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DEPARTMENT OF THE INTERIOR

BULLETIN

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OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 8

ON SECONDARY ENLARGEMENTS OF MINERAL FRAGMENTS IN CERTAIN ROCKS.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

ADVERTISEMENT.

(Bulletin No. 8.)

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive Departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map. A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl., 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Green Marls and Clays of New Jersey, by R. P. Whitfield.

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Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.
Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.
Lake Bonneville, by G. K. Gilbert. In preparation.
Dinocerata: A monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In preparation.
Sauropoda, by Prof. O. C. Marsh. In preparation.
Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A. 1882. 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xiv, 464 pp. 29 pl. Price $—.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. xix, 144 pp. 54 l. 54 pl. Price $—.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xii, 200 pp. 15 pl. Price $—.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, and 8 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 40 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Value of Troy Ounces of Fine Metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargement of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.

STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

WASHINGTON, D. C., *August* 30, 1884.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 8

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

HURONIAN QUARTZITE OF NEEBISH ISLAND, EAST SIDE ST. MARY'S RIVER. FROM THE WEST.

(The dip is towards the observer.)

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

ON SECONDARY ENLARGEMENTS OF MINERAL FRAGMENTS IN CERTAIN ROCKS

BY

R. D. IRVING and C. R. VAN HISE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

LETTER OF TRANSMITTAL

UNITED STATES GEOLOGICAL SURVEY,
Madison, Wis., April 1, 1884.

SIR: I have the honor to transmit herewith a paper on Secondary Enlargements of Mineral Fragments in Certain Rocks, prepared by myself and Assistant Geologist C. R. Van Hise.

The plates were all drawn from nature with the camera lucida, by Assistant Geologist W. N. Merriam.

I am, sir, very respectfully yours,

ROLAND D. IRVING,
Geologist in Charge of the Survey of
Pre-Cambrian Rocks of the Northwestern States.

Hon. J. W. POWELL,
Director United States Geological Survey,
Washington, D. C.

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ENLARGEMENTS OF QUARTZ FRAGMENTS AND GENESIS OF QUARTZITES.

By R. D. Irving and C. R. Van Hise.

GENERAL CONSIDERATIONS.

In his address before the Geological Society of London, delivered February 20, 1880,[1] Sorby describes sands whose grains are bounded externally by crystalline faces, but have in the interior the ordinary rolled grains, the crystalline faces having been produced by a secondary deposition of quartz upon the irregular surfaces of the original grains. He shows also that the quartz coatings of these grains are in perfect "optical and crystalline continuity" with the interior fragments, each original fragment having thus been changed to a definite crystal.

He states further that he had examined crystalline sands from the sandstones of various ages "from the Oolites down to the Old Red," and that they are commonly little coherent, but that in some specimens "a number of grains may often be seen cohering more strongly than the rest, and these show clearly that the cavities originally existing between the grains have been more or less completely filled with quartz. Moreover, on carefully examining the less coherent grains by surface illumination, we can see not only the planes and angles due to unimpeded crystallization, but also more or less deep impressions due to the interference of contiguous grains, thus proving conclusively that the deposition of crystalline quartz took place after the nuclei were deposited as a bed of normal sand. The very imperfect consolidation sometimes met with is, perhaps, not so very surprising when we reflect on the very small coherence of many large quartz crystals which are yet in close juxtaposition. However, it does seem probable that this crystallization of quartz sometimes contributes very materially to the cohesion of the grains in hard and compact quartzites. In such examples as the Gannister of the South Yorkshire coal-field we can see in a thin section that the grains fit alongside one another in a very striking manner, and it is only by extreme care that good proof can be obtained of the actual deposition of quartz between them. However, in the case of a highly consolidated sandstone from Trinidad the proof of the deposition of quartz is as complete as possible;

[1] Proc. Geol. Soc. Lond., 1880, p. 62.

the outline of the original grains of sand is perfectly distinct, and the cavities between them are filled with clear quartz in crystalline continuity with the contiguous grains; so that the whole is a mass of interfering crystals, each having a sand-grain as a nucleus. The rock has thus been converted into a hard quartzite, almost like a true quartz rock, but differs from such quartz rocks as those of the Scotch Highlands in containing no mica crystallized *in situ*. All my specimens of these quartz rocks are really highly quartzose mica-schists; and, so far, I have failed in my endeavors to trace the connection between them and true sandstones, though possibly this could be easily done in some districts which I have not examined."[2]

In the American Journal of Science for July, 1881, A. A. Young describes a sandstone from the Potsdam sandstone of New Lisbon, Wis., the rolled grains of which are enveloped in secondary crystal-faceted quartz coatings. In the same journal for June, 1883, the senior author of this paper showed what Sorby regards as probable, viz: that the "cohesion of the grains in hard and compact quartzites" is due to this deposition of interstitial quartz, to be certainly true in the cases of certain quartzites and mica-bearing quartz-schists of Archæan (Huronian) age. He also showed that irregular areas, often of very small size, and even thin crusts, due to a mere weathering, occur frequently in the Saint Peter's and Potsdam sandstones of Wisconsin, in which these sandstones have been changed to vitreous quartzites by the same mode of induration, *i. e.*, by the deposition of an interstitial quartz which has divided itself off into interlocking areas optically continuous with the original grains of quartz sand.

[2] So-called "crystallized" sands and sandstones have been described by many authors, beginning with Gerhard, in 1816, but none of them, so far as we have yet learned, understood that the crystal-faced grains were rolled fragments enlarged by secondary deposition. The idea with regard to these sandstones appears to have been that their crystal-faced grains were wholly separated out from solution, and the sandstones not really of clastic origin. Zirkel (Petrographie, II, p. 575) says of these crystallized sandstones that they "vielleicht gar nicht zu den klastischen Gesteinen gerechnet werden dürfen." See also Naumann's Geognosie, I, p. 530, and Von Cotta's Lithology, Lawrence's translation, pp. 296, 301. Zirkel (Petrographie, II, p. 590) gives a number of references among the older writers, but so far as I have been able to refer to them none seem to have had any idea of the true nature of the crystals.

Daubrée, who described the Vosges crystal-bearing sandstone as long ago as 1852, has quite recently (Études Synthétiques de Géologie Experimentale, 1879, pp. 226–230), in a résumé of earlier observations by himself and others (Elie de Beaumont, Hoffman, Gutberlet, Croisnier) on crystallized sands, stated distinctly his belief in their purely chemical origin. The Vosges sandstone, which is mentioned by Sorby (*loc. cit.*) as an admirable instance of the formation of crystallized sands by the enlargement of rolled grains, Daubrée cites as a typical instance of a sandstone of chemical origin. While admitting the occurrence of instances where it is difficult to see any such connection, he advances the view that, in the cases of the Vosges sand and many others, the deposit of crystals of quartz has been derived from a solution of an alkaline silicate supplied to the sea by the decomposition, before complete cooling, of masses of eruptive feldspathic porphyry, or of porphyry tuffs—a view which receives no substantiation from our own observations.

CRYSTAL-FACED ENLARGEMENTS OF QUARTZ FRAGMENTS.

A. Hoen & Co. Lith. Baltimore.

The latter observations were made in the beginning of 1883, but in ignorance of Sorby's results, announced some years before. Several other lithologists had in the mean time made similar observations. In the summer of 1881, Arnold Hague and Iddings noted this form of induration in the Silurian, Devonian, and Carboniferous quartzites of the Eureka district of Nevada, and Mr. Iddings prepared some drawings at the time which will appear in Hague's monograph of that district.[3] Bonney, Phillips, and others have made similar observations in Europe.[4] The peculiar induration due to weathering had also been previously observed both in Europe and in this country,[5] although it does not appear that the exact nature of the induration was in any case understood.

Since the publication, by the senior author of this bulletin, in the American Journal of Science, above referred to, we have been engaged in studying sandstones, quartzites, and other rocks from various formations, with a view of determining how widespread this mode of induration is. Our attention has been mainly turned to rocks of pre-Cambrian age, but, whenever we have been able to procure the material, we have studied also rocks of more recent formations down to the Cretaceous. From the list given below it will be seen that we have found this peculiar form of induration in rocks representing nearly all of the various Huronian areas of the Northwest, as well as in a number of quartzites and sandstones of various degrees of induration from the later formations. We have also noted a number of interesting new points in this connection.

The most important result of our study is, of course, the proving that most, if not all, of the ancient quartzites, as well as many of the quartziferous schists, are composed in the main of the original fragmental material, unaltered save by some of the ordinary metasomatic processes, but the fragments cemented together by a very subordinate quantity of a siliceous cement of secondary origin. This siliceous cement forms the only part of the rock that has crystallized *in situ*, the more or less intricate interlocking of its areas and its common optical continuity with the original quartz fragments giving rise to a deceptive appearance of complete original crystallization.

The least advanced condition of this process of induration is to be met with in sandstones that are quite loose, as was shown by Sorby. The rolled grains of quartz are each furnished with a border of newly deposited quartz, optically continuous with the nucleus, and furnished with more or less perfectly developed crystalline faces. At times the fragment is only partially buried by the newly deposited border, this being especially true of the more irregularly outlined grains, but more

[3] Monographs of the United States Geological Survey, not yet issued.

[4] Q. J. G. S., Vol. XXXIX, p. 20.

[5] A. Geikie, Text Book of Geology, pp. 158, 333. M. E. Wadsworth, Science, Vol. I, p. 146.

usually the grain is completely, though very thinly, covered, so that we have thus formed a quite perfect quartz crystal, whose greater part is, in each case, mainly composed of the old and worn grain. These crystal-faced borders we have observed running in thickness from films so thin as to be barely perceptible with the microscope to those 0.2 or 0.3^{mm}. in width. The presence of these crystal faces makes the surface of the sandstone affected by this induration sparkle and glisten like a frosted surface. Such crystalline sandstones have been known for a long time, and they are common in all formations from the Archæan to the Tertiary. Indeed, since our attention was first drawn to this matter, it has seemed to us as if the presence of at least some of the crystalline faces in quartzose sandstones is rather the rule than the exception. There can be no doubt, we think, that all owe their sparkling appearance to this same process of secondary enlargement of the original fragments. The crystalline faces are best developed, as already said, in loose sandstones, where the induration has not gone far enough to produce much interference, but they may coexist with a considerable degree of induration. The crystal-faced enlargements of the fragments in such sandstones may generally be separated from the nucleal grains by the presence of films of iron oxide on the surfaces of the nuclei, by the greater freedom from inclusions of the newly deposited as compared with the nucleal quartz, by the existence of a roughened surface on the inner grain, and by rows of cavities at the junction of the new quartz with the corroded surface upon which it was deposited.

Cases are met with in which it is exceedingly difficult to separate the two quartzes from each other. Sorby[6] mentions as such an instance the "Gannister" of the South Yorkshire coal field, and in our own experience we have met with two instances, those of the Huronian sandstones of Spurr Mountain, Michigan, and Penokee Gap, Wisconsin, both of which are alluded to in the list given below. The difficulty in all these cases arises from the great relative purity of the original quartz particles and the entire absence of an iron oxide coating to the nuclei, and, in the last two cases at least, from the smallness of the grains; but, in all, careful search discovers grains in which the separating lines may be perceived; and no doubt remains that in these cases also the crystals are enlargements of rounded fragments. These observations are of particular interest, since they render it evident that a completely indurated rock, apparently made up entirely of originally deposited quartz, may yet be only apparently so, the lines of separation between the new and old material being imperceptible.

In the very loose sandstones the nuclei and deposited quartz are best distinguished from one another by mounting the sand crumbled from the rock in balsam, while the crystalline faces are best seen in a dry mounting of this sand.

The whole process of enlargement in these crystal-bearing sandstones is of course, as Sorby shows,[7] precisely analogous to what is known to

[6] *Loc cit.*, p. 63. [7] *Loc cit.*, p. 62.

1

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A. Hoen & Co. Lith. Baltimore.

THIN SECTIONS OF QUARTZITES.

occur when a crystal of a soluble salt is placed in an evaporating saturated solution of the same substance. We have tried this experiment with fragments, from one-eighth inch to one-half inch in diameter, of alum ($K_2 Al_2 (S O_4)_4$), nickel ammonium sulphate ($(N H_4)_2 Ni (S O_4)_2$,) and sodium and potassium tartrate ($Na K (C_4 H_4 O_6)$.) The fragments in each case were thoroughly rounded and coated with iron oxide. Being then hung each in its appropriate solution, the angles and faces were soon rapidly developed, after which the crystal continued to grow over the whole surface. Sections made from these crystals showed the nuclei bounded by oxide of iron films and built out by newly deposited material with precisely the relations met with in the enlarged grains of crystal-bearing sandstones.

As instances of localities yielding sandstones with crystal-faceted grains may be mentioned the following: For Huronian sandstones—East Neebish Island, St. Mary's River, Canada; Spurr Mountain, Michigan; Penokee Gap, Ashland County, Wisconsin; Devil's Lake, Sauk County, Wisconsin; Redstone, Nicollet County, Minnesota. For Potsdam sandstone:—New Lisbon, Juneau County, Wisconsin; the great bluff known as Roche Écrit, Adams County, Wisconsin, and the railroad cut on the Chicago and Northwestern road just south of Madison.[8] For St. Peter's sandstones—Arlington Prairie, Columbia County, Wisconsin; Lancaster, Grant County, Wisconsin.

Plate II shows a number of instances of crystal-faced enlargements of quartz fragments. Fig. 1 of this plate shows a single grain of the sandstone intercalated in the Huronian quartzite of East Neebish Island, St. Mary's River, enlarged 67 diameters. The outlines of the crystal faces, which are more or less interrupted from lack of material, were drawn in from a dry mounting of the grain, after which it was covered with balsam, and the nucleal fragment, with its oxide of iron coating, drawn. Fig. 2 shows another grain from the same sandstone, enlarged 67 diameters, as seen in a balsam mounting. Fig. 3 represents a single grain from the Huronian sandstone of Spurr Mountain, Michigan, as seen in a balsam mounting. The enlargement is 100 diameters. Figs. 4, 5, and 6 show the appearance, in the balsam mounting, of single grains from the Potsdam sandstone of New Lisbon, Wisconsin, enlarged 95 diameters. Figs. 7 and 9 are similarly mounted single grains from the Potsdam sandstone of the quarry on the Torch Lake Railroad, Keweenaw Point, Michigan, enlarged 67 diameters. Fig. 8 is a portion of a thin section of the same sandstone, also enlarged 67 diameters, and drawn as seen between the crossed nicols, with the object of showing how the nucleal fragments and enlargements polarize together. The black lines on two of the grains in this figure indicate the positions of the elasticity axes. The black spaces are holes in the section.

[8] This is the layer described in the Wisconsin reports under the name of the Madison sandstone. The occurrence of crystal-faceted grains in the more siliceous and looser portions of this layer appears to be an all but universal phenomenon in Southern Central Wisconsin.

A more advanced condition of induration is met with in certain sandstones, which, while still showing to some extent the crystalline facets, have the secondarily deposited quartz areas more generally interfering with one another. This may be seen in much of the Huronian quartzite at Neebish, Saint Mary's River; Redstone, Minn.; and Devil's Lake, Wis.—at all of which localities may be seen rapid transitions from the loosest sandstone to the most compact and vitreous quartzite, as also in much of the Potsdam sandstone of the interior of Wisconsin, for instance the rock quarried at Grand Rapids, Black River Falls and Packwaukee. Fig. 1 of Plate III is drawn from a section of the vitrified crust of the St. Peter's sandstone of Arlington, Columbia County, Wisconsin. This crust, which is decribed somewhat fully on a subsequent page, is immediately below the surface without crystalline facets, the enlargements having interfered too thoroughly. But at a depth of one-fourth to one-half an inch the crystal facets begin to grow plentiful, until the loose sandstone is reached at the depth of about an inch or two, when every grain is furnished with the facets. The figure referred to shows one of the intermediate phases where there has been some interference, but crystal facets have been enabled to form in a number of places. The outlines of the nucleal grains are distinctly but not strongly marked. The brown filling material is oxide of iron.

A still more advanced stage of induration, but yet one which is still short of complete vitrification, is met with in those quartzites, which, while retaining something of a granular or arenaceous appearance, are yet without any of the crystalline facets, the interference of the secondary quartz areas having been general. An excellent instance of this is the sandstone from Gibraltar Bluff, Columbia County, Wisconsin. Much of a similar material occurs in the Huronian quartzites of the north shore of Lake Huron, of Marquette, Mich., and of Southwestern Minnesota. The Gibraltar Bluff rock is shown at Fig. 1 of Plate V, which represents part of a thin section, as seen in the polarized light, enlarged 35 diameters. A more arenaceous quartzite, but still one without crystal faces, is shown at Fig. 2, Plate III, which represents a thin section of the sandy Animikie quartzite of Portage Bay Island, Minnesota. The enlargement is 45 diameters, and the section is represented as seen in the polarized light. It will be noted that the enlargements of the grains are at times unusually broad.

In the most completely vitreous quartzites the arenaceous or granular appearance is entirely lost, the particles being fused into an apparently homogeneous mass, which appears both to the naked eye and under the microscope to be wholly composed of originally deposited, intricately interlocking areas of quartz. But closer study of the sections of such quartzites shows that, like those previously described, they are made up partly of fragmental material and partly of a secondarily deposited quartz, the interlocking areas of the latter being in large measure optically continuous with the original fragments, but also at times in part independent of them. The degree of intricacy of the interlocking of the areas of the secondary quartz will be found to vary greatly in different quartzites. At times these areas will meet each other along quite straight or only slightly curved lines, and again they will dove-tail into each other in the most intricate manner. As a type of the most completely vitrified quartzites, may be mentioned the "gannister" of Marquette, Mich., No. 22 of the list below. A thin section of this rock, as seen in the polarized light, and enlarged 31 diameters, is represented in the upper half of Fig. 1, Plate VI. It will be seen that the enlargements are often unusually broad and dovetail with each other somewhat intricately. Other vitreous quartzites are shown at Fig. 2, Plate V; Figs. 1 and 2 of Plate IV, and the upper half of Fig. 2 of Plate VI. The last three of these figures represent the red Animikie quartzite of Prarie River Falls, Minnesota. The rock of this place is described as being much of it sandy, but the specimen furnished us by the kindness of Prof. N. H. Winchell shows a quartzite in which but little of an arenaceous texture remains. Two of the figures are drawn from the section as seen in the polarized light, in order that the extent of the enlargements may be seen. It will be observed that in places they dove-tail quite intricately and the outlines of the very round nucleal fragments are rendered beautifully distinct by the fringes of oxide of iron.

The proportion of the infiltrated quartz which has crystallized independently of the original fragments varies very greatly in different cases. At times most of it, or even all, seems to occur in this form, the interstices between the much-rounded fragments being entirely filled with a secondary quartz in minute intricately interlocking areas, wholly independent of the original grains. As instances of rocks in which the independent deposition of quartz is the chief or only indurating material, may be mentioned the foot-wall rock of the Champion Mine, Michigan, much of the quartzite of the great range immediately east of Marquette, Mich., and the red quartzite of McClennan's Landing on the north shore of Lake Huron. From these extreme cases there are all phases down to the cases where all of the secondary quartz occurs as enlargements of the original fragments.

Thin sections of quartzites in which the fine interstitial quartz is present are not easily represented by figures. At the lower half of Fig. 1, Plate VI, an attempt is made to represent the Huronian quartz-schist from near Marquette. The section is drawn as seen in the polarized light and is enlarged 36 diameters.

In some cases where the enlargements of the original grains and the independently oriented quartz occur together, the enlargements present the appearance of fading out gradually into the finely interlocking interstitial material. This appearance arises from the fact that as the original fragment is receded from, less and less of the interstitial quartz is optically continuous with it, while more and more is separated out into relatively minute independent areas. It is thus evident that all of the interstitial quartz, including both that which is in independent areas and that which is oriented with the original fragments, has been deposited simultaneously, the crystalline influence of the fragment having lessened rapidly in power as the distance from the fragment increased. In those cases where all the interstitial quartz has been deposited independently of the original grains, the deposition went on too rapidly for those grains to exert their influence. The apparent fading out of quartz fragments also arises from another cause in the cases of certain argillaceous quartzites mentioned below.

In certain quartzites, that interstitial silica which has been deposited independently of the original fragments has in part separated out as chalcedonic or entirely amorphous silica. In fact, there is every gradation found in some of these cases from that quartz which is in independent areas of some little size, through more and more finely divided kinds, to that which is completely amorphous, presenting no perceptible effect when revolved between the crossed nicols. The amount of this cherty silica present varies between wide limits, in some cases predominating over the quartzose material, when the rock belongs more properly with the chert and chert-schists, which are considered separately below. The lower half of Fig. 2, Plate VI, shows the appearance in the polarized light of a thin section of a cherty Potsdam sandstone from Westfield, Sauk County, Wisconsin, enlarged 35 diameters. Most of the rock is taken up by the cherty matrix, but in this are buried quartz fragments of various sizes which have received small enlargements. The appearance of the upper side of the largest quartz grain of the figure suggests that it may have been dissolved away.

Commonly the quartz fragments of a sandstone or quartzite are fragments of single quartz individuals, but cases often occur where they are themselves complex, *i. e.*, made up of several or many differently oriented, interlocking areas. We have noted a number of cases where such complex grains have been enlarged, and in such cases the added quartz is divided off into areas oriented each with the part of the original grain with which it is in contact. This is very beautifully seen in the large grain of the upper half of Fig. 2, Plate VI, which is drawn from the red Animikie quartzite of Prairie River.

So far we have considered rocks that are purely quartzose, or nearly so, and it is in these that the enlargement of the quartzes is most striking, and generally most readily made out, but we have observed it also in a large number of rocks where the detrital material is composed more or less largely of other minerals than quartz, and even in cases where the quartz is a rather sparse accessory. A large part of the thickness of the original typical Huronian of Lake Huron is made up of gray to black fragmental rocks, grading from very coarse-grained kinds to those that are almost aphanitic. These rocks Logan called collectively, on account of their frequently containing pebbles of various kinds, by the name of "slate conglomerates." This name, however, covers kinds which differ much from each other. Some are almost pure quartzites, with a slight mixture of feldspathic fragments. In other cases the feldspathic fragments predominate, and in the finer kinds have often been decomposed to a clayey material, when the rocks become clay shales or slates. Most of the kinds, except those that are nearly purely quartzose, have undergone a considerable amount of metasomatic change, the principal result of which has been the production from the feldspars of a chloritic ingredient, whence chiefly the dark and often greenish hue presented by these rocks.

In all of the sections of these rocks examined by us evidence has been found of the secondary deposition of interstitial quartz. In a few cases this interstitial quartz has been deposited independently of the original quartz fragments, but oftener is more or less generally co-ordinated with them. Not only have the quartz areas of these rocks been enlarged, but the feldspar fragments also often present indications of similar enlargement.[9] The complex character of these rocks, the metasomatic alteration which they have undergone, their dark color, and the siliceous paste by which they have been permeated, place them among "greywackes,"[10] whilst the finer-grained and more fissile kinds are "greywacke-slates." These greywackes, which are, next to the quartzites, the most characteristic and important rocks of the type Huronian, are all "recomposed" rocks, and often, especially where the secondary quartz is abundant, and the alteration from feldspar to chlorite has progressed far, are not far in appearance, either macroscopically or microscopally, from true crystalline rocks, and would ordinarily be classed as metamorphic. Nevertheless they have undergone no other alteration than that which is involved in the secondary enlargement of quartz and feldspar particles, the metasomatic change of feldspar to chlorite, and the interstitial deposition of independently oriented quartz; and all of those changes are such as may be met with in the more recent and so-called unaltered formations. Indeed, we may say, setting aside those changes to be met within the immediate vicinity of the contact with eruptive materials, that in the typical Huronian, *i.e.*, that mapped by Logan as extending from the Saint Mary's to the Mississaugi River on the north shore of Lake Huron, there has been no other kind of alteration of sediments than this, the various greenstone beds of the series being taken as of eruptive origin.

Greywackes and greywacke-slates, with characters in each case of their own, but in general similar to those of the Lake Huron series, we have examined from the Animikie series of the region of Thunder Bay, and thence westward along the national boundary line, from the Huro-

[9] See infra, p. 27.

[10] Geikie's Text Book of Geology, p. 159.

nian of the Penokee region of Wisconsin, and from the folded slaty series of the region of Knife Lake on the national boundary line. All of these are plainly fragmental, being composed mainly of quartz and feldspar fragments, and permeated to a marked degree by a quartzose cement whose areas are always more or less generally optically continuous with the original quartz particles. A belt of rocks, composed of dark-colored sandstones and shales, which would come under Geikie's definition of greywackes and greywacke-slates, forms a prominent member of the Keeweenaw series between Keeweenaw Point and Bad River in Wisconsin, reaching a particularly large development in the region of the Porcupine Mountains. This is the belt which we have elsewhere described under the name of the Nonesuch Belt.[11] In many sections of this rock an interstitial quartz, occurring as enlargements of the original particles, is met with, and is particularly abundant in sections from that portion of the Porcupine Mountains known as the Iron River Silver Belt.[12] These greywackes, and particularly those of the silver belt, are no less metamorphic than the greywackes of the type Huronian, and yet they occur interstratified in a great thickness of unaltered sandstones. Moreover, they lie in that series many hundred feet above the latest of the great flows of eruptive material which characterize it, so that the alteration can in no way be attributed to igneous action.

Argillaceous rocks are not promising ones for the discovery of enlargements of quartz particles, and yet we have noted in them a number of instances of such enlargements, as, for example, in the cleaved slates of the Saint Louis River region of Minnesota, and in the Marshall Hill schists of the Upper Wisconsin Valley, in Central Wisconsin.[13] Mention has been made in a preceding paragraph of the peculiar way in which the enlargements of quartz fragments in certain quartzites are made to appear as if fading off gradually into the fine interstitial material. A somewhat similar appearance, but one which is evidently due to a quite different cause, is met with in these argillaceous rocks, in which the enlargements of the widely separated quartz fragments have enveloped, in the process of growth, portions of the clayey matrix.

In nearly all of the schistose areas of the Northwest which have been by us or other geologists referred to the Huronian, cherty rocks—that is, rocks more or less largely composed of a chalcedonic or amorphous silica—form considerable thicknesses. They are present in the Animikie series of the Thunder Bay region, in the folded slates of the region farther north, in the original Huronian of Lake Huron, in the iron-bearing series of the Marquette and Menomonee regions of Michigan, and in the Penokee and Wisconsin Valley regions of Wisconsin. At least some of the jaspers associated with the "jaspery iron ores" are of

[11] Copper-bearing rocks of Lake Superior. Monographs of the U. S. Geological Survey, Vol. v, pp. 220–224.

[12] *Loc. cit.*, p. 221.

[13] Geology of Wisconsin, Vol. IV, pp. 668, 681 to 683.

this nature. We are still engaged in a general study of these cherts, jaspers, etc., and are not yet prepared to give a systematic account of them. But there are several features that we have noted in regard to them that are of interest in the present connection. At times these cherts are for a considerable thickness wholly composed of chalcedonic silica, but in other cases they contain fragments of quartz, in smaller or greater quantities, up to a predominating amount. In such cases we have frequently noted that the quartz fragments are enlarged in the ordinary manner. These cherts seem, in part at least, to be of direct chemical origin, and the appearance in the thin sections is as if the quartz fragments had taken an enlargement of quartz simultaneously with the deposition of the mass of the amorphous silica. In these cherty rocks the enlargements of quartz fragments present the appearance of fading away gradually into the matrix material in a manner similar to that already noted in the case of certain quartzites, where the appearance has been explained by the lessening of the crystalline influence of the original particles, and the formation of more and more of independently oriented matter, as they are receded from. Here, however, we find a gradation all the way from the areas deposited so as to be optically continuous with the original quartz fragments, through a fine interlocking, independently oriented quartz, to the chalcedonic material.

There are many points as to the origin of these cherts which are yet obscure, chiefly because of the small amount of microscopic study given to them. We think, however, that it may be taken as certain that the Huronian cherts have in considerable measure originated in the same way as the cherts of the later formations. In the Potsdam sandstone, for instance, at a number of points in the region of the Upper Baraboo River, in Central Wisconsin, layers of sandstone are to be noted which are highly impregnated with chert, and in which at times the chert even predominates over the sand. Chert is ordinarily thought of as a characteristic of limestone formations, but the cherts of this region are wholly below and independent of any limestone formation. Evidently these cherty layers have been produced by the secondary deposition from solution of the interstitial cherty material, and they do not appear to differ, either as to the nature of the material or as to its origin, from some of the true Huronian cherts. These Potsdam cherty sandstones give interesting sections, in which the interstitial secondarily deposited material presents every degree of coarseness, from large areas optically continuous with the original quartz fragments to the finest, most completely non-polarizing amorphous silica.

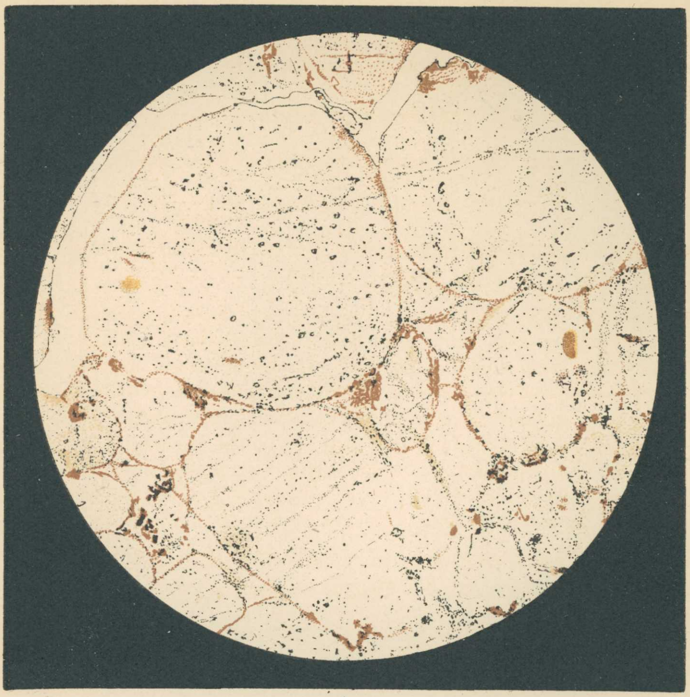
Our sections of true mica schists are not yet very numerous, but we have found unmistakable enlargements of quartz fragments in the mica-schist forming part of the "Lower Quartzite" of Brooks, north of the Michigamme mine, Marquette region, Michigan, and in the more quartzitic portions of the upper mica-schist member, Formation XXI, of the Penokee Huronian.[14] This member of the Penokee series is plainly the equivalent of the upper mica-schist member of the Marquette Huronian.[15] The latter mica-schist is finely displayed among the islands at the outlet of Michigamme Lake, where it is often plainly of an arenaceous appearance, but so far our sections have failed to prove the existence of secondary enlargements of quartz fragments in them, although what appears distinctly to be fragmental quartz is seen in these sections. The larger part, however, of the quartz present is fine and clear, so that it is difficult to determine whether it is wholly an originally deposited quartz or is a finely fragmental material, the particles of which are now so enlarged as to interlock.

A general fragmental appearance is not uncommon in the mica-schist sections that we have examined, while the presence, in some kinds at least, of very strongly marked and unmistakable sedimentary deposition bandings traversing the schistose or slaty cleavage directions is sufficient proof that in such cases the material is mainly of fragmental origin. But so far as our investigations have progressed we have only in a few cases been able to prove the enlargement of quartz fragments by secondary deposition. It seems probable, however, that in many cases where their existence cannot be proved the enlargements exist. In such cases we may suppose that they cannot be seen simply because of the absence of a bordering material or of roughened surfaces to the original fragments. None of the mica-schists above referred to are like those which approach the gneisses in character. The latter have often as a characteristic feature large flattened areas of quartz lying in the planes of foliation. We have not as yet examined any such rocks in this connection.

Below we give a list of the various localities of rocks in which we have discovered the secondary enlargements of quartz fragments. The induration of the rocks of these places is in most cases mainly due to the presence of these secondary enlargements, the remainder of the material being fragmental, but cases are included where, as explained above, the indurating silica has been separated out in part independently. The list does not represent nearly all of the sections in which this indurating quartz has been found. Often a number of sections from the rocks from one general neighborhood have been examined, but the locality is only referred to once. We have classified the localities (1) according to the general position of the rocks in the geological series; (2) according to geographical distribution; and (3) according to the lithological characters. Brief descriptive notes are added in each case.

[14] Geology of Wisconsin, pp. 145–149.

[15] Geological Survey of Michigan, Vol. I, p. 113. Geology of Wisconsin, Vol. III, p. 165.



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A. Hoen & Co. Lith. Baltimore.

THIN SECTION OF RED QUARTZITE

List of Localities.

HURONIAN ROCKS.

IN THE TYPICAL HURONIAN REGION OF LAKE HURON.

A.—*Vitreous Quartzites.*

1. Island two miles east of Thessalon Point, north shore of Lake Huron. (Logan's "3 a," "Grey Quartzite."[14])

A feldspathic quartzite, holding many granite pebbles and boulders. Rounded to angular fragments of quartz, orthoclase, and oligoclase, with a fine interstitial material, partly of the same nature and partly kaolinitic, make up most of the rock, but the induration is plainly due to secondary enlargements of the quartz fragments, the enlargements being narrow, and not interlocking intricately. In places the angularity and abundance of the feldspar fragments, the occurrence of granite fragments, including both feldspars and quartz, and the presence of the secondary enlarging silica, produce a rock which is macroscopically and microscopically similar in appearance to granite or gneiss. (Slides 1071 to 1079 inclusive.)

2. Islands 3½ miles northwest of Thessalon Point, north shore Lake Huron. (Logan's "3 c," "White Quartzite.")

A feldspathic quartzite. Quite intricately interlocking quartz areas make up the larger part of the rock, but the interlocking is plainly due to the enlargement of rounded fragments, whose outlines are here and there plainly to be seen. There is also much of a fine interstitial independently deposited silica, which here and there approaches very close to, if it does not reach, the amorphous form. (Slides 1183, 1184.)

3. Mainland, four miles northwest of Thessalon Point, north shore Lake Huron. (Logan's "3 c," "White Quartzite.")

A vitreous, white to brown quartzite conglomerate, in which the pebbles, 1 to 2 inches in diameter, are of white quartz and black chert, with rarer ones of red jasper. The matrix is composed of the same materials, along with fragments of feldspars. The induration has been chiefly by enlargement of the quartz fragments, among which are some originally complex. These have taken complex enlargements. The bounding lines of the original quartz fragments are only now and then perceptible. The larger pebbles of quartz do not seem to have taken any enlargements. There is also some fine independently deposited interstitial silica and a good deal of interstitial clayey material and flakes of chlorite, the latter probably a result of metasomatic change of the feldspars. (Slides 1185 to 1188 inclusive.)

4. Islands off east side Bruce Mine Bay, Lake Huron. (Logan's "3 c," "White Quartzite.")

A light-colored feldspathic quartzite, much like the last described, but with these differences: the quartz areas interlock much more intricately; the division lines between the original grains and enlargements are still more rarely visible, being plain in only two or three out of some twenty sections; the feldspars are much more abundant, and include microcline and plagioclase, as well as orthoclase. This rock has plainly received a larger quantity of siliceous cement than the last described. The abundance of feldspars, the presence of plagioclases, the intricate enlargements produced by secondary quartz, and the presence of much chlorite as a result of the alteration of the feldspars, all combine to produce a strong resemblance to some gran-

(16) See Atlas to Geology of Canada, 1863, Plate III, for Logan's subdivisions of the original Huronian.

itic rocks. The specimens are mostly taken from the neighborhood of some of the numerous dikes with which the rock is riddled, which may possibly have something to do with the large amount of siliceous cement and the consequent granitic appearance presented by this rock. (Slides 1191, 1192, 1194, 1196, 1197, 1201 to 1205 inclusive.)

5. North side of Campement d'Ours Island, Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

A red feldspathic quartzite, the feldspars including both orthoclase and plagioclase, the two together making up fully one-half of the rock. The quartz fragments are much enlarged, the enlargements interlocking with each other and with the feldspars somewhat intricately. There are present interstitially kaolin, chlorite, and oxide of iron, but only a very little fine secondary quartz. (Slide 1224.)

6. South side Campement d'Ours Island, Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

A feldspathic quartzite, the feldspars including both orthoclase and oligoclase, but not nearly so plenty as in the rock last described. The quartz fragments are very much enlarged, so as to interlock intricately. The lines of division between the enlargements and the original fragments are only rarely satisfactorily seen, some sections being quite without them. That the interlocking quartz areas of this rock are due to enlargement of quartz fragments would never be suspected but for their previous discovery in other similar rocks and in other parts of this same layer. Only a very small quantity of the interstitial quartz in this rock appears to have crystallized independently of the original fragments. (Slide 1226.)

A number of rocks on the west and south sides of Campement d'Ours, belonging with the same member of the series as the above, were examined, and all showed essentially the features above noted.

7. North shore of Lake Huron, two miles east of McClennan's Landing. (Logan's "3 f," "Upper Slate Conglomerate.")

A purple, vitreous, non-feldspathic quartzite, composed chiefly of rounded quartz grains, which have rarely, if ever, received any enlargement, and consequently do not interlock. Interstitially finely-divided secondary silica has been deposited, in part in an amorphous form. There is also a good deal of kaolinic material in the interstices. The presence of this material and also of a small quantity of iron oxide and the absence of enlargements give the sections of this rock just the appearance of those of an ordinary sandstone. Nevertheless it is much indurated, and the induration is plainly due to the independent secondary deposition of interstitial silica. (Slide 1233.)

8. McClennan's Landing, north shore of Lake Huron. (Logan's "3 g," "Red Quartzite.")

A light-red, non-feldspathic quartzite. This rock is a good deal like the last described, the induration being mainly due to the independently oriented interstitial silica, but the quartz fragments are, for the most part, somewhat enlarged. (Slide 1238.)

9. Two miles west of McClennan's Landing, north shore of Lake Huron. (Logan's "3 k," "Red Jasper Conglomerate.")

A white quartzite, made up chiefly of quite large quartz grains, all of which are more or less enlarged, though the bounding lines of the original fragments are only here and there perceptible. There is, however, not much interlocking of the quartz enlargements, there being a good deal of interstitial material in the shape of kaolin, muscovite scales, and finely-divided quartz. (Slide 1239.)

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A. Hoen & Co. Lith. Baltimore.

THIN SECTIONS OF SANDSTONE AND QUARTZITE.

10. Near the mouth of Echo River, Canada side of Lake George, Saint Mary's River. (Logan's "3 h," "Red Jasper Conglomerate.")

A conglomeratic quartzite composed chiefly of clear quartz pebbles, one-fourth to one-half inch in length, with rarer ones of red jasper. These are imbedded in a fine, much-indurated matrix, apparently composed of the same materials. Under the microscope the matrix is seen to be composed of finely-divided, perhaps sometimes amorphous silica, with kaolinic material and oxide of iron. The quartz fragments are enlarged, but never so much as to interlock with one another, and the outlines of the original grains are often imperceptible. Some of the large quartz areas appear to fade away into the fine matrix in the manner described on a previous page. This appearance is plainly due to the fact that, as the enlargement of the grain progressed, it became more and more difficult to thrust aside the clayey matrix, more and more of which was consequently included within the enlargements, more and more of the secondary silica at the same time departing from its allegiance to the original grain and depositing independently. (Slide 1242.)

11. North shore of St. Joseph's Island, Lake Huron. (Logan's "3 i," "White Quartzite.")

A gray, non-feldspathic quartzite. The induration is principally due to the enlargements of the original grains, which sometimes interlock closely, but in places there is a good deal of a fragmental matrix of kaolinic material, including muscovite scales, in which cases the grains sometimes appear to fade away into the matrix, as described in the preceding. The outlines of the original grains are often quite distinctly seen. (Slide 1228.)

12. East Neebish Island, St. Mary's River. (Logan's "3 i," "White Quartzite.")

A light gray to white quartzite. At times completely vitrified and without any trace of a fragmental appearance, but in other places a loose sandstone, with crystal faceted grains, there being every possible phase between those two extremes. In the thin section, the most completely vitreous kinds are found to be made up wholly of enlarged quartz fragments, there being none of the independently deposited interstitial silica or of any other interstitial material. The quartz areas interlock intricately, the outlines of the original fragments being everywhere strongly marked. In sections of the less completely vitreous kinds, a fine interstitial silica is to be seen in greater or less quantity. Some of the quartz fragments present the appearance of graduation into the matrix, due to the gradual change in the depositing silica from dependence upon the original fragments to independence of them. Fig. 2, Plate V, is drawn from the East Neebish quartzite. The arenaceous varieties of the East Neebish rock are noted below in another connection. (Slides 1019 to 1024, inclusive.)

13. Rocky islets in Saint Mary's River, northwest of Saint Joseph's Island, Lake Huron. (Logan's "3 i," "White Quartzite.")

These islands show a gray quartzite similar to that of Neebish Island. (Slides 1025, 1028.)

14. McDonald Township, six miles east of Saint Mary's River, Canada. (Logan's "3 i," "White Quartzite.")

A white, completely vitreous quartzite, entirely similar to the most vitreous phase of the Neebish quartzite. The outlines of the original fragments are everywhere very plain in this section. (Slide 1240.)

15. From near the mouth of Echo River, Canada side of Lake George, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

A completely vitreous quartzite, similar to that of Neebish Island, except in having a very small quantity of intrestitial kaolinic material. (Slides 1245, 1246.)

B.—*Schistose quartzites.*

16. Islands two miles southeast of Neebish Rapids, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

Light-gray, argillaceous, schistose quartzites, differing from the non-schistose quartzites above described in containing a very large amount of a clayey matrix, and in the schistose structure. The rather unusually large quartz fragments are wholly separated from one another by the matrix, and, as is generally the case when there is much of a clayey matrix, the enlargements are but slight. Some of the quartz fragments are complex, and appear to have received complex enlargements. (Slide 1031.)

C.—*Sandstones.*

17. East Neebish Island, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

Intercalated in and grading into the vitreous quartzite above described (No. 12) is a reddish, very coarse-grained, feebly indurated sandstone, each one of the grains being furnished with crystal faces from secondary enlargement. The crystal faces are in this case very much larger than in any other case that we have yet noted. Some of the grains, each a single quartz individual, reach as much as one-fourth inch in diameter, and have crystal faces of correspondingly large size, while half the mass of the rock is composed of grains which exceed one-sixteenth inch in diameter. Occasionally some of these grains are complex, but most of them are single individuals. The oxide of iron cement is very abundant, and the secondary enlargements of the grains have always between them and the original surfaces a heavy border of the iron oxide. Fig. 2, Plate II, represents one of these grains broken by hand from the rock, as seen in a balsam mounting enlarged 67 diameters. The crystal facets bounding the grain are not seen on this mounting, but only the rough, iron-stained surface of the original grain and the outlines of the pellucid enlargement. Fig. 1 of the same plate shows the positions of the crystal faces upon another grain, the positions of the faces having first been drawn in with the camera from a dry mounting, after which, without altering its position, the fragment was covered with balsam, and the kernel drawn in its position within the crystal. The very slight coherence of this rock as compared with the completely vitreous quartzite into which it grades within a few inches, is plainly to be attributed to the relatively coarse character of this rock, and to the supply of indurating quartz not having here been sufficient to fill out the large-sized interstices, and its having consequently developed crystalline faces. (Slide 1391.)

D.—*Graywackes.*

18. Palladreau Islands, north shore Lake Huron. (Logan's "3 d," "Lower Slate Conglomerate.")

A very dark greenish-gray, nearly black, fine-grained, compact rock, having an aphanitic matrix, in which are scattered minute particles of quartz and feldspar. Except for very sparsely scattered granite and porphyry pebbles, the appearance is more that of a very fine-grained porphyritic green-stone than that of a clastic rock. The clastic nature is, however, very evident in the thin section, which shows a ground-mass composed very largely of kaolin and chlorite, mingled with fine particles of feldspar and quartz, with more or less brown oxide of iron and magnetite.

The kaolin and chlorite are evidently the results of the alteration of the feldspathic portion of the matrix. Thickly scattered through this matrix are larger fragments of quartz and feldspar, between which and the particles of the matrix there is every gradation in size. The feldspars include both plagioclase and orthoclase. The rounded quartz fragments here and there show narrow enlargements, and also the gradual fading away into the matrix which is characteristic of rocks where there is much of a finely fragmental matrix. It is possible that some of the induration has been produced by the independent secondary deposition of fine silica, but it seems to be largely due in this case to the chloritic alteration of the matrix. (Slide 1032.)

19. From the mainland, four to five miles east of Campement d'Ours Island Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

The specimens collected from the "Upper Slate Conglomerate," as exposed along the north shore of Lake Huron, between the French Islands and Campement d'Ours, are chiefly of rocks nearly allied to the last described, though including also some true vitreous quartzites, some of which have been above alluded to, and between which and the predominating graywackes there is a complete gradation. A part of the rock is very highly conglomeratic, with pebbles of granite, felsitic porphyry, and jasper, but in other portions the pebbles are wanting, or are very sparse and small. These present a great variation in coarseness, the finest kinds being contorted clay-slates, but they are all composed of essentially the same materials as noted in the slate conglomerate from the Palladreau Islands above described, like which they are all dark colored from the presence of much chlorite. Enlargements of the quartz fragments are generally to be made out, and, at least in those kinds which are more distinctly quartzitic, much of the induration is due to these enlargements. Induration seems also to have been produced by the deposition of a fine interstitial quartz, and a chalcedonic or amorphous silica. The feldspar grains, including both orthoclase and plagioclase, also often present an appearance which suggests that they too have been enlarged by second growths. Sharp lines of division between the supposed enlargements and the original nuclei, as seen so often in the case of enlarged quartz fragments, we did not satisfactorily make out; but in many instances the outer portion of the grain is relatively undecomposed and free from inclusions, as compared with the nuclei. This appearance, taken together with the fact that secondary enlargements of feldspar fragments have been proved to occur in certain Keweenawan sandstones, lead us to believe that we have them here also.[17] All of these rocks carry a very large amount of a green chloritic mineral, which has plainly been produced from the feldspars by a metasomatic process.

These graywackes are all typically "recomposed" rocks, and while plainly fragmental, are no more so than many kinds that are classed as crystalline schists. The enlargement of the quartz and feldspar grains, the production of abundant chlorite, the presence of much feldspar, and the secondary deposition of an interstitial silica certainly would have to be carried but little further to give us a rock in which it would be exceedingly difficult to detect the presence of the detrital material. (Slides 1215 to 1218.)

IN THE IRON-BEARING SERIES OF MARQUETTE, MICH.

A.—*Vitreous quartzites.*

20. Quartzite range, south of Marquette, near shore of Lake Superior, (N.W. ¼, Sec. 6, T. 47, R. 24 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A bright-red vitreous quartzite, composed almost wholly of interlocking areas of quartz, which are all taken to have been produced by the enlargement of fragmental

[17] See Part II of this bulletin; also American Journal Science, May, 1884, p. 399.

nuclei, since in a number of them the outlines of these nuclei are plainly recognizable. The red color of the rock is due to the presence of a small quantity of red oxide of iron. (Slide 1009.)

21. Shore of Lake Superior, two and a half miles southeast of Marquette, (SE. ¼, Sec. 36, T. 48, R. 25 W., Michigan). (Brooks's "Formation V," "Lower Quartzite." [18])

This is the locality of the unconformable contact of the Lake Superior sandstone and Huronian quartzite, made classical by Foster and Whitney. A white, strongly vitreous quartzite. The induration appears to be almost wholly due to the interstitial deposition of fine quartz, the original outlines of the quartz fragments coinciding for the most part with the outlines as now seen of the individual areas. There is a little kaolinic interstitial material. (Slide 1013.)

22. Gannister quarries, north and south sides of Carp River, near Marquette (Secs. 35 and 36, T. 48, R. 25 W., Michigan.) (Brooks's "Formation V," "Lower Quartzite.")

Light-gray, highly translucent, completely vitrified quartzites. These rocks are composed almost wholly of quartz, there being a very minute quantity in some of the interstices of kaolinic material. Although coming from the same vicinity and layer as the rock last described, and not differing very much from it microscopically, we have in these rocks a case where the induration and vitrification are wholly due to secondary enlargement of the original fragments. The outlines of the nucleal grains are usually very distinct, and the enlargements interlock quite intricately, so that, as seen in the polarized light, this rock seems to be completely made up of originally deposited areas of quartz. In some portions the layers of the gannister quarries are quite thin-bedded. In sections from some of these thin-bedded portions in the quarries on the north side of Carp River the quartz areas are all elongated in a common direction, the lengths of the areas being usually great in proportion to their widths. These elongated grains of quartz interlock and overlap one another just as do the quartzes of many mica schists and gneisses. This arrangement in the present case is perhaps partly due to the pressing into this position of originally oblong areas, but it seems also to be due in part to the elongation of the quartzes by secondary enlargements. Fig. 1, Plate VI, represents a thin section of the non-schistose portion of this rock. (Slides 1012, 1479.)

23. Northwest corner of Teal Lake, Michigan. (Brooks's "Formation V," "Lower Quartzite.")

A gray and brown vitreous quartzite. The same ledge shows also greenish, chloritic quartz-schists. In the sections of the non-schistose portions the induration is seen plainly to be the result of the interlocking of the enlargements of the original clastic particles, whose smoothly-rounded outlines are strongly marked. The cementing silica has, however, not all of it united with the original grains, some of it having separated out interstitially in minute interlocking areas. The peculiar appearance of gradation of a quartz area into fine interstitial quartz, due to the diminution outwards in power of the crystalline influence of the nucleal grain, is here noticed also. The more schistose portions of the rock of this ledge are seen in the thin section to carry a larger proportion of kaolin, and to have but little of the indurating silica co-ordinated with the original fragments, most of it having been deposited independently of them. (Slide 988.)

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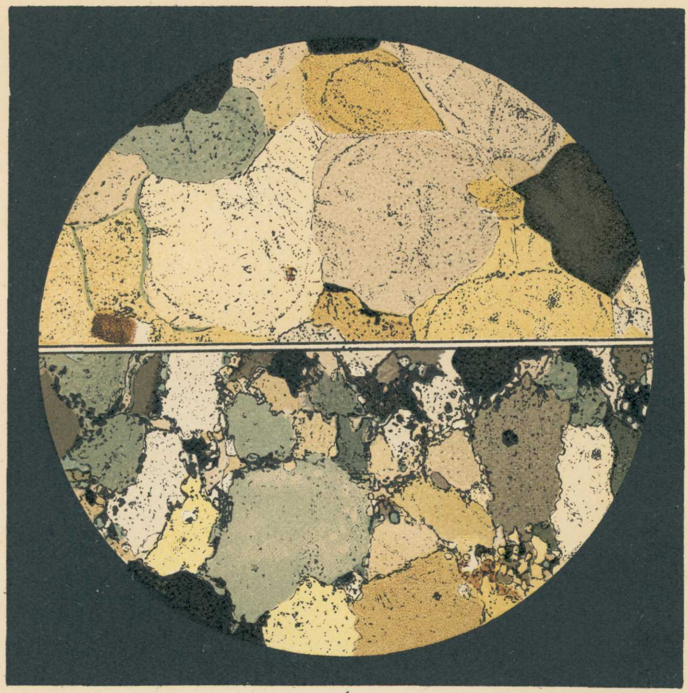
[18] Geol. Sur. of Mich., Vol. I, p. 83.



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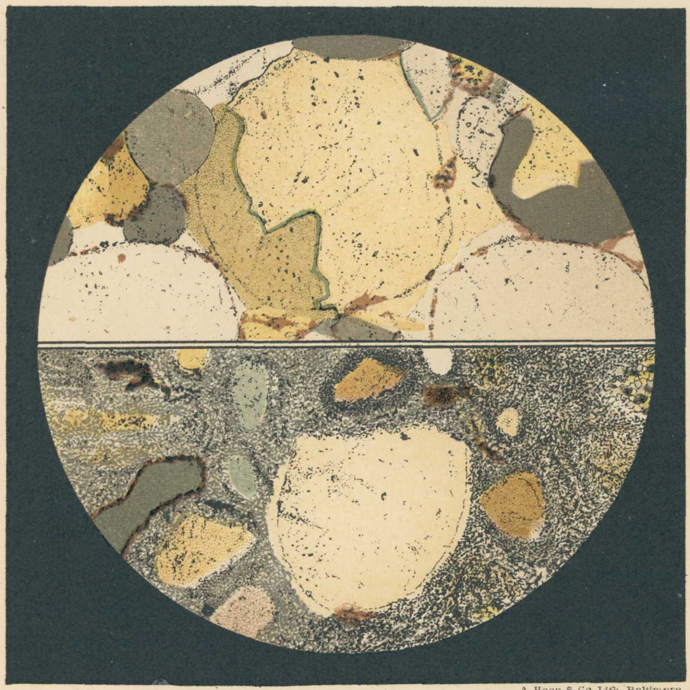

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THIN SECTIONS OF QUARTZITES.

24. Hanging wall of Palmer Mine, Michigan. (Brooks's "Formation V," "Lower Quartzite.")

A dark-gray, conglomeratic quartzite. The numerous, large-sized quartz fragments of this rock, some of them simple, some of them complex, are buried in an abundant matrix, which is composed of finely-divided quartz mingled with amorphous or chalcedonic silica, the latter at times predominating, along with kaolinic material, flakes of muscovite and chlorite, and of oxide of iron. The quartz fragments are often angular, but there is no evidence that the angularity is due to secondary enlargements of rounded grains. The induration seems to be wholly due to the independently deposited interstitial silica. (Slide 973.)

25. Hanging wall, Saginaw Mine, Negaunee District, Michigan. (Brooks's "Formation XIV," "Upper Quartzite.")

A very dark-colored, conglomeratic quartzite, the pebbles partly of clear quartz and partly of red and black jaspery or cherty material. The rock is very much indurated, the induration being chiefly due to the independent deposition of interstitial quartz and of some amorphous silica, there being but few and small enlargements of the quartz fragments. Oxide of iron is very abundant in the matrix, which includes also some kaolinic material and muscovite scales. (Slide 1457.)

26. Hanging wall, Spurr Mine, Michigamme District, Michigan. (Brooks's "Formation XIV," "Upper Quartzite.")

A highly vitreous, dark-gray, conglomeratic quartzite, mostly made up of large, clear, often interlocking quartz areas, which are in many cases plainly, and inferentially always, due to the enlargement of fragments. A few biotite flakes, often altered into chlorite, as also particles of muscovite, microcline, and orthoclase, are contained. Within six feet across the strike this clear, vitreous quartzite passes into the chlorite schist, which carries the well-known chlorite pseudomorphs after garnet. There is a complete variation from one rock to the other within this distance. (Slide 1279.)

B.—*Quartz-schists.*

27. Quartzite range, south of Marquette, near shore of Lake Superior (N. W. ¼, Sec. 1, T. 47, R. 24 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A red, dolomitic quartz-schist. This rock grades within a few feet into the red, non-schistose quartzite described above as No. 20, and in another direction, within an equally short distance, into a clay slate, with strong transverse cleavage. The thin section shows quartz grains imbedded in a fine matrix. The quartz grains often show strongly marked secondary enlargements. The matrix contains some little kaolinic matter and some fine quartz, but appears to be chiefly made up of a finely crystalline dolomite, which is to be regarded as of a secondary nature. The red color is due to a minute quantity of iron oxide. (Slide 1007.)

28. North of Michigamme Mine (N. W. ¼, N. W. ¼, Sec. 20, T. 48, R. 30 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A dark- and light-banded quartz-schist, the light-colored bands being vitreous and quartzitic, the dark-colored ones being much finer and more clay-slate-like. There is a tendency to transverse cleavage, especially in the dark-colored bands. In the thin section the light-colored bands are seen to be composed mainly of worn grains of quartz, which have often been enlarged, and sometimes so much so as to interlock quite deeply. An interstitial material is present, composed of very fine quartz, with biotite and kaolin scales, with a little chlorite and iron oxide. In sections of the dark-colored bands this matrix material becomes predominant. (Slides 1284, 1285, 1286.)

C.—*Mica-schists.*

29. North of Michigamme Mine (N. W. ¼, N. W. ¼, Sec. 20, T. 48, R. 30 W. Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A very fine-grained schist, strongly marked with very thin bands of sedimentary deposition, and exhibiting an imperfect slaty cleavage. Closely resembles much of the slate exposed along the Saint Louis and Mississippi Rivers, Minnesota, and grades into the rock last described, the only difference being that here the finer material predominates. In the thin section this resemblance is borne out, and the rock is seen to be composed as the matrix of No. 28. Some of the minute quartzes have distinctly been enlarged from fragmental particles. Crystals of garnet occur very sparsely scattered through the section. It is difficult to say how much of the fine quartz of this rock is the result of crystallization *in situ*, and how far the result of the enlargement of fragments. (Slide 1289.)

D.—*Sandstone.*

30. Short distance north of the foot-wall of Spurr Mine, Michigamme, District, Michigan. (Brooks's "Formation XII.")

A fine-grained, saccharoidal, very friable, white sandstone, the grains being provided with crystal faces. Certain bands, one-eighth to one-fourth of an inch wide, carry much magnetite. The sand crumbled from the rock by hand shows, in a balsam mounting, that each one of the faceted grains has a rounded fragment as a nucleus. It is only with a particular disposition of the light that the outlines of the original grains can be detected, so clear are both the nuclei and the enlargements. The crystal terminations are generally both present. See Fig. 3, Plate II. (Slides 1274, 1433, 1434.)

FROM THE IRON-BEARING SERIES OF THE PENOKEE REGION, WISCONSIN.

A.—*Vitreous quartzites.*

31. Near Penokee Gap, Ashland County, (N. W. ¼, Sec. 14, T. 44, R. 3 W., Wisconsin.) ("Formation III" of the Penokee series, "Siliceous Schist.")[19]

A greenish, vitreous quartzite, composed almost wholly of intricately interlocking quartz areas of some size, each one of which has, however, plainly been enlarged from a fragmental nucleus. Chlorite in small particles forms the only other ingredient. (Slide 1402.)

32. Gorge of Tyler's Fork, Ashland County (S.E. ¼, N.E. ¼, Sec. 33, T. 45, R. 1 W., Wisconsin). ("Formation III.")

A greenish, vitreous quartzite, closely like the rock last described, except that the induration, though chiefly, is not wholly due to the enlargement of the original fragments, there being present quite a quantity of a finely divided interstitial quartz. The chlorite, besides occurring in bunches, is noticed also to occur in films around the outlines of the nucleal grains of the quartz areas. (Slide 2094, Wisconsin survey series.)

[19] For the stratigraphy of the Penokee series, and the numbers given to its subordinate members by R. D. Irving, see Geol. of Wis., Vol. III, p. 104. For a description of Formation III throughout its extent, see the same, pp. 111–118.

33. Bad River, Ashland County (S.W. ¼, N.W. ¼, Sec. 11, T. 44, R. 3 W., Wisconsin). ("Formation XV."[20])

A very dark-gray feldspathic quartzite, composed of angular quartz and partly kaolinized feldspar fragments (the former often slightly enlarged) imbedded in an abundant matrix composed largely of the same materials, with a good deal of a blackish iron oxide in fine particles. As is usual where there is much of a fine fragmental or clayey matrix, the quartz fragments appear to merge into the matrix. (Slide 1496, Wis. sur. series.)

34. Near Penokee Gap (west line N.W. ¼, Sec. 11, T. 44, R. 3 W., Wisconsin). ("Formation XIX."[21])

A very fine-grained, dense, black, vitreous quartzite. Quartz in minute particles is the most abundant ingredient. Much of it appears clearly to be of a clastic origin, and the grains have often received secondary enlargements. Biotite in abundant, minute, brown scales; fragments of feldspar, pyrite, and brown iron oxide are the remaining ingredients. (Slide 1113.)

B.—*Quartz-schists.*

35. The gorge of Tyler's Fork, Ashland County (N.E. ¼, Sec. 33, T. 45, R. 1 W., Wisconsin). ("Formation III.")

A greenish-gray, vitreous quartzite, very clearly resembling No. 28 of this list. Quartz, in relatively large, interlocking areas, composes fully three-fourths of the section, each area having a distinctly marked, nucleal fragment. The enlargements of these fragments are often unusually wide, and the interlocking at times quite intricate. A little, finely-divided quartz is present in the interstices. Chlorite occurs in large rounded areas, which are taken to have resulted from the decomposition of feldspar fragments in films and patches between the quartz areas, and in films, following the outlines of the original grains, thus taking the place more usually occupied by iron oxide, which is, however, also present to some extent here. (Slide 1111.)

36. South line Sec. 27, T. 45, R. 2 W., Ashland County, Wisconsin, ("Formation XXI."[22])

A light-gray, fine-grained quartz-schist. Rather sparsely scattered fragments of quartz and feldspar, the former the most abundant, are scattered through a matrix composed of the same materials, with more or less kaolin, muscovite, chlorite, and iron oxide, in fine particles. The quartz fragments are often distinctly enlarged. (Slide 1113.)

C.—*Mica-schist.*

37. West line S.W. ¼, Sec. 2, T. 44, R. 3 W., Ashland County, Wisconsin. ("Formation XXI," the great mica-schist at the top of the series.)

A light-gray, very fine-grained, quartzose mica-schist. Quartz in closely fitting areas, in many of which a nucleal fragment may be recognized, is the chief constituent. There is also some fragmental orthoclase. The mica (biotite) lies between the quartz areas, and along with it there is often some brown oxide of iron. (Slide 2006, Wis. sur. series.)

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[20] Geol. Wis., Vol. III, p. 142.

[21] Geol. Wis., Vol. III, p. 144.

[22] Geol. Wis., Vol. III, pp. 145–149.

D.—*Graywacke and graywacke-slate.*

38. Tyler's Fork (N.E. ¼, Sec. 28, T. 45, R. 1 W., Ashland County, Wisconsin). ("Formation XVII."[23])

A very dark-gray, fine-grained rock, similar macroscopically and microscopically to No. 33 of this list, differing only in the larger proportion of the feldspathic and clayey material. Many of the quartz grains are distinctly enlarged, and present the common appearance of merging into the matrix. The decomposed feldspar fragments have about them often borders of a fresh feldspathic material, an occurrence suggesting that they too have received secondary enlargements. (Slide 2104, Wis. sur. series.)

E.—*Arenaceous quartzite and sandstone.*

39. Penokee Gap, Ashland County, Wisconsin, (N.E. ¼, N.W. ¼, Sec. 14, T. 44, R. 3 W., Wisconsin). ("Formation II."[24])

A milky-white, arenaceous or semi-vitrified quartzite. Except some few minute particles of brown oxide of iron, the slide shows nothing but quartz in closely fitting, sometimes interlocking areas, within many of which may be seen the outlines of the nucleal fragments. The slide is evidently from one of the more vitrified portions, the rock being quite irregular in the degree of induration. (Slide 1110.)

40. Mount Whittlesey, Ashland County (N.W. ¼, N.W. ¼, Sec. 16, T. 44, R. 2 W., Wisconsin). ("Formation II.")

A very fine-grained, white, indurated sandstone, closely like the last rock described, except that the enlargements of the grains are very frequently furnished with crystal faces, as may be seen both in the thin section and in the balsam mounting of sand crumbled from the rock. This is evidently a common peculiarity of this layer in the Penokee series, since hand specimens from different localites are made up of sparkling grains. There is often a very abrupt transition from the highly arenaceous to the strongly vitrified phase. (Slides 1406, 1465, 1482.)

IN THE SLATES OF THE SAINT LOUIS RIVER, MINNESOTA.

41. Knife Falls, Saint Louis River, Minnesota.

A fine-grained, light-gray, highly argillaceous schist. Minute fragments of quartz, orthoclase, and oligoclase, the first-named often with small enlargements, are buried in a fine matrix, composed partly of the same materials and partly of kaolin, with some chlorite.

42. Near Mahtowah, Minnesota.

An arenaceous schist, closely resembling the last described, both macroscopically and microscopically, except that it is somewhat coarser grained. The quartz fragments are often enlarged. (Slide 766.)

43. Saint Louis River, near Thompson, Minnesota.

A very dark-gray, fine-grained graywacke. The thin section shows the rock to be composed much like the last two described, except in containing a larger quantity of feldspar fragments, and in having a larger proportion of chlorite in the matrix. The quartz fragments are often distinctly enlarged.

These rocks are all somewhat nearly allied to the graywacke-slates of Lake Huron. They are, however, whilst fine-grained, only the coarser phases of the great slate formation in which they occur, the predominating phases of which are true-clay slates

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[23] Geol. Wis., Vol. III, p. 142.
[24] Geol. Wis., Vol. III, p. 108.

and a very fine-grained, shining mica-slate, in which the proportion of decomposed feldspar detritus is often very large, and the quartz fragments are so minute that if any secondary enlargements occur they are very difficult of detection. The whole series is affected by a very strong transverse cleavage, the fine bands of sedimentary lamination being at the same time often most beautifully preserved. (Slide 761.)

IN THE QUARTZITE FORMATION OF THE BARABOO REGION OF WISCONSIN.

A.—*Vitreous quartzites.*

44. Caledonia, Columbia County, Wisconsin.

A grayish-white quartzite conglomerate, the pebbles being of white quartz and of small size. In the thin section quartz fragments of some size, often showing distinctly secondary enlargements, are buried in a finer matrix, chiefly of the same material, some of which may be fragmental, but much of which appears to be originally deposited material. (Slide 729.)

45. Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

Dark purple, vitreous, close-granular quartzite, made up almost wholly of interlocking areas of quartz, each one of which has been produced by the enlargement of a fragmental nucleus whose outline is always strongly marked by oxide of iron. The lines along which the interlocking areas of quartz join are peculiarly jagged. There is also present some of a fine, independently deposited interstitial quartz. (Slide 745.)

46. Freedom, Sauk County, Wisconsin.

A pinkish white, very close-grained, vitreous, translucent quartzite. The thin section is made up entirely of irregularly outlined, interlocking, angular areas of quartz, all of which have evidently been formed by the enlargement of fragmental nuclei, the outlines of which, however, are usually very faintly marked. While plainly composed in the main of detrital material, this rock, but for the discovery that these enlargements exist in other quartzites, would undoubtedly be taken as made up entirely of quartz crystallized *in situ*. (Slide 744.)

47. Westfield, Sauk County, Wisconsin.

A pinkish, vitreous, translucent quartzite, composed chiefly of interlocking quartz areas, the outlines of the original fragments being generally very distinctly marked. The enlargements are usually not broad. There is a small quantity of fine interstitial quartz which appears to have been deposited *in situ*.

B.—*Quartz-schists.*

48. Lower Narrows of the Baraboo River, Sauk County, Wisconsin.

A yellowish-white, granular, argillaceous quartz-schist, composed in about equal proportions of a fine clayey matrix, and of rounded fragments of quartz with some of feldspar. The matrix includes also some fine quartz. The quartz fragments show the usual small enlargements and appearance of fading into the matrix, so often noted above as characteristic of clayey quartzites. (Slide 735.)

49. Ableman's, Sauk County, Wisconsin.

A dark-grayish, vitreous quartz-schist, made up chiefly of enlarged quartz grains, elongated in a common direction, whence the schistose structure. There is a minor quantity of fine interstitial quartz. (Slide 748.)

50. Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

Pink, fine-grained, quartz-schist, made up chiefly of grains of quartz, with their longer axes lying in a common direction, each enlarged from a nucleal fragment.

One-fourth of the rock is made up of a fine filling material, which is about equal parts of fine quartz and kaolin. (Slide 746.)

C.—*Sandstone.*

51. Devil's Lake, Sauk County, Wisconsin.

The larger portion of the quartzite in the Devil's Lake region is without arenaceous appearance, but now and then a tendency to an arenaceous appearance is notable, and occasionally small areas are met with where the rock is only a slightly indurated or even a quite loose sandstone. The transition from friable sandstone to the most indurated quartzite is quite abrupt. The present slides consist of a balsam mounting pulverized from one of the slightly indurated portions. Each rolled grain of sand is seen to be surrounded by a secondary border of limpid quartz, on which, however, crystal faces are not to be observed, the interference having been too great. (Slides 820, 821.)

IN THE QUARTZITE FORMATION OF SOUTHERN MINNESOTA.

A.—*Vitreous quartzites.*

52. Redstone, Nicollet County, Minnesota.

In southwestern Minnesota, and westward in Southeastern Dakota, as far as the James River Valley, are areas of a sandstone and quartzite formation, which evidently underlies all of this region, the exposures being detached from one another by the overlying Cretaceous and Quaternary formations. Unfortunately, the next newer formation with which it is seen in contact is the Cretaceous, so that stratigraphical proofs of its geological position are wanting. It is contrasted so completely with the Potsdam formation of the Mississippi Valley that there can be no question of its inferior position. So far all who have examined it of late years are agreed. Professor Winchell, if he is rightly understood by us, is disposed to regard it as the equivalent of the lower portion of the copper-bearing series. Certain of the reddish, more argillaceous, and more sandy parts of the formation are often much like some of the red sandstones of the copper series, although the similarity does not hold on closer inspection. In its quartzitic portions the formation is almost identical in character with the Huronian quartzites of the Baraboo region of Wisconsin. In its more argillaceous portions, also, it approaches very nearly the argillaceous members of the series of the Penokee region, and the pipestone-bearing quartzites of Barron County, Wisconsin. These resemblances, the evident considerable thickness of the series, and the differences between it and the Keweenawan rocks leave little doubt in our minds of the correctness of the position taken by those who would refer it to the Huronian. It may be said that much of the quartzite of this region is near to much of the quartzite of the Huronian of Lake Huron.

At Redstone the transitions from argillaceous, reddish sandstone to completely vitrified, brick-red to purple quartzite, and from these again to completely loose sandstones, are frequent and abrupt. In places, over considerable areas, the appearance is as if the rock at higher levels had been vitrified by exposure. But in the railway cutting it is seen that the vitreous quartzites are not restricted to the exposed portions, but are interstratified with, and arranged in irregular areas in, an entirely unindurated crumbling sandstone. The peculiarly irregular distribution of the induration, and the abrupt transitions from indurated to non-indurated material, suggest the possibility of its production by the descent along joints and the spreading thence through the layers of a silica-bearing solution. The thin sections of the completely vitrified quartzites of this place show the outlines of the original fragmental grains strongly marked by borders of oxide of iron. In the main the fragments are simple, but at times they are composed each of several interlocking quartz areas. All of these fragments have been enlarged, the simple ones in the usual manner and the complex ones into larger complex areas. The enlargements at times interlock, but in other portions of the sections interstices are left between them, which have been filled by an independently deposited silica, a portion of which is chalcedonic or amorphous. (Slide 1376.)

53. Near New Ulm, Nicollet County, Minnesota.

A fine conglomerate, forming the matrix of a boulder conglomerate composed of white quartz pebbles, imbedded in a still finer matrix of fine quartz, kaolin, and oxide of iron. The quartz fragments were in the main originally complex, but have been slightly enlarged. (Slide 1373.)

54. Delton, Cottonwood County, Minnesota.

A pinkish, glassy quartzite. The thin sections show essentially the same characters as No. 52 of this list. Some of the interstitial material of these rocks is fibrous, chalcedonic silica arranged radially about some of the complex grains of quartz. (Slides 1380, 1381, 1382.)

55. Mound Creek, Germantown, Cottonwood County, Minnesota.

An arenaceous, gray quartzite. The thin sections resemble those of the immediately preceding numbers, except that the induration has not proceeded so far, the enlargements of the grains not having commonly interlocked. There is much of a fine quartzose matrix. (Slide 1383.)

B.—*Sandstone.*

56. Redstone, Nicollet County, Minnesota.

A fine-grained, somewhat indurated, red, argillaceous sandstone. Fragments of quartz, partly simple, partly finely complex, the former often enlarged, are buried in a matrix of red iron oxide, clayey material and fine quartz. (Slide 1375.)

57. Redstone, Nicollet County, Minnesota.

One end of the specimen is a purple vitreous quartzite, like No. 52; the other a loose sandstone, with the grains faceted from secondary enlargement. We have, then, in this specimen the two extremes of the process of induration. (Slides 1377, 1378.)

IN THE ANIMIKIE SERIES OF NORTHERN MINNESOTA AND THE THUNDER BAY REGION OF LAKE SUPERIOR.

A.—*Vitreous quartzites.*

58. Prairie River Falls, (Sec. 34, T. 56, R. 25 W., Minnesota).

A red, vitreous quartzite, closely resembling much of the red quartzite of Southern Minnesota (*e. g.*, No. 54 of this list); also the red quartzites occurring in the Marquette (*e. g.*, No. 20) and Baraboo Huronian regions (*e. g.*, No. 47). The induration has been entirely produced by the enlargement of very much rounded fragments, whose outlines are beautifully marked in the thin section by lines of red and brown oxide of iron. The enlargements have often very intricately interlocked. Rutile needles are plentiful in the original fragments, coming up often quite to their outlines, but are altogether absent from the enlargements. There is no other mineral of importance present. The quartz fragments are usually simple, but are occasionally made up of two or more interlocking quartz areas. Figs. 1 and 2, Plate IV, magnified 39 diameters, represent portions of this rock in the ordinary and polarized lights, so that the present and original extents of the quartz areas may be readily seen. See also Fig. 2, Plate VI., upper half. (Slides 1088, 1089.)

59. Wauswaugoning Bay, Lake Superior, Minnesota.

A light-gray, vitreous quartzite. Angular quartz areas, each plainly enlarged from a nucleal grain, and often interlocking, make up most of the rock. There are also present fragments of feldspar and fragments made up of very minute interlocking quartz areas. Chlorite is present in the matrix, which appears to be in part composed of quartz deposited *in situ*. (Slide 413.)

60. Pigeon Point, Lake Superior, Minnesota.

A very dark-gray, nearly black, compact, very fine-grained, vitreous quartzite. Consists of angular quartz areas, plainly enlarged from fragmental nuclei, whose outlines are often visible, with some fragments of feldspar (both orthoclase and plagioclase), imbedded in a matrix made up of minute interlocking quartz areas, chlorite and biotite flakes and abundant small round grains of a brightly polarizing, colorless mineral, which is nearer in appearance to the sahlite variety of augite than to anything else with which we are familiar. This rock is very near to those described as vitreous graywackes, the only difference being in its greater richness in quartz, and highly vitreous character. It is also very close, indeed, to the more quartzitic phases of the "slate-conglomerates" of Lake Huron, and is quite as completely a "crystalline" rock as anything except the greenstones to be found in the type Huronian of Lake Huron. It is a type of rock which is largely concerned in the make-up of the Animikie series. It is directly interstratified with arenaceous quartzites or even sandstones. (Slide 423.)

B.—*Arenaceous quartzites.*

61. Portage Bay Island, Minnesota, coast of Lake Superior.

The light-gray, fine-grained arenaceous rock of Portage Bay Island is often little more than a slightly indurated sandstone, but in places it becomes a decided quartzite, and though always somewhat more arenaceous, gives sections which resemble very closely those of No. 59 of this list, the induration being merely not quite so strong. The outlines of the original fragments are beautifully distinct, and the enlargements are very broad. There is some calcite present in the matrix. (See Fig. 2, Plate III.) (Slides 402, 403.)

C.—*Vitreous graywackes.*

61. South side of Rove Lake, Minnesota (N.E. ¼, Sec. 28, T. 65, R. 1 E. Minnesota).

A fine-grained, dark-gray, much indurated rock, with conchoidal fracture. This rock differs from No. 60 in its larger content of feldspathic and chloritic material. It may be taken as the type of the rock which forms the larger part of the Animikie series. The quartz is the principal mineral and occurs in three phases: (1) in simple fragmental grains, always showing some secondary enlargements; (2) in complex fragments, which are also occasionally enlarged; (3) as an interstitial material in minute interlocking areas. The feldspar fragments include orthoclase and plagioclase, and are very plentiful, often closely interlocking with the enlarged quartzes. Some kaolinic material in the matrix probably represents decomposed feldspars. Some chlorite is also present in the matrix. The rock is fully as "crystalline" as anything in the original Huronian, to the graywacke-slates of which it is closely comparable, especially to the more quartzitic phases of those rocks. It is still closer to some of the quartzitic phases of the slate series of the Saint Louis River (*e. g.*, No. 43) and of the great series of folded schists of the Knife and Kingfisher Lake region on the national boundary. (Slides 1346, 1347.)

63. East end of Mountain Lake (S.W. ¼, S.W. ¼, Sec. 13, T. 65, R. 2 E., Minnesota.)

A lighter-colored rock than No. 62, but otherwise identical with it. (Slide 1350.)

64. Partridge Falls, Pigeon River, Minnesota.

A feldspathic quartzite or vitreous graywacke, very close to No. 62, differing only in having less interstitial material, and, consequently, more thorough interlocking of the enlarged quartz areas with each other, and with the feldspar particles. (Slides 1181, 1328.)

65. South side of Clear Water Lake (near center of Sec. 27, T. 65, R. 1 E., Minnesota.)

Differs from No. 62 only in being finer grained, being otherwise identical with it, macroscopically and microscopically. (Slide 1178.)

66. East side of Thunder Bay, Canada.

A dark-gray rock, near to No. 62, except that it is finer grained and is more argillaceous. The thin section shows a larger quantity of kaolinic interstitial material than No. 62, and a larger proportion of chlorite. The usual enlargements of the quartz fragments are found. (Slide 432.)

D.—*Argillaceous graywacke.*

67. Grand Portage Falls, Pigeon River, Minnesota.

A fine-grained, light-greenish-gray, argillaceous, not greatly indurated rock. The thin section is near to that of No. 62, but shows a very much larger amount of a clayey matrix, and less of a siliceous cement. The quartz fragments are often enlarged. (Slide 1355.)

IN THE FOLDED SCHIST OF THE NATIONAL BOUNDARY LINE, NORTH OF LAKE SUPERIOR.

68. Kingfisher Lake (S.W. ¼, S.E. ¼, Sec. 23, T. 65, R. 6 W., Minnesota.

A dark-gray, fine-grained, vitreous graywacke or quartzite, somewhat coarser grained than No. 62 of this series, but otherwise closely like it. This resemblance holds also in the thin section, except that this rock is, perhaps, somewhat more feldspathic. The quartz fragments are often enlarged. (Slide 1147.)

69. Kingfisher Lake (N.W. ¼,N. E. ¼, Sec. 26, T. 65, R. 6 W., Minnesota.

A dark-gray, fine-grained rock, resembling the last described, but somewhat coarser-grained. Close also to much of the graywacke of the slate-conglomerate of Lake Huron. In the thin section, quartz and feldspar fragments, the former often enlarged, and the latter including both orthoclase and plagioclase, are embedded in fine matrix composed partly of quartz, but also in part of amorphous silica and kaolin, with also numerous particles of oxide of iron. Chlorite is abundant as an alteration-product of the feldspars. (Slide 1144.)

70. Knife Lake (N. W. ¼, S. E. ¼, Sec. 17, T. 65, R. 6 W., Minnesota).

A fine-grained, dark-gray cherty quartzite or quartz-schist. The fragments of quartz are oftened enlarged. Orthoclase and plagioclase compose about one-half of the rock, the remainder being made up of an excessively fine, siliceous matrix material, which, in a large measure, has no effect on the polarized light.

It is of considerable interest as bearing upon the question of the structural relation of the rocks of the great slate series, from which these specimens come, to the Animikie series south of them, that there should be such a close lithological resemblance between the rocks of the two series.[25] (Slide 1151.)

KEWEENAWAN SANDSTONES.

71 Eagle Harbor, Keweenaw Point, Michigan.

A red sandstone from the uppermost part of the "great conglomerate." This rock, which is made up of the detritus of different acid porphyries, is described in detail in the second part of this bulletin, since the induration has been mainly due to the secondary enlargement of feldspar fragments. The few grains of quartz contained are observed at times to have received secondary enlargements. (Slides 596, 1474.)

72. Near Copper Falls Mine, Keweenaw Point, Michigan.

A red sandstone from a layer interstratified with amygdaloids and traps, much resembling No. 71, except that the principal indurating material is calcite. The occasional quartz grains show very distinct enlargements.[26] (Slide 526.)

73. North side Portage Lake (Nonesuch Belt[27]), Keweenaw Point, Michigan.

A fine-grained, dark-colored, strongly-indurated sandstone, composed in large part of the detritus of the acid porphyries and basic rocks of the Keweenaw series, but containing also a large proportion of quartz fragments, most of which show distinct secondary enlargements.[28] (Slide 614.)

74. Foot-wall of the Nonesuch Mine, Porcupine Mountains, Michigan.

A light-reddish brown, streaked, fine-grained sandstone, composed about two-thirds of fragments of basic and acid eruptives, the remainder being quartz fragments, many of which are quite angular, and seemed to have broken from the crystals of a quartz-porphyry. In many cases these fragments have received secondary enlargements.[29] (Slide 617.)

75. Little Iron River, (N. W. ¼, N. W. ¼, Sec. 12, T. 50, R. 43 W., Michigan).

A fine-grained, dark-gray, much indurated sandstone or graywacke, the silver-bearing rock of Iron River. The predominant quartz occurs in the two forms of interlocking areas of some size, each with a plainly fragmental nucleus, and of an independently deposited interstitial material. The quartz fragments are at times finely complex. The remainder of the rock is made up of quartz-porphyry detritus, with some infiltrated calcite. (Slide 620.)

76. Little Iron River, (S. W. ¼, Sec. 13, T. 51, R. 42 W., Michigan).

A rock close to the last described and coming from the same "silver belt," differing chiefly in having more infiltrated calcite in the matrix. The induration is, however, largely due to infiltrated quartz, which occurs both as enlargements to the quartz fragments and independently oriented.

The rocks from the same belt on Big Iron River, on the lake shore near Lone Rock,

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[25] Monographs of the U. S. Geological Survey, Vol. V. pp. 399, 417.

[26] For description and figure of this rock, see monograph on Copper-Bearing rocks of Lake Superior, p. 129, and Plate XVI, Fig. 3.

[27] *Op. cit.*, pp. 193, 220–224.

[28] For further description of this rock, see *Loc. cit.*, p. 131.

[29] *Op. cit.*, p. 131.

and in the vicinity of Presqu' Isle River, except that the basic detritus and infiltrated calcite become more abundant, present the same appearance. (Slide 655.)

77. Presqu' Isle River, (NE. ¼, sec. 5, T. 49, R. 45 W., Michigan). Upper sandstones of the Keweenaw series.

A dark-red, fine-grained sandstone, closely similar to the last two described. The quartz fragments are both simple and complex, the first often widely enlarged. (Slide 355.)

78. Silver Islet Landing, north shore of Lake Superior, Canada.

A fine-grained, cream-colored, indurated sandstone. Angular, often interlocking quartz areas, each with a fragmental nucleus plainly outlined, make up most of the rock. Independently deposited quartz and some dolomite occur interstitially.[30] (Slides 471, 472.)

79. East side of Black Bay, Lake Superior, Canada.

A fine-grained, red-and-white-streaked, quite indurated sandstone. Subangular fragments of quartz, often showing quite wide and distinct enlargements, along with feldspar fragments, are buried in a matrix of finer fragmental quartz, which, in the red bands, is mingled with red oxide of iron and, in the white ones, with dolomite. (Slide 477.)

80. Burnt Island, Nipigon Bay, Lake Superior.

A fine-grained, brick-red, very much indurated sandstone, almost a quartzite. The predominating quartz is in interlocking areas each with a distinctly outlined fragmental nucleus—the enlargements having at times been very wide—and also in the shape of an independently deposited finely divided material. The feldspar fragments are plenty, and the rock is stained with oxide of iron. (Slide 491.)

CAMBRIAN ROCKS.

IN THE GRAND CAÑON GROUP OF THE COLORADO RIVER.

81. The Grand Cañon of the Colorado, near the mouth of the Little Colorado River, Arizona.

The specimens from this locality, kindly furnished us by Mr. Walcott, of the U. S. Geological Survey, range from a moderately indurated sandstone to nearly wholly vitreous quartzite. They are nearly white in color, and consist almost wholly of quartz with a minute quantity of iron oxide. The outlines of the original fragments are everywhere distinct, but always lie some distance within the individual areas, which interlock more or less thoroughly. (Slides 1363–1366 inclusive.)

IN THE POTSDAM SANDSTONE OF THE MISSISSIPPI VALLEY.

82. Immediately above unconformable contact with Huronian iron ores, Cyclops and Norway mines, Menominee iron region, Michigan.

A very much indurated, buff to brown sandstone—at times almost a vitreous quartzite. The thin section is composed, almost entirely, of interlocking grains of quartz, each with its distinctly outlined fragmental core. There is a little independently deposited interstitial quartz, and a little fragmental feldspar. The rock is in no respect different from much that is to be seen among the quartzites of the Huronian. (Slides 959, 960.)

[30] For description of this rock see *Op. cit.*, p. 133.

83. Lower Narrows of Baraboo River, from near contact with Archæan quartzite.

A much indurated, fine-grained sandstone carrying quartzite pebbles. The quartz fragments, originally but little rounded, are all strongly enlarged, so that there is a considerable degree of interlocking. There is also present some fine independently deposited interstitial quartz. The section does not differ materially from those of many Archæan quartzites. (Slide 742.)

84. Roche Écrit, Adams County, Wisconsin.

A dark-purplish, in places very much indurated sandstone. The grains are all enlarged, and occasionally have crystal faces developed. (Slide 749.)

85. Packwaukee, Marquette County, Wisconsin.

A pale, buff-colored, much indurated sandstone, showing only very rare crystalline facets. In the thin section the grains are seen to have been enlarged slightly, so as to fit closely without any dovetailing. Occasionally the enlargements have had an opportunity to develop crystal faces. (Slides 731, 732.)

86. Black River Falls, Jackson County, Wisconsin.

A white, rather coarse-grained rock, not so much indurated as the last-described, and showing more crystal facets, although not very plentifully. The thin section is much like that of the rock last described, except that the enlargements are proportionally broader and have more often developed crystal faces. (Slides 733, 734.)

87. New Lisbon, Wisconsin.

A fine-grained, pink-and-white-mottled sandstone, from which the light is reflected in numerous sparkling points. The induration, while distinct, is only slight, small fragments crumbling readily in the fingers. The crumbled sand mounted in balsam shows every grain enlarged, the lines of junction between the old and new quartz being always strongly marked. The enlargements have in all cases developed crystalline faces, which are, however, only perfect and uninterrupted upon the smallest of the grains. In most cases they are more or less indented by the enlargements of contiguous grains. This rock may be taken as a type of the crystal-faceted sandstones. (Slides 710 to 716 inclusive.) (See Figs. 4, 5, 6, Plate II.)

88. Middleton, Dane County, Wisconsin.

A fine-grained, loose, white sandstone, showing the grains sparkling from crystal facets. The balsam mounting of the sand crumbled from the rock shows the grains with the usual cores and crystal outlines. (Slides 1469, 1470.)

IN THE EASTERN SANDSTONE OF LAKE SUPERIOR.

89. West Branch of the Ontonagon River (Sec. 13, T. 46, R. 41 W., Michigan).

A reddish, coarse-grained, indurated sandstone. The quartz fragments which make up the rock have all been enlarged, sometimes very much so, so as to interlock. There is also some independently oriented fine interstitial quartz. Some much reddened, feldspathic detritus is included. (Slides 95, 96, 97.)

90. Quarry on Torch Lake Railroad, Keweenaw Point, Michigan.

A white to pinkish, feebly indurated quartzose sandstone. Some of the less indurated portions show numbers of faceted grains. The slide here described is from one of these less indurated portions. It is seen to be made up almost entirely of much rolled quartz fragments, which have in nearly every instance been enlarged, the enlargements only occasionally showing crystalline outlines. These crystal outlines are, however, more frequently to be seen in the balsam mounting of crumbled sand. They are not nearly so numerous, however, as in some of the rocks previously described, the grains having interfered too much to form crystal outlines. The outlines of the original grains are usually very strongly marked by brownish iron oxide. There are occasional rounded fragments of feldspar present, and in each thin section may be seen a few particles worn from some of the fine-grained Keweenawan eruptives. (See Figs. 7, 8, 9, Plate II.) (Slides 513, 514, 1471, 1472, 1473.)

See with regard to this rock also Copper-Bearing rocks of Lake Superior, pp. 356–358. See also for an earlier description M. E. Wadsworth in Bull. Mus. Comp. Zool., Vol. VII, No. 1, p. 117. Wadsworth found the crystal-outlined grains abundantly in his sections, although we failed to do so in ours until recently. He regarded these crystal grains as being the usual dihexahedral crystals of quartz-porphyries, on which view the crystals antedate the formation of the sandstone instead of being subsequent to it. More recently (Science, Vol. II, No. 23, p. 52, July 13, 1883) he has reasserted this view. But a careful re-examination of this rock, as also of others from other places within the area of the Lake Superior sandstone, has served to convince us that in all of these cases, as in all sandstones yet examined by us, provided with such faceted grains, they owe their crystal faces to secondary enlargements of rolled fragments. It is of course possible and even probable that these quartz fragments were once, some of them, the quartzes of quartz porphyries, but if so they have rarely, if ever, retained their crystal faces, as it is, indeed, hardly conceivable that they should do.

91. Quarries at Marquette, Mich.

A reddish, fine-grained sandstone, showing numerous minute glistening flakes of mica. Quartz fragments make up rather more than half of the rock, many of the grains being finely complex. The simple quartz grains are mostly very angular; many of them show very distinct enlargements. The remainder of the rock is composed chiefly of fragments of feldspar, including othoclase and plagioclase, with chlorite, brown iron oxide, and muscovite flakes, the chlorite having resulted from the alteration of the feldspars. The plagioclase includes quite a number of large-sized pieces of microcline.

92. Near Rockland. South of the Trap Range (S. E. ¼, Sec. 7, T. 50, R. 39 W., Michigan).

A fine-grained, feebly indurated, pinkish, quartzose sandstone, sparkling from presence of crystal facets, each quartz fragment being enlarged, the enlargements being often provided with crystalline outlines. (Slides 1475, 1476.)

IN THE WESTERN SANDSTONE OF LAKE SUPERIOR.

93. Basswood Island, Ashland County, Wisconsin.

A fine-grained, feebly indurated, white sandstone, containing besides the quartz many feldspar fragments. The quartzes are often enlarged, the enlargements being in many cases supplied with crystal facets. (Slide 53, Wis. sur. series.)

SILURIAN ROCKS.

IN THE SAINT PETER'S SANDSTONE OF WISCONSIN.

94. Near Lancaster, Grant County, Wisconsin.

This rock is represented in our list only by slides kindly furnished by the Rev. A. A. Young, of New Lisbon, Wis. They are dry mountings of the sand crumbled by hand from the rock. The grains are furnished with crystal facets from secondary deposition.[31] (Slides 707 to 711.)

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[31] Amer. Jour Sci., July, 1883.

95. Arlington Prairie, Columbia County, Wisconsin.

The Arlington Prairie is part of a large elevated area underlain by the Lower Magnesian Limestone, but dotting it here and there are small outliers of the Saint Peter's sandstone. A group of these outliers occurs in the southwestern part of the town of Arlington.[32] Most of the rock of these outliers is quite loose, and of the ordinary character of the Saint Peter's sandstone. Along its weathered surface, however, and along the sides of joint cracks, it is very much indurated, becoming even a completely vitreous quartzite for the distance of one-fourth or one-half an inch inwards from the surface. Sections of this completely vitrified portion show the quartz fragments with enlargements that everywhere fit closely together or interlock, but sections taken from an inch or two below this crust show the enlargements frequently furnished with crystal facets, the enlargements having interfered with one another sufficiently to give a slight induration. Fig. 1, Plate III, shows the appearance of a thin section of this less indurated portion as seen in the ordinary light.[33] (Slide 724).

96. Gibraltar Bluff, Columbia County, Wisconsin.

A very much indurated, fine-grained rock, in which a fine arenaceous texture is visible only upon the closest inspection. The rock is one which, if found among the crystalline schists, would undoubtedly be classed as a true quartzite, and the appearance of the thin section would entirely bear out this classification. It is made up only of interlocking grains of quartz of two very different sizes, the larger ones predominating. The large ones of these areas, and many of the smaller ones, show each a more or less plainly outlined fragmental nucleus. The areas interlock, often very intricately, and in every possible sense the rock is fully as "metamorphic" as any quartzite yet studied from the Archæan formations, and yet it is a mere local phase wholly independent of any igneous or other apparent metamorphosing action, in a formation whose ordinary character is that of an incoherent sandstone. In no Archæan quartzite that we have examined is the interlocking of the quartz areas, and the consequent appearance of complete original crystallization, more marked than in this sandstone.[34] See Fig. 1, Pl. V. (Slide 727.)

IN THE EUREKA QUARTZITE OF NEVADA.

97. Eureka, Nevada.

This rock and the three following are the ones in which Hague and Iddings noted enlargements of quartz grains as long ago as the summer of 1881. They will be found fully described in Hague's monograph upon the Eureka district. Mr. Hague has been kind enough to furnish us specimens and slides for the purpose of comparing them with quartzites which we had examined. The specimen of Eureka quartzite furnished by Mr. Hague would be classed by us as a semi-vitreous quartzite. The enlargements of the quartz fragments of which the rock is composed has produced close fitting but never any considerable interlocking. But still the rock is fully as much altered as any of the true Huronian quartzites.

DEVONIAN.

98. Sandstone from the White Pine shale, Eureka, Nevada.

A fine-grained, strongly indurated sandstone, composed of fragments of quartz and of chalcedonic or amorphous silica. The quartz fragments are often enlarged and are sometimes furnished with crystal faces. (Slide 1436.)

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[32] Geol. of Wis., vol. II, p. 583.

[33] For figures drawn from the vitrified crust of this rock see Amer. Jour. Sci., June, 1883, p. 407.

[34] Amer. Jour. Sci., June, 1883, p. 408.

CARBONIFEROUS.

99. Eureka, Nevada, Diamond Peak quartzite.

A fine-grained, greenish-drab, feldspathic quartzite. In the thin section feldspar, often much altered, is seen to compose a large proportion of the rock. The minute grains of quartz show relatively wide enlargements. (Slide 1368.)

TRIASSIC.

100. Henry Mountains, Utah.

A light-gray to pinkish, fine-grained, feebly indurated sandstone from near contact with one of the laccolites. Small rounded grains of quartz compose the larger part of the rock. These have often been enlarged, and the enlargements fit somewhat closely. There are some grains of feldspar and, interstitially, calcite, fine quartz, clayey material, and iron oxide. (Slide 1367.)

CRETACEOUS.

101. Courtlandt, Nicollet County, Minnesota.

A light-gray, compact, calcareous sandstone, consisting of quartz fragments embedded in a matrix of crystalline calcite. The quartz fragments, only rarely in contact with each other, have quite often been enlarged. (Slide 1384.)

II.

ENLARGEMENTS OF FELDSPAR FRAGMENTS IN CERTAIN KEWEENAWAN SANDSTONES.

By C. R. Van Hise.

For some time past I have been on the outlook for evidence of the secondary enlargement of feldspar fragments. In the slate conglomerates of the north shore of Lake Huron (as mentioned in Part I of this bulletin) I have found what may be enlarged feldspar grains, but the evidence is not sufficiently satisfactory that any of the material is of secondary origin, the lines of separation between the supposed new material and the nuclei being illy marked. However, I have found what seem to be additions to grains of that mineral in certain of the Keweenawan feldspathic sandstones. The specimens in which the supposed enlargements were first found are taken from those portions of the sandstones almost in contact with overlying basic eruptives. This position is evidently a favorable one for the development of such enlargements, the heated alkaline waters which would naturally descend supplying appropriate conditions. Then, too, quartz enlargements, when most easily found, are shown by lines of ferrite about the nuclei, and are ordinarily best seen in the less indurated quartzites. The Keweenawan sandstones are highly ferruginous, and are of an open texture; hence, if in them the feldspar fragments have taken new growths, the conditions for their detection are favorable.

The feldspathic sandstone immediately underlying the diabase of Eagle Harbor, Michigan, is of a uniform medium grain, a magnifying glass showing but little quartz. The feldspar grains are stained red with iron oxide. Hydrochloric acid gives with the powder a slight effervescence. In the thin section the sandstone is seen to be composed largely of grains of different feldspars, next to which in abundance are rounded complex fragments derived from a granitic porphyry,[1] consisting of feldspars penetrated by a saturating quartz. Then follow in order of abundance complex fragments of some altered basic rocks. Finally, a few grains of quartz and a little secondary calcite are noted.

The feldspars are frequently somewhat kaolinized, but most of the grains are fresh enough to give quite uniform colors in polarized light, and, in the cases of the plagioclases, well defined twinning bands. The grains are all rounded, their boundaries being broad lines of ferrite. However, some subsequent mineral has used these grains as nuclei

[1] Third Annual Report U. S. Geol. Survey, p. 114.

about which to deposit, and now each individual appears in the polarized light to extend beyond its original limits. The newly formed borders as compared to the interiors are different, in that they show no decomposition and are freer from iron stains. When the borders from different feldspathic grains have extended so far as to come in contact, as they usually have done, they form sharply serrate, nicely fitting junctions, roughly comparable to the suture of a skull (Fig. 1).

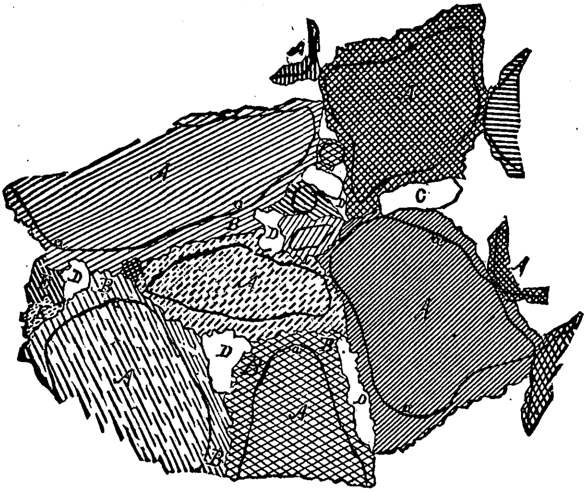

Fig. 1.—Portion of section of Eagle Harbor sandstone enlarged 50 diameters. AAA, feldspar fragments, bounded by oxide of iron borders, *aaa*, outside of which are enlargements, BBB, of the grains polarizing in each case with the nucleal fragment as indicated by the shading. C is a quartz fragment, D unfilled spaces, and E supposed secondary feldspars polarizing independently of the original fragments.

This newly added material appears to be feldspar, which has co-ordinated crystallographically with the grains about which it has deposited. It possesses no optical properties which would exclude that mineral, but cleavage and decomposition being absent, no comparison with feldspars can be made as to those characteristic features. The belief that the new material is feldspar is, however, based upon the following facts:

When the enlarged feldspar is orthoclase, the deposited substance polarizes uniformly with the nucleus about which it is seen (Fig. 1) ex-

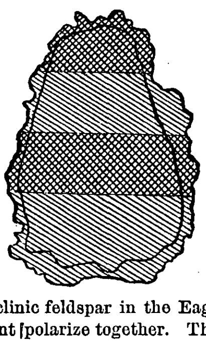

Fig. 2.—Enlarged fragment of triclinic feldspar in the Eagle Harbor sandstone, shaded so as to show how the fragment and enlargement polarize together. The black line is the heavy oxide of iron border of the original fragment.

actly as quartz enlargements polarize with the grains on which they have grown. Further, when plagioclase fragments present the enlargements, as they frequently do, the new material is twinned uniformly with the old, the twinning bands in polarized light running directly across cores and borders (Fig. 2). This phenomenon was observed in many different grains and in different sections.

Again, the complex fragments above mentioned as derived from a granitic porphyry, containing quartz and feldspar, often have enlargements, and the added portions resemble and usually polarize with the feldspars instead of with the quartz, with which they would naturally co-ordinate, if with either, were they composed of silica. Frequently the enlargements of this class of grains are apparently all of feldspar, even when a half or more of the edges of the original fragments (and in some places for considerable spaces continuously) are quartz (Fig. 3).

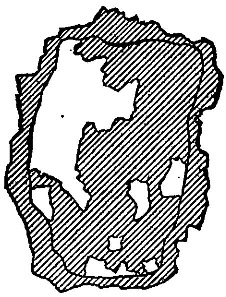

Fig. 3.—Enlarged fragment of feldspar, including some quartz, from the Eagle Harbor sandstone. The shading shows the feldspar fragment polarizing with the nucleus, even where not in contact with it. The black line is the oxide of iron border of the original fragment.

Finally, the complex basic fragments also have enlargements. These basic grains are often very feldspathic, the feldspar individuals being, however, small. Here a border, instead of being a unit, as it commonly is in the preceding cases, consists of several, or many individuals. The feldspars at the edge of the nucleus appear to have controlled the new growth, so that the new material polarizes with them in separate parts. These parts have, however, often extended upon each side beyond the immediately adjacent feldspars of the nucleus, and thus at times overlapped other feldspars whose conditions were less favorable for renewed growth, or other minerals, if such chance to be in contact with the division line between the fragment and its border.

The change which has taken place in one grain of orthoclase is of some interest. The grain has been broken into two parts, which have spread somewhat, and is now cemented with a new material which extinguishes with the original fragments, and also with the exterior second growth with which it is continuous in one place (Fig. 4.)

In some cases the new material deposited on a grain, instead of continuing as a single individual until it meets a similar growth from another grain, has crystallized independently in small interlocking grains (Fig. 1). This independent feldspar (if I am correct in so considering

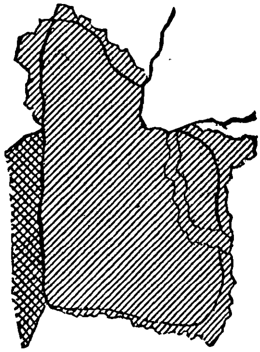

Fig. 4.—An enlarged fragment of orthoclase from the Eagle Harbor sandstone. This fragment has been broken across and cemented by a material that polarizes with the original fragment and the enlargement. The black line is the oxide of iron border of the original fragment.

it) is more plentiful about the basic fragments than about the feldspar grains or those of the granitic porphyry.

Uncovered thin sections were examined with acid, and the supposed feldspar enlargements found not to be affected. An attempt to test for hardness was not very successful. Micro-chemical tests from the nature of the case could hardly be applied.

This same secondary material has been found in other localities in the Keweenaw series, and in two cases the sandstone directly underlies eruptive greenstone.

III.

SUMMARY OF GENERAL CONCLUSIONS.

By R. D. IRVING.

Genesis of Huronian quartzites.—All the true quartzites of the Huronian are merely sandstones which have received various degrees of induration by the interstitial deposition of a siliceous cement, which has generally taken the form of enlargements of the original quartz particles, less commonly of minute independently oriented areas, and still less commonly of chalcedonic or amorphous silica; two, or even all, of the three forms occurring at times in the same rock. There may have been in some cases some solution and redeposition of the original quartz material, but in the main these rocks are still made up of the fragmental constituents that composed them before induration, the fragments retaining for the most part their original contours. That these quartzites are but altered sandstones is, of course, a truth which has long been generally recognized; it is the nature of the alteration that has not been understood.

It should be said that the term "Huronian" is here used, provisionally at least, to cover (1) the original Huronian on the north shore of Lake Huron, east of Sault Sainte Marie; (2) the iron-bearing formation of the Marquette and Menominee regions of Michigan and Wisconsin; (3) the slaty rocks of the Wisconsin Valley in the vicinity of Wausau; (4) the iron-bearing rocks of the Penokee-Agogebic range of Northern Wisconsin and Northwestern Michigan; (5) the cleaved slates of the Saint Louis and Mississippi Rivers in Minnesota; (6) the quartzites of the Chippewa River region of Western Wisconsin; (7) the iron-bearing schists of Black River, Wisconsin; (8) the quartzites of the Baraboo region, Southern Wisconsin; (9) the red quartzites and sandstones of Southwestern Minnesota and Southeastern Dakota; (10) the Animikie series of the Thunder Bay region, on the north shore of Lake Superior, and thence southwestward to Pokegama Falls, on the Mississippi River; and (11) some, at least, of the folded schists of the national boundary line.

Huronian quartzites no more "metamorphic" than numerous sandstones of later formation.—Without perhaps being definitely so stated, the generally accepted view with regard to the production of quartzites from sandstones has included the idea of a more or less thorough molecular rearrangement and recrystallization of the original fragmental material, quartzites having generally been classed as metamorphic or often even as crystalline rocks. But, so far as the Archæan quartzites of the Northwest are concerned, it appears that they have undergone no other alteration than that found to affect sandstones in the later and unaltered formations in all periods down to the Cretaceous. Irregular areas, and at times mere surface films [35] in the otherwise unaltered horizontal Potsdam and Saint Peter's sandstone in the Mississippi Valley have been changed to vitreous quartzites, indistinguishable microscopically and macroscopically from the quartzites of the Archæan, while great beds of as completely indurated quartzite as any of the Huronian are met with in the unaltered Paleozoic formations of the West. These later quartzites are plainly due to the interstitial percolation of silica-bearing waters, and to the same cause must be attributed the induration of the Huronian quartzites. In the case of the quartzites of the indurated portions of the Potsdam and Saint Peter's sandstones, no possible connection with any igneous action can be conceived, the surface crusts being due to a mere weathering, the interstitial silica-bearing waters having been drawn to the surface by evaporation and capillary action. These crusts are particularly interesting, because they are evidently in process of formation at the present time, occurring wherever the accidents of denudation have produced exposed surfaces of the rock, and one cannot conceive that either heat or pressure is concerned in their production, and yet they are as completely vitreous and crystalline as any of the true quartzites of the Huronian.

In the case of the quartzites of the Huronian and other formations where there is much interstratified eruptive material, the latter may have been the source of heated silica-bearing solutions, but I can see no reason to believe that there has been any other causal relation between igneous action and the induration of the sandstones than this.

It is of interest to note in this connection that since the quartzites of the various Huronian areas, and indeed the larger part of the other non-eruptive Huronian rocks, are in no sense more altered than any fossil-bearing quartzites, etc., of later formations, it may be taken as quite certain that the failure thus far to find fossils in the Huronian is not to be attributed to their destruction by metamorphic action, but rather to an actual, original barrenness of the series.

Other rocks in the Huronian than true quartzites have been affected by a siliceous induration.—It also appears that, besides the true quartzites, other rocks of the Huronian—for instance the graywackes—in which quartz is merely a subordinate, or at least not the principal, ingredient

[35] See Hawes's Lithology of New Hampshire, p. 239; Dana's Geology, p. 70; Geikie's Geology, p. 117, 127; Hawes noticed the complex character of some of the quartz fragments of certain New Hampshire quartzites, and took it to mean that these grains had been recrystallized rather than that they were originally complex.

have been affected by the same sort of siliceous induration, the indurating silica occurring both as enlargements of the quartz fragments and independently of them. Accompanying this induration there has been at times a replacement of feldspathic material by quartz, and the alteration of feldspar to chlorite, the chlorite occurring both as a pseudomorphic substitute for the feldspars, and independently crystallized in the interstices. Probably, also, the feldspar fragments have received secondary enlargements analogous to those described by Mr. Van Hise in Part II of this paper. By one or more of these processes rocks have been changed so as to present macroscopically and microscopically the appearance of more or less complete original crystallization, and yet they are made up almost entirely of the original fragmental material, the alteration which they have undergone having been merely metasomatic, and not "metamorphic" as the term is generally understood.

Besides the graywackes some at least of the mica-schists of the Huronian are mainly made up of the original fragmental material, unaltered, in some cases mingled with mica that appears to have developed *in situ*, the quartz grains often showing enlargements.

"Metamorphism" in the Huronian generally.—In the various Huronian areas above enumerated, one or more of quartzites, graywackes, and clay slates, with intermediate phases, make up most of the series, from which it follows that the bulk of the Huronian is made up of rocks not properly falling under the term metamorphic.[36] I may say, indeed,

[36] I am aware that the Huronian has often been spoken of as characterized mainly by other rocks than quartzites. In "Azoic Rocks" (Sec. Geol. Sur. Penn., p. 70.), Hunt speaks of Murray's first exploration of the north shore of Lake Huron as showing the existence there of "a great series of chloritic slates and conglomerates with interstratified greenstones, quartzites, and limestones." Murray's own words (Report Geol. Sur. Canada, 1847–1848, p. 109) are, "A set of regularly stratified masses, consisting of quartz rocks, or altered sandstones, conglomerates, slates, and limestones, interstratified with beds of greenstone." "Under the denomination of slates are included various thinly laminated dark green, blackish, and reddish rocks, some of which are very chloritic and some contain epidote." In Logan's description of the series (Geol. of Canada 1863, p. 55, and atlas to the same, Plate III) the Huronian section between the Mississaugi and Saint Mary's Rivers is made to include 10,820 feet of quartzites, 4,280 feet of slate conglomerates, 2,000 feet of "chloritic and epidotic slates and trap-like beds," and 900 feet of limestone and chert. Of the "slate-conglomerates" a large proportion is quartzite, the balance being the graywacke, graywacke-slates, and graywacke-conglomerates of the first part of this paper. It should be said that the various intercalated greenstone layers of the series are included by Logan in these measurements. Having carefully examined the ground myself, I am convinced of the general correctness of Logan's section. At least two-thirds of the series is made up of quartzite. Of the balance the graywackes of the slate-conglomerate make up at least one-half. Of the remaining sixth, one-third is limestone and chert and the balance "chloritic and epidotic slates, and trap." But these chloritic and epidotic slates, which, although so insignificant a portion of the series, have been made to serve as its most prominent characteristic, are, as I have convinced myself by examining them in their typical development east of Thessalon Point and in the thin sections, merely eruptive, diabasic greenstones in various degrees of alteration. It is possible that the occurrence of the greenish chloritic graywackes in the slate-conglomerates has

although the matter cannot be discussed in this place, that as my studies progress, rocks in the Huronian, to which the term "metamorphic"—meaning that they are altered from fragmental sediments, but now consist chiefly or wholly of material crystallized in situ—would properly apply, grow fewer and fewer, those that remain being restricted almost entirely to regions where the series is highly folded.

Mineral enlargements in rock alteration generally.—The wide-spread importance of the enlargement of quartz fragments in the production of quartzites and other quartz-bearing indurated rocks being proved, naturally the lithologist is led to query as to whether fragments of other minerals, each after its kind, may not have received secondary enlargements, and, if so, how far such enlargements may have been concerned in the production of "metamorphic rocks." As a partial answer to this query we can offer the enlarged feldspar fragments of certain Keweenawan sandstones, described in Part II of this bulletin, and the apparent enlargements of feldspar fragments in certain of the feldspathic graywackes of Lake Huron. Further than this we have as yet nothing to offer. Certainly the field is one deserving of investigation. We have not studied any gneisses or similar rocks since our attention was drawn to this matter. Theoretically, one can easily see how such enlargements might be of great importance in the production of the crystalline schists, the enlargements being accompanied, perhaps, by partial solution of the fragmental material, and by processes of replacement and pseudomorphism, and by some recrystallization, pressure coming in to produce the foliation. As noted before, Bonney has already suggested the importance of this matter of enlargement of mineral fragments. His words are worth quoting here in full. Speaking of certain banded crystalline schists of the Lizard district, Cornwall, England, he says:

"It seems, then, possible to me that in these and in some of the curiously-banded rocks in the upper groups, many of the constituents may be in part original. I do not mean that any one grain, as it now stands, is an original constituent; crystallization *in situ*, especially in the case of hornblende and mica, has taken place to a large extent. In the more minutely crystalline schist, the original structure is very prob ably wholly obliterated. Still, these large feldspar grains, for instance, may have as their nucleus feldspar grains which were original constituents, and may have survived the dissolution of the finer sedimentary materials in which they were imbedded. Then, in the process of reconstitution, feldspar (not perhaps always of the same species) may have been added to feldspar, quartz to quartz, mica to mica, and hornblende to hornblende or altered augite. This traces of the minuter structure of

contributed to the idea that chloritic and epidotic crystalline rocks are its main characteristics. The type Huronian, then, *i. e.*, that of the area between the Mississaugi and Saint Mary's Rivers; should be described as a great quartzite series, including subordinate quantities of graywacke, limestone, chert, and eruptive greenstones.

the original rock, even in a highly metamorphosed series, may now and then remain. In those beds where the chemical composition of the constituents facilitated change, or where the materials were finely levigated, the agents of metamorphism reduced the whole to a mere pulp (if the expression be permissible) from which the present mineral constituents crystallized, almost as they would do from the magma of an igneous rock; but in other cases, only a portion of the material was reduced to this condition, and those constituents which remained undigested would form nuclei around which the other minerals would crystallize, and would so continue to bear testimony to the original history of the rock itself. Thus the explanation of those granitoid bands, in some cases so curiously like granite veins, may be that originally they were a rather coarse quartz-feldspar grit. As regards some of the hornblende schists, one would suggest the possibility (as I believe has been elsewhere done by the late Professor Jukes) of their having been basaltic tuffs, with which in chemical composition they would agree fairly well.

"I have ventured on this digression because these Cornish rocks have presented structures which seem to me worthy of careful consideration by all who are studying the phenomena of metamorphism—a subject which has occupied my attention for some years past. The observations are not entirely novel. Dr. Sorby drew attention to somewhat similar structures in his very valuable and suggestive paper on the original constitution and subsequent alteration of mica-schist. The agglutination of identical mineral matter has been noticed in the case of quartz by that author, by Mr. J. A. Phillips, and by myself independently, not to mention others. In the gneissic series traversed by the upper part of the St. Gothard Pass, and in other districts, I have repeatedly noticed similar instances, all tending to show that the minute structures, and in some cases very probably the original constituents (at any rate as nuclei), may be preserved in rocks which are metamorphic in the fullest sense of the word.

"I trust some day to treat the subject more fully; but I take this opportunity of calling attention to it, because I believe that in it we find a clue which may ultimately enable us to solve many difficulties in that most perplexing inquiry—the relation of the metamphoric and of the igneous rocks."[37]

[37] (Quarterly Journal Geol. Soc. Lond., xxxix, p. 19.)

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