5. NOTES *on a* PART *of the* HURONIAN SERIES *in the* NEIGHBOURHOOD *of* SUDBURY (CANADA). By T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 9, 1887.)

DURING my visit to Canada in 1884, I had the opportunity, through the liberality of the Directors of the Canada Pacific Railway, of examining more minutely than is possible to the passing traveller the geological structure of a part of the route over which the line had recently been constructed. I had further the great advantage of being accompanied by Dr. Selwyn, the Director General of the Geological Survey of Canada, to whom I record my most grateful thanks, not only for advice and guidance on the spot, but also for information and specimens subsequently supplied. The study of these has brought out some peculiarities which I think may help to render more precise the term Huronian, and throw some light on general questions of metamorphism *.

On the Canada Pacific Railway, the Laurentian series, which has been traversed for nearly 240 miles †, comes to an end near a little station called Wahnepitae. The last rock seen is highly crystalline, an eclogite or garnetiferous hornblendic gneiss, which apparently dips at a rather low angle towards the S.E. Hard at hand is a river, on the opposite side of which rises an ice-worn range of low rocky hills considered to be the Huronian. The valley is believed to follow the line of a fault. The latter rock is mainly composed of quartz and felspar, with but little mica, though occasional thinnish bands of a fissile mica-schist occur. It is much jointed, and appears to have a flaggy bedding, reminding me in its general aspect of parts of the Highland "eastern gneiss," in Glen Docherty (that is, where the crushing is less conspicuous), or of the schistose series on the south side of Porth Nobla, Anglesey. The dip of the apparent bedding is rather more to the east and is slightly steeper than that of the Laurentian; but the difference both in direction and amount is not

* In my Presidential Address to the Geological Society (Quart. Journ. Geol. Soc. vol. xlii. Proc. p. 81) I gave a very short account of this region; but since then I have studied more minutely all the specimens noticed, as well as a series of slides cut from specimens sent to me by Dr. Selwyn in the spring of the present year. A description of part of the region will be found in Sir W. Logan's 'Geology of Canada,' pp. 50–52, 55. It is shown in the beautiful geological map of Canada published by the Survey in 1886, and is noticed in a paper by Mr. Irving in the fifth Annual Report of the Geological Survey of the United States (1883–4). This general survey of the North-American Huronian rocks, which embodies some most important observations by Professor Van Hise, should be studied by everyone who wishes to obtain a good idea of the Huronian rocks. Our conclusions in many respects seem likely to agree; but I may venture to say that my own were formed quite independently. His lucid statement of the problem presented by the Huronian could not be surpassed.

† This is roughly measured along the railway in a straight line, avoiding one or two outlying patches of Lower Palæozoic strata; the Laurentian zone is not far off 200 miles broad. There are, however, frequent patches of drift.

great. The zone over which rock of this character is exposed in some cuttings is not wide,—less than a mile, for at that distance outcrops of a rock distinctly fragmental are exposed. This may be described as a dark quartzite, at times rather flaggy, having a filmy greenish mineral, like a varnish, developed on the divisional planes. In parts the clastic structure is very distinct, the fragments from ·25″ downwards usually very slightly projecting on weathered surfaces, but there are occasional larger fragments of a grey granitoid rock up to about 2″ in diameter, subangular in form. Rock of this character, varying from the finer to the coarser varieties, continues for about ten miles till we reach the clearing where stands the village and railway junction of Sudbury.

Beyond Sudbury a dark quartzose rock, something like that seen on the opposite side of the village, but even more compact and schistose, occurs in the first cuttings. Then the rock assumes a rather streaky or porphyritic aspect, but on weathered surfaces is seen to contain small fragments less than ·5″ in diameter, the ground-mass being occasionally slightly schistose. There is a considerable thickness of this rock, my specimens being labelled "about ½ mile from Sudbury." After a time the rock becomes more coarsely fragmental (about ¾ mile from Sudbury), the fragments now showing very distinctly on a weathered surface, by a slight bleaching, some looking rather like a felsite, others more like a holocrystalline (? gneissose) rock; they are often from 1″ to 2″ in diameter, sometimes larger. Next (about 1 mile) comes a coarse breccia, looking rather like an agglomerate, the fragments often 8″ or 12″ in diameter; these are of a compact felsitic rock, containing ill-developed elongated prisms, about ·5″ long, very dark green in colour, like badly crystallized hornblende, the matrix in all the cases being apparently a more or less fine-grained quartzite, sometimes rather schistose. Quartzite without fragments now succeeds for a time. Then comes (about 1½ mile) another group of fragmental rocks (the matrix being crowded with subangular fragments); these are a slightly reddish-grey rock, resembling a microgranulite with dark green spots, gneissose and schistose rocks, and a greenstone or possibly chlorite-schist. The matrix occasionally had an ashy, sandy look, reminding me of some of the so-called quartzites of Blackbrook, Charnwood; sometimes it was the usual quartzose rock. Near the point where we turned back, about 1¾ mile from Sudbury, the fragments (this being apparently low in the series) were of smaller size in rather regular layers, the stratified arrangement being very conspicuous on weathered surfaces, where the fragments were bleached. The dip was generally throughout at a moderate angle, say 10° to 20°, roughly to the S.E. I was informed that this is the usual dip of the whole region, the observations varying from E.S.E. to S.S.E. *

* Possibly the rocks noticed in this paragraph may belong to the (lower) "slate conglomerate" of Logan's section, p. 56; but if the Limestone be thin or wanting here, the upper conglomerate also may be present: still, according to the dip, we were descending in the series; and I feel very uncertain about the correlation of these beds with the less altered conglomerates nearer Lake Huron, specimens from which are mentioned later.

The rocks forming the eastern zone of this "Huronian" region (the doubtful belt west of Wahnepitae station) must be passed over rather briefly; not because they are deficient in interest, but because their exceptional difficulty obliges me to speak of them with great hesitation. Their distinction in the field from the typical Laurentian is obvious; their special difficulty was not realized at the time, so that I only took specimens from two localities. That from the first (eastern) mass of rock referred to Huronian, the appearance of which in the field has already been noticed, when examined under the microscope is seen to consist chiefly of quartz, felspar, and a brownish mica. The quartz occurs in rather elongated irregular grains, is fairly clear, but contains occasional films of mica; occasionally there is a grain-like spot of chalcedonic quartz. The felspar exhibits the striping of plagioclase and the cross-hatched structure of microcline. The mica occurs in small but fairly well-defined flakes, lightish brown, sometimes inclining to greenish, and (especially in the smaller separate flakes) almost colourless *. The rock certainly exhibits a fragmental structure with secondary reconstruction. Is it, then, a rather fine-grained gneiss, modified by pressure, or an arkose of similar materials in which rather marked reconsolidation has occurred? Pressure indubitably has acted, as may be seen by the occasional cracking of the felspar and the strain-shadows which sweep across the quartz grains. I incline, though not without hesitation, to the former view, and to consider that, as in Scotland, an important fault has brought up some of the more fine-grained rock of the Laurentian series, and in so doing has given it a pseudoclastic aspect.

The constituents of the specimen from the western side of the belt are very similar to the above. In the field I took it for a variety of a fine-grained quartzite, but, though under the microscope there is indubitably a structure suggestive of a clastic origin, I am doubtful whether this is not really a member of the Archæan series modified by subsequent pressure. There has certainly been mineral change in either case, and until more evidence is obtained I think it safer to state the alternatives. It contains some small crystals, generally aggregated, of a dark olive-brown, almost opaque mineral, probably a very ferruginous mica or chlorite.

After this we enter a region where our hesitation is at an end, and microscopic examination confirms the impression formed in the field that (excepting some unimportant intrusions of a basic igneous rock) we are dealing with a series of clastic origin. I have already described the general succession in this region †. Time will be saved if in noticing their microscopic structure, I group them lithologically as follows:—

(A) Ordinary quartzites. Quartzites containing conspicuous fragments. Fine-grained schistose quartzites.

(B) Agglomeratic or conglomeratic rocks.

* It contains some crystalline grains, often aggregated, of a mineral granular in texture, varying from a golden-brown colour to all but opaque, perhaps an impure sphene or rutile.

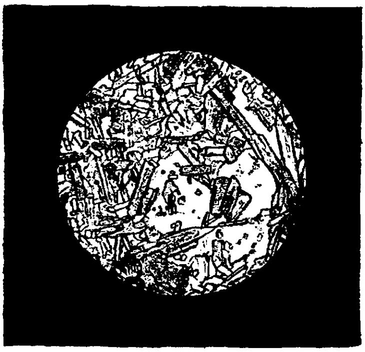
† See also Logan, p. 52, for one more detailed in a neighbouring district.

(A) *Quartzites.*—These rocks vary in colour from almost white to grey. The recognizable fragmental grains are commonly from about ·005″ to ·025″ in diameter. The rock consists of quartz, with occasional felspar (fragmental), and mica (variable in amount).

The grains of quartz are generally clear, though microlithic enclosures and exceedingly minute cavities do occur. The slightly ragged outline of the grains, and the way in which they are (so to say) fused one with another and with the matrix, prove to my mind that there has been secondary enlargement; but to what extent I cannot determine, for I have not been able to distinguish (as one sometimes can) the true boundary of the original grain. From their general outline I believe them to have been formerly angular. Chalcedonic quartz is also present, sometimes interstitially, sometimes in aggregates, and this occasionally may also be an original constituent. The felspar fragments exhibit in some cases the striping of plagioclase and the cross-hatched structure of microcline; it is possible that these also have been enlarged. The mica, which occurs in scales from about ·002″ or ·003″ downwards, is light brown in the darker, colourless or almost so in the lighter quartzites. Their well-formed outlines indicate that, even if there has been a nucleus of detrital origin, they have developed their present boundaries *in situ*.

Passing now to the quartzites with marked fragments—altered pebbly sandstones—we find that their matrix strongly confirms the view just expressed (specimens from about one mile west of Wahnepitae to one mile east of Sudbury Station). Brown mica is more abundant, the flakes are larger, often about ·005″, and occasionally

Fig. 1.—*Matrix of Conglomerate from the Sudbury District, showing well-developed mica flakes associated with quartz (the white ground of the figure).* × 140.



even more in length, excellently developed, but without any definite orientation (fig. 1). Smaller films of white mica are intermingled variably with quartz (probably interstitial)*. The larger quartz grains in the matrix are usually compound, consisting of several granules rather polygonal in outline, and sometimes containing between them tiny flakes of brown mica.

The fragments in this altered conglomerate, east of Sudbury, are interesting; those examined in this rock are more or less rounded in outline and light grey in colour. They consist of quartz, felspar, and mica (brown and white), but the condition of these minerals is peculiar. Broadly speaking, their association resembles that of a moderately coarse granite, but the quartz on examination proves to be not in single, or almost single, grains of fair size, but a mosaic, like a honeycomb, of different granules, among which occur, very sparsely, flakes of mica and earthy granules. The felspar has almost lost not only all definite external form, but also to a great extent its characteristic internal structure. Flakelets of white mica and specks of quartz are developed in large patches over most parts of the crystals, insulated portions only here and there remaining comparatively untouched, and exhibiting sometimes the parallel lamination of plagioclase, at others possibly the structure of microcline, while others may be orthoclase; nay, at times, even the larger clusters of polygonal quartz appear to have been developed in the heart of a large grain of felspar. The process of alteration seems to be as follows:—First a bit of the felspar assumes a 'dusty' aspect; next some tiny flakes of mica and a granule of quartz segregate; then the latter enlarges, as it were pushing back the mica, which forms an irregular ring round the grain (fig. 2). Then two or three grains

Fig. 2.—*Development of Quartz and flakes of Mica in Felspar Crystals.* (The mica is indicated by the outlined flakes, the quartz is dotted. In the upper part of the diagram the larger mass of quartz is beginning to show the "mosaic" structure.) × 27.

grow together, generally expelling the intervening mica, so that at last the felspar crystal is replaced by aggregated patches of quartz and of microscopic mica. It is singular that while, from the general appearance, one would be prepared to accept some of the quartz in

* Crystalline grains of black iron-oxide and of a dark granular mineral are present.

the slides as an original constituent, all of it, on applying the polarizing apparatus, breaks up into the above-described mosaic of separate crystalline grains. The change of the felspar is not always as above described; in some cases it is replaced by microscopic white mica and occasional interstitial quartz in the more usual manner. Dark brown mica occurs in the slide, occasionally in isolated flakelets, but commonly in aggregated patches of these, and there is, as usual, a little iron-oxide. It can, I think, hardly be doubted that these fragments were once a fairly coarse granite or granitoid gneiss, and that their present aspect is due to subsequent change. If so, it is interesting as indicating a very considerable freedom of molecular movement during the change, for the position of the constituents must sometimes have been altered by quite ·01″. I cannot but conclude that spots of quartz ·025″ in diameter have formed in the heart of felspar crystals, so that some of the constituents have been pushed aside for half that distance, and I believe that some, at least, of the larger patches have been thus formed. If I am right in inferring that formerly the quartz and the brown mica were in grains sometimes approaching ·1″ in diameter (and this the size of the felspar crystals, still occasionally discernible, appears to justify), then it would seem as if all the constituents had undergone a crystalline modification so as to form aggregated groups of smaller crystals *.

Was, then, the alteration of the fragments anterior or posterior to their inclusion in this conglomerate? As the matrix of the latter is altered, we might reasonably expect some marked change to have occurred in the fragments; but inasmuch as the matrix contains numerous small fragments (associations of from 3 to 6 or 7 granules) of the "mosaic" quartz, and two or three fragments, still recognizable, of the modified felspar, there can be no doubt that these changes occurred anterior to the formation of the conglomerate, so that we have here a case of "Pre-Huronian" alteration.

With this group I include a fine-grained schistose rock (occurring just west of Sudbury Station), which, though quartzose, is evidently less rich in that mineral than the rocks belonging to the great series already described. Assuming these to be altered sands and gravels, this would represent a more silty or earthy stratum. When examined microscopically, the latter rock is found to consist almost wholly of granules of quartz seldom exceeding ·002″ in diameter, and flakes of a micaceous mineral, commonly slightly larger, sometimes approaching near ·01″. Some of the quartz grains look as if they were fragments, but I expect the majority have been formed *in situ*. There are a few granules of magnetite scattered about. There is a slight, but only a slight tendency to banding in the arrangement of the constituents, and the flakes of the micaceous

* I have sought to calculate the proportion of silica which would be set free in converting a crystal of average orthoclase into quartz and potash-mica. Supposing none of the constituents removed, the quantity of silica set free would be nearly $\frac{4}{10}$, so the result would be about $\frac{4}{10}$ free quartz, and $\frac{6}{10}$ mica; but in reality a considerable percentage of the alkali is not needed to form an ordinary mica, and has probably been removed, so that the actual percentage of free quartz in the resulting compound would be rather higher.

mineral have not a well-marked parallelism. This mineral is in part of a pale olive or brownish-olive colour, in part colourless. The latter is the ordinary white mica, giving bright tints with crossed nicols ; the former is variably dichroic, giving only low dull tints, and is probably an altered brown mica. Distinct dichroism is often exhibited as a cloudy spot in a flake, when the remainder is feebly dichroic. This rock has some resemblance to one of the fine-grained mica-schists, but it is by no means identical with them. I have many typical specimens of the latter, such as occur in Anglesey, in the upper group of schists in the Alps, &c., from all of which this one differs, often very markedly.

Macroscopically similar to the above, except that some light-coloured specks are detected on close examination, are two specimens sent by Dr. Selwyn, one labelled "Sudbury," the other "Between Sudbury and Vermillion river." Under the microscope, the ground-mass is generally similar to the above, except, perhaps, that there is not quite so much mica, and a larger proportion of it is the colourless species. Many of the dark grains are rather prismatic in form, and on applying a high power, appear to be a yellowish mineral, blackened, often almost wholly, with opacite. The mica does not exhibit any orientation. The spots are rudely rhomboidal in form, and consist mainly of quartz granules with some mica, variable in quantity, and rather irregularly dispersed. The second specimen has only varietal differences, but here there is a rather well-defined border of white mica (chiefly) in the outer part of the rhomboidal "spot." The structure suggests that these may once have been separate crystals, and I think it possible that the rock was either a volcanic glass or tuff, containing crystals of felspar, in which both ground-mass and crystals have subsequently undergone a rearrangement of their constituents.

(B) Proceeding next to the remarkable group of breccias (for the fragments are more commonly angular than rounded) which occur at intervals for certainly more than a mile along the railway west of Sudbury, we find, as stated above, considerable variety in their mineral character. It was impossible for me to bring away materials for an exhaustive study, so I secured a few of the more remarkable specimens. The first, about half a mile from Sudbury, is a compact grey rock, with pale-coloured spots of rather irregular form, which weather to a pale cream-colour. In the field one could say no more than that it might once have been a rather peculiar porphyritic trachyte, but that it rather resembled a true breccia, where bits of a compact lava were imbedded in a somewhat quartzose, very fine-grained matrix. Under the microscope it appears to be a mosaic of irregular grains of quartz and felspar; in what proportion it is difficult to say, but the former certainly predominates, and in it are scattered rather irregular flakes of a brownish or greenish mica, occasional larger grains, commonly associated, of quartz, and grains of felspar with ragged outline, as if they had once been larger and had been corroded by the matrix. Hence, even after microscopic examination, one cannot venture to speak positively of the nature of the rock; its structure resembles that of some devitrified felstones; also, though more coarse, that of the Treffgarn hälleflinta.

Bearing some resemblance to this, but more distinctly fragmental (it contains a yellowish fragment, about $1\frac{1}{4}'' \times \frac{1}{3}''$, together with some little bits), is a small specimen sent by Dr. Selwyn, labelled "1 mile W. of Sudbury." The matrix consists of granules of crystalline quartz and the usual brown or greenish-brown mica, with occasionally a larger grain of quartz or of felspar. I have little doubt that all the constituents, if not developed *in situ*, have been enlarged, but I cannot detect the original boundary of any one. The fragments contain but little mica, and chiefly consist of granules of quartz much smaller than in the matrix, with rather more ferrite scattered among them. The slide includes a portion of the larger fragment and some of the smaller; all can be distinguished, but they are, as it were, "fused" into the matrix.

The next set of fragments are of a grey-speckled crystalline rock, which often occurs of large size and in great abundance. The matrix exhibits a structure identical with that just described, but the grouped quartz grains therein are rather larger in size, while the felspar-crystals are all larger and more distinct. These certainly give one the idea of being encroached upon by the matrix, as their actual outlines are so very irregular, and occasionally there appears a kind of intrusion of the matrix, but there is not, as one would expect, any appreciable amount of white mica formed. There are, however, in the slide, some yellowish mineral granules, and an occasional larger yellow-grey grain, which may be an alumina silicate. On the whole, then, I think it highly probable that these have once been a porphyritic rhyolite, though they have been subsequently greatly altered by molecular rearrangement.

The fragments with the dark hornblende-like crystals have a similar matrix, but it seems to contain more felspar; at any rate the "dusty" look of a considerable proportion of the granules indicates clearly the position of what is, or has been, this mineral. There is also more ferrite, opacite, or an impure chlorite (?) scattered about the slide than in the other cases. We find the compound grains of quartz and the porphyritic felspar in the condition already described. The supposed hornblende proves generally not to be a perfect crystal, but an irregularly outlined group of associated flaky grains of hornblende or chlorite (some a very dark indigo-green, others practically opaque) "clotted" together, with occasional interspersed quartz-grains. Where these flakes are cut transversely they show cleavage, are dichroic, and extinguish either parallel or at small angles with the cleavage. There is, however, in one slide a fairly perfect crystal, which is undoubtedly hornblende, and on the whole I am disposed to refer most of the granules to this mineral rather than to one of the chlorite group. The pale-brown mineral, looking like granules of gum, mentioned above, is not uncommon here. It would therefore appear probable that this rock also may be of igneous origin, but changed like the other.

The last to be described are the breccias (less coarse) at the greatest distance, all $1\frac{3}{4}$ mile from Sudbury; these, in the field, especially when weathered, as Dr. Selwyn pointed out, have a marked resemblance to beds of volcanic ash. The matrix has a general similarity to that of the schistose rock described above, except that the mica flakes (brownish or greenish, possibly in some cases a chlorite, and white in variable proportions) are rather larger, and the rock, as a whole, is nearer to a typical mica-schist. The fragments have a general structure resembling that described above, but the mosaic structure is less strongly defined, and there is, in one case, much more mica, especially white. They are not porphyritic, as in the other instances.

I travelled over the great belt of the Huronian, mapped as extending for more than 70 miles from Sudbury *, as far as Pagamaseng (59 miles), where the track ended at the time of my visit, but could only examine the rocks here and there, and then hastily. Still as the train went very slowly, and I was in an open van, I could form some notion of their general character. I believe that Laurentian gneiss is brought up by faults two or three times, the intervening and dominating rock being Huronian, interrupted occasionally by intrusive masses of granite, syenite, or diorite. It is, however, hardly worth while my transcribing notes gathered on a hasty traverse. I will merely say that near the east end of Geneva lake is a grand conglomerate which contains blocks of a grey granite-like rock, passing westward into a dark-grained slaty rock, interstratified with a grey quartzite distinctly banded with quartz-pebbles. Near Vermillion River I obtained an ordinary greywacke. At High Falls, on the Oneping (25 miles from Sudbury), we cut through a mass of fragmental rock like a volcanic ash, which is worth notice. The finer matrix is almost opaque, a very dark dust; the smaller fragments are quartz (not abundant) and altered felspar or devitrified glass. The larger have probably been a moderately acid glass, sometimes vesicular, the cavities being now occupied by a pale chloritic mineral, the matrix being partly microcrystalline, partly a mass of small felspar crystallites, with occasional groups of pale actinolite. The zonal arrangement of some of the evitrification-structures suggests that the changes have taken place *in situ*†.

The remaining specimens in my collection, not from the above line of section, and almost all given to me by Dr. Selwyn as typical varieties of the Huronian group, may be classified as follows:—

(1) Rocks little altered. These are grits, the fragments evidently being waterworn. One (from an island on Lake Huron between Delormine and Boulanger locations) contains in a rather earthy matrix fragments of three distinct varieties of lava: one is a very character-

* Measured on the map, Sudbury is about 12 miles by the railway from the eastern boundary of the Huronian, but the railway is here running about W.S.W. The total breadth of the Huronian belt, as mapped, is probably nearly 80 miles, measuring in a N.W. direction, the prevalent dip being roughly S.E.

† I obtained a specimen thus: the guard kindly jumped off the train as it was going along, and picked up a block for me! I mention this to show that the pace of a "construction" train on a new line gives more opportunity for geological observation than do modern expresses.

istic andesite, the others, more compact, are probably the same species; these are perhaps even better preserved than the fragments in the volcanic grits of Charnwood Forest. With them are two fragments of a granitoid rock, one of which has its quartz in compound streaks, *i. e.* exhibits a gneissic structure, probably the result of pressure, but anterior to the detachment of the fragment. Another (from the east end of the same island) consists of rather similar materials, but the volcanic rock is more basic, containing a considerable amount of viridite and chlorite, and the granitoid fragments (the commoner) indicate very curiously the results of fracture, under pressure, and recementation. A third (between Upper and Lower Rapids, Vermillion River, C.P.R.) consists of rather angular fragments of quartz and felspar, and of flakes of altered brown mica, evidently the detritus of an old granitoid rock, where the proportion of the materials has not been very much changed by drifting. Another (between Spanish and Sable Rivers, C.P.R.) has an argillaceous matrix, with a few scattered grains of quartz, but contains a comparatively large fragment of a rock which has the structure of a true granite rather than a gneiss. The last (Campment d'Ours*) is crowded with fragments, andesite or porphyrite (4 varieties), granitoid rock, and a fine-grained gneiss, with marked foliation. The matrix also is obviously the detritus of the above materials, chiefly of the second. That rock, it may be remarked, contains much microcline, and exhibits a structure characteristic of the granitoid gneisses so common in the lower part of the Laurentian series.

(2) The next group has undergone changes like and about equal to those described in the Sudbury district. White quartzites, from between Serpent River and Algoma Mills, *i. e.* about 8 miles from Lake Huron, on a line branching from Sudbury, and from between Sable and Spanish Rivers, C.P.R.† These have clear quartz grains imbedded in a colourless micaceous "paste," in which is sometimes a darker mica and iron-oxide. This is more abundant in the second (darker) specimen.

Lastly is a very interesting rock. The ground-mass consists of micas, greenish and colourless, in well-defined flakes from about ·002″ to ·004″ long, associated rather irregularly with granules of clear quartz, generally of less diameter, and some grains of opacite, in which occur somewhat oblong spots consisting chiefly of white mica and granular quartz, the mica being to a large extent collected about the edges. I suspect that this rock was once a microporphyritic igneous rock, probably an andesite or quartzless trachyte, subsequently changed.

With these rocks may be included a grey limestone (from Echo Lake, some distance east of Sault Ste. Marie), the outside of which is weathered very curiously into a sort of ridge and furrow‡.

* An island at the east end of the narrow channel between Lake George and North Channel on Lake Huron.

† These, according to Logan, come well above the great conglomerates. So also does the well-known "red-jasper conglomerate."

‡ Undoubtedly No. 5 in the series given by Logan, p. 56. Here, as in another place, it divides an upper from a lower mass of conglomerates. Here a thickness of 300 feet is assigned to it.

Macroscopically it is compact in structure, looking very like an argillite or felstone; under the microscope it is found to be a rather minutely crystalline granular dolomite, containing occasional granules of quartz, flakes of white and brownish mica (with probably one or two grains of tourmaline), with hæmatite and opacite, and occasional rather earthy-looking granules, chiefly occurring in streaky bands and causing the peculiar weathering. All the minerals look as if developed or completed *in situ*, so that the rock is a little more altered than would be supposed from a macroscopical examination; still I feel doubtful whether to class it with these or with the former group.

There are some igneous rocks of interest associated with those above described; but as they have no bearing on the questions discussed in this paper, I pass them by without further notice. I may, however, mention that when at Pagamaseng, a specimen was given to me of a rock (diabase) containing in porphyritic crystals the variety of anorthite called huronite. This was first described from specimens of the same rock occurring as boulders near Lake Huron. My specimen also came from a boulder near Pagamaseng, but I was afterwards informed by Dr. Girdwood that the rock had been ~~formed~~ *in situ* at no great distance from the settlement.

The results described above may be thus briefly summarized:—

(1) Putting aside rocks indubitably of igneous origin, and certain others the position of which is not clear, the Huronians of the Sudbury region obviously form a series separated from the Laurentian by a long interval of time. Though here and there among them rocks may occur the structure of which, inconspicuous from the first, has been yet more obscured by subsequent micromineralogical change, the majority are obviously of fragmental origin, and we need not hesitate to claim for them a place among the stratified rocks, so that these will carry the other less definite cases with them.

(2) Among the rocks in this region at present referred to the Huronian, two groups may be distinguished. One, where the alterations of the matrix are comparatively slight, merely such micromineralogical changes as are common in the older Palæozoic rocks, such as the deposit of secondary quartz, the partial micatization of felspars, the formation of viridite, &c.; another, where the changes are more strongly marked, where the enlargement of fragments, the generation of mica (especially of brown mica), has taken place on a larger scale, so that the original clastic character of the rock, though still to be discerned, is less obvious, and in the case of the smaller constituents it is often difficult to decide whether they are clastic or endogenous.

(3) This distinction must indicate either (*a*) that selective metamorphism has produced marked effects, viz., that diversity of material has led to different results being produced by one and the same cause, or (*b*) that we are dealing with a series of great thickness, the deposition of which occupied a very long time, so that the lower beds are more altered than the higher, or (*c*) that under the name Huronian two distinct series are included. I am well aware that in

structural and mineral changes much depends upon the constituents of a rock. Under certain circumstances, such minerals as epidote, chlorite, viridite, hydrous white mica, quartz, &c., readily form; a clean sandstone, for instance, is readily cemented into a quartzite, the calcareous constituents of a rock will crystallize, while the argillaceous are absolutely unchanged. But making all allowance for this, and confining my attention to the finer portion of the detrital materials, I find them in the case of the latter group more altered (especially where brown mica is developed) than I have ever yet seen in any Palæozoic fragmental rock, even the oldest, or even in the typical "Pebidian" of this country, except when affected by contact-metamorphism. Hence, I think, our choice lies between the second and third hypotheses, and, as at present advised, I incline to the latter; viz. that two distinct groups, of which, at any rate, one is Pre-Cambrian, are included under the name Huronian.

(4) It is a curious coincidence that fragments of lava bearing a general resemblance to those which in Great Britain are found, certainly or presumably, rather below the level which appears to be the natural base of the Cambrian series (*i. e.* in the so-called Pebidian), should occur so abundantly in a formation which also seems to be the record of a late phase in Archæan history—one of the concluding chapters of the volume.

(5) It seems also worth note that many of the fragments have assumed structures characteristic of Laurentian rocks, such as the peculiar "intermediate" structure, neither normal granite nor normal gneiss,—or a somewhat foliated structure, resulting from mechanical, followed by chemical change,—prior to the formation of these conglomerates. Also that certain other important changes, apparently of a somewhat segregatory nature, had taken place in other rocks, possibly of igneous origin. The occurrence, too, of fragments of a true schist, similar to those met with in old conglomerates elsewhere (*e. g.* Charlton Hill, Salop) and not at all unlike one which I obtained *in situ* near Straight Lake, is also interesting as showing that ordinary schists and gneisses, of comparatively fine-grained structure, existed at that period as well as granitoid rocks.

(6) The changes which have taken place in the more altered "Huronians" show that a gneiss might conceivably result from the alteration of a felspathic greywacke or a mica-schist from a muddy sandstone, so that it is possible for a series of banded gneisses and schists, of moderate coarseness, to have been produced by the metamorphism of a sedimentary series. Other specimens, however, indicate the possibility of certain gneisses and certain schists being due to the metamorphism of rocks originally igneous.

(7) While in the case of some of the fragmental rocks there is reason to believe that the mineral changes in the included fragments occurred prior to their being detached; others (which seem originally to have been very compact, possibly porphyritic lavas) appear to have undergone a change together with the matrix in which they are imbedded. It is possible that these breccias may be of volcanic origin, at any rate it appears probable that from "trachytic" mate-

rials quartz-mica rock has been developed, which, however, differs (chiefly in the absence of foliation) from a normal mica-schist.

(8) The evidence of these Huronian rocks, so far as it is positive, is in favour of the theory which regards the more coarsely crystalline gneisses and schists as produced, as a rule, only in early Archæan times; and so far as it is negative, it is against the theory which regards them as metamorphosed sediments of Palæozoic or even later age, because we find in them an approach, though an incomplete one, to the structure of crystalline gneisses and schists, and this approach is nearer than I have yet found in any rock indubitably Palæozoic*.

Postscript.—A common thread of thought and purpose runs through these three papers; they form a kind of trilogy; may I, then, be allowed to point the moral in a brief epilogue?

The first illustrates the effects of pressure on Palæozoic sediments; the result is micro-mineralogical change only, the production of tiny films of mica, of specks of secondary quartz, an enlargement probably of clastic granules of the same. Thus a microfoliation only is produced, which, strange to say, appears to be parallel to the original stratification and independent of the pressure which has subsequently cleaved the rock. If the temperature of a mass, thus modified, be considerably raised by the intrusion of igneous rock, further and more active chemical changes occur, the minerals already microscopically present grow larger, while others are produced. The result is a moderately good imitation of one of the fine-grained mica-schists.

The next paper illustrates the changes in a fragmental rock of unknown geological age, which has certainly been compressed, which may have had its temperature raised, though not by intrusive igneous rocks, and in which considerable change has been produced; the result, however, in this case also does not quite accord with a typical fine-grained mica-schist, though in one instance it comes very near to it.

In the last case we are dealing with rocks, certainly of great antiquity, which I suppose all would admit to be, in the main, Pre-Cambrian. Here we find changes very similar to those last described; these also have not produced typical gneisses and crystalline schists, and they further distinctly testify that when they were formed, such rocks already existed, and mineral changes occurred, seemingly with more facility than in later days. To what conclusions these results point, it is needless to suggest to a careful reader.

* This paper was completed (except for two or three trivial details) last August. Since my return to London in October, I have had the opportunity of reading the most valuable paper by Prof. R. S. Irving, "Is there a Huronian Formation?" (Amer. Journ. Sci. vol. xxxiv. pp. 204, 249, and 365). We appear to have arrived independently at very nearly the same conclusion. I think, however, that the Sudbury rocks exhibit, as a group, rather more alteration than those from the vicinity of Lake Huron, as described by him, and as confirmed by the specimens sent to me by Dr. Selwyn. Possibly the Sudbury rocks may be a slightly older group, the equivalents of his "iron-bearing (Animiké) series," p. 216.

Discussion.

The President remarked that the relations of foliation to stratification and cleavage would receive much illustration in the study of incipient crystallization in rocks. It was only possible to understand the origin of great changes by finding out what took place in cases of smaller change.

Dr. Geikie coincided with the President's views of the importance of beginning the study of metamorphosis by investigating the process of smaller changes. He hoped before long to lay a contribution to this subject from the north-west of Scotland before the Society. The Obermittweida conglomerate reminded him of some crushed Cambrian conglomerates in Scotland, where there is a passage from crushed conglomerates and sandstones into mica-schist.

Mr. Rutley said that one of the Morlaix rocks represented in the diagram resembled, in microscopic character, some of the slate from Boscastle in Cornwall. He was much interested in the evidence of transition between the two rocks figured in the diagrams. He thought the enlargement of crystals might in some cases give rise to pressure. He then, with reference to the Sudbury rocks, noticed the occurrence of some similar characters in certain Huronian rocks from Michigan.

Rev. E. Hill said he had seen the Morlaix beds, and described the locality. The age of the rocks might be determined with fair certainty.

Mr. Marr said the mode of occurrence of the Obermittweida conglomerate was in boat-shaped patches that looked like the loops of overfolded synclinals. The fossiliferous rocks of Saxony are unfortunately found at a distance, but at Hof, in Bavaria, and in the Bohemian basin primordial beds are found. Dr. Reusch considered the Obermittweida rocks very like Silurians near Bergen.

Mr. Bauerman had also been at Obermittweida and thought that Prof. Hughes's view was a fairly probable one of the structure of an obscure section.

Prof. Hughes, in reply, said he did not insist on the identity in age of the conglomerates, of which he exhibited specimens ; all were basement-beds and similar in partaking of the mineral character of the rocks on which they rested.

Prof. Bonney said he had scarcely anything to say in reply, except to thank the speakers for the way they had received his papers. He had unfortunately not been able to examine the rock noticed by Prof. Reusch in Norway. He was trying to work out the whole question of change of structure, approaching it from different sides. He had seen it noticed by Dr. Barrois that some Cambrians occurred near Morlaix. He mentioned instances of patches of sedimentary rocks infolded in old strata, as at Obermittweida, and said that he also was surprised at not finding the matrix of the Obermittweida rock more affected by pressure.