usually less than half their diameter apart, in some cases almost contiguous; margin slightly exsert, but calyx sunk below general surface; walls crenulated and infolded to form twelve short septa, extending inwards from one-quarter to one-third the diameter of the calyx. Smaller corallites (coenenchyma) not numerous, usually only 2-4 irregular rows between the larger corallites; polygonal in shape, with well-developed walls and regular horizontal and mostly equidistant tabulæ, so as to divide the tubes into a series of square cells.

MEASUREMENTS.

	mm.
Diameter of calyx of larger corallite	1-1.5
Length of corallum	80.0
Diameter of corallum at base	20.0
Diameter of corallum at crown	55.0

REMARKS.—This species differs from *H. Grayi*¹ in the rounded or lobate form of the branches, and in the number, approximation, and depression of the calices of the larger corallites. From *H. inordinata* it differs by possessing stouter, more lobate branches, more numerous, closer and larger corallites with depressed calices, and less abundant coenenchyma. A Norwegian species named *Plasmopora ramosa*, Kiær, has been recently described² which bears a considerable resemblance to *H. cæspitosa*, and is stated to be closely allied to *H. Grayi*. It differs in the more exsert margins of the corallites, the absence of septal prominences, and in the wider spaces between the corallites. The internal structure, moreover, which is the most important feature, appears to be distinct.

EXPLANATION OF PLATE XVI.

FIGS. 1, 2.—*Goniophora grandis*, Salter. Wenlock Limestone: Dudley. Fletcher Coll. Nat. size.

FIG. 3.—*Modiolopsis minus*, Salter. Upper Ludlow: Lesmahagow. Enlarged $\frac{2}{3}$ nat. size.

FIGS. 4, 5.—*Orthonota Hughesi*, Salter. Lower Llandovery Beds (Upper Bala, Salter): Sefin Llettyrhyddod, Llandovery. Fig. 4, side view; Fig. 5, hinge aspect of shell. Enlarged $1\frac{1}{2}$ nat. size.

FIG. 6.—*Heliolites cæspitosa*, Salter. Wenlock Limestone: Dudley. Fletcher Coll.

FIG. 7.—Portion of corallum, enlarged $\frac{2}{3}$ nat. size.

III.—ON THE MAKING OF A QUARTZ SCHIST.

By JOHN PARKINSON, F.G.S.

IN a paper published³ some eight years ago, Prof. T. G. Bonney discriminated between the dominant characteristics of quartz schists from the Alps and quartzites modified by pressure. The distinctions as therein pointed out may be thus summed up.

In a quartz schist we find an absence of indications of original fragments, the shape of the quartzes proving that they were formed *in situ*; together with no evidence "that the mica in its present form is derivative"; from which it almost necessarily follows that

¹ Edwards & Haime: Brit. Foss. Corals (Palæont. Soc.), p. 252, pl. lviii, fig. 1.

² Kiær: Die Korallenfaun, Ét. 5, Norweg. Silur., p. 32, t. v, figs. 5-6: Palæontographica, Bd. xlvii, 1899-1900.

³ GEOL. MAG., Dec. III, Vol. X (1893), p. 204; also GEOL. MAG., Dec. IV, Vol. III (1896), p. 400 ("On a Pebbly Quartz-Schist from the Val d'Anniviers").

the origin of the rock is "a matter of conjecture" rather than of proof (p. 209, etc.). In a quartzite the contrary holds. The elastic origin of the quartzes is obvious, and the form and mode of occurrence of the mica shows it to be detrital; hence the characters separating normal types of the two groups of rock are clear enough in a thin section, if not in a hand-specimen.

The rocks which form part of the subject of the present communication were collected from the neighbourhood of the Illecellewaet Glacier in the Selkirk Mountains; and microscopically present a structure intermediate between that of a quartz schist and that of a quartzite.¹

Since the gap which separates these two rock types is one which is seldom bridged, I venture to think it may be profitable—(1) to consider the changes which have taken place in the North American rocks which will be referred to as quartz felspar grits; (2) to compare the latter with some of the older quartzites of India, which present indications of change of a rather different kind; and (3) to see what help the whole affords in elucidating the difficult problem—the making of a quartz schist.

1. THE QUARTZ FELSPAR GRITS.²

These form a group of rocks exhibiting slight variations in degree of coarseness and manner of fracture, commonly speckled with obvious grains of felspar and quartz; although the sheer surfaces, formed through the development of secondary mica, record the pressure which the rock has undergone. In a few localities, e.g. the moraine of the Illecellewaet Glacier, elongated ellipsoidal spots are conspicuous, exhibiting a parallel arrangement, and which average in size .5 in. $\times$.15 in. $\times$.05 in. As seen in a thin section they consist of very irregular grains of calcite, outlined by an iron staining, which straggle through the other constituents instead of forming a clearly defined patch. These may possibly be the remains of worm burrows distorted by pressure.

¹ See also a paper by Professor T. G. Bonney in *Quart. Journ. Geol. Soc.*, 1888, vol. xlv, p. 32, on the Huronian Series in the neighbourhood of Sudbury (Canada); a sedimentary series showing changes which approximate them in character to a true schist. I am greatly indebted to Professor Bonney for opportunity to study his slides of these rocks, and for suggestions given from time to time on this and kindred subjects.

² The age of these rocks is a matter of interest. The identification is a rather difficult one, and I am indebted to Dr. Whiteaves and Dr. H. M. Ami, of the Canadian Geological Survey, for kindly replying to my question on the subject. To the E.N.E. of, and about eighteen miles as the crow flies from, the Illecellewaet Glacier, a Lower Cambrian fauna has been found, and to the westward lies the Shuswap Series, probably of Archaean age. Above the latter and to the east are "dark argillites passing into micaceous schists" (Summary Rep. 1890-1, n.s., v, pt. 1, p. 20A). These are the Nisconlith Series (Lower Cambrian), probably equivalent to the Bow River Series. See also papers by the late Dr. G. M. Dawson, *Bull. Geol. Soc. Amer.*, vol. ii, pp. 165-176, "Note on the Geological Structure of the Selkirk Range," and *Ann. Rep. Geol. Surv. Canada*, 1896, vol. vii, pt. B, pp. 28B-34B, in which the quartzites in the vicinity of the Glacier House, Mountain Sir Donald, etc., are placed in the Cambrian system under the name of the Selkirk Series and overlying the Nisconlith Series.

The remnants of original mineral grains are conspicuous in most of the thin sections. The presence of feldspar, both orthoclase and plagioclase, together with quartz, indicate either a quartz feldspar grit or a quartz felsite. The great preponderance of quartz and the very clastic appearance of the feldspars clearly point to the former rock; in fact, in many instances the names of quartzite and quartz feldspar grit are still applicable, in spite of considerable mineralogical and structural modifications.

The condition of the feldspars is the most interesting feature. Mineralogical change is made manifest by a cloudiness in the interior of the crystal, due to the presence of innumerable minute scales, flakes, or prisms of a mineral which, no doubt, is a mica. Towards the periphery of the crystal the latter pass into a fringe of well-formed flakes intermingled with grains of quartz, the character of the former being identical with that of the typical quartz schists of the Alps. Occasionally a system of lines of greater change, and probably of incipient fracture, traverses the crystal, and is marked by closely aggregated scales and flakes of mica. At the same time crush shadows form, followed in due course by fracture and loss of uniform polarization; while, frequently, more or less clear spots appear representing developing individuals of quartz or secondary feldspar; the outcome being complete disintegration and reconstitution.

Some of the larger quartz crystals have exceedingly irregular edges and exhibit undulose extinction; and in the smaller grains a similarity of size and of polarization tints is often characteristic, together with some elongation in the direction of foliation. In a more advanced stage of reconstruction a more marked parallelism exists between the flakes of mica. While these are for the most part spread through the rock in thin and irregular bands, they are also embedded in the quartz grains, or wedged between their edges, and have even trespassed the boundary between two individuals. In some sections they reach $\cdot 009$ inch in length. The presence of a mica flake in the centre of a quartz grain, which is large in proportion to it, and situated near a system of fine cracks by which this grain is traversed, indicates the passage of the mica substance in solution by capillary action. The cracks contain specks of a mineral (about $\cdot 0025$ inch across) which may be referred to mica. Now and then such flakes appear where no obvious cracks exist, and occasionally a long thin wedge of mica flakes penetrates the quartz grain. The condition of the mica is different to that of the mineral produced by the mere crushing of a quartz feldspar grit; the distinction consisting in this, that in the rocks under consideration the mica forms definite flakes usually bounded by definite lines, whereas simple crushing produces a matted intergrowth of film-like scales which ordinary powers and ordinary thin sections fail to resolve into its components. The smaller quartz grains—commonly $\cdot 004$ to $\cdot 009$ inch across—possess angular or subangular outlines, are not conspicuously elongated at right angles to the direction of pressure, and do not exhibit undulose extinction to any

noticeable degree. Hence the strain produced by the pressure the rock has undergone has been removed from the greater part of the rock, while the larger and obviously clastic grains still bear its marks.

The rock does not appear to have undergone serious deformation since it assumed its present condition, and as regards the state of the quartzes at the time of maximum pressure we are met with evidence of two and diverse kinds. Firstly, we find clear indications of incipient cracks, conical in section but with slightly concave outlines, which are usually characteristic of mineral matter stressed beyond its elastic limit, and pointing to the crushing of a practically rigid solid; whereas, secondly, the irregular shape of the quartzes under the microscope are suggestive of a plastic deformation, e.g. some have been apparently bulged out by an intruding finger of the rock, or the like.

On the whole I conclude that the constituents of the rock have been partially plastic under the stress to which they have been subjected, but at the same time sufficiently rigid to have cracked in the process.

With the assumption of these characters disappears the smashed-looking aggregate so universally indicative of crush. The mica clearly has been formed *in situ*, and the production of the quartz mosaic by crushing and subsequent reconstitution could not be safely predicated simply from an examination of this part of the section. The grains of felspar scattered throughout the slide are plentifully sprinkled by minute crystals of mica, or slightly discoloured by brownish dust, but otherwise are quite translucent, and show well-defined polysynthetic twinning (12° to 15°). We find, then, almost a new rock; the traces of original quartz grains are few in number; the mica has been formed *in situ* and does not suggest a clastic origin; and the greater proportion of the felspars have undergone reconstruction.

2. THE QUARTZITES OF DELHI AND JAIPUR.

Of great antiquity¹ and greatly altered, the old quartzites of India near Delhi and Jaipur yet show no resemblance to the rocks above described. A specimen taken from the celebrated 'Ridge' at Delhi consists of quartz and thickly scattered, exceedingly small crystals of various minerals. The most common of these are shapeless flakes and scales of a quite colourless mica, averaging roughly $\cdot 003$ inch across, distributed without any orientation through the rock, commonly at the junction of two or more quartzes. Indications of the basal cleavage are usually wanting, and there is no evidence that the mineral is detrital. In addition, we find flakes of a gummy brown to greenish brown tourmaline (and possibly some of brown mica), many of which are exceedingly minute, often not more than $\cdot 0006$ inch in diameter, and which usually exhibit rounded outlines, especially in the smaller grains. Other constituents occur, but are

¹ They are a member of the transition system, i.e. they occupy an intermediate position between the gneisses and the older Palaeozoic rocks.

not easy to identify, including, however, calcite, zircon, specular iron, and pyrites. Between crossed nicols we realize the shapelessness of the quartz grains, which interlock the one with the other as irregular polygons without any trace of an orientation. They average $\cdot 019$ inch across. A slice taken from the very similar quartzite of the Kutub, 11 miles south of Delhi, possesses less white mica and associated minerals, and the quartzes are dustier and exhibit outlines still more fantastically irregular.

As in the preceding slide, although we find indications of undulose extinction, this is the only sign of pressure, so that any crushing of the grains which may have occurred has been almost entirely obliterated. Now and then, indeed, we seem able to recognize that the longer axes of the grains have a common direction; but the haphazard cross-sections show outlines sometimes almost of a horse-shoe shape with waved edges, at others elongated with many irregular projections. The quartzes contain many rounded spots of felspar; these are unstriped, rather opaque, and often roughly rectangular in section, exhibiting then an obscure orientation. So far as it goes this last-named feature indicates rearrangement *in situ*. An average size is $\cdot 008 \times \cdot 003$ inch. A few brown zircon prisms and some crystals of magnetite are found. A specimen from the top of the ascent to Ambér from Jaipur also contains felspar fragments, in many of which polysynthetic twinning (extinction 15°) is still discernible, but which also occur as rounded grains included in a quartz crystal, and often are better defined than happens in the preceding slide.

The quartz contains rows of inclusions and gas cavities which have a common direction and occasionally extend without interruption from one grain to another. Strain shadows are inconspicuous, but the parallel lines of inclusions indicate that the rock has been subjected to a certain degree of pressure. The felspars, however, appear not to have suffered in the least, and we find no attempt to break up into mica and quartz. The slide contains also grains of bluish-green tourmaline up to $\cdot 016$ inch in length, magnetite, zircon, and a few elongated flakes of a green mica.

These rocks form a group usually possessing a saccharoidal lustre and close-grained texture, and are distinguished microscopically by the absence of evidence of pressure and by the irregular outline of the quartz grains. These outlines must naturally have been acquired *in situ*, the structure of the whole proving great alteration.

CONCLUSIONS.

The recent researches of Messrs. Adams and Nicolson on the 'Flow of Marble'¹ are of considerable interest in the present enquiry.

In these experiments stumpy columns² of Carrara marble were enclosed in tightly encasing jackets made of a material possessing

¹ "An Experimental Investigation into the Flow of Marble": Phil. Trans., 1901, vol. 195 A, p. 363.

² An inch or rather less in diameter and about 1.5 inches in length.

a high elastic limit and considerable ductility. The marble, which alone was subjected to pressure, was shorter than its casing, and was squeezed by means of plugs passing into the ends of the jacket; pressure being continued until the bulging of the latter was carried almost to the point of rupture. The rock was squeezed under three sets of conditions—in the first at normal temperature and dryness; in the second heated to 300°–400° C.; and in the third permeated by water vapour at a pressure of 460 lbs. per square inch, the heating being the same as in the second series. The following results appear significant.

1. The crushing load of the deformed marble of the first series was considerably less than that of the natural rock; due, it is thought, to the production of 'cataclastic structure' along certain lines; in the second series the crushing loads were nearly equal, and in the third series that of the deformed rock was at least equal¹ to that of the natural. Messrs. Adams and Nicolson remark that in these experiments the presence of water was not observed to exert any influence.

The absence of cataclastic structure in series two and three and the high crushing load of the deformed rock indicate that the constituent grains of the marble have suffered no loss of elasticity, but that the conditions were such as to allow different molecular groupings as the pressure increased.

2. The experimenters conclude that under the second and third sets of conditions the marble "has not been crushed in the ordinary sense of the term," but that deformation has been principally produced by slipping on the gliding planes of the component crystals.

3. The shape and character of the grains thus produced closely resemble those of a schist.

In accord with these results is the conclusion reached by Messrs. Ewing and Rosenhain² in describing the deformation of certain metals, that "each crystalline grain changes its shape through slips occurring within itself, and its position through slips occurring in other grains"; and they point out elsewhere³ that, if the adaptability of the grains to accommodate themselves to the increasing pressure by this means is insufficient they will be "driven into and through one another"; a result readily conceivable in the case of such a material as lead, but which, in the widely different substances usually considered by the geologist, seems to require something more than mere pressure.

The 'Upper Slate Member' of the Penokee Iron-bearing rocks (Huronian) described by Irving and Van Hise⁴ is a case where the work of pressure appears to have been reduced to a minimum. Here we have the production of a new rock from a greywacké, a quartz or mica schist in which no trace of a clastic origin remains.

¹ Sufficient experiments were not made to determine this point.

² Proc. Roy. Soc., 1899, vol. lxx, p. 90.

³ In an experiment on "the effect of very severe strain on lead": Phil. Trans., 1901, vol. 195 A, p. 285.

⁴ U.S. Geol. Surv. Monographs, xix, 1892, p. 296.

Van Hise concluded, moreover, that the heat produced by any superincumbent mass of strata, i.e. mere burying, is inadequate to produce the results observed.

That the conditions imposed on the marble by Messrs. Adams and Nicolson may be imitated in Nature with sufficient nearness to produce closely similar results, may be taken as established; but it does not follow necessarily that such conditions imposed upon a quartzite would result in the production of a quartz schist. The pronounced cleavage, the habit of twinning, and the softness of calcite allow of a comparatively easy adaptation to altered circumstances; hence marble no doubt readily shows the effects of pressure and heat.

Not only so, but we have frequently to deal in Nature with a rock which instead of being a homogeneous aggregate of grains consists of two or more minerals, the physical properties of which are very different. Apply to such great pressure, accompany it by heat, and limit freedom of movement, then we should expect greatest plasticity to be found in that constituent whose point of fusibility was most nearly approached; and rupture, in varying degree, in the remainder. Since a quartzite or a quartz felspar grit is an obdurate rock, we must infer pressure and temperature to be increased beyond the limits assigned them in Messrs. Adams and Nicolson's experiments, if similar results are to be produced. A cataclastic structure is not a characteristic of a true schist; hence we must rely on heat, and heat plus water, to play the greater part in the reconstruction; while to pressure may be imputed the flattening of the individual grains and the foliation.

In the Delhi quartzites we appear to possess an example of the work of the two former agents, in the Canadian grits of all three combined.

IV.—A VINDICATION OF BACON, HUXLEY, DARWIN, AND LYELL.

By ARTHUR R. HUNT, M.A., F.L.S., F.G.S.

THE recent attempt I have made to show that the absolutely unanimous adverse criticism of Dean Buckland has arisen from a misapprehension of the facts of the case, has led me to enquire further whether the same cause may not account for far more important results in other similar cases, e.g., the attacks of Huxley on Bacon; of Lord Kelvin on Huxley; and of Lord Kelvin and Professor Sollas on Lyell: attacks which cannot fail to lead the unlearned to believe, not that the critics are right, but that all are wrong together, and unworthy of attention.

Having been geologically educated from first to last on the principles of Bacon and Lyell, I have been genuinely mystified by the intense aversion of Huxley to Bacon, as evidenced by a remark made in 1878: "I have been oppressed by the humbug of the 'Baconian induction' all my life, and at last the worm has turned." Now, if ever there was a genuine Baconian it was Huxley himself, as the following extracts taken in order of succession from Bacon's "*Novum Organum*" will suffice to prove:—