ON THE

LIGHT THROWN ON GEOLOGY BY SUBMARINE RESEARCHES;

BEING THE SUBSTANCE OF A COMMUNICATION MADE TO THE ROYAL INSTITUTION OF GREAT BRITAIN, FRIDAY EVENING, THE 23D FEBRUARY 1844.

By EDWARD FORBES, F.L.S., M.W.S., &c.
Professor of Botany, King's College, London.

From the Edinburgh New Philosophical Journal for April 1844.

About the middle of the last century, certain Italian naturalists* sought to explain the arrangement and disposition of organic remains in the strata of their country, by an examination of the distribution of living beings on the bed of the Adriatic Sea. They sought in the bed of the present sea for an explanation of the phenomena presented by the upheaved beds of former seas. The instrument, by means of which they conducted their researches, was the common oyster-dredge. The results they obtained bore importantly on Geology; but since their time, little has been done in the same line of research,—the geologist has been fully occupied above water, and the naturalist has pursued his studies with far too little reference to their bearing on geological questions, and on the history of animals and plants *in time*. The dredge, when used, has been almost entirely restricted to the search after rare animals, by the more adventurous among zoologists.

Convinced that inquiries of the kind referred to, if conducted with equal reference to all the natural history sciences,

* Marsili and Donati, and after them Soldani.

and to their mutual connection, must lead to results still more important than those which have been obtained, I have, for several years, conducted submarine researches by means of the dredge. In the present communication, I shall give a brief account of some of the more remarkable facts and conclusions to which they have led, and as briefly point out their bearings on the science of geology.

I. *Living beings are not distributed indifferently on the bed of the sea, but certain species live in certain parts, according to the depth, so that the sea-bed presents a series of zones or regions, each peopled by its peculiar inhabitants.*—Every person who has walked between high and low water-marks on the British coasts, when the tide was out, must have observed, that the animals and plants which inhabit that space, do not live on all parts of it alike, but that particular kinds reach only to certain distances from its extremities. Thus the species of *Auricula* are met with only at the very margin of high water mark, along with *Littorina cœrulescens,* and *saxatilis*, *Velutina otis*, *Kellia rubra*, *Balani*, &c.; and among the plants, the yellow *Chondrus crispus* (*Carrigeen*, or Iceland moss of the shops), and *Corallina officinalis.* These are succeeded by other forms of animals and plants, such as *Littorina littorea, Purpura lapillus, Trochi*, *Actineæ*, *Porphyra laciniata* (Laver, Sloke), and *Ulvæ.* Towards the margin of low water, *Lottia testudinaria*, *Solen siliqua*, and the Dulse, *Rhodomenia palmata*, with numerous Zoophytes and Ascidian molluscs, indicate a third belt of life, connected, however, with the two others, by certain species common to all three, such as *Patella vulgata*, and *Mytilus edulis.* These sub-divisions of the sea-bed, exposed at ebb-tide, have long attracted attention on the coasts of our own country, and on those of France, where they have been observed by Audouin and Milne Edwards, and of Norway, where that admirable observer Sars has defined them with great accuracy.

Now this subdivision of the tract between tide-marks into zones of animal life, is a representation in miniature of the entire bed of the sea. The result of my observations, first in the British seas,* and more lately in the Ægean, has been to define a series of zones or regions in depth, and to ascertain *specifically* the animal and vegetable inhabitants of each. Regarding the tract between tide-marks as one region, which I have termed the *Littoral Zone,* we find a series of equivalent regions, succeeding it in depth. In the British seas, the littoral zone is succeeded by the region of Laminariæ, filled by forests of broad-leaved Fuci, among which live some of the most brilliantly coloured and elegant inhabitants of the ocean. This is the chosen habitat of *Lacunæ,* of *Rissoæ,* and of *Nudibranchous mollusca.* A belt generally of mud or gravel, in which numerous bivalve mollusca live, intervenes between the laminarian zone (in which the Flora of the sea appears to have its maximum), and the region of Corallines, which, ranging from a depth of from 20 to 40 fathoms, abounds in beautiful flexible zoophytes and in numerous species of Mollusca and Crustacea, to be procured only by means of the dredge. The great banks of Monomyarious Mollusca, which occur in many districts of the Northern Seas, are for the most part included in this region, and afford the zoologist his richest treasures. Deeper still is a region as yet but little explored, from which we draw up the more massy corals found on our shores, accompanied by shellfish of the class *Brachiopoda.* In the Eastern Mediterranean (where, through the invaluable assistance afforded by Captain Graves, and the Mediterranean Survey, I have been enabled to define the regions in depth, to an extent, and with a precision which, without similar aid, cannot be hoped for in the British seas), between the surface and the depth of 230 fathoms, the lowest point I had an opportunity of examining, there are eight well-defined zones, corresponding in part, and presenting similar characters with those which I have enumerated as presented by the sea-bed in the North. The details of these will be given in the forthcoming volume of the Transactions of the

* The first notice of these was published in the Edinburgh Academic Annual for 1840.

British Association, to which body I had the honour of presenting a report on the subject, at the last meeting.

When we examine the distribution and association of organic remains, in the upheaved beds of tertiary seas, we find the zones of depth as evident as they are in the present ocean. I have proved this to my own satisfaction, by a minute comparison of the newer Pliocene strata of Rhodes, where that formation attains a great thickness, with the present state of the neighbouring sea, and carrying on the comparison through the more recent tertiaries with the more ancient, have found indubitable evidences of the same phenomena. The strata of the cretaceous system yield similar evidences, and doubtless, in all time, the element of depth exercised a most important influence in regulating the distribution of animal life in the sea. If so, as our researches extend, we may hope eventually to ascertain the probable depth, or, at any rate, the region of depth, in which a given stratum containing organic remains was deposited. Every geologist will at once admit, that such a result would contribute materially to the history of sedimentary formations, and to the progress of geological science.

II. *The number of species is much less in the lower zones than in the upper. Vegetables disappear below a certain depth, and the diminution in the number of animal species indicates a zero not far distant.*—This conclusion is founded on my Ægean researches. Vegetables become fewer and fewer in the lower zones; and dwindle to a single species,—a *nullipora,* at the depth of 100 fathoms. Although the lower zones have a much greater vertical range than the higher, the number of animal species is infinitely greater in the latter. The lowest region (the 8th) in the Mediterranean, exceeds in extent all the other regions together; yet its fauna is comparatively small, and at the lowest portion explored, the number of species of testacea found was only eight. In the littoral zone, there were above 150 species. We may fairly infer, then, that as there is a zero of vegetable life, so is there one of animal life. In the sea, the vertical range of animals is greater than that of vegetables;—on the land, the reverse is the case. The geological application of this fact, of a zero of life in the ocean, is evident. All deposits formed below that zero, will be void, or almost void, of organic contents. The greater part of the sea is far deeper than the point zero ; consequently, the greater part of deposits forming, will be void of organic remains. Hence we have no right to infer that any sedimentary formation, in which we find few or no traces of animal life, was formed either before animals were created, or at a time when the sea was less prolific in life than it now is. *It might have been formed in a very deep sea.* And that such was the case in regard to some of our older rocks, such as the great slates, is rendered the more probable, seeing that the few fossils we find in them, belong to tribes which, at present, have their maximum in the lowest regions of animal life, such as the Brachiopoda, and Pteropoda, of which, though free swimmers in the ocean, the remains accumulate only in very deep deposits. The uppermost deposits, those in which organic remains would be most abundant, are those most liable to disappear, in consequence of the destroying action of denudation. The great and almost nonfossiliferous strata of Scaglia, which form so large a part of the south of Europe and of Western Asia, were probably, for the most part, formed below the zero of life. The few fossils they contain, chiefly nummulites, correspond to the foraminifera which now abound mostly in the lowest region of animals. There is no occasion to attribute to metamorphic action the absence of traces of living beings in such rocks.

III. *The number of northern forms of animals and plants is not the same in all the zones of depth, but increases either positively, or by representation, as we descend.*—The association of species in the littoral zone is that most characteristic of the geographical region we are exploring ; but the lower zones have their faunas and floras modified by the presence of species which, in more northern seas, are characteristic of the littoral zones. Of course, this remark applies only to the northern hemisphere ; though, from analogy, we may expect to find such *inversely* the case also in the southern. The law, put in the abstract, appears to be, that *parallels in* *depth are equivalent to parallels in latitude*, corresponding to a well-known law in the distribution of terrestrial organic beings, viz. that *parallels in elevation are equivalent to parallels in latitude :* for example, as we ascend mountains in tropical countries, we find the successive belts of vegetation more and more northern or southern (according to the hemisphere) in character, either by identity of species, or by representation of forms by similar forms ; so in the sea, as we descend, we find a similar representation of climates in parallels of latitude in depth. The possibility of such a representation has been hypothetically anticipated in regard to marine animals by Sir Henry De La Beche,* and to marine plants by Lamouroux. To me it has been a great pleasure to confirm the felicitous speculations of those distinguished observers. The fact of such a representation has an important geological application. It warns us that all climatal inferences drawn from the number of northern forms in strata containing assemblages of organic remains, are fallacious, unless the element of depth be taken into consideration. But the influence of that element once ascertained (and I have already shewn the possibility of doing so), our inferences assume a value to which they could not otherwise pretend. In this way, I have no doubt, the per-centage test of Mr Lyell will become one of the most important aids in geology and natural history generally ; and, in fact, the most valuable conclusions to which I arrived by the reduction of my observations in the Ægean, were attained through the employment of Mr Lyell's method.

IV. *All varieties of sea-bottom are not equally capable of sustaining animal and vegetable life.*—In all the zones of depth there are occasionally more or less desert tracts, usually of sand or mud. The few animals which frequent such tracts are mostly soft and unpreservable. In some muddy and sandy districts, however, worms are very numerous, and to such places many fishes resort for food. The scarcity of remains of testacea in sandstones, the tracks of worms on ripple-marked sandstones, which had evidently been deposited in a

* Ten years ago, in his " Researches in Theoretical Geology."

shallow sea, and the fish remains often found in such rocks, are explained, in a great measure, by these facts.

V. *Beds of marine animals do not increase to an indefinite extent. Each species is adapted to live on certain sorts of sea-bottom only. It may die out in consequence of its own increase changing the ground.*—Thus, a bed of scallops, *Pecten opercularis*, for example, or of oysters having increased to such an extent that the ground is completely changed, in consequence of the accumulation of the remains of dead scallops or oysters, becomes unfitted for the further sustenance of the tribe. The young cease to be developed there, and the race dies out, and becomes silted up or imbedded in sediment, when the ground being renewed, it may be succeeded either by a fresh colony of scallops, or by some other species or assemblage of species. This "rotation of crops," as it were, is continually going on in the bed of the sea, and affords a very simple explanation of the alternation of fossiliferous and nonfossiliferous strata; organic remains in rocks being very rarely scattered through their substance, but arranged in layers of various thickness, interstratified with layers containing few or no fossils. Such interstratification may, in certain cases, be caused in another way, to-wit, by the elevation or subsidence of the sea-bottom, and the consequent destruction of the inhabitants of one region of depth, and the substitution of those of another. It is by such effects of oscillation of level, we may account for the repetition, at intervals, in certain formations of strata indicating the same region of depth.

VI. *Animals having the greatest ranges in depth have usually a great geographical, or else a great geological range, or both.*—I found that such of the Mediterranean testacea as occur both in the existing sea, and in the neighbouring tertiaries, were such as had the power of living in several of the zones in depth, or else had a wide geographical distribution, frequently both. The same holds true of the testacea in the tertiary strata of Great Britain. The cause is obvious: such species as had the widest horizontal and vertical ranges in space, are exactly such as would live longest in time, since they would be much more likely to be independent of catastrophes and destroying influences, than such as had a more limited distribution. In the cretaceous system, also, we find that such species as lived through several epochs of that era, are the few which are common to the cretaceous rocks of Europe, Asia, and America. Count D'Archiac and M. De Verneuil, in their excellent remarks on the fauna of the Palæozoic rocks, appended to Mr Murchison and Professor Sedgwick's valuable memoir on the Rhenish Provinces, have come to the conclusion that the fossils common to the most distant localities, are such as have the greatest vertical range. My observations on the existing testacea and their fossil analogues, lead to the same inference. It is very interesting thus to find a general truth coming out, as it were, in the same shape, from independent inquiries at the two ends of time.

VII. *Mollusca migrate in their larva state, but cease to exist at a certain period of their metamorphosis, if they do not meet with favourable conditions for their development;* i. e. *if they do not reach the particular zone of depth in which they are adapted to live as perfect animals.*

This proposition, which, as far as I am aware, is now put forward for the first time, includes two or three assertions which require explanation and proof, before I can expect the whole to be received. First, *that mollusca migrate.* In the fourth volume of the Annals of Natural History (1840), I gave a zoo-geological account of a shell-bank in the Irish Sea, being a brief summary of the results of seven years' observations at a particular season of the year. In that paper, I made known the appearance, after a time, of certain mollusca on the coasts of the Isle of Man, which had not previously inhabited those shores. They were species of limpet, about which there could be no mistake, and one was a littoral species. At that time, I could not account for their appearance. Many similar facts have since come to my knowledge, and fishermen are familiar with what they call "shifting" of shell-beds, which they erroneously attribute to the moving away and swimming off of a whole body of shell-fish, such as mussels and oysters. Even the *Pectens,* much less the testacea just named, have very little power of progressing to any distance, when fully developed. The "shifting" or migration is accomplished by the young animals when in a larva state. This brings me to a second point, which needs explanation. *All mollusca undergo a metamorphosis* either in the egg, or out of the egg, but, for the most part, among the marine species out of the egg. The relations of the metamorphoses of the several tribes are not yet fully made out; but sufficient is now known to warrant the generalization. In one great class of mollusca, the *Gasteropoda*, all appear to commence life under the same form, both of shell and animal, viz. a very simple, spiral, helicoid shell, and an animal furnished with two ciliated wings or lobes, by which it can swim freely through the fluid in which it is contained. *At this stage of the animal's existence, it is in a state corresponding to the permanent state of a Pteropod,** and the form is alike whether it be afterwards a shelled or shell-less species. (This the observations of Dalyell, Sars, Alder and Hancock, Allman, and others prove, and I have seen it myself.) It is in this form that most species migrate, swimming with ease through the sea. Part of the journey may be performed sometimes by the strings of eggs which fill the sea at certain seasons, and are wafted by currents. My friend, Lieut. Spratt, R.N., has lately forwarded me a drawing of a chain of eggs of mollusca, taken eighty miles from shore, and which, on being hatched, produced shelled larvæ of the forms which I have described. If they reach the region and ground, of which the perfect animal is a member, then they develope and flourish; but if the period of their development arrives before they have reached their destination, they perish, and their fragile shells sink into the depths of the sea. Millions and millions must thus perish, and every handful of the fine mud brought up from the eighth zone of depth in the Mediterranean, is literally filled with hundreds of these curious exuviæ of the larvæ of mollusca.†

---

* It is not improbable that the form of the larva of the Pteropod, when it shall be known, will be found to be that of an Ascidian polype, even as the larva of the Tunicata presents us with the representation of a hydroid polype.

† The nucleus of the shells of the Cephalopoda is a spiral-univalve,

Were it not for the law which permits of the development of these larvæ only in the region of which the adult is a true native, the zones of depth would long ago have been confounded with each other, and the very existence of the zones of depth is the strongest proof of the existence of the law. Our confidence in their fixity, which the knowledge of the fact *that mollusca migrate* might at first shake, is thus restored, and with it our confidence in the inferences applicable to geology which we draw from submarine researches.

Some of the facts advanced in this communication are new, some of them have been stated before: but all, for which no authority is given, whether new or old, are put forth as the results of personal observation.

---

similar in form to the undeveloped shells above alluded to, and it is yet to be seen whether all Cephalopoda do not commence their existence under a *spiral-shelled Pteropodous form.*