tion will be $5280 \times 2 \times 3000 \times 3 = 95,040,000$. *The time that has elapsed since the commencement of the Cambrian is therefore in round figures 95 millions of years.*

CONCLUDING REMARKS.

Although the foregoing computation of post-Archæan time is on a different principle to that adopted by Sir Archibald Geikie in his Presidential Address to the British Association referred to, it is satisfactory to find that the results come out much the same. It has been objected to the latter method that deposition goes on much more rapidly than denudation, because it is assumed by those who hold this opinion that material which is denuded is spread over a much smaller area than that from which it was derived, consequently it must accumulate more rapidly. Checked by the method adopted in this paper it would appear that the earth's age geologically speaking must be, as inferred in the Presidential Address, somewhere between 100 million and 600 million years.¹

This is a large margin no doubt, but it is an important thing to know. Different men may put different values on the three factors, bulk of sediment, rate of denudation, and area of denudation; but I think a fair and impartial examination of the reasoning involved in this paper will show that the principle of the calculation is sound.

II.—ON OOLITIC AND OTHER LIMESTONES WITH SHEARED STRUCTURE FROM ILFRACOMBE.

By FREDERICK CHAPMAN, F.R.M.S.

(PLATE V.)

Introduction.

IN 1886 the author, during a visit to Ilfracombe, obtained some specimens of Middle-Devonian limestones which, at the time of collecting, he supposed to be formed of *Syringopora*, on account of the granulated weathered surface, and especially since the coral named had been recorded from the locality.

After revisiting the spot in 1890, and making a somewhat extensive collection therefrom, principally for the hope of finding micro-organisms, this particular rock again attracted his attention by the peculiar granulate surface produced by weathering. A section of the rock was made which proved it to be a good example of a limestone formed of oolitic grains. Subsequently a series of specimens showing shearing in all stages was found, and these were capable of being traced back to their original source in the rock with oolitic structure.

It is the main purpose of this account of the limestones to point out the interesting changes due to dynamical and chemical agencies, in the form of shearing, silicification, and the growth of dolomite

¹ It must not be forgotten that to arrive at the earth's age Archæan time has to be added to my estimate of 95 million years, which very materially increases the margin of geologic time on which we are allowed to draw.

Sheared Limestones from Ilfracombe.

and other crystals, which have taken place in the rocks of this district.

Description.—The limestones which appear to be in their least-altered condition are some encrinite-limestones from the east side of Hele Strand, and the cliffs at Hagginton Beach; and also others formed entirely of *Cyathophyllum cespitosum* and many other species of Rugose corals, occurring in lenticular masses in the slates of Hagginton Hill. In these limestones, nevertheless, solitary quartz and dolomite crystals can be often seen, though the latter mineral makes its appearance in any abundance only in those rocks which have been subjected to pressure. In the specimens obtained from the neighbourhood of Rillage, and on to Watermouth, the dolomite occurs well crystallized although it performs a subordinate part in forming the mass of the limestone; but nearer to Combe Martin the rocks become completely dolomitized, where here and there, in a microscopic section, one meets with a stem-joint of an encrinite or other organism which points to the origin of the mass.

The oolitic limestone before mentioned occurs over Sampson's Cave, which is about 300 yards east of Rillage; but the rock was inaccessible *in situ*, though tumbled blocks of it were obtained at the mouth of the cave at low water. The same kind of rock was also found in freshly broken blocks at Watermouth Cave, about three-quarters of a mile to the east of Sampson's Cave. The oolitic rock is of a dark blue-grey colour, and the separate granules which weather out at the surface are quite black. Some of the specimens of this rock from Sampson's Cave have not, apparently, been subjected to much pressure, though all that were obtained show a greater or less tendency to cleave. The granules, under the microscope, are seen to be formed upon a nucleus of a shell-fragment or sometimes a quartz-grain; and they are perfectly spherical in the plane of cleavage (where such exists), and nearly so at right angles to it. The oolitic granules were found to be much harder than the surrounding matrix, when polishing a section of the rock on a snakestone; the granules standing out in relief. This hardness was found to be due to the almost entire replacement of the original grain by microcrystalline quartz. Fig. 1 shows the oolitic structure before the distortion of the granules; the latter are circular in outline and $\frac{1}{8}$ inch (.925 mm.) in diameter. Around the grains may be seen a transparent boundary or fringe with a ragged margin, which is an outgrowth of the pseudomorphous or secondary quartz replacing those grains. When the section of the rock is examined under a high-power (i.e. $\frac{1}{2}$ inch), innumerable crystals of iron pyrites can be seen, showing triangular, square, pentagonal, and hexagonal outlines, and occurring disseminated through the oolitic grains in isolated crystals, without any regard to the concentric structure of the former; and also in the matrix in patches and strings, filling up incipient rifts and cracks. The blue-grey colour of the limestone and the dark tint of the granules is due to this occurrence of the iron pyrites; and the mineral performs an interesting part in the subsequent alteration of the rock, as will presently be seen.

Fig. 1a is from a specimen which has been boiled in HCl before preparing the microscopic section from it, so that only the silica and iron pyrites are left. It will be seen that the spaces between the grains, and occasionally the centres of the latter are dissolved out, showing that a very small proportion of the original rock exists in this oolite.

Fig. 2. represents a section taken from a slightly cleaved limestone, and in a direction vertical to the cleavage, from Watermouth Cave. In this example we have the first definite appearance of shearing in the rock. At this stage the grains have only suffered slight flattening, without much distortion, but irregular fissures have been made in the mass, passing through both grains and matrix in sinuous, but roughly parallel, lines. This specimen is also more or less silicified.

At the next stage, shown in Fig. 3, there has been a great change in the structure of the rock-mass; it has been subjected to such pressure as to have caused the oolitic grains to be lengthened out to a remarkable degree, and to closely overlies one another. The length of the grains in this condition is nearly twice the probable original diameter, and the proportionate length and breadth as 5 to 1. A siliceous fringe is seen bordering these lengthened grains, when viewed between crossed nicols, but the silicification does not apparently affect the grains themselves, since a section, decalcified upon the slide, which had been cut from this rock, exhibited after the treatment dolomite crystals with a little silica around the precincts of the grains, but showing that the grains themselves had been dissolved out. It therefore appears evident that the silicification of the limestones has only happened in the case of those oolitic rocks which have escaped shearing, or which have only been slightly acted upon by pressure. In the lengthened-out grains of this specimen, the concentric layers of the oolitic grains can be distinctly seen, as can also the radial structure which is so characteristic of the older oolitic rocks. The dolomite crystals occur in lenticular strings, the centre of each lenticle being occupied by granular material (perhaps ankerite), whilst on the outer margin are very well-developed crystals of dolomite often showing zone-structure. Seen under a high power these dolomite crystals show inclusions of very minute particles of iron-pyrites, and this latter mineral also occurs in some abundance in the fissures formed by the shearing of the limestone.

In a hand-specimen this rock is of a dark blue-grey colour, with a distinct schistose structure; and traversing it, generally at right angles to the plane of schistosity, are numerous veins of pure white calcite, representing faults produced by the folding and crushing of the beds.

An analysis of this dolomitized limestone has been made for me through the kindness of Prof. Thorpe, F.R.S., by Mr. Ernest A. Pinchin, in the Chemical Laboratory of the Royal College of Science, and is as follows:—

ANALYSIS OF DOLOMITIZED LIMESTONE (dried at 100° C).

Calcium carbonate (CaCO_3)	...	...	...	...	...	74.88
sulphate (CaSO_4)	...	...	...	...	...	0.24
phosphate (Ca_3PO_4) ₂	...	...	...	...	...	trace.
Magnesian carbonate (MgCO_3)	...	...	...	...	...	14.95
Ferrous carbonate (FeCO_3)	...	...	...	...	...	4.75
Insoluble (SiO_2)	...	...	...	...	...	5.06
Total	...	...	...	...	...	99.88

As sulphide of iron is present in the rock it would appear that in the analysis it is represented by the other iron and sulphur compounds.

The extreme condition of the sheared rocks found is shown in Fig. 4, from a specimen collected at Rillage Point. In this specimen the grains are drawn out to about ten times their present breadth. In one instance a grain was affected by the shearing force on a portion only, one side having been drawn out whilst the opposite side exhibits the almost circularly concentric layers of the grain. In this rock we see, besides the lengthened and contorted grains which give an appearance of fluxion structure to the mass, numerous well-formed crystals of dolomite disposed along the lines of cleavage, and which are stained by ferruginous material; also "eyes" of calcite, which can be traced to their origin as portions of joints and ossicles of crinoids.

Fig. 4a is from a more highly magnified photograph of the same kind of rock, but from a different specimen. In this we see the decomposition which has taken place in the included iron pyrites, and the subsequent hydration, giving rise to a brown staining which in most cases obscures the centres of the dolomite crystals and in rarer cases brings out their zone-structure. The rock itself is of a rusty-brown colour instead of the dark blue-grey colour of the fresher kinds.

Fig. 5 is taken from a rock collected at Rillage Point, and differs somewhat from the preceding series on account of the scarcity of the sheared granules and abundance of calcitic fragments and encrinure remains. In this rock there is no dolomite, and its absence is quite exceptional. The organic remains, it will be seen from the illustration, are conspicuously unaffected by the shearing, whilst the oolitic grains are very much attenuated.

Fig. 6. is from a section taken across the coralla of *Cyathophyllum cæspitosum* in a limestone formed of that coral. The attenuated form of these coralla is probably entirely due to the shearing action upon the rock. This specimen was obtained from Watermouth.

Conclusions and Suggestions.—Although the sheared oolitic limestones were all found in the immediate neighbourhood of Rillage Point, whilst the less altered specimens were obtained from localities to the east of that place, it is highly probable that further investigation will show that the comparatively unaltered oolite alternates with the sheared rock; that is to say, according to the evidence afforded all along this part of the coast of the excessive crumpling and crushing of the strata, it is only reasonable to suppose that the

different stages of this sheared rock recur at intervals according to their position in the plications where they have suffered greater or less pressure.

The dolomite crystals most probably owe their origin to percolating water charged with salts of magnesia derived from the surrounding shales; and perhaps, in the case of the coral limestone, from the corals themselves, as a small quantity of magnesia is often present in the corallum.

Besides forming the intercalated beds of sandstone, silica is abundant in the limestones and clay-slates in the form of minute quartz-grains and crystals; and these would readily dissolve and re-crystallize during and after the processes of contortion and shearing, as is seen in the replacement and fringing of the oolitic grains.

It is interesting to note the close association of the oolitic granules in these beds with masses of the old reef-forming corals, an association similar to that found at the present time in tropical areas.

The patches of limestone in the shales undoubtedly owe their lenticular form to the forces which produced the shearing; but on account of the superior hardness of the limestone the surrounding shales have suffered more in being squeezed out of position, and have been altered into talc on the surfaces of the mass.

In concluding these notes it remains for me to express my obligations and thanks to Professor Judd, F.R.S., for his kind and valuable advice; to Professor Thorpe, F.R.S., for his kindness in supplying me with the analysis of the dolomitic limestone; and to my brother, Mr. R. S. Chapman, for his skill in producing the photographs from which the plate has been made.

EXPLANATION OF PLATE V.

- FIG. 1.—Oolitic limestone of Devonian age, practically unaffected by pressure, from Sampson's Cave. $\times 14$.
 FIG. 1a.—The same rock treated with acid to show the siliceous portion. $\times 14$.
 FIG. 2.—Oolitic limestone with incipient cleavage, from Watermouth Cave. $\times 14$.
 FIG. 3.—Sheared and dolomitized oolitic limestone, from Rillage Point. $\times 14$.
 FIG. 4.—Extreme condition of sheared oolitic limestone, with "eyes" of calcite, and dolomite, from Rillage Point. $\times 14$.
 FIG. 4a.—A portion of the same more highly magnified, to show the dolomite crystals with their centres occupied by ferruginous material. $\times 36$.
 FIG. 5.—Sheared limestone formed of encrinite remains and oolitic grains; the ossicles and stem-joints of the encrinites are almost unaffected by the shearing forces. From Rillage Point. $\times 14$.
 FIG. 6.—Sheared coral limestone, from Watermouth. $\times 4$.

III.—THE SUBMERGENCE OF THE BRITISH ISLES DURING THE GLACIAL PERIOD.

By Prof. EDWARD HULL, LL.D., F.R.S., F.G.S.

THE question of the submergence of the British Isles during, at least, one stage of the Glacial period, is deserving of careful consideration by geologists. Until the visit of the late lamented Prof. Carvill Lewis to this country, no one, as far as I am aware, questioned the view that the British Isles have been submerged to a depth, in some places, amounting to 1300 or 1400 feet—this being the level at which shell-beds are found in some parts of England, Wales, and