

THE ARCHEAN ROCKS WEST OF LAKE SUPERIOR*

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(Read before the Society December 30, 1892)

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THE NOMENCLATURE ADOPTED.

In this paper I shall adopt the nomenclature employed for many years in the publications of the Canadian Geological Survey without at present making any attempt to justify it. The term "Archean," then, will be used, not in the restricted sense advocated by Geikie,* nor in that held by Van Hise,† but in its broadest application, as embracing all the rocks stratigraphically inferior to the Animikie rocks of Lake Superior.

THE REGION STUDIED.

Its Boundaries.—The portion of the Dominion of Canada to which attention is here drawn may be briefly described as the southern half of Rainy River district, in the province of Ontario, lying between our trans-continental highway and the international boundary, and the Lake of Woods, in the west, to the western boundary of Thunder Bay district.

Geologically complex.—It would be difficult to imagine a more interesting field or one that offers such facilities for geologic investigation, yet from the complexity of the structure of the rocks; from their antiquity; the tremendous movements they have suffered, as well as the changes they have undergone, and from the absence of all fossil remains, there is perhaps no part of the country about which so many difficulties cluster or in which lie so many pitfalls for the feet of the unwary, the hasty, or the dogmatic geologist.

Its topographic Character.—Physically, the country presents a vast network of lakes which with their connecting streams, afford a ready

* Anniversary address before the Geol. Soc. of London on the volcanic rocks of England by Archibald Geikie, F. R. S., February, 1891.

† Am. Jour. Sci., vol. xii, p. 117.

means of transport by canoes. The lakes vary in size from mere ponds to great island-dotted sheets of water, of which the largest—the Lake of the Woods—embraces within its shore lines an area of hardly less than six thousand square miles. Probably one-fourth of the whole area is occupied by water. The land surface presents a tumbled and irregular succession of low, rounded hills, with here and there a sharp ridge or steep escarpment, but bold and rugged scenery is extremely rare. The surface has a gentle average slope from the watersheds to the drainage basins, and it is doubtful if the top of the highest hill is over seven hundred feet above the bottom of the lowest and deepest lake. This area occupies the southern margin of the Arctic basin.

Present Status of the Investigations.—A description of the distribution of the various rocks would be tedious and incomprehensible without constant reference to a good map. A large portion of the area is depicted on maps already published by the Canadian Geological Survey. A report upon and map of part of the remainder have been prepared by the writer and are now in press, while topographic and geologic materials relating to still another portion of the remainder have been collected and are now being prepared for publication. In addition to this, the writer has made several preliminary reconnaissances and surveys in those portions in which the field-work is incomplete.

DISTRIBUTION AND RELATION OF THE ROCKS.

Without entering into the details of rock distribution, there is one important feature of it which is worthy of attention.

TWO GREAT DIVISIONS AND THEIR EXTENT.

Lower Archean Series.—Separating the rocks for the present into two great divisions, (1) the lower granitic and syenitic rocks, more or less massive, and (2) the upper micaceous, hornblendic and trappean rocks, for the most part distinctly schistose, we find that the former occupy large rounded or ovoid areas which sometimes anastomose and the peripheries of which approach each other to within comparatively narrow limits. The longest axes of these areas are rudely linear to and parallel with each other and have a general northeast or east-north direction. In geographic extent these granitoid rocks cover considerably more than half of the whole country. It is interesting to note that such nuclear areas of granite are reported by Barlow north of Lake Huron and are mapped by Hitchcock in New Hampshire. As we pass from the Lake of the Woods in an east-southeast direction obliquely across the granitic areas we find that they become proportionately narrower and longer in

an increasing ratio as the shores of Lake Superior are approached. It would seem as if the Archean rocks after their consolidation in their present relations had been crushed together by a tremendous lateral force emanating from the southeast, the effect of this pressure becoming less and less as the distance from the supposed center of force increases.

Upper Archean Series.—Surrounding the nuclear ovoid and lenticular areas of granitic rocks as an irregular but almost uninterrupted network and dipping away from them generally on all sides lie the complex and varied rocks of the upper Archean series. The tendency of the two great divisions of Archean rocks to assume this relative distribution was first pointed out to me by Dr A. C. Lawson, and subsequent explorations in parts of Rainy River district unvisited by him have so far confirmed his opinion that such a relative distribution would be found to be characteristic of this region.

TERMS CONTCHICHING AND KEEWATIN SERIES SUGGESTED BY DR LAWSON.

The rocks occupying the ellipsoid synclinal troughs between the nuclei of granite have been separated by Dr Lawson (the classic authority on this region) into two divisions, for which he suggested the names of Contchiching for the lower and Keewatin for the upper. He has since proposed the name Ontarian to include these two groups. For the underlying granitic rocks the term Laurentian is used.

CHARACTER AND FIELD RELATIONS OF THE LAURENTIAN ROCKS.

The Laurentian rocks of this region are for the most part essentially granites. A gneissic foliation is often apparent and frequently well marked, particularly in the peripheral zones of the areas, while the central portions are usually more granitoid. The rocks vary in texture from fine- to coarse-grained and pegmatitic, and in color from light to dark gray and from pink to deep red. In composition they present many various characters. Usually the ferromagnesian mineral is biotite with more or less muscovite. Hornblende granites are not uncommon. The latter sometimes merge into the biotite granites by a gradual change in composition, but usually a sharp line of demarkation separates them. The relations in the field are sometimes suggestive of large brecciated fragments of hornblende granite caught up in the biotite granite, and sometimes of intrusions of the former into the latter. The relations of these two varieties of granite form an interesting problem for future study, but as yet the writer is not prepared to formulate any general theory concerning them; indeed, it is doubtful if any generally applicable theory is possible, as there is reason to believe that the hornblende granite is sometimes

the younger, sometimes the older and sometimes a contemporaneous rock, while it is not probable that there is any great difference in their respective ages. In this connection it is interesting to note that in Finland Dr J. J. Sedesholm* finds that there are two main series of granites, of which the earliest plagioclastic and hornblendic are eruptive in their relations to the Archean schists and younger than them; the other series, red garnetiferous muscovite microcline granites, the coarser varieties of which merge into a pegmatite, are the latest eruptive rocks of the Archean complex. On Hunters island there is a considerable development of red garnetiferous muscovite granite, very coarse-grained in places, the relations of which are not so clear.

Frequently the granites of Rainy River district are almost devoid of bisilicate, merging into red felsites and compact, massive gray feldspathic rocks approaching quartzites, which a well-marked system of cleavage planes sometimes cuts into regular rhomboidal blocks.

Again the bisilicate is frequently altered to chlorite. The granites sometimes exhibit a distinct porphyritic structure, evinced by the large crystals of feldspar in a finer-grained groundmass. These porphyritic granites have often a distinct gneissic foliation.

For convenience of reference the separate areas of granite in this region have received distinctive geographic designations in the reports of the Canadian Geological Survey. One of them, which in the forthcoming report on the Seine River district will be named the Seine area, is remarkable for the predominance of plagioclase in the rocks of its southwestern portion; this, in association with chlorite, which is probably derived from hornblende, characterizes the rock rather as a quartz-diorite than a granite. The microscopic examination of the rocks of this area is not yet complete, but in the field there seems to be a gradual passage of the quartz diorite or chloritic plagioclase granite into the ordinary orthoclase granite; certainly the writer has so far been unable to find anywhere a sharp line between them. Plagioclase in greater or less proportion occurs in many of the granites of the whole region.

RELATION OF CONTCHICHING AND KEEWATIN SERIES TO LAURENTIAN GRANITES.

Before proceeding to a consideration of the rocks of the Contchiching and Keewatin series, it would be well to refer briefly to the relations which the Laurentian granites bear to them.

Contact Phenomena Criterion of Relative Age.—In the absence of paleontologic evidence the most important criterion that remains for the determination of the relative age of contiguous rock series are the features

*The Archean Eruptive Rocks of Finland, by Dr J. J. Sedesholm.

of the contact between them, as justly observed by Barlow.* These features have been so clearly and precisely described by Lawson in his official reports that it is unnecessary to repeat them here; suffice it to say that I have found his description to apply to all the contacts that I have observed in the portions of Rainy River district not reported on by him. While it is true that some of these features, such as the intimate interbanding of the gneisses or foliated granites and the schists, may be regarded as analogous to the intimate interbanding frequently observed in sedimentary strata; and while it is also true that some other features, such as the angular fragments of one rock embedded in the other may, where these brecciated zones are narrow, be due to the shattering of the rocks along a line of fault, still there are many contact features which cannot be accounted for on any theory which holds to the sedimentary origin of the granite gneisses; such features are the apophyses of granite which can be traced directly into the main mass, and which sometimes are parallel to the planes of schistosity of the rocks which they invade and sometimes cut across these planes. It must not be forgotten that the phenomena that have been described by Lawson are not isolated instances of peculiar occurrences extending in the aggregate over but a small proportion of the contact line, but are typical examples everywhere characteristic of the contact, and the absence of which is rare.

Character of the Contact.—A comprehensive and careful study of the contact of the Laurentian and Ontarian rocks of Rainy River district forces us to the conclusion that it is eruptive or irruptive in character.

Origin of the Laurentian Rocks.—Either, then, the so-called Laurentian rocks of this district have been irrupted in the form of a plastic magma into the overlying rocks after these had become consolidated (the attractive theory of Dr Lawson) or else a remarkably continuous series of later eruptions have been extruded in the planes of contact between the Laurentian and Ontarian rock, presumably the line of weakness.

Laurentian Rocks the younger.—This latter theory is open to so many and serious objections that it has few adherents. If the former theory is correct, the granite gneisses, with regard to all the relations of which we have any certain knowledge, are younger than the rocks which they invade, and, as they pierce both the Contchiching and Keewatin, their present condition is of post-Keewatin origin.

Selection of the Term Laurentian based on imperfect Knowledge.—The earlier descriptions of the Laurentian rocks of eastern Canada must be regarded as imperfect, and the contact features have not been described. They are therein spoken of as metamorphic sediment inferior to the

* The Contact of the Laurentian and Huronian Rocks North of Lake Huron, by A. E. Barlow, *Am. Geologist*, vol. vi, no. 1, p. 19. Also ante, pp. 313-332.

Huronian, and the writer is not aware of any general contradiction that has been given to the assumption by more recent writers on Quebec and eastern Ontario. For this reason the application of the term Laurentian to the irruptive granite gneisses west of Lake Superior is perhaps unfortunate, as involving a hasty and undetermined correlation.

Considerations affecting the Status of the Term Laurentian.—Admitting for the moment that the Laurentian rocks of Quebec are of sedimentary origin, and that the granite gneisses west of Lake Superior are irruptive in their character, it is still possible, nay, probable, that the two are contemporaneous in age and identical in primal origin on the assumption that these latter rocks but represent metamorphism carried to the extreme of fusion (as a consequence of the relatively higher local elevation of the isotherms), resulting in their irruption into the overlying Huronian strata and their recrystallization in the form of consolidated magma. The question, then, of the most appropriate name for these western Ontario granites becomes a question of the era of our chronology.

Shall we date them from the time of their intrusion into the overlying strata, or shall we go further back into their obscure history and date them from the time when in all probability they formed the solid floor on which the Contchiching and Keewatin rocks were laid down? In other words, shall we call them Huronian (the term is here used to include all the rocks between the fundamental granites and the Animikie) because they are intrusive into Huronian strata, or Laurentian on the above assumption of their genetic identity with the Laurentian gneisses of the east? If we can regard the irruptive origin of the present relations of these granites to the Upper Archean rocks as indubitably established, it would seem unwise to go behind this fact into the uncertain realm of theory to justify for them the name "Laurentian," as the term "Huronian granite" embodies a more precise statement of our conclusions.

But the passage of the granitic phases into the gneissic is so gradual, the lithologic similarity between the gneisses of the east and of the west is so marked, and their geographic continuity so highly probable, if not an established fact, that it is difficult to conceive of any great genetic difference or of any considerable geologic interval between their respective ages. The applicability of the term Laurentian, as applied to the granites of Rainy River district, is also supported by the fact that as the Laurentian of Quebec is being reëxamined in the light of modern knowledge, the opinion is gaining ground that at least the "Lower Laurentian" rocks present characters precisely analogous to these of the west. Perhaps some of the rocks that have hitherto been called Upper Laurentian in the east are the equivalents of the Contchiching series of Lawson, although they differ from them in some lithologic characters.

THE CONTCHICHING SERIES.

Rocks composing it.—The Contchiching series consists essentially of fine-grained evenly laminated biotite gneisses, light gray in color; of fine to coarse grained mica schists, generally highly feldspathic and sometimes very quartzose, from dark gray to light gray in color and brownish or "rusty" weathering, and of fine-grained hornblendic mica schists.

Position and Relation of its Rocks.—In the southeastern part of the district they occupy a position always intermediate between the granite gneisses, which in the contact zone generally invade them in parallel bands, apophyses and dikes, and the hornblende schists and altered traps at the base of the Keewatin, which overlie them in conformable position. They frequently merge into these by a gradual change in mineral composition across the strike. N. H. Winchell* refers to a gradual and conformable transition between Vermiline (Contchiching) and Keewatin.

In the Lake of the Woods there is a series of mica schists which, according to Dr Lawson's descriptions,† are closely similar to those which he subsequently separated from the Keewatin and designated under the name of Contchiching. In his hypothetical sections of this district, the accuracy of which, however, he does not insist upon, he relegates these mica schists to the highest position in the Keewatin scale. By a reference to the map, however, it will be seen that in their most important development they occupy a position on the margin of the Keewatin trough in the southwestern part of the lake and in direct contact with the Laurentian granites. While developments of these mica schists are found in interior portions of this Keewatin trough, such a position may easily be accounted for on the assumption that they represent the crests of anticlinal folds exposed by denudation. Indeed, the foldings and disturbances in this trough have been so great that almost any position in the scale may be attributed to the mica schists of this complex series. The inference is strong that these rocks in the Lake of the Woods are the equivalents of the Contchiching series of Rainy lake.

Its Thickness.—In this latter region Dr Lawson attributes to the Contchiching series‡ a maximum thickness of from 24,000 to nearly 29,000 feet. On a similar interpretation of the structure east of this, in the western part of the Hunters Island region, about the same thickness may be inferred. The writer, in his report on this latter region, now in press, states at some length his reasons for doubting that these rocks have such

*17th Ann. Rep. of the Geol. and Nat. Hist. Survey of Minnesota.

†Report on the Geology of the Lake of the Woods, by Andrew C. Lawson. Part C E of the Ann. Rep. Geol. Surv. of Canada, 1885.

‡Report on the Geology of the Rainy Lake Region, by Andrew C. Lawson, M. A., Ph. D., part E, Ann. Rep. Geol. Surv. of Canada, 1887-'88.

an enormous thickness. Without recapitulating these reasons here, it will be sufficient to state that in his opinion the Contchiching series nowhere in the Rainy River district attains a greater thickness than 9,000 feet, the greater apparent thickness being due to multiple folding.

Clastic in Origin.—The clastic origin of the gneisses and mica schists of this series can hardly be doubted by any one familiar with them in the field; their fine and even lamination and their bedded appearance affords in itself almost conclusive evidence and the microscopic descriptions of them by Lawson strongly support this view. Their mineral composition indicates derivation from the denudation of a granitic floor.

Structural Conformity between Contchiching and Keewatin.—Between the Contchiching and the Keewatin rocks there is everywhere a strict conformity of structural relations. In rocks which have suffered such great mechanical deformation, however, it must always be borne in mind that much of the original structure may have been obliterated and replaced by subsequent cleavage, so that it is hazardous to state that because there is now strict parallelism in the existing schistose planes of contiguous rock series that this necessarily indicates original conformity. Dr Lawson argues an interval of erosion between the Contchiching and Keewatin series from the presence at the base of the Keewatin of a conglomerate on the Seine river and on Rat Raot bay of Rainy lake. The former of these conglomerates is for the most part an integral portion of the Keewatin series and for only a small proportion of its development does it occupy a strictly basal position, so that it rather marks a local break in the Keewatin itself than one between the Keewatin and Contchiching, serving in a measure rather to bind these series together than to separate them. The so-called conglomerate of Rat Raot bay is mapped as lying wholly between the two series, but from what the writer has seen of it he regards it as rather of volcanic than of detrital origin.

The Contchiching and Keewatin lithologically Distinct.—That the Contchiching series is lithologically distinct from the Keewatin, and marks a period subsequent to which a profound change in the conditions of rock formation took place, cannot be denied, and the term is useful and appropriate as designating a well-marked and perhaps the most important formation of an extensive series; but the Contchiching cannot be regarded as in any respect coëqual or coëxtensive with the Keewatin. There is no stronger evidence of unconformity between the two than there is between any two distinct horizons of the Keewatin, particularly where conglomerates are developed, and the Contchiching would seem to be therefore essentially the basal portion of the Keewatin.

CONDITIONS UNDER WHICH CONTCHICHING AND KEEWATIN WERE FORMED.

The close of the period during which the Contchiching rocks were laid down ushered in an era of intense and long-continued volcanic activity, interrupted perhaps and succeeded by periods of compensative quiescence during which erosion and sedimentation took place; but during Keewatin times no certain evidence of any great or extensive crustal movements is afforded. The whole Keewatin and Contchiching series seems to have been folded by one great and perhaps simultaneous upheaval of the original floor. This folding marked the close of the Keewatin epoch. Barlow* suggests that the concentric lamination in the ovoid areas of granite gneiss indicates that the forces of upheaval acted from certain centers; this may be so, but the phenomenon may also be accounted for by the flow of the magma being directed by its proximity to the hard schists. It may be more correct to say that the folding of the schists was caused not so much by an upheaval of the sub-crustal magma acting from centers of force as by the crumpling, due to lateral compression, forcing their synclinal folds into the plastic magma.

THE KEEWATIN SERIES.

Rocks composing it.—The Keewatin series consists for the most part of plutonic, volcanic and pyroclastic rocks. While some of the upper members seem to be more or less altered aqueous sediments, the proportion of undoubtedly clastic rocks is small.

Its stratigraphic Succession.—Unfortunately the microscopic study of these rocks is as yet incomplete. The solution of their stratigraphic succession is confronted by almost insurmountable difficulties, and only a general suggestion as to the sequence of broad and ill-defined groups can be offered. The line of demarkation between the numerous horizons is seldom clear, and where those horizons can be separated at all they are not always found to occupy the same relative position. They are seldom very persistent, and overlap each other as more or less attenuated lenticular bands. I know of no place in this district presenting a complete section of the Keewatin. The most important and complete development of this series is found in the Lake of the Woods and Rainy Lake regions.

Speaking generally, then, the basal members of this great series consist of dark green or black crystalline hornblende schists, generally fine-grained, and which are sometimes seen to merge into the mica schists of the Contchiching; of dark and light green altered traps, generally massive, but sheared and broken by pressure and sometimes rendered schistose; of green chlorite schists, which sometimes seem to be altered hornblende schists and often again are almost undoubtedly but highly

*Am. Geologist, vol. vi, no. 9, July, 1890.

schistose phases of the altered traps. At the top of the series are found soft, fissile, light-gray schists, micaceous schists and some altered clay slates. Between the rocks which may be always recognized as the basal rocks and those which appear to be always in the highest position in the scale are a complex group of volcanic detritals, agglomerates, tuffs and trap, ashes, felsite schists, sericite schists and fine-grained evenly schistose quartz porphyries. Some of these rocks were probably thrown out as volcanic ejectamenta and, falling in the waters of ancient lakes, were sifted and stratified by their restless motion. In this way perhaps some of the conglomerates have been formed. Others again are probably but volcanic breccias, of which the harder fragments have been more or less rounded in their passage through the vents and in subsequent movements before they became consolidated in the matrix. On the Seine river the chlorite schists in one locality contain abundant lenticules of quartz which are often very wide in proportion to their length, giving the rock a conglomeratic aspect. These again are sometimes lengthened out and appear as irregular lenticular quartz stringers. While some of the Keewatin conglomerates have the appearance of being true sedimentary depositions on old beaches, there is yet a degree of uncertainty as to their character and origin. These are for the most part local in extent and narrow in development and occur at various horizons in the middle and lower portions of the Keewatin. They may, as Sir Archibald Geikie* says, "undoubtedly indicate local disturbance connected perhaps with terrestrial readjustments consequent upon the waning of volcanic energy;" but it is extremely doubtful if in this part of the country they mark a great or continuous break dividing the Keewatin rocks into a lower and upper division at any recognizable horizon. Their significance seems to be merely local. Professor Van Hise† attaches importance to several described occurrences of conglomerates. In only one case, however, was an undoubted unconformity observed below the conglomerate, and this may be accounted for by the assumption of a fault. The collective extent of all the conglomerates described by these authors is insignificant in comparison with the area to which they would apply their conclusions. The absence of unconformity of structure between the conglomerates and underlying rocks, which is likewise, so far as observed, in the Canadian area northwest of Lake Superior an invariable rule, is in itself a significant fact, for the same cleavage-producing forces which might entirely obliterate all original structure in the fine-grained schists would not

* Anniversary address before the Geological Society of London on "The volcanic Rocks of England," 1891.

† "An Attempt to harmonize some apparently conflicting Views of Lake Superior Stratigraphy," *Am. Jour. Sci.*, vol. lxi, p. 117, and "Observations on the structural Relations of the Upper Huronian, Lower Huronian and Basement Complex on the north Shore of Lake Huron," *Am. Jour. Sci.*, vol. lxiii, p. 224. This latter paper was prepared in collaboration with Mr Pumpelly.

obliterate all traces of the original bedding planes in these coarse clastics. In so far, therefore, as the conclusions of Van Hise and Pumpelly are applied to the lower Archean rocks of Canada northwest of Lake Superior, the writer regrets that he finds himself at variance with these eminent authors, being a follower of Geikie in the belief that conglomerates do not necessarily mark any stratigraphic discordance in these old rocks. These conglomerates have not yet received the attention which they deserve, and we may hope that a more detailed and extensive study of them will elucidate some of the problems of Archean geology.

THE STEEP ROCK SERIES.

Discordant in Character.—The Laurentian and Ontarian rocks hitherto considered do not embrace all the presumably Archean rocks found in this country. Mr Smyth, late of the United States Geological Survey, recognized and described* a discordant series, which is almost undoubtedly of post-Keewatin age, about the shores of Steep Rock lake.

Its Stratigraphy.—This Steep Rock series consists of the following horizons in ascending order:

I. Basal quartz conglomerate, sometimes represented by a massive quartzite, estimated to be 430 feet thick.

II. Lower limestone, dark and light bluish-gray, with the bedding marked by cherty seams, weathering in relief. The upper part of this formation is a characteristic breccia of limestone and trap fragments in a matrix of consolidated calcareous floor; thickness, 500 to 700 feet.

III. About 600 feet of a very soft, fissile, dull green, pyritiferous, volcanic ash, containing beds of jasper and iron ore.

IV. Interbedded, coarsely crystalline, greenish-gray traps (probably diorite), with layers of dynamic green schists; thickness, about 1,000 feet.

V. Upper calcareous green schist, with thin seams of limestone, 600 feet thick.

VI. Upper conglomerate, varying from hydromica schist, with many grains of quartz, to a rather coarse conglomerate. The inclosed pebbles consist entirely of quartz and granite; maximum thickness, 100 feet.

VII. About 1,400 feet of light greenish-gray, close-textured, massive greenstone and greenstone schist.

VIII. Agglomerate, 300 feet thick.

IX. Dark gray clay slate, of unknown thickness. Higher horizons probably occupy the country to the south of the lake.

Such are briefly the descriptions of horizons by Smyth in his admirable memoir. The work since done by the writer in connection with the rocks of this series suggests no important modification of them.

* "Structural Geology of Steep Rock Lake, Ontario," Am. Jour. Sci., vol. xlii, p. 317.

A folded Syncline.—The discovery of a well-marked band of brownish gray clay slates very similar to those on the shore of Steep Rock lake, striking in an easterly direction and dipping to the north, though at high angles, which lie about a mile and three-quarters south of the southern bend of the lake, and which would seem to represent the southern upfold of the horizon (IX), would indicate that the series must be regarded rather as a folded and buckled syncline than as a tilted and buckled monocline. This simplifies the conception, as it answers the somewhat troublesome question as to what has become of the corresponding half inferred by the supposed monocline. The country south of the middle bend of Steep Rock lake and lying between its western and eastern long-extending arms is extremely rugged and is almost impassable, so that the sequence of the rocks could not be worked out.

Its Thickness.—If the conclusions drawn from the discovery of the clay slates south of the lake are just, the higher horizons inferred by Smyth seem to consist principally of coarsely crystalline traps and light greenish-gray, close-textured traps, with their schistose mechanical derivatives paralleled by horizons IV and VII, and about 4,000 feet must be added to the total thickness of the series as estimated by Mr Smyth.

Its Relation to the Laurentian and Keewatin.—This extensive series appears to have been laid down upon the eroded surface of the Laurentian and Keewatin rocks long after the irruption of the Laurentian granites.

Effect upon it of orographic Movement.—It appears, then, as pointed out by Smyth, to have been folded by crustal movements into a cynclinal trough, whose axis had a northwest and southeast direction. Subsequent to this a great lateral pressure, acting in a direction nearly parallel with this synclinal axis, has buckled the whole series in a horizontal plane and crushed and sheared the underlying basement rocks. Relief from this pressure was also afforded by a slipping of the rocks in the vicinity of Northwest bay of Steep Rock lake, indicated by a complicated series of faults which are clearly recognizable in the Steep Rock series and may be inferred by the distribution of the Laurentian and Keewatin rocks to the north and to the south. These faults indicate a horizontal dislocation of nearly 7,000 feet in the aggregate, and that the vertical dislocation must have been of even greater extent is inferred by the volume of these newer rocks which were faulted below the present level of denudation.

Older than the Animikie.—The lateral pressure which produced these faults and the remarkable structure of the Steep Rock series acted in a northwest and southeast direction, and it is most highly probable that it was the same pressure which, acting from a center of force to the southeast, produced the lenticular character of the granitic areas referred to in an earlier part of this paper. As the Animikie rocks northwest of Lake

Superior exhibit no trace of this or of any lateral pressure, the inference is strong that the Steep Rock series is older than the Animikie.

Its Unconformability not always Observable.—The unconformity between the Steep Rock series and the Laurentian dioritic granites and anticlastic chloritic schists of the north and east shore of Steep Rock lake admits of scarcely any doubt, but the unconformity above the Keewatin schists of the Seine river to the southwest is not at all obvious. Lithologically the green altered traps and schists of the two series are strikingly similar and could not probably be separated by the most careful study, but it is significant that west of the faults of Steep Rock lake the most careful search on the part of both Mr Smyth and myself has been rewarded, as far as I know, by the discovery of only one exposure (and that of a few square yards in extent) of rock that can with any degree of certainty be regarded as representing the characteristic limestone formation of the Steep Rock series. This was found by the writer on the north side of Seine river, about four miles west of the mouth of the Atic Oban river. Farther down the Seine river some thin bands, which are very doubtfully representatives of the upper calcareous formation (VI), are seen in two or three localities, but these are of trifling extent. West of Steep Rock lake and north of Seine river are some important developments of traps, light greenish-gray and fine-grained, with some dynamic schists, probably derived from them, which are macroscopically quite similar to those grouped under horizon VII. We would expect, however, to find the remains of the eruptive members of this series among the lower rocks of the neighborhood. It seems, therefore, that to the west the Steep Rock series has been faulted up and swept away, and whatever significance may attach to discordance of present structural relations on opposite sides of a fault plane, these relations point to the conclusion that this series lay unconformably on the Keewatin.

The Unconformity a Measure of geologic Time.—If the above interpretation of the structure and relations of this series is correct, it is most interesting, as it is the most important if not the first recognized undoubted unconformity in the Huronian system of the Canadian geologists. As the period of time predicted by this series is enormous, it strongly emphasizes Lawson's statement that the erosion interval between the Keewatin and the Animikie is the greatest in American geology.

Its Relation to the Atic Oban Series.—To the south the Steep Rock series appear to have been removed by the same causes. South of the southwest arm of Steep Rock lake it appears to be cut off by the quartz porphyries of Smyth's tentative Atic Oban series, but the writer's subsequent examinations have convinced him that the southwestward extension of these quartz porphyries is not great and almost certainly

does not reach to the probable southern extension of the great fault in the western part of Steep Rock lake. These quartz porphyries become distinctly finer grained in the vicinity of the Steep Rock series to the northwest and west and less certainly so as the massive altered traps to the south are approached. They are extremely massive and coarse-grained in the intermediate portions. The altered traps to the south, the writer thinks, belong to the Keewatin, being succeeded in descending order by chloritic, hornblendic and micaceous schists and Laurentian granites. The quartz porphyries appear to be a unit mass erupted, since the deposition of the Steep Rock series, along a probable fault plane or line of contact between the underlying Laurentian and Keewatin rocks, presumably the line of weakness. They extend several miles to the east, north of and rudely parallel to the general direction of the Atic Oban river, and send out long apophyses northeast into the Seine granite area. Their contact with the "greenstone" to the south seems to be less irregular.

The introduction into the already confused Archean nomenclature of the unnecessary term "Atic Oban series" is to be deprecated, as it can only include this unit mass of eruptive rock, the correlation of which with other similar masses must always be uncertain.

Whether the eruption of these quartz porphyries preceded or succeeded the great oratechnic movement which buckled the Steep Rock series must remain as yet an open question. Their massive character on Margaret lake favors the view that they are of later date than this movement. On the other hand, they are here found in their broadest development, and their mass and perhaps a superior hardness may have enabled them to resist this pressure. In the terminations of the apophyses which they send into the Seine area of granites the rocks are found to be intensely crushed; and if the isolated bands of crushed and sheared quartz porphyries which are found in the Seine area northeast of Steep Rock lake are of the same age, they must have antedated this lateral pressure.

ECONOMIC GEOLOGY OF THE ARCHEAN.

Present Knowledge superficial.—Our knowledge of the economic geology of the Archean rocks is purely superficial, as no real mining has been done and no facilities are thus afforded for an exhaustive study of the ores and their intimate relations. The writer cannot refrain from expressing his opinion here that the laws of Ontario are primarily to blame for this stagnation in mining. As they encourage every evil tendency of mining speculation and discourage every attempt at scientific exploitation and healthy development, the mineral wealth of this undeveloped country remains unimproved and unremunerative.

Iron Ores.—Iron ores, in many places known to be rich and in others reasonably presumed to be so, below the surface are more or less abundant in three distinct horizons. During the last two seasons the writer has discovered magnetic ores, free from sulphur, phosphorous and titanitic acid, in micaceous schist, probably of Contchiching age. These ores on the surface are of low grade and intimately interbanded with the inclosing rock, but they may fairly be regarded as indicating extensive ore bodies below the surface, probably of great economic value.

The iron ores in association with the traps near the base of the Keewatin in the Hunters Island region and north of the Atic Oban and Seine rivers are well known to western geologists. In the former locality they are associated with jasper and are the extension of those great ore bodies which form one of the wonders of Minnesota. In the latter locality the ores are known to exist in extensive deposits and are of very high grade, running as high as 70 per cent of metallic iron. Here as a rule no jasper is associated with them. The ores of the same belt of Keewatin rocks in which these occur, where found in the vicinity of Rainy lake, are often so highly titaniferous that they are of little value in the present stage of metallurgic science, but this seems to be but a local phase due to local causes.

The ores of the third horizon of the Steep Rock series are somewhat problematical, but there are indications of extensive ore bodies in these rocks.

Gold.—Gold has been mined in the Lake of the Woods in a feeble and half-hearted way for many years, but the industry has languished under many difficulties and misfortunes. Most of the quartz, however, is extremely rich, but the mining in almost every case has been conducted unscientifically, and the geologic problems connected with it have never been properly worked out. Most of the gold-bearing quartz veins have been found in the Keewatin rocks; but some of them, and these of the richest, occur in granites, probably eruptive, usually coarse-grained and chloritic, and somewhat resembling the quartz porphyry of the Atic Oban river. These latter rocks are frequently found to contain very rich auriferous quartz veins. The gold-bearing quartz porphyries of Harold lake (north of the Seine river and about three miles west of Steep Rock lake) are probably of the same age as the Margaret lake quartz porphyries, though geographically the two are disconnected. It is possible that the granites in the Lake of the Woods, which contain auriferous quartz veins, are of the same era of eruption as these.

Nickeliferous Diorite.—Nickeliferous diorite has been recently discovered in the vicinity of Rat portage, but as yet none has been found containing a high percentage of nickel.