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ON THE CONSTITUTION AND HISTORY OF GRITS AND SANDSTONES.

On the Constitution *and* History *of* Grits *and* Sandstones.

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[Plates I. & II.]

The careful and exhaustive researches relative to the constitution and mode of formation of arenaceous rocks which have recently been published by Professor Daubrée, Dr. Sorby, and others, leave open a comparatively restricted field for the pursuit of similar investigations. Having, however, during the last two years paid considerable attention to the study of rocks of this class, I now venture to bring before the notice of the Geological Society some facts and deductions therefrom which would appear to have escaped the attention of previous observers.

For the convenience of developing certain ideas relative to this subject, I propose in the present paper, in the first place, to describe various grits and sandstones which have been microscopically and otherwise examined. In doing this the older rocks will be considered first, and those of more recent age subsequently noticed in the order of their geological sequence. The chemical composition of some typical rocks will also be given.

Secondly, the results of observations bearing on the effects produced by the action of flowing water on particles of sand and gravel transported thereby will be described; and finally, the more important observed facts will be summarized, and their bearings discussed.

The difference between grit and sandstone is one not always distinctly marked; and numerous definitions of the two rocks, often somewhat contradictory, have been given by various geologists at different times. It has even been stated by an eminent authority that rocks which in the north of England would be called grits, receive the name of sandstones in the south*.

In order, therefore, to avoid misunderstanding upon this point, I may state that in the following descriptions the term grit is applied only to coarse-grained arenaceous rocks of which the component fragments are for the most part angular, and which, although frequently crystalline in structure, seldom contain either perfect or nearly perfect crystals. The cementing material of such rocks is, as a rule, highly siliceous.

Sandstones differ from grits in being finer in structure than the latter, and in their component grains being usually less completely incorporated with the cementing medium. The quartz in many sandstones occurs principally in the form of perfect crystals, or in that of crystalline aggregations.

In quartzites the spaces between the component grains are completely filled by a siliceous cement, in which respect they closely resemble some varieties of fine-grained grit.

* 'Manual of Geology,' by John Phillips, F.R.S., p. 654.

Composition and Structure.

Cambrian.—The well-known Barmouth Grits of North Wales, which occupy a large extent of country lying between Barmouth and Harlech, are usually of a greenish-grey colour. They are extremely hard, and often enclose angular fragments of quartz above a quarter of an inch in diameter. Sometimes these grits become fine-grained, and assume a purple tint; they are intermingled with occasional bands of greyish-green and bluish slates, which, especially towards the lower part of the series, attain considerable development. Of these rocks Professor Ramsay remarks:—"The beds seem to have been formed principally by the direct waste of rocks of a granitic character, or at least into the composition of which crystalline quartz and felspar largely enter"*.

When a thin section of this rock is examined under the microscope, it is seen to consist, mainly, of an aggregation of fragmentary quartz and felspar united by a siliceous cement, which is throughout permeated by a moss-like greenish mineral, a portion of which is probably chlorite. The larger pieces of quartz and felspar are often distinctly rounded, although they also sometimes present irregular and perfectly sharp outlines. Fig. 1, Pl. I., drawn by Mr. F. Rutley, represents, in black and white, a section of this rock as seen in polarized light, magnified 18 diameters, and containing much felspar.

The quartz occasionally contains liquid-cavities enclosing moving bubbles, but these are by no means numerous; the greenish mineral of the cement sometimes penetrates into fissures in the siliceous grains. Two distinct species of felspar are present in considerable quantities, the larger grains being, for the most part, somewhat rounded fragments, which, after having assumed the form of pebbles, have sometimes been broken across their smaller diameter, thus presenting one angular and one rounded termination. The orthoclase is not much altered; and a triclinic felspar, which, from the optical properties it exhibits, is probably oligoclase, shows brilliant lines of twinning when seen in polarized light. Some of the quartz encloses hair-like crystals of rutile, while calcite, magnetite, iron pyrites, and a few imperfect garnets are present in the cementing siliceous base. An analysis of this rock is given, page 21.

The grits in the neighbourhood of Harlech are usually finer in grain than the foregoing, but otherwise differ from it only in containing a few imperfect crystals of epidote.

Silurian.—Stiper Stone, from the neighbourhood of Shrewsbury, is a fine-grained and exceedingly hard sandstone, the grains of which are so closely cemented together by crystalline silica as to form a quartzite. Many of the fragments of quartz, of which this rock is mainly composed, are somewhat cloudy and are considerably rounded, while others are colourless and transparent, with but few fluid-cavities, which are, for the most part, full. The average diameter of the grains is about $\frac{1}{50}$ inch, and some of the most pebble-

* Geology of North Wales, p. 17, ed. 1.

like among them form the nucleus of a crystalline growth of colourless transparent quartz, which converts them into more or less perfect crystals of that mineral. Felspar is not abundant, and is often considerably altered; the cementing material occasionally contains minute crystals of a mineral which is probably epidote.

A grit of a grey colour, speckled with minute white points, from the neighbourhood of Aberystwith, is seen under the microscope to be composed of an almost equal amount of quartzose and felspathic grains united by a siliceous cement, everywhere permeated by a moss-like chloritic mineral, to which reference has already been made. In this rock the constituent fragments are sometimes as much as $\frac{1}{35}$ inch in length, and their angles are usually to a certain extent rounded, although they occasionally exhibit very sharp and irregular outlines. The quartz, which exceptionally contains a few needles of schorl, is colourless and transparent, containing exceedingly minute fluid-cavities, of which the majority are full, although others enclose constantly moving bubbles.

The felspar has been subjected to considerable alteration, and is not unfrequently obscured by flocculent microliths resulting from chemical re-combinations; a portion of it, however, evidently belongs to a triclinic species. In addition to the above, there are inclusions which are undoubtedly fragments of a volcanic rock of basaltic character.

The siliceous cement contains a few crystals of iron pyrites, as well as small flakes of brown and colourless mica, of which the edges are much rounded.

It is evident that some portion, at least, of the quartz constituting this grit has been derived from the disintegration of quartz-felsite (quartz-porphyry), since its general characteristics are not only similar, but it, moreover, includes the blebby masses of an amorphous ground-mass so characteristic of the quartz of such rocks.

A fine-grained foliated rock belonging to the same series, from Llangrannog, sometimes locally called a grit, of which the grains vary from $\frac{1}{500}$ to $\frac{1}{1000}$ inch in diameter, has a composition generally similar to that of the foregoing. In addition, however, it contains numerous water-worn flakes of mica, which occur chiefly in distinct bands, and which are arranged with their cleavage-surfaces parallel to the plane of foliation of the rock. The fragments of quartz, which are of a nearly uniform size, are all sharply angular, and elongated or flattened grains are rare.

An examination of sections prepared from May-Hill Sandstone, containing numerous casts of *Pentamerus oblongus*, shows that this rock is mainly composed of angular grains about $\frac{1}{200}$ inch in diameter, united by a turbid siliceous cement, suggesting the idea of its having been deposited from waters holding clay in suspension. In addition to the smaller grains, of nearly equal dimensions, there are a few fragments of, at least, four times the size above stated. These, like the smaller ones, sometimes contain a few hair-like crystals of rutile; but fluid-cavities containing bubbles are exceedingly rare.

Sandstones, or rather quartzites, of Upper-Llandovery age are developed in the Lower Lickey hills in Worcestershire. A specimen from this locality was found to be chiefly composed of much-rounded grains of quartz, having an average diameter of $\frac{1}{50}$ inch, cemented together by a growth of transparent crystalline quartz. This mode of formation is rendered evident by the circumstance of the rounded grains being frequently composed of cloudy or slightly turbid quartz, while the cementing silica is perfectly colourless and transparent. When examined in polarized light, the cementing quartz is seen to exhibit, for a certain distance around each grain, the same colour as the grain itself, and appears to have been deposited in crystalline continuity therewith. Fluid-cavities, with bubbles, are numerous in some of the grains, while others are entirely without them. Rutile and schorl are sometimes present in the form of minute crystals.

A specimen of Denbighshire grit from Pont Cletwr Yspytty, when examined, was found to consist of an exceedingly fine-grained mosaic of cementing concrete containing minute granules of quartz, and enclosing larger fragments of the same mineral, with felspar and colourless or brown mica, each grain being from $\frac{1}{50}$ to $\frac{1}{100}$ inch in diameter. Some of the quartz fragments are so traversed by the moss-like greenish mineral, often forming a constituent of the cement of sandstones, as almost to suggest the idea of their being pseudomorphs after a mineral which has disappeared. If seen in polarized light, however, they will be observed to be each made up of several distinct grains, in the fissures between which the substance referred to has obviously been deposited. The quartz of this sandstone occasionally encloses a few needles of schorl or hair-like crystals of rutile ; cavities containing bubbles are rare.

A rock belonging to the Coniston-Grit series from Green-quarter Fell, Westmoreland, consists of angular grains of quartz and felspar, united by a siliceous cement traversed in all directions by numerous greenish microliths. The average size of its constituent particles does not exceed $\frac{1}{1000}$ inch, although there are a few larger ones, measuring about $\frac{1}{50}$ inch in diameter. The quartz contains few fluid-cavities with bubbles; but when these occur they are extremely minute. This rock contains a little iron pyrites, and the cement is sometimes stained by hydrated ferric oxide; a few flakes of colourless and dark-brown mica are occasionally seen between the grains of quartz and felspar.

Devonian.—The majority of the siliceous grits of Cornwall are usually regarded as being of Devonian age; but it is probable that some of them may be of older date.

Two distinct beds of such rock, of a greenish-grey colour, which are worked for road-metal, are quarried on the farms of Tregian and Dairy, in the parish of St. Ewe, near St. Austell, and were noticed in a previous paper under the name of slaty agglomerates*.

In both these localities the grit contains angular fragments of a soft clay-slate of a greenish-blue colour, and is exceedingly hard and tough. The rock quarried at Tregian is composed of a mixture

* Quart. Journ. Geol. Soc. 1878, vol. xxxiv. p. 476.

of angular pieces of quartz and felspar, of which some of the larger fragments have a diameter of $\frac{1}{10}$ inch; they are cemented by a siliceous concrete enclosing particles of granular quartz, through which minute greenish microliths are plentifully disseminated. Comparatively few fluid-cavities, either with or without bubbles, are present. In addition this rock contains a few crystals of schorl enclosed in the quartz, some water-worn flakes of silvery-white mica, a few crystals of pyrites, and perhaps a little altered magnetite. The felspar chiefly belongs to a triclinic species, but orthoclase is also present. The rock at Dairy differs from that at Tregian only inasmuch as it contains a few water-worn crystals of hornblende and a little magnetite.

In addition to the foregoing, through the kindness of Mr. J. H. Collins, I have been enabled to examine four other specimens of Cornish grit, namely, one from St. Allen, four miles north of Truro, two from Ladock, five miles further east, and one from Perranzabuloe, on the Bristol Channel.

Hand specimens of all these rocks closely resemble one another, excepting that those from Ladock enclose numerous angular fragments of a greenish slate, which the others do not, and that one of them contains a number of rounded quartzose and other grains $\frac{1}{4}$ inch in diameter.

When examined under the microscope, the St. Allen grit differs little from those at St. Ewe; the quartz is angular and transparent, the largest fragments having a diameter of about $\frac{1}{25}$ inch, and they sometimes, though rarely, enclose minute crystals of tourmaline. A little hornblende, with white mica and epidote, are also present. The felspar is, to a large extent, triclinic, but there is also some altered orthoclase; the quartz contains but few fluid-cavities.

In the rock from Ladock, which contains small rounded grains of quartz, felspar, and other material, these bodies are sparsely disseminated throughout the mass of the normal grit; and a microscopical examination shows that some of them are fragments of volcanic rocks closely akin to the "greenstones" and "dunstones" of many parts of Cornwall, but which have often become so altered as to be recognizable only by their felspars and general structure.

Fig. 2, Pl. I., represents, in black and white, a fragment of volcanic rock which occurs in this grit, as seen in polarized light, magnified 18 diameters.

The second specimen from this district is made up chiefly of angular fragments of quartz and felspar, united by the usual cementing concrete. It contains a considerable amount of felspar, a large proportion of which is triclinic. The largest pieces of quartz are about $\frac{1}{12}$ inch in diameter; and fluid-cavities, although by no means abundant, are more plentiful than they are in the Cornish grits before described. Some of the quartz contains a notable quantity of disseminated epidote (?), and flakes of white mica are frequently jammed between the fragments of which the rock is composed. A few minute garnets are present, as well as some fragments of a volcanic rock.

The microscopical structure of the gritty rock from Perranzabuloe so closely resembles that of those from the other localities that a special description of it is unnecessary. The felspar, of which a large proportion is triclinic, is present in large quantities; and, as in the case of the other specimens examined, the quartz contains but few fluid-cavities. It will be observed that in this respect the quartz of these grits materially differs from that of the Cornish granites, in which fluid-cavities with bubbles are abundant.

Carboniferous.—A fine-grained yellowish-white sandstone from Shalk Beck, Cumberland, belonging to the Yoredale series, much spotted by stains of hydrated ferric oxide, and rendered somewhat mealy by the presence of kaolin, contains but few fragments of more than $\frac{1}{150}$ inch in diameter. The quartz is in angular pieces, colourless and transparent, and, to a large extent, free from fluid-cavities, which, when present, are, for the most part, full, and consequently without bubbles. In addition to quartz, with a little felspar and kaolin, the only recognizable mineral is white mica. For the analysis, see p. 21.

A sandstone from Brigham, Cumberland, belonging to the Millstone-Grit series, was examined both microscopically and chemically, and is essentially composed of fragments of quartz with a little felspar, the grains being usually about $\frac{1}{125}$ inch in diameter, united by a siliceous cement, which is sometimes a little cloudy. Between the constituent fragments of this rock there are sometimes minute crystals of a mineral which may perhaps be epidote; and the quartz, which is colourless and transparent, encloses a few needles of tourmaline, besides containing occasional fluid-cavities, but few of which contain bubbles. For the chemical composition of this sandstone, see page 21.

At Spinkwell quarry, near Bradford, a foliated siliceous sandstone, which can be raised in the form of very large slabs, is worked in the Lower Coal-measures, and is much used in the construction of chemical apparatus on a manufacturing scale. This sandstone is mainly composed of fragmentary quartz and felspar, of the latter of which a portion is triclinic, united by the usual siliceous cement. The quartz is colourless and transparent, and contains but few fluid-cavities, although it sometimes encloses needles of schorl.

In addition to quartz and felspar, this rock contains kaolin, with a few minute garnets, and flakes of dark-brown and colourless mica, which are more abundant along certain lines of foliation than elsewhere. A few minute crystalline scales of micaceous oxide of iron were observed in the quartz of this sandstone. The component fragments rarely exceed $\frac{1}{250}$ inch in diameter. For analysis of this rock, see page 21.

The fine-grained yellowish-grey Coal-measure sandstone of Stonyhough, Workington, Cumberland, is, to a large extent, composed of minute crystals or crystalline aggregations of quartz of about $\frac{1}{200}$ inch in diameter, somewhat loosely united by a siliceous cement, often much stained by hydrated ferric oxide.

A considerable number of sandstones belonging to the Carboniferous period are chiefly composed of quartz crystals, which have evidently crystallized *in situ*, since they exhibit the freshness of outline peculiar to crystals which have not been subjected to the slightest amount of abrasion subsequently to their formation, not a point being broken or an angle removed. Sometimes the original grains of quartz have, by the subsequent deposit of silica upon their surfaces, become converted into complete double-terminated crystals; but the forms are frequently less simple, and the faces bounding the exterior cannot all be referred to the same crystal. That this crystallization is produced by a deposit of silica around the original grains of quartz, subsequently to their having become members of an accumulation of sand, was first noticed in British rocks by Professor Bonney*, and has been subsequently demonstrated by Dr. Sorby†. It is almost equally certain, as will be subsequently shown, that a portion, at least, of the silica so deposited has been derived from the decomposition of felspar.

Among highly crystalline Carboniferous sandstones may be mentioned one belonging to the Mountain-Limestone series, which occurs at Yeathouse, in Cumberland, that of Parkhead, in the same county, and that of Augill, near Brough, Westmoreland; the two last of Yoredale age. Another sandstone in the Lower Coal-measures, worked at Barngill quarry, in the county of Cumberland, is also crystalline.

Permian.—The St. Bees Sandstone, at Rheda, Cumberland, is a fine-grained reddish-brown rock, composed of a mixture of angular fragments and minute crystals of quartz with a little felspar, the whole being united by a cement rendered, to some extent, opaque by ferric hydrate. The grains and crystals of quartz have usually a diameter of about $\frac{1}{200}$ inch, and contain but few fluid-cavities. The colour of this sandstone, like that of the majority of similar rocks, is caused by a coating of hydrated oxide of iron over the surfaces of the grains and crystals of which it is composed, but which is readily removed by digestion in acids. Felspar is present in notable quantity, and is often considerably altered; no triclinic species was observed. A small amount of colourless mica is present in the form of water-worn flakes, together with a few imperfect crystals of schorl.

Numerous other crystalline sandstones of Permian age might be cited; but those of Penrith, which have been described by Dr. Sorby, are probably the most interesting and remarkable examples.

Triassic.—Among the Bunter sandstones of Lancashire and Cheshire are certain reddish-brown friable beds, possessing but little cohesion, and of which the constituent grains are all so completely rounded, that the disintegrated sand flows between the fingers as readily as shot. Deposits of such sandstones, which are distinguished by the name of "Millet-seed beds," occur plentifully in the Lower Mottled series, and occasionally among the Upper Mottled sandstones, as well as in the Frodsham beds of the Keuper.

A specimen of millet-seed sandstone from the Lower Bunter, obtained in the form of a core, at a depth of 1039 feet, from the

* Quart. Journ. Geol. Soc. vol. xxxv. p. 666.

† Address delivered at Anniversary Meeting of the Geological Society of London, 20th February, 1880, p. 36.

Bootle bore-hole of the Liverpool water-works, was, with a large number of others from that district, kindly furnished to me by Mr. Charles E. De Rance, of the Geological Survey, but was found to be too friable to admit of the preparation from it of thin sections. On examination by reflected light, however, it was found to be so entirely made up of rounded grains, varying in diameter from $\frac{1}{50}$ to $\frac{1}{200}$ of an inch, that I did not hesitate to suggest to Mr. De Rance the probability of its origin being due to blown sands united by a ferruginous cement.

These grains, of which the majority are quartz, are so rounded as to represent miniature pebbles, while a few, consisting of partially decomposed felspar, are often corroded into deep cavities on one or more of their sides.

The granules of quartz, as well as those of felspar, have been covered by a thin coating of hydrated ferric oxide; while on the surfaces of the former a beautiful growth of crystals of transparent quartz has frequently taken place.

These crystals do not often exceed $\frac{1}{100}$ inch in length; but they are sometimes very perfect, with sharply defined angles, and frequently exhibit both plagihedral modifications and horizontal striation. A few crystals of pyrites and of calcite have also been formed on the surfaces of the rounded quartz-grains.

Figs. 1, 2, 3, and 5, Pl. II., drawn by Mr. F. Rutley from specimens which I selected for that purpose, and magnified one hundred diameters, represent crystals of quartz attached to rounded grains of the same mineral forming the basis of this sandstone. Fig. 4, magnified to the same extent as the others, is a grain of quartz which exhibits a depression at its point of contact with another similar body. Specimens presenting this appearance, which are not very numerous, may sometimes be the result of one grain of quartz having been forced or ground into the substance of another. A careful examination, however, of such depressions leads to the conclusion that in some cases when this pitting of a grain is observed a deposit of silica may have taken place upon all parts of its surface, excepting where it has been protected by contact with adjoining grains.

Angular cores of a siliceous material which have been deposited in cavities at the point of junction of several grains are sometimes detached when the rock is carefully disintegrated by friction with a hard brush. When these adhere to one only of the adjacent grains, having separated from the others, they obviously might give rise to depressions of the kind referred to.

If, after treating this sandstone by hydrochloric acid, the residue be examined under the microscope, the presence of these siliceous bodies becomes at once apparent. They are sometimes slightly coloured by ferric oxide, and do not always exhibit colours when seen in polarized light; in other cases they afford evidence of imperfect crystalline structure, and are occasionally colourless and transparent.

Fig. 6, Pl. II., is a grain of felspar which has become so corroded that two distinct cavities have been produced in its substance. A crystal of iron pyrites attached to a rounded grain of quartz is seen in fig. 7, which, as well as the preceding figure, is represented as magnified to the same extent as the other illustrations contained in the Plate.

Prolonged digestion in hydrochloric acid removes the oxide of iron, leaving the surfaces of the rounded quartz granules clean and colourless. The minute crystals of quartz which have been formed upon them, however, adhere firmly to the rounded grains, after this treatment, and no stain of ferruginous matter can be observed between their point of attachment and the grain of sand on which they have been formed. It would therefore appear that, although the sand had been covered generally by ferric hydrates previous to the growth of quartz crystals, these have nevertheless originated at those points only where a chemically clean surface of the quartzose nucleus was exposed. An analysis of this sandstone is given, p. 21.

Sandstones chiefly composed of rounded weather-worn grains occur in the Lower Mottled series, at a depth of 80 feet from the surface at Stock's Well, belonging to the Widnes water-works, and at Scott's bore-hole near St. Helens, as well as at a depth of 260 feet in the Winwick boring of the Warrington water-works.

Beds of loose, rounded sand of the age of the Lower Mottled Sandstone are known to occur at Chapel Bridge, Prescot, and in a boring a little east of Newton Bridge, near Warrington.

Sandstones of this character are met with north of Eccleston hill, and a similar bed belonging to the Upper Mottled group comes to the surface in the yard of the Bridgewater Foundry at Runcorn. By no means, however, do all the sandstones of Lancashire and Cheshire which belong to this geological age exhibit characteristics suggestive of their formation from æolian sands. At Wirral, in Cheshire, as well as sometimes in the neighbourhood of Liverpool, the Pebble-beds of the Bunter are represented by a brownish-yellow sandstone containing numerous pebbles, which is much employed for building-purposes.

In many of these beds the quartz is almost entirely in the form of minute crystals, or crystalline aggregations, often united by a ferruginous cement, which has manifestly been introduced subsequently to the covering of the original grains with crystalline quartz. An excellent example of a non-ferruginous crystallized sandstone belonging to the Upper Mottled group occurs at Town Green, near Ormskirk. This rock is mainly composed of crystals of transparent quartz, of which the edges and angles are beautifully perfect. It is of a far too friable nature to allow of the preparation of thin sections; but it appears to have little or no cementing material, and to be, to a large extent, merely felted together by the intergrowth of its constituent crystals. It will be needless to remark that the grains of sandstones of Bunter age are not always either rounded or enveloped in crystals of quartz.

Among the Keuper division of the Triassic sandstones, which are mainly composed of well-rounded siliceous grains, may be cited a grey, friable, fine-grained rock from the base of this formation, which is exposed in the railway-cutting at the Runcorn station, and a dark-red sandstone of still finer texture, belonging to the Frodsham beds, at no great distance from the same locality. The Lower Keuper cupreous sandstones of Alderley Edge, Cheshire, are frequently made up of quartz crystals on which still more minute crystals of *vanadinite* may sometimes be distinguished by the aid of a lens.

In many localities the quartz pebbles occurring in crystalline arenaceous rocks have their surfaces, and more particularly their upper surfaces, covered by minute crystals of that mineral. This may be observed in the case of pebbles found in Lower Keuper sandstone in a quarry near Litherland.

At Dymoke, Worcestershire, there is a Lower Keuper sandstone which is sufficiently coherent to admit of the preparation of thin sections. This is a fine-grained, quartzose, distinctly laminated rock, of which the component grains are usually about $\frac{1}{250}$ inch in diameter. These to a large extent consist of quartz, sometimes enclosing hair-like crystals of rutile, and occasionally fluid-cavities, in some of which bubbles were observed. A certain amount of felspar, a portion of which is triclinic, is present in this rock. A few flakes of colourless mica, and a little of the fibrous mineral which has been referred to as often occurring in the cement of certain sandstones, were also observed. The cementing material, which contains a little kaolin, encloses a few minute garnets, and is frequently stained by hydrated ferric oxide.

The Waterstone beds belonging to this series enclose numerous angular fragments of dark-coloured slaty rock, some of which are as much as $\frac{1}{2}$ inch in diameter. The quartz grains, many of which are $\frac{1}{15}$ inch in diameter, are usually much rounded, and not unfrequently enclose fluid-cavities. In addition to quartz and the cementing material felspar is present, as is also, in small quantities, another mineral of a light yellowish-green colour, which I have been unable to identify, but which occasionally forms part of the cement.

A fine-grained sandstone of Upper Keuper age, which occurs at High House, Warwickshire, is to a large extent composed of quartz crystals, while a bed of loose sand, found 25 feet below the surface at Frodsham, above the Keuper Marl, is, on the contrary, entirely made up of much-rounded grains.

The rounded quartz grains of Triassic sandstones, when examined in a suitable medium, after the removal of their external ferruginous coating, are found to be colourless and often transparent. Grains containing fluid-cavities are comparatively rare, but they are apparently more numerous in the Keuper sandstones than in rocks of Bunter age. A few crystals of schorl occasionally present themselves in the quartz of these rocks, which is not unfrequently rendered turbid by the enclosure of what is probably a little ferruginous clay. It is, however, probable that the grains containing fluid-cavities in which crystals of schorl are also found owe their origin to a different source from that whence the supply of quartz which does not contain such cavities was derived.

Jurassic.—A fine-grained Upper Lias sand, of a greenish colour, from Seizincote, Stow-on-the-Wold, Gloucestershire, effervesces when treated with hydrochloric acid, leaving grains of transparent quartz, which are generally angular. In some instances, however, their more acute angles appear to be slightly rounded, although the mean diameter of the fragments is only $\frac{1}{200}$ inch. Besides quartz containing occasional fluid-cavities, usually without bubbles, there are present a few pieces of somewhat doubtful felspar, together with numerous fragmentary crystals of schorl and garnet.

The only coherent arenaceous rock of this age which I have had an opportunity of examining is that quarried at Egton, near Whitby, under the name of "Moor Grit," which is locally much employed for road-metal. It is white and fine-grained, being often so compact as to be entitled rather to the name of quartzite than to that of grit. Its geological horizon is above the Grey Limestone in the estuarine series of the Lower Oolite in North-east Yorkshire.

Under the microscope this rock is seen to be almost entirely composed of transparent, colourless quartz, of which the largest pieces are about $\frac{1}{75}$ inch in diameter, and of which the angles are usually more or less removed. Around and between these grains a deposit of transparent crystalline quartz has taken place, thus forming a cementing medium. A few small garnets are present, but no fluid-cavities with bubbles were observed, although some of the quartz encloses minute crystals of a yellowish mineral which I have been unable to identify; these are exceedingly minute, often not exceeding $\frac{1}{10000}$ inch in length. Many of the smaller grains in this rock exhibit, when examined in polarized light, that complex structure so frequently observed in the quartz of clay-slates and other somewhat similar rocks.

A sand resulting from a disintegrated Portland Stone at Fonthill Giffard, Wiltshire, is largely composed of ovoid grains of calcite. After being attacked by hydrochloric acid, a rounded quartzose sand, amounting to about one quarter of the total bulk of the mixture, remains behind. This sand, of which the grains vary from $\frac{1}{70}$ to $\frac{1}{250}$ inch in diameter, contains but few fluid-cavities, and these, as a rule, are without bubbles. The fragments of quartz are associated with, and not enclosed by, the ovoid grains of calcic carbonate.

Cretaceous.—The Tilgate Sandstone, Ashdown Sands, from Newick Park, Sussex, is composed of slightly rounded grains of colourless transparent quartz, united by a cement consisting partly of calcic carbonate and partly of flint. The quartz is almost entirely free from fluid-cavities, but encloses a few hair-like crystals of a mineral which is probably rutile. If felspar be present it has become too extensively altered to admit of identification.

Sections have been examined of the chert known as Sevenoaks Stone, as well as of several others of Lower Greensand age. They all contain numerous fossils, particularly sponge-spicules, and in some cases consist, to a large extent, of amorphous silica; in others the rock becomes crystalline and distinctly chalcedonic. The flinty varieties often contain crystals of calcite, which cluster around an included fossil as a nucleus. All the specimens examined contain glauconite, and occasionally grains of ordinary quartz, some of which are much rounded, while others are angular.

The "Carstone" of Hunstanton, near King's Lynn, Norfolk, and of various other localities, is a friable ferruginous sandstone belonging to the upper portion of the Lower Greensand formation, and occurring in beds of which the relations have not, as yet, been accurately determined. A series of specimens from this locality was kindly furnished me by Mr. S. B. J. Skertchly, of the Geological Survey, who is at present occupied in working out the geology of the district. With the exception of certain variations in colour, these beds so closely resemble one another in their general characteristics that a description of one of them will suffice for the present purpose.

A specimen of Carstone from immediately below the Red Chalk exposed in the cliff at Hunstanton was found to be mainly composed of a mixture of somewhat rounded grains of quartz, with small pebble-like granules of dark-brown iron-ore. The individual grains of these minerals vary in diameter from $\frac{1}{10}$ inch to the most minute sand, although small pebbles of larger size than the highest limit quoted are not of unfrequent occurrence. The quartz contains schorl and rutile, together with a few fluid-cavities, of which the majority are without bubbles. In addition to ordinary quartz grains, this rock, when carefully disintegrated, exhibits numerous examples of the angular bodies resulting from the breaking-up of a siliceous deposit formed between the grains of the original sand, which have been noticed (p. 13) in connexion with millet-seed sandstones of Bunter age.

By the prolonged action of hydrochloric acid the quartz of this rock is rendered colourless, while the globules of ferric hydrate are dissolved, with the exception of a siliceous skeleton which preserves the exact form of the original grains. These bodies do not usually exhibit colours when mounted in balsam and examined by polarized light; but in a few cases the presence of a dark cross indicates a pisolitic structure in the siliceous residue*. In addition to the foregoing, this rock contains a few minute scales of mica and a very small quantity of felspar. The majority of the grains of quartz have their angles distinctly abraded; in some instances they have been completely removed, and a pebble-like form has been the result.

A specimen of Carstone obtained from a bed directly beneath the Red Chalk, afforded on analysis the following results:—

* Both Dr. Percy and Professor Judd have described siliceous skeletons which occur in the pisolitic grains of Northamptonshire iron-ore:—Metallurgy, Iron and Steel, pp. 225, 226; Memoirs of the Geological Survey, Geology of Rutland &c. p. 119.

Water	hygrometric	3·85
	combined	6·56
Silica		49·81
Phosphoric anhydride		0·42
Alumina		5·17
Ferric oxide		29·17
Ferrous oxide		0·35
Lime		2·43
Magnesia		0·95
Potassa		0·48
Soda		0·84
		100·03

Another variety of this rock from the same locality, but darker in colour, was found to contain 37 per cent. of ferric oxide and 45 per cent. of silica; the amount of phosphoric anhydride was nearly the same as in the first specimen analyzed.

An examination of the spherules of various pisolitic iron-ores shows that they exhibit all the characteristics of the globular ferruginous grains found in these sandstones; and it may therefore be inferred that they have had a similar origin. A pisolitic iron-ore of Middle Neocomian age, which occurs at Market Rasen in Lincolnshire, consists to a large extent of spherules very closely resembling the ferruginous grains in the sandstones at Hunstanton.

Tertiary.—Hertfordshire Puddingstone, Lower Eocene, is a conglomerate of flint pebbles united by a concrete consisting of fragments of transparent quartz and greyish flint held together by a flinty cement. In this concrete the quartz is considerably in excess of the flint, and sometimes contains fluid-cavities. Its fragments are all angular, and vary in diameter from $\frac{1}{75}$ to $\frac{1}{250}$ inch.

A specimen of sand from Hordwell, Hampshire, equivalent in age to the Headon beds, contains no recognizable felspar. All the quartz down to a diameter of $\frac{1}{75}$ inch is completely rounded; and even the smallest particles have had their angles entirely removed. Fluid-cavities with bubbles are abundant in some of the quartz constituting this sand.

Sand from the Marine beds, near the top of the Hempstead series, Isle of Wight, was, after treatment with hydrochloric acid, found to be composed chiefly of grains of quartz, of which about three fourths had a diameter of less than $\frac{1}{50}$ inch. These, down to the finest particles, are much rounded, although still roughly retaining the form of the original fragments.

The fine-grained brilliantly coloured sands at Alum Bay, Isle of Wight, of Upper Eocene age, usually classified as Lower Bagshot, have not, as yet, been definitely identified with the beds of the London Basin. By digestion in hydrochloric acid the quartz becomes colourless; and, although not completely rounded, the angles even of the smallest fragments have generally been modified by attrition. Fluid-cavities are not plentiful, and when present seldom enclose bubbles.

Needle-like crystals of schorl are sometimes enclosed in this quartz.

The most considerable bed of sand at Bovey Heathfield, Devonshire, no. 27 of Mr. Pengelly* (Miocene?), consists largely of quartzose fragments, nearly all of which are sharply angular, transparent, and colourless. They contain fluid-cavities with bubbles; but the latter appear to be less numerous than in the quartz of some Cornish granites. Schorl is present in considerable quantity, both as detached crystals and as portions of crystals, also as needles penetrating quartz.

Post-Tertiary.—Sand washed from the Lower Boulder-clay at Holywell, Flintshire, is largely composed of small quartz pebbles, rounded grains of various felspathic and other rocks, and numerous fragments of millet-seed sandstone. A few unworn quartz crystals resulting from the disintegration of crystalline sandstones, and some angular grains of quartz, were also observed. Even the smallest particles of this sand are often rounded.

The larger grains of a sand of Middle Glacial age which occurs in this locality are either rounded grains of quartz or of some other rock, or small pebbles of millet-seed sandstone. Those of medium size are millet-seed quartz grains, mixed with a few unworn crystals and angular pieces of the same mineral.

A specimen of Middle Glacial sand from Bagilt in the same county differs in no respect from the foregoing, excepting that crystals of quartz derived from crystalline sandstones are rather more numerous, angular fragments are less rare, and broken millet-seed grains are of more frequent occurrence.

The Middle Glacial drift at Colwyn Bay is mainly composed of small pebbles of various rocks, principally of quartz, with a few unworn crystals of the same mineral, resulting from the disintegration of sandstones. In this drift the smallest fragments, although generally rounded, have not been converted into minute pebbles.

At different times I have examined numerous specimens of recent water-borne sands. Among these, that on the sea-shore at Pentewan in Cornwall is, as described, p. 24, perfectly sharp and angular, as is the sand on the beach at Par, about six miles further east. According to Dr. Sorby such is also the case with regard to the sands of the modern beach at Scarborough, and those of the river-terraces at Dunkeld.

A large proportion of the quartz in the sands of the Thames valley is sharply angular, although mixed with rounded grains of the same size. The grains of the auriferous sands collected on the coast of Northern California are likewise for the most part angular, although perfectly rounded ones are at the same time present.

Among the blown or æolian sands which have been examined is one from the Great African Desert, and another from Arabia Petræa. The grains of these are, without exception, much worn; and there is no admixture of the angular fragments found in

* "The Lignites and Clays of Bovey Tracey," Phil. Trans. 1862, vol. clii. p. 1019.

all subaqueous deposits; the majority are in the state of minute well-rounded pebbles. As in the case of water-borne sands, the effects of attrition are more conspicuous in the larger fragments than in the smaller ones; but even the most minute particles are in these sands much rounded. Exceptionally the quartz encloses fragments of a felspathic material; and fluid-cavities with bubbles are not entirely absent in African specimens.

A bed of sandstone, said to occur in a salt-producing district sixty miles south-east of Tebessa, of which some years ago I brought a specimen from Tunis to London, is entirely made up of rounded grains. In that respect this rock resembles the millet-seed sandstones of Lancashire and Cheshire; but it is unlike them, inasmuch as no crystals of quartz, or of any other mineral, have been deposited upon the surfaces of the rounded granules.

Modern blown sands, of which we have numerous examples in this country, differ from desert sands and from those of certain sandstones only in being usually somewhat less completely rounded. Among the sands of this description which have been examined are specimens from the dunes at Rhyl, Flintshire, Colwyn Bay, Denbighshire, Lytham, Lancashire, and from Perranzabuloe and Lelant, in Cornwall. Speaking generally, the sands from the northern localities have been more completely rounded than those from Cornwall, and consist of a mixture of worn quartz and various slaty and other rocks, with a little felspar and a few fragments of shells. Fluid-cavities with bubbles are rare in the quartz of these sands. In addition to rounded grains of various slaty and other rocks, quartz, felspar, and fragments of shells are present; among these quartz largely predominates. The Cornish sands contain a few partially rounded prisms of tourmaline.

Chemical Composition of Sandstones &c.—A microscopic examination of a large number of sections of grits and sandstones having led to the conclusion that many of the published analyses of such rocks must be of a very imperfect character, five different specimens were selected for analysis.

In making these analyses I have received the valuable assistance of Mr. E. W. Voelcker, A.R.S.M.; and in each case fusion with alkaline carbonates was adopted. The estimation of alkalies was made after an attack by hydrofluoric acid, and was checked by a fusion with carbonate of calcium and chloride of ammonium.

*Analyses**.

	I.	II.	III.	IV.	V.
Water { hygrometric	·125	·150	·050	·400	·150
Water { combined............	·935	·700	1·290	·850	·300
Silica	80·600	75·750	87·400	85·550	87·150
Alumina........................	9·200	8·227	3·997	7·570	3·948
Carbonic anhydride	1·025	....	1·876	....	1·200
Phosphoric anhydride	·076	0·15	trace.	·070	trace.
Sulphuric anhydride	trace.	·171	·060	trace.	·094
Ferric oxide	trace.	10·521	....	....	1·352
Ferrous oxide	2·370	1·352	1·366	1·915	
Ferric persulphide (FeS_2) .	....	....	·300	·753	·203
Manganous oxide	·232	trace.	·279	....	
Lime	1·330	·532	1·932	·588	2·681
Magnesia	1·285	·360	·684	·612	1·080
Potassa	1·647	1·059	·741	·915	1·273
Soda	1·372	1·283	·332	1·113	·840
	100·197	100·120	100·307	100·336	100·271
Specific gravity	2·689	2·464	2·710	2·531	2·660

I. Grit, Cambrian: Barmouth, North Wales.
II. Sandstone, Carboniferous †: Yoredale Series, Shalk Beck, Cumberland.
III. Sandstone, Carboniferous: Millstone-Grit Series, Brigham, Cumberland.
IV. Sandstone, Carboniferous: Lower Coal-measures, Spinkwell quarry, Bradford.
V. Sandstone, Triassic: Bunter, Bootle Well, Liverpool.

Examination of Water-borne Sands.

With the view of to some extent studying the action of running water upon the mineral fragments which it transports, a microscopical examination was made of the sands of the St. Austell river, in Cornwall. This stream, which during the summer months is a mere rivulet of moderate size, sometimes in winter becomes a considerable torrent. Its eastern arm arises at a distance of two miles and three quarters from the town, and at a height of 470 feet above the foot of the weir at the "Old Bridge." Its western arm, which meets the other a little north-west of the town, takes its rise in a small valley only a mile from the point of origin of the more easterly branch. From the bridge the distance to the sea at Pentewan is four miles, while the total fall is only 114 feet.

This stream formerly carried with it into the bay vast quantities of the granitic sand which is separated by washing from china-clay at the different clay-works in the district. As, however, catch-pits have of late years been employed for the purpose of retaining it at

* Since the above were completed, my attention has been directed to some analyses published in U. S. Geol. Survey, XLth Parallel, vol. ii. pp. 35 & 246, which agree very closely with those here given.

† A white fine-grained sandstone, much spotted with brown.

the several works, the quantities thus transported are now very small.

On the eastern branch a certain amount of granitic sand escapes into the stream almost immediately at its source; this is repeated at short intervals for a distance of a mile and a half, and finally ceases a mile and a quarter above the Old Bridge, at a height of about 200 feet above the weir-foot.

The first introduction of sand into the western branch takes place nearly a mile below its source, and is discontinued half a mile further down its course, but at a somewhat lower level than in the case of the eastern fork.

It follows that, before arriving at the bridge, each grain of sand must have travelled over a distance of at least a mile and a quarter, with a fall of above 150 feet, while a portion of it has been transported two miles and three quarters through a channel thickly strewn with granite boulders, and having a fall in that distance of 470 feet.

Before arriving at the sea, therefore, the whole of the sand must have travelled at least five miles and a quarter, with a minimum fall of about 270 feet, while a portion of it will have been transported a distance of six miles and three quarters over a total declivity of 584 feet.

The first samples of material were collected from the bed of the river a little below the bridge, and a mile and a half from the point at which the last granitic sands are discharged into the stream.

For the purpose of facilitating a microscopical examination of these sands, they were divided into four different parcels by a series of sieves, the first sieve allowing to pass through it all fragments less than $\frac{1}{40}$ inch in diameter, the second those having a less diameter than $\frac{1}{80}$ inch, and the third all particles having a smaller diameter than $\frac{1}{160}$ inch.

The largest fragments, retained upon the coarsest sieve were about $\frac{1}{4}$ inch in diameter, graduating to a diameter of $\frac{1}{40}$ inch.

This sand consists of a mixture of quartz, felspar, schorl, and mica, in which the last-named mineral is present in smaller proportion than any of the other minerals. When examined by reflected light, and magnified 20 diameters, the edges and points of the different fragments of quartz and schorl are found to be sharp and unrounded; the only exception being in the case of certain grains of quartz, which Dr. Sorby suggests may have been corroded by the action of alkaline waters, but which may have perhaps never possessed other than rounded outlines.

The angles and edges of the felspar and mica are, on the contrary, distinctly rounded; and although this might have been anticipated as regards the mica, it is at first sight not so easily understood in the case of felspar, whose density and hardness differ but slightly from those of quartz. It must, however, be remembered that the grains of felspar had become externally kaolinized while still forming an integral portion of the decomposed granite, and that, on the removal of this coating of china-clay by washing, a rounded central nucleus will remain.

Sand which had passed through the $\frac{1}{40}$-inch apertures of the first sieve, but which was retained by the $\frac{1}{80}$-inch openings of the second, has a similar composition to that of coarser grain. The quartz and schorl are both angular; the felspar is more rounded than the quartz; and the mica, which is more plentiful than in the coarser sand, is much worn on the edges.

The sand, which after passing through the $\frac{1}{80}$-inch sieve was retained on the $\frac{1}{160}$-inch sieve, consists of a mixture of angular quartz, unworn crystals of tourmaline, grains of felspar (some of which are rounded) and flakes of mica (which are much worn on the edges).

An examination of the material which passed the sieve having apertures $\frac{1}{160}$ inch in diameter, shows that its grains are entirely unwaterworn. The proportion of mica is much larger than in the coarser sands, and there is less felspar; but most of the grains have had their angles removed. The quartz is generally in the form of tabular flake-like fragments, while the schorl often occurs as small acicular crystals.

The quartz of these sands is frequently penetrated by needles of schorl; and when mounted in balsam it is seen to be full of fluid-cavities containing bubbles—in this respect differing entirely from the quartz of the Cornish grits, as well as from that of the majority of sandstones.

Specimens of the sandy deposit were taken from down the course of the river, at intervals of a mile apart, the last having been obtained at a point slightly above the sea-level at high water at Pentewan. In every case, however, they so exactly resembled those first taken from below the Old Bridge at St. Austell as not to require detailed description. The quartz and schorl are angular, the felspar is more or less rounded, and the larger flakes of mica are worn at the edges. With regard to the distribution of sand along the river-bed, it is needless to remark that the coarser fragments are found towards the centre of the stream, while the finer silt, with minute flakes of mica and quartz, accumulates in less rapidly moving currents near the banks.

Having found that quartz grains below $\frac{1}{10}$ inch diameter are not in the slightest degree rounded by a minimum transit of five miles and a quarter down the course of the stream, it was thought desirable to ascertain the effect of a prolonged action of the waves upon the sand lying on the sea-shore.

It must be here remarked that since the first opening of china-clay works in this district, now about sixty years since, millions of tons of granitic sand have been carried into the sea by the streams into which it was discharged. The effect of this at Pentewan has been to silt up the harbour to a very serious extent; while the whole of the sands upon the sea-beach bear evidence of having been derived from the same source.

The point from which the specimens were taken for examination is situated at a distance of half a mile west from the present mouth of the stream by which the sands were brought down. They were collected from the water's edge at half-tide; and as the discharge of granitic sands into the river has been very small during the last ten or twelve years, and this point is considerably removed from its mouth, it is evident that a large proportion of the grains taken must have been subjected during many years to the wearing action of the waves.

An examination of this sand shows that quartz having a diameter between $\frac{1}{20}$ and $\frac{1}{50}$ inch is usually angular, although some of the larger pieces are distinctly (but not considerably) rounded. The schorl, like the quartz, generally presents sharp angles, although somewhat abraded grains of this mineral are occasionally met with. Nearly all the felspar is rounded to a considerable extent, as is also the small quantity of mica which is present.

Below $\frac{1}{50}$ inch in diameter the angularity of the fragments of quartz and schorl is perfect, with the exception of occasional "corroded" grains; the felspar has, for the most part, rounded outlines; and mica is almost entirely absent.

At page 32 of his Address to the Geological Society of London (1880) Dr. Sorby remarks:—"Unfortunately I am not acquainted with sufficient facts to prove how long it would require to thoroughly wear down and round a grain $\frac{1}{100}$ inch in diameter. It is evident it is a very different thing from the wearing of a pebble, and may require a longer period of wear than we might suspect, if we did not bear in mind that when buoyed up by water the friction of such small particles on the bottom must be always small." Again, at page 34, he says:—"It appears to me sufficiently proved that a great amount of drifting and mechanical action must be required to wear down angular fragments of quartz into rounded grains $\frac{1}{100}$ inch in diameter, which I have taken as the standard for comparison."

Professor Daubrée states that the diameter of grains capable of floating in slightly agitated water is about $\frac{1}{10}$ millimetre, or, say, $\frac{1}{250}$ inch, and remarks that all smaller grains must of necessity remain angular*. He subsequently says that a current or wave capable of carrying off in suspension particles of that diameter, without in any way affecting their form, would cause larger fragments of the same mineral to so rub one against another as gradually to produce rounded sand. According to an experiment quoted by this author, a sand of which the grains have a diameter of $\frac{5}{10}$ millimetre, say $\frac{1}{50}$ inch, to which a movement of one metre per second is imparted, becomes rounded, with a loss equal to $\frac{1}{10000}$ of its weight per kilometre traversed.

This experiment appears to indicate that a grain of quartz $\frac{1}{50}$ inch in diameter requires, before becoming completely rounded and assuming the form of a miniature pebble, an amount of abrasion equal to that which would result from having travelled a distance of three thousand miles. In arriving at this conclusion the fact must not be lost sight of that, after the first rounding of the

* Géologie Expérimentale, p. 256.

angles and edges, the operation will gradually become slower as the surfaces become more worn and the weight of the grain decreases.

That angular fragments of quartz having a diameter of less than $\frac{1}{50}$ inch remain unrounded by the continuous action of breakers after many years' exposure, is evident from an examination of the sands at Pentewan. It has been shown by other evidence, as well as by the recent experiments of Professor Daubrée, that the rounding-down of such sands by the action of running water must be an exceedingly slow operation, and one requiring a somewhat active current with an amount of friction equivalent to transport over enormous distances. Grains of quartz of similar dimensions are, in blown sands, completely rounded.

Summary and General Conclusions.

The Cambrian grits of Barmouth contain quartz and felspar, both in the form of angular fragments and also as rounded pebbles. The materials presenting these different forms have probably been derived from two distinct sources; while the large size and complete sharpness of the angles of many of the irregular grains appear to indicate that they cannot have been transported from any considerable distance, and that the felspar cannot have been derived from kaolinized granite.

All the arenaceous rocks of Silurian age which have been examined contain a small proportion of felspar, the grains of the various constituent minerals being in some cases angular, and in others rounded.

Many of the rocks belonging to this period are composed of a mixture of grains of both forms. Among rocks mainly composed of rounded grains are the Stiper Stones of Shropshire and the Lower Lickey Quartzites of Westmoreland. Some of the grits from the neighbourhood of Aberystwith enclose fragments of a volcanic rock of doleritic character.

The grits of Cornwall, which are of at least Devonian age, include flakes of soft slaty rocks, the edges of which are perfectly sharp, together with angular fragments of the well-known "greenstones" and "dunstones" of that county.

A large number of the Carboniferous, Permian, and Triassic sandstones are composed almost entirely of quartz crystals, which have undoubtedly been produced *in situ*, as they not only penetrate and interpenetrate one another, but also exhibit the most perfect sharpness and freshness of outline. As confirmatory of this hypothesis it may be mentioned that in a quarry at Foggen Tor, on Dartmoor, the felspar has in places become decomposed into soft kaolin, in which the liberated silica is imbedded in the form of aggregations of well-formed and transparent quartz crystals *. Unworn double-pointed crystals of quartz, likewise resulting from the decomposition of felspar, have recently been found near St. Austell, Cornwall, in soft china-clay; one of these, more than three

* Quart. Journ. Geol. Soc. vol. xxxvi. p. 9.

inches in length, is now in the collection of the Museum of Practical Geology. Sandstones of this description are not unfrequently without any kind of cementing matrix, being merely felted together by a matted intergrowth of their constituent crystals.

Professor Daubrée entertains the opinion that crystalline sandstones frequently owe their origin to chemical agencies resulting from an outpouring of igneous rock; but, although this may sometimes have been the case, many of the most completely crystalline British sandstones are situated at distances of many miles from any known rock belonging to this class. The same author maintains that the presence of anhydrous ferric oxide in sandstones affords evidence of their having been subjected to a high temperature*. It must, however, be remembered that the carnallite of Stassfurt, which has evidently never been highly heated, contains crystals of specular iron-ore.

Numerous fine-grained sandstones, particularly among those of Triassic Age, are composed of quartz grains so completely rounded as, under the microscope, to resemble well-worn pebbles. These "millet-seed" sandstones are often coloured either red or brown by variously hydrated oxides of iron; and in some cases minute, perfectly formed, and beautifully transparent crystals of quartz have been developed upon their surfaces.

On attacking the sand of such sandstones with hydrochloric acid, the oxide of iron is easily removed, but the crystals of quartz still remain firmly attached to the surface of the grains upon which they have grown. It would also appear that crystals have been formed upon those parts only of the grains which, having been free from a coating of oxide of iron and from every other extraneous material, have admitted of direct chemical contact between the silica of the rounded quartz and that of the subsequently formed crystals †.

In addition to silica in the form of perfect crystals of quartz, that substance has often been deposited in such a way as to fill cavities existing between the original grains of sand.

As this silica has frequently been thrown down upon a thin deposit of ferric hydrate, it is generally detached by prolonged digestion in hydrochloric acid, by which the intervening ferruginous coating of the grains is ultimately removed. When such a deposit of silica adheres to only one of the adjoining grains it may give rise to a depression upon its surface of the kind represented in fig. 4, Pl. II.

On examining a considerable number of modern sands, none of them, excepting such as had long been subjected to the wearing effects of wind action, were found to resemble those of the millet-seed sandstones in having all their grains reduced to a pebble-like form. Among these the grains of blown desert-sands most completely resemble those of millet-seed sandstones.

* Géologie Expérimentale, pp. 226–230.

† With regard to the Torridon Sandstones of the Central Highlands it has been observed by Professor Bonney that wherever "dirt" has been deposited upon the siliceous grains their agglutination has been prevented (Quart. Journ. Geol. Soc. vol. xxxvi. p. 106).

The above facts would appear to render it probable that the rounded grains of these sandstones may be of æolian origin, and that, during certain periods of Triassic time, desert areas with blown sands extensively prevailed in this country.

Mr. De Rance has observed that the millet-seed beds are usually free from pebbles, shale-beds, pseudomorphs after common salt, and from all traces of life*—conditions which are characteristic of deposits produced by wind-currents.

The granules of brown iron-ore which are so plentiful in the "Carstones" of Hunstanton are pisolitic grains, and not fragments of that mineral rounded by attrition.

An instructive example of the occurrence at the same time of rounded and angular grains is met with in the Interglacial sands of Flintshire, where some of the pebbles are fragments of a millet-seed sandstone, while many of the smaller particles are grains detached from the same rock.

EXPLANATION OF PLATES I. & II.

Plate I.

Magnified 18 diameters.

Fig. 1. Group of felspar crystals in Cambrian Grit. Polarized light: p. 7.
2. Grit from Ladock, Cornwall, enclosing a fragment of a volcanic rock. Polarized light: p. 10.

Plate II.

Magnified 100 diameters.

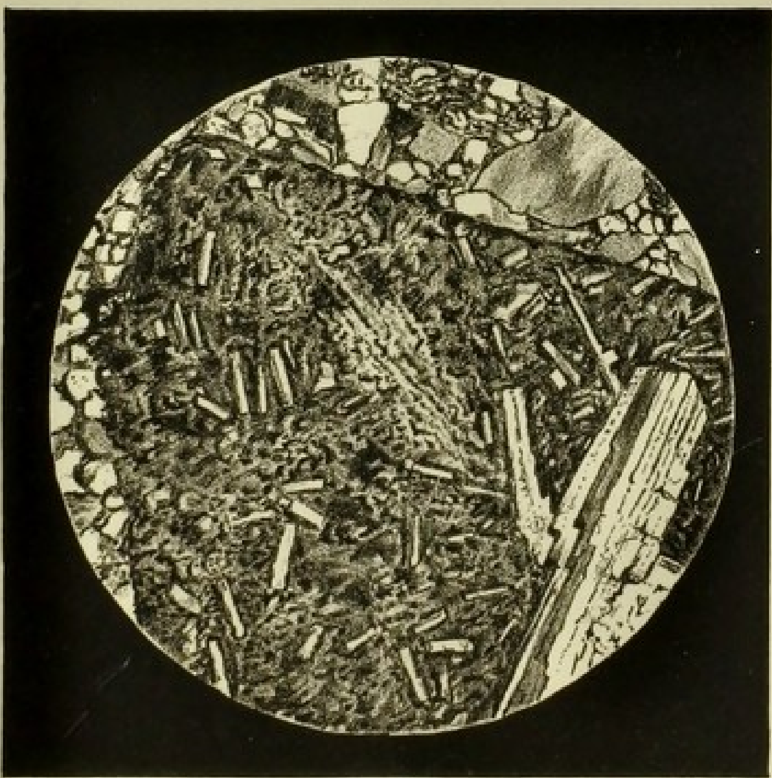
Figs. 1, 2, 3, & 5. Crystals of quartz deposited upon rounded grains of the same mineral in Bunter Sandstone: p. 13.
4. Depression in a grain of quartz from the same sandstone.
6. Corroded grain of felspar from the same.
7. Rounded grain of quartz with attached crystal of iron pyrites.

* "Further Notes of Triassic Borings near Warrington," read before the Manchester Geol. Soc. June 29th, 1880.

1.

x 18

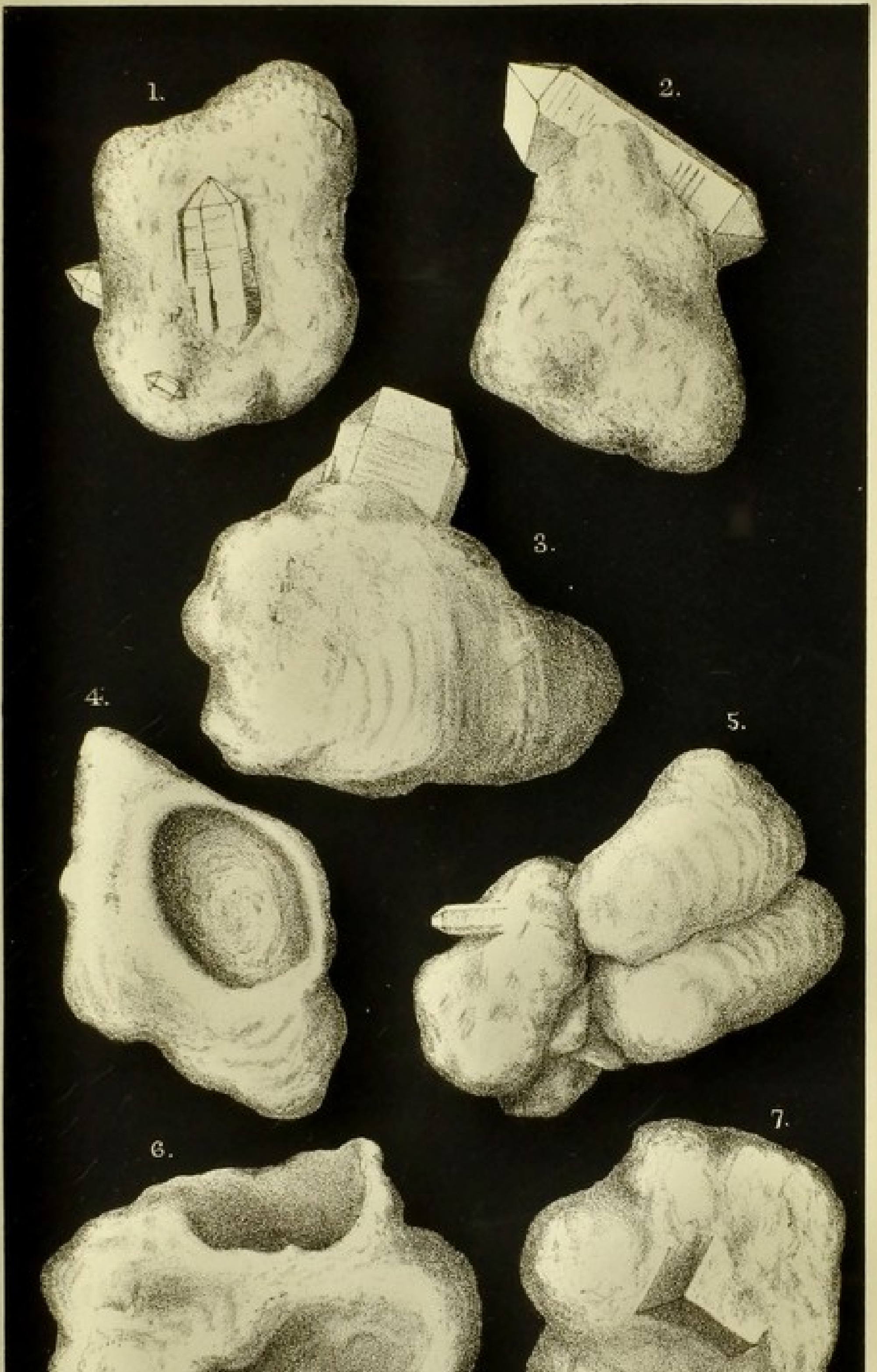
2.



x 18

Frank Rutley, del. Mintern Bros. imp.

SECTIONS OF GRITS.



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SAND GRAINS.