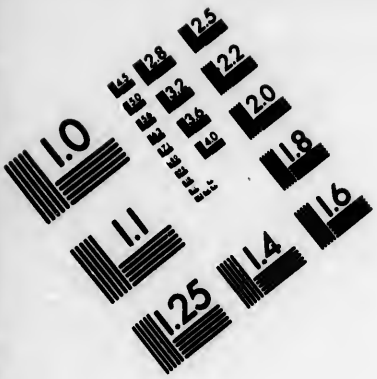

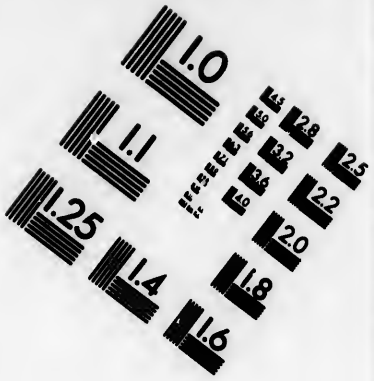

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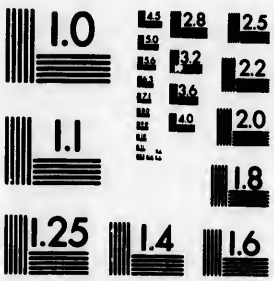

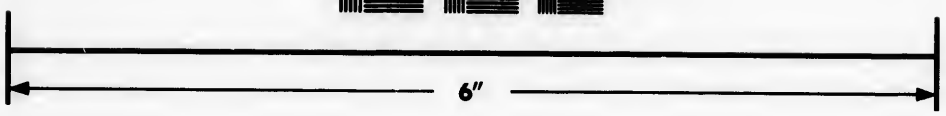

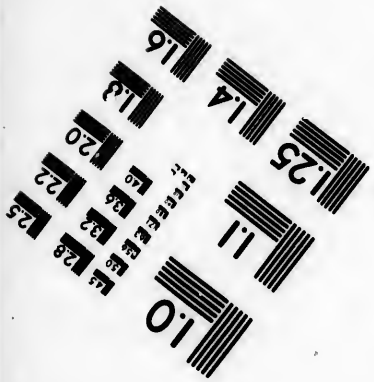

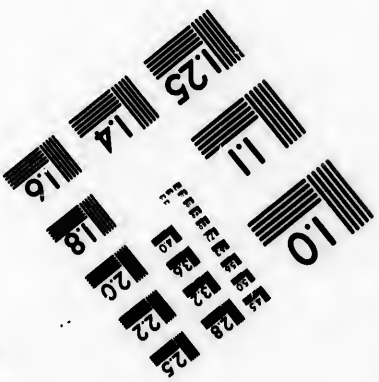

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NOTE ON THE PRE-PALEOZOIC SURFACE OF THE ARCHEAN TERRANES OF CANADA

THE INTERNAL RELATIONS AND TAXONOMY OF THE ARCHEAN OF CENTRAL CANADA

BY

ANDREW C. LAWSON

WASHINGTON
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BY ANDREW C. LAWSON, PH. D.

(*Read before the Society December* 27, 1889.)

CONTENTS.

INTRODUCTORY REMARKS.

Since the establishment of the glacial theory the cause of the hummocky and *roches moutonnées* character of the rocky surface of the Archean terranes of North America has generally been ascribed to the action of the ice of the glacial epoch. Two opinions have been prevalent, having this belief as their basis. The first and older view was, in accordance with the theories promulgated by the Scotch geologists, that the hummocks and their complementary hollows were produced by the direct plowing or gouging action of glacier ice loaded with rock débris. The second and more modern view is, that just as south of the terminal moraine we find the crystalline rocks extensively decomposed *in situ*, so prior to the advent of the glacial epoch the Archean terranes of the north were similarly decomposed, and the present hummocky

surface represents the locus to which rock decay had extended in depth. In this view the ice simply removed the rotten rock, scouring and polishing the fresh surface upon which it rested, and the hummocky character is due rather to the principles which govern the decay of rocks than to ice action, which is only held responsible for laying the surface bare. All students of glacial geology will concede that in both of these opinions there is a certain amount of truth, though much more in the second than in the first.

Some observations, however, which the writer has been enabled to make at odd times during the past few years, indicate that these hypotheses do not afford us the correct explanation of the hummocky aspect of the Archean surface, but that the latter, in its essential and prominent features, long antedates the glacial epoch, and was as characteristic of the surface upon which the earliest Paleozoic sediments were deposited as of that upon which the great Canadian glacier rested in glacial times. These observations have been made along the northern limit of the undisturbed Animikie and Nipigon strata, where they rest directly upon the Archean surface, on the north shore of Lake Superior, between Gunflint lake on the international boundary and the meridian of the Slate islands. The conclusions which they forced upon the writer have been confirmed by an inquiry which he has made into the conditions which prevail along the line of contact of the undisturbed Paleozoic rocks upon the Archean in more eastern portions of Canada.

In a paper of the present compass it will scarcely be possible to do more than indicate the localities where the evidence may be found, and to sketch the latter at each place in scant outlines.

The Phenomena of Central Canada.

Contacts between the Animikie and the Archean.—On the north side of Gunflint lake the superposition of the northern edge of the Animikie upon the Archean is well seen. To the north of the edge of the Animikie formations the Archean rises in low hummocky hills, the ridges of which, when these are present, coincide with the strike of the rocks. This hummocky surface may be walked over close up to the Animikie, and it may be seen to form an undulating surface upon which the latter rests. At the west end of the lake, on the north side of Black-fly bay, on mining locations R. 315 and R. 317, is an outlier of the basal beds of the Animikie resting on a ridge of Laurentian gneiss, with hollows on either side of it, and the Animikie at the bottom of that on the south, the whole showing very clearly that the present shape of the surface of the Laurentian was practically that upon which the Animikie was laid down. The direct repose of the flat Animikie upon the upturned edges of the Keewatin schists is also observable a mile and three-quarters from the east end of the lake, and here the surface

is of the same uneven character as that of the uncovered, glaciated country to the north. Similar contacts may be seen inland a short distance, near the head of the lake; and on Gunflint river the Laurentian gneiss, in low *roches moutonnées*, appears partially encircled by the Animikie rocks.

On the north side of North lake there flows in a creek at the bottom of a deep gorge, which cuts down through 200 feet of flat Animikie strata to the basement of Laurentian gneiss upon which they rest; and the basement is distinctly *roches moutonnées*. Similar conditions are observable two miles up the creek which flows into the east end of North lake, and on Sand lake, where escarpments of Animikie strata overlook and appear to overlie a hummocky surface of Laurentian gneiss. The same is true of the escarpments in the vicinity of Little Gull lake.

To the north and northeast of Little Gull lake is a group of five small steep-sided, flat-topped hills, known as the Outpost hills, which are outliers of the Animikie, capped as usual with a sheet of columnar trap. The distance which separates them from the main area of these rocks varies from one to four miles. This space is occupied by a very hummocky and *roches moutonnées* stretch of Laurentian gneiss which maintains the general level of a line extending from the base of the Animikie on the face of the escarpment to the base of the same series, where it rests on the Laurentian at the foot of the Outpost hills. The writer has been over the ground between the escarpment and the hills; and Mr. E. D. Ingall, of the Geological Survey of Canada, who has examined the hills carefully, informs the writer that the actual base of the Animikie may be distinctly observed resting upon the uneven, hummocky Laurentian surface, the sections being perfectly exposed.

Less than half a mile above Kakabeka falls small outlying patches of the basal beds of the Animikie may be seen lying in the hollows of the mammillated surface of the Laurentian, and the latter, as it rises from beneath the Animikie, above the falls, is exceedingly hummocky.

Along the Dawson road, a few miles back of Port Arthur, low, rounded domes of Laurentian gneiss appear in the midst of the Animikie, projecting above the level of the local upper beds.

On Current river the Laurentian rises in hummocky hills from beneath the Animikie slates and traps, although the actual contact has not been observed. Between this and McLean's siding, seven miles east of Port Arthur on the Canadian Pacific railway, the Archean rises in the same hummocky hills from beneath the Animikie, the line of contact being concealed by a narrow strip of swamp. At the siding the contact is only concealed by the width of the road-bed, and the surface of the Laurentian gneiss is seen to plunge down under the flat Animikie rocks with the slope of a steep dome, appearing again in a less prominent but still hummocky outcrop close to the con-

tact of the Animikie, on the wagon trail about midway between Green point and Wild Goose point.

At Silver harbor, farther up the north side of Thunder bay, there is a strip of the Animikie consisting of 15 to 20 feet of flat slates and cherty beds, capped by 50 feet of trap, from beneath which on the north, across a narrow strip of swamp, rises the Archean surface in well-defined *roches moutonnées*.

Contacts between the Nipigon and Older Rocks.—In the vicinity of Loon lake the basal beds of the Nipigon series overlap the northern edge of the Animikie and rest in undisturbed attitudes directly upon the Laurentian. On the north side of Loon lake and eastward to the vicinity of Pearl river the Laurentian rises from beneath the Nipigon sandstones and conglomerates in prominent hummocky hills. These conglomerates are made up very largely of boulders and rounded pebbles of the Laurentian, which are indistinguishable in general aspect from the more rounded erratics in the glacial drift.

In the bed of the creek at the tank of Pearl river station a low, rounded hummock of Laurentian gneiss appears from beneath the Nipigon sandstones; and at the first rock cut east of the station, 200 or 300 yards distant, the sandstones may be seen in the vertical section of the cutting, resting upon the slope of a hummock of Archean schists and dipping away from it to the east at an angle of 15°. Here the schists are rotted in places, leaving a few harder nuclei or boulders of disintegration *in situ*. Half a mile farther east along the track prominent, lumpy knobs of Laurentian rise above the level of the Nipigon sandstones to a height of over 100 feet, and on the east side of these, in a rock cut of the railway, the sandstones may be seen reposing directly upon their slopes, as an outlying patch.

About ten miles east of Nipigon, on the Canadian Pacific railway, there is a prominent bluff of Nipigon sandstone, capped with a thick sheet of vertically columnar trap, the whole presenting escarped faces which rise on three sides precipitously for several hundred feet above the hummocky plain of Laurentian rocks upon which it rests. The bare Laurentian basement is traceable up to the talus at the bases of the cliffs, and presents the appearance of passing under the column of superincumbent strata in the same hummocky condition as that which it has beyond the cliffs.

About ten miles east of Mazokama station on the Canadian Pacific railway a prominent point runs out into the lake, the core of which consists of hummocky Laurentian gneiss, and the outer margin or shore of superimposed Nipigon sandstones and conglomerates. Here again the Laurentian appears to pass under the Nipigon with its characteristically hummocky surface, the country being well bared; and that it does so is proved beyond question by the fact that scattered over the Laurentian area, away from the edge of the Nipigon rocks, there are numerous outlying patches of the basal

beds of the Nipigon resting *in situ* in the hollows between the Laurentian hummocks, both at the bottoms of the hollows and on the steep slopes. These patches are usually not more than a few chains in diameter; and their relation to the Laurentian affords incontestable proof that the surface of the latter has undergone no material change since they were deposited upon it. At Rossport the Animikie rocks come in again between the Archean and the Nipigon, and here also may be seen, near the railway station, in a hollow between the Laurentian hillocks, an outlying patch of the basal beds of these rocks.

Along the shore of the lake between Rossport and Black river, north of the Slate islands, there are occasional patches of the Nipigon amygdaloidal traps which have escaped removal by erosive agencies, and these all repose upon a hummocky Archean surface. In none of these instances is there any evidence of a perceptible reduction of the mean level of the glaciated surface of the Archean below that upon which the Nipigon or Animikie rocks rest. A noteworthy fact also is, that with one exception none of the Archean rocks, where they pass immediately beneath the Animikie or Nipigon, show the slightest evidence of decay. On the contrary, they are remarkably fresh and free from even the incipient decomposition of weathering. The exception is the case of the schists in the rock cut east of Pearl river mentioned above. All the Laurentian gneisses and granites are perfectly fresh in their macroscopic aspects. Another interesting point, which will be alluded to again, is the transgression northward of the newer Nipigon rocks beyond the edge of the older Animikie.

The Phenomena in Eastern Canada.

On instituting a comparative inquiry into the conditions which obtain along the escarped line of the abutment of the undisturbed Paleozoic upon the Archean in eastern Canada, it is found that the evidence here confirms the conclusions arrived at on Lake Superior as to the general character of the pre-Paleozoic Archean surface.

Contacts between the Paleozoic and the Archean.—Laflamme in his "report of geological observations in the Saguenay region"* seems to have arrived at much the same conclusion as the writer. After describing a new area of the Trenton rocks in the vicinity of the Saguenay "which rest directly on the gneiss," and stating that "their thickness is so slight, at least on the border of the formation, that the undulations of the gneiss are brought to light through their edge," he gives an account of various outliers and says by way of summary: "I have pointed out in the course of these remarks the fact that limestones (Trenton) are often found in nests or outliers amongst the

*Geol. Survey of Canada, Report Progress for 1882-3-4, Part D.

granites. Therefore, these depressions and hills of Laurentian must necessarily have existed at the bottom of the Paleozoic ocean when the limestone beds were being deposited."*

Mr. A. P. Low, of the Geological Survey of Canada, who has been more recently engaged in tracing out the northern limits of the Paleozoic on the north side of the St. Lawrence, west of Quebec city, informs the writer that at several places he has noted the superposition of the Trenton or Lorraine beds directly upon the hummocky Laurentian surface, and that there has been no reduction of the surface where it projects from beneath the escarpments, below that where the flat strata rest upon it. He notes the following localities as affording particularly good sections:—Between Loretto village and St. Ambrose railway station, Q. L. St. J. railway; west of Belair station, C. P. railway; Pont Rouge station, C. P. railway (section on Jacques Cartier river); Deschambault, near railway station. Mr. Low also informs the writer that the undisturbed limestones of Lake Mistassini, in southern Labrador, may be observed to rest upon hummocky Laurentian surfaces; and that on the East-main coast of Hudson's bay similar flat lying strata may be seen in the transverse section afforded by Richmond gulf, resting on a very hummocky surface.

In eastern Ontario, the best evidence we have bearing on this question is contained on Mr. E. Coste's "Geological and Topographical Map of the Madoc and Marmora Mining District," recently published by the Geological Survey of Canada. No report accompanies the map as yet, but the writer has had the benefit of frequent conversations with Messrs. Coste, Ami, and White, who were employed in the field-work necessary for its construction. From the map and from the information thus supplied, it is clear that in the area mapped we have a remarkably striking illustration of the superposition of flat, undisturbed Paleozoic strata (Birdseye and Black River) upon a very hummocky and mammuillated Archean surface. The northern border of the Paleozoic is here very irregular in outline, and beyond the limit of the main area there are very numerous outliers scattered over the country. Both along the edge of the escarpment and at the periphery of many of the outliers, the flat strata may be seen resting directly on the rounded hummocks; and these, out beyond the escarpment, often rise high above the lower horizontal strata. Many of the outliers, also, are mere patches resting *in situ* upon the steep slopes of these hummocks. Many are but a few chains in diameter, and others only a few yards. Further, there may be repeatedly seen projecting through the upper surface of the Birdseye and Black River formations rounded knobs of the Archean, in the shape of inliers well within the Paleozoic area. These are clearly the crests of partially

* Loc. cit., p. 15.

uncovered hummocks; and the phenomenon is so common as to leave no doubt as to the character of the underlying surface.

Review of the Evidence.

Thus, wherever careful observations have been made as to the nature of the superposition of the undisturbed Paleozoic rocks upon the Archean, whether in the Lake Superior country, eastern Ontario, Quebec, or Labrador, the evidence points to the same conclusion, *i. e.*, that the early Paleozoic rocks were laid down upon a surface which did not differ essentially from that presented by the exposed Archean surface of the present day upon which the great Canadian glacier rested; and that there is no good evidence of that surface having undergone any material reduction in level, in consequence of the conditions of the glacial epoch, either by any plowing power sometimes ascribed to glacier ice, or by the removal of the products of extensive rock decay.

General Considerations.

In the foregoing pages the evidence, although briefly sketched, has been specific, and attention has been confined to the immediate vicinity of the edge of the Paleozoic formations. Let us turn now to a somewhat broader aspect of the question.

Former Extension of the Paleozoic.—There is excellent presumptive evidence that the greater part, if not the whole, of the Canadian Archean terranes were at one time covered by Paleozoic strata, and the assumption so generally made that they have always formed an upland region, serving as a source of supply for the sediments which built up the Paleozoic formations, appears to be scarcely warranted by the facts.

The reconnaissance work of the Geological Survey of Canada, while it has only effected an examination of a number of linear sections across the arms of the V-shaped Archean nucleus, along the various canoe routes which traverse it from the waters of the St. Lawrence and Lake Winnipeg systems to the waters of Hudson's bay, has yet established the fact that there are basins and outliers of Paleozoic rocks scattered over its surface which appear to be but the remnants of once far wider spread formations. In the region of the Saguenay, Laflamme * has described various outliers of Trenton other than the well known one at Lake St. John, and the distribution of these shows clearly that this formation must have extended for at least 150 miles north of the St. Lawrence, over what is now for the most part bare Archean surface, and the probability is that it extended much farther.

* Op. cit., pp. 10–15.

To the north the explorations of McOuat and Low have established the existence of another large and important outlier of undisturbed Paleozoic rocks over 100 miles in extent, about 150 miles beyond Lake St. John, at Lake Mistassini. These rocks are chiefly limestone in which as yet no fossils have been found, and which are referred provisionally to the Cambrian from certain resemblances to the flat strata of the east coast of Hudson's bay which are supposed to be of that age. These latter rocks occur along the East-main coast, resting in undisturbed attitudes upon the Archean. Inland from this coast, also, Mr. Low found in the drift which comes from the east, or the interior of Labrador, a limestone boulder containing Silurian fossils, which indicates the presence of an outlying area of such rocks in that region.*

On the upper Ottawa, in the vicinity of Pembroke, we find extensive Cambro-Silurian outliers as much as 50 miles from the edge of the present main Paleozoic basin. Other outliers are also found on the islands of Lake Nipissing, and on Lake Temiscaming nearly 100 miles north of Lake Nipissing. There is thus good reason for supposing that the Paleozoic seas extended far over the whole of the upper Ottawa country.

The great Siluro-Devonian basin of the west side of James's bay extends southward to within 100 miles of the north shore of Lake Superior, and farther west the rocks of the Nipigon basin extend northward for 100 miles. The former extends south and the latter north of the 50th parallel of latitude, and the east and west distance between the two basins along the parallel is only about 100 miles. It is entirely probable that both of these basins only represent what is left by erosion of a much more extensive distribution of the respective formations constituting them; and that they do not in reality correspond in area to the original basins of deposition, but are rather basins of shelter from erosion, such as all the Paleozoic outliers appear to be.

On the southwest side of Hudson's bay there is another extensive area of Silurian rocks, traversed by the lower stretches of the Churchill, the Nelson, the Hayes, and the Severn rivers. These rocks resemble those of the same age in the basin of the Red river and Lake Winnipeg, both as regards their fossil remains and their lithological characters. The Hudson's bay area of these rocks is separated from that on Lake Winnipeg by about 200 miles of Archean country, with no prominent elevations between, and it is therefore quite probable that they were once connected, and that the formations of which they are constituted extended continuously across this northwestern arm of the V-shaped Archean "nucleus." An outlying area of sandstones of unknown age also rests upon the Archean at the east end of Athabasca lake.

Thus, considering the very limited extent to which this Archean "nucleus"

* Geol. Survey of Canada, Annual Report, Vol. III, 1887, Part J, p. 59.

has been explored, the indications that it was once very extensively if not wholly covered by formations of Paleozoic age are both numerous and important. The lines of examination have been chiefly confined to the ordinary routes of travel followed by the fur traders, and these are not numerous. When the country comes to be more closely explored there is every reason to suppose that many other outliers, such as those of lakes St. John, Mistassini, Nipissing, and Temiscaming and the Ottawa river, will be found scattered over its surface, and that the evidence of the once wide-spread distribution of the Paleozoic formations will accumulate.

Transgressions and Oscillations in Level.—But here a word of caution and modification is necessary. While the evidence indicates that a covering of Paleozoic (Cambrian to Devonian) once spread over the Archean surface, it does not indicate that the rocks of the lower horizons were thus widely spread. On the contrary, it is to be noted that there are distinct evidences of the transgression of the formations of higher horizons over the limiting edges of the lower. Thus, on Lake Superior, the Nipigon rocks may be distinctly observed to overlap the northern edge of the Animikie formation and extend northward far beyond it. In the St. Lawrence and lower Ottawa region, rocks of Potsdam and Calciferous age are abundant. Further north these are absent, and in the upper Ottawa outliers the Chazy rests directly upon the gneiss. In the vicinity of Madoc this also is lacking, and the Birdseye and Black River beds rest directly upon the gneiss. This appears to be true also of the outliers on Lake Nipissing. Thus, in ascending the Ottawa, the Chazy overlaps or transgresses both Potsdam and Calciferous, while at Madoc and Nipissing all of these are transgressed by the Birdseye and Black River. This, in turn, and all older formations, were transgressed by the Niagara, as is indicated by beds of that age resting directly on the Archean on Lake Temiscamany.

In the Province of Quebec the same condition of affairs is found. In the vicinity of the St. Lawrence, the Chazy and Calciferous rocks abound. To the north of this, in the Saguenay country, Laflamme remarks as a noteworthy fact, that in all the points of contact which he has been able to observe between the Laurentian and the Trenton, the latter rests directly upon the former, no traces of Potsdam, Calciferous, or Chazy being seen. Moreover, whilst the Utica formation is present only in a few instances, still débris from it are found on the shores of the lake (St. John), and very often inland to such an extent that we are forced to conclude that the whole area of the Trenton was formerly covered with this formation.

Thus, while the evidence indicates that the Archean "nucleus" was once covered very extensively by Paleozoic formations of one horizon or another, it appears probable that it was not extensively submerged till the time of the Trenton, and that it was much more extensively submerged during the

deposition of the Niagara than in earlier epochs. It would follow from these considerations, that as Paleozoic time advanced from Cambrian to late Silurian or Devonian there was a gradual and progressive subsidence of this portion of the continent. As we have no evidence of the deposition of post-Devonian formations anywhere over the Archean "nucleus" till we come down to post-Tertiary, it may be tentatively inferred that after the Devonian it was again elevated, and this elevation probably only reached its maximum during the glacial epoch, affording the conditions of altitude contended for by many writers to explain the great precipitation of snow. In post-glacial times we know from the distribution of such formations as the *Leda* clay and *Saxicava* sand that the northern part of the continent was again partially submerged for several hundred feet, from which depression it has since recovered; we thus have evidence of a slow vertical pulsation of the surface of this part of the continent, of which there have been at least four great beats since early Cambrian times.

But this is a digression, and the argument which has led to these remarks was inaugurated to show simply that the surface of the Archean "nucleus" was once very extensively if not wholly covered by Paleozoic sediments. This covering probably accounts in a large measure for the remarkable preservation of the Archean surface in the condition in which pre-Paleozoic denudation left it. There are other considerations which help us to understand this preservation, such as the levelness of the plateau and its comparitively low altitude, combined with the very resistant character of most of its rocks, which appear to be little susceptible to that erosive or corrasive action of streams which is so effective in removing the more yielding strata of post-Archean age. These considerations will not, however, be entered upon here.

The Erosion of the Archean.—One is constantly impressed by the perfectly appalling amount of denudation to which the Archean has been subjected in order to truncate its formations down to the surface which it presents to-day. And when we reflect, as a result of the conclusions here arrived at, that this denudation was practically completed before the beginning of earliest Paleozoic times, and has not been, as commonly supposed, the result of later agencies, there looms up a conception of the pre-Paleozoic interval necessary for such denudation which staggers even the most stalwart geological imagination. To say that it must have been comparable with all the time which has succeeded from the earliest Cambrian to the present seems but a feeble way of expressing it.

Source of Paleozoic Sediments.—The conception of a covering of Paleozoic strata over the surface of the Archean "nucleus," which probably endured into comparatively recent geological times, enables us to a large extent to understand the preservation of the pre-Paleozoic surface, but it also raises the

important question of the source of the sediments composing those strata. If such a wide-spread formation as the rocks of Niagara age was deposited over the surface of the Archean "nucleus," as well as over the regions which encircle it, it is clear that the Archean "nucleus" could not have been the source of supply of those sediments. Some other portion of the continent, or some other region now submerged, must have constituted the dry land of that time. Where that region lies is a question yet to be answered.

DISCUSSION.

Professor J. W. SPENCER: The facts set forth in this very interesting paper by Dr. Lawson have their counterparts in the geological structure of the South. The hummocky and rounded rock surfaces have always had an interest for me, on account of their common occurrence in regions which have been glaciated, and hence regarded by many as evidence of glacial erosion. But in the paper of Dr. Lawson we learn that such surfaces existed before the formation of the early Paleozoic terranes. Some of you may be familiar with Stone Mountain, about fifteen miles from Atlanta, Georgia. This is a rounded granite hummock of over a mile, in longer diameter, rising 700 feet above the plain. The rock is remarkably free from joints, and is rarely traversed by even an insignificant vein. Thus its structure has been favorable to the preservation of the rounded form, whose outline is as perfect as any of the domes of glaciated Norway or Canada; or of southeastern Missouri, which lies outside of former glacial action. Stone Mountain rises from beneath very much disturbed strata of gneiss, whose beds dip to the southeast, and there is no gradation of any importance between the granite and the gneiss. The gneiss is decayed to a depth, in some places, of at least sixty feet; but the granite is compact, without being weakened by even incipient decay. The surface materials, as fast as decomposed, are washed off by the rains. Thus the contrast between the two formations of rocks is preserved. This Stone Mountain is only one of many in Georgia and Alabama. Here, then, we have, in the South, pre-Paleozoic surfaces as old as or older than those described by Dr. Lawson in the Lake Superior region, and brought to light by simple atmospheric action. Along the Potomac river we find hummocks being formed by the progress of atmospheric invasion along lines of joints, but these are now in process of formation, and do not represent so ancient surfaces as those of the granite hummocks of the South.

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THE INTERNAL RELATIONS AND TAXONOMY OF THE ARCHEAN OF CENTRAL CANADA.

BY ANDREW C. LAWSON, PH. D.

(*Read before the Society December* 28, 1889.)

CONTENTS.

PRIMARY SEPARATION OF THE ARCHEAN INTO TWO DIVISIONS.

Throughout North America, geologists have long recognized in the great fundamental complex of rocks, known generally to-day as the Archean, a natural division into two well-characterized portions, related to each other in space as upper and lower. The lower division is commonly known as the Laurentian, and consists for the most part of an assemblage of rocks of the character of granites, syenites, diorites, and gabbros in mineralogical composition, but more or less foliated or gneissic. Involved with these in a way not hitherto understood there are also, in some regions, portions of

various gneiss, schist, limestone, quartzite, and conglomerate formations, which, not being easily separable from the foliated granite rocks, have been sometimes classed with the latter as Laurentian.

The Upper Division.

Nomenclature.—The upper division is of very varied lithological character, and various names have been applied to it, or to portions of it, in different regions. Until recently it has been customary to apply the term Huronian to a part of this upper division on account of its supposed equivalence to the series of rocks so named by Logan and Hunt in 1855.* But if the original conceptions of these eminent geologists and the more recent contentions of Irving, corroborated by Professors N. H. Winchell and A. Winchell, are correct—viz., that the Huronian and Animikie are geologically equivalent,—then we cannot in reason perpetuate the incongruity of applying the same name to two groups of rocks which lie one on either side of probably the greatest hiatus in American geological history. The term Huronian must be retained for the group of rocks on Lake Huron first so named and its equivalents; and, in view of the evidence which has been adduced of the unconformable superposition of that group upon the Archean and its probable equivalence with the Animikie, which rests upon the Archean in glaring unconformity, it seems inappropriate at present to apply the term Huronian to any portion of the Archean. We are thus, at the outset of any inquiry into the Archean, hampered by the lack of an acceptable designation for the great system of rocks which constitutes its upper division. Even if the Huronian group be demonstrated to lie upon the remote side of the great post-Archean hiatus, it would then be only one of several groups that go to form the system which constitutes the upper division of the Archean complex, and the system itself would still be nameless. At least one other great group of rocks—the Coutchiching (possibly the equivalent of the Montalban of Hitchcock)—has been brought to light, which is not second in taxonomic importance to the various belts of rocks similar to the Keewatin, which have been correlated with the Huronian. So, granting that the Huronian shall one day hold an unchallenged position in Archean taxonomy, it will not have a higher rank than that of a group.†

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*A Sketch of the Geology of Canada, serving to explain the Geological Map and the Collection of Economic Minerals sent to the Universal Exhibition at Paris, 1855, by W. E. Logan and T. Sterry Hunt; in Canada at the Universal Exhibition of 1855, p. 415 *et seq.* In this sketch, in which the term Huronian is first defined, the rocks now known as the Animikie and Nipigon series are taken together as the equivalent of rocks on Lake Huron, and the whole is called the "Huronian or Cambrian system," which is stated to rest unconformably upon the Laurentian.

†In this paper the terms "system" and "group" have the significance assigned to them by the United States Geological Survey, in the scheme published in the Second Annual Report, 1880-'81, p. xlviii. The writer recognizes, however, two great "systems" in the Archean complex. The terms may later be transposed or otherwise changed to accord with any general decision of the International Geological Congress as to usage.

Having these considerations in mind, it seems desirable, in the cause of the concise expression of our knowledge and of the furtherance of clear and simple conceptions of Archean geology, that the taxonomic value of this upper division of the Archean should be recognized by the adoption of an appropriate designation of systemic import. There is probably no other equal area of the earth's surface where the formations of this system are better or more extensively exposed than in the Canadian province of Ontario. The writer therefore begs to suggest to his fellow-workers in American Archean geology that this system be known as the *Ontarian System.*

Petrographical Description.—The formations of different groups of the Ontarian system present for the most part a sharp contrast in lithological character and mode of occurrence to those of the Laurentian system. The latter, as has been indicated, consists essentially of an assemblage of more or less foliated or quite massive varieties of rocks which are to-day recognized by petrographers as plutonic igneous rocks—*e. g.*, granites, syenites, diorites, gabbros, etc. The former is composed of rocks which are with varying degrees of certainty recognized as normal sedimentary and volcanic formations disguised by metamorphism of different kinds. Among the more easily recognizable formations may be mentioned conglomerates, grits, quartzites, graywackes, clay slates and limestones; various pyroclastic rocks, such as ashes, tuffs and agglomerates; and massive volcanic rocks, both acid and basic, notably quartz-porphyries and diabases; all of which rocks, far from being peculiar to the Archean, are normal constituents of Paleozoic and later geological systems. In all of these, schistosity may be a feature of the rock.

With these normal or only slightly altered rocks occur also more highly altered facies of the same formations, whose derivation is known, and others still more differentiated from unaltered types, whose historical derivation from normal rocks cannot be traced with certainty, but only inferred by analogy as highly probable. Of those rocks whose original character is more or less obscured, the most prominent are certain phyllites, mica schists and feldspathic mica schists or gneisses, so called; hornblende schists and amphibolites, serpentines, soft, dark, glossy, green schists, and various light-colored acid porphyroid schists, nacreous sericitic schists and felsitic schists with quartz grains. These are all rocks upon which there has, in recent years, been concentrated a great amount of research both in the field and in the laboratory, and many facts have been established concerning them in various parts of the world which enable us to formulate definite and well-grounded conceptions as to their origin and development, where formerly only more or less indefinite speculation was possible.

The rocks known as phyllites or phyllitic schists are very common in fossiliferous series in disturbed regions, and their clastic origin is rarely ques-

tioned. In the Archean, rocks of this and more pronounced micaceous character to true mica schists are traceable into clay slates and siliceous clastic rocks with unobscured original characters. Other mica schists are directly traceable into conglomerates and agglomerates, and appear to be but excessively squeezed facies of these rocks where the conglomeratic or agglomeratic characters have been obliterated and much mica developed. And in some mica schists, where no direct transition can be established, traces of conglomeratic structure can occasionally be detected. The most distinctly crystalline of these mica schists are entirely comparable with the mica schists of the Bergen peninsula in Norway, where Reusch a few years ago found beautiful Silurian fossils,* some of which the writer has himself more recently collected under the guidance of that distinguished geologist.

Many mica schists of the Ontarian system are, further, entirely similar to the "hornfels" or crystalline schists of the contact zones of various post-Archean granitic irruptions, which are undoubtedly the altered facies of normal sediments. Some of the feldspathic mica schists, of a fine-grained, thinly laminated aspect, commonly called gneisses, are in parts of the Ontarian system traceable into quartz-porphyries of the same normal character as those which constitute the volcanic portions of many Paleozoic series. The researches of Lehmann † have established such transformations as facts, the explanation of which, as demonstrated by that eminent investigator and now generally accepted, is found in the deformation of the rock by pressure and in the chemical activity induced thereby. For the most part, however, the feldspathic mica schists, such as are abundant in the Coutchiching group, are, like the non-feldspathic mica schists associated with them, very probably of metamorphic derivation from normal sediments.

In portions of these formations the writer has recently detected vestiges of conglomeratic structure. In places they pass into rocks that are little more than slightly micaceous quartzites, and their distinct bedding and regular stratigraphy are those of sedimentary rocks as contrasted with the lenticular arrangements which obtain in volcanic accumulations. Their contact phenomena against the granites and granite-gneisses of the Laurentian are identical, so far as studied, with intrusive granites, particularly in the development of andalusite crystals. They correspond closely in lithological character and in the nature of their relations to the Laurentian with the descriptions given us by Barrois ‡ of the feldspathic mica schists of Cambrian age, which in Brittany are pierced and altered by great irruptions of granulite (the true granite, or granite with two micas, of the Germans), which rock forms very extensive portions of the Laurentian northwest of Lake Superior.

* Die Fossilien Führenden Kryst. Schiefer von Bergen. Leipsic, 1883.
† Entstehung der Altkrys. Schiefergest. Bonn, 1884.
‡ Comptes Rendus des Excursions de la Soc. Geol. de France dans le Finistère. Bull., 3me Série, t. XIV, 1886, p. 832, et seq.

As to the hornblende schists, the field evidence points to their derivation from basic volcanic rocks. In places this derivation can be traced step by step from the massive rock to the schist; but for the most part no such transition is observable, and at the base of the Keewatin, in contact with the Laurentian, there is commonly found a formation of hornblende schists of whose origin and development we can only judge by comparison with cases where the history of similar rocks has been thoroughly worked out and established beyond question. Teall,* in Scotland, and Reusch,† in Norway, have shown that some typical hornblende schists and more chloritic hornblende schists may be produced by the shearing of diabase dikes. The writer has collected specimens of the crushed and squeezed diabase dikes of Bömmelö described by Reusch, which are indistinguishable from many of the schists of the Keewatin on the Lake of the Woods and Rainy lake. Teall's description of the hornblende schists resulting from the shearing of dikes would also apply to many of the Keewatin schists which occur in bedded formations. The augite-porphyrites of the Silurian of the southeast coast of Norway, which have been described by Brögger,‡ are, at the contact with the intrusion of the augite-syenite of Langesundfjord, where observed by the writer, altered in places into black glistening hornblende schists, which are very similar to the hornblende schists of the Keewatin at its contact with the Laurentian gneisses. Thus, both the conclusions arrived at in the field and supported by microscopic studies, and the analogies furnished by the investigations of geologists elsewhere, point to the derivation of the bulk of the hornblende schists from normal volcanic massive rocks, which were originally bedded with other stratified rocks, either as flows or as injected sills. Other hornblende schists are probably derived from an analogous alteration of tuffs of basic volcanic rocks.

The amphibolites are rocks very analogous to the hornblende schists in mineralogical composition, but massive or non-schistose in structure. They have probably undergone the same chemical development as the schists, with pressures so adjusted that no foliation was induced. They are comparatively local in their occurrence and do not generally make extensive formations.

The various serpentines, so far as they are known, are for the most part beyond doubt the alteration products of local bosses of highly magnesian, massive irruptive rocks. This conclusion is based not simply upon the investigation of the rocks of this particular field by the writer, but upon the numerous instances that might be cited from the petrographical writings

*Metamorphosis of Dolerite into Hornblende-Schist; Quart. Jour. Geol. Soc., Vol. XLI, May, 1885, p. 133.
†Bömmelöen og Karmöen med omgivelser geologish beskrevne, 1888, pp. 392–397.
‡Spaltenverwerfungen in der Gegend Langesund; Nyt Magazin for Naturvidenskaberne, XXVIII Bind, 3die—4de Hefte, p. 352.

of recent years, establishing such an origin for the bulk of the serpentines at present known the world over.

There is a great variety of fissile, more or less glossy, rather soft, green schists, partly hornblendic and partly chloritic, the origin of which in some cases is closely fixed from the fact that they form the matrix of well characterized pebble and bowlder conglomerates. In this case they must have been composed of epiclastic or pyroclastic material. The writer inclines to the opinion that they are of proximately pyroclastic origin from the fact that precisely similar schists, free of pebbles, are frequently associated with massive or only slightly schistose diabases, as if the tuffs of these extravasations. There are many other bedded green schists some of which can be shown to be squeezed and otherwise altered facies of diabase, while the precise origin of others is yet quite obscure.

The porphyroid schists, the felsite schists with quartz grains, and many of the nacreous sericite schists, represent squeezed, schistose and otherwise altered forms of quartz-porphyries and petrographically allied rocks, and their tuffs, which, as before stated, enter not uncommonly into the composition of the volcanic portions of normal Paleozoic series. Some others of the sericitic schists may probably have been developed from sediments rich in orthoclase débris; but this, except where they pass over into rocks of the character of phyllites, is not so easily established as the direct derivation of many of them from the acid volcanic rocks.

Original Characters and Metamorphism.—From the foregoing statement, brief and incomplete as it is, of the broad lithological characters of the formations which constitute the Ontarian system, or upper division of the Archean, it must be apparent that, although there are rocks within it whose history is more or less obscured by the changes which they have undergone, the system is an assemblage of once normal rocks, all of which may be found even in their most altered phases in series of Paleozoic and later ages. This conclusion will not appear startlingly new to the very powerful school of American geologists, who have always claimed the metamorphic derivation of the whole of the Archean from normal rocks.

But, as will appear in the sequel, the metamorphic explanation of the whole of Archean phenomena is not tenable, and is only applicable, in the opinion of the writer, to its upper division, here designated the Ontarian system. Moreover, it is to be noted that the conclusion in question offers an important modification of the old view of the metamorphic development of such rocks as constitute this system, inasmuch as volcanic formations have scarcely been recognized in our leading American text-books as having a share in the composition of the older rock series. Much of the Archean was properly recognized as the alteration products of sediments, and the whole complex was therefore inferred or supposed to be of similar derivation from

sediments. It is only in very recent years that the possibility of the derivation of a portion of the schists of the Archean from volcanic rocks has been looked into and the important rôle played by volcanic agencies in building up the older rock series has been appreciated.* There are, however, not a few geologists who continue to advocate the extreme plutonic view that the whole of the Archean is of igneous origin and represents the first-formed crust of the earth. Hunt's creuitic hypothesis, also, is a challenge to the metamorphic theory.

In deference to these and other anti-metamorphic schools of thought, in which for the most part theory seems to crowd out fact, it becomes necessary, with the accumulation of evidence of recent years, to point out the great additional strength acquired by the theory of metamorphism as applied to the Archean, by the recognition of the volcanic origin of much of the material upon which metamorphic agencies have operated, and by the limitation of its application to the upper division of the Archean; the rocks of the lower division, or Laurentian, being susceptible of an entirely different explanation. The lack of discrimination between the essentially different characters of the upper and lower Archean and the lumping of the whole complex together as having necessarily the same origin and development has been the great mistake alike of the metamorphic and the extreme plutonic schools. Just as the metamorphic theory, properly limited, affords the explanation of the development of the rocks of the upper Archean from normal formations, so by a similar limitation of the plutonic theory and the introduction of some modifying considerations we will find in the latter a rational and consistent explanation of the origin of the rocks of the Laurentian.

Relations between the two Divisions.

The General Relations.—The full significance of the sharp separation of the Ontarian system, as a bedded assemblage of prevailingly schistose and otherwise altered normal rocks, from the Laurentian, as a non-bedded assemblage of more or less foliated plutonic igneous rocks, will appear from an inquiry into the relations in space and in time between these two great systems, which it is the object of this paper to institute.

That portion of the Ontarian system which for some years has been somewhat loosely referred to as Huronian, from its supposed equivalence with the rocks of Lake Huron, now held to be possibly post-Archean, presents in many parts of central Canada contacts or lines of junction with the Laurentian. The nature of this contact has been a subject of discussion. The question has ever been raised whether these rocks are conformable or un-

* The first suggestions of volcanic admixtures in the upper Archean rocks of central Canada were thrown out by G. M. Dawson in his description of the agglomerates of the Lake of the Woods in the Report on the Geology and Resources of the 49th Parallel, 1875, p. 52.

conformable upon the Laurentian; the assumption being always that both assemblages of rocks were composed of metamorphosed sediments. The answer was held to hinge upon the parallelism or absence of parallelism between the foliation of the Laurentian granites and syenites and the planes of bedding and schistosity of the rocks which are in contact with them. Bell, Dawson, Selwyn, and McKellar contended for a conformable sequence. Logan is silent on this question, but seems to have been in no doubt as to the unconformable superposition of the true Huronian of Lake Huron upon the Laurentian. Hunt has always contended for an unconformity, but as he also had in mind the true Huronian, which he once regarded as Cambrian, his contentions do not seem to apply to such rocks as are clearly Archean and intimately involved with the Laurentian gneisses. It is therefore fair to say that the drift of opinion in Canada, and probably also in the United States, is in the direction of conformable sequence throughout the Archean, without a break between the lower (Laurentian) and upper (Ontarian) systems. This view has recently been emphatically endorsed by Professor Alex. Winchell* as a result of his observations in northern Minnesota. Dawson has recently, as a result of his studies of analogous conditions on the Pacific coast, thrown over his earlier opinions as to the conformable sequence between these two divisions of the Archean on the Lake of the Woods, and is now in accord with the writer as to the nature of the relations which obtain there, and which will be set forth in the sequel.†

Irruptive Contact on Lake of the Woods.—Up to the date of the publication of the writer's report on the geology of the Lake of the Woods (1885), the possibility of any other relationship between the two great divisions of the Archean than those of conformity or unconformity do not seem to have been entertained. In that report the writer pointed out that the relationship was one of neither conformity nor unconformity, but of an entirely different order. Evidence was adduced in some detail to show that the conditions of the contact between the Laurentian and the Keewatin are essentially those which obtain between any Paleozoic or later intrusion of granite and the bedded rocks through which it breaks. The contact was shown to be a brecciated one, the granitoid gneiss ramifying through the schists in apophyses, both transverse and parallel to the strike of the schist, and holding in abundance fragments from the Keewatin formations, which had clearly been broken off from the latter while it was in a hard and brittle state and had found their way into the Laurentian often for considerable distances from the contact, as well as more notably in its proximity. The conditions observed indicate clearly that we had no question of conformity or unconformity to deal with, but with the contact of an irruptive igneous mass, of

*Geol. and Nat. Hist. Survey of Minnesota, 15th Annual Report, 1886, pp. 181, 190, et seq.; 16th Annual Report, 1887, pp. 335, 336, 350, 364, et seq.

†Annual Report Geol. Survey of Canada, Vol. II, N. S., 1886, p. 13B.

later formation than the schists of the Keewatin series, and breaking through them.

Irruptive Contact in Rainy Lake Region.—The studies here inaugurated about Lake of the Woods have since been continued into the Rainy lake region, and still farther eastward to Lake Superior. A portion of the results are contained in a recently published report of the Geological Survey of Canada.*

Throughout this region, it was found that the Keewatin is not the only group in the upper division of the Archean, but that another very voluminous group intervenes between it and the Laurentian, to which the name Coutchiching has been given.† The relations of the Laurentian to this group of schists was found to be the same as to the Keewatin, with even clearer and more abundant evidence of the irruptive and later origin of the Laurentian. With extended observations it was also noted that the bedded rocks of the Ontarian system, whether belonging to the Keewatin or Coutchiching, present a more highly altered or more crystalline and schistose facies in proximity to the contact with the Laurentian granite-gneiss than in the middle portions of the trough, where the rocks are frequently not greatly altered from the normal character of their analogues in Paleozoic formations.

In other words, there is evidence of contact metamorphism where the Laurentian rocks come against the shattered and ragged edge of the local base of the Ontarian system. All the conditions of contact, therefore, whereby we recognize any mass of granite to be irruptive through stratified rocks, are found to hold here between the rocks of the Laurentian and Ontarian systems. The detailed geological mapping of the country shows also that the Laurentian rocks, while continuous beneath the schist belts, come to the surface in areas which may be described as isolated bosses. Each of these is surrounded by a belt of the Ontarian rocks, usually in the form of a sharply folded trough sunk down into the Laurentian and separating the surface exposure of the boss from those of its neighbors. These belts of formations of the Ontarian system are, for the most part, compact and con-

* Annual Report, 1887, Part F.

† It is unfortunate that two new names have become current for this group of rocks. The term Coutchiching was proposed by the writer in a paper which left his hands in March, 1887, bearing that date, and which was published in the *American Journal of Science* in June of the same year. The geological position, lithological character, known geographical distribution, relations to Keewatin and Laurentian, and the importance and distinct individuality of this great group, were stated and discussed in that paper. In the Fifteenth Annual Report of the Geological Survey of Minnesota, bearing the date of May 1, 1887, but appearing much later, there is a multitude of valuable observations and details, but no systematic statement of the geology of the region; and the differentiation of the group in question, as geologically separable from the rest of the complex, does not appear to have been recognized at the time of the writing of the report, although the term "Vermilion series" occurs once, apparently as an afterthought, inserted on page 299 of Professor N. H. Winchell's report. On the maps accompanying the report, however, it is distinguished clearly by a color and named the "Vermilion series," although here including formations that had earlier been designated Keewatin. From this it would appear that the term "Coutchiching" was somewhat prior to "Vermilion," and was more fully and precisely defined as to its geological significance. Moreover, the term "Vermilion Lake series" was used earlier by Irving in another sense than that proposed by Professor N. H. Winchell, and in the same Annual Report (Fifteenth) the terms "Vermilion series" and "Vermilion system" are used by Professor A. Winchell, on pp. 192, 195, 196, in another and much more comprehensive, but still undefined, sense.

tinuous, forming a great anastomosing mesh-work, the general strike being always concave to the Laurentian areas which they encircle.

Sometimes, however, where denudation has exposed their deeper portions along anticlinal or synclinal arcs, as in parts of the Lake of the Woods and Rainy lake regions, and better in Hunter's island, the formations in contact with the Laurentian granite-gneiss are found to be excessively shattered, and countless numbers of fragments are strewn throughout the mass of the irruptive rocks. The country is well bared, and what is stated is clearly visible on well-exposed continuous rock surfaces. These included detached fragments of the formations overlying the granite-gneiss range in size from pieces a few inches across to immense masses. Their longest diameters are, as would be expected, in the plane of schistosity. Where the enclosing rock is gneissic, the inclusions have usually a constant orientation parallel to the foliation of the gneiss, which also coincides, as a rule, with the nearest edge of the belt through which it breaks, where not too remote from the edge. Other inclusions in the Laurentian have been observed whose derivation from the Ontarian rocks cannot be established. Suggestions as to their origin have been thrown out by the writer in his report on the Rainy lake region.

Along the edges of the belts of the Ontarian rocks, there may frequently be observed, running out from the main belt and in continuous strike with it, tongues of schist which taper more or less gradually and eventually end in points. These also are seen to be immersed and congealed in the granite-gneiss; and many of the larger detached inclusions are doubtless portions of such tongues which have been separated from the main belt by the lowering of the plane of surface truncation by denudation, rather than by actual detachment at the time of disturbance. This would in a large measure account for the fact that the common orientation of the larger fragments, and their parallelism with the edge of the belt, holds for the dip as well as the strike.

Numerous long, attenuated, parallel tongues are also formed at the edges of the schist belts by the injection along the planes of schistosity of portions of the granite-gneiss magma, forming an evenly ribboned alternation which simulates bedding. Its formation by injection is, however, sufficiently apparent. Similar ribboned alternations are described and figured by Barrois* as occurring at the edge of the Cambrian schists of Brittany, where pierced by irruptive granites. The detached inclusions are, also, not infrequently ribboned, parallel to the schist planes, with apophyses from the main area of the enclosing granite-gneiss.

If, at the base of the Ontarian system, we had bedded rocks which on metamorphism gave rise to crystalline limestones, quartzites, etc., we would

* Bull. Soc. Géol. de France, 3me Serie, t. XIV, 1886, p. 833.

have these involved with the Laurentian gneiss, just as the hornblende schists and mica schists are, and intercalations would be produced which would, as in the case of the schists, frequently simulate interbedding of quartzite or limestone, as the case might be, with the gneiss. The deception would, of course, be intensified by subsequent further deformation of the crust by pressure so as to be practically beyond detection, if the clue were not followed up from a starting point where such subsequent dynamic agencies have not obscured the true relationship. This, the writer is persuaded, is the explanation of many of the intimate associations of gneiss and quartzite or limestone, whereby rocks really metamorphic sediments are so involved and welded with rocks of plutonic irruptive origin that they have been taken together as a simple sequence of deposited strata.

In some portions of the Laurentian country, which the attitude of the flanking rocks indicates was once arched over by an anticlinal dome of the latter, there are found patches of schist lying quite flat, or nearly so, upon the granite, showing, in favorable cliff sections, a brecciated or intrusive contact on the under side. These remnants seem to show that the anticlinal dome was flat or very lowly rounded, and that only on the flanks of the Laurentian boss did the strata composing the arch plunge down at high angles.

Significance of Relationship.—Bearing in mind the essential distinctions which exist between the rock formations of the Ontarian and Laurentian systems, both as to their lithological character and their mode of occurrence, and remembering also their relative geographical distribution, the foregoing statement of the relationship which obtains between the two systems leads clearly and unavoidably to this conclusion, viz., that the formations of the Ontarian system at one time rested, as a volume of hard rocks, upon a magma which subsequently crystallized as the Laurentian granite-gneiss; so that the present line of demarkation between the two systems must be regarded as representing the trace of what was once a plane of contact between the then crust and the magma upon which it floated.

This conclusion affords us a conception of the Archean which is ideal in its simplicity and which gives us the key to the raveling of the mystery in which the subject has been involved. The fact that the crust, which constitutes what we now call the Ontarian system, was crumpled while it floated on the magma; the fact that its lower portions were shattered by disturbance so that the magma penetrated the fissures and enclosed detached fragments; the fact that there were currents in the magma which arranged the inclusions in streams and also produced the foliation of the gneiss; the fact of contact metamorphism—all these are incidental and concomitant circumstances of the great essential condition of a crust resting on a magma.

But from the nature of the rocks of the Ontarian system it is clear that

they could not have been deposited upon a magma. There must have been a firm crust presenting a floor upon which they were laid down. That floor, together with portions of the system of rocks which lay piled upon it, has disappeared. That it has sunk down to a zone of fusion and become absorbed by liquefaction in a sub-crustal magma, which later crystallized out as the Laurentian, is the only explanation that is open to us. It follows also that the Laurentian rocks are younger than those of the Ontarian system, as has been before indicated.

Principles of Classification.

The bearing of the facts and conclusions recorded above upon the taxonomy of the Archean is apparent. The argument establishes this cardinal principle in the classification of that great complex of rocks, viz., that its primary subdivision depends upon a distinction of cosmical importance between an older assemblage of altered normal surface-formed strata and a younger assemblage of rocks resulting from the crystallization of a sub-crustal magma.

Principles applicable to the Upper Division.—To the upper or Ontarian system the ordinary stratigraphical methods of classification are applicable. The system separates stratigraphically into two great groups. The lower and older, consisting of strata free from volcanic admixtures, so far as has been observed, is the Coutchiching. It resembles in its lithological characters and in its position the Montalban of Hitchcock. The upper group, consisting of rocks which are dominantly volcanic in composition, is the Keewatin. It rests upon the Coutchiching in probable unconformity, the beginning of the period in which these rocks were deposited being signalized by the advent of a widespread and continued volcanic activity. This group falls into line with the Green Mountain series in the position assigned to it by Hitchcock. Other groups may quite possibly be discovered which will swell the volume of the Ontarian system.

Principles applicable to the Lower Division.—In the Laurentian the ordinary stratigraphical principles of classification do not apply, since there are no strata properly so called; and we must seek for a principle appropriate to an assemblage of rocks essentially different in their development and mode of occurrence from all those of the stratigraphical column. The Laurentian is not homogeneous throughout its surface distribution. It is composed of different members or masses, which, while they present wonderfully constant general characters within themselves, are distinct from one another lithologically. A study of the relationship between the masses thus differentiated in space leads us to the chief moment of all geological classification, namely, their differentiation in time; and we have to consider the possibility

of different generations of Laurentian rocks. This possibility presents itself as soon as we familiarize ourselves with the sub-crustal igneous and later formations of the Laurentian.

Different Generations of Laurentian Rocks.—To the writer this conception of different generations has never been more than a possibility till the present year. In his report on the Rainy lake region, two broadly distinct members of the Laurentian were distinguished, lithologically and on account of their systematic relative distribution, as the "peripheral zone" and "inner nucleus" of the Stanjikoming area, the former being composed chiefly of hornblende-granite and syenite-gneiss, and the latter of very quartzose biotite-gneiss. The relationship in time between these two rock masses remained indeterminate. During the past summer, however, he has been able to establish, in the Hunter's island region, chronologically distinct generations of Laurentian gneisses. In that region there are two broadly distinct members of the Laurentian, analogous petrographically and in relative distribution to those of the Stanjikoming area. Below the Keewatin rocks there is a great mass of hornblende-granite-gneiss, which presents an irruptive or intrusive contact against them. Towards the central part of Hunter's island this hornblende-granite-gneiss is pierced by an enormous irruption of biotite-granite, which is sometimes very distinctly gneissic and sometimes quite undifferentiated in structure. In texture it varies from fine-grained, almost micro-granitic, to a moderately coarse granite. This biotite-granite-gneiss traverses the hornblende-granite-gneiss in innumerable clearly defined dikes cutting it in all directions, and holds innumerable included blocks of the same rock. It comes up from beneath the hornblende-granite-gneiss, and is unquestionably of later age.

Thus we have in this area at least two distinct generations of Laurentian rocks, both the result of the crystallization of a sub-crustal magma. At the time of the second generation the rocks of the first generation constituted the lower portion of the crust.

It is upon the recognition of facts of this order that an intelligible and profitable classification of the Laurentian rock masses and the geological events which they represent must be established.

Other Conditions considered.—The relationship which has been found to obtain between the upper and lower Archean leads, as has been said, to a conception which is at once grand and simple. So long as we confine ourselves to regions like that northwest of Lake Superior, where no great complications have been introduced by post-Archean crust-crumpling agencies, it affords a full explanation of all the phenomena of Archean geology.

There is a possible simpler case which would still present the essential conditions of the relationship in question; *i. e.*, the case in which the sub-

crustal magma might be irrupted within the overlying crustal rocks without the intense folding of the latter. Here we should expect to find a less pronounced alteration, due only to the proximity of the magma, and an absence of those phases of metamorphism which accompany the rock shearing, crushing, and stretching due to dynamic agencies. In the common case, where the upper crustal rocks are folded, varying phenomena would also be observed according as the folding took place before the fusion which produced the magma immediately beneath the crust or while the latter was floating upon the magma.

There are also more complicated cases which are doubtless common. These are due to the superimposed action of crust-crumpling, rock-shearing, strata-squeezing forces subsequent to the establishment of the Archean conditions in their primal simplicity. These are possibilities which must be borne in mind in attempts to apply the theory here advanced to the Archean in other regions. It is easily conceivable that had the country northwest of Lake Superior been subjected to extensive deformation in post-Archean times, the evidence whereby the irruptive character of the Laurentian has been demonstrated might have been entirely obscured, and the true relationship might have remained unsuspected, as appears to have been the case in better known regions.

Similar Observations elsewhere.

In various parts of the world observations have been recorded which show that the phenomena arising from the irruption of a local or general subcrustal magma through an overlying crust, and the consequent development of a complex of gneissic igneous rocks and metamorphic strata, are not peculiar to the region studied by the writer.

MacFarlane* long ago described and figured good evidence of the irruptive character of the Laurentian of the northeast shore of Lake Superior; but, in accordance with the views of the extreme plutonic school, he regarded the whole complex of intrusive and intruded rocks as the first crust of the earth, and the angular fragments of hornblende schist as earlier separations from the same magma as that which crystallized into the Laurentian granite or syenite-gneiss.

Mr. Frank Adams, who has been for some years past engaged in a study of the Laurentian of the Province of Quebec, north of the St. Lawrence, says—

"The unexpected fact was ascertained that the so-called massive and stratified varieties of this rock [anorthosite; hitherto regarded as upper Laurentian and meta-

* Geological Formations of Lake Superior. Canadian Naturalist, N. S., Vol. III, 1867, p. 177.

morphic] are in reality only different portions of one and the same mass. * * * As a result of this summer's work, I think it may be safely concluded that the rocks comprising the principal area of anorthosite above referred to, as well as most, if not all, of the smaller areas, are of eruptive origin." *

He confirms this in his summary for 1888 in the following words:—

"All the areas of anorthosite now known to occur in the district have been examined, and mapped, and have proved to be either eruptive masses cutting through the gneisses, or masses interstratified with the latter, but probably still of eruptive origin." †

Callaway has shown, in his paper on the granitic and schistose rocks of northern Donegal, that the granite-gneisses of that region, which have been regarded as Laurentian and which correspond closely in lithological characters and mode of occurrence with the Laurentian of Canada, are really irruptive through older rocks, which must have arched them over, and present all the evidences of irruption which have been adduced by the writer in support of the irruptive origin of the Laurentian northwest of Lake Superior. He thus states his conclusions:—

"1. The granite rock of northern Donegal, originally supposed to be the result of the metamorphism of sediments, and recently referred to the Laurentian system, is a true igneous granite, as seen in its intrusion into the adjacent schists, in its inclusions of masses and fragments of other rocks, and in its metamorphic action on limestone in contact. 2. This granite is distinctly foliated, the gneissic structure being caused by lateral pressure, * * * 3. The granite is intrusive in a thick group of quartzites, quartz-schists, hornblendic, micaceous and talcose (?) schists, and crystalline limestones, called the *Kilmacrenan series*. These rocks are truly crystalline, but usually thin-bedded and fine-grained. 4. The crystalline schists are bounded on the east by a semi-crystalline series, consisting of quartzose grits and itacolumites, quartzites, crystalline limestones, compact dolomites, phyllites, interlaminations of grit and schistose matter, and finely foliated micaceous schists." ‡

These conclusions as to the irruptive origin of the gneiss are confirmed by later observations of the same investigator on the Galway gneiss. §

In the pre-Cambrian or Archean of Brittany, Barrois recognizes the irruptive character of the gneisses which correspond to our Laurentian. He says—

"Ces gneiss alternent avec des lits interstratifiés de micaschistes et d'amphibolites, et passent à des granites gneissiques qui les pénètrent à la façon d'une roche éruptive. L'ensemble des *gneiss et micaschistes granitiques* avec granites gneissiques rappelle par ses caractères lithologiques *l'étage dimétien*, proposé par M. Hicks, dans le pays de Galles, le gneiss fondamental d'Ecosse, certains gneiss laurentiens du Canada,

* Geol. Survey of Canada, Summary Report for 1887 and 1888, 1889, p. 27A.
† Ibid., p. 85A.
‡ Quart. Jour. Geol. Soc., Vol. XLI, 1885, p. 239.
§ Quart. Jour. Geol. Soc., Vol. XLIII, 1887, p. 517.

* * *. Ils [micaschistes] y alternent avec des lits subordonnés de gneiss à grains fins, d'amphibolites, de chlorito schistes, de schistes micacés, et comprennent des masses interstratifiées de diorites et de granulites, d'origine éruptive. Ces roches subordonnées forment avec les micaschistes, dans lesquels elles sont injectées, de longues bandes parallèles, * * *."*

Newton's description of the geology of the Black Hills of Dakota† leaves little room for doubt but that the rocks which he calls Archean correspond to the upper Archean or Ontarian system of central Canada, and that his irruptive granite, though not described as foliated, is the analogue of the commonest phase of the Laurentian. The same relationship holds between the two rock systems in both regions, and many of the Laurentian granites are devoid of foliation.

Geognostical Equivalents of the Archean.

In assemblages of rocks of indeterminate or post-Archean age complexes of gneissic irruptive rocks and older metamorphic strata of clastic or volcanic origin are now well known. These cannot be spoken of as the geological equivalents of the Archean complex on account of their diverse age, but may be referred to as its geognostical equivalents, since their development appears to depend upon universal sub-crustal conditions, which are to a large extent independent of geological age.

McMahon,‡ in his studies of the great "central gneiss" formation of the Himalaya mountains, has demonstrated clearly that the formation is not, as was long supposed, the Archean basement upon which the Paleozoic sediments were deposited, but is an irruptive mass breaking up through the Silurian and later rocks, altering them, holding detached fragments of their strata, and being injected within the strata. Speaking of this formation, which he calls gneissose granite, he cites the following evidences in proof of its irruptive origin: 1. The granite has produced a certain amount of contact metamorphism on the rocks touching it. 2. Tongues and intrusive veins have been sent from the granite into the adjoining rocks; in other places the granite appears in sheets between the beds of the sedimentary rocks at some distance from the junction of the latter with the main mass of the granite, and in some cases these sheets or dikes have cut through the beds and passed from one horizon to another. 3. The main mass of the granite appears at different geological horizons.§ 4. The granite contains

*Structure Geologique du Finistére. Bull. Soc. Geol. de France, 3me Serie, t. XIV, 1886, p. 657.

†Report on the Geology and Resources of the Black Hills of Dakota. By Henry Newton and Walter P. Jenney, Washington, 1880, pp. 45-80, 220-222.

‡Geol. Survey of India, Records, Vol. XVIII, Part 4, 1884, p. 168; ibid., Vol. XVIII, Part 2, 1885, p. 79. Geol. Mag., N. S., Decade III, Vol. IV, 1887, p. 212.

§As it does when it comes at one place against the Keewatin and at another against the Coutchiching in the Rainy lake region.

veins similar to those caused by shrinkage on cooling in granite of admittedly eruptive origin. 5. It contains fragments of slates and schists imbedded in it. He also states that the evidence afforded by the study of thin slices confirms the conclusion arrived at by the stratigraphical evidence, and gives a summary of the microscopic evidence.*

The very able and precise descriptions by Barrois† of the various granitic irruptions which have affected Brittany at different ages from the pre-Cambrian up to the Carboniferous show beyond question that not only in Archean times, but at various subsequent periods were the conditions which characterize the Archean of Canada reproduced. He describes particularly the "granite gneissique," demonstrates its irruptive origin, and notes not only the contact metamorphism, but also the injection of these rocks "en filonnets minces et répétés" within the encasing schists. His descriptions and figures of repeated injections of granite within the schists, so as to produce an alternation simulating bedding, closely corresponds with the contact phenomena described by the writer as observed between the Laurentian and Keewatin on the Lake of the Woods, the interpretation of which is entirely in accord with that of Barrois, though questioned by Professor A. Winchell.‡ It would appear that just as in Hunter's island, northwest of Lake Superior, we have two generations of Laurentian rocks from a sub-crustal magma, so in Brittany there have been several generations of similar rocks breaking through the overlying crust, extending in time as late as the Carboniferous.

In Norway Kjerulf§ places the "Gebanderte granit, oder gneisgranit" with the eruptive rocks, and states that in numberless places such rocks break through the strata of the grundgebirges, and also, indeed, through the Bergenschiefer in which Reusch has since found Silurian fossils.‖ In the greater part of Norway he says (translated freely)¶—

"What was formerly recognized as gneiss must on the map be now designated as granite. The reason why the older observers assume it to be gneiss is the granular banded structure, which we must distinguish from the appearance of bedding. On older maps are shown also other great regions in which the dip and strike of the beds is given, an attribute which they do not in reality possess; and the reason for this lies in the confounding of foliation with bedding. * * * The rock, according to the old conception, is granite when no bedding occurs in it. The modern view, which had already been announced by Delesse, says: 'En reálité c'est [le gneiss granit] seulement une variété du granit, qui est veinée et qui parait avoir été gênée dans sa cristallisation.'" **

*Geol. Mag., loc. cit.
†Bull. Soc. Geol. de France, 3me Serie, t. XIV, 1886, pp. 655–898.
‡Geol. Survey of Minnesota, Fifteenth Annual Report, 1886, p. 201, § 5.
§Die Geologie des Süd. und Mit. Norwegen, Bonn, 1880, p. 237.
‖Fossilien Führenden Schiefer von Bergen, Leipsig, 1883.
¶Op. cit. p. 282.
**Delesse, Etudes sur le Metamorphism, 1861.

The syenites of the southeast coast of Norway, also, which have been studied particularly by Brögger, and which are irruptive through fossiliferous Silurian and Devonian strata, are eminently gneissic in places. They are indistinguishable in this respect from the more distinctly foliated varieties of our Laurentian gneiss.

Lehman's masterly work * on the rocks of Saxony and other geologically similar regions has clearly established that many of the gneisses of central Europe are irruptive in their origin.

The foliated gabbros or gabbro-gneisses of the Lizard are regarded as eruptive by such eminent observers as Teall † and McMahon,‡ though they differ as to the precise mode of the development of the foliation.

Harper § has shown that the "granite and gneissic granite" of Larn, Caernarvonshire, which was formerly held to be Archean, is in reality irruptive and of more recent age than the Upper Arenig strata:

"The actual contact of the two rocks is easily found, and the granite is seen to send out little tongues between the laminæ of the shale. Specimens of the latter rock, indurated and firmly adhering to the granite, may be obtained. * * * The shale is clearly altered and exhibits little spots and nodules supposed to represent the incipient development of chiastolite. Another quarry, well within the boundary of the granite, shows entangled masses of baked shales."

In a paper submitted to the International Geological Congress at its London session || in 1888, the writer quoted Dr. G. M. Dawson ¶ at some length to show how entirely the conditions which obtain between the Triassic rocks of the west coast and the younger subjacent irruptive granite are analogous to those which obtain between the rocks of the upper Archean or Ontarian system and the Laurentian granite gneiss. Dr. Dawson's account of the history of geological events in that region in post-Triassic times confirms the correctness of the writer's interpretation of the Archean of central Canada.

The interesting geognostical equivalent of the Archean on the Pacific coast is paralleled on the Atlantic coast by the great irruption of "gneissic granites" which in post-Cambrian times, possibly as late as the Devonian, have broken up through the Cambrian slates and quartzites.** These "gneissic granites" are indistinguisable from many of the Laurentian gneisses.

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* Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, Bonn, 1884.
† Origin of Certain Banded Gneisses; Geol. Mag., N. S., Decade III, Vol. IV, 1887, p. 484.
‡ On the Foliation of the Lizard Gabbro; ibid., p. 74.
§ Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, p. 442.
|| Etudes sur les schistes cristallins, p. 66.
¶ Geol. Survey of Canada, Annual Report, 1887, Part B, pp. 11-13.
** The Lower Cambrian rocks of Guysborough and Halifax Counties, N. S. By E. R. Faribault; Geol. Survey of Canada, Annual Report, 1886, Part P, p. 129.

These references and quotations by no means exhaust the literature of the subject. They are taken mostly from very recent writings, and much to the same effect might be quoted from the older geologists, such as Von Cotta, Neumann, Darwin, Delesse, and others, who have insisted on the irruptive character of gneissic rocks or have regarded gneiss as but a differentiated variety of irruptive granite. But enough has been adduced to show that the writer's interpretation of the Archean geology of central Canada, in so far as it depends upon the irruptive nature of the Laurentian gneisses, is not without the strong support of many analogies.