSIDAE Eisenack, 1938

Genus, Leiofusa Eisenack, 1938

<u>Leiofusa</u> sp.

(see Plates 14, 23, 25)

Test of this species is fusiform, hollow with smooth membrane. Both size of test (long diameter) and length of spine range from 10 - 20 μ in the collected specimens.

Occurrence: Middle Member, Airfield Formation, and Polls Head Formation.

<u>Leiofusa jurassica</u> Cookson and Eisenack

(see Plates 17, 25)

See page No. 267 for characters. Overall size 62 μ, Fig. 3 of Plate 17, central body measures 33 x 20 μ.

Occurrence: Airfield Formation.

<u>Leiofusa filifera</u> Downie

(see Plate 23, Fig. 40)

The ends of this species are drawn outwards and thus constitute long hollow threads. Fig. 40 exhibits broken threads. Body width is approximately one-quarter of its length. Size of the test (long diameter) is 70 μ. This is a very rare species in the Airfield Formation and only one specimen was discovered.

Genus, Poikilofusa Staplin, Jansonius and Pocock

<u>Poikilofusa</u> sp.

(see Plate 17, Figs. 4, 5, 6, 7)

This is a rare species in Bell Island rocks. Only four specimens were discovered from the Airfield Formation. Vesicle of this species is fusiform which is provided with two small spines, wall is thin. The discovered specimens are broken. Size of the test (long diameter) range from 30 to 60 μ.

Genus, Deunffia Downie

<u>Deunffia monospinosa</u> Downie

(see Plate 23, Fig. 1)

This is a very rare species in the Bell Island rocks. The specimen shown in the Figure 1 contains a hollow ellipsoidal body of pale yellow colour. Long dimension of the body is 16 μ. The single hollow spine equals length of the test, hence its specific determination is doubtful.

Occurrence: Airfield Formation.

<u>Fungal spore</u>

(see Plate 15, Fig. 42)

This specimen is a fungal spore having a septa in the center of the body. Size (long diameter) of the body 26 μ.

Some species of hystrichospheres similar to Baltisphaeridium longispinosum (Eisenack), Baltisphaeridium trifurcatum (Eisenack), Veryhachium trispinosum (Eisenack) from Ordovician "Herscheider Schiefer" of the Rhenish "Schiefergebirges" originally described in a paper by Eisenack, and from Upper Carodocian Phosphate Deposits of Montgomeryshire, North Wales, described by Professor H.P. Lewis are similar to forms which the present writer recovered from the Lower Ordovician of Bell Island. Similarly several specimens from Bell Island may be compared with some species from the Baltic Ordovician described by Eisenack.

The shales and silty shales in Bell Island which are rich in phosphatic contents yielded large numbers of hystrichospheres in contrast to those shaly rocks which are deficient in phosphatic contents. It is interesting to note that Professor H.P. Lewis, in 1940, had collected several specimens of hystrichospheres, a few chitinozoa along with other microfossil groups from the Upper Carodocian phosphate-band at Pen-y-garnedd, Montgomeryshire, North Wales, United Kingdom. Dr. Jean Deunff discovered microfossils (Hystrichospheres and Chitinozoa) in the vicinity of Veryhach, France. His microfossils exhibit an affinity with Bell Island microfossils at both the generic and specific taxonomic level.

Indeterminate species illustrated in some of the Tables of this thesis may be either new species or, if not, one would require literature, which is not presently available to me, for their identification.

Figures in Plates Nos. 32 and 33 are 'Problematica' microfossils.

EXPLANATION OF PLATE 14

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Bells Head Formation.
All figures x 540.

Figs. 1, 2. Leiofusa sp.
Figs. 3, 7. ?Veryhachium macroceros Deunff.
Fig. 4. V. trisulcum Deunff.
Figs. 5 - 7. V. rhomboidium Downie.
Fig. 8. Veryhachium sp.
Figs. 9 - 12. Multiplicisphaeridium sp.
Figs. 13 - 16, 19 - 23, 25, 26, 29 - 32. Micrhystridium stellatum Defl.
Figs. 17, 18, 27, 28. Baltisphaeridium sp.
Fig. 24. Baltisphaeridium brevispinosum (Eisenack).
Fig. 33. Baltisphaeridium longispinosum (Eisenack).

EXPLANATION OF PLATE 15

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Townsquare Formation.
All figures x 600.

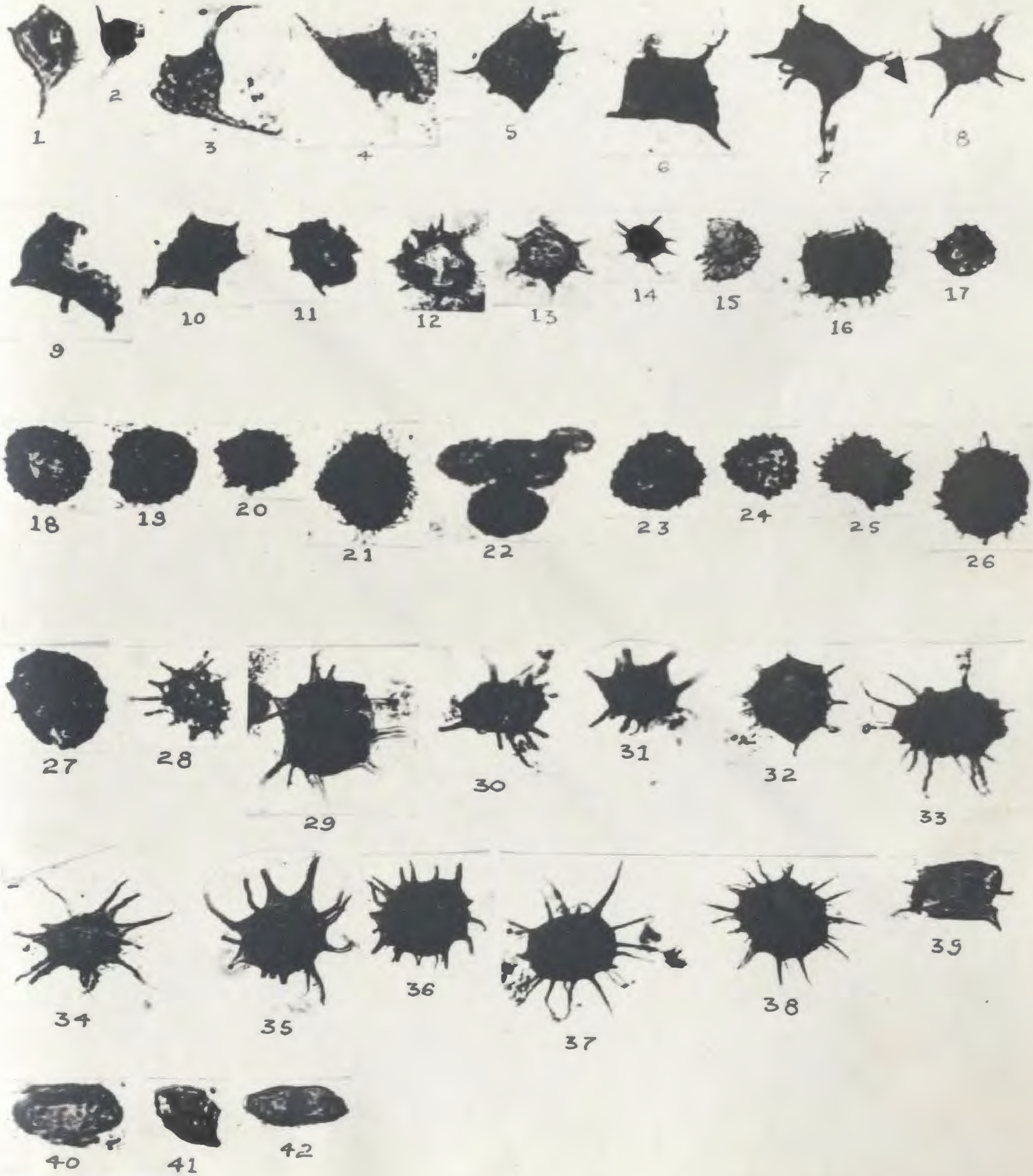
Figs. 1, 3, 9 - 12, 39. Veryhachium sp.
Fig. 2. Veryhachium trispinosum (Eisenack).
Figs. 4 - 8. Veryhachium rhomboidium Downie.
Figs. 13, 14, 31, 32. Micrhystridium stellatum Deflandre.
Fig. 15. Baltisphaeridium brevispinosum var. nanum Defl.
Fig. 17. Micrhystridium sp.
Figs. 16, 18 - 25, 27, 29, 30. Baltisphaeridium sp.
Fig. 26. Baltisphaeridium brevispinosum var. wenlockensis. Downie.
Fig. 28. Baltisphaeridium brevispinosum (Eisenack).
Figs. 33 - 38. Baltisphaeridium longispinosum (Eisenack).
Figs. 40, 41. Indeterminate spp.
Fig. 42. Fungal spore (separate type).

EXPLANATION OF PLATE 16

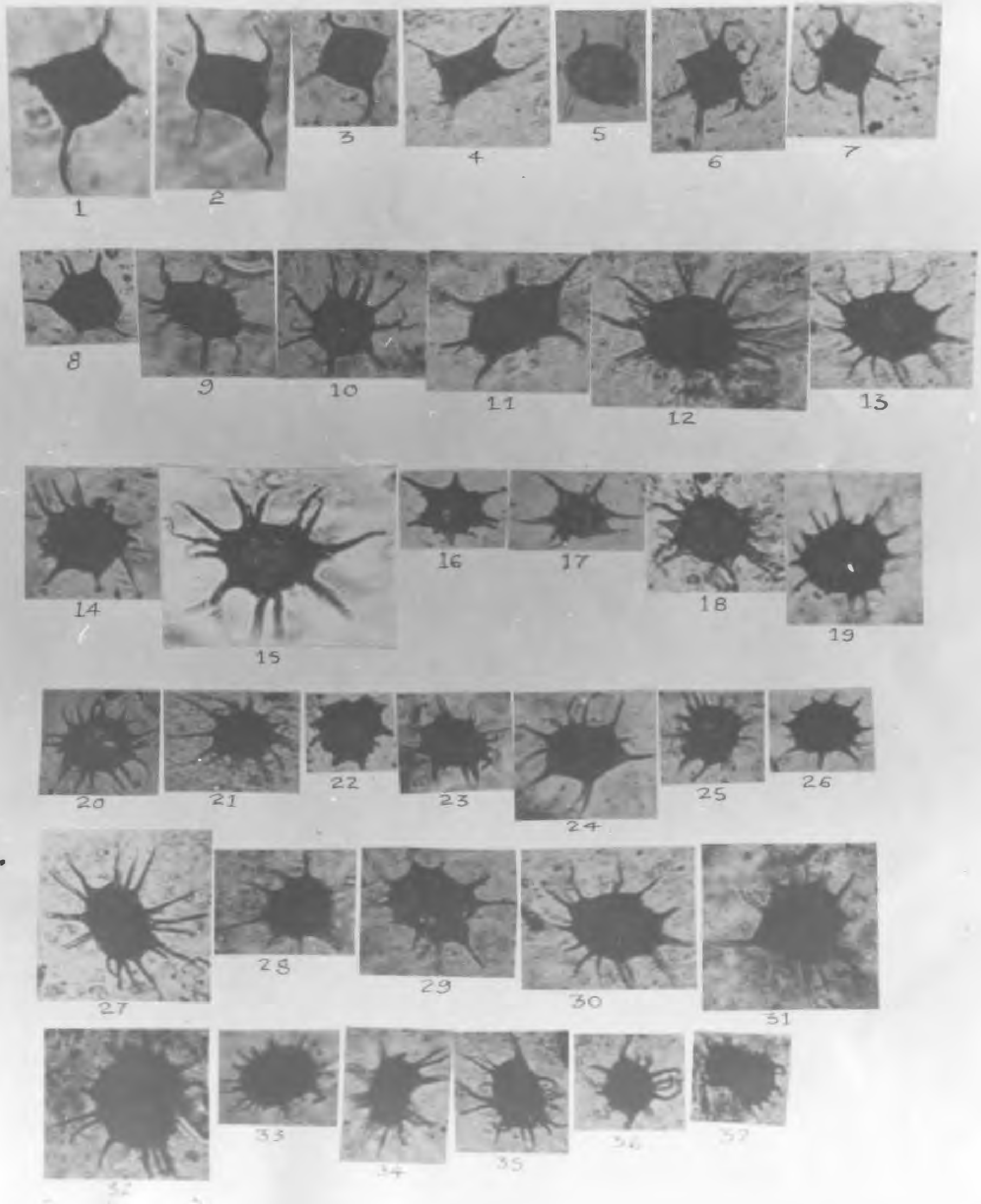
Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: At immediately south of Ruins (Sample No. 344,0, silty shale), Airfield Formation.
All figures x 540.

Figs. 1 - 3. Veryhachium rhomboidium Downie.
Fig. 4. V. (Hystrichosphaeridium) lairdi (Defl.) Dff.
Fig. 5. Veryhachium sp.
Figs. 6 - 11. Micrhystridium stellatum Deflandre.
Figs. 12, 27, 32. Baltisphaeridium longispinosum (Eisenack)
Fig. 13. Hystrichosphaeridium lucidum.
Figs. 14 - 26, 28 - 31, 33 - 37. Micrhystridium stellatum Deflandre.

NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island.



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island

EXPLANATION OF PLATE 17

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Airfield Formation (Locality 344,D).
All figures x 510.

Fig. 1. Indeterminate sp.
Figs. 2, 3. *Leiofusa jurassica* Cookson and Eisenack?
Figs. 4 - 7. *Poikilofusa* sp.
Figs. 8 - 10. *Veryhachium rhomboidium* Downie
Fig. 11. *Veryhachium* sp.
Figs. 12, 17, 32, 33. *Baltisphaeridium* sp.
Figs. 13, 15, 16, 28 - 31. *Indeterminate* spp.
Figs. 14, 22. *Micrhystridium* sp.
Figs. 18, 19. *Baltisphaeridium brevispinosum* (Eisenack).
Figs. 20, 21. *Micrhystridium stellatum* Deflandre.
Figs. 23 - 26. *Multisplicisphaeridium* sp.
Fig. 27. *Veryhachium* sp.

EXPLANATION OF PLATE 18

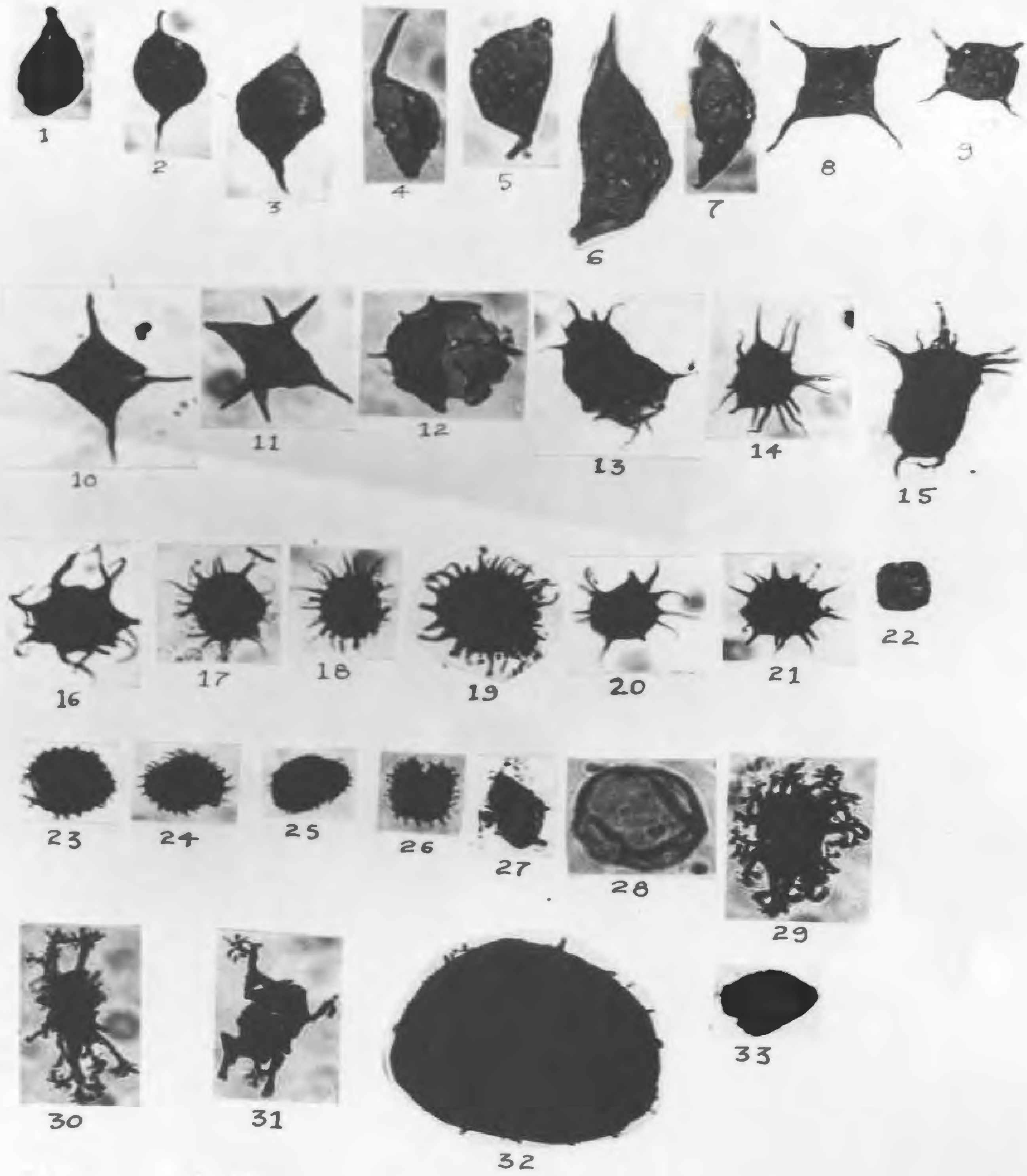
Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Airfield Formation.
All figures x 570.

Figs. 1, 2. *Veryhachium trispinosum* (Eisenack).
Figs. 3, 4, 5, 8. *V. rhomboidium* Downie.
Figs. 6, 7. *V.? irregulare*.
Figs. 9, 11, 12, 14, 16, 31. *Veryhachium* sp.
Figs. 10, 21, 25, 28, 29, 30. *Baltisphaeridium brevispinosum* (Eisenack).
Figs. 13, 19. *Micrhystridium* sp. ?
Figs. 15, 17, 27, 32. *Baltisphaeridium* sp.
Figs. 18, 33. *Micrhystridium stellatum* Deflandre.
Figs. 20, 22, 23, 24, 26. *Multiplicisphaeridium* sp.
Figs. 34 - 36. *Baltisphaeridium longispinosum* (Eisenack).
Figs. 37, 38. Indeterminate spp.

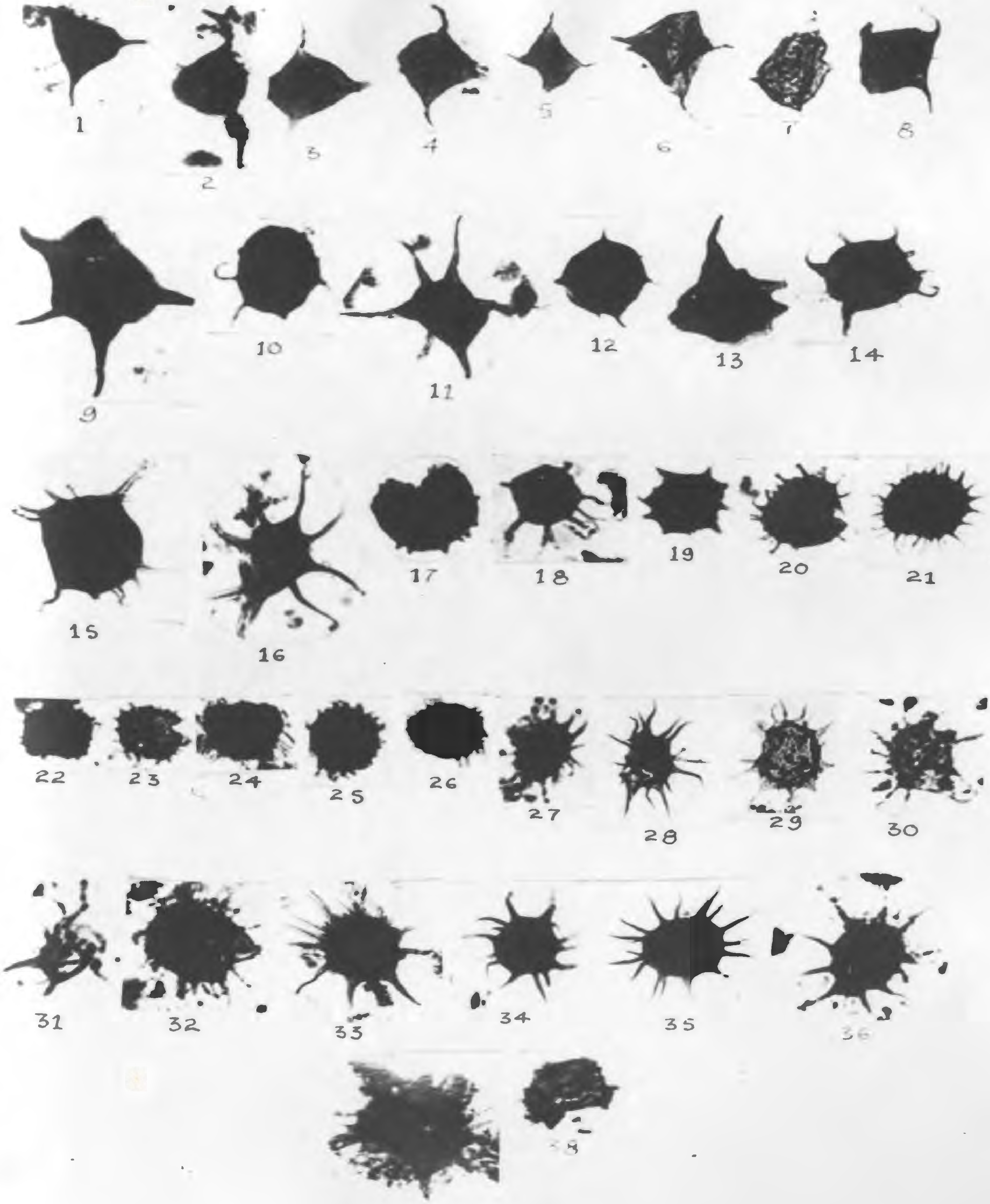
EXPLANATION OF PLATE 19

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Airfield Formation.
All figures x 570.

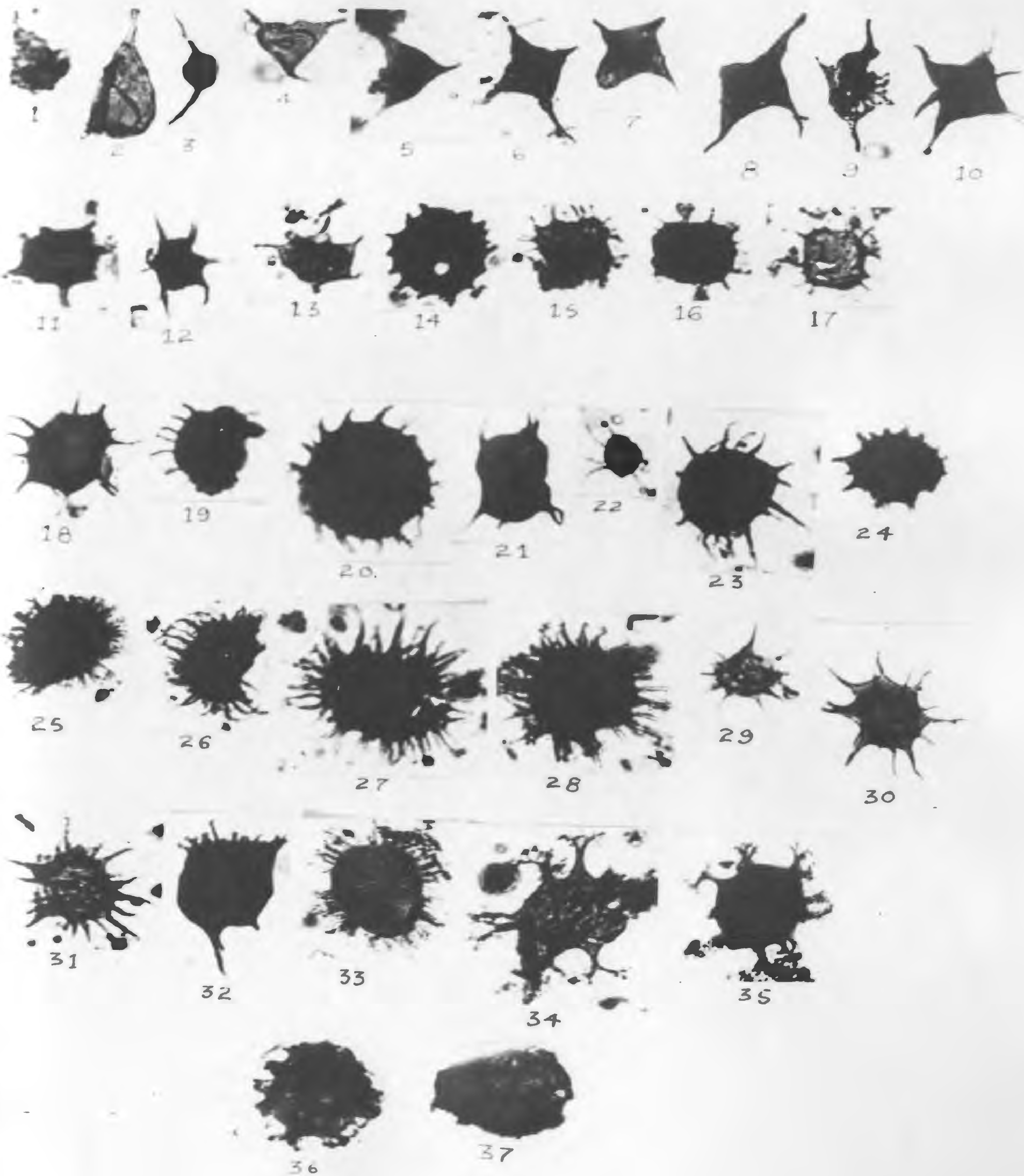
Figs. 1, 2, 21, 32,- 37. Indeterminate spp.
Fig. 3. *Veryhachium* sp.
Figs. 4, 5, *V. trispinosum* (Eisenack)?
Figs. 6 - 10. *V. rhomboidium* Downie.
Figs. 11 - 13, 22, 29 - 31. *Micrhystridium stellatum* Deflandre.
Figs. 14, 23. *Baltisphaeridium longispinosum* (Eisenack)?
Figs. 15, 17. *Multiplicisphaeridium* sp.
Figs. 16, 18 - 20, 24, 25. *Baltisphaeridium* sp.
Figs. 26 - 28. *Baltisphaeridium brevispinosum* (Eisenack).



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island

EXPLANATION OF PLATE 20

Lower Ordovician hystrichospheres, Bell Island.
Occurrence: Airfield Formation.
All figures x 540.

Figs. 1, 34 - 36. Indeterminate spp.
Figs. 2, 3. _Veryhachium trispinosum_ (Eisenack).
Figs. 4 - 8. _V. rhomboidium_ Downie.
Figs. 9 - 14. _Veryhachium_ sp.
Figs. 15 - 17, 31, 32, 37, 38. _Baltisphaeridium longispinosum_ (Eisenack).
Figs. 18 - 20. _Multiplicisphaeridium_ sp.
Figs. 21, 23, 24, 26 - 30, 33. _Baltisphaeridium_ sp.
Figs. 22, 25. _Micrhystridium_ sp.

EXPLANATION OF PLATE 21

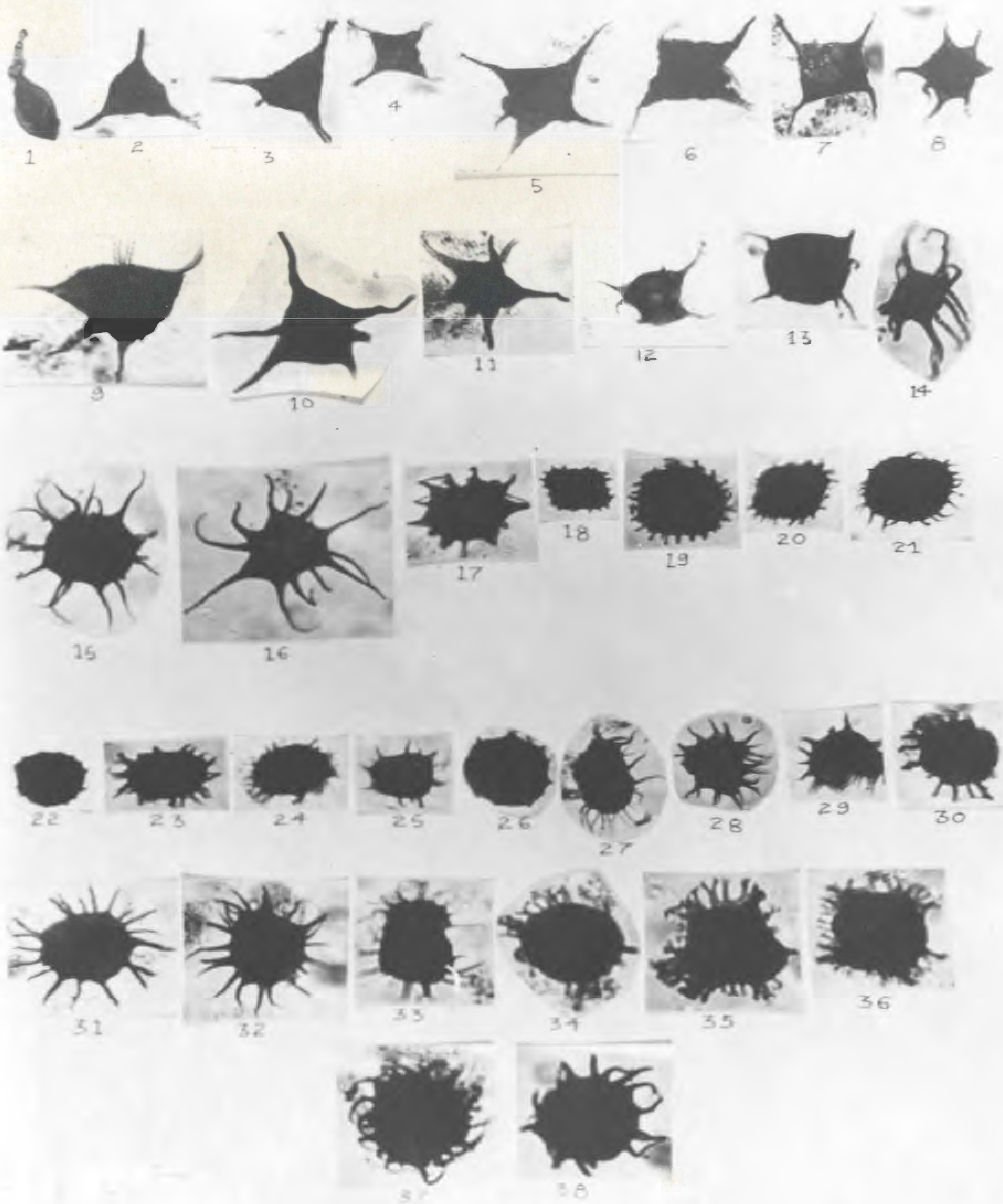
Lower Ordovician hystrichospheres, Bell Island.
Occurrence: Airfield Formation.
All figures x 540.

Figs. 1 - 5. _Veryhachium rhomboidium_ Downie.
Figs. 6 - 8. _Veryhachium_ sp.
Fig. 9. _Veryhachium_ sp.?
Figs. 10, 26 - 28. _Micrhystridium stellatum_ Deflandre.
Figs. 11, 12, 16, 18, 20 - 23. _Baltisphaeridium_ sp.
Figs. 13 - 15. _Multiplicisphaeridium_ sp.
Fig. 17. _Micrhystridium_ sp.
Figs. 19, 31 - 36. Indeterminate spp.
Figs. 24, 25, 29, 30. _Baltisphaeridium longispinosum_ (Eisenack)

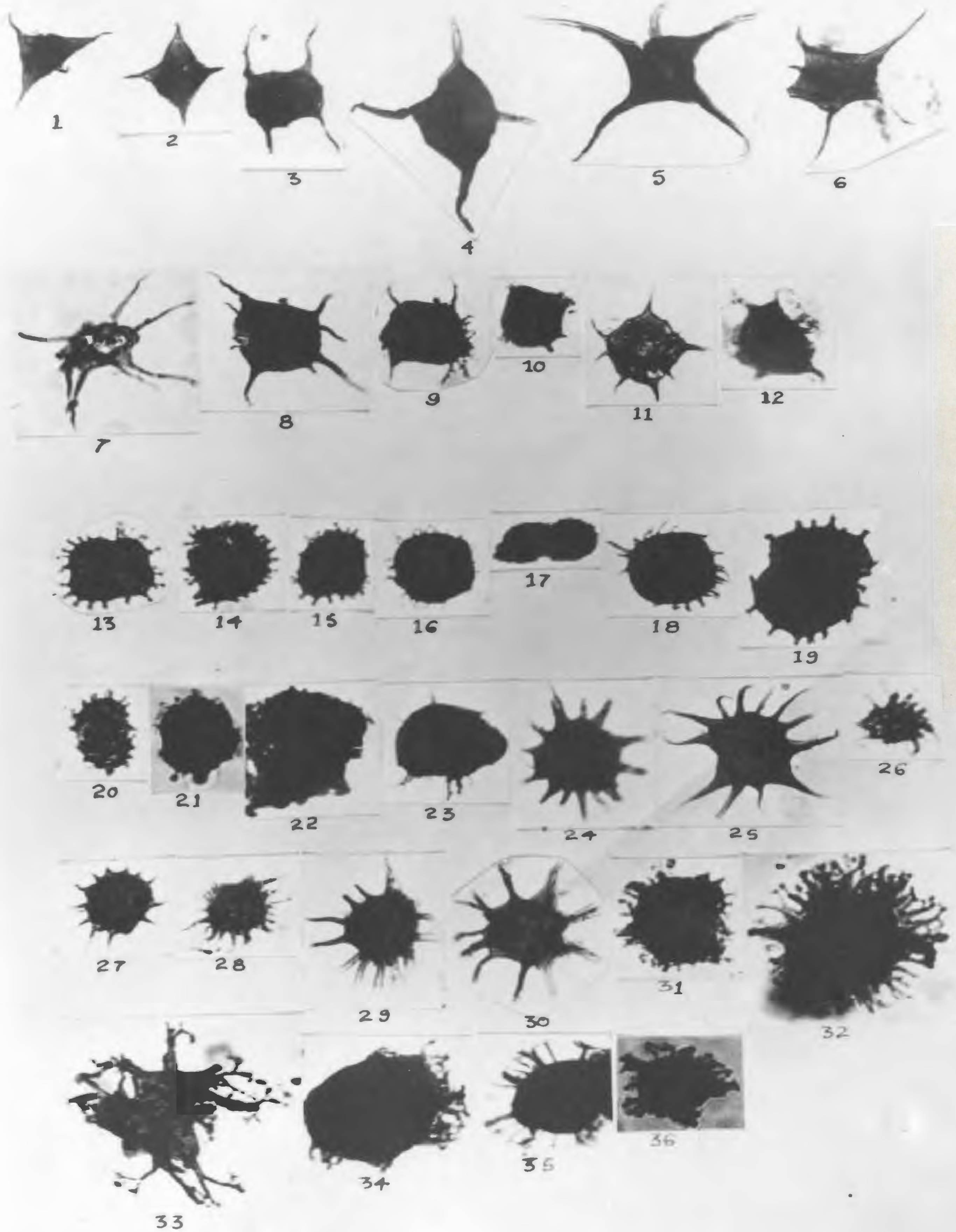
EXPLANATION OF PLATE 22

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Airfield Formation.
All figures x 540.

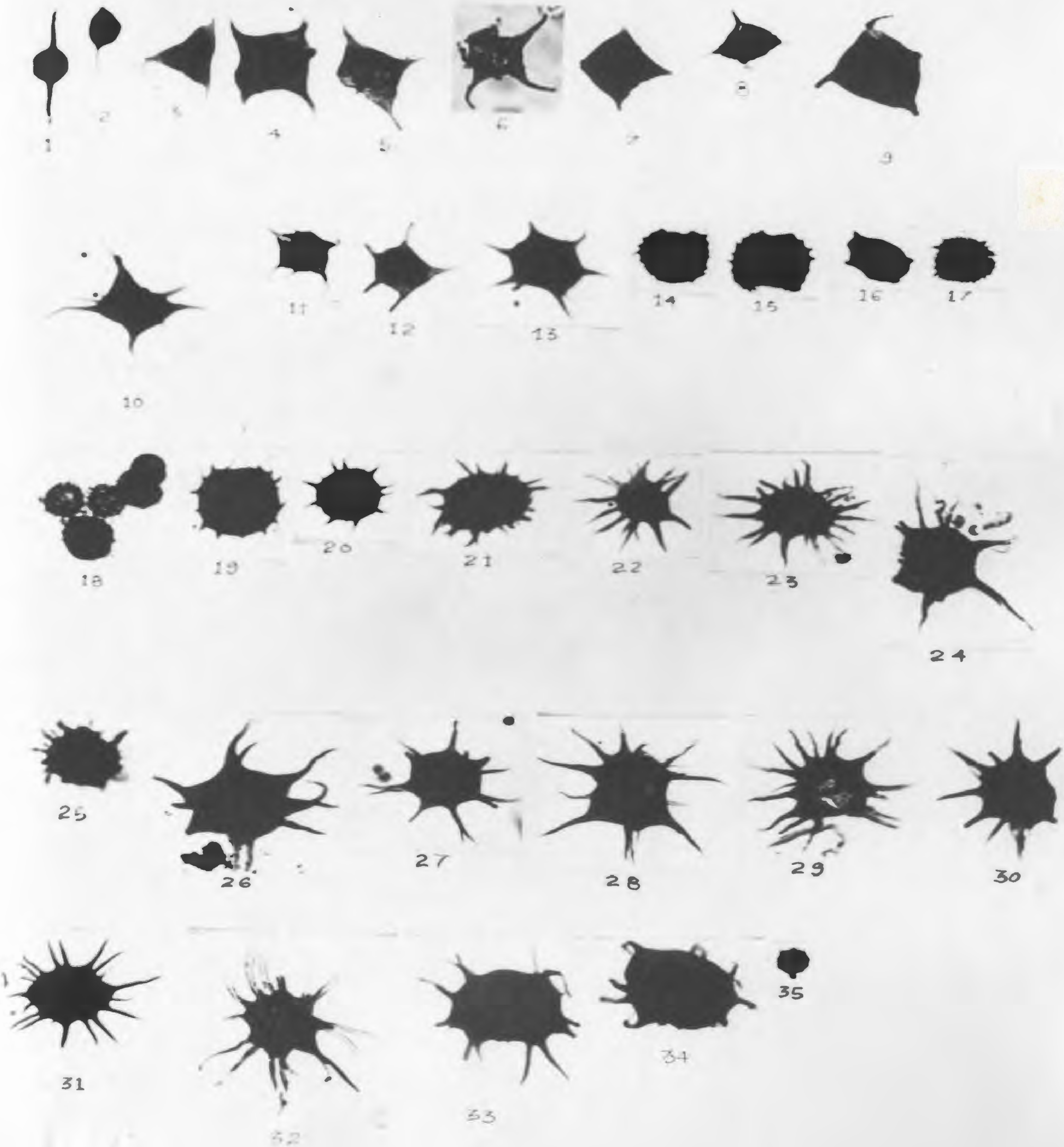
Figs. 1, 2. _Leiofusa_ sp.
Fig. 3. _Veryhachium trispinosum_ (Eisenack).
Figs. 4 - 11. _V. rhomboidium_ Downie.
Figs. 12, 13, 16. _Veryhachium_ sp.
Figs. 14, 15, 17. _Multiplicisphaeridium_ sp.?
Figs. 18, 20, 22, 23, 25, 35. _Micrhystridium stellatum_ Deflandre.
Figs. 19, 21. _Baltisphaeridium_ sp.
Figs. 24, 26 - 34. _B. longispinosum_ (Eisenack).



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island

EXPLANATION OF PLATE 23

Lower Ordovician hystrichospheres, Bell Island.
Occurrence: Middle Member, Airfield Formation.
All figures x 540.

Fig. 1. *Deunffia monospinosa* Downie?
Figs. 2, 3. *Leiofusa* sp.
Fig. 4. *Veryhachium trisulcum* Deunff.
Figs. 5, 6, 7. *V. trispinosum* (Eisenack).
Figs. 8 - 12. *V. rhomboidium* Downie.
Figs. 13 - 17. *Veryhachium* sp.
Figs. 18 - 20, 31. *Baltisphaeridium* sp.
Figs. 21, 24 - 27, 29, 32 - 39. *Micrhystridium stellatum* Defl.
Figs. 22, 23, 28, 30. *Multiplicisphaeridium* sp.
Fig. 40. *Leiofusa filitera* Downie.

EXPLANATION OF PLATE 24

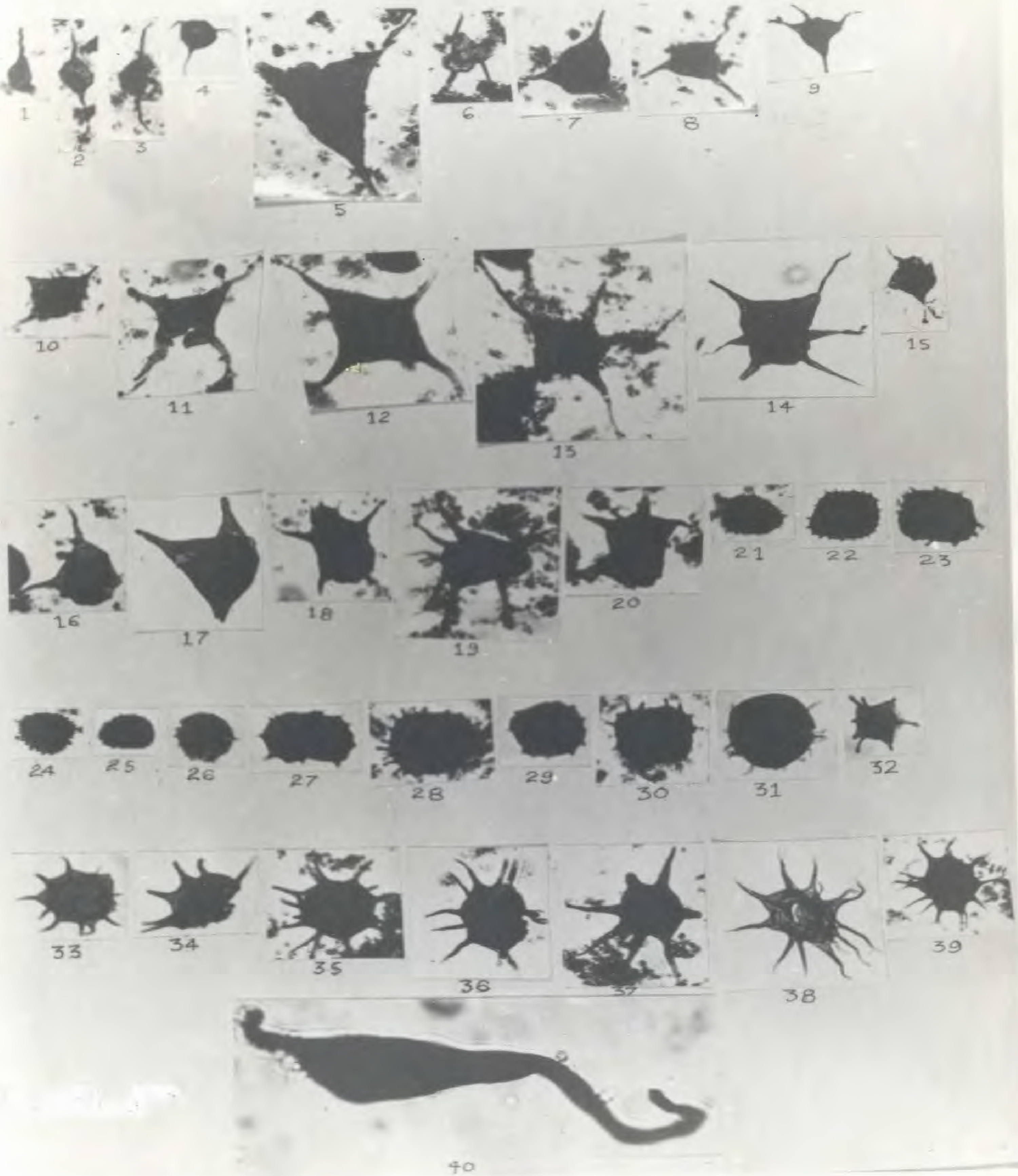
Lower Ordovician hystrichospheres, Bell Island.
Occurrence: Middle Member.
All figures x 660.

Figs. 1, 2, 33, 37 - 40. Indeterminate spp.
Fig. 3. *Veryhachium trisulcum* Deunff.
Figs. 4, 6 - 11. *Veryhachium rhomboidium* Downie.
Fig. 5, 12 - 14. *Veryhachium* sp.
Figs. 15, 23 - 26, 28 - 32. *Micrhystridium stellatum* Defl.
Figs. 16 - 22. *Multiplicisphaeridium* sp.
Fig. 27. *Baltisphaeridium* sp.
Figs. 34 - 36. *B. longispinosum* (Eisenack)

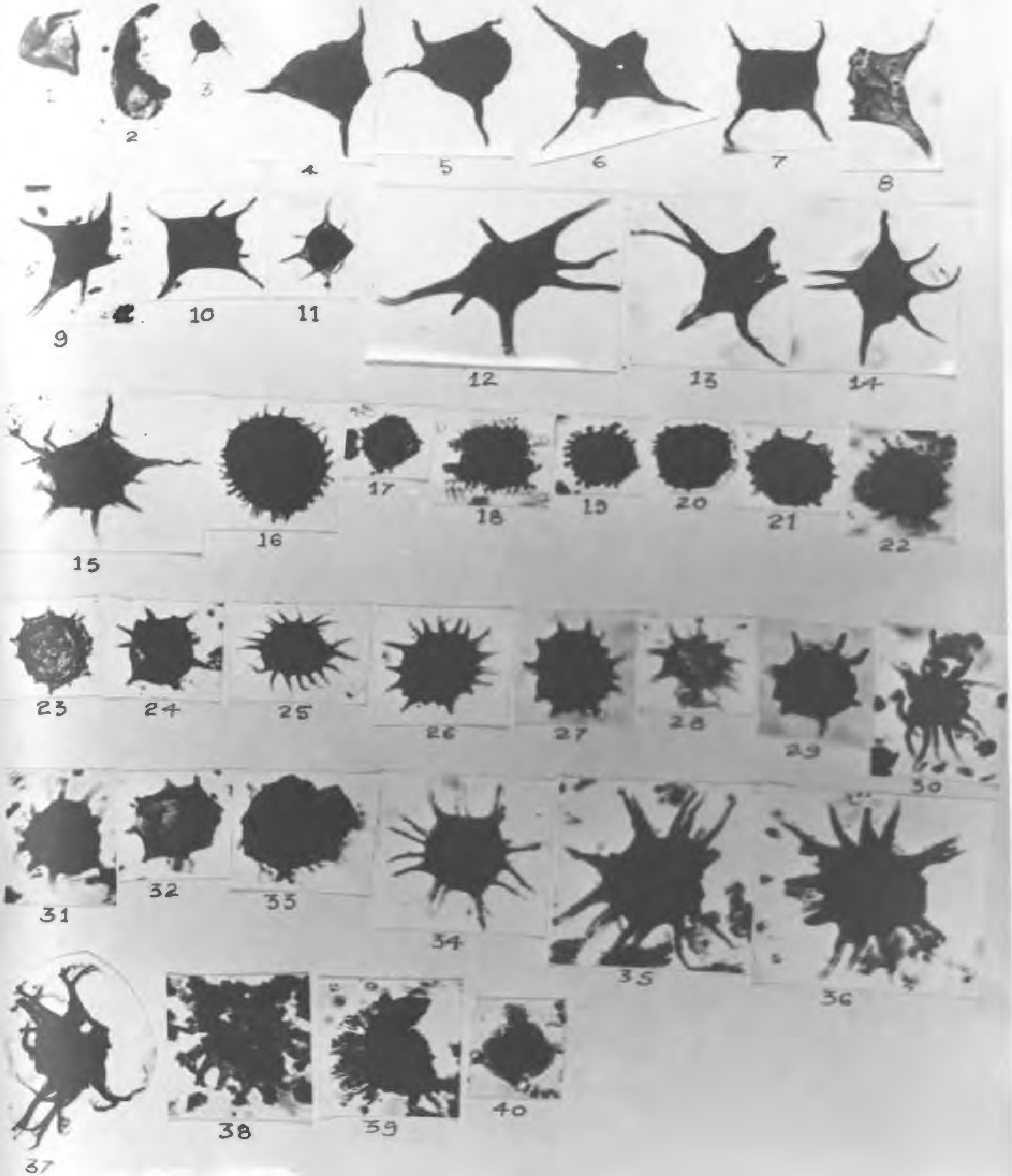
EXPLANATION OF PLATE 25

Hystrichospheres from the Lower Ordovician rocks of Bell Island.
Occurrence: Phosphatic nodules of hematitic oolites, Middle Member.
All figures x 645.

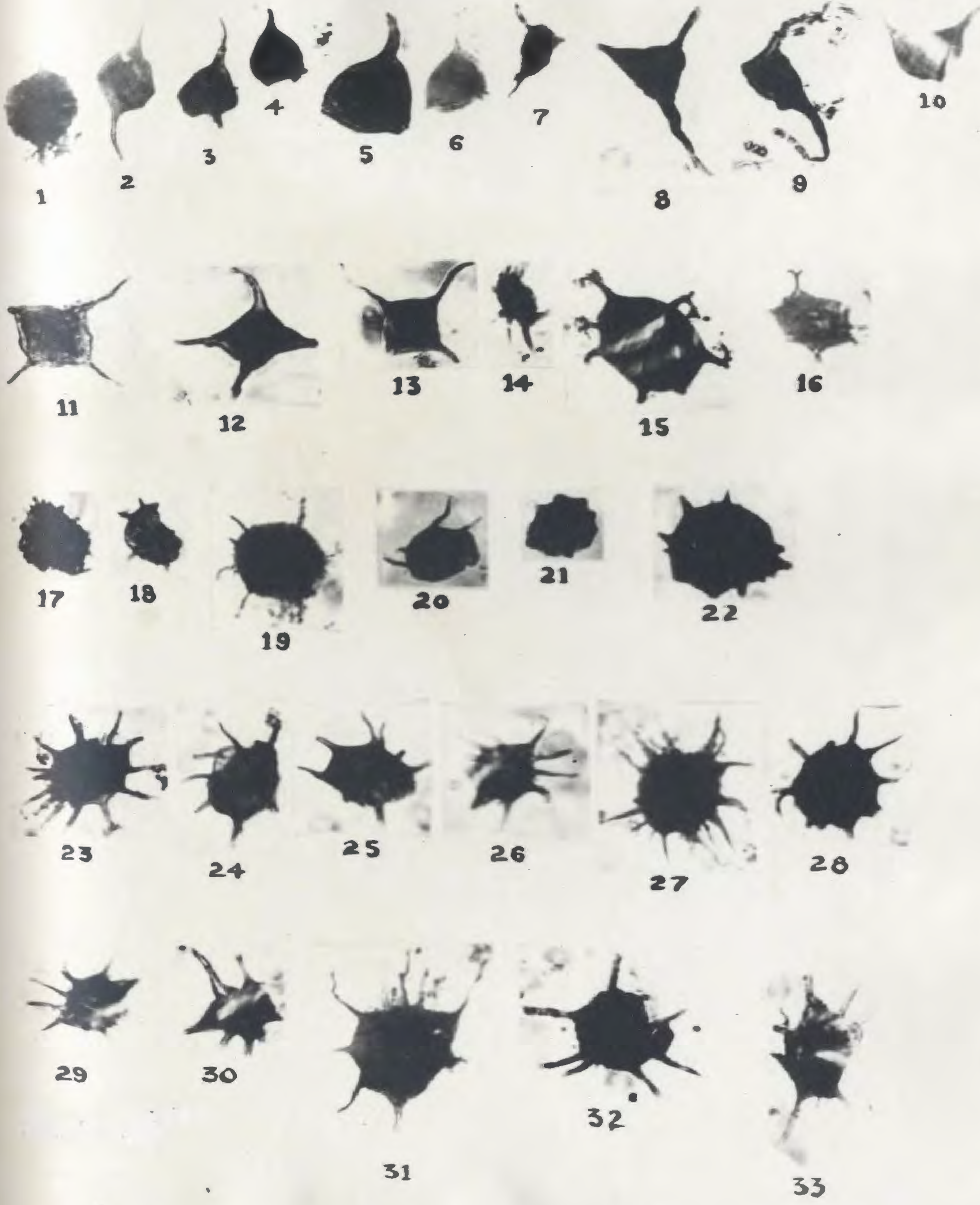
Figs. 1 - 4. *Leiofusa* spp.
Figs. 5 - 6. *Veryhachium trisulcum* Deunff.
Figs. 7 - 9. *V. trispinosum* (Eisenack).
Fig. 10. *Veryhachium* sp.
Figs. 11 - 13. *V. rhomboidium* Downie.
Figs. 14, 21. *Micrhystridium* sp.
Fig. 15. Indeterminate sp.
Fig. 16. *Hystrichosphaeridium trifurcatum* Eis.
Figs. 17, 18, 22. *Baltisphaeridium* spp.
Figs. 19, 20, 23 - 33. *B. longispinosum* (Eisenack).



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island

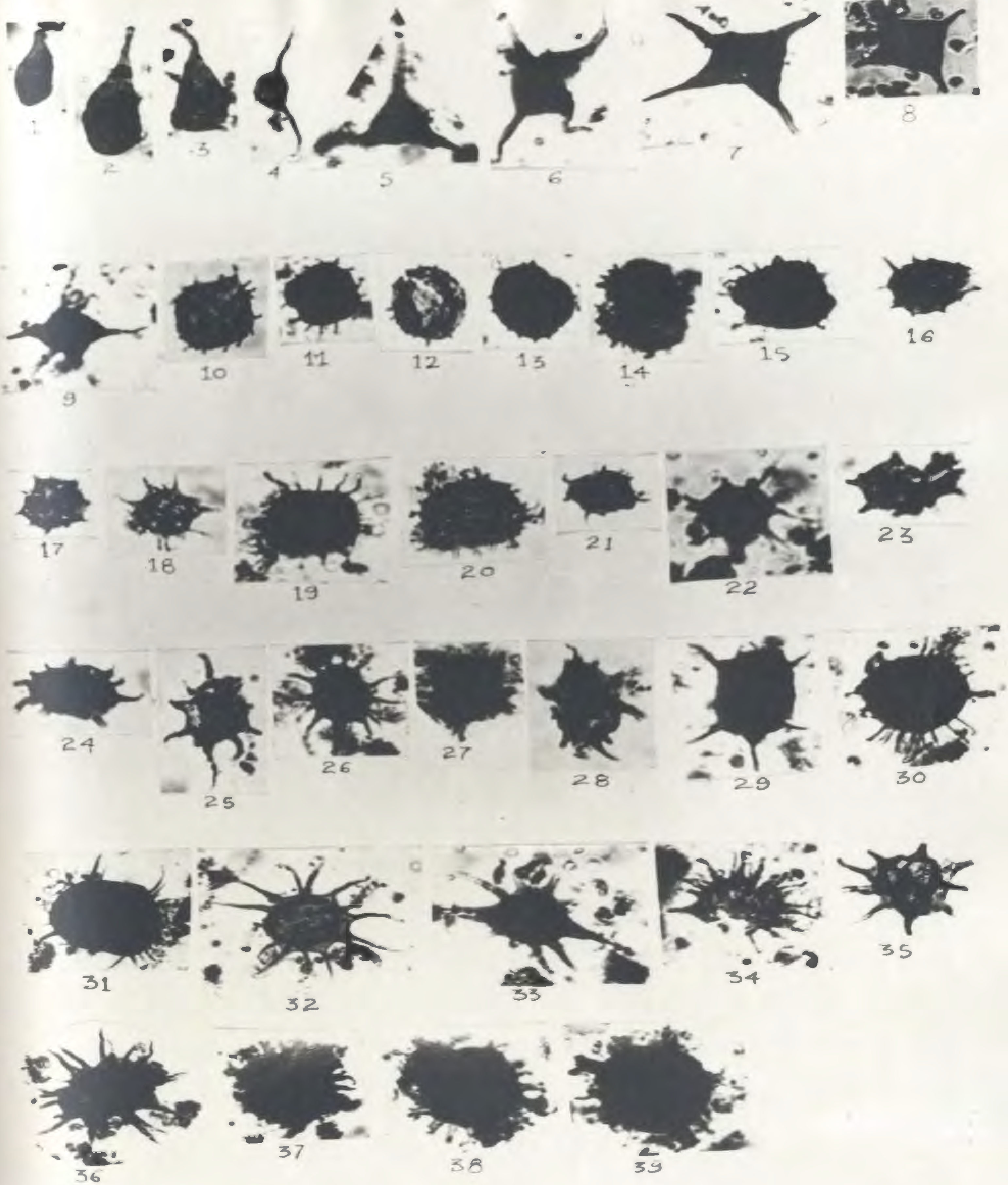
EXPLANATION OF PLATE 26

Lower Ordovician hystrichospheres, Bell Island.
Occurrence: Upper and Lower Members.
All figures x 600.

Figs. 1 - 3, 37 - 39. Indeterminate spp.
Fig. 4. Veryhachium trisulcum Deunff.
Fig. 5. V. trispinosum (Eisenack).
Figs. 6 - 9. V. rhomboidium Downie.
Figs. 10 - 12, 14, 15, 27. Multiplicisphaeridium sp.
Figs. 13, 19, 20, 24, 25, 28, 35. Baltisphaeridium sp.
Figs. 16 - 18, 21 - 23, 26, 32 - 34. Micrhystridium stellatum Defl.
Figs. 29 - 31, 36. Baltisphaeridium longispinosum (Eisenack).

In this Plate, hystrichospheres shown in Figure Nos. 10, 12, 14, 15, 16 - 18, 20, 25, 28, 34, 35, are recovered from dark gray shales, immediately overlying Pyrite beds, Lower Member.

PLATE 26



NAUTIYAL, Lower Ordovician hystrichospheres, Bell Island

Chitinozoa

Tests of chitinozoa are composed of organic substances. They are found in such various shapes as: rounded, oval-, rod-, club-, bottle-shaped, and, sometimes, flask-shaped. Usually they are open at their oral end and closed at their proximal end. Surfaces of tests are either smooth or may have simple or branched spines; small rings or longitudinal ribs may be present. In the Lower Ordovician sequence of Bell Island, their tests were found to occur either singly or, sometimes, in bead-like chains. Micropaleontologists disagree about the composition of the wall. Eisenack believes that chitinozoan tests are composed of a chitin-like substance which is extremely resistant to the effects of strong acids.

Lower Ordovician shale rocks contain abundant and distinctive assemblages of chitinozoa, and twenty two zones were discovered in the present study. Shale strata of the Airfield Formation and of the Lower Member of the Wabana Formation yielded chitinozoa in large numbers.

Systematic paleontology

Charles Collinson and Howard Schwalb have mentioned in their paper on '<u>North American Paleozoic Chitinozoa</u>', 1955 that Eisenack in 1931 settled the Chitinozoa which were later revised by the joint work of Eisenack and Deflandre. Collinson and Schwalb, 1955, recognized Chitinozoa as an order and placed them in the class Rhizopoda.

Phylum, PROTOZOA Goldfuss, 1818

Class, RHIZOPODA Dujardin, 1841

Order, CHITINOZOA Eisenack, 1931

Family, LAGENOCHITINIDAE Eisenack, 1931

Genus, Lagenochitina Eisenack, 1931

(see Plate 27, Figs. 1 - 7)

The genus has a flask-shaped or bottle-shaped test having greatest diameter near the midlength. The chamber tapers towards mouth which leads into a tubular neck and this neck is terminated finally by a smooth mouth. Forms are devoid of spines.

Occurrence: Middle Member, Airfield Formation, Townsquare Formation and Polls Head Formation.

This genus contains the following species:

Lagenochitina cf. spherocephala (?) Eisenack

(see Plate 27, Fig. 8)

This form has a flask-shaped body with a long neck. Part of neck is broken in figure. This form may be compared with the form illustrated in Plate XI, Fig. 120 of 'Microorganismes plactoniques du Primaire Armoricain, I - Ordovicien du Veryhaćh' (presqúile du Crozon) by Dr. Deunff, 1959.

Occurrence: Airfield Formation.

Genus, Angochitina Eisenack, 1931

Angochitina is a flask-shaped form having spines. Owing to this latter character, it differs from Lagenochitina. Angochitina (?) sp.

(see Plate 27, Fig. 12) may be compared with illustrated form by Dr. Deunff in Plate XII, Fig. 131 but the specimen in Lower Ordovician of Bell Island is smaller.

Occurrence: Airfield Formation.

<u>Angochitina</u> <u>flasca</u> Collinson and Schwalb

(see Plate 27, Figs. 10 - 12)

This species is pyriform to subpyriform. The chamber leads into a short neck which is terminated at oral end by a simple mouth. The aboral end contains concave base. The chamber's surface is smooth with scattered short but well marked spines. Chamber has a moderately thick wall.

Occurrence: Airfield Formation, Polls Head Formation.

Genus, Conochitina Eisenack, 1931

This genus conochitina is polymorphic to such an extent that Collinson and Schwalb in 1955 have indicated it to be of little taxonomic value. Owing to this reason they have emended Conochitina to merely slightly tapered, club-shaped chitinozoans. Plate 27, Figs. 13 to 20 and Plate 28, Figs. 1 - 38, exhibit large numbers of polymorphic forms of the genus Conochitina collected by the writer. Some of them are incomplete (broken during maceration) and distorted specimens.

Occurrence: Lower and Middle Members, Airfield Formation, Townsquare Formation.

Concochitina dactylus Collinson and Schwalb

(see Plate 28, Fig. 39)

Chamber of this species is club-shaped and has a greatest diameter near the aboral end. Both orally and aborally the form tapers slightly from greatest diameter and can be well marked in the specimen. Aboral end broadly rounded which is partly broken in the specimen. External surface of the chamber is smooth and moderately thick. This specimen can be compared with the illustrated species by Collinson and Schwalb, 1955, in Plate 2, Fig. 16.

Occurrence: Airfield Formation, and Polls Head Formation.

Genus, Illichitina Collinson and Schwalb

Collinson and Schwalb, 1955 have mentioned that Eisenack has proposed Illichitina for a number of species assigned to Conochitina. They have further mentioned that Illichitina do not belong to that genus as so emended. According to Collinson and Schwalb, Illichitina consists of all those species that have a shape suggestive of a bell with a maximum diameter at aboral end which is closed at oral end having a small opening. Forms taper rapidly from the maximum diameter for a short distance and then gradually form a cylindrical neck towards oral end. The species collected by the writer (see Plate 29, Figs. 1 - 3) exhibit some variations in their proportions.

Occurrence: Lower Member, Airfield Formation, Polls Head Formation.

Genus, Rhabdochitina Eisenack, 1931

(see Plate 29, Figs. 4 -18)

This genus includes those species which are fairly long, tubular and terminated in no specific manner. Collinson and Schwalb have mentioned that Eisenack included some species under this genus which showed basal parts broadly rounded or flat, basal bulbs, and some provided with basal flare. Specimens collected by the writer (see Plate 29, Figs. 4 - 9 and 13 - 18) exhibit this character. Some specimens are partly distorted and broken.

Occurrence: Lower Member, Airfield Formation.

Genus, Desmochitina Eisenack, 1931

Desmochitina sp.

(see Plate 29, Figs. 19 -25)

Several more or less bottle-shaped individuals occur united in chain-like (bead like) colony. The primary individual has a disc for attachment which is not apparent in the collected specimens. Chains shown in the figures may be compared with the illustrated Figure No. 3 of text plate of 'Association de chitinozoaires sahariens du Gothlandien supérieur (Ludlowien)' by Philippe Taugourdeau, 1962.

Occurrence: Airfield Formation.

Genus, Urochitina ?

Urochitina ? sp.

(see Plate 29, Figs. 26 - 31)

This species is flask-shaped with long neck. Writer's collected specimens may be compared with the illustrated Urochitina sp. in Figs. 4 to 8 of the text plate by Philippe Taugourdeau, 1962.

Occurrence: Airfield Formation, Polls Head Formation.

Family, HOEGISPHAERIDAE Wilson and Dolly, 1964

Genus, Hoegisphaera Staplin, 1961

(see Plate 29, Figs. 32, 33)

This genus shown in the figures is more or less spherical with aperture circular and simple which is bordered by an annular thickening. This latter character is not evident in the collected specimen. Its generic identification is doubtful.

Occurrence: Airfield Formation, Townsquare Formation.

Genus, Ancyrochitina

Ancyrochitina sp. 1

(see Plate 29, Fig. 34)

This species has a maximum diameter near the aboral end. From this end the test narrows towards oral end into conical and finally into a cylindrical neck which makes up about one-half of the total length in the specimen collected from Bell Island.

The spines at the aboral end are missing (broken). The specimen shown in the figure is a distorted specimen. However, this specimen may be compared with the illustrated species in Plate I, Fig. 4 of '<u>Chitinozoaires De L'Ordovicien Des U.S.A.; Comparaison Avec Les Faunes De L'ancien Monde</u>' by Ph. Taugourdeau, 1965.
Occurrence: Airfield Formation.

Genus, Sphaerochitina Eisenack, 1955

<u>Sphaerochitina nodulosa</u> Collinson and Scott ?

(see Plate 29, Fig. 35)

Body chamber of the collected specimen is slightly mushroom-shaped which is provided with a subcylindrical neck. Body chamber at its base is slightly convex. Part of the neck in the specimen is broken off and very small tubercles (indistinct) are partly confined to the lower part of the body chamber.
Occurrence: Middle Member.

<u>Operculum of chitinozoa</u>

(see Plate 29, Figs. 36 - 39)

Figures 36 - 39 show detached operculum of some chitinozoa, probably of <u>Desmochitina</u> sp.?
Occurrence: Upper Member, Airfield Formation, Polls Head Formation.

Indeterminate spp.

(see Plate 29, Figs. 40 - 45, and Plate 30, Figs. 1 - 20)

Figures shown in Plates 29 and 30 are either distorted specimens or new species of Chitinozoa and one would require literature for their generic or specific identification.

Occurrence: Wabana Formation and Bell Island Group.

Graptolites

(see Plate 30, Figs. 21 - 32)

Chemical maceration of some shale samples immediately overlying the Pyrite beds yielded fragments of some graptolites. Figures 21 to 28 exhibit sicula of graptolites, and Figures 29 to 32 fragments of their skeletons.

Occurrence: Lower Member and Airfield Formation.

EXPLANATION OF PLATE 27

Chitinozoa from the Lower Ordovician rocks of Bell Island.
Occurrence: Upper and Middle Members, Airfield Formation, Townsquare Formation and Polls Head Formation.
Magnification: Figures 1, 2, 18, 19 = x 195; 3 - 5, 10 = x 115; 6, 11, 12 = x 595; 7 - 9, 13 - 17, 20 = x 395.

Figs. 1 - 7. Lagenochitina baltica Eisenack
Fig. 8. Lagenochitina cf. spherocephala (?) Eis.
Figs. 9, 10. Angochitina flasca Collinson and Schwalb.
Figs. 11, 12. Angochitina sp.
Figs. 13 - 20. Conochitina.

EXPLANATION OF PLATE 28

Lower Ordovician chitinozoa, Bell Island.
Occurrence: Middle and Lower Members, Airfield Formation, Townsquare Formation.
Magnification: Figures 1 - 11, 13 - 16, 18 - 24, 27 - 33, 35, 36 = x 200; 12, 17, 25, 26, 37, 38 = x 400; 22, 39 = x 120; 34 = x 600.

Figs. 1 - 38. Showing polymorphic forms of Conochitina.
Fig. 39. Conochitina dactylus Collinson and Schwalb.

EXPLANATION OF PLATE 29

Lower Ordovician chitinozoa, Bell Island.
Occurrence: Upper, Middle, and Lower Members, Airfield Formation, Townsquare Formation, and Polls Head Formation.
Magnification: Figures 1, 15 = x 192; 2, 26, 27, 31 = x 112; 3, 14, 20, 25, 28, 29, 34, 35, 37, 42 = x 392; 4 - 13, 16 - 18 = x 72; 19, 21 - 24, 30, 32, 33, 36, 38, 39, 43 - 45 = x 592; 40, 41 = x 32.

Figs. 1 - 3. Illichitina sp.
Figs. 4 - 18. Rhabdochitina magna Eisenack.
Figs. 19 - 25. Desmochitina.
Figs. 26 - 31. Urochitina sp.
Figs. 32 - 33. Hoegisphaera sp.
Fig. 34. Ancyrochitina sp.
Fig. 35. Sphaerochitina nodulosa Collinson and Scott?
Figs. 36 - 39. Detached operculum of Desmochitina ?
Figs. 40 - 45. Indeterminate spp.

NAUTIYAL, Lower Ordovician chitinozoa, Bell Island

NAUTIYAL, Lower Ordovician chitinozoa, Bell Island

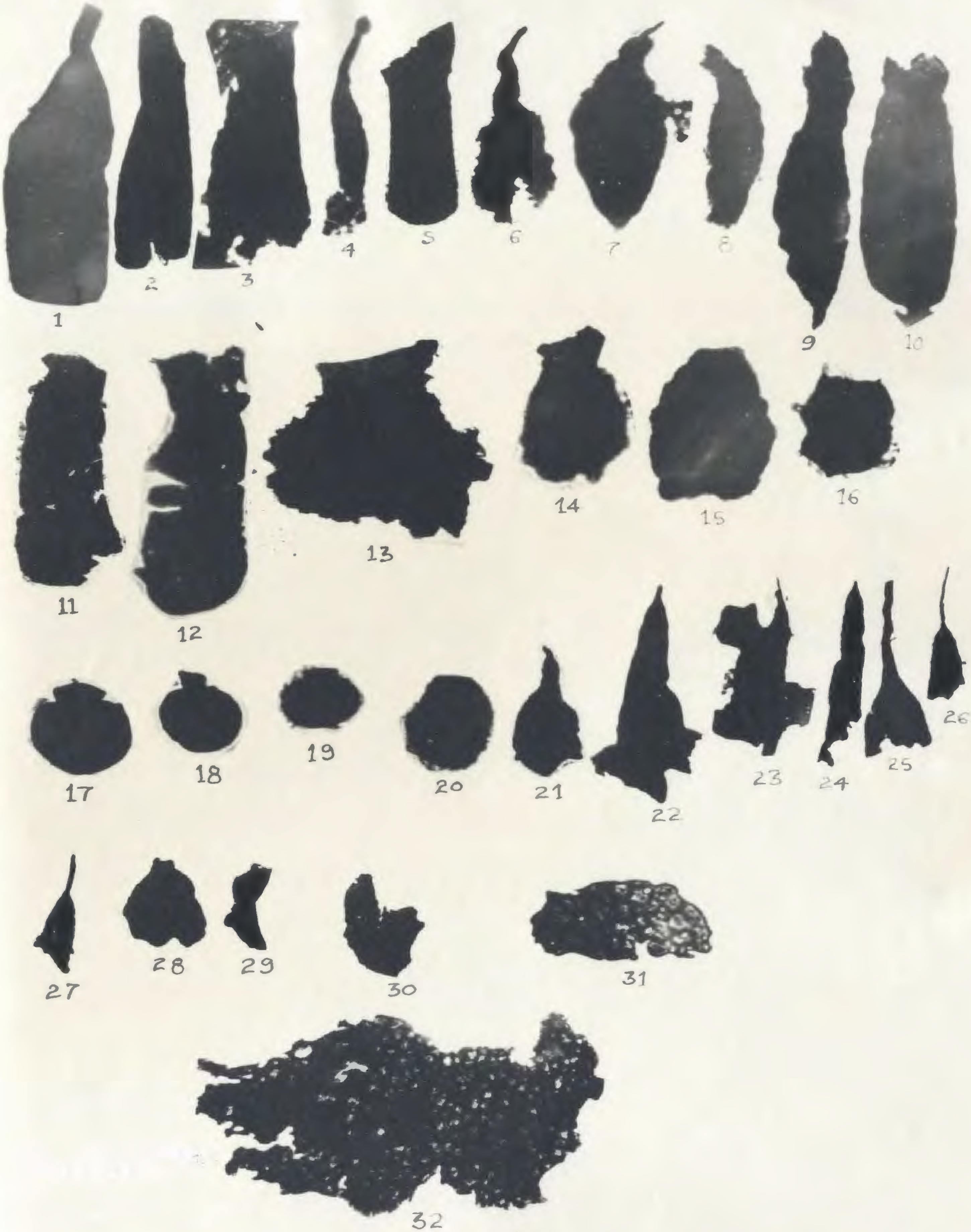
NAUTIYAL, Lower Ordovician chitinozoa, Bell Island.

EXPLANATION OF PLATE 30

Lower Ordovician chitinozoa and graptolites, Bell Island.
Occurrence: Upper and Lower Members, Airfield Formation, Townsquare Formation, and Polls Head Formation.
Magnification: Figures 1, 6, 15 = x 400; 2, 7, 9, 23, 25, 28 = x 80; 3, 22, 24, 26, 27, 30 = x 40; 4, 8, 13, 14, 16 - 20, 31 = x 600; 5, 10 - 12, 21, 32 = x 200; 29 = x 20.

Figs. 1 - 20. Indeterminate spp. (Chitinozoa).
Figs. 21 - 28. Sicula of graptolites.
Figs. 29 - 32. Fragments of graptolite skeletons.

PLATE 30



NAUTIYAL, Lower Ordovician chitinozoa & graptolites, Bell Island

Scolecodonts

Scolecodonts have been presumed to be annelid jaws. Several paleontologists have compared these fossil chitinous jaws with modern polychaeta jaws. In the present study, six shaly zones, containing scolecodonts, were discovered: five zones in the Airfield Formation, and one in the Upper Member of the Wabana Formation. These scolecodonts are the first reported find from Eastern North America known to the writer.

Systematic paleontology

Phylum, ANNELIDA

Class, POLYCHAETA

Order, ERRANTIA

Genus, Arabellites Hinde, 1879

Arabellites sp.?

(see Plate 31, Fig. 1)

Figure 1 is a part of a maxilla which is known as an anterior hook or fang. The dentary part of the maxilla is missing in this specimen, hence its specific identification is doubtful.
Locality: 345, D.

Arabellites comis Eller

(see Plate 31, Figs. 2,3)

Figures 2 and 3 show small, subtriangular jaws of maxilla 1 containing a denticulate inner margin with a fang, short projections of dentary extend posteriorly from the inner margins of the base. In these specimens the posterior parts are missing.

Locality: 345, D, 345', C.

Genus, Ildraites Eller, 1936

Ildraites sp.?

(see Plate 31 , Fig. 4)

Figure 4 shows a jaw of maxilla 1 with a prominent hook which is missing in this specimen. The inner margin is denticulate with more or less sickle-shaped posterior margin. About 10 denticles are present in the specimen which extend posteriorly. This is an incomplete specimen.

Locality: 345', D.

Genus, Staurocephalites Hinde, 1879

Staurocephalites sp.?

(see Plate 31, Figs. 5, 6, 7)

Figures 5, 6 and 7 show broken specimens. The anterior tooth is missing in the specimens; its position is followed by a series of posteriorly directed, diminishing denticles.

Locality: 345,D, 345', C, G.

Jaws of maxilla

(see Plate 31, Figs. 8 - 20)

Figures 8 to 20 illustrate incomplete specimens but in general these are jaws of maxilla.

Locality: 344 B, 345, D, 345', C, G.

Scolecodont fragments

(see Plate 31, Figs. 21 - 25)

Figures 21 to 25 are scolecodont fragments. Figures 23 and 24 may be compared with the scolecodont fragment illustrated in Plate XI, Figure 121 of Ordovicien du Veryhach (Presquile de Crozon). (1), France by Jean Deunff.

Locality: 345', C, G.

EXPLANATION OF PLATE 31

Lower Ordovician scolecodonts, Bell Island.
Occurrence: Middle Member, and Airfield Formation.
Magnification: Figures 1 - 5, 7 - 14, 16, 18 - 25 = x 320; 6 = x 40; 15, 17 = x 520.

Fig. 1. Anterior hook of *Arabellites* sp.?
Figs. 2, 3. *Arabellites comis* Eller.
Fig. 4. *Ildraites* sp.?
Figs. 5 - 7. *Staurocephalites* sp.?
Figs. 8 - 20. Jaws of maxilla.
Figs. 21 - 25. Scolecodont fragments.

EXPLANATION OF PLATE 32

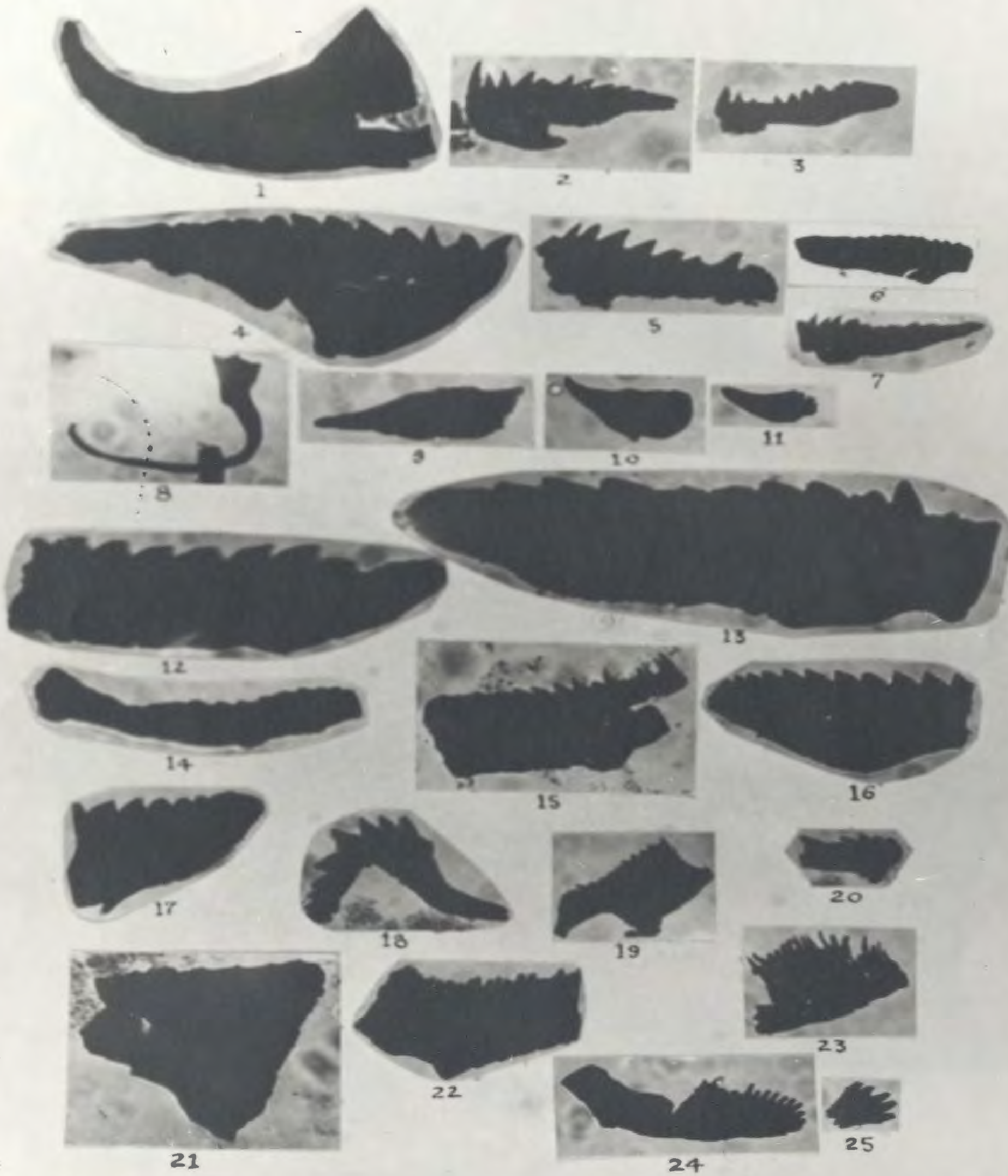
Lower Ordovician 'Problematica' microfossils, Bell Island.
Occurrence: Airfield Formation.
Magnification: Figures 1 - 6, 8 - 11, 13 - 19 = x 600; 7, 12, 20 - 22 = x 400.

Figs. 1 - 22. 'Problematica' microfossils.

EXPLANATION OF PLATE 33

Lower Ordovician 'Problematica' microfossils, Bell Island.
Occurrence: Upper and Middle Members, Airfield Formation, Polls Head Formation.
Magnification: Figures 1, 2, 15, 27 - 29 = x 420; 3 - 14, 16 - 25 = x 630; 26 = x 210.

Figs. 1 - 29. 'Problematica' microfossils.



NAUTIYAL, Lower Ordovician scolecodonts, Bell Island

PLATE 32

NAUTIYAL, Lower Ordovician 'Problematica' microfossils, Bell Is

NAUTIYAL, Lower Ordovician 'Problematica' microfossils, Bell Is.

BIBLIOGRAPHY

1. Ager, D.V., 1963, "Principles of Paleoecology", International series of earth sciences, pp. 38 - 39.

2. Berg, G., 5th May, 1923, "Petrographical studies on the Microstructure of the Wabana ores", Berlin. Unpublished typescript.

3. Brown, C.A., 1960, "Palynological Techniques", copyright by C.A. Brown, 1180, Stanford Ave., Baton Rouge 8, La.

4. Baird, D.M., March, 1945, "Notes on the Geology of Kellys Island", Geological Survey of Newfoundland.

5. Caster, K.C., February, 14, 1966, Personal Letter, Department of Geology, University of Cincinnati, Cincinnati, Ohio, U.S.A.

6. Сопержание, 1962, "Microspores of the older Paleozoic from borehole Uszkowce 1". Kwartalnik Geologiczny, pp. 343-344, Plate III.

7. Cooper, G.A., 1956, "Chazyan and related Brachiopods", Smithsonian Miscellaneous Collections, Washington, Vol. 127, Part I, II, Pl. I, Fig. E, p. 199.

8. Dean, W.T., and Krummenacher, R., April 1961, "Cambrian Trilobites from the Amanox Mountains, Turkey", Palaeontology, London, Vol. 4, Pt. I, pp. 76, 77.

9. Decker, C.E., and Hassinger, N., July, 1958, "What higher modification is doing for the study of Graptolites (Reproductive structures)", Journal of Paleontology, Vol. 32, No. 4, pp. 697 - 700.

10. Downie, C., 1963, "Hystrichospheres (Acritarchs) and spores of the Wenlock Shales (Silurian) of Wenlock, England", Palaeontology, Vol. 6, Pt. 4, pp. 625 - 652.

11. Deflandre, G., 1947, "Le Problème des Hystrichosphères", Bulletin De L'Institut Océanographique, No. 918, p. 18, Oct. 1947.

12. Downie, C., Evitt, W.R., amd Sarjeant, W.A.S., 1963, "Dinoflagellates, Hystrichospheres, and the classification of the Acritarchs", Stanford University Publications, Geological Sciences, Vol. VII, No. 3.

13. Deunff, M.J., April, 1958, "Microorganismes Planctoniques Du Primaire Armoricain", I. Ordovicien Du Veryhach (Presquîle de Crozon). (1), Bulletin de La Societe Geologique et Mineralogique de Bretagne, Nouvdle Serie, Fascicule 2, Pl. 1 - 12, pp. 1 - 36.

14. ——————— 1951, "Micropaléontologie - Sur la présence de microorganismes (Hystrichosphères) dans les schistes Ordoviciens du Finistère", Comptes Rendus Hebdomadaires des séances de L'académic des Sciences, Tome 233, No. 4, Paris pp. 321 - 323.

15. ——————— 1965, "Acritarches du Dévonien supérieur de la presquîle de Crozon", Compte Rendu sommarie Des Séances de La Société Geologique de France, Fascicule 5, pp. 162 - 164.

16. Deflandre, G., 1944, "Microfossils Des Calcaires Siluriens de la Montagne Noire", Annales de Paleontologie, t. XXXI, pp. 41 - 73.

17. ——————— Oct. 1947, "Le Problème des Hystrichosphères" Bulletin de L'Institut Oceanographique, No. 918, pp. 1 - 23.

18. Downie, C., and Sarjeant, W.A.S., 1963, "On the interpretation and status of some Hystrichosphere genera", Palaeontology. Volume 6, Pt. I, pp. 83 - 96.

19. Downie, C., 1959, "Hystrichospheres from the Silurian Wenlock Shale of England", Palaeontology, Vol. 2, Pt. I, pp. 56 - 71.

20. Evitt, W.R., Feb. March, 1963, "A discussion and proposals concerning fossil Dinoflagellates, Hystrichospheres, and Acritarchs, I and II", Proceedings of the National Academy of Sciences, Vol. 49, Nos. 2, 3, pp. 158 - 302.

21. Eisenack, A., 1964, Katalog der fossilen Dinoflagellaten, Hystrichosphären und verwandten Mikrofossilien, Band I Dinoflagellaten, E. Schweizerbartsche Verlagsbuchhandlung, Stuttgard.

22. Furnish, W.M. and Glenister, B.F., 1964, "Nautiloidea - Ellesmerocerida", Treatise on Invertebrate Paleontology, Pt. K, Mollusca 3, pp. k 151 - 170.

23. Hutchinson, R.D., 1952, "The Stratigraphy and Trilobite faunas of the Cambrian sedimentary rocks of Cape Breton Island, Nova Scotia", Memoir 263, Geological Survey of Canada, pp. 68 - 73.

24. ——————— 1962, "Cambrian stratigraphy and Trilobite faunas of southeastern Newfoundland", Bulletin 88, Geological Survey of Canada, pp. 69 - 87.

25. Howell, B.F., 1925, "The faunas of the Cambrian Paradoxides beds at Manuels, Newfoundland", Bulletins of American Paleontology, Paleontological Research Institute, Ithaca, New York, Vol. II, pp. 91 - 94.

26. Hayes, A.O., 1915, "Wabana Iron ore of Newfoundland", Department of Mines, Geological Survey of Canada, Memoir 78.

27. —————— Nov. 1929, "Further studies on the origin of the Wabana Iron ore of Newfoundland", Economic Geology, Vol. XXIV, No. 7.

28. —————— Jan. - Feb. 1931, "Structural Geology of the Conception Bay region, and of the Wabana Iron ore deposits of Newfoundland", Economic Geology, Vol. XXVI, No. 1.

29. —————— 1948, "Geology of the area between Bonavista and Trinity Bays, Eastern Newfoundland", Part I, Newfoundland Geological Survey Bulletin No. 32.

30. Jenness, S.E., 1960, "Late Pleistocene glaciation of eastern Newfoundland", Bulletin of the Geological Society of America, Vol. 71, pp. 161 - 180, Fig. 7.

31. Kummel, B., and Raup, D., May, 1964, "Handbook of Paleontological Techniques", W.H. Freeman and Company.

32. Lake, P., Sept. 1942, "A Monograph of British Cambrian Trilobites", Part XIII, Palaeontographical Society, pp.330 - 332.

33. ————— 1935, "A Monograph of the British Cambrian Trilobites", Part IX, Palaeontographical Society, London, pp. 203 - 206.

34. Love, L.G. and Zimmerman, D.O., 1961, "Bedded pyrite and micro-organisms from the Mount Isa shale", Economic Geology, Vol. 56, pp. 873 - 896.

35. Love, L.G., Oct. 1962, "Further studies on microorganisms and the presence of syngenetic pyrite", Palaeontology, Vol. 5, Pt. 3, pp. 444-459.

36. McCallie, 1908, "The geological conditions during the deposition of the Clinton rocks", Report on the Fossil Iron ores of Georgia, Bulletin No. 17, Geological Survey of Canada, pp. 160 - 163.

37. Matthew, G.F., 1903, "Report on the Cambrian rocks of Cape Breton", Geological Survey of Canada, No. 797, Pl. XIV, Figs. 4a-f, 5a-b, pp. 199 - 204.

38. Moore, R.C. (Editor), 1955, "Treatise on Invertebrate Paleontology", Pt. V, Graptolithina.

39. ---------- 1959, "Treatise on Invertebrate Paleontology", Pt. O, Arthropoda 1 (trilobitomorphs).

40. Nils Spjeldnaes, April, 1963, "Some Upper Tremadocian Graptolites from Norway", Palaeontology, Vol. 6, Pt. I, pp. 121 - 131.

41. Potter, P., and Pettijohn, F.J., 1963, "Paleocurrents and Basin Analysis", Academic Press Inc., Publishers, New York, pp. 155 - 159.

42. Pettijohn, F.J., and Potter, P., 1964, "Atlas and geology of Primary Sedimentary Structures", Springer - Verlag, New York, Inc.,

43. Pettijohn, F.J., 1956, "Sedimentary Rocks", second edition.

44. Rigby, J.K., 1958, "Lower Ordovician Graptolite faunas of Western Utah", Journal of Paleontology, Vol. 32, pp. 907 - 916.

45. Ruedemann, R., 1947, "Graptolites of North America", Geological Society of America, Memoir 19, pp. 315 - 469.

46. Rowell, A.J., 1959, "Brachiopoda", Treatise on Invertebrate Paleontology, Geological Society of America Inc. and the University of Kansas Press, Part H.

47. ---------- 4 March, 1966, Personal letter, Department of Geology, University of Nottingham, Nottingham, England.

48. Rose, E.R., 1948, "Geology of the area between Bonavista, Trinity and Placentia Bays, Eastern Newfoundland", Part II, Newfoundland Geological Survey Bull. No. 32.

49. ---------- 1952, "Torbay Map-Area, Newfoundland", Department of Mines and Technical Surveys, Geological Survey of Canada, Memoir 265.

50. Rasetti, F., 1951, "Middle Cambrian Stratigraphy and faunas of the Canadian Rocky Mountains", Smithsonian Miscellaneous Collections, Vol. 116, No. 5, pp. 241 - 247.

51. Sarjeant, W.A.S., 1962, "Microplankton from the Ampthill clay of Melton, South Yorkshire", Palaeontology, Vol. 5, Pt. 3, pp. 478 - 497.

52. ---------------- April, 1962, "Upper Jurassic Microplankton from Dorset, England", Micropaleontology, Vol. 8, No. 2, Text Fig. 8.

53. ---------------- 1961, "Microplankton from the Kellaways rock and Oxford clay of Yorkshire", Palaeontology, Vol. 4, Pt. I, pp. 99 - 107.

54. Šnajdr, M., 1956, "Trilobiti Českého Středního Kambria", Rozpravy, Ústředniho Ustavugeologického, Svazek 24, pp. 203 - 205.

55. Staplin, F.L., 1961, "Reef-controlled distribution of Devonian Microplankton in Alberta", Palaeontology, Vol. 4, Pt. 3, pp. 392 - 424.

56. Staplin, F.L., Jansonius, J. and Pocock, S.A.J., 1965, "Evaluation of some Acritarchous Hystrichosphere Genera", N.Jb. Geol. Paläont. Abh., Stuttgart, Vol. 123, 2, pp. 167 - 201.

57. Seilacher, A., 1960, "Lebensspuren Als Leitfossilien", Geologische Rundschau, Stuttgart, pp. 44 - 46.

58. Shimmer, H.W. and Shrock, R.R. 1955, "Phylum Mollusca", Chapter X, Index Fossils of North America, Massachusetts Institute of Technology, Plate 164, Fig. 6, p. 411.

59. Stockmans, F., et Williere, Y., 1962, "Hystrichosphères du Dévonien belge (Sondage de l'Asile d'aliénés à Tournai)", Plate I, II, pp. 41 - 77, Extrait du Bulletin de la Söciété Belge De Géologie, De Paléontologie et D'Hydrologie, Tome LXXI, fascicule 1, annee.

60. ---------------------------------- "Hystrichosphères du Dévonien belge, (Sondage de Wepion)", Plate I, II, pp. 83 - 99.

61. Timofeyev, B.V., May - June, 1963, Phytoplankton and dispersed spores of the Ordovician, Silurian and Lower Devonian of the Baltic region, The Góry Swietokrzyskie and Podolia", Doklady of the Academy of Sciences U.S.S.R., Earth Science section; Vol. 150, Nos. 1 - 6, pp. 26 - 29.

62. ———————— March - April, 1963, "Ordovician and Silurian Phytoplankton of the Siberian Platform", Doklady of the Academy of Sciences U.S.S.R., Earth Science section, Vol. 149, pp. 45 - 48.

63. Walcott, C.D., 1924, "Cambrian geology and paleontology", Smithsonian Miscellaneous Collection, Smithsonian Institute, Washington, Vol. 67, No. 9, Pt. 4, Plates 108, 122, Figs. 5 - 8, pp. 491 - 506.

64. ———————— 1912, "Cambrian geology and paleontology" Smithsonian Miscellaneous Collection, Smithsonian Institute, Washington, Vol. 57, No. 7, Pt. 2, Plate 35, Figs. 1 - 6, p. 232.

65. ———————— 1913, "Cambrian geology and paleontology" Smithsonian Miscellaneous Collection, Smithsonian Institute, Washington, Vol. 57, No. 11, Pt. 2, Plate 50, Figs. 4 - 9, p. 311.

66. Wall, D. and Downie, C., 1962, "Permian Hystrichospheres from Britain", Palaeontology, Vol. 5, Part 4, pp. 770 - 784.

67. Wilson, L.R. and Dolly, E.D., Oct. 1964, "Chitinozoa in the Tulip Creek Formations, Simpson Group (Ordovician) of Oklahoma", Oklahoma Geology notes, Vol. 24, No. 10, pp. 224 - 232.

68. Whittington, H.B., Sept. 1955, "Additional New Ordovician Graptolites and a Chintinozoan from Oklahoma", Journal of Paleontology, Vol. 29, No. 5, pp. 837 - 851.

69. West, E.S. and Todd, W.R., 1959, "Chitin", Textbook of Biochemistry (second edition), pp. 266 - 267.

<u>References (not in alphabetical order) obtained during continuing studies while Thesis was receiving final typing</u>.

70. May, 1961, "Code of Stratigraphic Nomenclature", American Commission on Stratigraphic Nomenclature I, The Bulletin of the American Association of Petroleum Geologists, Vol. 45, No. 5, pp. 645 - 665.

71. 1963, "Rock Colour Chart", The Rock Colour Chart Committee, distributed by the Geological Society of America, New York, N.Y.

72. Coughlan, W.K., 1965, "Geology of the Wabana deposit with comments on exploration and development problems peculiar to a submarine deposit", 'Selected Technical Papers', C.I.M.M. Meeting, Toronto.

73. Neale, J.W. (Editor), 1963, "Chitinozoa (Chapter 9)", Hystrichospheres and similar Microorganisms (Chapter 10)", 'Principles of Zoological Micropalaeontology', Vol. 1, pp. 491 - 514.

74. Van Ingen, G., 1914, "Cambrian and Ordovician faunas of south-eastern Newfoundland", Geological Society of America, Bulletin, Vol. 25, (Abstract), p. 138.

75. ——————— Table of geological formations of the Cambrian and Ordovician systems about Conception and Trinity Bays, Newfoundland and their northeastern American and western European equivalents, based upon the 1912 - 1913 field work. Princeton, N.J.

76. Mohr, P.A. and Allen, R., 1965, "Further Considerations on the Deposition of the Middle Cambrian Manganese Carbonate Beds of Wales and Newfoundland", Geological Magazine, Vol. 102, No. 4, pp. 328 - 337.

77. Boswell, P.G.H., 1961, Muddy Sediments, W. Heffer and Sons Ltd., Cambridge, pp. 9 - 126.

78. Berner, R.A., 1962, "Experimental studies of the formation of sedimentary iron sulfides", Biochemistry of Sulfur Isotopes, Proceedings of a National Science Foundation Symposium, April 12 - 14, pp. 107 - 120.

79. Edwards, A.B., and Baker, G., 1951, "Some occurrence of Supergene iron sulphides in relation to their environments of deposition", Journal of Sedimentary Petrology, Vol. 21, No. 1, pp. 34 - 46.

80. Honjo, S., Fischer, A.G., and Garrison, R., 1965, "Geopetal pyrite in fine-grained limestones", Journal of Sedimentary Petrology, Vol. 35, No. 2, pp. 480 - 488.

81. Kanwisher, J., 1962, "Sulfur chemistry in marine muds"; Biogeochemistry of Sulfur Isotopes, pp. 94 - 97.

82. Love, L.G., 1958, "Micro-organisms and the presence of syngenetic pyrite", Geological Society of London Quart. Jour., Vol. 113, pp. 429 - 440.

83. Love, L.G. and Murray, J.W., 1963, "Biogenic pyrite in recent sediments of Christchurch Harbour, England", American Journal of Science, Vol. 261, pp. 433 - 448.

84. Tyler, S.A. and Barghoorn, E.S., 1963, "Ambient pyrite grains in Precambrian cherts", American Journal of Science, Vol. 261, pp. 424 - 432.

85. Temple, K.L., 1964, "Syngenesis of sulfide ores: an evaluation of biochemical aspects", Economic Geology, Vol. 59, pp. 1473 - 1491.

86. Degens, E.T., 1965, "Sulfides", Geochemistry of Sediments, A Brief Survey, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp. 158 - 159.

87. Sylvester, R.K., 1959, "Scolecodonts from Central Missouri", Journal of Paleontology, Vol. 33, No. 1, pp. 33 - 49.

88. Stauffer, C.R., 1933, "Middle Ordovician Polychaeta from Minnesota", Bulletin of the Geological Society of America, Vol. 44, pp. 1173 - 1218.

89. Taugourdeau, 1965, "Chitinozoaires de L'Ordovicien des U.S.A.; Comparaison Avec les Faunes de L'ancien Monde", Revue de L'Institut Francais du Pétrole, XX, No. 3, pp. 462 - 484, Plates I, II, III.

90. Lewis, H.P., 1940, "I - The Microfossils of the Upper Carodocian Phosphate Deposits of Montgomeryshire, North Wales", The Annals and Magazine of Natural History, including Zoology, Botany, and Geology, Vol. V, No. 25, pp. 1 to 39, Plates III, IV.