REPORT ON THE GEOLOGY OF THE PURCELL'S COVE AREA, HALIFAX COUNTY, NOVA SCOTIA.

CLAUDE K. HOWSE.

Dept. of Geology, Dalhousie Univ., Halifax, N. S.

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ABSTRACT.

The slates of the Halifax formation form part of the roof of the Devonian batholithic intrusion, and have been considerably metamorphosed by that intrusion, the final consolidation of which took place at considerable depth below the surface. Two types of drag-folds occur, normal and reverse. It is probable that the normal drag-folds were formed during the period of folding of the Halifax-Goldenville formation, and that the reversed drag-folds were formed by the upward force of the magma. The sediments contain large amounts of iron pyrites, appearing definitely as a replacement product, and were a component of the hydrothermal stage of the intrusion. The granite is definitely porphyritic in texture, and in the south of the area is much more coarsely crystalline than in the north. This has been interpreted as due to the domed-shape of the magma in the southern part of the area as it stoped its way upwards. A study of the contact zone shows that the mode of intrusion was by stoping.

The investigation of this area was undertaken as a class in Field Geology at Dalhousie University, for the College year 1932-33. The work was done under the supervision of Prof. G. Vibert Douglas, of Dalhousie.

Purcell's Cove lies to the southwest of North West Arm, Halifax (see Key Map). The area investigated is roughly one-third of a square mile in area, and through the middle of the rectangle surveyed runs the contact zone of the granite batholithic intrusion and the sediments of the Halifax formation. The land rises from sea level to a maximum height of 200 feet, the greatest elevation being the summit of the hill in which the two granite quarries are situated. The general topography is a function of sub-aerial erosion modified by ice movement, the hills and outcrops showing a general parallelism, with the intervening valleys running generally from northwest to southeast, which was the direction of glacial movement. Actual evidences of glaciation will be discussed later.

Method of Survey.

The type of survey used was that of regular straight line traverses. A base line running magnetic N-S was laid out for 2500 feet north of Purcell's Pond, the road and the shore line were traversed, and the three lines tied in by E-W lines. These lines were run by compass and chain.

For the actual geological survey, compass and pace lines were run from the West Boundary Line to the Road, which covered the exposed granite, while to the east of the road the traverses on the sediments were run from North to South. The actual traverse system is shown on the Key Map. The map accompanying the report shows that the Herring Cove Road follows roughly the granite-sediment contact for the greater part of the area.

The survey was run to determine, primarily, the following points:

a. The attitude of the sediments, as the roof of the batholithic intrusion.

b. The effect of the sedimentary roof on the structure and texture of the granite intrusion.

c. The effect of the intrusion on the sedimentary rocks.

d. The manner in which the batholith was intruded.

These will be discussed in the general reports on

I. The Sediments.

II. The Granite.

The Sediments.

The sediments of the area are of pre-Cambrian age and belong to the Halifax Formation[1]. They form here part of the south limb of the Point Pleasant Syncilne[2], and have a fairly uniform dip of 30-35°N. Owing to their nearness to the granite batholith they have been intensely metamorphosed, though at even a few feet from the contact distinct bedding planes can be seen, and it is quite easy to take strikes and dips.

[1]J. W. Goldthwait, "*The Physiography of Nova Scotia,*" p. 8. Can. Geol. Survey, Mem. 140, 1924.

[2]E. R. Faribault, Sheet No. 68, *Province of Nova Scotia Map.* Can. Geol. Survey, 1908.

The Dalhousie Quarry was of great help in the study of these rocks, as here there were to be had good exposures of fresh rock. Jointing is not at all uniform over the area, though it is fairly well developed. A good cleavage is developed along the bedding planes.

The exposed bedding planes of the quarry show several examples of stylolites, or washboard structure. This structure is the result of compression during the period of folding[3]. Fig. VI shows an example of this washboard structure.

Drag-folding in the area has presented some interesting if difficult problems. The major drag-folding is normal[4], and

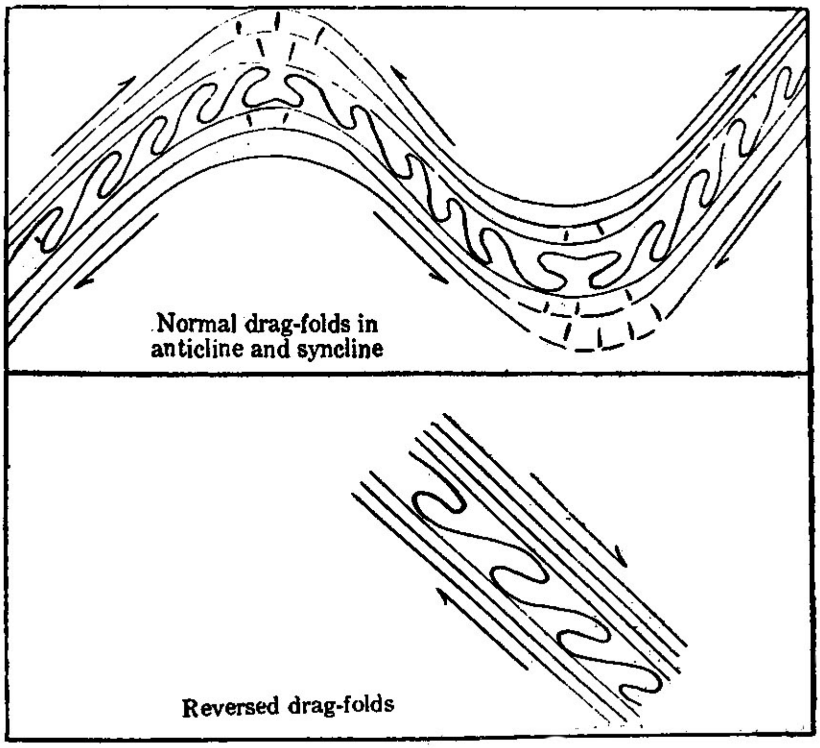


Fig. I.

[3]B. R. MacKay, "*Beauceville Map Area,*" p. 28, Can. Geol. Survey, Mem. 127, **1921**.

[4]Bailey Willis, "*Geologic Structures,*" McGraw-Hill Book Company New York. **1929**. pp. 132, 144, 168.

is developed on a comparatively large scale. A discussion of drag-folding might not be amiss here.

Drag-folding is the response of the weaker beds of a series to a tectonic movement. In the formation of anticlines and synclines in a sedimentary series it is likely that there will be some beds less rigid than the enclosing ones, and when folding occurs the upper part of the incompetent bed will follow the direction of stress of the bed above it and the lower part will follow the direction of stress of the lower bed. In this way characteristic folds are formed. Fig Ia shows the attitude of dragfolds to the opposite flanks of an anticline or syncline, as the case may be. The section through C-D (accompanying map) is an example of a drag-fold in the southern limb of the Point Pleasant syncline, the axis of which is roughly east-west.

If, however, drag folds are found to have an abnormal or reversed attitude, Fig. Ib, to the strata, one of two things must be assumed:

(a) the strata have been overturned 'en bloc', or

(b) forces other than those normal forces producing anticlines and synclines were at work, imposing a stress in a direction directly opposite to those present during the formation of a normal anticlinal structure.

This area is problematical in that distinct normal and reverse drag-folds are both to be found, the two types having been definitely determined in the field by Prof. Douglas and the writer. It is likely that the normal drag-folds were formed during the period of folding and compression, so that no overturning of the beds may be assumed. It is possible that the reversed drag-folds are the result of the granite intrusion. The granite exerted an upward force on the lower part of the enclosing beds, which resolved itself into two forces, one being along the bedding in an upward direction. This is in a direction opposite to that imposed during a period of normal folding, and thus a reversed drag-fold would be formed. This seems to account for the two types of drag-folds, and there is no reason, then, to assume overturning of the beds. In fact, the whole region shows that such a thing has not happened.

Faulting. There has been little pronounced faulting in the area. Four faults have been definitely mapped and appear to have formed when the series was comparatively young and plastic, or when a heavy overburden had given them an imposed plasticity. They can be traced for not more than twenty or thirty feet in any case, and are all normal faults with a displacement of not more than a few inches. Faulting, however, on a scale which might be said to affect the region as a whole, is not present.

Mode of deposition. The sediments in the northern part of the area, i. e., the upper part of the series, show many cases of cross-bedding, but it occurs in all directions, so that while it may be assumed that the sediments were laid down in comparatively shallow water, no conclusions may be drawn as to the direction of the shoreline of the sea of deposition. To the north of the area, along the shore of North West Arm, Prof. Douglas and the writer discovered cross-bedding on a larger scale, from which might be determined the direction of the shoreline, but we were not certain as to whether we were dealing with a very large boulder or an outcrop with its base partly eroded by the sea. It has approximately the same dip and strike as the neighbouring outcrops known to be in situ, and, if it is an outcrop, it provides good evidence that the shoreline was to the south and that the sediments were transported from that direction.

Lithology. Microscopic examination of thin sections shows that the sediments are predominantly quartzitic, with varying amounts of sericite and iron pyrites. The quartz and sericite form an allotriomorphic aggregate, and the pyrite is always to be seen as a definite replacement product. Fig. VII shows pyrite replacing the other minerals.

Cordierite was not identified, though several sections supposed to contain it were examined carefully.

On the eastern side of Purcell's Cove, slightly beyond the limits of the area, an interesting rock formation was observed, and on examination in thin section, it was seen to be made up of a quartzitic rock that had been heavily stained with iron oxide and in these stained areas large beautiful crystals of chiastolite were seen to have developed. Fig. VIII shows these crystals.

All over the sedimentary area there are to be seen, on joint planes at right angles to the dip and parallel to the strike, elliptical formations, from one to six or more feet along the major axis, which is parallel to the bedding planes. They are composed of a material which on a fresh fracture resembles chert. In some of these the original bedding planes are to be seen continuing through the sharply defined border to the surrounding sediments ,while in others laminations appear to have formed typical cross-bedding structure. They are typical shallow water deposits[5], the finer sediments having been rolled together in some way. In thin section there is to be seen a comparatively large amount of secondary pyrite deposition. It is possible that these inclusions were originally composed of more argillaceous material than the surrounding sediments, and were thus more susceptible to replacement by circulating waters.

Another type of 'elliptical inclusion' was found in a large erratic boulder on the shoreline. It was at first thought that the two types has a common origin, but a definite vein system was to be seen feeding these formations, which did not in all cases follow the bedding planes. They are areas where the circulating waters found a greater permeability and a wider range of replacement activity. It is possible that some of the syngenetic elliptical inclusions were modified by a similar process, but there is a distinct difference between the two types. Fig. IX shows a weathered face of a syngenetic inclusion. On weathered surfaces some of these inclusions are seen to have a noticeable white ring around the outer edge. This is a Liesegang effect and is produced by the action of meteoric waters, which formed sulphuric acid by interaction with the iron pyrites, this in turn acting on the aluminous

[5]W. H. Twenhofel, "*Treatise on Sedimentation*", The Williams and Wilkins Company, Baltimore. **1926.** p. 506 et seq.

minerals, forming kaolin[6]. In other types a surface hardening effect is to be seen. The surfaces are of a white siliceous nature, containing cavities from which the pyrites has been leached. This surface effect is due to the action of $Fe_2(SO_4)_3$ working its way up and out of the inclusion, and on the outside surface there is left only the most insoluble of the constituents.

THE GRANITE.

The granite of the area is part of the large Devonian batholith[7] which is over ninety-five miles in length, extending from Halifax through the northern part of Lunenburg County, the southern part of Kings County, down through Annapolis to Shelbourne and Yarmouth Counties. It is distinctly porphyritic in texture, the feldspar phenocrysts often attaining a length of two inches or more.

One of the most outstanding features is the difference in texture of the granites in the north and south of the area respectively. There is a fairly distinct dividing line running east and west through the area along the road running from the Herring Cove Road to the west of the quarries. The average composition of each part is similar, quartz, orthoclase and microcline feldspars, and biotite mica being the component minerals. Biotite however, forms a rather small percentage of the composition, with the orthoclase and microcline forming the greater part of the rock volume. The granite quarries afforded good opportunities for studying the structure and texture of the intrusion, and also in the securing of unweathered samples.

Several 'basic segregations' were found in the remaining quarry-blocks, but when these were placed side by side with xenoliths which were undoubtedly inclusions from the overlying sediments a distinct gradation[8] could be seen, from specimens exactly similar to the sediments at the contact to biotitic segregations so completely altered that it would have

[6]W. Lindgren, "*Mineral Deposits*", McGraw-Hill Book Companv, New York. **1919.** p. 327.
[7]J. W. Goldthwait, "*Physiography of Nova Scotia*", p. 12.
[8]J. F. Kemp, "*The Pegmatites*", Ec. Geol. Vol. XIX. No. 8. Dec., **1924.**

been impossible to correlate the two without the intervening types. The development of cyanite in these segregations is further proof that the processes which these segregations underwent were related to those of contact metamorphism[9]. Fig. X shows these crystals of cyanite developing in a larger grain of quartz.

The jointing of the granite was mapped rather carefully, and though it might be said that there is a tendency to two sets of joints, one at about 50° and another at 110°, the area is so small and the divergences so large that no definite information may be deduced from them.

Two zones of local shearing were observed but in each case they appeared superficial and were probably a function of late cooling of the magma.

The shoreline from the granite quarry to the south boundary line gives a wonderful picture of the mode of intrusion of the magma. It is generally accepted[10] that there were three miles of Goldenville formation originally underlying the slates of the Halifax formation. There must have been a considerable thickness of Archean rock to withstand the enormous pressures of these sediments during and after their formation. Also, the total vertical thickness of the formation was considerably increased during the period of folding. The magma stoped[11] its way up through this enormous thickness of solid rock, and along the shoreline there is ample evidence to show that magmatic stoping was the means of ascent. Granite dykes are to be seen cutting the sediments in all directions, and it requires very little imagination to see the three-dimensional attitude of the granite to the sediments.

Along the shoreline, too, there are to be seen lenticular pegmatites[12] containing quartz, orthoclase and muscovite.

[9] F. F. Grout, "*Petrography and Petrology*", McGraw-Hill Book Company, New York, **1932**. p. 356.

[10] J. W. Goldthwait, "*Physiography of Nova Scotia*", p. 8. W. Malcolm, "*Gold Fields of Nova Scotia*", Can. Geol. Survey. Mem. **156**, **1924**. p. 29.

[11] R. A. Daly, "*Igneous Rocks and their Origin*", McGraw-Hill Book Company, New York, **1914**. Ch. X.

[12] F. F. Grout, "*Petrography and Petrology*", p. 69 et seq.

The crystals are large and the quartz predominates. They are similar to the pegmatites of Minnesota described by F.F. Grout, being concentrated at the edge of the granite mass, with their walls merging into the surrounding granite without marked delineation. In the north of the area there is an absence of these lenticular pegmatites, but there are several aplitic dykes cutting the granite. The majority of them are from two to three inches in width and can be traced for from ten to fifty feet, but one larger one occurs. It is well over one foot in width and can be traced for a hundred feet or more, retaining its aplitic structure throughout.

In the small quarry at the northwest of the area only one pegmatitic aggregation was observed. It is on one of the vertical faces of the quarry and is circular, about one foot in diameter. In texture it resembled the coarse-grained pegmatites, but its walls were sharply defined and it could not be determined whether, in three dimensions, it was circular, ellipsoidal, or pipelike.

In this area the complete physico-chemical history[13] of a cooling magma can be traced. The first period of cooling and solidification is represented by the granite. This orthomagmatic stage passed into the pneumatolytic stage with the formation of the pegmatites. The next stage was the hydrothermal, when the hydrothermal solutions worked their way through the sediments and deposited iron pyrites, while in the joint planes of the granite there are to be found small amounts of fluorite.

GLACIOLOGY.

The area shows distinct evidences of the Pleistocene glacial movement. The North American ice sheet spread from three or four centres[14], the main two being the upland districts, east and west of Hudson's Bay respectively. It is not known how thick this ice-sheet was in Nova Scotia, but in the Eastern United States it is known to have passed over

[13]P. Niggli, "*Ore Deposits of Magmatic Origin,*" Thomas Murby and Sons, London, **1929**. Ch. 1.

[14]J. W. Goldthwait, "*Physiography of Nova Scotia*", p. 60.

mountains 6000 feet in height, and it may be assumed that it attained at least that thickness in Nova Scotia. In parts of the province it rearranged the old and deposited new regulus[15], but in the area under investigation there is no evidence of such a happening. The granite is for the most part bare, except for a few inches of regulus, which are undoubtedly the result of post-glacial subaerial erosion. This erosion has removed all traces of striae or chatter marks which the ice-sheet might have left on the granite.

The sediments, however, have preserved perfectly the marks left by the ice. Striae and Lee and Stoss slopes are common, and there is a divergence of some fifteen degrees in the directions of the striae at different points. There are several well marked grooves, one to the east of the Dalhousie quarry being about eight feet deep, with the sides showing characteristic striation. Several large sedimentary boulders similar in composition to, and possessing the same degree of metamorphism as the sediments of the area are to be seen a short distance to the south of the Stone Pier, North West Arm. The greater part of the sediments is covered by a mantle too thick to allow detailed mapping. In the contact zone along the shoreline the grooves cut by the ice have left wonderful exposures of the granite dykes cutting the sediments, and afford a good opportunity to get a clear idea of the mode of injection of the magma.

Lee and Stoss slopes and striae show that the direction of movement was from northwest to southeast.

If the steep sides of North West Arm are examined, evidences of glaciation will be found. It can then be assumed that the existing valley is an older structure modified by the ice movement.

Structural History to be Inferred from Observations.

There is a remarkable uniformity in the dip and strike of the sediments along the contact zone, the general strike being

[15]Idem, p. 63. Cf., J. W. Dawson, "*Acadian Geology*", Macmillan & Co., London, **1878**. Ch. V.

magnetic E-W, and the dip from 30-50°N. From this it can be assumed that at the time of the intrusion there was a thickness of thousands of feet of rock above the now exposed contact zone, and that the magma stoped, rather than pushed, its way upward, appearing to favour an anticlinal structure rather than a synclinal. All along the shoreline to the south of the granite quarry the granite may be seen pushing its way in all directions into the sediments.

The xenoliths found enclosed in the granite of the quarry vary from blocks which are not more metamorphosed than the sediments at the contact to almost completely digested portions resembling basic segregations[16].

The slates of the Halifax formation were formed into their well-known anticlinal structure during the Caledonian period of mountain building[17]. From the extreme regularity of the formations it is evident that the sediments at this time were in a comparatively plastic condition, though the plasticity might have been imposed by a great weight of overlying rock. On the advent of the magma and its subsequent cooling through the orthomagmatic to the pneumatolytic stage it seems as if the sediments were rather impermeable, which would account for the lenticular pegmatites to be found along the contact zone, their further passage having been stopped by the impermeability of the sediments. Upon the advent of the magma the heat tended to indurate them and its upward force probably produced the jointing, resulting in a very much increased permeability. As a result, the later phases of the pneumatolytic stage and the solutions of the hydrothermal stage were able to permeate the country rock, and, owing to lack of any particular structural control, iron pyrites was injected almost indiscriminately through the sediments. The solutions worked

[16]F. D. Adams, A. E. Barlow, "*Geology of the Haliburton and Bancroft Areas, Prov. of Ontario*", Can. Geol. Survey, Mem. 6, **1910**. p. 87. H. H. Thomas and W. Campbell Smith, "*Xenoliths of Igneous Origin in the Tregastel Ploumanac'h Granite, Cote du Nord, Frence.*" Quart. Jour. Geol. Soc. London, Vol. **88**, (May, 1932). Charles H. Warren and Charles Palache, "*Pegmatites of Quincey, Mass.*", Geol. Soc. Am. **21**, p. 784. (1910).

[17]W. Malcolm, "*Gold Fields of Nova Scotia,*" pp. 39-40.

their way along the jointing and bedding, and most of the pyrite is to be found as a replacement product along the bedding planes. Polished sections and thin sections confirm this.

The distinct difference in texture of the granite of the north and the south of the area is to be explained by structural control. Fig V gives a diagrammatic representation of this, being a section drawn through E-F on the accompanying map. The batholith formed a great dome[18] projecting upward into the sediments. Along the contact with the roof it cooled quickly with the formation of fine-grained granite, and, in addition, during the cooling of the surface there was contraction, with the formation of aplite dykes. Later subaerial and glacial erosion have removed that portion above the present erosion surface, on which we get the two distinct types of granite.

Economic Geology.

The area has furnished no economic minerals, but large amounts of both granite and sediment have been quarried for building stone, and some thousands of tons of granite were used as filling by the Halifax Harbour Commission in the construction of the Ocean Terminals. Five quarries exist in the area, though none are at present being worked. Three are in the granite, the two large ones in the centre of the area being known as the King's and the Queen's quarries. These furnished the material for the Ocean Terminals, the Canadian Bank of Commerce in Halifax, and for several other building projects. The quarries in the sediments are the property of Dalhousie University, and furnished the stone for the facing of the buildings on Studley Campus, and the Cathedral of All Saints, Halifax. The quarry in the northwest of the area is a smaller quarry which was worked several years ago for building stone.

It has been ascertained from quarrymen who worked in the King's and Queen's quarries that the rift was along a

[18]F. F. Grout, "*Petrography and Petrology*", Fig. 140, p. 218.

horizontal plane, the grain on a vertical plane running approximately N-S, and the hardway a vertical plane running E-W.

SUMMARY AND CONCLUSIONS.

The contact of a granite batholith with the slates of the Halifax formation runs through this area. The sediments show contact metamorphism and hydrothermal replacement as a result of the intrusion. The upward force of the magma caused reversed drag-folding in some of the sediments.

The granite formed a high dome in the southern part of the area, the northern part, as at present revealed by erosion, being near the contact, and consequently finer-grained than that to the south.

Enormous masses of iron sulphide are disseminated in this area and in its vicinity, and are to be found as a replacement product in the sediments of the area.

This iron sulphide undoubtedly represents the hydrothermal stage of the magmatic differentiation.

ACKNOWLEDGEMENTS.

The writer wishes to acknowledge the help of Messrs. Sheppard, Johnston, and Sutherland, who assisted in field and laboratory investigations; of Miss Helen Belyea, who assisted in the making of thin sections; and, finally, that of Prof. Douglas, for his criticism and advice in the preparation of this report.

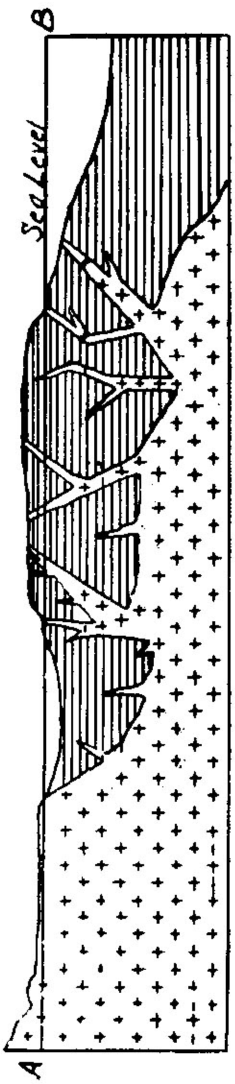


Fig. IV. Diagrammatic section through A-B.

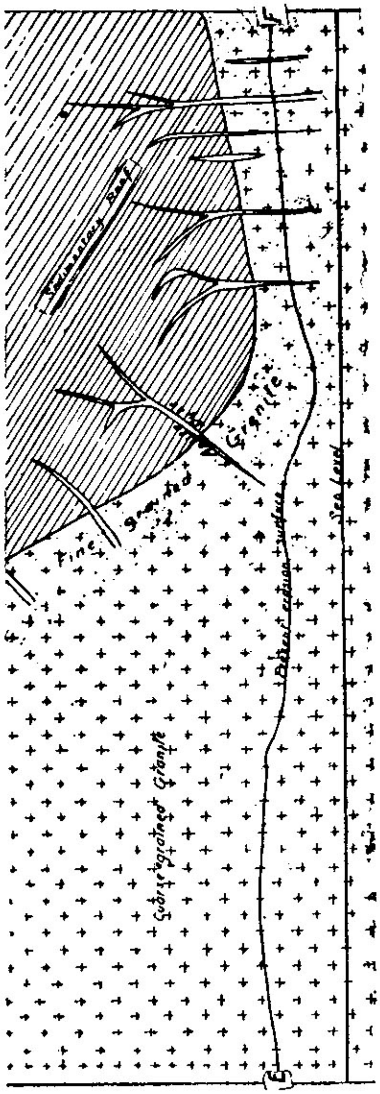


Fig. V. Diagrammatic section through E-F.
To explain difference in texture of granite in North and South of area.

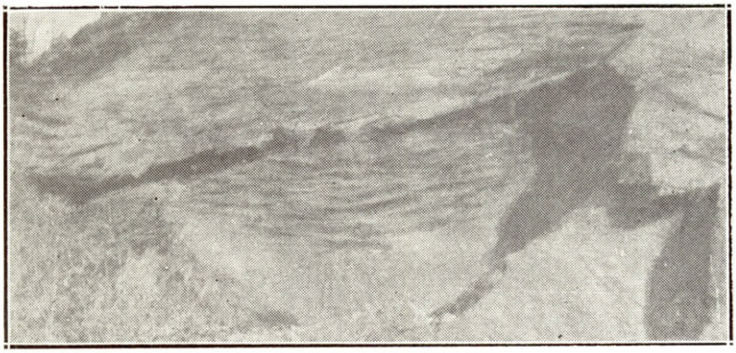


Fig. VI. Stylolites or washboard structure in sediments.

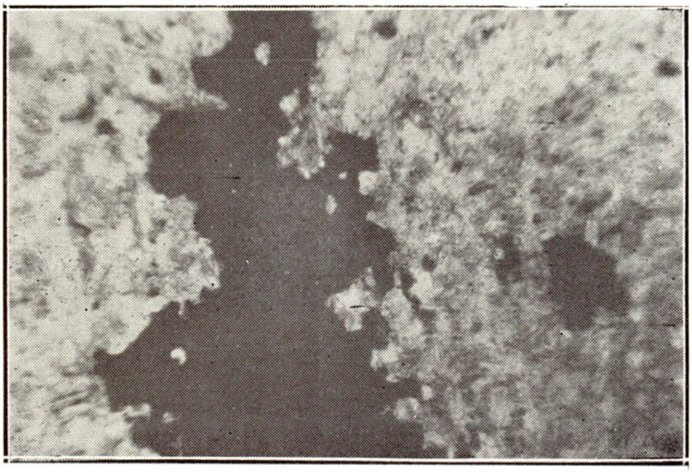


Fig. VII. Photomicrograph of pyrite replacing quartz and sericite. x100.

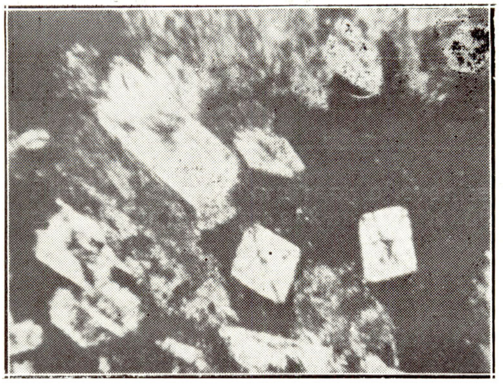


Fig. VIII. Chiastolite crystals in sediments stained with iron oxide. ×80.

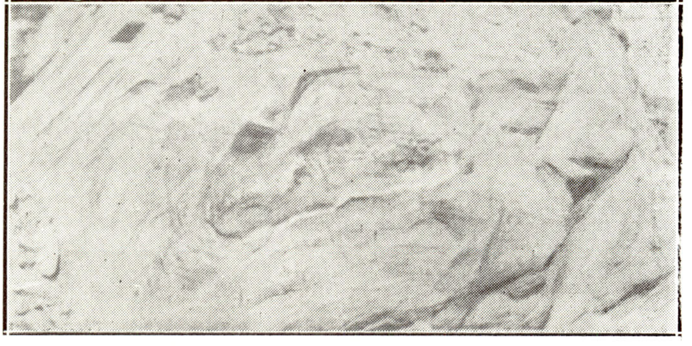


Fig. IX. Weathered syngenetic inclusion, showing Liesagang effect due to leaching.

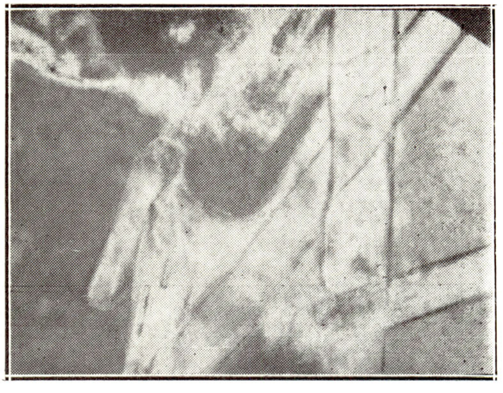


Fig. X. Photomicrograph of cyanite developing in quartz of xenolith. ×250.

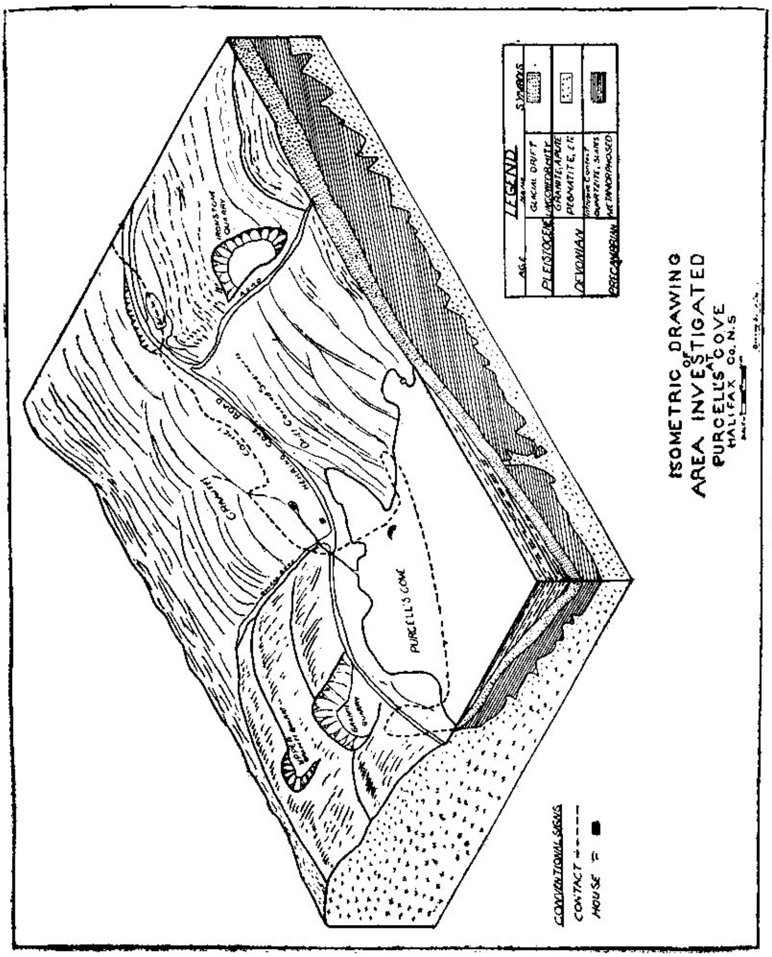

ISOMETRIC DRAWING
OF
AREA INVESTIGATED
AT
PURCELL'S COVE
HALIFAX Co. N.S
LEGEND
AGE
SYMBOLS
PLEISTOCENE
GLACIAL DRIFT
UNCONFORMITY
DEVONIAN
PRECAMBRIAN
CONVENTIONAL SIGNS
CONTACT
HOUSE
PURCELL'S COVE
IRONSTONE QUARRY
ROAD

Fig. XI.

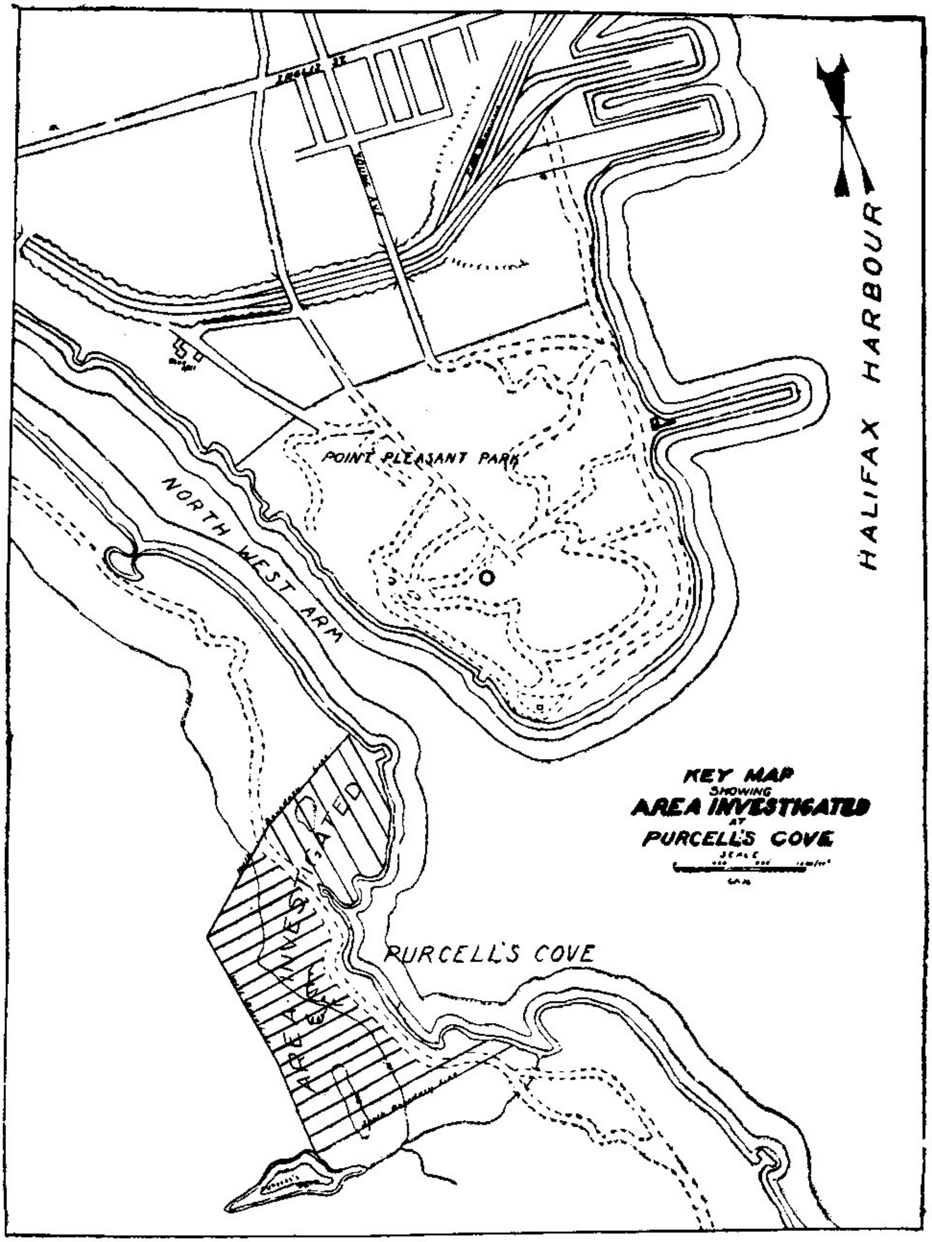
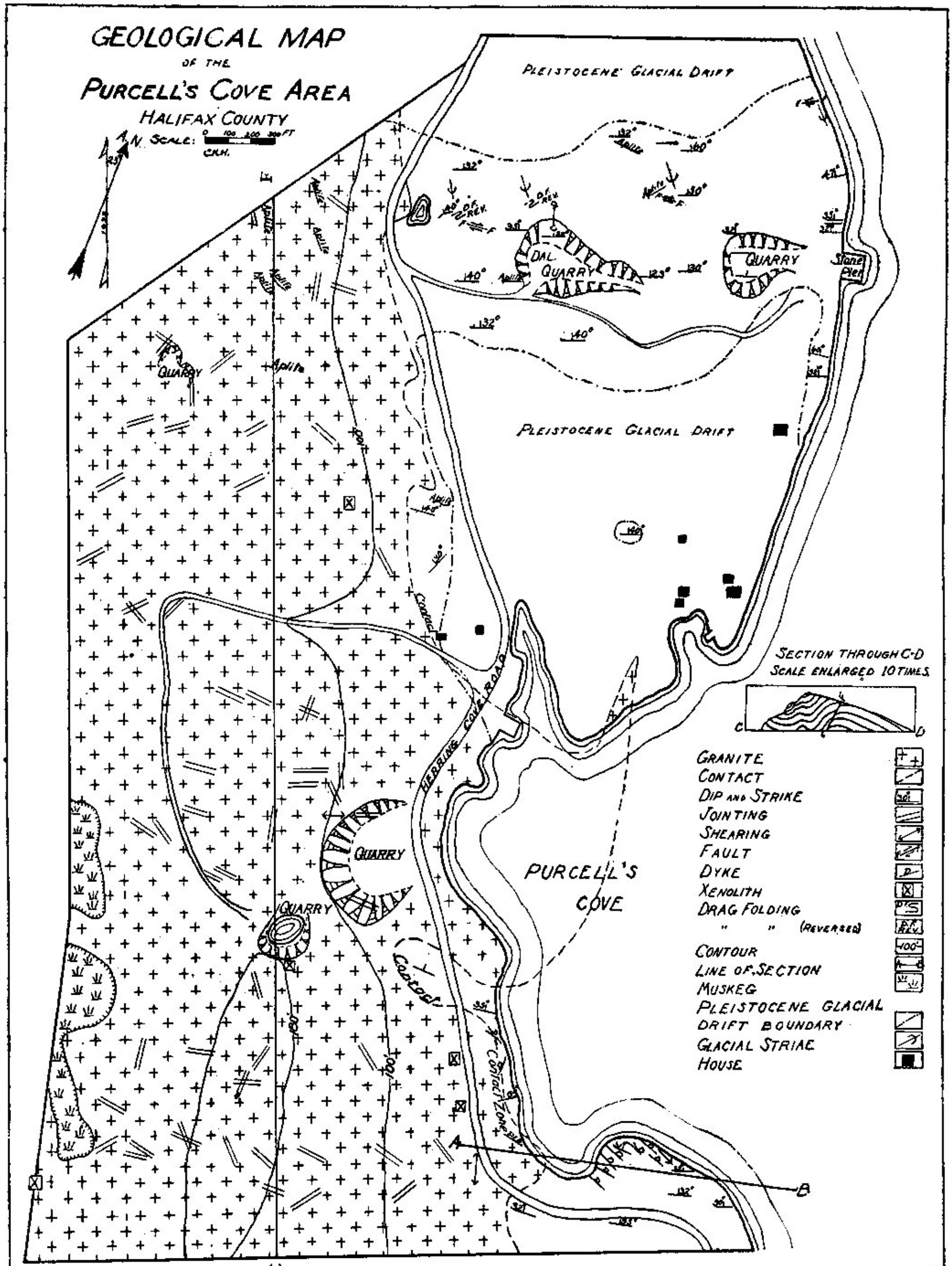

INGLIS ST
POINT PLEASANT PARK
NORTH WEST ARM
HALIFAX HARBOUR
KEY MAP
SHOWING
AREA INVESTIGATED
AT
PURCELL'S COVE
SCALE
PURCELL'S COVE

Fig. II.


GEOLOGICAL MAP
OF THE
PURCELL'S COVE AREA
HALIFAX COUNTY
SCALE: 0 100 200 300 FT
PLEISTOCENE GLACIAL DRIFT
PLEISTOCENE GLACIAL DRIFT
DAL. QUARRY
QUARRY
QUARRY
QUARRY
QUARRY
Stone Pier
Aplite
Contact
Contact
Contact Zone
HERRING COVE ROAD
PURCELL'S COVE
SECTION THROUGH C-D
SCALE ENLARGED 10 TIMES
C
D
A
B
GRANITE
CONTACT
DIP AND STRIKE
JOINTING
SHEARING
FAULT
DYKE
XENOLITH
DRAG FOLDING
" " (REVERSED)
CONTOUR
LINE OF SECTION
MUSKEG
PLEISTOCENE GLACIAL DRIFT BOUNDARY
GLACIAL STRIAE
HOUSE