ART. XXXI.—*Structural Geology of Steep Rock Lake, Ontario*; by HENRY LLOYD SMYTH. With Plate XI.

GEOGRAPHY.

STEEP ROCK LAKE is situated in the Province of Ontario, Canada, northwest of Lake Superior and south of the Canadian Pacific Railway. It lies about twenty-five miles east of the center of the rough quadrilateral formed by the Canadian Pacific Railway on the northeast, the Lake of the Woods on the northwest, the United States boundary on the southwest, and the shore of Lake Superior from Pigeon River to Port Arthur, on the southeast. As given on the map of the Province, scale 1 inch = 30 miles, published by the Crown Lands Department, Toronto, 1884, the geographical position of the extreme southern point of the lake, where it receives the waters of the Aticokan River from the east, is about lat. $48^{\circ} 52'$ N. and long. $91^{\circ} 30'$ W. from Greenwich; or, it is about halfway upon the map between Lac des Milles Lacs and Rainy Lake.

TOPOGRAPHY.

Steep Rock Lake is one of the many that, collectively, connected by longer or shorter links of river make up the River Seine from Island Falls as far as, and doubtless below, the Aticokan River. In shape the lake resembles, as shown on the map, an irregular and slightly distorted letter M, of which the western or left arm, (looking north), runs north and south, and the eastern or right arm northwest and southeast. This peculiar form is closely related to the character and to the structure of the rocks in which the lake lies as will be seen in what follows. The Seine River, after a beautiful fall, two hundred feet across, and forty to fifty feet high, over granite, some three hundred yards northeast of the lake, flows into it at a point about a mile southeast of the northwest extremity of the eastern arm. It leaves the lake at the extreme southern end of the western arm. Between the points of entrance and

exit there is no current observable by the eye and the difference in level must be exceedingly small.

As regards dimensions:—from the southern extremity of the eastern arm to the mouth of the river near the Falls is about $3\frac{1}{2}$ miles; from the Falls to the Elbow, 3 miles; from the Elbow to the Upper Narrows, $1\frac{1}{2}$ miles; and from the Upper Narrows south to the Aticokan River $3\frac{1}{2}$ miles. The entire lake including the portion of Lake Margaret shown on the map could be inscribed within a rectangle 6 miles from east to west, and $5\frac{1}{2}$ miles from north to south, or within an area of 33 square miles. As the name implies the lake has bold rocky shores, which, in places rise 150 feet from the water in nearly perpendicular cliffs. The total length of shore line is approximately 28 miles not counting the smaller bays and indentations. Not less than $\frac{3}{4}$ of this length shows rock in place either at the water's edge or within a few hundred feet of it, and of this perhaps $\frac{1}{4}$ may be studied without leaving the boat.

The contour of the water line shows a very beautiful dependence upon structural conditions. The eastern arm follows the general strike of the rocks from the bay north of Lake Margaret portage northwest to Falls Bay. On the northeastern shore of this arm the lower limestone makes several bold headlands that rise abruptly from 60 to 100 feet above the water. In the bays between these headlands the basement granites intersected by a large number of greenstone dikes form the shore, and rise more gently into the broken hummocky hills that generally characterize the granitic areas of the region. A few hundred feet back from the southwestern shore the great trap intrusions or flows of Horizon IV make a continuous ridge, which is estimated to reach a height of 250 feet above the water. This ridge runs, without interruption, the top showing only a few minor sags, from the shore west of the portage into Lake Margaret, for 3 miles along the strike in a northwest direction as far as the wide expansion of Falls Bay.

The gneissic phases of the granites, and associated irruptives compose the west shore of Falls Bay, from the great limestone exposure at the head, south to the Elbow. As far south as Wiegand's Point, the granite cliffs are high and very steep and are broken across only in two or three places. On the south shore of Falls Bay from Trap Point to Jack Pine Pt. the shore line cuts the strike of the rocks nearly at right angles, and from Jack Pine Pt. south to Pine Beach obliquely at a less angle. The ridges descend rather gradually to the lake along this shore, the harder rocks making little headlands separated by sand and shingle beaches.

From the southern point of Pine Beach the shore again follows the strike of the rocks, as it sweeps round the south pitching axis of the middle anticlinal; and in the stretch from Boulder Point to the Upper Narrows, in which the strike locally varies between N. 2° W. and N. 18° E. the water line minutely corresponds to the minor deflections. This shore shows continuous rock exposure, and the cliffs reach a height in places of 40 or 50 feet above the water, having perpendicular faces along cleavage surfaces.

The highest land about the lake is north and west of Conglomerate Bay, and in the peninsula between it and Northwest Bay. Except for a fringe of the Conglomerate and lower limestone (Formations I and II) along Northwest Bay, and of the upper horizons of the series east of the fault line that crosses the southeast extremity, the peninsula is composed entirely of the basement gneisses and granites, which rise from the water west of Conglomerate Bay in a steep cliff (along a surface of faulting) 100 feet or more high. The hills in the northern part of the peninsula may reach a height of over 300 feet, but this as well as other figures concerning elevations is an eye-estimate only, and not a measurement.

GEOLOGY.

The rocks exposed around the shores of Steep Rock Lake and of Lake Margaret, are divisible into three principal groups. The lower division consists of granites and gneisses, which typically are medium grained, hornblende, and granitoid, with faint foliation. Locally they present considerable variations in composition and very great variations in structure.

Resting upon these basement rocks is a series of rocks showing a thickness of about 5000 feet in exposure along the shores of the lake. Upper members that are not seen upon the lake probably exist in the trough of the eastern synclinal, southeast of Jack Pine Pt. The series is divisible into nine formations which as far as known are perfectly persistent along the strike throughout the area studied. It offers many important points of difference, lithologically, in structure, and in its relations to the underlying granites, from any series of rocks previously described in western Ontario. Leaving the question of correlation to be discussed after the series has been described it will be called for purposes of description in this paper, the Steep Rock Series.

At the southeastern extremity of the eastern arm, at the north end of the portage into Lake Margaret, lying across the edges of the Steep Rock Series, begins a succession of later granite porphyries, and massive hornblende rocks, striking

N. 55 to 65 E., which pass upward, in going south across the strike, into the schists of the Aticokan River. These will be termed the Aticokan Series.

Basement Complex.—The granites were very hastily examined in the narrow fringe in which they are exposed along certain shores of the lake. They were studied mainly with reference to their distribution and structural relations to the overlying Steep Rock series; no attempt can now be made to separate geographically the various kinds of rocks which are included in the basement series, or to indicate their relations to one another.

The predominant rock in the basement series is a hornblende muscovite granite of medium grain, composed of clear to bluish quartz, feldspar, a green hornblende mineral, and muscovite. The color on the weathered surface is white, slightly tinged with green, and on the fresh fracture a darker well marked green. This is the usual type. Occasionally a red granite carrying biotite is seen, which owes its color to flesh-colored feldspar. True gneisses are rare, but they are occasionally found as at locality 50 on the ridge north of the mouth of the creek emptying into the bay north of Lake Margaret portage, and in the peninsula east of Northwest Bay, at locality 125. At both localities the rock is a coarse hornblende gneiss, exhibiting a parallel arrangement of the constituent minerals, and pegmatization. At locality 125 the coarse gneiss carries angular inclusions, which are finer grained and darker than the mass of the rock, but similar in composition.

Distinguishable from these gneisses in which the origin of the gneissic foliation is unknown is a great body of chloritic gneisses which have unquestionably been derived from the hornblende granite by crushing. These are found at and near the turn of folds; for example, at the head of Falls Bay, north of the Elbow, and along the north and west shores of Northwest Bay. Good examples are seen on the west shore from the head of Falls Bay to the Elbow where the whole series has been forced round through an angle of more than 120°. All stages in the process are seen. At one end of the series is found the typical hornblende granite, traversed by little wavy fissures, generally parallel to the regional direction of cleavage, N. 43° E., along which part of the hornblende is represented by thin leaves of fresh chlorite. At the other end of the series the quartz and feldspar are greatly granulated, and the hornblende has entirely disappeared; the chlorite is arranged in parallel bands, and the rock has developed in it a highly perfect schistose structure.

All these granitic rocks are traversed by an immense number of dikes of greenstone, and more rarely of quartz porphyry, all of which for structural reasons are conveniently considered with the basement complex.

These belong to three eras of irruption. (1) Those which supplied pebbles to the conglomerate at the base of the Steep Rock series. (2) Those which are seen to traverse both the granitic and Steep Rock series, and to have participated in the folding. (3) A single massive dike of porphyrite (?), which cuts through the most schistose phase of the granite at the turn of the sharp fold at the head of N.W. Bay, and is clearly subsequent to the latest period of folding of the region. The dikes of class 2 are best seen along the N.E. shore of East Bay. They are rudely parallel, the walls are straight and nearly vertical, trending from N. 45° to N. 65° E., and in a general way cutting the granites and the lower horizons of the S. R. series in a direction normal to the contact and strike. They vary in width from one to two feet up to 70 feet, and clearly were the chimneys through which passed up the material for the great mass of interbedded traps on the south side of the same arm.

The contact phenomena with the country rock are uniformly as follows: When the dike is less than 6 or 8 feet in width it is fine grained, without crystalline structure, and throughout is highly schistose in the general regional direction. The wider dikes have massive and crystalline interiors, but are fine grained and schistose in a direction parallel to the induced regional cleavage, for a distance of $2\frac{1}{2}$ or 3 feet from the wall. The country rock also is schistose next to the wall of the dike, the belt affected being narrower where the adjacent rock is granite than where it is limestone.

With regard to distribution, it may be said in a general way that all shore lines north of the water, from Lake Margaret to Northwest Bay, are, with few exceptions, made up of the rocks of the basement complex. The exceptions are the headlands in East Bay and at the Elbow which are of limestone, the great mass of limestone at the head of Falls Bay, and the limestone between Camp Bay and Conglomerate Bay, and the Conglomerate along the latter.

Steep Rock Series.—The Steep Rock series consist of 9 well marked and persistent horizons exposed about the lake. It is very probable that other higher members exist in the land area southeast of the shore from Jack Pine Pt. to Pine Beach. The 9 formations are given in the table below which reads upward in ascending order:

- IX. Dark Gray clay slate.
- VIII. Agglomerate.
- VII. Greenstones and greenstone schists.
- VI. Upper conglomerate.
- V. Upper calcareous green schist.
- IV. Interbedded crystalline traps.
- III. Ferruginous formation.
- II. Lower limestone.
- I. Conglomerate.

In the foregoing description of the basement complex the northern limit of the Steep Rock series has roughly been indicated. Formations I and II occur in isolated patches north of the water on shores that are otherwise occupied only by the granites. Along the whole course of the lake they dip, at very steep angles, ranging from 60° to 80° away from the basement rocks, upon which they hang as a time-worn fringe, having no extension inland. The shore line lies sometimes in the granites and sometimes in the Steep Rock series, but in a general way follows closely in direction the boundary between them. It is only along these northern shores that formations I and II are seen at all, and as they are usually found together, separated from the higher members by intervening water, it will be convenient to keep them apart from the rest for purposes of description. The basal member of the Steep Rock series, which is generally found between the granites and the lower limestone, is a bed having a maximum thickness of nearly 100 feet, presenting the various phases of a conglomerate, coarse and fine, a quartzite and a quartz schist with feldspar. The formation occurs as a coarse conglomerate at the eastern end of Conglomerate Bay. The lowest member exposed at the water consists of rounded and water-worn pebbles of quartz and greenstone, of considerable size, the largest seen being a foot in diameter, imbedded in a green schistose matrix. The strike of the rock is about N. and S., as indicated both by the alignment of the pebbles, and the lines of junction of layers carrying no pebbles. No granitic pebbles were found at this locality. In the higher portion of the bed pebbles become smaller and relatively fewer, and the rock passes into a green schist, with small clastic grains of quartz.

On the northern end of the island in Northwest Bay formation (I) is represented by a fine conglomerate consisting of closely-packed small quartz grains (128) with little cementing material, holding occasional pebbles up to 3 or 4 inches in diameter, of rounded and water-worn quartz, bluish, milky-white and dark. A layer of limestone of uncertain thickness is also interbedded. The lowest formation does not usually occur as a coarse conglomerate in East Bay. It there consists,

as a rule, of beds of quartz pebbles, none larger than buckshot, with little cement, alternating with layers of massive quartzite.

In crossing from the base of the limestone to the granite it becomes at first slightly and then more and more feldspathic as the latter is approached. Near the junction both rocks are very similar in composition, so that it is quite impossible to draw the line between them from considerations of composition. There is an apparent transition from one rock into the other. This transition zone, which is from 20 to 30 feet in width, is uniformly highly schistose, in the regional direction N. 43° E., which, in the eastern arm, where the strikes are from N. 50° to 60° W., crosses the courses of the contact and the bedding nearly at right angles. The schistose structure is traceable through the transition zone into the undoubted granite in which it dies out gradually, being represented a few feet away by little discontinuous wavy cracks, along which chlorite is usually developed, and by a faint foliation.

From these facts it appears certain that the granitic complex supplied by erosion the materials for Formation I, and that the contact is therefore one of unconformability. There is no unconformability of structure; for the only normal structure possessed by the basement rocks, that of schistosity, was demonstrably imposed upon them at a time long subsequent to the accumulation of the various materials which now compose the Steep Rock series. The absence of a sharp line of demarkation between the complex and Formation I, which may seem to be a difficulty in the way of accepting the existence of an unconformability, is believed to be capable of a satisfactory explanation. In considering the orotechnic history of the region the transition zone will be shown to represent, not a transition in time, but a mechanical transition in composition, dating from a time subsequent to the accumulation of the rocks of the Steep Rock series.

Formation II, the lower limestone, lies above Formation I, with which it is seen in direct contact at a number of localities. The rock is very uniform in character wherever exposed. It is a dark to light bluish gray limestone, not at all highly crystalline, often banded with layers of lighter color, along planes of original bedding. The light bands vary in width from a fine line up to 6 or 8 inches. Bedding planes are also often marked by thin cherty seams. Basal portions are frequently massive and siliceous, and in some localities are highly charged with pyrites the decomposition of which causes the rock to weather brown. The upper part of the formation is a breccia, composed of fragments of limestone, showing original structure, and of trap, imbedded in a matrix that seems to be mostly made up of a consolidated calcareous flour. It is widely

distributed, and is nearly if not quite coextensive with the limestone. The total thickness of the lower limestone cannot be determined precisely, as it is nowhere seen in contact with the overlying Formation III, but quite surely is not less than 500 nor more than 700 feet. A much greater thickness is exposed in the north side of Conglomerate Bay, in part resulting from duplication by faulting. On the eastern arm, where the rocks are comparatively undisturbed the limits indicated are those given above.

Formation III is found only on the south shore of the eastern arm which it fringes from the Point N.W. of Lake Margaret Portage to Falls Bay, in much the same way that the limestone fringes the north shore. As a whole the formation consists of an extremely soft, fissile dull green, very pyritiferous rock, which carries in some localities many pebbles of limestone and a few of trap. In the lower parts of the formation the limestone fragments, which are identical with the rock of Formation II, are rather numerous, and some are large, one, angular in shape, being over two feet in diameter. Others are apparently rounded and waterworn. In other localities pebbles are not found at all. For the most part the only structure observable is the regional cleavage which is very perfectly developed. At two localities a fine banding parallel to the strike of the rock was observed. At loc. 27, south of trap bluff this banding is very prettily shown. The rock carries a few rounded pebbles of limestone. The banded structure is thrown into little compressed S W. pitching folds the tangent plane to which is parallel to the plane of the dip in the limestone across the bay. Apart from the limestone inclusions and this banding the rock shows no trace of sedimentary origin. Under the microscope it is seen to contain no clastic material and all the evidence, which is not however conclusive, seems to point to its having been originally a volcanic ash. At two localities a bed of banded jasper and iron ore, generally magnetite, is found, which belongs near the base of the horizon. A high bluff of trap in East Bay, probably a lenticular intrusion, must also be included in it. Except on this south shore of the eastern arm Formation III is everywhere covered by the waters of the lake, within the area studied. Sufficient evidence of its continuity is afforded however by the presence of boulders from the characteristic iron ore horizon at several widely distant points. The thickness varies considerably but may be taken at a maximum of 600 feet.

Formation IV consists of interbedded eruptives, which may reach a maximum thickness of 1000 feet. The rock is very uniform in character, the variations occurring being mainly in texture. It is normally a massive, rather coarsely crystalline

greenish-gray rock, made up of plagioclase and hornblende, and is probably a diorite. Locally it includes layers of green schist which are to be regarded as mechanical derivatives, analogous to the chloritic gneissic phases of the basement granite. The formation is best seen south of the eastern arm, where it forms a long ridge running from Lake Margaret portage N.W. to Falls Bay, and in the two natural sections made by the shore line at both the northern and southern ends. Small patches are exposed at a number of localities about the lake. It is uncertain whether this is an intrusive sheet or a flow.

Formation V is a very calcareous green schist containing thin seams of limestone. The included layers are quite pure finely crystalline limestone. Thin sections of the less calcareous portion show that the rock consists of 50 to 60 per cent of calcite, and for the rest, of argillaceous material and secondary quartz. Originally it was probably in the main a very calcareous shale, with thin beds of limestone. The thickness is about 600 feet.

Immediately above the limestone comes Formation VI, a conglomerate, having a maximum thickness of about 100 feet. It varies in habit, from a hydromica schist, carrying many grains of quartz, the elastic character of which is evident in thin section, to a rather coarse conglomerate, the pebbles in which seem to be entirely of quartz and granite. The locality in which it may be best seen is on Falls Bay, on the shore east of Jack Pine Point.

Formation VII. The type rock of this horizon is a light greenish gray, massive, close textured rock, which weathers a light brown. In thin section it appears to be of eruptive origin, but owing to the complete alteration of the bisilicate it is uncertain whether it was originally a diabase or a diorite. Departing from this as a type, on the one hand are found members which show crystalline structure macroscopically, and on the other banded green schists which to the eye have every appearance of being altered sediments. Under the microscope however they show no trace of sedimentary origin. This banding is of two kinds. (1), a fine banding due to an alternation of thin seams differing slightly from one another in color and in texture. (2), a coarser, due to the interbedding of layers of the massive varieties with the schistose. These layers are of all thicknesses, from a few inches up to several feet. The structure, of both varieties, appears to be antecedent to the last folding of the series, since it is often greatly contorted, and frequently intersected by the regional cleavage, and in general is parallel to the true strike. A graphitic schist, twenty feet or more in thickness, is also included. There is an

evident stratigraphical succession in the various members, the banded schists predominating towards the top. The peculiar gray green color and close texture are characteristic of the rocks of this horizon. The thickness is about 1400 feet.

Formation VIII. The agglomerate is best seen at Jack Pine Point and at locality 79 to the south of it. At locality 79, it consists of pebble-like inclusions, greatly resembling the type rock of Formation VI, imbedded in a light gray-green fissile

matrix which is bright on the cleavage surfaces. The inclusions vary in size from a fraction of an inch up to 5 or 6 in. long diameter. They are elongated, and have rounded outlines, though tapering to rather sharp points. They are all of the same material, which is the same as the matrix apparently, differing from it only in lacking the schistose structure. They are hardly distinguishable from the matrix in color, on the fresh fracture, but on the weathered surface the inclusions stand out, and weather a lighter brown. Under the microscope the inclusions are seen to consist of an eruptive rock

Scale of inches

0 3 6 9 12

Fig. 1.—Agglomerate, Loc. The shaded inclusions in nature are lighter in color than the enclosing green schist. The wavy lines indicate plications in the matrix.

entirely similar to the massive form of VII. On Jack Pine Point the agglomerate is beautifully plicated and the inclusions follow the little folds. (Fig. 1.)

Formation IX. Above the agglomerate, at locality 81 a fine grained clay slate is found, which besides a perfect slaty cleavage in the regional direction, shows alternating light and dark bands, which probably represent planes of deposition.

Structure.—The Steep Rock Series is folded into an eastern synclinal, a middle anticlinal and a western synclinal, which is faulted across the axis near the sharp turn.

A line drawn from the limestone exposure at the head of Falls Bay to Jack Pine Point indicates approximately the position of the axial plane of the eastern synclinal. East of this line the various members uniformly strike to the west of north. The dips are high to the S.W. ranging from vertical to 60, and on the average may be taken at 70. From the agglomerate at Jack Pine Point southward to the point north of Pine Beach, where the upper part of Formation IV is ex-

posed, the shore line again crosses the intermediate formations in descending order, the strikes bending round gradually to N. 20° E. A line drawn a little west of south through the eastern point of the limestone of the Elbow marks the intersection of the axial plane of the middle anticlinal with a horizontal plane. West of this line the limestone of the Elbow, Formation VI, and the various members of Formation VII, which alone are exposed on the southern and western shore, strike again to the northwest, gradually bending round along the latter to the east of north. The limestone at Conglomerate Bay abuts against a cliff of the basement granite, the line of separation marking the position of a fault. About 6000 feet S.W. along the line of this fault, which is well marked by a breccia in the peninsula N.W. of the upper narrows, Formations I and II are found again on the opposite side, striking N.W., and farther north on the large island in N.W. Bay, bending round again to the southwest. On the west shore of the lake west of N.W. Bay green slates, probably belonging to Formation VII, are found west of Formation II, and again on Birch Point indicating another fault which trends to the west of north. These two faults so complicate the structure of the western part of the lake, that the relations of the rocks, which are all recognizable as belonging to one or another of the IX formations of the series, could not be worked out in the time available.

There are two points in the general structure of the rocks of the lake which are especially noteworthy and significant. They are:

1st. The high pitch of the axes of the great folds. At the turn of the middle anticlinal at the Elbow, dips, which are well marked in the limestone, range from vertical to 75° to the south, (Section II.) At the turn of the western synclinal in Northwest Bay the dip is about 60° in the same direction. We have here, then, folds with very high south-pitching axes, the pitch in the case of the anticlinal being nearly 90° and in the case of the synclinal at a lower angle. In the case of the eastern synclinal the pitch is also high, though apparently considerably less than 90°, as indicated by the greater thickness of the series measured along the axis than across it. The Steep Rock series therefore dips away from the granites, at the turns of folds, at angles which do not differ materially from those observed in the long straight stretches; as, for example, that in East Bay.

2nd. The regional cleavage. Throughout the whole area is observed a regional cleavage, which has a tolerably uniform direction between the limits N. 38° and N. 48° E., and traverses all the rocks of the region, both the eruptive and sedimentary members of the Steep Rock Series, and the rocks of basement complex. It has largely obliterated the original

lamination of the sediments and banded schists of the Steep Rock Series, and is now the dominant structure.

In inferring the orotechnic history of the region the origin of the N.E. cleavage must be ascribed to a force acting perpendicular to it, or in a N.W. and S.E. direction; and since this cleavage runs through, and in many cases masks all previous structure, the force which produced it must have been the last force which has left its marks upon the rocks of the lake. To this force also must be ascribed the action which left the Steep Rock series in its present folded attitude.

What was the position of the rocks just before this cleavage-producing force acted upon them? It could not have been horizontal, for in the long stretch in East Bay, where the strike runs nearly straight for four miles, and in the limestone exposures N.W. of the Elbow, the plane of the dip nearly coincides with the direction of this force, and the cleavage planes intersect it nearly at right angles. A N.W. and S.E. force acting parallel to the present strike in the plane of the dip, could not have tilted these portions of the Steep Rock Series into their present nearly vertical position. It seems necessary to suppose, therefore, that before the cleavage-producing force acted, that part of the Steep Rock Series that we know, existed as a N.W. and S.E. striking monocline, having a high dip to the S.W. as the result of previous folding by a N.E. and S.W. force.

Fig. 2.—Diagram showing the attitude of the Steep Rock Series just previous to the second folding.

Fig. 3.—Diagram showing attitude of Steep Rock Series after second folding.

The folding of the Steep Rock Series indicates therefore two periods of orotechnic action. In the first period, the force acted in a N.E.—S.W. direction, and folded the series about horizontal axes, having a N.W.—S.E. direction. That part of the series now exposed about the lake was left as a N.W.—striking monocline, with a high dip towards the S.W. In the second period, the cleavage-producing force acted in a N.W.—S.E. direction upon this monocline and produced upon it two effects. 1st, it caused it to yield as a whole, not by vertical arching over horizontal axes, to which the nearly vertically

standing leaves of the series would oppose their maximum rigidity, but by horizontal buckling about nearly vertical axes, to which the opposed rigidity would be a minimum. Figures 2 and 3 illustrate this point. 2nd, consequent upon the regional movements attending the folding were produced minute fissures, and a rearrangement of particles along planes perpendicular to its direction; or, in other words, the regional cleavage.

These two periods of orotechnic action explain also the schistose dikes and the transition zones between Formation I, and the granitic complex. The dike at locality 41 will serve as an example of the class. It is from 60 to 70 feet in width and cuts the granitic complex, the southeast wall running N. 48° E. For a distance of three feet from the wall the dike is very schistose and fine grained. The interior is massive and crystalline. Under the microscope the interior is seen to be a quartz diorite, consisting of quartz, plagioclase, hornblende,—in places altered to chlorite and epidote, magnetite and apatite. The feldspars are nearly all saussurized. A slide from the schistose portion shows it to be a hydromica schist, with a great deal of normal chlorite. The quartzes are strained and broken, and the magnetite is granulated and drawn out into fissured “augen.” Some epidote is arranged along planes of foliation. The rock shows shearing and crushing in an eminent degree.

Previous to the first orotechnic period we may suppose that the Steep Rock series lay in a horizontal position upon the basement complex. The parallel dikes, of which 41 is an example, which supplied the materials for the interbedded eruptives of the series, constituted a system of thin vertical beds running through and binding together the granitic complex, and the sediments and interbedded eruptives of the upper series. The effect of the first force was to arch the series about horizontal axes parallel to the present strikes in East Bay, and perpendicular to the course of the chimney series of dikes. It acted parallel to the direction of these dikes and therefore opposed to their greatest rigidity. As the upper series bent under the action of the force, there must have been a difference in the rate of yielding of the bedded sediments and thin horizontal eruptives, on the one hand, and the vertical dikes and massive granitic complex on the other. This difference in rate of yielding must have produced grinding: 1st, of the basal sediments on the granitic complex; 2nd, between the vertical dikes and the rocks through which they passed, whether sediments, interleaved eruptives, or of the complex.

The grinding would result in shearing and comminution of both rocks in zones adjacent and parallel to the contacts. The

transition zone at the junction of the basement complex and Formation I, represents the depth to which the granites, previously weakened by disintegration, were affected by the grinding. In this zone there was also doubtless a certain intermingling of particles produced by the action of gravity.

The later orotectonic force has imposed schistose structure in these zones of comminution just as in the sedimentary members of the upper series.

Behavior of the complex.—How have the crystalline rocks of the basement complex yielded to the tremendous stresses which produced the buckled folds in the upper series? This most interesting question must be left incompletely answered. A few points, however, are clear. Great relief was afforded by the fault across the northern end of the lake. The dip of the fault plane, unfortunately, was not observed, but it is conceived that the movement was essentially horizontal, and that the 6000 feet of observed throw is nearly the full measure of its amount. In the zone adjacent to the Steep Rock Series, in which alone the granites were studied, the presence of numerous folded dikes, in the localities in which the whole series has been specially folded, seems to show that the granites

Fig. 4.—Plan of folded Dike. *a*=Greenstone Dike. *b*=Chloritic gneiss, autoclastic from granite. The surface dips gently to the North, 15°.

yielded by bending and not by faulting. One of these is shown in figure 4. It is one of many seen in the stretch of shore north of Wiegand's Point. This bending in the granites implies, of course, according to Heim's law, a tremendous load upon them.

Thickness.—The thickness of the members of the Steep Rock series given in the description of the

separate formations, is that measured in the section across East Bay, and is undoubtedly too great. This part of the series underwent tremendous longitudinal compression by the cleavage-producing force; the thinly bedded members have been thrown into little compressed folds, and the more massive members have been contorted on a larger scale. In both ways

the thickness of the series measured in section has been largely but indeterminately increased. In the stretch from the Elbow north to the head of Falls Bay, west of the axial plane, the series is much thinner, probably as the result of three causes: (1) A general stretching in this direction. (2) A possible faulting along the axis. This has not been observed, however. (3) A probable thinning out of the trap horizon in going west.

For these reasons a measurement across the series there would probably be at least as much less than the true thickness as the East Bay section is greater. A mean between them, or 4500 feet, may be taken as an approximation to the true thickness.

General Considerations.—The study of the Steep Rock series shows some results both positive and negative which have a general interest in connection with the geology of the region N.W. of Lake Superior.

1st. The contact of Formation I with the basement complex is one of erosion.

2d. The complex at the time of the deposition of the Steep Rock series was made up of consolidated crystalline rocks, and there is no evidence whatever that it has since undergone fusion, or recurred to the condition of a magma.

3d. The rocks of the Steep Rock series have been subjected at two periods, more or less distant, from one another, to the action of great orotechnic forces, which acted—the first in a N.E. and S.W. direction, and the second in a N.W. and S.E.

4th. The latter force has imposed upon all the rocks of the region a N.E. structure, which has largely, but not entirely, obliterated preëxisting lamination in the sediments and schists of the Steep Rock series.

5th. The two orotechnic actions have produced great developments of autoclastic* schists, both in the granites and in the rocks of the Steep Rock series; the present structure in which was induced and determined in direction by the last force.

The consideration of the Aticokan series, with a more general discussion of the mutual relations of the three series of rocks, and an attempt at correlation, must be deferred to another paper.

The author wishes to express his great obligations to Prof. Raphael Pumpelly for many valuable suggestions. Mr. C. Livy Whittle, of Cambridge, Mass., has kindly examined a number of thin sections from the Steep Rock series, and the results of his study are incorporated in the above description of formations.

Port Arthur, Ontario, June, 1891.

* That is, schists formed in place from massive rocks by crushing and squeezing, without intervening processes of disintegration or erosion, removal and deposition.