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CONDITIONS OF SEDIMENTATION OF THE HALIFAX FORMATION AS OBSERVED IN POINT PLEASANT PARK.

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ABSTRACT.

The Precambrian sediments in Point Pleasant Park consist of a series of alternately banded quartzites and slates. These bands are in turn finely laminated and show cross-bedding of a minute current ripple type. The rocks are metamorphosed to a certain extent and the slates have a typical spotted appearance, the spots being the residual unaltered rock. These deposits, which are some 30,000 feet in thickness, have been laid down in a broad sinking geosyncline. The rhythmical banding is the result of the rapid deposition of sands from rivers in flood followed by the slower deposition of silts after the flood season is past. These have accumulated in a shallow sea, the bottom of which has been stirred by waves and currents causing the typical cross-bedding.

The object of our work is to find a satisfactory hypothesis to explain the conditions under which the sediments of the Halifax formation were laid down. This problem resolves itself into three parts: 1. What general conditions existed to enable such a thickness of sediment to be deposited? 2. What caused the alternating beds of quartzite and slate which give the rocks their present banded appearance? 3. What is the explanation of the minute cross-bedding so prevalent throughout the area?

GENERAL GEOLOGY.

Point Pleasant Park is the southern part of the Halifax peninsula. The country is largely overlain by glacial drift and outcrops are found chiefly round the shore. The land rises from sea level to a maximum height of 100 feet. The general topography has been very much modified by military earthworks. Fig. I.

The rocks are sediments belonging to the Halifax formation which rests on the Goldenville quartzites and extends the length of the South Shore of Nova Scotia. The Halifax formation is approximately 15,000 feet in thickness[1]. The Halifax-Goldenville formations are now generally accepted as Precambrian in age. W. A. Bell[2] suggests that they may be correlated with the Avalonian of Newfoundland, a series of Precambrian sediments consisting of conglomerates, quartzites and slates. The rocks in the Park were folded during a period of mountain-building at the close of the Silurian. Thus they are now part of what is known as the Point Pleasant Syncline the axis of which runs practically east and west and plunges to the west. The outcrops on the south west shore show evidence of a minor fold with its axial plane nearly parallel to that of the major synclinal axis. During this process incompetent beds were extensively drag-folded. Very fine examples of this are to be seen near the Martello Tower. This period of mountain building was followed by the intrusion of the great granite batholith, a portion of which comes in contact with the sediments at Purcell's Cove. This intrusion came in either at the close of the Silurian or early in Devonian times. This, as well as the folding itself, is responsible for the metamorphism of the rocks from sandstone and mud to quartzite and slate. During the following Mesozoic and Tertiary eras, with the exception of a few down-warped areas where rocks of Carboniferous age have been laid down unconformably on the Halifax formation, this district must have been dry land, as there is no further sedimentation. The next event of importance in its geological history is the great Pleistocene ice sheet, when the whole country was planed off by glaciation. Several outcrops show glacial striae. In one

[1] J. W. Goldthwait. *Can. Geol. Survey, Mem.* **140**, p. 8. (1924).
[2] W. A. Bell. *Can. Geol. Survey, Mem.* **155**, p. 22, (1929).

Fig. II. Rhythmic Banding Due to Seasonal Deposition.

place there is a very good example of "roche moutonnée," grooving, and plucking, caused by the passage of the ice. The ice sheet evidently advanced from north to south. This suggests that it was part of the Labrador sheet, as Dr. A. P. Coleman has postulated in his "Ice Ages Recent and Ancient"[3]. This conflicts with Grabau[4] who considers it a part of the Newfoundland sheet, but, if Grabau were correct, the glacial striae would lie east and west.

PETROGRAPHY.

The sediments in the Park present a rhythmically banded appearance. This is caused by the alternation of beds of gray quartzites with beds of slate, the quartzites usually being of a lighter colour than the slates. Fig. II. The width of these alternating beds varies from a fraction of an inch to several feet. The quartzites are as a rule thicker. These beds in turn are finely laminated with darker and lighter layers varying from microscopic proportions to perhaps a quarter of an inch in width. A microscopic examination has shown that the lighter layers consist almost entirely of quartz and that the dark laminae are caused by flakes of biotite and iron minerals.

A notable feature of the rocks is the characteristic cross-bedding which appears in the majority of the quartzite beds and many of the slate ones. "Cross-bedding is commonly present in sands and consists of their arrangement in parallel laminations transverse to the planes of general stratification the latter commonly truncating the upper edges of the laminations[5]".

Our cross-bedding is of a minute type and the foreset beds dip in all directions at varying angles. The topset beds are truncated and the foreset beds make tangents with the bottomsets, suggesting that deposition has been followed by

[3] A. P. Coleman. *Ice Ages Recent and Ancient,* The MacMillan Co., New York, **1926**, p. 11.

[4] A. W. Grabau. *Principles of Stratigraphy,* A. G. Seiler and Co., New York. **1913**, p. 326.

[5] W. H. Twenhofel. *Treatise on Sedimentation,* Williams and Wilkins Co. Baltimore. **1926**, p. 439.

erosion. The cross-bedding is repeated across the length of a bed and in many cases one band contains two layers of it with horizontal laminae between. The inclined beds range from one to four inches in length and show an angle of inclination of from 12° to 23°. The thin sections show a microscopic cross-bedding in several places barely visible to the eye. Fig. III.

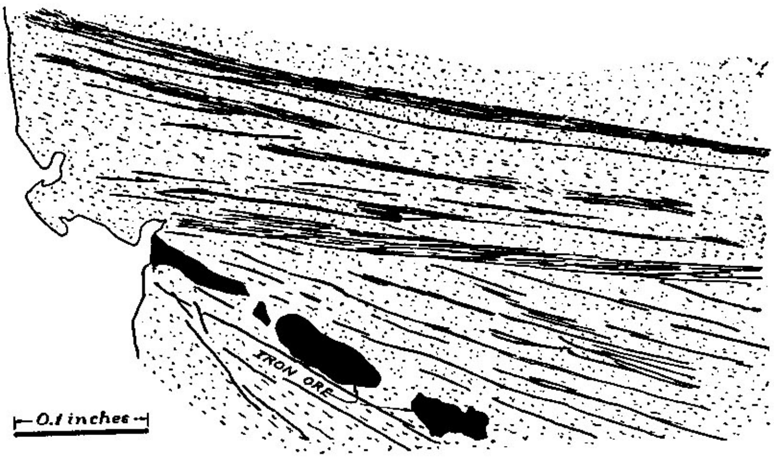

FIG. III. Enlarged Thin Section Showing Cross Bedding.

The typical quartzite beds are composed of small irregularly shaped crystals of quartz which range in diameter from an average of 0.04 mm. in some beds to 0.10 mm. in other beds. These crystals are held together by a fine sericitic cement which seems to be of the same composition as the ground mass of the slaty member. Most of the quartzite shows an abundance of biotite flakes and in some a small amount of plagioclase feldspar was observed. Both the quartzites and the slates show abundant iron minerals, chiefly pyrite, and some outcrops show a distinct iron stain. Garnet was observed in a section from a nodule.

The typical slates consist of scattered crystals of quartz and biotite embedded in a fine crystalline ground mass composed chiefly of quartz, biotite, muscovite, sericite and iron minerals. The slates present a characteristic spotted appearance.

These rocks are all metamorphosed to a certain extent, though the slates show a higher degree of metamorphism than the quartzites. This is to be expected, since the argillaceous material which forms the slates offers less resistance to heat and pressure than quartz and, furthermore, these beds are more permeable than the quartzitic beds. Metamorphism has not destroyed the original bedding planes of the quartzites but has accentuated them, since what alteration there is has tended to take place along the bedding planes leaving the interbedded portions unchanged. The alteration found here along the bedding planes is very similar to that found in the arenaceous shales of Roundout, N. Y.[6]

The successive stages of advancing metamorphism are indicated by corresponding mineralogical changes, each successive stage or zone having a characteristic mineral. Dr. Harker[7] has named the zones of progressing metamorphism according to their characteristic minerals.

ZONES OF METAMORPHISM

(0) Zone of clastic micas.
(1) Zone of digested clastic micas.
(2) Zone of biotite.
(3) Garnet zone.
(4) Staurolite zone.
(5) Cyanite zone.
(6) Sillimanite zone.

According to this classification our rocks would be placed for the most part at the end of zone (1), the zone of digested clastic micas, or perhaps intermediate between this and zone (2), the biotite zone. The abundance of biotite in the rocks

[6] R. W. Clark. *Petrographic Collection of American Rocks.* Ward's Natural Science Establishment, Rochester, N. Y., 1916.

[7] A. Harker. *Metamorphism,* Methuen and Co., London, 1932, p. 208.

would suggest this, although we are not certain to what extent this biotite is an alteration product. One of the less resistant beds shows garnet, which is typical of zone (3). The spotted slates present the most interesting problem. The spots are darker in colour than the body of the rock and are surrounded by a light halo which grades into the general ground mass. The spots are due to an accumulation of tiny black iron minerals with the extremely minute crystals of quartz and mica. The halos surrounding the spots consist chiefly of fine quartz and sericite.

The explanation of how these spots were formed is open to question but we believe they are residual unmetamorphosed rock which has been the last to resist alteration, rather than the spots in which metamorphism has taken its beginning and from which the alteration would be expected to spread. Our hypothesis is as follows: The argillaceous material of the ground mass has been altered and this alteration is spreading throughout the rock, the sericitic halos around the spots being the advance phase of the alteration which has not yet touched the spots to any extent. This view is further supported by the fact that the original bedding planes are quite evident in the spots though they have been completely obliterated in the surrounding ground mass. Some exhibit fracture cleavage crossing the bedding planes which is comparable to that shown by Leith.[8]

EXPLANATION.

It is impossible logically to consider the origin of these banded rocks without first forming a general picture of the conditions under which the Halifax formation was laid down. Professor Schuchert[9] has postulated that in Precambrian times the Appalachian Geosyncline covered this area, its northern shore lying in the region of the present Gaspé Peninsula, its southern following approximately the line of the Grand Banks.

[8] C. K. Leith. *Structural Geology*, Henry Holt and Co., New York, **1913**, p. 149, fig. 52.

[9] Pirrson and Schuchert. *Introductory Geology*, John Wiley and Sons, **1924**, p. 498.

Fig. IV. If this is a correct conception these sediments are being laid down nearly in the centre of a broad shallow inland sea. In contrast to modern inland seas, the ancient geosynclines seem to have had practically flat bottoms and thus the sea was nearly the same depth over the whole area.[10]

These conditions correspond to the facts which we have observed as follows: Cross-bedding, the extent of which has

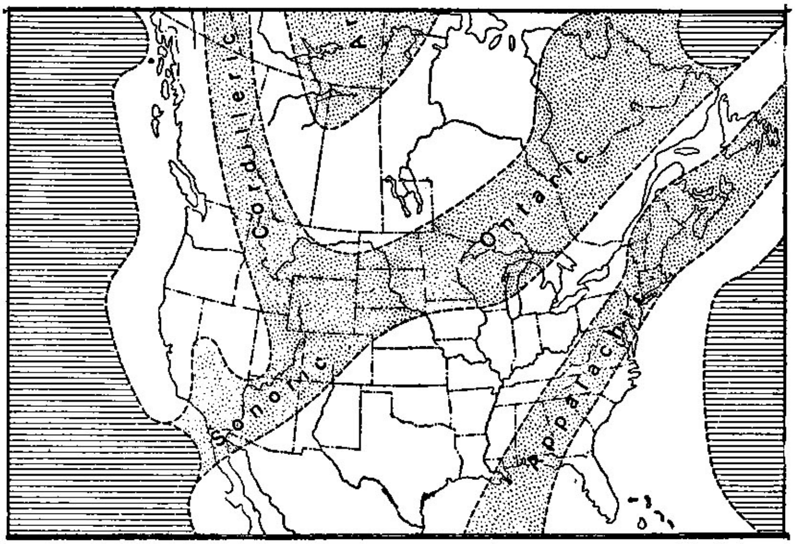

FIG. IV.
North America during the later Proterozoic. After Schuchert.

already been mentioned, is essentially a shallow water phenomenon. "When aquatic, cross-bedding is indicative of shallow water marine conditions".[11] It is obvious that this must be the case since such a structure could not be developed in water too deep to be affected by waves or currents. The reasons for believing this cross-bedding to be aquatic, not aeolian, will be discussed later. Our belief is that muds and sands

[10] Joseph Barrell, *Bull. Geol. Loc. of Am.*, vol. 23.

[11] J. M. Marr. *Deposition of the Sedimentary Rocks*, Cambridge University Press, **1929**, p. 40.

were carried down by one or more rivers and deposited beyond the delta region. The suggestion that these sediments were deposited at some distance from the shore line is borne out by the fact that no conglomerate is known either in the Goldenville or in the Halifax formation. The larger pebbles which form conglomerates are always deposited first fairly close to shore, while the finer sands and silts of which the quartzites and slates are composed are carried farther out.[12] At this point it should be noted that the Halifax formation, and the Goldenville underlying it, constitute one great series in which the Goldenville is predominantly quartzite with lesser amounts of interbedded shale. The Halifax formation on the other hand, as has been pointed out, has more shale members than the Goldenville. This order suggests that the seas, at the time when the Goldenville formation was being laid down, were deeper than the seas at the time of the deposition of the Halifax formation and thus the silts were carried further out. This points to a lag in isostatic readjustment at the beginning of this great period of sedimentation, or alternately it means that in Goldenville times rainy conditions were much more extensive than dry, whereas in Halifax times the seasons were about equally divided.

The conditions in the basin of deposition while these sediments were being laid down must have been very uniform. However, to allow a thickness of thirty thousand feet to be deposited under similar conditions in a shallow trough, the sea floor must have been slowly sinking, thus keeping the water at an approximately constant depth.[13]

If these deposits were laid down, as has been suggested, quite far out from shore, what caused the formation of alternating bands of quartzite and slate? The Baron de Geer has made a study of banded clays which he describes as the result of seasonal downwash from glaciers. In the summer when the ice is melting a quantity of material is brought down and forms a light coloured band. In the winter when less material

[12] J. M. Marr. Loc. cit., p. 79.

[13] F. F. Grout. *Petrology and Petrography*, McGraw-Hill Book Co., New York, 1932, p. 319.

is deposited a narrower dark band is formed. These bands are known as varves and form a valuable record of the annual deposition from glaciers.[14]

There are several other ways in which rhythmic banding may develop[15]. It may be due to weather changes. That is, it may be caused when the sea bottom is disturbed by storms and sand is carried out and deposited in the silt area. As conditions return to normal the sand settles into a distinct layer and mud is laid down over it again. In this way successive storms cause bands of differing materials to be formed.

It is possible that banding is also caused by climatic cycles in which a number of mild years are succeeded by years of more rigorous weather; the cycle, repeating itself, forms bands. An example of this is the Bruckner Cycle in which similar conditions recur every thirty-five years.

Rise and fall of sea level causes alternating bands of detritus. As the sea advances sands are laid down over the former conglomerate area and then muds on top of that. When the sea retreats the process is reversed. It should be made clear that by change of sea level a much more lasting condition is implied than a temporary change caused by tides or floods.

Lastly, rhythms may be caused by seasonal changes. During the flood seasons material of a certain coarseness is deposited and then in the dry season finer material is washed down over it, so that two beds represent a year's deposition.

One must consider each possibility with reference to the existing conditions in the banded rocks with which we are dealing. Firstly, could they be glacial varved clays? There are two reasons why this is not probable. Most varved clays contain an occasional striated pebble showing definitely that they are of glacial origin. We have not found a trace of one. De Geer describes varves as having a thin bed of fine material for the winter deposit and a thicker layer of coarser material for the summer. In many outcrops in the Park, on the other hand, the fine grained slate predominates over the coarser

[14] R. W. Sayles, *Bull. Geol. Loc. of Am.*, vol. 27, no. 1, p. 111.
[15] W. H. Twenhofel. Loc. cit., p. 442.

quartzites, but there is no constant relationship between the two. Fig. V.

It seems improbable that banding so uniform in nature and extending over such an area should be caused entirely by storms though it is possible that they may affect the thickness relation between certain bands.

There is no evidence to suggest that the relationship between mild and stormy years followed any definite cycle.

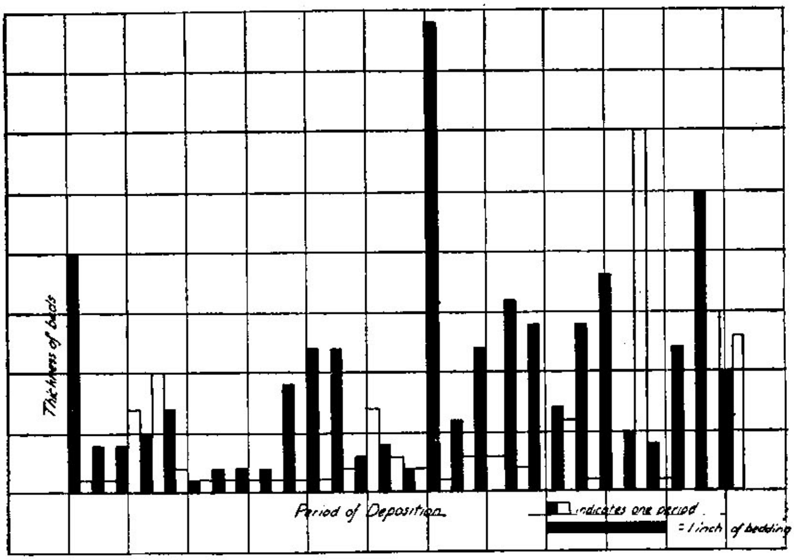

FIG. V. Rhythmic Banding, Oakland Road Ferry.

The relationship between their thicknesses is too variable to suggest such a succession.

In the next case, when a twelve foot vertical section of rock shows as many as fifty bands it seems hardly possible that these are caused by a successive rise and fall of sea level. In this connection Graton speaking of the Witswatersrand says, "One might admit a moving beach as the cause of moving one mantle of pebbles but I could not tolerate such a means for a succession of horizons".[16] This applies equally well,

[16] L. C. Gratan, *Economic Geology Supplement*, May 1930, p. 23.

in our own case where numbers of successive beds show such similar characteristics.

After studying these possibilities and the rocks themselves we have finally come to the conclusion that the banding is due to seasonal change. We visualize a broad shallow sea receiving the drainage from a number of rivers. During the rainy season when the rivers are in flood coarser material was brought down and deposited while the finer silts remained in suspension. During the dry season when the volume of water was less, finer silts were brought down and deposited over the sands along with the material already in suspension. The width of each bed is thus determined by the length of a season. During a number of years this type of deposition leaves a good deal of scope for variation in relationships between the thickness of light and dark beds such as are shown in the sediments in the Park. These suggestions agree with those of the late Professor Barrell[17] who thought that, though rhythmic banding might be due to fluctuations of current at a river mouth, such regularity of occurrence suggested rather climatic change. This is, of course, quite rapid deposition; but here again the facts point to such a condition. It is thought that a high angle of inclination in cross-bedding indicates rapid deposition.[15] The angles which we have measured run as high as 23°. This is well above the general average for marine cross-bedding. Under the microscope it has been found that the grains show no very careful sorting either according to size or composition. This also suggests quick deposition. The adoption of this seasonal banding theory opens an interesting field of examination into the climatic record thus left and into the length of time taken for the deposition of a given depth of sediment.

Cross-bedding may be formed by:

1. Aggrading deltas.
2. Torrential alluvial fans.
3. Current ripples.
4. The action of wind on desert sands or exposed bars.

[17] J. Barrel. *Bull. Geol. Soc. of Am.*, vol. 23, p. 425.

It is impossible that our cross-bedding is caused by an aggrading delta or an alluvial fan as these two types occur on a much larger scale, usually being measured in terms of feet. In successive layers the beds will slope in the same direction. As the sketches clearly show, that is not the case of those which we have been examining. Fig. VI.

G. K. Gilbert[18] describes cross-bedding of a type very similar to ours which he attributes to current ripple, as follows: "It appears that sediment may be added to a rippled surface without any disturbance of the pattern but there is usually a coincident shifting of the pattern in some direction. In order that sediment may be brought it is necessary that there be a general current in addition to the oscillation current caused by waves and it may be safely assumed that the shifting of the ripple pattern follows the direction of this general current. Just as the direction of the general current may make any angle or no angle with the direction of the oscillatory current so the direction toward which the pattern is shifted may bear any relation to the trend of the ripples. The shifting of the ripple profile during the accumulation of sediment makes the accumulation unequal on the two sides of the trough and if the ratio of shifting to deposition exceeds a certain amount there is deposition only on one side of the trough and erosion on the other. In each case an oblique structure or cross lamination results, and in the second case the general structure given to the sand mass includes two systems of oblique planes. One system is produced by deposition and laminae represent the successive positions of the concave ripple-profile. The other system is produced by erosion and its planes represent the progress of the profiles of the troughs along certain tangents. This structure may be called compound cross-bedding". This description applies equally well to our cross-bedding and may serve as an explanation of the way in which it has been formed.[19]

Grabau[20] does not agree with Gilbert but suggests that the cross-bedding with which he is dealing is aeolian. We have

[18] G. K. Gilbert. *Bull. Geol. Soc. of Am.*, vol. 10, p. 139.
[19] See also E. M. Kindle, Can. Geol. Survey. Museum Bulletin 25.
[20] A. W. Grabau. Loc. cit., p. 705.

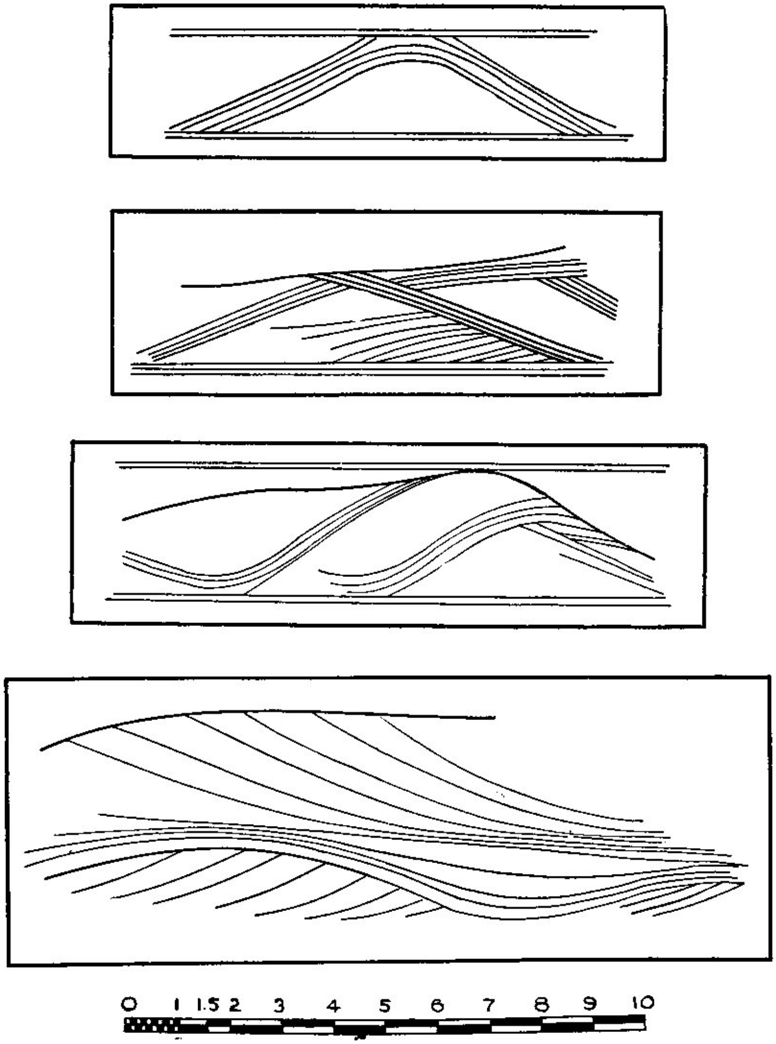

FIG. VI. Examples of a current-ripple type of cross-bedding from Point Pleasant Park with a centimeter scale.

considered this possibility in our own case, but have discarded it because, under the microscope, the grains showed no sign of the frosting and rounding typical of desert sands. No faceted pebbles common in aeolian deposits have been found. "Desert sands may be expected to contain abundant feldspar."[21] Sediment from the Park examined under the microscope shows little feldspar. In addition to these facts a sample of cross-bedded quartzite from Point Pleasant Park was sent to Dr. E. M. Kindle, Chief of the Division of Palaeontology of the Geological Survey of Canada, who stated that he considered it to be caused by currents, not by wind, as in the latter case the beds usually showed an inclination of 33°, whereas, as we have already mentioned, these do not exceed 23°. In support of this theory we find that Thorolf Vogt[22] describes a type of cross-bedded quartzites in the Scottish Highlands similar to ours which he attributes to current action. A type of current cross-bedding corresponding to ours in dimension and form is found in parts of the Dalradian succession[23] of sediments. The presence of fossil ripple marks on several faces of the rock seems to endorse the opinion that current ripple is the most probable cause. Therefore, taking all the evidence into consideration we have come to the conclusion that current ripple built up this cross-bedded structure.

In conclusion let us present the whole picture which we suggest as accounting for existing conditions. In Precambrian times these sediments were laid down in a broad shallow geosyncline. The material was brought down by rivers and deposited at a considerable distance from shore. The banding was caused by the seasonal variation in the size of grains of detritus deposited in this area. As the material was deposited, it was acted on by waves and current, developing a current ripple type of cross-bedding. The uniformity of condition was maintained by a gradual sinking of the sea floor.

[21] A. Harker. Loc. cit., p. 65.
[22] T. Vogt. Geol. Mag. Feb. 1930.
[23] Allison. Quarterly Journal Geol. Soc. of London. p. 125, April 1934.

ACKNOWLEDGEMENTS.

The work of this report was undertaken as a course in Geology at Dalhousie University under the direction of Professor G. Vibert Douglas whom the writers wish to thank for his constant assistance and advice. They also wish to acknowledge the assistance of Mr. Julius Forster and Mr. Claude Howse.

NOTE. A paper by F. P. Shepard, J. M. Trefethen, and G. V. Cohee in the Bull, Geol. Soc. of Am. for April, 1934 has come to our notice, but too late for discussion in this paper. Reference is made on p. 283 to the belief, supported by Warren Upham and D. W. Johnson, that there previously existed a land mass to the south-east of N. S. which accords with the theory developed in our paper.

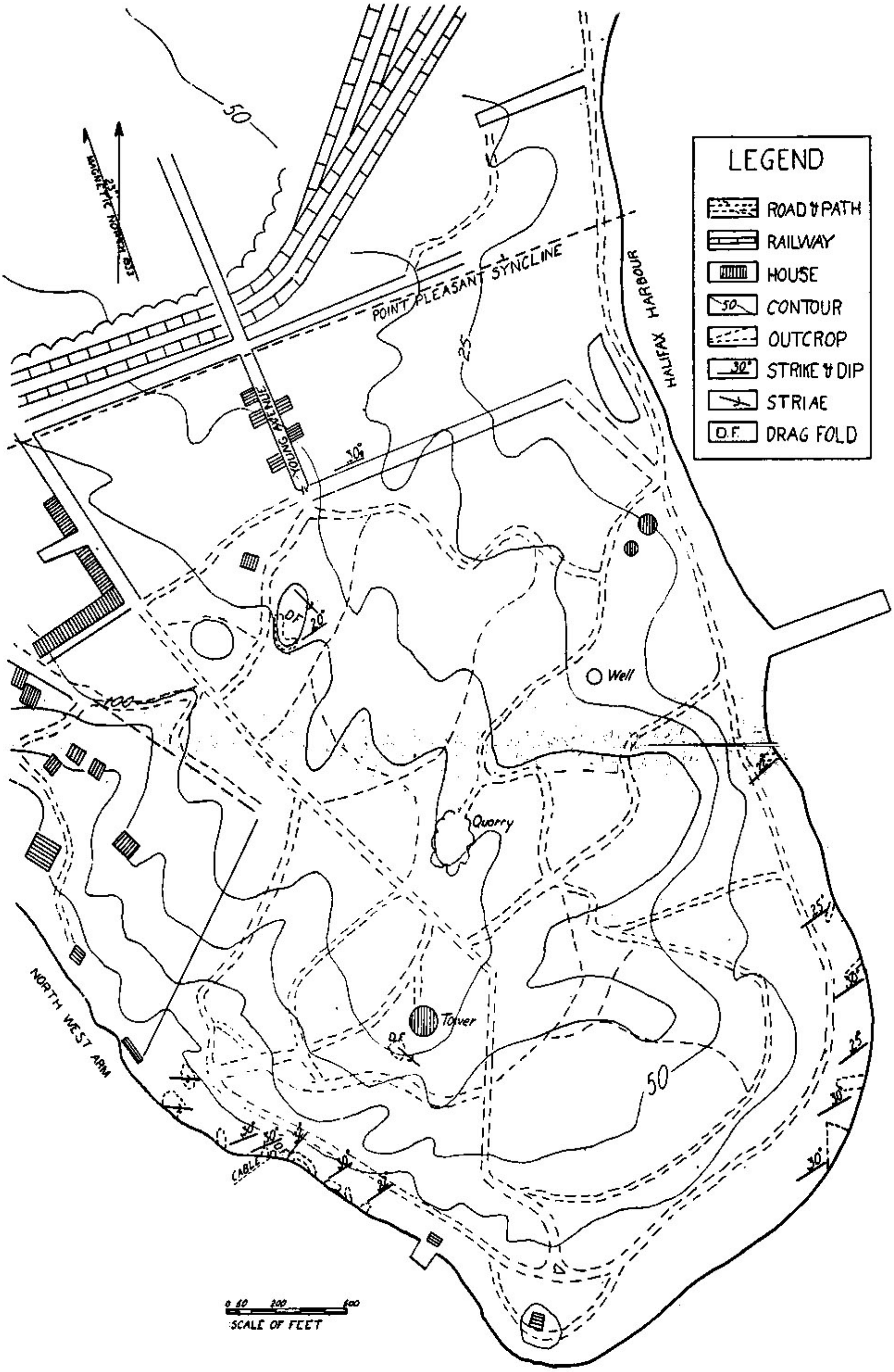
LEGEND
ROAD & PATH
RAILWAY
HOUSE
CONTOUR
OUTCROP
STRIKE & DIP
STRIAE
DRAG FOLD
POINT PLEASANT SYNCLINE
YOUNG AVENUE
HALIFAX HARBOUR
Well
Quarry
Tower
NORTH WEST ARM
CABLE
SCALE OF FEET

Fig. I.