GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF MINES
AND TECHNICAL SURVEYS

BULLETIN 100

CLEARWATER LAKE,
NEW QUEBEC

S. H. Kranck, and G. W. Sinclair

Price, 75 cents

1963

CLEARWATER LAKE,
NEW QUEBEC

2,000—1963—3036

65923-5—1

GEOLOGICAL SURVEY
OF CANADA

BULLETIN 100

CLEARWATER LAKE, NEW QUEBEC

By

S. H. Kranck and G. W. Sinclair

DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
CANADA

65923-5—2

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

1963

Available by mail from the Queen's Printer, Ottawa,
from Geological Survey of Canada,
601 Booth St., Ottawa,
and at the following Canadian Government bookshops:

OTTAWA
Daly Building, corner Mackenzie and Rideau

TORONTO
Mackenzie Building, 36 Adelaide St. East

MONTREAL
Aeterna-Vie Building, 1182 St. Catherine St. West

or through your bookseller

A deposit copy of this publication is also available
for reference in public libraries across Canada

Price 75 cents Catalogue No. M42-100

Prices subject to change without notice

PREFACE

The occurrence at Clearwater Lake of fresh-looking, flat-lying volcanic rocks associated with remnants of Ordovician limestone, in an area otherwise underlain by some of the oldest rocks in the Canadian Shield is surprising. In this report these rocks are described and a possible mode of origin suggested.

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

OTTAWA, November 14, 1961

65923-5—2½

Bulletin 100—Clearwater Lake (Neu Quebec).
Von S. H. Kranck und G. W. Sinclair

Beschreibt zwei kreisförmige Vertiefungen im Nordosten Kanadas. Man nimmt an, dass sie vulkanisch-tektonischer Entstehung sind und durch den Einsturz der Erdkruste an kreisförmigen Brüchen gebildet wurden.

Бюллетень 100 — Озеро Клируотер, Новый Квэбек.
I. Геология и генезис. Автор: С. Х. Кранк.
II. Исследования ордовиких известняков.
Автор: Г. В. Синклер.

Описание двух круглых депрессий в северовосточной Канаде. Этим депрессиям приписывается вулкански-тектоническое происхождение. Они очевидно образовались путем осаждения земной коры по круговым разломам.

CONTENTS

PART I—GEOLOGY AND ORIGIN

S. H. Kranck

PART II—OBSERVATIONS ON THE ORDOVICIAN LIMESTONE

G. W. Sinclair

Illustrations

CLEARWATER LAKE, NEW QUEBEC

Abstract

Clearwater Lake in New Quebec consists of two circular depressions 19 miles and 16 miles in diameter located on a highland of Precambrian granitic gneiss east of Richmond Gulf.

Geological evidence suggests that the lake is of volcanic-tectonic origin, having formed by collapse of the earth's crust along circular fractures. A ring of islands concentric with the shore of the larger basin is composed of dacitic lava and volcanic breccias made up of granite fragments in an iron oxide cement.

The structure of the islands suggests that they represent volcanoes, and were formed by extrusion of lava along a circular fracture probably concurrently with caldera collapse. Caldera collapse occurred at a time when this part of the Shield was covered with Palaeozoic limestone since blocks of this limestone were found in the volcanic breccia. The small drainage basin and the amount of glass in the volcanic rocks suggest the subsidence occurred in Tertiary time.

Résumé

Le lac à l'Eau-Claire, au Nouveau-Québec, prend la forme de deux dépressions circulaires, de 19 milles et de 16 milles de diamètre respectivement et est situé dans les hautes terres, constituées de gneiss granitique du Précambrien, à l'est du golfe Richmond.

Suivant les faits géologiques, il semble que ce lac soit d'origine volcano-tectonique et qu'il se soit formé par suite de l'effondrement de la croûte terrestre le long de fractures circulaires. Un anneau d'îles concentrique à la rive du plus grand des deux bassins se compose de laves de dacite et de brèches volcaniques composées de fragments de granite cimentés avec de l'oxyde de fer.

La structure des îles porte à croire qu'elles représentent d'anciens volcans formés par extrusion de lave le long d'une fracture circulaire qui se serait probablement ouverte au moment de l'effondrement de la caldeira. Cet effondrement s'est produit lorsque cette partie du Bouclier était recouverte de calcaire paléozoïque, car des blocs de ce calcaire ont été retrouvés dans la brèche volcanique. Le petit bassin hydrographique et la quantité de verre au sein des roches volcaniques portent à croire que l'effondrement s'est produit au Tertiaire.

PART I

GEOLOGY AND ORIGIN

Introduction

Clearwater Lake consists of two circular basins, 19 and 16 miles in diameter, on the highland of the Precambrian Shield east of Richmond Gulf. The most striking aspect of the geology of the lake is a ring of islands of volcanic origin. The work on which this report is based was done during the summer of 1959 as a special project in conjunction with Operation Fort George, for the purpose of checking the very interesting geology reported by personnel of the Dominion Observatory.

The lake attracted the attention of the staff of the Dominion Observatory in connection with their study of circular depressions of possible meteoric origin subsequent to the discovery of the New Quebec crater in 1952. Many such depressions have been discovered (Beals, Ferguson, Landau, 1956), and the problem is whether the Clearwater Lake basins should be included with them.

No definite conclusion as to the origin of the lake was reached by scientists of the Dominion Observatory, but the suggestion was advanced (Beals, Innes, Rottenberg, 1960) that impact by twin meteorites may have produced the basins and initiated volcanism in the larger one. The writer questions this hypothesis because a reasonable explanation of the structures is possible without recourse to other than volcano-tectonic processes. The astronomers are struck by the similarity between the Clearwater Lake basins and moon craters, most commonly assumed to be of meteoric origin, but the writer is struck by their similarity with collapse calderas. This does not, of course, mean that they are necessarily unlike moon craters, as many workers are of the opinion that the moon craters are also collapse features (Spurr, 1944; Green, 1960).

On the earth there are many isolated circular depressions like those of Clearwater Lake for which both a meteoric and a volcanic origin have been proposed; for example the Meteorite crater in Arizona, the New Quebec crater in Ungava, Lake Bosumtwi in Ghana, Loom Lake in India, and the Steinheim basin in Bavaria. All these structures have caused considerable controversy among geologists and there is still no unanimity of opinion as to how they formed. For the Arizona and New Quebec craters a meteoric origin is generally accepted, but for the other structures an origin by purely geological processes is favoured. Each of these structures has its own peculiarities and it is pointless here to review the arguments that have been put forward to support this or that manner of formation. The literature on craters of presumed meteoric origin has been reviewed by Hardy (1954) and Spencer (1933). Caldera type depressions have been discussed in an excellent paper by Williams (1941). The writer prefers to regard the Clearwater Lake structures as calderas.

Calderas, a common landform in areas that have been affected by volcanism, consist of large circular depressions or grabens. They are formed by foundering of the crust as a result of tension produced by an underlying magma shrinking during cooling or being ejected as lava, pumice, and gases during volcanic eruptions. Some of the largest known collapse calderas are the Valles caldera in New Mexico, and the Aso and Askja calderas in Japan. These are fully as large as Clearwater Lake. Many calderas are bordered by a rim of volcanoes in the same way as at Clearwater Lake, for example the Niuafoou caldera in the Pacific, the Aira caldera in Japan, the Sierra de Bonca caldera in Italy, and Crater Lake in Oregon.

Clearwater Lake differs from typical calderas principally by its isolated location in a Precambrian Shield. In this respect it is comparable to the Lappajarvi and Janisjarvi basins in Finland and Lake Dellen in Sweden where Tertiary lavas have erupted in isolated grabens in a Precambrian Shield. Other examples of volcanism in otherwise tectonically stable areas may be found in the Swabian Alps where 125 cryptovolcanic features, including the Steinheim basin, dot a circular area underlain by flat-lying limestones, an area in southwestern Scotland where Carboniferous sediments are perforated by clusters of cryptovolcanic vents mainly resulting from gas explosions, and an area in southeastern Missouri closely coinciding with the Ozark uplift where a swarm of cryptovolcanic features have been produced by explosive volcanism. Rust (1937) has noted that such areas of cryptovolcanic activity appear to be related to broad uplifts possibly coinciding with the emplacement of magmatic rocks at depth. It also appears to be located on a topographic high (see *Physiography,* p. 4).

Another indication that Clearwater Lake is structurally controlled is its location in line with Richmond Gulf near the middle of the arc formed by the coast-line of the Belcher basin. Kranck (1951) noted that Tertiary movements have taken place along this coast-line, and it is probably not too far fetched to assume that this was the same uplift that produced the domes in the Clearwater Lake area.

Finally the similarity of the Clearwater Lake structure to the Manicouagan-Mushalagan basin should be pointed out. Rose (1955) concluded that the Manicouagan-Mushalagan basin was a result of differential erosion, but the circular outline of the volcanic area indicates that the volcanic rocks fill an earlier formed depression, very likely a volcano-tectonic depression of similar origin as Clearwater Lake. The volcanic rocks found in the two places are very similar (pers. com. E. R. Rose).

The writer would like to conclude from the existence of these volcanic features that the Canadian Shield has not been as immobile as is generally assumed. Fracturing and movement may have occurred at other places on the Shield in connection with more recent orogenies, though these movements generally are difficult to detect because of the scarcity of datable geological features associated with them. With this point of view in mind, Clearwater Lake in this paper is dealt with as a purely geological problem. Those readers who would like to consider a different approach are referred to papers by Dr. Beals and his group.

Previous Exploration

A. P. Low (1889) visited Clearwater Lake in 1885 on his travels from Richmond Gulf to Ungava Bay. He did not observe the volcanic rocks on the islands in the lake, but was the first to report fossiliferous limestone float near the lake believing its source to be the flat area around Upper Seal Lake.

FIGURE 1. Index map.

In 1958, the year that the Dominion Observatory party visited Clearwater Lake, J. R. Woodcock of Kennco Explorations Ltd. spent an hour on one of the islands in the island ring and concluded that the island was a volcano, and probably one of rather recent age as shown by the presence of unaltered glass (private report, 1958).

65923-5—3½

The Dominion Observatory party found that the ring of islands in the lake consisted mainly of a micro-breccia, at least partly of volcanic origin. In addition abundant float of fossiliferous limestone was found at the lake. A number of gravity readings were taken and some soundings made of the lake bottom (D. B. McIntyre, C. S. Beals, J. G. Tanner, pers. com.).

The writer spent six days at the lake accompanied by Phillip Reynolds, a student assistant. The lake was reached by Beaver aircraft from an Operation Fort George base-camp 240 miles to the southeast. Most of the data collected are from the main island in the south part of the island ring, here called Volcano Island. Two other islands, the one immediately northeast of Volcano Island and one of the shoals in the middle of the lake, were visited briefly.

Physiography of the Region

The physiography of the area round Clearwater Lake has not been studied in detail, but some observations should be mentioned.

Airphotos show that the area is a highland broken by rounded granite knobs and long lake-filled valleys. Most lakes occupy depressions that have been carved out by glacial erosion along joints of more than one set. The most distinct lineaments trend east-west probably reflecting the direction of ice flow. A few well-defined fractures trend north-northwest, and some curve concentric with the Clearwater Lake depressions.

The vegetation is of the type characteristic of areas close to tree-line. A sparse tree-cover grows in the valleys but the hill tops are completely barren.

The lake itself, with its large stretches of deep clear water and high rocky shores, is an impressive and beautiful sight, and seems completely alien to the flat and featureless terrain characterizing the Shield area farther east. The shorelines are dotted by islands and protruding points and an occasional delta plain at the river mouth. Away from the shores the smaller southeastern basin is completely free of islands. Soundings made by the Dominion Observatory field party show that the smaller basin has a flat bottom at a depth of a little less than 400 feet. The larger basin contains two sets of islands besides the islands and shoals along the shore. There is the spectacular ring of eleven high islands concentric with the shore about 5 miles from the centre of the basin, and there are a few low shoals right in the centre of the basin. Both these landforms appear to be of volcanic origin. No soundings of more than 320 feet were recorded in this basin.

The islands in the ring are made up of high ridges, estimated to be in the order of 490 feet, bordered by steep, red, vertically jointed cliffs. The ridges generally have an east-west trend. This trend reflects the direction of flow of the continental ice-sheet, but the form of the hills may also have been influenced by an east-west trending joint system and possibly by the regional foliation in the area, as most of the bigger lakes and other major topographic features in the vicinity have this trend.

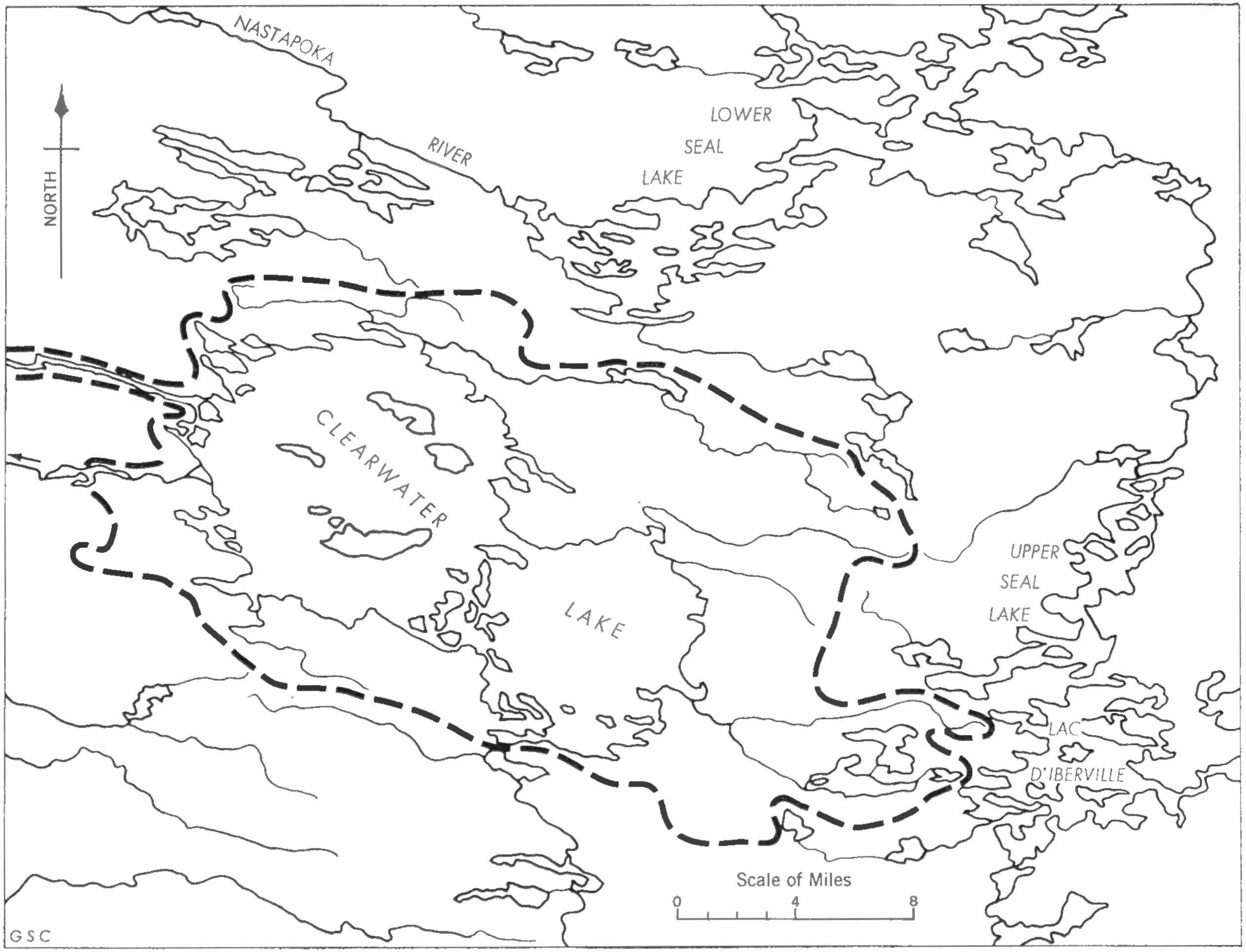


FIGURE 2. Clearwater Lake area showing drainage basin of Clearwater Lake.

The tops of the ridges on the larger islands in the eastern and southern sectors of the ring consist of fairly flat high plateaus. These, as far as could be determined from Volcano Island, are all about the same height and may also be the same height as the hill tops in the surrounding highland. If this is so—a closer study is needed to confirm it—it would be evidence of a period of peneplanation subsequent to the formation of the basins.

The fact that a limestone capping (the remains of which are preserved on the bottoms of the basins as shown by the float around the lake) is not found in the surrounding highland is good evidence that a moderate amount of erosion has taken place in the area subsequent to the volcanic activity. On the other hand, it is noteworthy that the drainage basin of Clearwater Lake is very small; only from the east do a few streams drain into the lake. A study of a topographic map of the area indicates that there is a tendency for a radial drainage pattern around the lake. Some lakes only a few hundred feet from the shore of Clearwater Lake on the south and west sides drain away from the lake rather than into it, and the water from Upper Seal Lake east of the area takes a very round-about route to the north via Nastapoka River (*see* Fig. 2) to reach the sea. The radial drainage pattern suggests that the depressions are located on the crests of uparched domes in the basement. As was noted in the *Introduction,* this is a common characteristic of cryptovolcanic structures. Thus it appears as if the large-scale features of the topography are the result of volcano-tectonic processes, erosion being limited to the cutting down of the highlands around the basins, probably mainly by removal of the soft limestone capping.

It does not seem likely that Clearwater Lake itself could have been deepened by river erosion of the limestone. This would require a profound change in the tilt of the land surface subsequent to the last peneplanation. A more positive statement about this matter has to await a better knowledge of the relief of the bottom of the basins and the physiography of the surrounding country.

Volcano Island

Most of the information recorded by the writer on the geology of the Clearwater Lake feature is from a large island in the south part of the island ring, here called Volcano Island because it is concluded that the island represents the remnant of a composite volcano.

The island consists of gently rolling highlands bordered by steep cliffs along the shores (*see* Fig. 3). The elevation of the hills is in the order of 400 feet, the highest point being on the rim west of the central lake. Two north-south trending valleys divide the island into three parts, thought to be the result of separate volcanic eruptions. A few lakes lie in depressions in the highland, the largest being situated in the central part of the island between a northern and a southern ridge.

A sparse brushy tree cover is present in spots along the shores and in protected valleys. The hill slopes are covered with dense, almost impenetrable alder and birch, but the uplands are mostly barren.

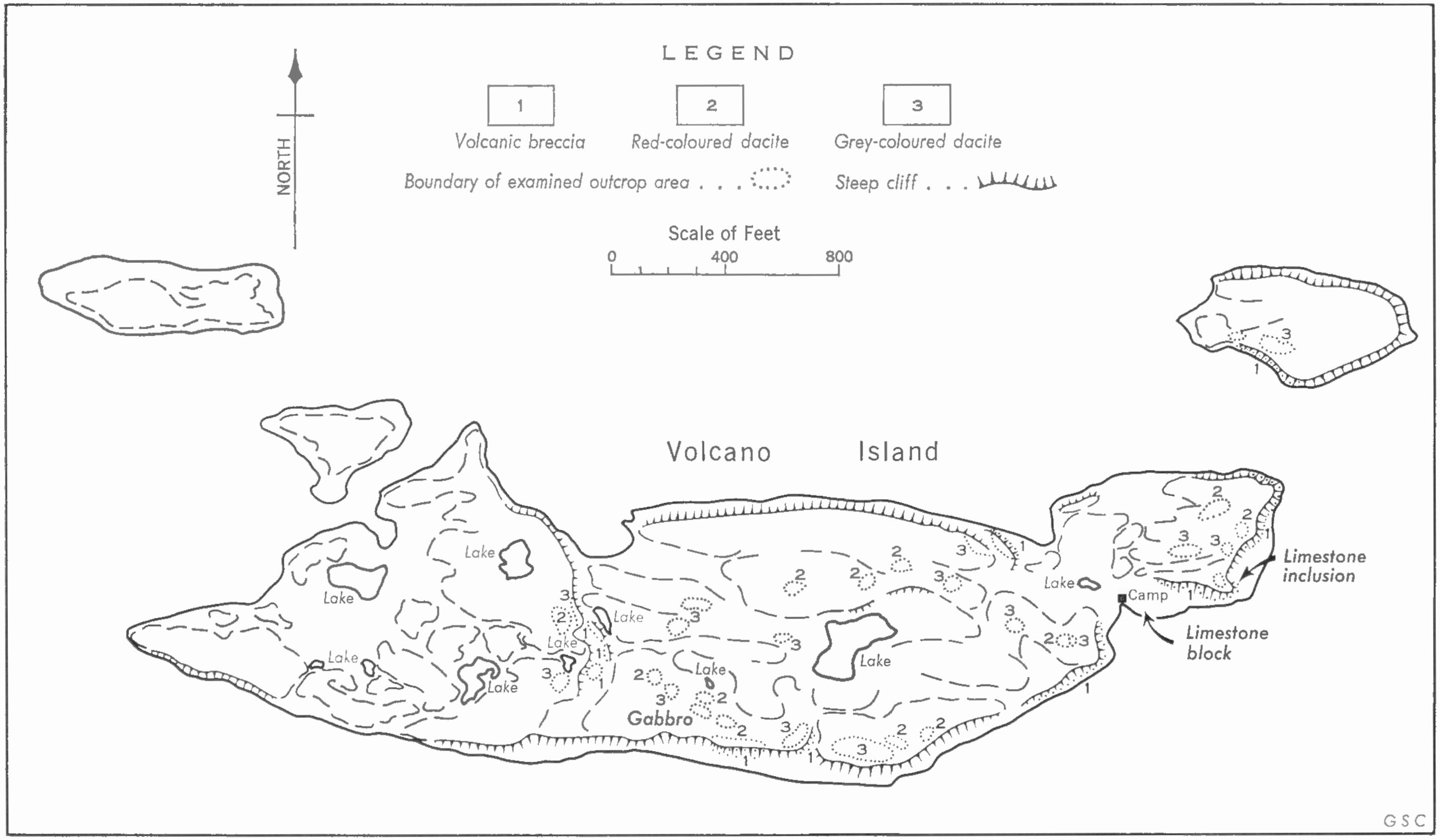


FIGURE 3. Volcano Island, Clearwater Lake.

The most striking feature of Volcano Island, and also of the other islands, is the steep cliffs of red volcanic breccia showing a columnar-like jointing. Such cliff-faces follow the shoreline on the south side of Volcano Island (Pl. II A), the central part of the north shore, and the west side of the more westerly valley cutting across the island (Pl. I A).

On the highlands outcrops are relatively scarce, but isolated exposures consist mainly of massive grey and red lavas. Apparently massive lavas occupy the central cores of the highlands and breccias the peripheries of the hills (Fig. 3).

On the island northeast of Volcano Island where only the southwest face was studied the lower cliff face is red breccia and the cap is massive grey lava.

Description of Rock Types

In the field the bedrock of Volcano Island was subdivided into three lithologic units, namely, red volcanic breccia, red massive dacite, and grey massive dacite. The red and the grey lavas, where present in the same outcrop, grade into each other within a few feet, the gradational rocks being characterized by red spots on a grey base. The colour of the rock appears to correspond to the degree of oxidation of the mafic minerals. There is also a complete gradation between the lavas and the breccias. As a rule the grain size and homogeneity of the lavas increase and foreign fragments become increasingly scarce and difficult to identify as one moves away from the peripheries of the hills.

Most of the breccia is a red massive unit made up of rock fragments ranging in size from submicroscopic to outcrop in a matrix of iron oxide, glass, and crypto-crystalline lava. In some places the fragmental character of the rock is plainly visible in outcrops, with rounded and angular granitic and gneissic fragments scattered through a groundmass richly stained by red iron oxide. The contained rock fragments are partly well-defined angular pieces of granite and gneiss and partly poorly defined ghosts of disintegrating fragments, outlined by concentrations of loose feldspar and quartz grains. In other places the rock as a whole is fine textured and only a close look reveals that it consists of a mixture of red, glassy blebs, greyish coarser textured patches, scattered feldspar fragments, and patches of varying texture, coarseness, and shade of red. In places the rock is soft. This rock breaks along irregular surfaces and is shot through with hollows partly or completely filled with chalcedony and zeolites. In other places the foreign fragments are embedded in a harder, deeper red, more homogeneous groundmass.

A study of thin sections shows that the hardness, colour, and homogeneity of the groundmass of the breccias can be related to the amount of magma present.

The soft, fragmental rocks typically consist of fragments of granite and gneiss, loose, angular grains of microcline, plagioclase, quartz, rusty pyroxene, and biotite, as well as glassy to microcrystalline blebs and stringers cemented together by fine, unidentifiable rock powder and a large amount of hematite dust (Pl. IV A). The fragments are mainly angular and fresh looking except for oxidation products of the ferromagnesian minerals. The freshness of the rock fragments and the presence of thin glass threads and shards indicate that the rock was emplaced not far from the surface of the earth. It may represent either a true tuff-breccia or more probably welded tuffs, a mixture of gas, glass, dust, and wall-rock fragments extruded as incandescent clouds (nuées ardentes).

In the harder rocks the magmatic material is mixed with the oxide and rock dust, first as a pale brownish, glassy to microcrystalline mass that is difficult to distinguish from the contained rock dust. It is identifiable more positively in the rocks in which the grain size is large enough that evenly distributed, haphazardly oriented microlites of feldspar can be seen against an isotropic background. As the amount of foreign material in the rock decreases the grain size of the primary magmatic material in the breccias increases, reflecting the diminishing effect of the chilling action of the wall-rock debris.

Interesting reaction phenomena can be observed between the formerly molten fraction and the enclosed foreign material (Pl. IV B). The feldspar, quartz, and different rock grains take on a rounded form as they become corroded and absorbed by the lava along the edges. Most of the rock fragments have recrystallized along the edges to finer grained, commonly isotropic material, and the smaller grains stand out from the magmatic groundmass only faintly as rounded patches outlined by rims with a slightly different texture, mostly allotriomorphic as compared to the more idiomorphic texture of the groundmass, and by slightly different proportions of minerals. In single mineral grains it may be difficult to decide whether the grains represent phenocrysts or pieces of wall-rock. Generally if they are foreign grains they show evidence of reaction with the magma. The plagioclase grains commonly are surrounded by an almost isotropic aureole presumably a mixture of glass and more calcic plagioclase. The quartz and microcline grains in some thin sections are surrounded by a rim of pyroxene and iron oxide. Probably these grains acted as crystallization nuclei for early formed crystals in the magma.

The dacite lavas are massive, fine-grained rocks, weathering yellowish to reddish grey. Except for the colour variation in red and grey they are homogeneous throughout the island. The colour of the rock appears to reflect the degree of oxidation of the iron-bearing minerals, probably as a result of different degrees of mixing with surface air at the time of the extrusion. Two chemical analyses of the lava have been performed, one of the red variety and one of the dark grey. The analyses are fairly similar but the slightly lower CaO/NaO and MgO/FeO ratios in the grey specimen show that it represents either a more advanced stage of fractionation or alternatively a smaller degree of mixing with assimilated wall-rock material, more probably the latter. The specimens were taken from widely different parts of the island, suggesting that the lavas have a fairly constant chemical composition everywhere and probably are the result of a single period of eruption.

The dark grey specimen is composed of approximately 60 per cent plagioclase, including antiperthite, 15 per cent quartz, 15 per cent sanidine, and 10 per cent pigeonite (Pl. V A). A part of the rock is too fine grained for the mineral constituents to be identified positively in the thin sections, but the calculated norm agrees fairly well with the estimated mineral content. The main mass consists of fine-grained, haphazardly oriented, anhedral to subhedral tablets of plagioclase ($2V_z 85°$) with pronounced zoning and with or without multiple twinning. Scattered

Chemical Analyses of Lavas

	weight %	cation %	molecular norm	
	1. Grey dacite (GSC No. A934)			
SiO_2	63.5	60.0		
TiO_2	0.6	0.5	Or	19.4
Al_2O_3	16.0	17.8	Ab	28.4
Fe_2O_3	2.9	2.0	An	20.5
FeO	1.87	1.4	Q	18.1
MnO	—	—		
MgO	2.7	3.8	Di	1.2
CaO	4.7	4.8		
Na_2O	3.1	5.7	Hy	8.2
K_2O	3.3	3.9	Ap	0.6
H_2O	1.3	—	Il	1.0
P_2O_3	0.3	0.2	Hm	2.0
	2. Red dacite (GSC No. A935)			
SiO_2	62.0	59.3	Or	19.0
TiO_2	0.6	0.5	Ab	27.2
Al_2O_3	15.7	17.7	An	21.3
Fe_2O_3	4.5	3.2		
FeO	0.72	0.6	Q	17.8
MnO	—	—	Di	3.6
MgO	3.0	4.3	Hy	7.1
CaO	5.0	5.1	Ap	—
Na_2O	2.9	5.4	Il	0.9
K_2O	3.1	3.8		
H_2O	1.36	—	Hm	3.2
P_2O_3	—	—		

subhedral to euhedral microphenocrysts of plagioclase, mostly with an antiperthitic texture in the central part, are also present. Most of these grains are surrounded by an untwinned, unzoned rim that is probaly sanidine. Patches consisting of cryptocrystalline feldspar and quartz make up about 10 per cent of the rock. Another 10 per cent is made up of micropegmatitic intergrowths of quartz and sanidine. The quartz commonly is in networks of thin spears of uniform optical orientation surrounding euhedral sanidine grains. Pigeonite occurs as anhedral grains partly scattered through the rock, partly concentrated in patches.

The red variety of the lava has an almost identical mineral composition and texture except for the greater abundance of iron oxide dust and alteration products of the ferromagnesian minerals. The pigeonite grains are partly or completely altered to tremolite and talc and are surrounded by red oxidation products, partly hematite, partly a deep red, iddingsite-like mineral. Other thin sections of the massive rocks are very similar, so that the chemical analyses are probably representative of most of the magma core of the island.

A special rock type was seen in an outcrop on one of the low shoals in the centre of the lake, and in a few outcrops on Volcano Island. It is a grey massive rock with a coarser texture than the volcanic rocks, and consists of pyroxene and partly or completely fused plagioclase (Pl. V B).

The exposures on the shoal consists of medium-sized anhedral grains mixed with patches of light coloured isotropic material that appears to be fused plagioclase grains. Locally, along the edges of the pyroxene grains the glass has been devitrified into radiating, microcrystalline, brown spherulites. The pyroxenes are of two types, a pale augite (faintly pleochroic in pale red and pale green, $2V_z$ 70°, Z C 35° and a bronzite (X, pale greenish brown; Y, dark greenish brown; Z, green; $2V_x$, between 60° and 70°). Minor biotite also is present.

Another fairly coarse grained, pyroxene-bearing rock makes up an outcrop west of the summit in the central part of Volcano Island. It consists of colourless clinopyroxene mixed with plagioclase whose crystal structure has been almost completely destroyed by fusion. Along the edges of the pyroxene grains is a rim of finer grained olivine granules partly altered to iddingsite. A part of the slide has a mylonitic texture, the pyroxene and feldspar grains having been broken down into a jumble of finer grained fragments. Dark green chlorite occurs with the pyroxene in these places.

Structural Features

The short stay on the island did not allow a complete study of the structural relationships of the rocks, but the collected data give a fairly good general idea of the makeup of the island.

As the lavas and breccias in most places are completely massive it is difficult to deduce the orientation of the flows. In a few places on the cliffs on the south side of the island a rough horizontal layering was noted in the breccias, produced by a parallel arrangement of the wall-rock fragments (Pl. II B). Also, the vertical, columnar-like jointing in the breccias indicates that the movement of the breccias during their emplacement along the edges of the islands was in a horizontal direction. On the other hand, in some places away from the edges of the islands, particularly, in stream-cut gullies in the south-central part of the island, the columnar jointing is replaced by a closely spaced, vertical east-west striking, almost slaty cleavage. The slaty cleavage and the east-west trending ridges characterizing the island are best explained by an upward movement of magma along a central east-west trending axis. The fact that the rocks apparently flowed sideways along the edges of the hills at the time of their emplacement and the tuffaceous nature of some of the breccia rocks are good evidence that the rocks were emplaced on the surface of the earth from volcanoes. Probably the breccias with their contained wall-rock debris were pushed out in front of the lava flows and along their fringes. Where a clean channel had been produced the clean massive lava poured out from the centres of the vents and piled on top of the earlier ejected breccias. To what extent glacial and river erosion have modified the shapes of the volcanic ridges is not known and it is unwise to attempt to deduce too much about the structure from the landforms. The streamlined shape of the east-west trending ridges is of course a result of glacial erosion and the preglacial form of the volcanoes may have been profoundly different from their present form. However, it seems reasonable to assume that the different ridges represent separate lava outpourings and some of the lakes may represent remnants of the original craters. Most of the lava making up the island seems to have been frozen in the act of breaking its way to the surface, but some of the long tongues striking out towards the centre of the lake in the western part of the island (Fig. 3) may represent surface flows that have spilled over the breccia rim and flowed down towards the inner basin. The same interpretation may be offered for the flat inward-sloping tongue on the island northeast of Volcano Island and perhaps also for the west parts of the other islands along the east side of the island ring. However, a more extensive study of the islands is needed before any definite conclusions as to the mechanism of emplacement of the lavas can be drawn.

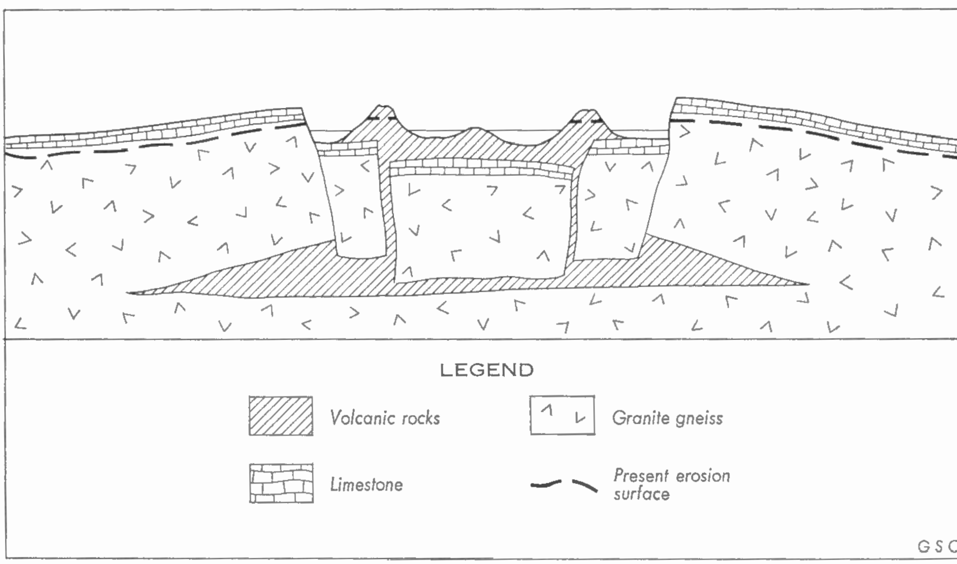


FIGURE 4. Schematic section illustrating suggested mode of formation of Clearwater Lake.

Limestone Float

Much limestone float was seen by the writer on Volcano Island, principally along the shore on the southwest side of the island. The float is mostly rounded boulders but just east of the camp a large block of about 20 square feet was seen (Pl. III B). It is probably from a local source, having been preserved in down-faulted blocks of the calderas from a time when limestone covered this part of the Canadian Shield.

Proof that the limestone predates the formation of the caldera and the extrusion of the volcanic rocks was found in the form of a large block of crystalline limestone within the volcanic breccia itself. The block is a slab about 20 feet in diameter on top of the hill at the east end of Volcano Island (Pl. III A). It is in contact on three sides with the red breccia and is altered along the contacts to wollastonite and other calc silicates. About 100 feet west of this block another smaller block of altered limestone sticks out of the moss, but it is not certain that this block is in place. Furthermore, several blocks of altered limestone were noted in the talus slope below the breccia cliff west of the camp.

The crystalline limestone presumably represents fragments caught in the magma as the lavas broke through the limestone layer. Whether limestone still is in place in the basins is of course not known, but it seems likely that some may be preserved on the bottoms of the lakes, particularly under the lava flows.

Low, in his report of 1887-88, mentions the occurrence of a limestone boulder on top of a hill near the outlet of Clearwater Lake. This observation, however, was buried in the literature, so that the discovery in 1958 by staff of the Dominion Observatory of a large amount of fossiliferous limestone float on the islands between the two basins was a complete surprise.

A number of specimens of this limestone float were studied by G. W. Sinclair of the Geological Survey, and his observations are given in Part II of this report.

Conclusions

A preliminary examination of Clearwater Lake suggests that the circular basins of the lake are the results of volcano-tectonic processes that took place in Mesozoic or early Cenozoic time.

The following hypothesis seems to cover the known facts. The volcanism probably was preceded by a regional uplift in the area, possibly the same uplift that produced movements along the circular rifts on the shore of the Belcher basin. The uplift is believed to have been the result of emplacement of magmatic rocks at depth and a general rise of isotherms in this part of the crust (Fig. 4). The roof of the magma chamber caved in as a result of tension produced either by cooling of the magma or by penetration of the magma close enough to the surface to enable it to eject gases and pumice. As the circular collapse calderas were formed glowing avalanches and dacite lava were ejected through a ring dyke concentric with the side of the larger caldera. At the time of the collapse the Precambrian basement rocks still were mantled by Ordovician limestone. The limestone capping has since been eroded away from the surrounding area but is still preserved in the down-faulted blocks within the calderas and as fragments in the volcanic breccias. Concurrently with the erosion of the limestone capping the tops of the larger volcanoes were levelled down to the elevation of the surrounding peneplain, and glacial erosion further modified the form of the volcanoes.

This very provisional picture of the happenings at Clearwater Lake is based on incomplete evidence and is presented mainly as a guide to further exploration. The lake is a fascinating object for geological research and a fine tourist attraction and should be visited by other geologists who have access to the area.

Bibliography

Beals, C. S., Ferguson, G. M., and Landau, A.
1956: A search for Analogies between Lunar and Terrestrial Topography on Photographs of the Canadian Shield; Part II, *Royal Astron. Soc. Canada J.*, vol. L, pp. 250-261.

Beals, C. S., Innes, M. J. S., Rottenberg, J. A.
1960: The search for fossil meteorite craters; *Current Sci.*, No. 6, pp. 205-262.

Bell, R.
1879: Report on an Exploration of the East Coast of Hudson Bay in 1877; *Geol. Surv., Can., Rept. of Prog.* 1877-1878, pp. 1-37C.

Escola, Penti
1921: On Volcanic Necks in Lake Janisjarvi in Eastern Finlande; *Comm. Geol. Finlande Bull.*, vol. 10, No. 55, pp. 1-13.

Green, J., Poldervaart, A.
1960: Lunar defluidization and its implications: *Twenty-first session International Geological Congress,* Pt. 21, pp. 15-33.

Hardy, C. T.,
1954: Major Craters Attributed to Meteoric Impact: *Bull. Am. Assoc. Petrol. Geol.,* vol. 38, pp. 917-923.

Hess, H. H.
1938: A Primary Peridotite Magma: *Am. J. Sci.,* vol. 35, 5th ser., pp. 321-344.

Kranck, E. H.
1951: On the Geology of the East Coast of Hudson Bay and James Bay observed during a Research Journey in the Summer of 1947; *Acta Geographica,* vol. 11, No. 2, 1950/51, pp. 1-71.

Low, A. P.
1889: Report on Explorations in James Bay and Country East of Hudson Bay, drained by the Big, Great Whale and Clearwater Rivers; *Geol. Surv., Canada,* Ann. Rept. 1887-88, vol. III, Pt. J.

Rose, E. R.
1955: Manicouagan Lake-Mushalagan Lake Area, Quebec; *Geol. Surv., Canada,* Paper 55-2.

Rust, G. W.
1937: Prelim. Notes on Explosive Volcanism in Southeast Missouri; *J. Geol.,* vol. 45, pp. 48-75.

Spencer, L. J.
1933: Meteorite Craters as Topographical Features on the Earth's Surface; *Geog. J.,* vol. 81, pp. 227-248.

Spurr, J. E.
1944: Geology applied to Selanology; Science Press, Lancaster, Penn.

Williams, Howel
1941: Calderas and their Origin; *Univ. of Cal. Pubs., Bull. of the Dept. of Geol. Sci.,* vol. 25, pp. 239-346.

Woodcock, J. R.
1959: Private Rept. on Clearwater Lake, Kennco Explorations Ltd.

PART II

OBSERVATIONS ON THE ORDOVICIAN LIMESTONE

Introduction

Six pieces of limestone were submitted for examination, and registered as locality 44420, the individual fragments being numbered 1 to 6. The fragments are fresh and normally angular, and show no signs either of transportation or of prolonged weathering, their appearance being entirely consistent with the assumption that they were essentially in place where collected.

The few macrofossils visible on weathered and broken surfaces suggested that at least some of the samples might be of Ordovician age, but no certain conclusions could be drawn from them. Pieces of each sample were therefore dissolved in formic or acetic acids, and the residues searched for microfossils. After a preliminary report had been completed, the conodonts were examined by Dr. W. M. Furnish and Dr. Brian Glenister of the State University of Iowa, who kindly provided precise identifications which are included in the lists below.

It is concluded that the samples are all of one age, and probably are derived from beds correlant with the Red River Formation of southern Manitoba.

Fossil Determinations

Sample No. 1

- sponge spicules
- echinoderm fragments, including square crinoid columnals
- *Calapoecia* sp.
- *Catenipora* sp.
- indeterminate brachiopod and gastropod fragments
- *Drepanodus homocurvatus* Lindstrom
- *Belodina* cf. *B. compressa* (Branson and Mehl)
- *Panderodus* spp.

Sample No. 2

- sponge spicules
- *Receptaculites* sp.
- *Streptelasma* sp.
- *Cyclocystoides* sp.
- fragments of crinoids and ophiurians, including square columnals
- fragments of brachiopods, including ?*Dinorthis* sp.
- *Hormotoma* cf. *H. gracilis* (Hall)
- *Panderodus* spp.
- *Cordylodus robustus* Etherington and Furnish
- *Drepanodus homocurvatus* Lindstrom

Sample No. 3

sponge spicules
echinoderm fragments, including cirrate crinoid columnals
Cornulites sp.
unidentified scolecodonts
orthoid brachiopod
Zygospira sp.
Hormotoma? sp.
Kraussella? sp.
Panderodus spp.
Cyrtoniodus sinclairi Etherington and Furnish
casts of *Leiosphaera*

Sample No. 4.

sponge spicules
echinoderm fragments
Metaconularia sp.
Arabellites sp., and other scolecodonts
Hormotoma? sp.
Panderodus spp.
Leiosphaera macrocystis (Eisenack)

Sample No. 5.

astylospongid spicules
Receptaculites sp.
Arabellites sp.
Streptelasma sp.
echinoderm fragments, including square columnals
and circular cirrate columnals
orthoid brachiopod

Sample No. 6.

Streptelasma sp.
Catenipora sp.
echinoderm fragments

Homogeneity of Samples

Although each sample is small, so that no complete representation of the fauna can be expected, the faunules of samples 1, 2, 3, 5, and 6 are so similar that it can be said with confidence that they are derived from the same source. This similarity is greater than can be expressed in faunal lists, for many of the fossil fragments that can be recognized as being identical from one sample to another cannot be assigned to particular taxa, and so cannot be named. This is especially true of dismembered echinoderms, which make up much of samples 1, 2, 3, and 5. A square crinoid columnal with distinctive markings occurs in

1, 2, and 5: a small discoid columnal with stout cirri occurs in 3 and 5: ophiurian ossicles of distinctive pattern are common. None of these can be assigned to described genera or species, but they are recognizable and valuable in demonstrating the identity of the samples in which they occur. These five samples are indistinguishable lithologically.

Sample 4 differs from the other five both physically and faunally. The texture of the rock is somewhat more dense, and the residue from it was the only one containing an appreciable amount of clayey material. However, the abundant *Leiosphaera* which dominates the sample seems to be represented in No. 3 by steinkerns of the same form, and the conodonts found in sample 4 are also present in 1, 2, and 3. It is felt that the differences in aspect and preserved fauna are not greater than could be expected in contiguous beds of the same formation, and sample 4 is considered to be of the same age as the other five.

Age of Samples

Although indeterminate fragments may be used with some assurance to indicate correlation between the samples, only those specimens that can be referred to described genera or species may be used as evidence of age in broader terms. Many of the genera listed above have ranges so long that they lack significance, but others are more closely restricted. The presence of *Calapoecia, Catenipora* and *Receptaculites* rules out a pre-Wilderness age; the *Cyclocystoides* indicates that the samples are not as late as Silurian. Thus, we can say with certainty that the age of the samples is Middle or Upper Ordovician.

Within this span, some correlations may be regarded as more probable than others. The late Wilderness Simard Formation of Lake St. John, which contains many of these genera, has been rather extensively sampled for microfossils, and the suites recovered are not similar to those from Clearwater Lake, differing especially in the nature of the sponge spicules, which are abundant in each but quite different in detail. I am not familiar with samples from beds of Trentonian age prepared in such a way as to be comparable.

Of all the samples I have seen, those most similar to the present material were derived from the Dog Head Member of the Red River Formation of Lake Winnipeg. A tentative conclusion that the Clearwater Lake beds might therefore be Edenian had been reached before Furnish and Glenister's report on the conodonts was made. They find (in a letter of April 19, 1960) that the significant species are *Cordylodus robustus* and *Cyrtoniodus sinclairi,* both of which were described from the Gunn Member of the Stony Mountain Formation, which is the member immediately overlying the Red River Formation (*see* Etherington and Furnish, *J. Pal.,* March 1960, pp. 265-274).

Since two lines of investigation each suggest a correlation with the Edenian or Maysvillian stages, this may be accepted as a reasonable approximation, keeping in mind the small size of the available samples.

Palaeogeography

A large part of the interest in the Clearwater Lake occurrence lies in the fact that it is so far within the Shield, and so distant from previously described Ordovician areas. It would be well, then, to attempt to incorporate this new information into the general picture of Ordovician geography, even though many points are still obscure.

The sea in which the Clearwater Lake limestones were deposited was derived from the north, as it brought with it the genera (*Calapoecia, Receptaculites, Catenipora*) which have come to be known collectively as the "Arctic Ordovician" fauna. This fauna, and therefore we assume seas from the north, apparently never extended so far to the southeast as the Mingan-Anticosti region. In this direction the farthest recorded limit is in the district north of Chicoutimi, where the Simard Formation (of late Wilderness age) carries this Arctic fauna (*see* Sinclair, 1953, p. 845). However, by the time that the Clearwater Lake beds were laid down, the margin of this northern sea had shifted, for we have in the Saguenay Valley beds extending throughout the Trentonian and Edenian, and in the Richmondian, in which there are no northern elements, the fauna being entirely southern in aspect[1]. Thus we must imagine a southern sea extending somewhere north of Lake St. John, but not so far as Clearwater Lake, and a separate northern sea extending some distance south of Clearwater Lake, but not so far as Lake St. John.

More directly to the south, we know that a northern sea covered the district around Haileybury and New Liskeard on Lake Timiskaming in Trentonian time, but unfortunately we cannot say when it arrived or how long it stayed, as the Liskeard Formation rests directly on the Precambrian and it is not known what beds may be between the Liskeard and the Silurian. All that can be said with certainty is that this sea covered Lake Timiskaming at a time when it had already withdrawn from Lake St. John.

It has been suggested above that the most plausible correlation of the Clearwater Lake beds is with those found to the west, in Manitoba. If these regions were under water during Wilderness or Trentonian time, no convincing evidence of this inundation remains. The first recorded sea, which reworked the available fragmental material to form the Winnipeg Sandstone and then, as it cleared, produced the Red River Formation, seems to have invaded the region in Edenian time. Later, probably at about the Maysvillian Stage, a new source of clastic material brought about the change in deposition which we see as the red Gunn Shales. This Red River sea carries the Arctic fauna, but the available evidence does not allow us to choose between the possibility that it was a vast sea, extending as far east as Clearwater Lake, and the possibility that it was a more restricted sea with separate embayments to the east and to the west.

[1] In 1953 it was necessary to leave open the question whether any beds lay between the Simard and the Shipshaw (Sinclair, *Am. J. Sci.*, v. 251, p. 849). Later work now permits the statement that such beds do not exist, and that the Shipshaw rests directly on the Simard, and that the Lower Trentonian (Hull and Sherman Fall equivalents) are absent from this region. This hiatus is not surprising, for if the Simard sea came from the north, and the Shipshaw sea from the south, it is reasonable to expect that there would be a time between when neither would be present in this region.

Table of Suggested Correlations

Stage	Ontario-Ottawa	L. St. John	L. Timiskaming	Manitoba	Clearwater Lake
Maysvillian				Gunn	
Edenian	Hallowell	"Utica" Galets		RED RIVER Winnipeg	XXXXXX
Trentonian	Hillier Sherman Fall Hull	Shipshaw	LISKEARD		
Wilderness	Rockland-Kirkfield	SIMARD			

Formations that carry the 'Arctic' fauna are in capitals, others are given to provide a context. The names of Ottawa Valley and Central Ontario formations are included for comparison. Relative position only is indicated, with no suggestion that the limits of units coincide from one column to another. The Liskeard and Winnipeg rest directly on the Precambrian; the Kirkfield and Simard are underlain by older Ordovician beds. In all these regions younger beds are omitted as irrelevant.

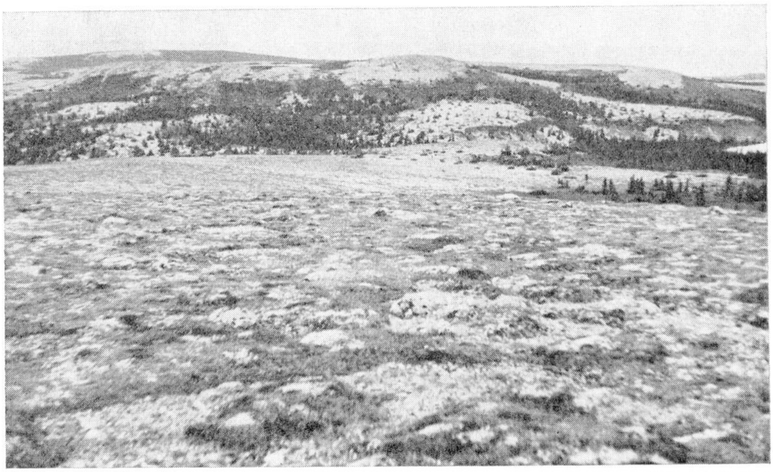
Note on *Leiosphaera*

As this organism is so abundant in one of the Clearwater Lake samples, and has not been noted in America before, a brief note may be in order.

The fossils as found are partly collapsed spheres, mostly between 0.3 and 0.5 mm in diameter, with an extremely thin wall, of amber colour (that is, various tones of orange-brown and red-brown). No appendages have been seen on our material, and the original surface seems to have been smooth. This evenness of surface is now broken into large depressed facets separated by narrow rounded ridges, but these show no regularity of arrangement and are clearly the result of partial collapse of the sphere after shrinkage of the material filling the interior. Although specimens are abundant, none has been observed flattened, and from this fact it is assumed that the sphere contained some organic material sufficiently solid to maintain its shape until the surrounding matrix had become consolidated.

That the spheres were not empty is also attested by the occurrence of steinkerns in the residues; some in sample No. 4 with patches of test adhering, in sample No. 3 without them. These samples show no surficial signs of silicification, and the residues are so small as to suggest that replacement was only partial and very selective. Yet the material within these spheres was replaced by silica, and so must have been composed of some material that differed from the matrix.

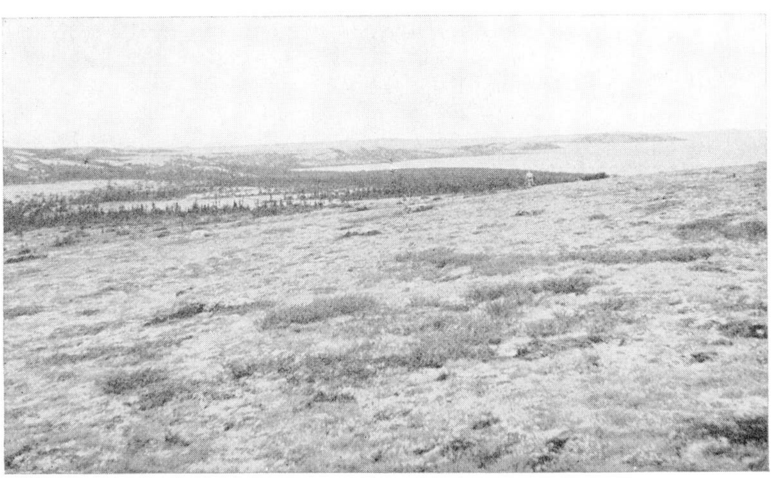
Applying Eisenack's name to this material means little, except to indicate that we have smooth spheres which are the same size as those he found in the Baltic regions. Nothing is known of the biological nature of the spheres, nor even if they were produced by plants or animals. Regnéll has described in detail similar, but smaller, spheres from the Lower Ordovician of Sweden (*Geol. Fören. Förhandl.* Bd. 77, p. 546, 1955) and Eisenack has discussed their relationships to other spheroid fossils (*Palaeontographica,* ser. A, Bd. 110, 1958).



S.H.K., 1959, 2-8

A. Volcano Island—view westward across western cross-valley; lower flank of hill in background is volcanic breccia, upper part is massive dacite.

PLATE I



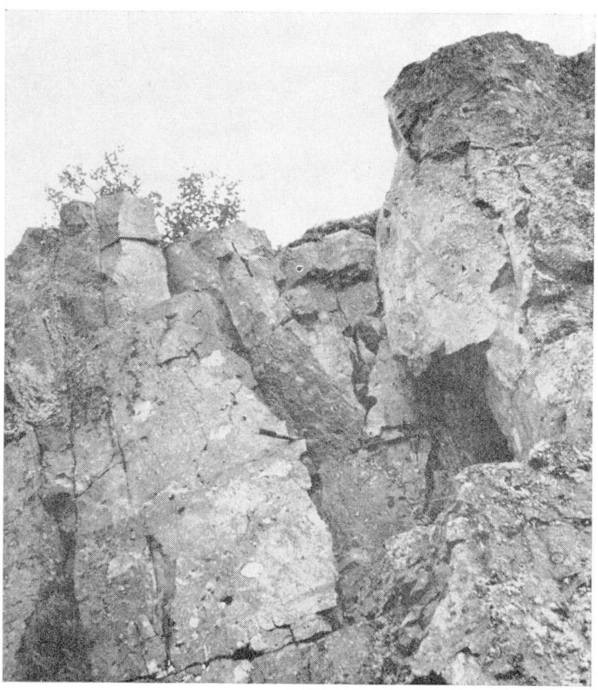
S.H.K., 1959, 2-1

B. View over northwestern part of Volcano Island.

S.H.K., 1959, 2-2

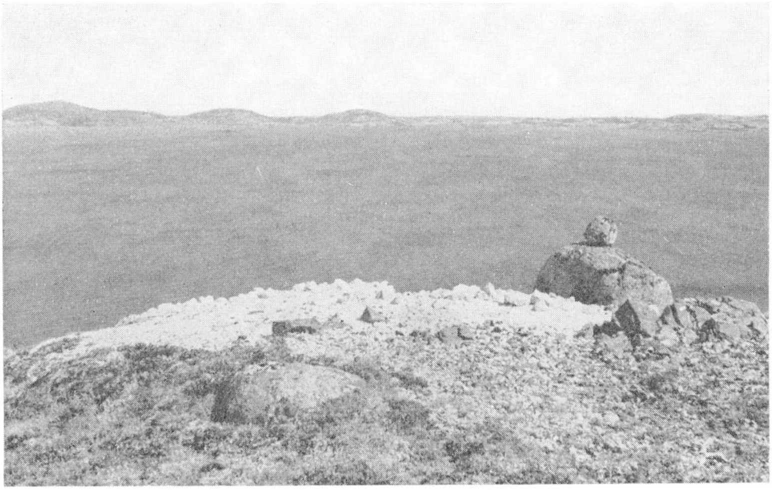
A. Cliffs of volcanic breccia with columnar jointing—southeast side of Volcano Island.

PLATE II



B. Granitic fragments in volcanic breccia.

S.H.K., 1959, 1-15

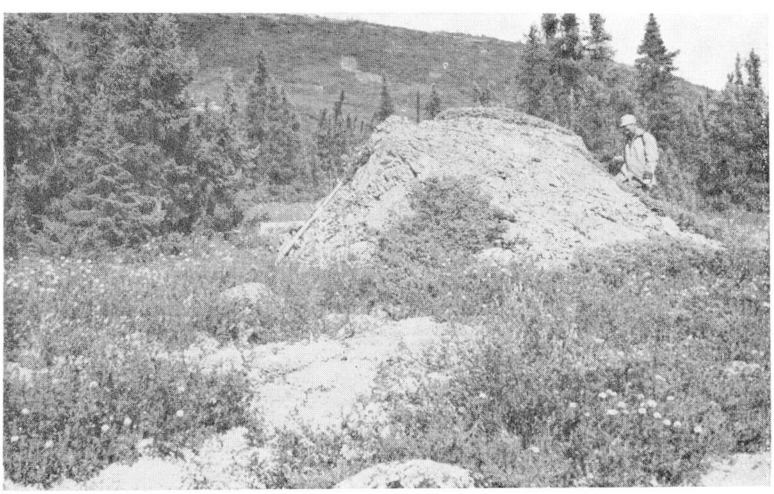


S.H.K., 1959, 2-13

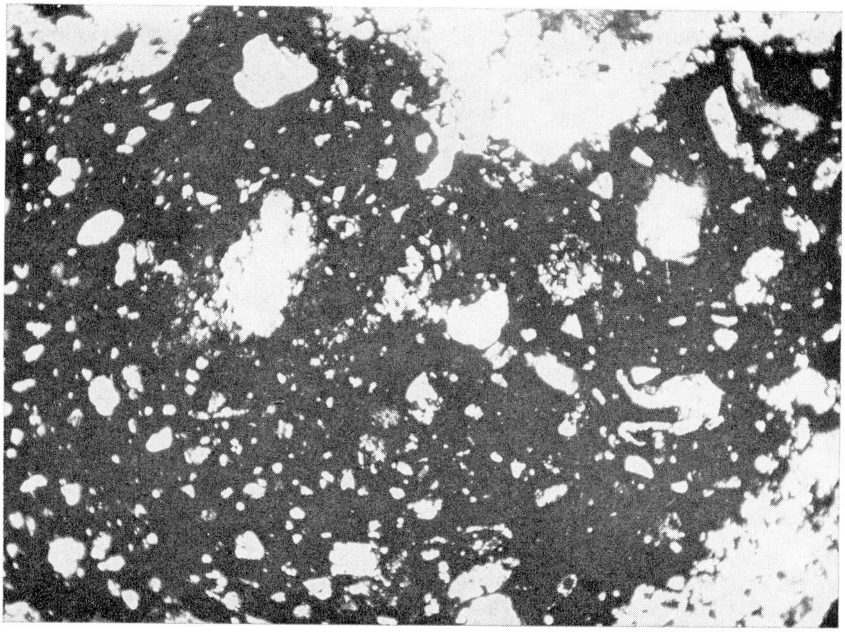
A. Crystalline limestone in contact with volcanic breccia. View from east end of Volcano Island with the southeastern basin of Clearwater Lake visible behind the islands at the horizon.

PLATE III

B. Block of Ordovician limestone on Volcano Island.

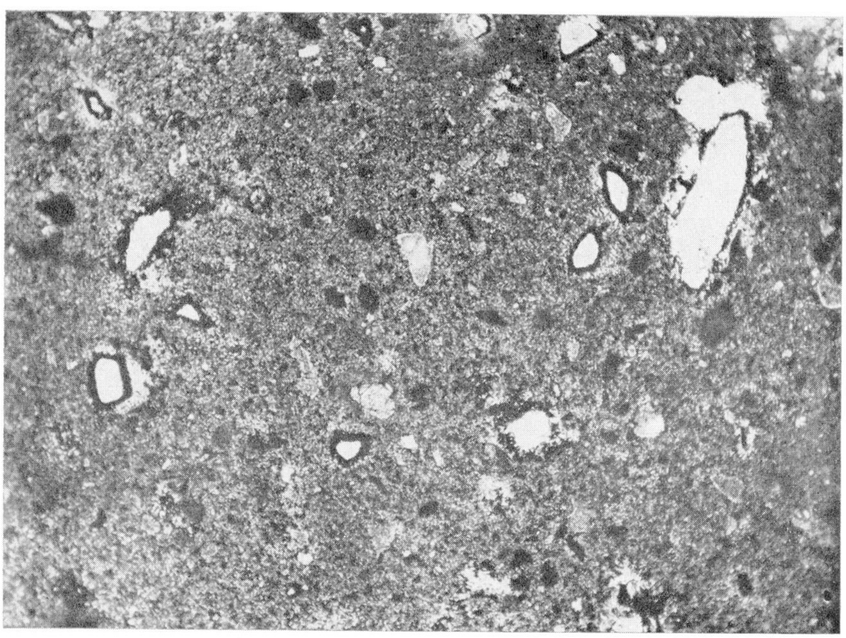


S.H.K., 1959, 2-14



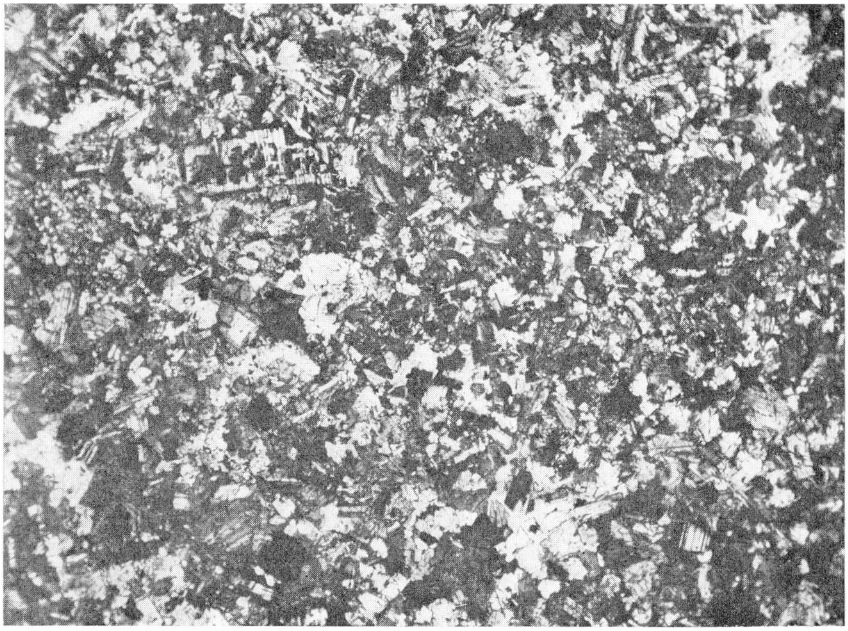
111908-D

PLATE IV. A. Photomicrograph of soft breccia showing rock fragments and shards in opaque, fine-grained groundmass consisting mainly of iron oxide. Non-polarized light, ×18.



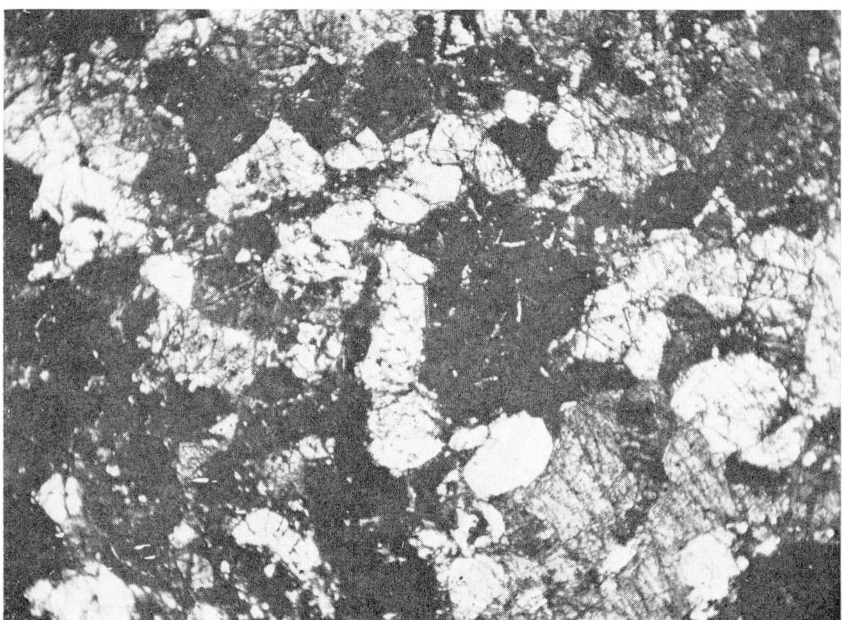
111908-B

PLATE IV. B. Photomicrograph of hard breccia showing corroded rock fragments in fine-grained lava. Note rim of iron oxide and pyroxene around the rock grains. Non-polarized light, ×18.



111908-C

PLATE V. A. Photomicrograph of dark grey lava; composition given in analysis 1. Polarized light, ×18.



111908-A

PLATE V. B. Photomicrograph showing rock composed of pyroxene and glass, probably fused feldspar. From shoal in centre of Clearwater Lake. Polarized light, ×18.