The Building of the Derbyshire Limestone.

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IN previous *Journals* I have dealt with the origin of Derbyshire scenery. In the present paper it is my intention to trace the origin of one of the rocks whose varied forms give rise to scenery. My earlier papers dealt with the cause of the external form assumed by rocks, the present one deals with the origin of the rock itself. Investigation teaches us that matter, like energy, is constantly undergoing transformation—passing through a cycle of changes. The matter which constitutes our limestone rocks is no exception, and I propose here to deal with this fleeting phase of its transformations.

The Derbyshire limestone is of great interest, both from economic and purely geological standpoints. It is rich in mineral lodes and veins yielding ores of lead, zinc, &c., valuable building stones and ornamental marbles. It forms an immense mass of very great but unknown thickness, during the formation of which several submarine volcanic eruptions took place, the ejected lava forming the beds of toadstone which are found interstratified with the limestone. Looked at as a whole, the limestone area forms part of a great fold or anticlinal, the axis of which runs from north to south, forming the southern portion of the great Pennine anticlinal. From above this central area the millstone and newer rocks have been eroded, leaving the limestone exposed at the surface.

The limestone differs widely in different districts, and at different levels. In the upper portion it is thinly bedded and contains layers and nodules of chert, below which is a great thickness of pure massive limestone, here and there of a semi-crystalline character; and below this comes a mixture of more or less thickly-bedded limestone.

A practical geologist can, in most cases, at once distinguish a limestone, although the different varieties exhibit considerable differences in texture and colour; but a simple test consists in the application of a drop of hydrochloric acid, when, if there be much carbonate of lime present, vigorous effervescence will take place. When strongly heated, limestone is decomposed into quicklime and carbon dioxide.

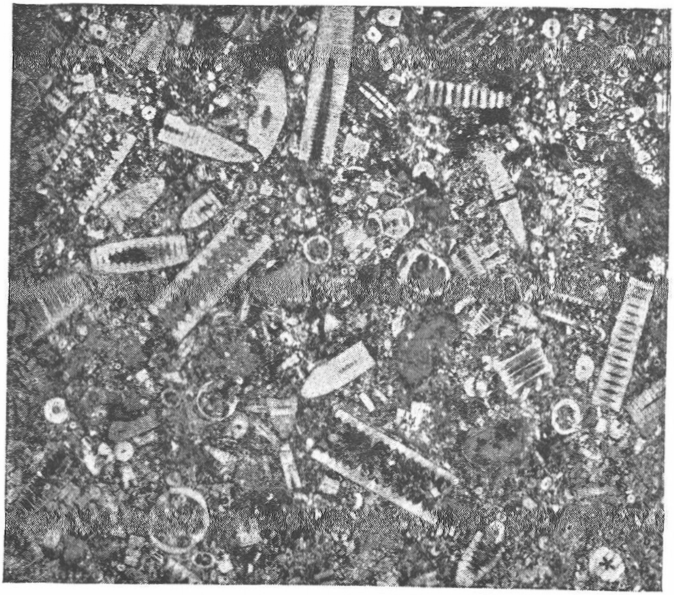

FIG. 1. POLISHED SECTION OF CRINOIDAL MARBLE (WIRKSWORTH).

A common and typical variety of limestone met with in Derbyshire is called crinoidal, encrinital, or entrochal marble. A polished section of this is represented in Figure 1. A consideration of the marks seen upon its surface, which are usually white upon a grey background, will lead us to the origin of the rock; they are the hieroglyphics which, rightly interpreted, enable us to read the history of the rock. It will be obvious that the marks upon the polished surface of the marble must be sections of some predominant fossil which enters largely into the substance of the rock, and a little consideration will show that this must be of cylindrical form. The outlines are, as will be seen, longitudinal, oblique and transverse sections of a cylindrical body, with a transversely corrugated tube running through it. It would not be easy from these marks alone to construct the objects of which they are the sections, but we derive assistance from "weathered" masses of the rock. It is found that when the face of the rock has been exposed for a considerable time, these fossils,

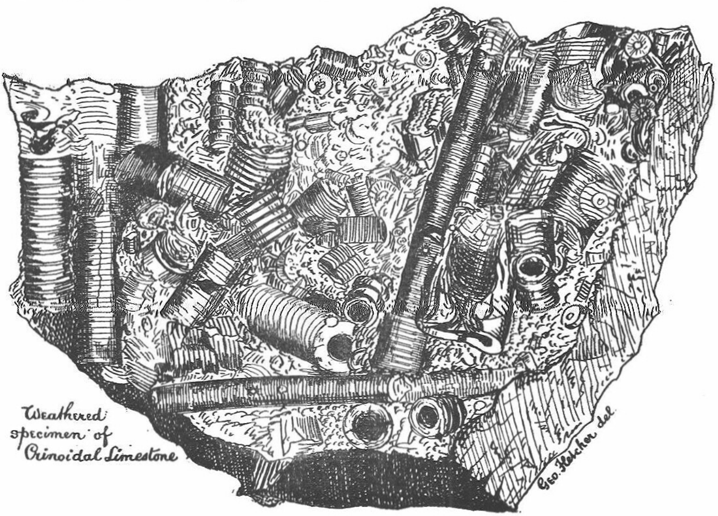

FIG. 2.

being of a more resisting nature than the surrounding material—the *matrix*—in which they are embedded, stand out in relief. This is due to the manner in which the calcium carbonate is built up in the fossil, and not to any essential difference of chemical composition. Such weathered masses are to be found in many old limestone quarries. There is an excellent case at Monyash, from which the specimen represented in Fig. 2 was obtained. The structure of the cylindrical fossils now becomes clear. No wonder they should have been called "stone lilies," for these long pencils might well be likened to the stem of a plant; and in specimens in which the crown is preserved the resemblance is more complete. Prolonged weathering shows these stems to be made up of a number of joints having a thickness of a sixteenth of an inch or more.

As our knowledge of the *fauna* and *flora* of the depths of the sea was enlarged by the discoveries made during the *Challenger* and other expeditions, the nature of the fossil contents of this limestone became more and more clear. Forms of life bearing a close resemblance to those described as occurring in a fossil condition in the limestone were dredged up. That they lived in

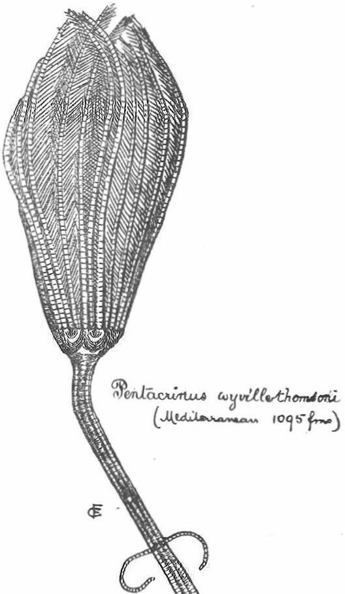

FIG. 3.

colonies was evident from the fact that when brought up there were usually a number, and the mode of life of the extinct forms may be inferred from those which are now living. They are termed Crinoids, and certain genera existing at the present time are also found fossil, as, for example, the form Pentacrinus. Fig. 3 is a drawing of Pentacrinus wyville-thomsoni, which was dredged up from a depth of 1,095 fathoms in the Mediterranean during the voyage of the *Porcupine*. Only a portion of the stem is shown.

Crinoids belong to the large, and, to the geologist, important group of animals termed Echinodermata. The soft and living portion of the animals possesses the power of separating calcium carbonate from the sea water, and forming from it a skeleton made up of a large number of separate parts. A typical Crinoid consists of a crown, stem, and root. In some forms, the stem is absent, the crown swimming freely. The crown consists of a calyx and dorsal cup, the former containing the viscera and arms, the latter being made up of two circlets of five calcareous plates. The whole organism exhibits a five-fold symmetry, five radial planes passing through it longitudinally.

The crown surmounts the stem, which, like the arms, is composed of numerous ossicles or joints—circular, pentagonal, or elliptical in form (Fig. 4)—and perforated by a circular or

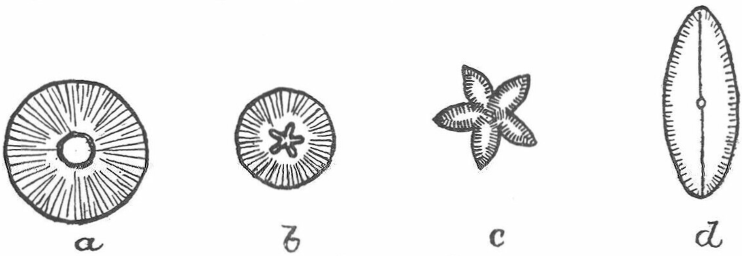

FIG. 4. STEM OSSICLES OF CRINOIDS.
(*a. b.*) Genera uncertain (Carboniferous, Eng.)
(*c.*) Pentacrinus (Lias, Eng.)
(*d*) Platycrinus (Carboniferous, Eng.)

pentagonal axial canal. They are connected by a fibrous organic tissue. The stem grows in length by the intercalation at the end nearest the crown of new ossicles which increase in size. It is surrounded at intervals by whorls of cirri, having the same structure as the stem, and the mode of attachment to the sea-bottom differs in different genera according to the nature of the bottom. Some stems terminate in a flattened expansion adapted to a rocky bottom. Others terminate in a number of radicular cirri, adapted for an oozy bottom.

The mouth is at the centre of a membrane on the ventral surface of the calyx. The upper surfaces of the arms are provided with food grooves lined with fine vibratile filaments called cilia, which, by their movement, cause currents of water containing food to flow down the grooves into the mouth of the animal.

On examining the minute structure of the calcareous skeleton by means of a microscope it is found to consist of a fine meshwork of carbonate of lime deposited in organic tissue. In the fossil forms, the interstices of the meshwork are usually filled with crystalline carbonate of lime (calcite), and hence these fossils

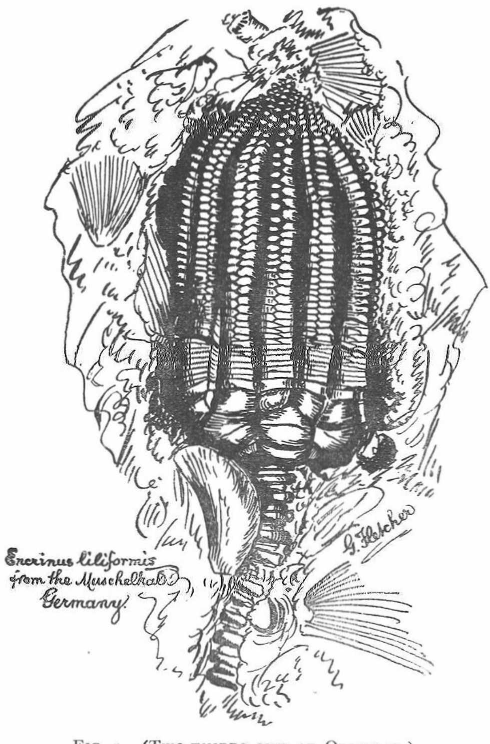

FIG. 5. (TWO-THIRDS SIZE OF ORIGINAL.)

usually cleave in planes parallel to the faces of a rhombohedron in the same manner as an ordinary crystal of calcite. Sometimes the spaces are filled with silica, the calcareous substance being subsequently dissolved, and frequently the minute structure is obliterated. Many of the structural features described will be seen in the drawing of the magnificent fossil specimen of Encrinus liliformis (Fig. 5) in the Derby Public Museum.

That these animals were abundant in the sea in which the Derbyshire limestone was formed is certain, for we find strata hundreds of feet in thickness, made up almost entirely of their calcareous skeletons. The fragmentary nature of the fossil remains is explained when we remember that the numerous ossicles are held together by organic tissues which, on the death of the animal, decay, allowing the skeleton to fall in confusion on the sea floor. Cases occur, however, where we get almost perfect skeletons, as in the fossil Encrinus shown in Fig. 5.

Thus, by the accumulation of the skeletal remains of countless generations of Crinoids, have thick masses of limestone rock been built up. In addition to the Crinoids, however, are abundant remains of Corals and Molluscs (Brachiopoda, Gasteropoda, Cephalopoda, Pteropoda, etc.) which sometimes prevail to the exclusion of the Crinoids, and thus we get, sometimes in the same section, crinoidal, coralline, and shelly limestone. In several localities, also, as at Castleton, Millers Dale, and Ticknall, occur beds composed largely of Foraminifera.

Considerable interest attaches to the question of the nature and origin of the silicious and other impurities which are found disseminated throughout the limestone. A piece of limestone treated with concentrated hydrochloric acid is found to yield an insoluble residue, which proves, when examined microscopically, to be of great interest. Mr. Wethered has studied the insoluble residues obtained from the carboniferous limestone series at Clifton, and finds them to consist mainly of minute fragments of quartz, together with a smaller proportion of tourmaline, zircon, and felspar. Many of the quartz fragments are crystalline, and the crystals are observed to contain nuclei of detrital quartz. It is a well-known fact that damaged crystals placed in a solution of the same substance possess the power of repairing themselves, and we may regard the rounded nuclei as water-worn crystals, which have attracted silica from solution to again build up the crystalline form. There is little doubt that the insoluble residues of our own limestone will, on investigation, yield interesting results.

In the upper limestones of Derbyshire we find interstratified layers and nodules of a flinty deposit called chert, the origin of which forms an interesting geological problem. Frequently it occurs in large masses, and contains silicious casts of the organic remains it has replaced. Often these silicious pseudomorphs retain the minute structure of the original object, which has evidently been replaced particle by particle as it was removed, in the manner in which silicification of wood gives rise to the formation of wood opal with all the delicate structure of the original matter. These chert bands occur in the upper carboniferous limestone of Ireland, and formed the subject of a paper by Messrs. Hull and Hardman.* It may be well to point out that silica occurs not only in the crystalline condition, in which it is insoluble, but also in a colloid condition, in which state it is to some extent soluble in water. Microscopical examination of chert tends to show that its silica is colloid. Professor Hull, in the paper referred to, came to the conclusion "that carbonate limestone chert is essentially a pseudomorphic rock, consisting of gelatinous silica replacing limestone of organic origin, chiefly foraminiferal, crinoidal and coralline," and that the replacement was not of organic origin. He regarded it as probable that the coralline and crinoidal beds would, after their formation, be porous and open. The sea-water, containing dissolved silica, would percolate through this, and, since it has been shown that mineral or organic objects formed of carbonate of lime are liable to be replaced by silica when submerged in water in which this mineral is dissolved, the replacement of calcium carbonate by silica would follow as a purely chemical process. Subsequently, Dr. Hinde brought forward evidence to show that the silica had been derived from the silica of sponge remains.

It has already been pointed out that the organic remains met

* "Scientific Transactions of the Royal Dublin Society," Vol. I. (New Series).

with in the Derbyshire limestone, closely resemble the deposits which are forming in modern seas. We find analogues to the shelly, crinoidal, and coralline deposits; but, while we find numerous foraminifera, extensive deposits such as the chalk or the modern Globigerina ooze are conspicuous by their absence. Nor do we find anything at all comparable to the silicious oozes which are being formed of the shells of radiolaria and other silica-secreting organisms. It is possible that the silica of the chert may have been partly derived from such deposits, if they ever existed, but this seems doubtful. The question is a deeply interesting one, and will probably repay further investigation.

Let us now endeavour to call up to our imagination the physical conditions under which this limestone was formed. It has already been stated that in Derbyshire its base has never been reached; nevertheless, it has been calculated, from the measured geological sections, that it is not less than 5,500 feet in thickness. The whole of this is a marine deposit of great purity, and therefore must have been formed in a fairly deep sea, to which sedimentary matter from the land rarely found its way. We also infer, from its great thickness, that while it was being formed, subsidence was taking place. We are driven to this conclusion by the fact that in this thick deposit the fossils in the upper beds do not differ from those in the lower ones to such a degree as would be the case if the gradual accumulation of the deposit had involved a shallowing to the extent of 5,500 feet. Differences do occur, but we look in vain for such a change in the fauna as would be brought about by a shallowing of the sea to the extent of the thickness of the marine deposits. While we may regard the mountain limestone as a deep sea deposit, we are forbidden to imagine that its depth approached that of the deeper parts of the Atlantic. Soundings, made in the deeper parts of the Atlantic, reveal the fact that oozes are being formed of the calcareous and silicious shells of minute organisms which inhabit the surface and bottom waters. From a depth of about 2,000 fathoms in the South Atlantic has been brought up an ooze made up of globigerina, orbulina, coccoliths, rhabdoliths, etc. In some places this

Globigerina ooze is replaced by one made up almost entirely of the frustrules of diatoms, while from below 2,000 fathoms, silicious oozes, composed of radiolaria, are brought up. From still greater depths (over 3,000 fathoms), a red clay, devoid of organisms, is brought up. None of the pelagic deposits find analogues in the mountain limestone, and it would appear that the sea in which it was formed never attained such depths.

If we trace the limits of the limestone area in different directions, we are able to make out the probable limits of the sea in which it was laid down, and thus get an idea of the physical geography at the period of its formation. If we trace the Derbyshire limestone westward into Wales, we find that it gradually becomes thinner, and associated with it are beds of sandstone and shale. This is a sign of shallow water, and indicates the nearness of an ancient coast-line. If we follow it to its junction with older rocks, we find it resting unconformably upon them. It rests against the metamorphic rocks of Anglesey; in Shropshire, North Wales, Westmorland, etc., upon Silurian rocks; while in many localities it conformably overlies beds of a deep red colour, which were early referred to the Old Red Sandstone. It would appear, however, that these intermediate rocks, which belong to the system known as the Devonian, represent various periods of the long interval which elapsed between the close of the Silurian and the beginning of the Carboniferous periods. These beds represent the shore-line of the sea in which the carboniferous limestone was deposited. Following the limestone northwards, we trace the ancient beach passing under Ingleborough, and in the dales cut into the mountain may be seen the lowest beds of the carboniferous system, the lower ones consisting of angular fragments derived from Silurian rocks, and passing upwards into beds containing large water-worn pebbles, and these again into a calcareous sandstone. Tracing it northwards and eastwards into Durham and Northumberland, we find intercalated with the calcareous strata beds of shale, sandstone, and coal, indicating the existence of land in that direction. In Ireland the lower carboniferous sea overspread the greater portion of the country, and its beach may be traced at intervals on the eastern sides of the hills of the west of Ireland. From here it stretched eastwards across England, for a distance of 750 miles, into what is now Holland, Belgium, North France, and the valley of the Rhine. To the north-west lay a great continent, to which Professor Dawkins has given the name Archaia, from the fact that it was mainly composed of archaian rocks; and on the shores of this ancient continent our mountain limestone was deposited. "The hills of Down, and the Wicklow mountains, were islands, the latter, not improbably, being connected with Wales, across what is now the Irish Sea, while the higher ranges in the Isle of Man and the Highlands of Scotland stood over the sea, between the island of Mayo and the island of Cumbria." *

After a time a shallowing of this ancient carboniferous sea took place, for we find, overlying the limestone, the series of shales and sandstones known as the Yoredale Rocks. Further shallowing, with the accumulation of the Millstone Series, and finally a land surface, upon which grew the luxuriant vegetation of the Coal Measures, and which underwent numerous oscillations of level with the successive accumulations of vegetable matter which gave rise to our coal seams.

* Professor W. B. Dawkins.