THE MICROSCOPIC STRUCTURE OF THE ZONES OF THE CHALK.

BY A. J. JUKES-BROWNE, B.A., F.G.S.

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INTRODUCTORY.

It is somewhat curious that such diverse views should be held by different geologists respecting the origin of the formation known as the Chalk, and regarding the conditions under which it was accumulated. This difference of opinion is probably owing to several distinct causes, and I think that before anyone can hope to arrive at a just and sound conclusion on this much debated question, he should fully and fairly consider the reasons why previous investigators have been led to take such different views. There are at least four causes which have conduced to this divergence of opinion.

(1) The minute structure of the Chalk has not been sufficiently investigated. The Chalk is not a simple formation of moderate thickness and extent like many other limestones, nor is it of similar composition throughout. Its thickness is great, 1,700 feet in the Isle of Wight, and its component strata are found to differ much from one another when they are examined with the microscope, though to the eye they may seem to have a very similar structure. Consequently, the inspection of a few slides of Chalk will not reveal the history of its formation, and no one ought to discuss the origin of the Chalk, as a whole, unless he has examined a large series of slides from different horizons and from different areas of Chalk.

(2) When any kind of Chalk is compared with modern deposits, either chemically or microscopically, it should be remembered that certain chemical and minerological changes must have taken place during the consolidation and upheaval of the formation. Some of these changes probably occurred while the formation was still below the Cretaceous Sea, and others were accomplished by the percolation of subaerial water through the mass. Some ingredients, such as the organic silica, the oxides of iron and manganese and the alkalis, have been dissolved and re-distributed or concentrated into concretions.

(3) It must also be remembered that the original structure of some parts of the Chalk may have been different from that of any deposit which could be formed at the present time. Chalk is mainly of organic origin, and the organisms of the Cretaceous period were different from those which now exist, and, as some of the Chalk-builders belong to extinct genera, we cannot be sure that their habits and habitats were similar to those of their nearest living allies. This is especially the case with the Mollusca. The Foraminifera, and especially the arenaceous forms, are more likely to have been similar in these respects to their modern congeners.

(4) Some of those who have discussed the origin of the Chalk, as a whole, have been more or less biassed by preconceived views regarding the permanence of continents and ocean basins, and have therefore sought to minimise the resemblances which some parts of the Chalk present to modern deep-sea deposits; while their opponents have naturally made the most of these resemblances. The problem of the Chalk should be considered by itself, and the evidence must be balanced by a mind which is free from the bias of any previous theoretical views regarding the origin and growth of oceans and continents.

In the present communication I propose to follow one line of investigation only, and to point out the inferences which may be deduced from the facts so far as they are at present known to me. This branch of the subject is the minute structure of the successive zones of the Chalk as revealed by the microscope. Most of my information on this subject is derived from the work of my friend, Mr. W. Hill, published in several papers and in the *Journal of the Geological Society of London*, but an important contribution has recently been made by Dr. W. F. Hume, in his essay, entitled "Chemical and Micro-minerological Researches on the Upper Cretaceous Zones of the South of England," 1893.

2. CONSTITUENTS OF CHALK.

Before entering into particular descriptions it will be desirable to give some account of the general structure of Chalk and of its principal constituents. Most kinds of Chalk have a matrix of more or

less fine-grained material, which encloses a greater or less number of larger particles, such as fragments of shell or Foraminifera. Sometimes the matrix forms the greater portion of the material; sometimes the definite organic and inorganic particles are in larger quantity. The matrix may be either wholly calcareous or may include some very fine argillaceous matter, and occasionally the mass is bound together by a cement of crystalline calcite.

The larger particles may be classified under four heads—Shell Fragments ; Perfect Shells ; Sponge Spicules ; Mineral Grains.

(1) *Shell Fragments*. These are small angular fragments of the calcareous shells and spines of various marine animals. The most abundant are pieces of *Inoceramus* shell, varying in size from what may be called a large piece, under the microscope, down to single detached and broken prisms. Next to these in abundance, at some horizons, are fragments of the plates and spines of Echinid shells. Portions of the shells of *Terebratula*, *Rhynchonella*, *Ostrea*, and other genera can sometimes be distinguished. Broken Foraminifera are also common.

(2) *Perfect Shells*. Of these the most universally diffused are very small hollow spheres, which have often been mistaken for the detached or primordial cells of some kind of Foraminifera. Dr. G. J. Hinde, however, informs me that he has no doubt they are perfect shells and not detached cells ; they occur also in modern oozes, but it is not known to what organism they belong.

Foraminifera are sometimes common, but are never so abundant as to occupy much space in the field of a slide. Both arenaceous and porcellaneous forms occur. Entomostraca occur in some beds, and both they and Foraminifera may have contributed largely to the material of the fine calcareous dust of the matrix.

(3) *Sponge Spicules*. These are frequently present and are sometimes abundant, but are not always in their original condition, being often entirely replaced by calcite.

(4) *Mineral Grains*. These are partly such as have been formed on the sea-floor, and partly mineral fragments derived from terrestrial sources. Glauconite is the most common mineral ; it generally occurs in grains of rounded outlines, and as it is often seen filling

the chambers of Foraminifera and the axial canals of Sponge Spicules there seems no reason to doubt that the loose grains have been formed in such situations. Of detrital minerals quartz is the commonest, but minute grains of other minerals also occur in some parts of the Chalk and in some districts; among those observed are Zircon, Tourmaline, Hornblende, Felspar, Rutile, and Apatite.

Next let us consider the physical conditions which these constituents may serve to indicate. Little can be learnt from the shells or shell-fragments because most of them belong to extinct species, and we know nothing of their habits. The Foraminifera, however, do furnish some evidence, for many of these seem to be identical with species now living, and the bottom-living arenaceous forms may perhaps be relied on as giving some indication of the depth of water.

The glauconite grains are more definite indicators of certain physical conditions. In modern deposits glauconite is formed inside Foraminifera shells at various depths down to 1,000 fathoms, but is most abundant where the deep water begins, that is from 100 to 400 fathoms. It does not occur where large rivers enter the sea, but only along tracts off bold coasts where the water is comparatively clear. From these and other facts mentioned in the Challenger Reports, it appears that glauconite is formed in areas where deposition goes on slowly, where the amount of land-derived sediment is small, and where, consequently, it lies exposed for a long time to the decomposing action of sea-water. An extensive deposit of glauconite sand or marl will, therefore, indicate clear water of from 100 to 500 fathoms, and within 200 miles of an extensive coast-line. Moreover, if the accompanying quartz-grains are small it is likely to have been formed nearer to the 500 fathom than to the 100 fathom-line.

The detrital minerals, quartz, felspar, zircon, &c., have generally been derived from the erosion of the land, and their presence in any quantity may usually be taken as proof of the deposit having been formed within 200 miles of land. Such particles, especially of the heavier minerals, are generally absent from the deeper oceanic deposits. In some regions, however, small particles of quartz do occur in oceanic oozes at great distances from land, and these can always be traced to wind-blown sands, so that the presence of minute

quartz-grains does not prove the deposit to have been formed within the influence of shore currents. Again fine volcanic dust, containing recognisable particles of felspar, augite, hornblende and olivine, is often carried to great distances from land by the wind currents in the higher regions of the air.

3. STRUCTURE OF SUCCESSIVE ZONES OF THE CHALK.

We now come to a consideration of the composition of the different zones into which the Chalk can be divided. Much more work is required before any such account can be considered complete, and the following statements only apply to portions of that part of England which lies to the east of a line drawn from the Wash to the South Coast at Weymouth. The Chalk of Yorkshire has not yet been sufficiently studied either in its zonal or structural aspects.

The Chalk Marl, or *Zone of Ammonites varians*, exhibits great differences in minute structure as it is traced from Norfolk to Dorset. In the N.W. of Norfolk the beds, which represent the Chalk Marl, are hard and highly calcareous; some are of fine some of coarser grain, according to the relative abundance of shell-fragments, but glauconite is absent except in one bed (the so-called "*Inoceramus Bed*,") and the quartz grains are few and small. As the zone is traced southwards, through Norfolk and Suffolk, beds of soft marl come in between the harder layers, and particles of quartz and glauconite become more frequent throughout. When traced further south these grains become rather larger, as well as more numerous, till in Berks and Wilts, where the zone attains its greatest thickness, the material is at its coarsest. Wiltshire Chalk Marl consists mainly of shell fragments, quartz particles, glauconite grains, and sponge spicules in varying proportions; and some beds contain much globular colloid silica. Near the base the grains of quartz are of comparatively large size, gradually becoming smaller in the higher beds. On the South Coast the following minerals have been found in Chalk Marl:—Quartz, Felspar, Zircon, Tourmaline, Apatite, Hornblende, Rutile and Garnet.

The Chalk Marl of the Isle of Wight, and to a less extent that of Folkestone, is characterised by the abundance of arenaceous Foraminifera, especially species of *Tritaxia*, *Textularia* and *Bulimina*.

The Grey Chalk or zone of *Holaster subglobosus* has the Totternhoe Stone at the base over a large area; this stone is a shelly Chalk, containing much glauconite and some quartz. The Chalk above it consists of fine calcareous dust in which there are some shell fragments and a little glauconite. In the highest part of the zone, from Norfolk to the Thames Valley, there is no visible glauconite or quartz, but south of the Thames both minerals occur sparingly up to the very top; the grains are, however, small, and other minerals are very rare.

Arenaceous Foraminifera are abundant in some localities, or at certain horizons, especially at Folkestone, and resemble those in the Chalk Marl. Calcareous spheres are also very abundant in the upper half of the zone.

In the zone of *Belemnitella plena* the material of the marls resembles that of the Grey Chalk, except that the amount of fine clay in it is much larger, and that the arenaceous Foraminifera belong chiefly to the genera *Ammodiscus* and *Haplophragmium*. Glauconite grains are very rare even on the south coast.

The Melbourn Rock is a very pure limestone; its whiter portions consist almost entirely of a fine calcareous paste, through which calcareous spheres are abundantly distributed, but the marly veins between the white lumps are full of shell fragments. No minerals have yet been recorded from it.

The Melbourn Rock passes up into the zone of *Rhynch. Cuvieri* or *Inoceramus mytiloides*, both fossils being common in it, and broken *Inoceramus* shells being so distributed through it as to give it a gritty character. The Chalk itself, however, is largely made up of calcareous spheres, shell fragments becoming less and less abundant as a microscopic constituent. The most remarkable point is the recurrence of mineral grains in the South of England and North-east of France; whether they occur in this zone further north is not yet known. The quantity is very small, less than 0.3 per cent. of the mass; the grains are mostly quartz and felspar, and are generally of decidedly rounded outline, but are sometimes large. Glauconite seems to be absent, for none has been observed.

The zone of Terebratulina gracilis is everywhere a purely cal-

careous deposit, consisting of a fine calcareous matrix crowded with minute calcareous spheres, and including a few scattered shells of large Foraminifera (*Globigerina*, *Rotalia*, &c). The insoluble residue consists almost entirely of very fine light-brown clay, coloured by hydrous oxides of iron. Mineral grains are very rare, but Dr. Hume found a few small particles of quartz in one sample from the Isle of Wight.

The Chalk Rock has a remarkable structure. It always contains a great variety of organic fragments derived from the shells of Echinoderms, Lamellibranchs and Brachiopods, with remains of siliceous sponges. Glauconite is abundant in the south central counties, but the grains become fewer and smaller to the north and east, and detrital minerals have only been found in the Chalk-rock of the southern counties. Quartz is there common in small angular grains, and sometimes in large rounded grains. Dr. Hume has also observed Angite, Hornblende and Tourmaline in the rock of the Isle of Wight.

The Chalk of the *Micraster breviporus* and *cortestudinarium* zones is generally rough and shelly; it consists of a fine calcareous matrix, enclosing shell fragments and large Foraminifera in varying amounts. In the South of England detrital minerals appear in the insoluble residue; these include Quartz, Apatite, Felspar and Tourmaline, the quartz grains being of various shapes "from perfectly rounded to strikingly angular" (Hume), and some of it is granite quartz. Glauconite is either absent or in very small quantity. No arenaceous Foraminifera have been observed.

The *Micraster coranguinum* Chalk resembles that of the *cortestudinarium* zone in general structure, but the insoluble residue is almost entirely fine clay, containing minute spherules and rods of Glauconite. Only a few very minute particles of quartz have been found.

The Chalk of the *Marsupite* zone is purer than any of the lower zones, the amount of insoluble residue being generally under one per cent., and the greater part of this being fine clay; but, by washing, a small residue is obtained, which includes minute angular fragments of quartz, grains of brassy iron pyrites, and of a reddish limonitic mineral, and rarely of glauconite, all very minute.

The zone of *Belemnitella mucronata* has the same characteristics, generally under one per cent. of clay, no glauconite, and detrital minerals very rare. The material is a fine calcareous dust or paste, in which small calcareous spheres and a few small Foraminifera and shell fragments are distributed.

4. INFERENCES.

There is one fact which seems clearly proved by the preceding details, and this is that the inorganic constituents of Chalk are most abundant in the South of England. There seem to be several zones in which the amount of quartz and glauconite increases as they are traced southward. From this we may infer that the main mass of land lay somewhere in a southerly direction.

I may here mention that the evidence of the French Chalk shows that this land lay to the east of France, and consequently to the south-east of England. At the same time there are indications of land to the south-west and good reasons for believing that this was a large island which presented a rocky shore to the east, its rivers draining toward its western coasts.

With respect to the depth of the Chalk sea we know that the period was one of great and extensive subsidence, but there is evidence that this subsidence was at any rate in one area interrupted by upheaval. It is obvious that if we can form an opinion as to the depth in which the Chalk Marl was formed, we shall have a basis from which to trace the subsequent changes.

We must remember that the Chalk Marl is not the base of the Upper Cretaceous series. The beds beneath it are not shore sands but marly clays and greensands, which seem to have been formed in water that was not less than 100 fathoms in depth, and may have been much more in the central part of our area. There is every reason to suppose that the Chalk Marl was formed in deeper water than the Gault, but the large amount of sand and glauconite which it contains, especially in the southern counties, makes it probable that no part of this southern area was more than 200 miles from land.

Two lines of evidence lead to the conclusion that the Chalk Marl was formed in water of from 300 to 500 fathoms. One is the

general similarity of the deposit to that now forming in certain parts of the Gulf of Mexico and the Florida Straits, and especially in depths of from 200 to 500 fathoms, according to Dr. J. Murray.* Again, the assemblage of arenaceous Foraminifera is best matched in depths of from 350 to 500 fathoms at the present time.† If this conclusion is correct we may safely assume that the rest of the Lower Chalk was formed in rather deeper water, probably from 400 to 600 fathoms.

The Melbourn Rock and zone of *Rhynchonella Cuvieri* do not afford much positive evidence. The absence of glauconite suggests distance from land, but the presence of large quartz grains is puzzling. The stratigraphical and palæontological evidence connected, the Belemnite Marls and Melbourn Rock indicate the occurrence of considerable geographical changes at this time, affecting the direction and strength of the marine currents and largely altering the fauna. All the facts harmonize with the inference that these changes were brought about by continued subsidence.

Conditions then seem to have settled for a time, and the structure of the central part of the Middle Chalk seems to indicate the quiet deposition of purely calcareous ooze in deep water at some distance from land. The almost entire absence of mineral particles in the *Ter. gracilis* zone is a striking fact, for there are few modern oozes which are so free from minerals. The absence of pumice and the extreme rarity of augite and olivine is proof that no active volcanos existed within many hundred miles of our area, and it is the absence of this volcanic material which makes the Chalk seem so much purer than modern *Globigerina* ooze. The mass of the Chalk of the *Ter. gracilis* zone seems to be entirely made up of fine powder derived from the shells of Foraminifera, Calcareous spheres, Deep-sea Echinoderms, certain Mollusca and Brachiopoda, and Coccoliths.

The Chalk Rock presents a great contrast to this; the recurrence of glauconite and of quartz in Southern England suggests a partial re-elevation of land, and there are other reasons for thinking that there was an upheaval of the western island at this time. The character

* Bull. Mus. Comp. Geol., Harvard Coll., U.S., vol. xii., p. 52.

† W. F. Hume, Op. Cit., p. 81.

of the Chalk Rock fauna confirms the above inference, for it abounds in Gasteropoda and recalls that of the Chalk Marl. If the depth of the water over Hampshire had increased to 700 or 800 fathoms during the epoch of the *Ter. gracilis* zone an uprise of the south-western land may have brought its coast line within 100 miles without decreasing the depth of water by more than 100 or 150 fathoms, and without bringing the eastern shore of the Cretaceous Ocean any nearer our area because the upheaval may have been a tilting movement only lifting the western islands.

From this time we seem to be following the progress of a great and extensive subsidence. The grains of glauconite become smaller and fewer and eventually die out altogether; the same may be said of the detrital minerals, only a few minute angular particles of quartz being found in the higher beds of the Upper Chalk, quite invisible in a slice even under a half-inch lens. Arenaceous Foraminifera are also absent except *Ammodiscus incertus*.

The mere thickness of deposit above the Chalk Rock amounts to 200 fathoms in the Isle of Wight, and the fineness of the material shows that its accumulation was very slow. Its other characters indicate distance from *Continental* land and a considerable depth of water. At the same time the deposit is purely calcareous and shows no tendency to pass into a Red Clay; this however is due to the absence of volcanic material and is not a reliable indication of depth, for *Globigerina* oozes, with over 90 per cent. of Calcium Carbonate, occur in the South Atlantic at depths of about 2000 fathoms. It is, therefore, quite possible for a purely calcareous deposit to be formed at that depth.

It has been asserted that Coral-mud is more like Chalk than any other modern deposit, but the resemblance is probably quite superficial. Dr. J. Murray describes Coral-mud as always containing the debris of *reef-forming* organisms, such as Corals, Calcareous Algæ, Echinoderms, Alcyonaria, Pteropoda, small Gasteropoda, and other Mollusca. I need not say that such an assemblage is not to be found in any part of the Chalk. The only bed which presents any approach to such a structure is the Chalk Rock, but few corals and no Alcyonarians or calcareous Algæ have yet been observed in that. Prof.

UPPER CHALK.
(Scale of 200 ft. to an inch.)

MIDDLE AND LOWER CHALK.
(Scale of 100 ft. to an inch.)

Zones after Barrois, thickness of
Lower Chalk corrected by Geol.
Survey Memoir, 2nd Edition.

A DIAGRAM OF THE ZONES OF THE CHALK AS DEVELOPED IN THE ISLE OF WIGHT.

Agassiz, who has examined both Chalk and Coral-mud, has no hesitation in saying that "Chalk is certainly not derived from the disintegration of Coral-reefs."^{*}

The White Chalks agree with the Globigerina and Pteropod oozes in containing Coccoliths and calcareous spheres; they differ from both in containing fewer perfect shells. The most highly calcareous Globigerina oozes of the present day are crowded with, and often almost entirely made up of, Globigerina shells, while the more purely calcareous Chalks consist mainly of fine calcareous dust, and the single calcareous spheres are always more abundant than the Globigerinae. This difference, however, may be due to the fact that we only possess samples of the highest layer of the modern oceanic ooze, this layer naturally consisting largely of fresh Globigerina shells. In deeper layers the fine material resulting from the decay and disintegration of the shells is likely to be more abundant, and such a deposit would greatly resemble Chalk.

While, therefore, no exact modern counterpart of Cretaceous Chalk has yet been discovered, yet it is a fact that certain varieties of Globigerina ooze resemble Chalk more than any other modern deposit, and I think we may reasonably infer that this similarity implies the existence of similar physical conditions.

^{*} Three Cruises of the "Blake," vol. i., p. 148.