THE FORMATION OF CHERT AND ITS MICRO-STRUCTURES IN SOME JURASSIC STRATA.

By CATHERINE A. RAISIN, D.Sc.

[PLATES XIV and XV.]

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INTRODUCTION.

CHERT is attractive even superficially in the curious forms which it exhibits, and in the picturesque features of cliff and scarp which it helps to develop. It is a subject well-fitted for discussion here, since numerous examples of the rock are found in English localities, associated with many formations.* Most of these would be more or less typical in the character of the problems they present, and I have selected examples mainly from Jurassic rocks. To mention others, however, the early Radiolarian cherts of Ordovician age and of the Culm Measures are known through recent investigations. The massive chert of Carboniferous Limestone is a marked feature in Derbyshire, in North Wales and Ireland, in the Mendips and elsewhere. Chert of perhaps Rhætic age occurs in the last-named hills at Harptree, and Permian silicified wood is found in some Midland localities. The Jurassic cherts yield much material, chiefly among the Upper Oolites. In Dorsetshire the fine cliffs and quarries of Portland Isle, and the cliffs along the Isle of Purbeck, often an almost continuous series of quarries, give excellent study for this investigation. Equally valuable are many quarries in the Vale of Wardour, as at Tisbury and Chilmark. Chert can be followed at places in the Lower Greensand from Hindhead and Leith Hill to Maidstone and beyond, and in the Upper Greensand from Dorset or farther west to the Isle of Wight and Kent. While

* The subject was treated by Prof. T. Rupert Jones in parts of the paper "On . . . Forms of Silica . . ." *Proc. Geol. Assoc.*, 1876, vol. iv, p. 439. Also in the Appendix to the interesting account of the Vale of Wardour given by Mr. Hudleston, *Proc. Geol. Assoc.*, 1881, vol. vii, p. 180.

flints in the overlying Chalk can be tracked over a wider area and even in Tertiary beds a little poor chert occurs.

A preliminary question is the difference of chert from flint, but it is not easy to define precisely.* Distinctions can be drawn between typical specimens, but various gradations connect such types. Thus flint is more often in nodules but may be in layers; chert frequently builds up layers but may be in nodules. Chemically, chert has, on an average, a rather lower percentage of silica—has more impurities in it (the substance chiefly associated being carbonate of lime)—but the silica percentage may rise until this distinction from flint disappears. Specimens of flint have usually a conchoidal fracture, chert a splintery. The microscopic structure of flint is generally finer grained, more uniform, containing some colloid silica†—that of chert often more varied and more coarsely cryptocrystalline. But the homogeneous character may be lost from parts of flint; may be taken on by chert. Notwithstanding the gradations, these distinctions (especially that of texture) might perhaps be used if we apply them to any mass or fair-sized specimen, not to a microscopic slice; thus certain very compact bands or nodules in the Portlandian strata would be termed flint.‡ This would be more useful than the common practice of retaining that name for structures in the chalk, and chert for rock elsewhere.

I have visited many examples since I began some years ago to study various specimens of chert§ in the hope that the investigation might throw light on the micro-structure of certain rocks, and the results of crystallisation in different minerals; and it was my intention to limit my discussion to this point of view. But I was led necessarily to some observations which bear upon the general development of chert, and it seemed more useful to include these considerations. I have therefore used a wider title, although these notes are only a small and limited contribution to the work which has been done by more experienced investigators.

The various views as to the origin of the rock have been formulated generally in connection with special cases, and, as has been pointed out by other writers, the origin of different examples may have differed. One possible hypothesis is that the chert (or flint) as we now see it represents the original condition of the solid rock, and that the silica was drawn directly from the waters of sea or lake by chemical precipitation and laid down in colloid

* See Prof. T. Rupert Jones, *Proc. Geol. Assoc.*, vol. iv, p. 448.

† *Cf.* Prof. Judd, "On the Unmaking of Flints," *Proc. Geol. Assoc.*, 1887, vol. x, p. 218.

‡ They are so named by Mr. Hudleston, *Proc. Geol. Assoc.*, vol. vii, p. 180.

§ Some of my earliest study in the field was made during certain of the annual geological expeditions conducted by Professor Bonney for his students from University College.

form. Instead of this process the silica may have been extracted from the water by the action of organisms, and then directly deposited to form the chert. More probably the two processes might have combined, so that if the chert were a contemporaneous formation it represents a nucleus, generally of siliceous skeletal parts, sometimes even of other organic centres, to which a colloid silica from the water or surrounding mud had aggregated, as is described by Prof. Prestwich for the flints of the chalk.*

Many writers consider that chert represents a secondary condition of a rock originally different, generally a limestone. Some authorities who have given the most definite statement of this view have maintained that the deposit occurred partly or wholly during the formation of the beds.† The source of the replacing mineral in the pseudomorphism has to be inferred, and in those rocks it was described as colloid silica deposited by chemical precipitation. Other authors have maintained that the pseudomorphic replacement occurred in a subsequent period.‡

The presence and often abundance of siliceous organisms, however, has been shown in many cherts by Dr. Hinde,§ by Prof. Sollas,|| and by others, and to the former author we owe the investigation of these organisms in various formations from widely distant localities. The evidence is claimed as proving in these rocks, or establishing for chert generally, that the silica was organic in its origin. In this contention the question as to the epoch of deposit is often not discussed.

Thus the main problems to be answered are whether chert is contemporaneous or subsequent—whether it is from inorganic sources or due to organisms. The latter is the question to which recent investigations mainly refer, but, in these Portlandian beds, I have attempted to consider first the previous problem.

I. ORIGIN OF CHERT—Epoch of Formation.

We see in the field that chert frequently occurs in a massive stratum, which often tails off or extends as an elongated lenticular layer. This might be formed as an original deposit or might result from secondary change, but the layer sometimes ends abruptly, which would be more difficult to explain on the former hypothesis. A fine lamination and current bedding are clearly

* *Geology*, p. 323.

† Prof. Hull states that it was "during and after" the formation of the limestone before the overlying beds were deposited. Both Prof. Hull for Ireland and Prof. Renard for Belgium describe the process as occurring in the Carboniferous Limestone while the strata were "in a pasty condition." *Trans. of Roy. Dublin Soc.*, vol. i, n. s., 1878, p. 82, and *Bull. de l'Acad. Roy. de Belg.*, 1878, 2 s., t. xlvi, p. 497.

‡ *Cf.* C. R. Keyes, *Am. J. of Sc.*, 1892, ser. 3, vol. xliv, p. 451, "that the siliceous impregnation had been acquired long after the original deposition of the beds."

§ *Geol. Mag.*, 1887, 3rd ser., vol. iv, p. 435. *Ann. & Mag. Nat. Hist.*, vol. vi, ser. 6, p. 40, 1890. *Phil. Trans.*, 1885. *Pal. Soc. Mem.*, British Fossil Sponges.

|| *Ann. & Mag. Nat. Hist.*, 1881, ser. 5, vol. vii, p. 141.

seen in many Portlandian cherts, as at Tisbury and parts of Portland Isle, and the latter structure especially seems suggestive of the deposit of clastic materials or true sediments, as if the chert had resulted either from the accumulation of siliceous fragments or from the pseudomorphism of a previous fragmental rock like a fine calcareous grit.*

Another mode of occurrence often described for chert and flint is in bands transverse to the stratification. Thus in one of the large Chilmark quarries in addition to the roughly horizontal strata, bands of chert extend both obliquely and at right angles to the lamination, generally tailing off at the end in a wedge fashion, but enlarged at intervals, thus becoming somewhat moniliform or knotted in appearance. Such bands often seem to follow joint planes and may have been deposited either as veins in cracks or spaces, or, starting from the plane of weakness, might represent an infiltration and change of the neighbouring rock.† Both in hand specimens and in slices examined under the microscope, traces of organisms can sometimes be seen,‡ and although some fragments might be enclosed in a fissure, the chert in many examples is evidently a silicified part of the sedimentary mass.

The occurrence of nodular chert yields perhaps even more definite suggestion. The layers already described at Chilmark as ending abruptly, seem sometimes continued beyond by a line of nodules, and, like the transverse bands, the layers may be moniliform. In other cases isolated nodules are scattered through the rock, varying in form, sometimes very irregular, sometimes rounded or elongated, and even thinning out along bedding planes showing relations to the lenticular bands previously described. Other rock surfaces expose a ring of chert, the section of a spheroidal shell which surrounds rock not silicified. The size of nodule or ring is various, from one inch or less in diameter to one foot or more. At Tillywhin, below the fossiliferous freestone, the section of the cliff includes layers of chert along the strata, sometimes cross bands in a vein-like form, and many nodules, small and large, and occasionally a ring of chert. At one part the irregular, rather small nodules project in high relief on the weathered surface of the limestone. To account for the nodules of chert by any original deposition we must suppose that the silica was laid down in the plastic ooze of the sea bed in spots and patches. It seems doubtful if in such cases the chert would exhibit, as perfectly as it often does, the lamination and other characters of the adjacent mass. Indeed the formation of a large nodule (one foot across or more) within

* It is almost needless to say that the siliceous material does not now exhibit a fragmental character. Even if this had been originally shown, it would have been modified by subsequent change.

† See Prof. T. Rupert Jones, *Proc. Geol. Assoc.*, vol. iv, p. 450. Mr. Hudleston, *ibid*, 1881, vol. vii, p. 183.

‡ *Ibid*, Pl. I, figs. 3, 4.

the plastic ooze would not be easy to understand, and the "rings of chert" especially would be difficult to explain. In some nodules structure planes occur roughly parallel with the circumference, but these are like wave marks of infiltration. Moreover, comparison may be made with various "concretions," such as the ferruginous nodules of the Neocomian, and these are often hollow, thus like the "chert rings" except that in the ferruginous sands the material within the crust is more often removed. The cementing of sand grains is a different process, but it is caused by infiltration.

By study with the microscope, we often find fragments of calcite crystals or organisms scattered in the siliceous ground, and they are doubtless generally *residua* left after partial replacement (Pl. xiv, fig. 3). In banded strata the change from limestone to chert might be partly due to changed materials of deposit, like the gradual passage from calcareous grit to limestone or sand. But the transitional zone, with numerous calcitic *residua*, occurs also where the boundary crosses the stratification, and thus must be due to secondary alteration.

Numerous calcareous structures show clear evidence of gradual attack and corrosion*. They often exhibit a crenate margin with rounded chalcedonic ingrowths. Gradually the siliceous deposit seems to extend, and towards the last the ghostly remains of the original calcite may be seen in the midst. These replaced structures are often parts of shells or other organisms. This is clearly seen even in the field or in hand specimens. The silicified *Isastræa* of Tisbury is not common, but the quarries in that locality exhibit beautiful examples of Trigonias and other mollusca now formed of chalcedonic silica. These can be studied in detail in the microscopic slides. Among the organisms which can be recognised are Foraminifera, Corals, Echinoderms, and Mollusca.

Another structure of great interest may be compared—that of the silicified oolite.† The silicification extends sometimes within an irregular boundary like that of a nodule. Study with the microscope shows that gradations and transitions are here even better marked than in other cherts. In specimens from Portland a calcareous oolite adjoins, and is evidently becoming modified into a rock completely siliceous. In one slice oolite grains in a transitional zone stretch across the boundary, and each is itself partly calcareous, partly silicified. Other rocks exhibit calcareous oolite grains embedded in a silicified ground (Pl. xiv, fig. 1). In others the grains are partially attacked, not always in the same

* *Cf.* M. Renard, *Bull. de l'Acad. Roy. de Belg.*, 1878, 2 s., t. xlvi, pp. 471-498, Pl.I. *Cf.* Mr. Hudleston, *Proc. Geol. Assoc*, 1881, vol. vii, Pl. I, Figs. 5, 6, p. 184.

† See *Geol. Surv. Mem.*: "The Middle and Upper Oolitic Rocks of England," edited by H. B. Woodward. Results of the examination of a partially silicified oolite from Chilmark by Mr. Teall are given, p. 234. *Am. J. Sc.*, 1890, ser. 3, vol. xl, p. 248, E. H Barbour and J. Torrey. Also 1897, ser. 4, vol. iv, p. 202, G. R. Wieland.

manner (Pl. xv, fig. 8). In recent discussions the formation of the silicified oolite of Pennsylvania has been attributed to the action of siliceous springs.* That rock, however, occurs scattered on the surface of the ground, associated with blocks, claimed as parts of the geyser basin. And, comparing a slice of the Pennsylvanian oolite, it exhibits differences from the Portlandian examples. The grains are generally more circular in section, show a more marked concentric structure, and an external, sharply-defined, more nearly homogeneous crust. They bear more resemblance to the pisolite of the hot springs at Carlsbad, only in different material.

Occasionally some minor character can be traced continuously from limestone to the adjacent chert, as in a specimen from near Gadcliff, which has a slightly cavernous structure. The small cavities are exactly similar in the two materials, and in both are filled with chalcedony.

Among the results of a pseudomorphism in the Portlandian chert, the siliceous deposit along planes apparently due to jointing, even the abrupt or truncate ending of various layers, and the occurrence of large rounded nodules and "chert-rings," are all suggestive of a later replacement of the solid rock. And it would be difficult to imagine that the same sea, which allowed the formation of the oolite, yielded an infiltration of water containing silica to attack and replace the oolitic grains. Further, no indication seems given that the nodules or "rings of chert" occupy patches which in the pasty ooze were more easily attacked.† Thus the evidence (apart from any question as to the origin of the silica) proves a pseudomorphism, and makes it probable that this was subsequent to the consolidation of the rock.‡

II.—MICRO-STRUCTURES.

The study with the microscope of silicified rocks raises some questions of theoretical interest, such as the order in the processes of mineralisation, its connection with structures in the rock, and their influence on the form assumed. Some problems are suggested by comparison with rocks of a different origin. If we place side by side the slice of a cryptocrystalline acid igneous rock and certain of these cherts, the likeness is often marked, and thus investigation of the latter may perhaps throw light on the more obscure processes which have occurred in the former.§

In siliceous rocks, a uniform, fine-grained character is familiar

* *Am. J. Sc.*, 1897, ser. 4, vol. iv, p. 262. G. R. Wieland, "Eopalæozoic Springs."
† As suggested in the paper, "On the Chemical Composition of Chert." E. T. Hardman, *Trans. Roy. Dublin Soc.*, 1878, p. 94.
‡ *Cf.* C. R. Keyes, *Am. J of Sc.*, 1892, vol. xliv, ser. 3, p. 451.
§ *Cf.* F. Rutley, *Quart. Journ. Geol. Soc.*, xxxv, p. 327.

(as in many chalk flints), but chert shows often a heterogeneous or differentiated structure, and the explanation of this in each case is an interesting and often not easy problem. It may be partly connected with the succession in the silicification. The more usual order (although with some exceptions) seems to be: first, change of the ground mass; secondly, of organisms or oolitic grains*; thirdly, of large crystals of calcite. Thus in partly silicified rock, the residual calcite (which is often dolomitised) is embedded in a siliceous ground, and oolite grains or parts of them are found similarly surrounded. A reversal of this order if it occurs is generally very local.

It is difficult to conclude how far different organisms are differently affected. Silicified fossils from various groups occur, but most classes are only sparsely represented in these Portlandian rocks. The numerous examples to which I have referred are Mollusca.

The last structures to yield to modification seem to be any large calcite crystals. This may explain a characteristic feature of the Crinoidal chert from the Carboniferous Limestone of Derbyshire and other localities which exhibits silicified casts.† In the unweathered rock the crinoid stem consists (as is common) of well-cleaved crystalline calcite. Thus its resistance to silicification may be due to this character, as is suggested by Prof. T. Rupert Jones and by Prof. Renard.‡ As a corroboration we find that the actually silicified echinoderm plates or ossicles, so far as I have seen, are those which retain their columnar network, thus possibly those which still had an organic structure. The partial preservation of the substance of a Serpula in a rock otherwise silicified (from Winspit) is perhaps due to its massive calcareous character (Pl. xiv, fig. 4).

The present structure of the silica in chert may sometimes be a modification of an earlier form of deposit. Often a small border of radial or mammillated chalcedony appears without polarised light as a uniform pale brownish substance like a deposit of opal.§ The resemblance is more marked in certain patches traversed by white lines, like the cracks in the drying mud of a pool, although with crossed nicols the substance is seen to consist of chalcedonic tufts. The silica may have been deposited in colloid form and afterwards modified.

The heterogeneity in chert, however, must be largely due to the influence of original structures in the rock. If cavities

* *Cf.*, however, Mr. F. Chapman "On Oolitic . . . Limestones . . . from Ilfracombe." *Geol. Mag.*, 1893, dec. 3, vol. x, pp. 100-104.

† It is interesting to learn that the same results are shown in Carboniferous Crinoidal chert from America. See *Am. J. of Sc.*, 1894, ser. 3, vol. xlviii, p. 401. "Cherts of Missouri," E. O. Hovey.

‡ By Prof. T. Rupert Jones in *Proc. Geol. Assoc.*, vol. iv, pp. 447, 449, 1874-6. By M. Renard, *Bull. de l'Acad. Roy. de Belg.*, 1878, 2 s., t. xlvi, p. 488.

§ *Cf.* E. O. Hovey, *Am. J. Sc.*, 1894, ser. 3, vol. xlviii, p. 401. *Cf.* Mr. Hudleston, *Proc. Geol. Assoc.*, 1881, vol. vii, p. 183.

existed, the infiltrating silica apparently filled them with a clear deposit of chalcedony like that in amygdales or small agate nodules, sometimes forming a radial or spherulitic border and a central mosaic. Such cavities exist in the chambers of organisms, but some occur in a slice cut from a chert ring at Gadcliff, both in the slightly cavernous limestone and in the adjacent chert, or even extending across the boundary. The chert consists of a fine-grained siliceous ground mass, and the cavities are filled with clear chalcedony. No calcite is deposited within them, even in the limestone, as if the infiltrating silica filled these spaces first and before it would attack the surrounding mass.

The shells of Mollusca replaced by silica generally exhibit radial arrangement along the margin with an interior of clear, granular chalcedony (Pl. xiv, fig. 5). In the fragments which have the close columnar network of an echinoderm* (and in other reticulate structures) the chalcedony has spread as a fine granular mosaic, the minute network being sometimes picked out by a brown staining. Thus a fragment with well-defined boundary and with structure planes parallel or normal to it (like a shell) seems to start radial growth, but where the structure is a network extended in various directions, a granular deposit is formed.

The silicified oolite grains have generally a narrow marginal zone, often finer grained, and with radial and sometimes concentric structure. Within this is a granular chalcedonic mosaic, often clear, but sometimes with a brown-stained irregular network. The replacement can be traced in different ways. Generally it proceeds from the exterior, forming crenate ingrowths (Pl. xiv, figs. 1, 2), or extends to a ragged and irregular limit. In a late stage the mosaic in the oolitic grain is spread over scattered specks of calcite which indicate faintly the remains of concentric structure. Sometimes the oolite grain exhibits concentric layers of residual calcite alternating with zones where silica has been deposited. One interesting oolite (a very local development in the Lower Oolite north of Frome†) consists of oolite grains separated by well-crystallised dolomite ‡ (Pl. xv, fig. 8). They are themselves partially replaced, but the silica has spread irregularly, often aggregated towards the centre of the grain, or scattered in granules among residual calcite.

The larger crystals of calcite are corroded from the edge (Pl. xiv, fig. 3), but are replaced within by a granular mosaic extending over cleavage planes, of which faint traces persist. Where such a regular structural hindrance occurs, it appears to

* These fragments are small and few in the Jurassic rocks, but they exhibit the same character in other cherts (*e.g.* Carboniferous). Since I wrote the above, Prof. Lloyd Morgan has kindly sent to me a slide exceptionally rich in replaced echinoderm fragments from the carboniferous chert of the Mendips.

† I am much indebted to Mr. H. B. Woodward for kindly telling me of this locality when I was conducting an expedition for students in that neighbourhood.

‡ *Cf. Ann. Mag. Nat. Hist.*, 1881, ser. 5, vol. vii, p. 142, Prof. W. J. Sollas; also M. Renard, *Bull. de l'Acad. Roy. de Belg.*, 1878, 2 s., t. xlvii, p. 486.

cause the spreading of coarser granules. In some cases, especially of organic structures, as in a shell, it may even induce a definite orientation of the grains. Where they develop under less constraint they sometimes exhibit angles or a hexagonal outline, evidently an incipient crystal form.

The interspaces between any enclosures are occupied often by a fine grained cryptocrystalline ground mass. This seems more common where much foreign material—mud or fine irony deposit—is present. In other cases a radial growth may start from the enclosure, whether crystal or organism, or oolite spherule or sand grain. In narrow interspaces the radial growth may give rise to confused spherulites, in wider intervals may be followed by an infilling mosaic (Pl. xiv, fig. 5).

Thus among the principal differentiated structures in a chert, a radial development is evidently one of the most important. Since, however, the exact character of the original structures modifies so slightly the forms assumed, when silicification is complete it is clear that it will be difficult to recognise what those structures were, except by their outline. The frequent formation of chert from limestone is connected with the ready solution of the carbonate. Where dust is present it may remain, and thus the clearer spaces in a developed chert often mark the former presence of organisms, whether originally calcareous or siliceous. The origin of many differentiated patches, however, can at most be only surmised.

Throughout these rocks (and elsewhere) silica seems to exhibit certain tendencies. Just as actinolite grows usually into elongated prisms, the more marked in form when opposed by the resistance of finely-divided material,* so chalcedonic silica tends to grow into close radial groups or to develop spreading granules.† The forms of chert are mainly modified (first) by this tendency in chalcedony, (secondly) by the presence of starting points for its growth, (thirdly) by the effects of pre-existing structures.

The irregular and differentiated appearance then presented bears often a remarkable resemblance to many Felsites. Certain distinctive structures can be paralleled in the two rocks. A felstone is often a granular cryptocrystalline mass, the modifications in which may be due to a radial or tufted growth, or to an elongation of irregular constituents, or to an incipient development of crystals. Spherulitic forms on the one hand or micropegmatitic on the other may result. The variations are imitated in cherts (Pl. xiv, fig. 4); even a kind of micropegmatite is to be seen sometimes, but it may be not easy to infer exactly what structure it replaces. The forms assumed in a felstone, like those in a chert, probably are mainly governed by the heterogeneity of the original mass, not by the actual character of its different parts.

* Prof. T. G. Bonney, *Quart. Journ. Geol. Soc.*, 1898, vol. liv, p. 369.
† *Cf.* M. Levy, *Mineralogie Micrographique*, pp. 194, 196.

In the felsite, similar developments may start from the surface of the streaks in a fluidal glass, or from included fragments or crystals. The deposit, however, may be sometimes modified by pre-existing structures. Where the crust of a pyromeride exhibits large irregular granules, they are often elongated radially. This might be caused if a later alteration had taken place in a spherulitic structure, which influenced the form and direction of the secondary granules.

III.—ORIGIN OF THE SILICA.

In the first part of this paper, I laid stress on the process of change in the formation of chert, and I had originally no intention of discussing what might have been the earlier condition of the silica. Reference to this question in connection with Jurassic rocks has been made in more important memoirs.* But the specimens I have examined present certain evidence which ought to be recorded. The investigation has warned us what difficulties will be caused by the obliteration and change of previous structures. Often it will be doubtful whether traces of organisms once occurred, and negative evidence of many slides must be expected. While the advocate of an inorganic supply has even a greater difficulty, since an organism may be capable of recognition, a speck of precipitated colloid silica cannot.

In many slides of the chert, sponge spicules can be clearly identified, some resembling the Tetractinellid *Pachastrella* described by Dr. Hinde from the Isle of Portland and Upway,† or, in one case at least, a possible *Geodites;* and the sections of spicules are abundant at certain parts. But the exact distribution may be an important fact. In a junction slice of limestone and a chert nodule from Tillywhin, sparse scattered spicules occur in the limestone, but on the border of the nodule they are crowded, where a few can be recognised in longitudinal, many in transverse section (probably *Pachastrella antiqua*) (Pl. xv, fig. 7). In another nodule from Winspit, the sponge spicules include one larger, possibly *Geodites* (Pl. xiv, fig. 6), and abundant sections of a smaller form (? *Pachastrella*), while in a banded chert from the same locality they are also numerous. Some specimens occur in a silicified oolite from Portland Bill in the part of the slide where the oolite is more sparse. Spicules have already been recorded by Dr. Hinde in nodules from other Dorsetshire districts.‡ In these cases, the silica seems probably derived from organisms, which grew, or died, or drifted—on the particular spot, and the mineral substance was not carried far.

* *Pal. Soc. Mem.* "British Fossil Sponges," Part III, p. 193.
† *Pal. Soc. Mem.* "British Fossil Sponges," Part III, p. 209.
‡ From Isle of Portland, and Upway, *ibid.*, p. 193.

If the chert is largely a pseudomorphic rock, and if the silica is derived from siliceous organisms, we must consider whether they can be traced usually in such close proximity, and how far this would be an argument for the early and almost contemporaneous formation of the chert. On the former of these two problems, wider observations must be consulted, but even some of the rocks which I am describing suggest a contrary view. On the latter, we may recall the modes of fossilisation so clearly described by Dr. Hinde, showing the changes which are exhibited in the mineral substance of sponge spicules.* Such modifications occur slowly and occupy time. Since, however, organic structures yield silica which is readily soluble, the changes include the possible conveyance of the silica through the neighbouring rock —the mineral might be transferred as well as transformed—and this might occur at some later epoch after consolidation of the mass. The possible transformation from opal to chalcedony† would thus give no evidence on the question of original precipitation. By the solution of any silica it might be transferred and deposited in colloid form. Indeed, as in various rocks, a mineral may have passed many times through a certain condition before it reached its present resting stage. If the silica was originally mainly organic, for the process of silicification in so much rock and so many calcareous structures hosts of sponges or their like must have been destroyed, of which we can see only some remnants. This would probably offer no difficulty, but I leave to others better acquainted with living growths to make more definite statement.‡

Thus, finally, if we try to summarise the history of cherts, it is clearly somewhat various in different rocks. Some, like the Pennsylvanian oolite, might be direct deposits of hot springs, although even then the action of lowly Algæ may have caused the extraction of silica from the waters if the conditions were like those described by Mr. Weed.§ In some cherts it is possible that the silica from the sea of the period may have been directly deposited within the ooze, but positive evidence for this view would be difficult to obtain, and I can record none in these Portlandian cherts. Often limestone strata accumulated, with siliceous organisms more or less numerous and perhaps locally distributed. In the molecular changes afterwards going on in the rocks, infiltrating water removed the soluble carbonate, and substituted, in patches or layers, the silica previously occurring

* Dr. Hinde records among fossil sponges only some Tertiary spicules, in which the silica is similar to that in recent sponges, in being in colloid condition and beautifully clear like perfect glass.—" British Fossil Sponges," Part I, p. 54.

† See *ante*, p. 73.

‡ *Cf. Trans. Geol. Soc.*, vol. vi, Part I., 2nd ser. 1840, note p. 191. Dr. Bowerbank describes their habit . . . " to unite and form vast masses, which spread over a great extent of surface."

§ Geol. Survey U.S., 9th Annual Report, 1887-8, p. 650.

in the material around. The accretion of this towards centres or areas formed the cherts which help so markedly to build up the scenery of the present earth.

DESCRIPTION OF PLATES XIV AND XV.

The specimens have been taken from the Portland Beds except that represented in Fig. 8.

Photographs of micro-sections. (Magnification about 30 diameters in Figs. 1, 2, 3, 4, 5; and about 50 diameters in Figs. 6, 7, 8.)

Fig. 1 (× 30).—Partly silicified Oolite from Portland Bill. The ground mass is silicified. The calcareous oolite grains have become indented at the margin through silicification at the exterior. Occasionally a chalcedonic granule is included, and in one grain (the lower on the right hand side) comparatively clear dolomite is formed along apparent cracks.

Fig. 2 (× 30).—Chert around nodule from Tillywhin, completely silicified, exhibits the faint outlines of former oolite grains. The ground mass contains numerous circular sections of small sponge spicules.

Fig. 3 (× 30).—Junction of Limestone and chert from quarry at Easton, Isle of Portland. On the left is the Oolitic Limestone which contains sparse granules of chalcedony. The chert to the right encloses a residual fragment of crystalline calcite crossed by cleavage lines, and (below this in the illustration) the calcareous centre of one oolite grain. The others which are completely silicified are only faintly visible.

Fig. 4 (× 30).—Chert band, Winspit, Isle of Purbeck. A transverse section of a Serpula, partly silicified, occurs within a completely silicified ground mass. The chalcedony replacing the Serpula wall forms several spherulitic groups; one black cross is seen in the illustration above the central tube, one below, and two to the left of it.

Fig. 5 (× 30).—Chert (with included shell) from west of Tisbury, all completely silicified. The chalcedony along the margin of the shell section exhibits radial structure, and spherulitic along the centre. Coarser spherulitic aggregates occur within the space partly enclosed by the curve of the shell.

Fig. 6 (× 50).—Chert nodule from Winspit completely silicified. (Elsewhere in the slice, parts of Serpulæ occur like that in Fig. 4.) The large sponge spicule (probably *Geodites*) exhibits a wall of coarser granular chalcedony and a canal filled with finer-grained deposit. The sections of smaller spicules crowded in the ground mass are less distinct.

Fig. 7 (× 50).—Chert nodule from Tillywhin. This slice taken from the margin of the nodule (close to the Limestone) shows crowded sponge spicules in longitudinal, transverse, and oblique sections (probably *Pachastrella antiqua*). A little calcite or dolomite occurs in the centre of some spicules and fringing their outer margin.

Fig. 8 (× 50).—Oolitic Limestone partly silicified from inferior Oolite near Frome. Oolitic grains, showing concentric and occasionally radial structure, include single chalcedonic granules formed along concentric zones, or aggregated in the centre. A mosaic mainly of dolomite occurs between the oolite grains.

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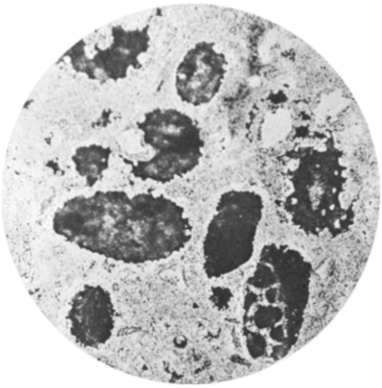

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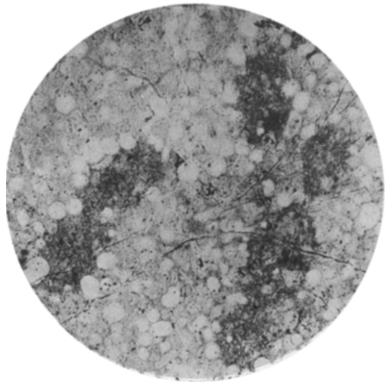

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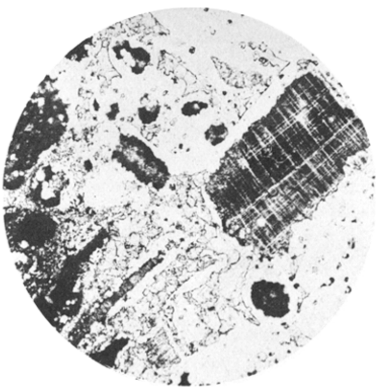

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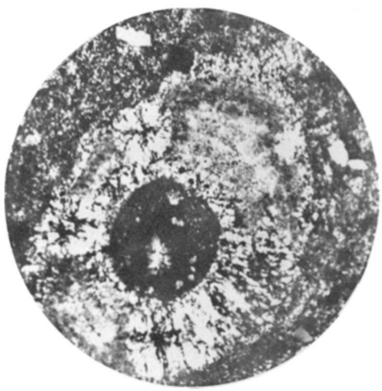

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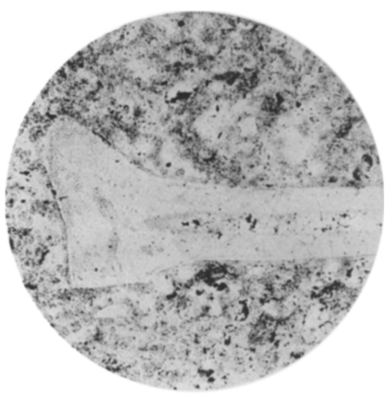

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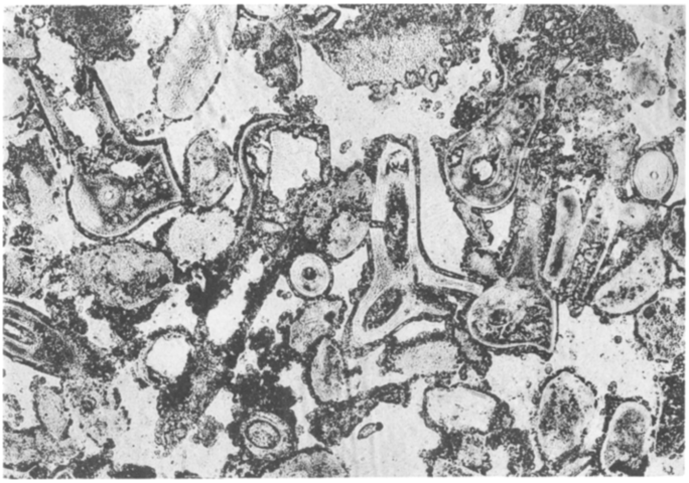

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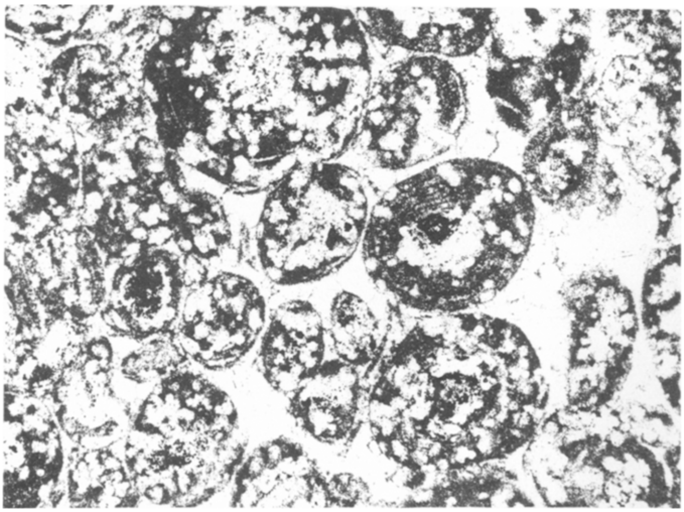

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