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CLIMATE AND PHYSICAL CONDITIONS OF THE KEEWATIN

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INTRODUCTION

It is intended in this paper to bring together evidence which has been accumulating during recent years as to the climate and general physical conditions of the Keewatin. Most of this evidence has to do with the sedimentary rocks of this age in western and northern Ontario, and a considerable part of it has been obtained by myself and my assistants in mapping the iron ranges of the province for the Bureau of Mines of Ontario.

Not long ago the pre-Cambrian as a whole was looked on as a geological "no man's land," full of doubt and difficulty because of the obscurity of its relations. Now, however, the succession as far as the base of the Huronian has been worked out in detail in several areas of the pre-Cambrian in America; and we find that the source of these rocks and their general relations are entirely similar to those of later, fossiliferous, series. The mystery has largely departed from them.

So far as the Huronian or Algonkian is concerned everyone admits that the rocks, both sedimentary and eruptive, were formed like those of later times. It is true that the absence of fossils in the east and their great rarity in the West is a puzzle; but all agree that the pre-Cambrian seas were not so different from later waters as to be uninhabitable, and that forces at work in the Huronian did not differ materially from those which formed the Cambrian or later rocks.

To have this brought concisely before one it is only necessary to read Van Hise and Leith's late edition of the pre-Cambrian geology in North America, a work of admirable completeness and impartiality, summing up a literature of appalling dimensions. The former chaos has then been so far set in order that we find evidence in Huronian or Algonkian times of climates not unlike those of later ages, when wind and weather, flowing rivers and beating waves, and even great ice sheets did their regular work. In northern Ontario glaciers formed bowlder clay in lat. 46°, showing no hint of the action of primeval heat, such as the usually accepted version of the Nebular Hypothesis demands.

But there is much less certainty and much less unanimity regarding pre-Huronian times. The Huronian is cut off from the underlying rocks by one of the greatest known discordances. During the interval left unrecorded in this great unconformity the previous rocks were raised into mountains, metamorphosed by the action of intrusive granite and gneiss, and then profoundly eroded. The proofs of this are to be found in the bowlders of the Huronian tillite, which include all the lower rocks in their present metamorphosed conditions; and in the hummocky plain formed from the previous mountain ranges which in many places underlies the little-disturbed Huronian.

The world was already very old and had undergone many vicissitudes before the Huronian ice sheets began their work. What light can be thrown on the vast and vague pre-Huronian time?

Many geologists have been inclined to see in the underlying "basal complex," or *Urgebirge*, portions of the earth's original crust or its downward extension. For example, Rosenbusch in the new edition of his *Elemente der Gesteinslehre* speaks of the crystalline schists underlying all later rocks as representing, at least in part, the earth's *erste Erstarrungskruste.*[1] Like some others of the older geologists he still holds to the Nebular Hypothesis and looks on the basal complex as having been formed at the stage when the molten earth had so far cooled as to consolidate on the surface, producing plutonic rocks and crystalline schists. According to this hypothesis it was still too hot to permit the condensation of water, so that no rivers or oceans were possible.

Elaborate theories of continent- and mountain-building are still founded on this idea of the earth's progressive cooling, and it is hard for geologists brought up like the present writer on the fiery diet of a Nebular Hypothesis as an introduction to historic geology to rid their minds of so firmly imbedded a prepossession. That astronomers also are afflicted with these bad dreams is plain from certain recent popular writings on the history of Mars as compared with earth. The conviction is however growing in the minds of many geologists that even the pre-Huronian or Archaean cannot be looked on as exceptional; that the Huronian basal conglomerate means a break in time, but no break in the continuity of marine and terrestial processes; that the affairs of the world were conducted in the same way before this great interval as after it.

Evidence of various kinds in favor of this will be given in subsequent pages.

THE KEEWATIN ERUPTIVES

"The basal complex" of the western lakes region was split up many years ago by Lawson into the Laurentian granites and gneisses and the Keewatin, the latter looked on as consisting essentially of eruptives. In the original Keewatin region on Lake-of-the-Woods eruptive rocks are in great preponderance, though Lawson recognized the presence of subordinate amounts of sediments, which will be referred to later.

These eruptives are chiefly basic—now mostly transformed

[1]*Op. cit.*, 35.

into greenstones and green schists; but there are acid rocks in important amounts—quartz porphyries, felsites, etc., and their schists. In a number of places these eruptives were lava flows showing pillow and amygdaloidal structures, and often pyroclastic materials accompanied the outbreaks of lava. It is probable that most of the characteristic Keewatin eruptives were volcanic, though the squeezing and shearing they have undergone often obscure their origin as lavas or ash rocks. Undoubted plutonic rocks occur among these surface eruptives, but often they can be proved to be much later in age, since they have penetrated the other rocks and carried off fragments of them.

There are also many dikes of both basic and acid rocks cutting the volcanics, and there were probably laccolithic sheets and masses invading them; but later mountain-building processes, connected mainly with the elevation of granite batholiths, have greatly obscured the relationships. While terrestrial lava flows and falls of bombs and ashes played the most prominent part in the formation of the Keewatin in many places, submarine lava flows may have taken place also, since the pillow structure is generally regarded as resulting from the action of water on hot lava streams. There is every reason to suppose that then as now there were volcanic eruptions both on land and from the sea bottom.

Through what substratum these volcanic rocks came to the surface is unknown. At present they commonly rest on the gneiss and granite of the Laurentian—deep-seated eruptives of a later age, which have invaded and swept off fragments of the Keewatin rocks in ways showing that they were cold and solid at the time. The floor on which the lavas flowed and the volcanic ashes were rained down has generally vanished, though in places the volcanics rest on sedimentary schists or gneisses of the Couchiching, which will be described later.

In most cases the old volcanoes themselves have disappeared, but the base of one of them, consisting of gabbro, anorthosite, and granite, has been described by Lawson, from Shoal Lake east of Rainy Lake.

It was an age of intense volcanic activity, and the results were just such as we find in the Keweenawan and more recent eruptive periods; though the rocks are of course far more altered by metamorphism.

The Keewatin of the states near Lake Superior is described as consisting almost entirely of eruptives such as have been referred to above, though bands of iron range rocks occur with them in Minnesota. President Van Hise and others therefore look on the Keewatin as essentially eruptive with the exception of the oldest iron ranges.

It will be shown in succeeding pages that this is by no means true of the Keewatin of Ontario.

KEEWATIN SEDIMENTS

When Lawson began his study of the Lake-of-the-Woods region he was specially impressed with the wide-spread eruptives and ash rocks, though he found associated with them subordinate amounts of sediments such as carbonaceous slates and quartzites; and he defined the Keewatin as essentially an eruptive series. As his work extended eastward, however, he made the acquaintance on Rainy Lake of a great series of sedimentary rocks, to which he gave the name of Couchiching.

The correlation committee which adjusted the terminology of the western Great Lakes region chose the name Keewatin instead of Couchiching for the whole series; so that the Keewatin as now defined includes both eruptives and sediments older than the Laurentian.

By Lawson and later workers in northern Ontario it has been shown that every type of water-formed sedimentary rock is represented in the Keewatin: limestones and dolomites, carbonaceous and ordinary slates, mica schist and gneisses representing more altered muddy sediments, quartzites, arkoses, and graywackes, and even conglomerates and breccias, though the last-mentioned rocks are not always easily separated from agglomerates, etc., of volcanic origin.

With the exception of the Couchiching, most of these sedimentary rocks are not extensively developed in the region studied by Lawson; iron formation occurs only in small outcrops and remained unobserved in the hasty field work of early days.

In reality the iron formation is found in practically every Keewatin area, always near the top of the series, and sometimes with a thickness of 1,000 or 1,500 feet.

The iron formation differs so much from later sediments that some geologists regard it as something peculiar and apart, belonging perhaps to the earth's earliest times and produced only under conditions very different from those of the present. It has been described, for instance, as a chemical sediment deposited in a hot sea where volcanic eruptions were taking place. So many speculations have been indulged in on this fascinating subject that too much space would be required to recapitulate them.

In many places in Ontario, however, the iron formation is so closely associated with commonplace sedimentary materials, slate charged with carbon, arkose, and crystalline limestone, that one can hardly believe it to have been formed under peculiar conditions not repeated in later times.

In any case the other sedimentary rocks, often covering large areas and with considerable thickness, must be looked on as normal products of conditions which have persisted ever since.

In the following pages descriptions will be given of the chief Keewatin sedimentary rocks, and their distribution will be outlined. As the iron formation, because of its economic importance, has been most carefully studied, it will be taken up first.

THE IRON FORMATION IN ONTARIO

In the states near Lake Superior the Keewatin iron formation consists mainly of jasper of varying colors closely interbanded with hematite, less often magnetite. Iron formation of a very similar kind has been found between the Vermilion range in Minnesota and Fort William on Lake Superior, and in smaller areas near Batchawana Bay, Lake Temagami, and in a number of other places in northern Ontario. More commonly in Ontario, however, the silica is in the form of chert, quartzite, or a sandstone-like aggregation of grains, while the interbanded iron ore is mostly magnetite. Probably the differences are largely due to more extensive metamorphism in the latter as compared with the former type.

In most of the regions of Ontario where the iron formation has been carefully mapped and studied it includes also more or less siderite, or pyrite, or pyrrhotite, so that not the whole of the iron is contained in the oxides.

There is, however, another variety of the formation which has received less attention, consisting of granular silica with little or no iron, but sometimes interbanded with gray or green schistose materials. This appears to be the common form in the far west, near Fort Frances on Rainy River, and near Kenora on the Lake-of-the-Woods. In these localities sandstone-like rocks are found quite extensively with the gray schists described by Lawson as Couchiching. It may be that the sources of iron ran out toward the west, leaving only the silica.

The sandstone-like variety of iron formation, when first found by the present writer, was thought to be an ordinary sediment. It resembles a white or gray or brownish sandstone of even grain, and is often so loosely cemented that the rock may be crumbled in the fingers. Thin sections, however, show little or no clastic structure. The quartz grains are polyhedral individuals which have grown from centers until they met. Every transition may be found between these relatively coarse-textured varieties and the very fine-grained silica, often chalcedonic, of the jaspers. The quartzitic variety occurs in or near the eruptive granite of the Laurentian. In it the anhedra of quartz are firmly cemented together.

As mentioned before, in most places in Ontario the silica and iron ore are accompanied by ordinary sedimentary material. In a number of thin sections sillimanite occurs, a silicate of alumina that must have been recrystallized from clay. On the east shore of Lake Nipigon, and in other places, the banded silica and magnetite are interbedded with gray slate or phyllite and often pass gradually into this rock, which is, of course, a metamorphosed clay. Frequently also a few feet of black carbonaceous slate underlie the iron formation, as at the Helen mine, Michipicoten, and at Grassy Portage on Rainy Lake.

At Goudreau Lake southwest of Missanabie, the iron formation contains a small amount of granular silica with magnetite, and a large amount of pyrite, the sulphide replacing the oxide; and parallel with it runs a band of crystalline limestone 30 feet thick and more than a mile long.

In the cases just mentioned sediments such as clay, limestone, and carbon were deposited with silica and iron oxide or sulphide. The carbon makes it altogether probable that sea weeds lived on the muddy bottom, so that the waters must have been cool enough for life and free from poisonous substances.

In a number of places near Lake Nipigon the iron ranges include large amounts of arkose as well as the slaty rocks mentioned above. Thin sections present the usual angular or subangular fragments of quartz and feldspar imbedded in a finer grained matrix. The formation of these greenish gray arkoses suggests a land surface of granite or gneissoid rocks exposed to weathering in a cool and moist climate, as shown by Professor Barrell, in his excellent study of *Climates and Terrestrial Deposits*. These rocks cover in all many square miles and must have a thickness of a thousand feet or more, unless greatly reduplicated by folding. Near Poplar Lodge they have a width of a quarter of a mile with dips of from 60° to 80°, though banded jasper and hematite and also a little green schist are interleaved with the arkose, making up perhaps one-tenth of the whole.

THE COUCHICHING PHASE OF THE KEEWATIN

Associated with the iron formation at a number of points on Rainy Lake, Rainy River, near Dryden, etc., one finds gray fine-grained schists and gneisses having the character of the Couchiching as described by Lawson; but these rocks occur in larger areas apart from known iron ranges. They are composed of quartz, biotite, sometimes muscovite, and often some orthoclase or plagioclase; and they frequently contain sillimanite, garnet, and staurolite, or pseudomorphs after staurolite. They are evidently sandy or clayey sediments recrystallized, and may be compared with the sedimentary gneisses and quartzites of the Grenville series of eastern Canada so well described by Adams.

The materials of which they were formed must have been derived from granite or gneiss and not from the basic eruptives with which they are associated. In the decay of the original rocks much of the feldspar must have been decomposed, the alkalies being removed. They are often seen resting on Laurentian gneiss, but the latter was not the source of the sand of which they were formed, since the Laurentian is everywhere in eruptive relationships with the Couchiching and hence is of later age. The gneiss penetrates the overlying schist and has often broken off slices which have been floated away by the molten flood.

As mapped by Lawson, Couchiching schists are widely distributed on Rainy Lake, which must be looked on as the type locality. In my field work many outcrops of these rocks have been studied near Rice Bay, Grassy Portage, Gash Point, Goose Island, Sand Point Island, and at other places on the way eastward toward Bear's Passage; and I can confirm Lawson's description of them.

Near Grassy Portage and Nickel Lake they include iron range rocks of a somewhat unusual variety, in which pyrite and pyrrhotite largely replace iron oxides; and some miles to the west on Rainy River, below Fort Frances, they are found with sandstone-like silica almost free from iron.

In general, however, the Couchiching schists occur in large areas by themselves, always dipping at high angles (60°to 80°), often having widths across the strike of hundreds of yards, sometimes of a mile or more. They may have various relations to the green Keewatin schists, sometimes underlying them and at others appearing to be interbedded with them. Near Shoal Lake there are, however, schists resembling the Couchiching which lie above the basal Huronian conglomerate and are evidently of much later age.

Lawson maps the Couchiching as extending from west to east across almost the whole Rainy Lake sheet, a distance of more than 60 miles; and the Hunter's Island and Seine River sheets, to the southeast and east respectively, contain large areas also, as mapped by Lawson, W. H. Smith, and McInnes. The whole length shown is about 90 miles, and the breadth 24 miles.

Lawson estimates the thickness of the Couchiching at about 25,000 feet, but in such ancient rocks, now folded in mountain structures, it is possible and perhaps probable that this thickness is excessive. The real thickness may be repeated many times by folding, but it can hardly be less than some thousands of feet.

COUCHICHING IN OTHER REGIONS

Schists of the Couchiching type are widely found in northern Ontario. They occur at various points on Lake-of-the-Woods, e.g., on the southern edge of the Grande Presqu'isle, and near the Scramble mine east of Kenora, where they are accompanied by a band of granular silica having the look of sandstone. They are found also in large areas near Clearwater and Manitou Lakes, north of Rainy Lake, and extend for miles along the railway east of Dryden, here associated with the iron formation.

Mica schist or gneiss of the same kind, and also arkose and slate, are found on Sandy and Minnitakie Lakes north of Wabigoon; so that areas of Couchiching occur for a distance of more than 100 miles north of the Minnesota boundary.

Within the past year or two similar rocks have been described by E. S. Moore from near Round Lake, north of Lake Nipigon, and by the present writer from Black Sturgeon Lake to the south of Lake Nipigon.[1] In 1908 A. L. Parsons gave an account of schists like the Grenville gneisses on the Algoma boundary[2] and in the following year gray schists of the same sort were observed by myself north of Jackfish and along the shore of Long Lake. The Couchiching here has a width of several miles across the strike, with dips of 60° or 70°. W. J. Wilson in a "Summary Report on the Algoma and Thunder Bay Districts"[3] describes such gneisses containing garnet, cordierite, sillimanite, etc., as occurring extensively, and compares them with the Couchiching and also with the Grenville gneisses; and W. H. Collins gives an account in the same report of rocks of the same kind southwest of Long Lake, containing garnets and graphite. He mentions quartzite and arkose as occurring there also.[4]

There are sillimanite gneisses and arkose, as well as ordinary and carbonaceous slate, in various places in the Michipicoten region 150 miles southeast of Long Lake, but the known area of these rocks is not very large.

Mica schist with staurolite has been found by M. B. Baker in the Abitibi region more than 200 miles to the east, and he men-

[1] *Bur. Mines* (1909), 144 and 158.

[2] *Ibid.* (1907), 101.

[3] *G.S.C.*, No. 980, 5 and 6.

[4] *Ibid.*, No. 1081, 14.

tions also graphitic slate, rusty weathering dolomite, and a coarse fragmental series accompanying typical iron range rocks. He suggests that the fragmental rocks may imply a break in the Keewatin, and quotes Miller and Brock as favoring this view.[1]

Morley E. Wilson briefly describes similar rocks from the Temiscaming region to the south as follows: "On the north shore of Larder Lake there is a belt—nearly a mile wide—of interbanded phyllites, slates, and graywackes, which parallels the lake shore for several miles. These rocks have a nearly vertical attitude; a uniform northeasterly strike; are in places graphitic; and locally contain small quantities of iron ore formation."[2]

From the citations given above it will be seen that sedimentary rocks like the Couchiching or the Grenville series are widely spread in the Keewatin of Ontario. They often cover large areas and in many places equal or surpass the eruptives in extent. It is true that there are large gaps where no ordinary Keewatin sediments are known to exist, but doubtless many small areas remain undiscovered because unlooked for. A few years ago no one could have foretold that the iron formation would be found in almost every Keewatin area in Ontario, but we now know that this is the case.

The Keewatin sediments can no longer be overlooked as negligible in any account of the Canadian Archaean. In reality these sedimentary rocks are the true Keewatin, and the accompanying eruptives and ash rocks must be considered less important, in a sense accidental, members of the series.

The Keewatin of the states near Lake Superior seems from the published accounts to contain a much smaller proportion of sedimentary materials than of volcanics; which no doubt accounts for the prevalent opinion among American geologists that the Keewatin, or the older part of the basal complex, consists essentially of eruptive rocks.

RELATIONS OF THE KEEWATIN TO THE GRENVILLE SERIES

Having shown that the Keewatin contains sedimentary rocks of every kind, some of them having a wide extent and a great thickness, it is natural to compare them with the ancient sedi-

[1] *Bur. Mines* (1909), 275–78.
[2] *Sum. Rep., Geol. Sur.* (1909), 175.

mentary rocks of the Grenville and Hastings series of southern and eastern Ontario and Quebec. These were studied long ago and were originally included in the Laurentian; though now the term Laurentian is confined to the eruptive granites and gneisses which penetrate them and rise from beneath them.

The nearest Grenville rocks to the Keewatin sediments described above begin about 150 miles south of the Larder Lake region in the township of Loring, just south of Lake Nipissing, where graphitic schist occurs. Between this and Parry Sound crystalline limestone and gray garnetiferous schists and gneisses are widely found and were compared by myself in 1900 with the western Couchiching.[1] There are also green schists in the region suggesting western Keewatin schist of eruptive origin.

In eastern Ontario the Grenville and Hastings series often greatly resemble the Keewatin, including banded silica and iron ore, slate, quartzite, and fine-grained gray sedimentary gneiss containing graphite. There are, however, some marked differences. Limestones are rare in the western Keewatin but make the most prominent rock in the Grenville and Hastings series, even reaching a thickness of more than 50,000 feet, according to Adams; while volcanic rocks play a larger part in the west than in the east. Just how the eastern Archaean is related to the western is still a matter of discussion, Adams thinking that the Grenville and Hastings series are both probably the equivalent of the western Huronian, while Miller believes that the Hastings series represents the Huronian, and the Grenville series the Keewatin.

From my own observations it may be said that a considerable part of the Grenville rocks are closely like the western Keewatin. If they were found in the Upper Lakes region they would certainly be classed on lithological grounds as Keewatin; and the two series of rocks are also related in the same way to the Laurentian batholiths. In the east as well as in the west these great eruptive masses are later than the overlying rocks and have pushed up through them, often nipping them in as synclines. In neither case has the foundation on which these earliest sediments were laid down been preserved.

[1] *Bur. Mines* (1900), 169; also 182.

CONCLUSIONS

It has been shown in the foregoing pages that the oldest known rocks in Canada, the Keewatin in the west, and the Grenville and Hastings series in the east, stretching for 900 or 1,000 miles across the country, include large amounts of sedimentary materials. Among these rocks are limestones and dolomites, slate of ordinary kinds and also slate charged with carbon, mica schist, and gneiss having the composition of clayey sandstones, arkoses with angular bits of quartz and feldspar, and in a few places also coarser fragmental rocks. In the east the seas were clearer and deeper, so that limestone predominated. In the west volcanic activity was very pronounced and lava streams, lapilli, and ashes occur on a large scale, either mixed with the water-formed sediments or making up thousands of feet of rock in themselves.

There must have been great land surfaces from which rivers flowed, bringing down sand and clay. Much of the material suggests well-weathered products derived from granite and gneiss; but the arkoses, which are widespread and thick, probably imply a cool and moist land surface. The sea contained plants to furnish the carbon, often reaching several per cent in slates, gneisses, and limestone; and the limestones hint at calcareous algae or animals having hard parts.

All varieties of geological work seem to have been under way in pre-Huronian times as they have been ever since; and there is no evidence of special primeval conditions different from those known to later geology.

In this paper the earliest Canadian sediments have been discussed from the point of view of climate and physical conditions, and no attempts have been made to marshal the evidence from other lands; but the Canadian Keewatin and Grenville are probably as old as any known rocks, and the same conclusions have been reached from a study of the Archaean rocks of Europe and other continents. Similar sediments penetrated by granites and gneisses occur in the Lewisian of Scotland and the Ladogian of Finland and other parts of Scandinavia. Last summer in Sweden I had the opportunity to study Archaean sediments exactly like our Keewatin, so that the conclusion reached in this paper may be extended to cover the most ancient formations of the Old World also.

Though the Keewatin and Grenville series are the oldest known formations in America, it is evident that they do not take us back to the commencement of geological time, since they include clastic sediments that imply the weathering and erosion of previous rocks before they were spread out on the sea bottom. We have extended our outlook much farther into the past, but there is still an impenetrable background beyond. We shall perhaps never be able to say "in the beginning"; but we may safely say that there is no hint of a molten earth in process of cooling down. If the earth was ever hot it had so far cooled down before the oldest known rocks were formed as to allow air and water and life to do their work in the world very much as they do now. If the earth ever passed through a period of great heat it was at a time too remote in the past to leave a geological record or to have any special interest for the geologist.