XXVI.—*Oceanic Sediments, and their Relation to Geological Formations.* By Professor William King, Sc.D. &c.

The valuable "preliminary reports" by Professor Wyville Thomson, M.D. &c., in parts 154 & 156 of the 'Proceedings' of the Royal Society, demand the special attention of geologists, as making known some important facts elucidating the sedimentary or depositional phenomena of the ocean in past periods of our globe.

When my Notices * were published on the various objects obtained by the soundings of H.M.S. 'Porcupine,' during her Atlantic-Telegraph Survey Expedition off the west coast of Ireland, in 1862, the belief was gaining ground that the calcareous ooze occurring at great depths in the ocean is formed of the testaceous débris of Foraminifera that habitually live on its bottom. Ehrenberg, finding sarcode in the foraminifer-shells brought up from the bed of the subarctic Atlantic by Colonel Schaffner, appears to have been the first to give a decided expression to this view; though it had previously found favour with Professor Bailey, and was forcibly advocated afterwards by Wallich. The discoveries of Huxley, Berryman, and others strongly tended in the same direction. Influenced by these authorities, and taking various matters into consideration, I was induced to express the belief that the floor of the deep Atlantic is crowded with living *Globigerinæ* and *Orbulinæ*. Subsequently, in 1869, Doctors W. B. Carpenter and Wyville Thomson formed and expressed a very strong opinion on the same side. However, the researches lately made by the latter have led him to renounce this opinion, and to contend, like Major Owen and Dr. Gwyn Jeffreys, that the ooze-forming organisms inhabit the superficial stratum of the ocean, from the surface to about 100 fathoms in depth. I should have readily subscribed to the same view, but for certain facts which appear to oppose it. There are no unequivocal instances of living examples of the organisms referred to having been found in *mid-ocean* at the surface †. Major Owen's accounts (also apparently Lieut. Palmer's, which I have not been able to consult) have been accepted as proving that *Globigerina* and *Orbulina* are inhabitants of the superficial stratum, rising and

* See 'Nautical Magazine,' December 1862; and 'Fraser's Magazine,' October 1863.

† The cases cited of Müller and Häckel having taken live specimens of *Globigerina* and *Orbulina* in the tow-net must be eliminated, as they belong to shallow depths not far from land, where the creatures may not only live at the bottom, but may occasionally rise to the surface, or be brought up through adhering to pieces of seaweed that have got detached from the bottom.

sinking in it at will; but there is nothing recorded to support the idea that they are alive, except their occurring in the greatest numbers on the surface after sunset; from which it is inferred that they avoid the light. The presumed fact is certainly singular if the creatures are dead, though it may not be beyond a physical explanation. But if they are living, it is equally singular that no manifestations of vital functions have been observed, as far as I can ascertain, in any captured specimens, by those who have had the opportunity of examining them. Prof. Wyville Thomson and assistant Mr. Murray (who has been paying the closest attention to the floating Foraminifera) would scarcely be unmindful of this matter; yet it is noteworthy that they "never have been able to detect in any of the large number of *Globigerinæ* which have been examined" by them "the least trace of pseudopodia, or any extension in any form of the sarcode beyond the shell." Moreover the chambers are often almost empty, even in the freshest-looking specimens; or they contain sarcode apparently in no other than the unsatisfactory condition it presented to Bailey, Ehrenberg, Wallich, and others. So far, then, I see no reason to change the opinion which is expressed in my Notices of 1862.

In order to explain all the circumstances under which the ooze-forming foraminifers occur, I am induced to make the following suggestions in accordance with the assumption that they live at the bottom. As soon as a Globigerine or an Orbuline dies, the decomposition of the sarcode generates within the chambers sufficient carbonic-acid gas to cause it to rise to the surface. Here, the sarcode being still in process of decomposition, gas continues to be discharged from the chambers alternately with the intromission of water: these actions give rise to variations in the specific gravity and, as a consequence, to opposite vertical movements of the shell. It is conceivable, all other conditions being favourable, that occasionally, after the superficial stratum of the ocean has got warmed by the noon-day sun, the elevated temperature, and the consequent acceleration of the decomposition of the sarcode, would largely increase the generation of gas, thereby causing the shell to rise to or near the surface towards or after sunset: during the night, on the gas escaping and its replacement by water, the shell would descend again *. Thus, as long as decomposition

* It is stated by Lewy that the amount of oxygen in sea-water is somewhat greater during the day than it is at night, the reverse being the case as regards carbonic acid (Bischof, vol. i. p. 115). May not this difference have something to do with the rising of the shells during the night?

of the sarcode was carried on within its chambers, a foraminifer-shell would be limited to the superficial stratum, rising and sinking therein, as if it were animated and it preferred darkness to light. Eventually, gas ceasing to be generated, and the chambers becoming filled with water, the shell sinks to the bottom.

These suggestions, it appears to me, are fully capable of explaining not only the presence of foraminifer-shells in the greatest abundance in the superficial stratum after sunset (assuming that the observations made by Major Owen and others are conclusive on this point*), but how it is that the specimens taken in the tow-net are often fresh, transparent, and occasionally furnished with spines in a wonderful state of preservation†; while those obtained from the bottom are usually in an opaque or chalky condition. On the view that these organisms habitually live at the bottom, it may be urged that some specimens in the living state ought to be brought up by the dredge or sounding-apparatus. Considerable doubt, however, may be entertained as to such possessing any vital power, considering the greatly altered conditions of temperature and pressure they would be subject to during the ascent; and it is highly improbable that many of them would retain their delicate spines. As the problem does not seem to be difficult of solution, let us hope that it will not remain long in its present unsettled state.

As regards the nature of the various substances forming the sea-bottoms, the general concurrence of the recorded observations goes far to prove that generally wherever the depth increases beyond 2600 fathoms the foraminifer-ooze gives place to argillaceous deposits, one kind marked "grey ooze" and the other "red clay" in the 'Challenger's' charts,—that, instead of a substance convertible into limestone or chalk, there occurs at depths approaching and exceeding 3000 fathoms a sediment essentially consisting of silica, red oxide of iron, and alumina. The two formations pass into each other by

* The naturalists of the 'Challenger' are silent on this point: on the contrary, they mention that *Pulvinulina Menardi*, which largely contributes to the formation of the ooze, is very abundant at the surface, and still more so during the day at a depth of from 10 to 20 fathoms.

† Häckel has thrown out the suggestion that the spines with which *Orbulina* and *Globigerina* are crowded "probably contribute essentially to enable these little animals to float below the surface of the water by greatly increasing their surface, and consequently their friction against the water, and rendering it more difficult for them to sink." But the force of this suggestion is altogether weakened by the fact that *Pulvinulinæ*, equally considered to be surface-swimmers, do not possess any spines.

gradations apparently consequent on occupying intermediate depths, and often represented by the grey ooze. It would also appear that at the greatest ascertained depths conditions prevail unfavourable to the existence of organisms with calciferous tissues or calcareous skeletons. Life, however, still exists in the abyssal basins where the grey and red clays are formed. In several hauls, in one instance from 2975 fathoms, there were brought up :—holothurids of considerable size with *rudimentary calcareous* neck-rings ; delicate branching, *almost membranous* Bryozoa ; tube-building annelids, and tests of Foraminifera, the two latter being made up of particles of the red clay alone. And on one occasion, between Kerguelen Island and Melbourne, the "red clay," at the depth of 2600 fathoms, yielded Holothurias, starfishes, Actinias, Palliobranchs, *Euplectella*-sponges, &c. : those with calcareous parts were rather stunted.

Considering the existence in the ocean of vast numbers o diatoms, polycystines (these, there is no doubt, habitually live at or near the surface), sponges, and other organisms, whose skeletons consist of silica—also that rock-particles in the finest state of division, from their occurrence everywhere in the atmosphere, must be scattered over the sea-bottom by the distributive action of currents, it was to be expected that the foraminifer-ooze would not be purely calcareous. The analyses published by Messrs. David Forbes and John Hunter (late of the Queen's College, Belfast) show that such is actually the fact—the former having found, in a specimen from the depth of 2435 fathoms, 23·34 silica, 5·91 ferric oxide, 5·35 alumina* ; the latter, in a specimen taken in 1443 fathoms, 26·77 fine insoluble gritty sand (rock-débris), 1·33 alumina (soluble in acids), and 2·17 sesquioxide of iron (soluble in acids) †. Mr. Buchanan, of the 'Challenger,' has found 1 per cent. of a reddish mud, consisting of silica, alumina, and red oxide of iron, after washing and subjecting samples of the ooze to the action of weak acid. These results seem to have satisfied the scientific Director of the Survey that, allowing certain difficulties as mere matters of detail, the question as to the origin of the red clay is in the main solved. Grant sufficient free carbonic acid in the water of deep ocean-basins to dissolve all calcareous bodies, such as foraminifer-shells, that fall into them, the insoluble constituent alone will remain as a deposit. Professor W. C. Williamson proposed a similar hypothesis many years ago to account for the absence of calcareous shells in the siliceous (Diatomaceous) deposits of Bermuda and Vir-

* Proc. Royal Soc. vol. xviii. p. 490. † *Ib.* p. 428.

ginia, assuming that at one time they were like the Levant mud, in which there is generally an admixture of calcareous and siliceous organisms *.

There are certain facts in geology which show analogous changes effected by the agency of carbonic acid: the most striking that occurs to me is the conversion, by means of this solvent, of beds of argillaceous limestone (Carboniferous) into highly aluminous rotten-stone, in Derbyshire and Glamorganshire. Nevertheless there are some grounds for refusing to look upon the "red-clay" basins as so many Upas valleys. If carbonic acid destroyed all the shell-structures carried into them, the water would necessarily become charged with bicarbonate of lime in solution; but from the various analyses hitherto made of sea-water, the quantity it contains of this salt appears to be very small compared with the amount of sulphate of lime. Carbonic acid may be the agent; but I am more in favour of sulphuric or rather sulphurous acid, considering that such is not unlikely to be produced by the oxidation of sulphuretted hydrogen, derived from the decomposition of organic matter—also the presence of its decomposing agent (oxygen), as determined by Messrs. Lant Carpenter and Buchanan, in the depths of the ocean †.

Subjected to the action of sulphurous acid, the substance of all calcareous shells in a *dead* condition would be ultimately converted into soluble sulphate of lime, with liberation of carbonic acid ‡; and thus the ocean would be perpetually supplied

* Transactions of the Manchester Literary and Philosophical Society, 1847. It must not be overlooked that the siliceous organisms which occur in the foraminifer-ooze in appreciable proportion have likewise for the most part disappeared in the red clay, through the action of some dissolving agent. Crystals of quartz, from Zinnwald, are not uncommon with their planes corroded and deeply excavated in places originally occupied by oligist—showing that the silica has been in some way removed by the action of a ferric oxide; the fact is of some significance in connexion with the disappearance of the siliceous organisms from the red clay. I may add that Mr. H. J. Carter has called attention to the rapid wasting or decay which siliceous (also calcareous) spicules of sponges undergo in his cabinet, whether mounted or unmounted, also in living specimens (see Ann. & Mag. Nat. Hist. 1873, vol. xii. pp. 456, 457). This destruction appears to be due to solvent action of another kind.

† I have had some experience of the presence of sulphuretted hydrogen in the ocean during a strong gale of three days' duration on the west side of the Doggerbank, while on one of my dredging-expeditions, some thirty years ago. The agitation of the sediment at the depth of about forty fathoms by the heavy seas caused so much of this gas to rise to the surface that my watch, a silver one, became quite blackened by its action.

‡ When Bischof wrote his 'Chemical and Physical Geology' very little was known respecting the abundance of calcareous organisms at the bottom of deep oceans. Fixing his attention on the vast amount of

with its most abundant calcic constituent. The same process, it may be urged, would take place over the shallower areas covered with foraminifer-ooze. Admitted, but with this difference: in the "red-clay" basins foraminifer life evidently approaches zero, whereas in shallower areas it is unquestionably in the ascendant; therefore any loss of lime the latter areas may sustain through the action of sulphurous acid, would be made up by *living* Foraminifera converting the sulphate of lime in the surrounding water into the carbonate composing their shells.

Doubtless, whatever the agent may be that produces the "red-clay" deposit, it has contributed more or less to the production of similar or related formations belonging to different geological periods—though they may be of any colour, depending on the relative amount of their constituents and the nature of their combination. Certain supersilicated rocks (as novaculite, fuller's earth, chamoisite, &c.) suggest themselves in connexion with this idea; and it is highly probable that many of the glauconites were originally red clays (the residue of foraminifer-ooze), part of the peroxide of iron of the latter having been reduced to a protoxide by organic matter. I cannot, however, think it is correct to associate the Oldhamian schists (Cambrian) with this idea—that is, "to suspect that they may be organic formations like the modern red clay of the Atlantic and Southern sea, accumulations of the insoluble ashes of shelled creatures." The thousands of feet of Cambrian schists would require the existence somewhere of vastly more thousands of feet of synchronous limestones. But where are they? In the recently published paper by Mr. T. Davidson and myself on the *Trimerellidæ* this question was briefly discussed *. Failing to ascertain the existence of any limestones of the kind, we made the suggestion that the Cambrian seas were not inhabited by organisms furnished with calcareous skeletons, or they did not contain the ordinary amount of calcic constituents. I do not dispute that

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bicarbonate of lime carried into the sea by rivers, he naturally concluded that this salt was appropriated by shell-fish. Nevertheless I must still adhere to the opinion I expressed in 1862, that pelagic animals obtain calcic matter from the sulphate of lime contained in the surrounding water. I find that Forchhammer is of opinion "that Testacea decompose the latter substance by means of carbonate of ammonia formed by their agency." Bischof thinks that "it might likewise be decomposed by the organic matter of marine animals into sulphide of calcium, which would be decomposed by the carbonic acid produced by them" (see 'Chemical Geology,' vol. i. p. 180, footnote).

* Quarterly Journal of the Geological Society, May 1874.

calcareous rocks belonging to the Cambrian system may yet be found; but considerable doubts may be entertained of their occurring in it to any extent except as methylosed members.

The facts brought to light by the various submarine surveys that have been made show how simple, yet grand, are the depositional phenomena of the ocean; but they place before the geologist nothing more than the materials that enter into the composition of ordinary sedimentary rocks in their *normal* condition. During the Wernerian stage in the progress of geology the doctrine was taught that crystalline rocks were the products of oceanic precipitations. Other doctrines took its place. Of late years, however, it has been revived, with novel accessories. Judging from the results of the surveys referred to, the chances seem to be extremely remote that any sea-bottoms will ever yield to the dredge samples of *direct crystalline precipitates* having the least relation to the Laurentian diorites, ophites, syenites and the like, as products of our present oceans.

XXVII.—*Remarks on Professor Owen's Arrangement of the Fossil Kangaroos**. By Gerard Krefft†.

The first part of Professor Owen's work describing the fossil kangaroos has just been received; and as some new genera have been added, it will no doubt interest readers of the 'Sydney Mail' to hear how these divisions have been defined. The learned Professor pays a just tribute to John Gould, F.R.S., "through whose adventurous journeys, and by the noble works in which he has given the result of his observations in Australia and Tasmania, we mainly know the extent and kinds of variations under which the kangaroo there exists." There is more in this sentence than many people imagine, because Professor Owen no longer hesitates to speak "evolutionally" ‡ about the subject. It has been pointed out by me on several occasions, and chiefly in papers read before the Royal Society of New South Wales, that the whole of our extinct and living marsupials were offshoots or branches of a kind of animal which combined the dental structure of both the carnivores and herbivores of the marsupial section. The

* "On the Fossil Mammals of Australia.—Part VIII. Family Macropodidæ: Genera *Macropus*, *Phascolagus*, *Sthenurus*, and *Protemnodon* (Phil. Trans. 1874, pt. i. pp. 245–287, pls. xx.–xxvii.), by Professor Owen, F.R.S.

† From the 'Sydney Mail,' Dec. 26, 1874. Communicated by the author.

‡ Royal Society's 'Philosophical Transactions' for 1874, p. 255.