now within the Arctic circle glaciers have streams of running water issuing from their fronts; there must have been, therefore, very great erosion in the glacier valleys by running water during the maximum glaciation, and the valleys became rapidly deepened. When the climate became severer and the glaciers became smaller owing to insufficiency of supply, they no longer flowed down the valley as it originally existed, but in the narrower gorges excavated by the sub-glacial streams in earlier times. This fact, that during maximum glaciation there was necessarily a milder climate and consequent greater melting and erosion, may perhaps explain how glacier valleys in Europe and America have been scored by ice from their bottoms to heights of 3,000 and 4,000 feet above. To maintain that such valleys at one time were filled from top to bottom with ice is, to my mind, equivalent to saying that in an ordinary river valley, with terraces high up the sides, the valley was once filled with water from the present level to the topmost water-mark.

VI.—Further Notes on the Stratigraphy and Fauna of the Trimmingham Chalk.

By R. M. Brydone, F.G.S.

(PLATES VIII AND IX.)

(*Concluded from the February Number, p.* 78.)

THE very uniform trend of all these ridges will have been noted, but my previous remarks on the general strike of the foreshore chalk require considerable modification. The whole of the chalk so far exposed may be divided into four sections. Each of these comprises an exposure in or close to the cliff of what appears to be the highest part of a ridge running down the beach in a direction from 10° to 30° south of east (and sinking as it goes) to about the half-tide level. Here three of them (the exception being the brickfield chalk) turn and run for some way roughly parallel to the shoreline, and then resume their original direction and run out to sea. The brickfield chalk only varies from this plan by running out to sea with practically no change of direction on the way. Except where a ridge is running up to the cliff, the substratum of the beach is invariably glacial clay down to about half-tide level. Here it is either banked against what appear to be vertical faces of chalk or else (*between* the foreshore exposures) disappears under the sand. It has never been seen to run out to sea, and every time a fresh bit of the foreshore below the half-tide level is cleared of sand it is chalk that is revealed. In the case of the section attached to the north bluff there is below the half-tide level a continuous mass of chalk with perfectly regular bedding exposed for at least 1,000 yards along the shore, and directly opposite the north bluff I have myself seen chalk continuous from the foot of the bluff for over 200 yards straight out to sea (except about 20 yards close up to the bluff, which, however, are covered by Mr. B. B. Woodward's letter in the October (1905) number of the Geological Magazine), the regular sequence of the beds being only broken by one fault. The section attached to the ridge coated with a sheet of flint is a good second in size, showing chalk in regular sequence for a length of over 400 yards, and maximum (exposed) breadth of about 45 yards.

There seem to be only two possible theories as to the nature of these chalk masses, as Mr. Reid's theory is quite impossible of general application, and appears to be only applicable to the north bluff subject to very important modifications. One is the erratic theory. This theory involves the possibility of an erratic 1,000 yards by 200 yards in superficial area and unknown depth, and others smaller but still of monstrous size. It offers no explanation of the rude symmetry of tectonic structure exhibited by the chalk, nor any plausible origin for these erractics, which have no known counterpart in fossil contents, and cannot from the perfection in which they have retained their stratification and fossil contents have travelled far. It is also a coincidence almost past belief, until every other possible explanation has failed, that an ice-sheet should chance to leave at one spot all the known remnants (a very large number) of a very strongly marked epoch without the admixture of a single erratic mass belonging to any other epoch. If a final nail in the coffin of the erratic theory be required, it is to be found in the Mundesley well section recorded in the Geological Survey Memoir on the Upper Chalk of England as having shown a great thickness of chalk, obviously *in sitû*, containing *O. lunata* at intervals.

The other theory is that of the buried chalk cliff, set forth in my previous pamphlet (of which Mr. Jukes-Browne's buried sea stacks are really a variant very near the truth, but not quite borne out by my investigations). The numerous sections on the foreshore where the clay is piled up against apparently vertical faces of chalk, the uniformity with which the clay has hitherto been found to be bounded to seaward by chalk, the occasional disturbances in the chalk along its junction with the clay never penetrating more than a short distance into the body of the chalk, the newly exposed cavities in the southern part of the south bluff, and the great masses of flint shingle in the cliffs immediately above the bluffs, all tend strongly to confirm the supposition that the chalk once presented at this point a low cliff with projecting headlands to a sea lying where now we have the land, and that up against this cliff the boulder-clay was piled. It is not at all uncommon to find the chalk much disturbed along the junction with the clay, while a few yards further seawards there commences an extensive area of wholly undisturbed chalk, and this is no doubt due to the dislocation of the chalk in the face of the old cliff by clay forced into cracks and acting under continued pressure from behind like a gigantic wedge. The erratics behind the north bluff have almost demonstrably been torn from the parent mass by clay pressing up from below, which must have reached a position below them either in caves or along cracks.

There are, as will have been gathered, many apparent instances on the foreshore of clay passing under the chalk. Some of these are undoubtedly genuine cases, to be explained as above. But it is quite possible that the majority are only apparent. If boulder-clay was banked up against a vertical wall of chalk, the plane of junction would often be a waterway of some importance. The water percolating along this plane would, of course, have little or no effect on the boulder-clay, but would tend to dissolve away the chalk, and the deeper below the surface the water got the greater would be the pressure on it and consequently its solvent power. There would thus be a constant tendency for the chalk face to recede, and recede less rapidly at the surface than deeper down, and so to develop an overhanging vertical face. The clay, being comparatively plastic, would of course follow the receding chalk wall, and in time lie under the chalk for a short distance. The shortness of this distance would not be apparent in the foreshore sections we have, which are almost always along the chalk walls and never across them, but I have several times been able to satisfy myself by digging that the distance for which the infraposition of the clay to the chalk extended seawards was a matter of inches only.

It may perhaps be permissible to speculate on the epoch at which this chalk cliff existed. Now we know, of course, that the early Crag sea was a warm and tranquil sea, and therefore it must have been protected from the North Sea of the period by a land barrier, the gradual breaching of which would allow the gradual admission of colder water and Boreal forms, which can be so clearly traced in the upper Crag beds. Such a barrier, if it lay anywhere in or near Norfolk, must have been of chalk, which is the basement bed, so to speak, of the county, and we should therefore hope to find with great luck the cliffs left by the cutting through of the barrier, and possibly also the floor of chalk formed in the gap. Now we have between Cromer and Weybourne an almost flat surface of chalk at sea-level, which presumably has not been formed by the recent sea, as the cutting back of the cliffs always reveals a platform of chalk at their very base, which, except between Sheringham and Weybourne, shows no sign of rising into the cliff, and therefore must be of pre-glacial age. Is it fantastic to suggest that the chalk between Cromer and Weybourne is part of the floor of the old breach, and that at Trimmingham we have the only remains yet disclosed of the east cliffs formed by that breach, and that the west cliffs are buried at some point between the chalk at sea-level round Cromer and the chalk at a considerable height above it round Holt and Melton, a slight tilt having brought the cliffs at Trimmingham nearly down to modern sea-level? The behaviour of the Pliocene beds themselves confirms this supposition as to the relative Pliocene positions of the Trimmingham and Cromer chalk, for the Pliocene beds near Cromer are all above the surface of the chalk there, while we know on the authority of Mr. Reid that corresponding Pliocene beds at Trimmingham close by the chalk occur well below high tide mark, and consequently many feet *below* the highest point to which the undisturbed chalk there reaches in the south bluff. This theory would involve the existence at one time of a (probably now buried) chalk cliff running along the bed of the North Sea, and such a cliff would be a possible source, and the only one that can be suggested, for the erratics between Trimmingham and Weybourne. Some cliff the source must have been, for ice with all its powers can neither shovel up nor suck up large masses of chalk out of a horizontal surface. This hypothetical buried cliff would probably be running more or less north and south, and would therefore be nearer to the present coastline at Overstrand than further north, and the difference in distance travelled would account for the enormous difference between the condition of the Overstrand erratics, which have suffered somewhat, but not much, from pressure, and those west of Cromer, which have been crushed until they are barely coherent, and crumble most rapidly on exposure. The suggested Pliocene chalk cliffs would also afford a source for the enormous supply of carbonate of lime which must have been required for the building up of the vast masses of shells of which the lower Crag beds are composed.

[After this paper had taken more or less its present shape, Professor Bonney and Mr. Hill published in the GEOLOGICAL MAGAZINE for September, 1905, a paper dealing somewhat sketchily with the purely stratigraphical aspect of the Trimmingham Chalk on apparently very incomplete data. This paper has been effectively criticized by Mr. B. B. Woodward in the October number of the same Magazine, pp. 478 and 479, and by Sir Henry Howorth in the November number, and I have nothing to add to the criticisms made by these gentlemen, to whom I am much indebted for their intervention. We have, however, to thank Professor Bonney and Mr. Hill for a record of chalk at the base of the cliff under Trimmingham itself, where I have long expected it, but never had the good fortune to see it.]

PALÆONTOLOGY.

A. *Chalk of Trimmingham.*

The greater number of the additions and corrections to the list given in my previous pamphlet have been incorporated in the list to be found in the recent Survey Memoir above referred to, but for convenience a complete list of all corrections and additions is given here :—

SPONGIDA.

Add *Porosphæra globularis*, Phill. ; *Ventriculites decurrens*, T. Smith ; *V. impressus*, T. Smith ; *V. quincuncialis*, T. Smith ; *V. radiatus*, T. Smith.

Omit *P. Woodwardi*—the light recently thrown by Dr. Hinde on the species which has so long borne this name makes me doubtful if I can prove its occurrence.

ACTINOZOA.

Add *Diblasus Grevensis*, Lonsd.

Omit *Calamophyllia faxeensis*—the specimen which distantly suggested this species to Professor Deecke has proved to be a fish-spine (*Cœlorhynchus cretaceus*) ; *Onchotrochus serpentinus*—this appears to have been based on specimens of a very slender *Porina*.

ECHINODERMATA.

Add *Epiaster gibbus*, Lam. ; *Micraster cor-anguinum*, Klein. One specimen of the former and two of the latter are in the collection of Mr. Savin. *Echinoconus Orbignyanus*, Ag. (the bun-shaped *Echinoconus* of my previous pamphlet according to Mr. Sherborn).

CIRRHIPEDIA.

Add *Pollicipes fallax*, Darw. (very abundant).
Substitute *Brachylepas cretaceus*, H. Woodw., for *Pollicipes cancellatus*, which has proved to be a synonym.

POLYZOA.

Add *Siphoniotyphlus tenuis*, Hag., a species of remarkable range for one so specialised.

LAMELLIBRANCHIATA.

Add *Avicula cærulescens*, Nilss.; *Ostrea canaliculata*, Sow.; *O. inæquicostata*, S. Woodw.—if the Trimmingham specimens are rightly identified, this species can hardly be identical with *O. semiplana*, as suggested in the recent Survey Memoir; *Plicatula sigillina*, S. P. Woodw.; *Spondylus spinosus*, Sow.
Correct *Diceras inæquirostratus* in Survey Memoir. This record appears to be founded on adherent valves of an *Exogyra* so identified at South Kensington.

GASTEROPODA.

Add *Dentalium* sp. There frequently occur casts of Gasteropods, mainly *Trochus* and *Cerithium*, but so small and delicate as to require an expert to identify them.

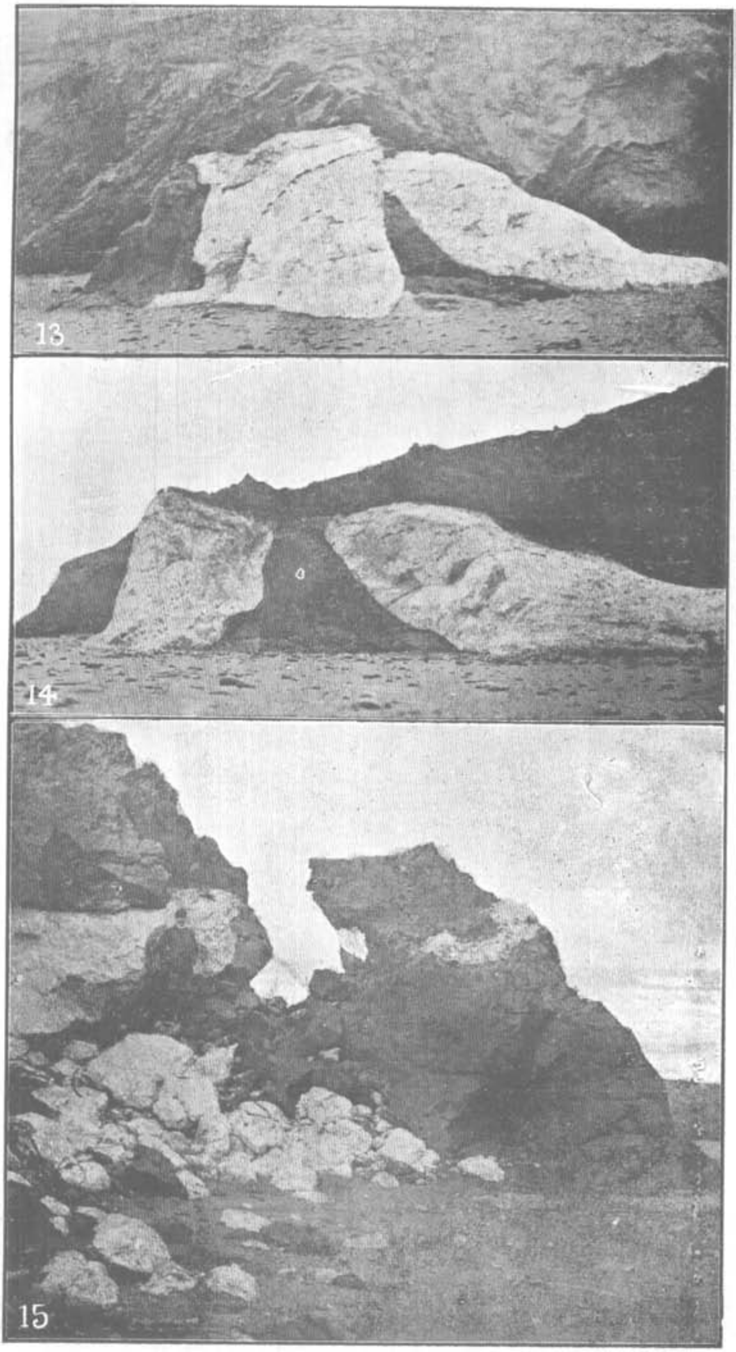
CEPHALOPODA.

Add *Bayfieldi*, F. & C., after *Nautilus*.
Substitute *Aptychus rugosus*, Sharpe, for *A. peramplus*.
Omit *Belemnitella* sp. Dr. Blackmore is convinced that the very numerous specimens of this slender form are only young *B. mucronata*, the infant mortality among which must have been terrible.

PISCES.

Add *Cœlorhynchus cretaceus*, Dix; *Corax* sp.; *Scaphanorhynchus subulatus*, Ag.

It will, perhaps, be well to comment on some statements made by Dr. Rowe in his paper on the Dorset Chalk, in which he compares the fauna of the *B. mucronata* zone in Dorset and Norfolk, as they are calculated to mislead anyone having only a slight knowledge of the Trimmingham fauna. He states that *Pecten concentricus* is common at Trimmingham. As I have never seen a specimen of it there, I can only conclude that he is confusing the smooth *Pecten Nilssoni* (which is common at Trimmingham) with *P. concentricus*. He also states that a certain hexagonal *Serpula* was considered by me to be *S. difformis*, but that it differed from the Trimmingham examples, "which are always pentagonal." He has here confused at least three perfectly distinct species. The first is a free-growing, tapering, uniformly *heptagonal* form of carious surface, which is either *S. difformis* or a very near relation. This form, or one barely separable from it, occurs also in the *B. mucronata* chalk of Hampshire down to its base. The second is a very remarkable form with a *polished* surface. It starts with a broad base and triangular cross-section with a strong dorsal carina, and is then incapable of being separated from *S. macropus*. But very soon the tube rises free from the base and *proceeds* to develop six more carinæ placed at regular intervals round the tube. But the new carinæ are not all developed at once, and the specimen forwarded to me by Dr. Rowe for identification was, if I remember rightly, a youngish specimen with six carinæ fully developed and the seventh just appearing. This form is not uncommon in the *B. mucronata* chalk of Hampshire, but I have not yet found it (at any rate, to be certain of it) at Trimmingham. At the time I saw Dr. Rowe's specimen I was still under the impression that this form would prove to be



Views of the Trimmingham Chalk Bluffs, Norfolk Coast.

S. difformis, so I gave this name to Dr. Rowe, but with the same caution with which, it will be seen, I recorded it at Trimmingham in my previous pamphlet. Whether it ought to be included in the same species as the typical *S. macropus* on account of its initial stage is a question for a specialist, but it seems to me very undesirable, seeing how greatly the two forms differ in the adult stage. (The question is further complicated by a Trimmingham species, which generally begins with a *macropus* stage like the form just described, and then grows to a great length as a free round tube slightly curved, with a carious surface and devoid of carinæ. The same form is, however, often to be found in the same beds free from its earliest infancy.) *S. canteriata*, the third species, is evidently the Trimmingham form which Dr. Rowe had in mind, as it is the only free pentagonal species at Trimmingham (except occasional specimens of *S. fluctuata*). Not content with gratuitously attributing to me an intention to identify his specimen of a heptagonal form with *S. canteriata*, which is never even hexagonal, he has made misstatements about that species from which a wider experience would have saved him. If he had said it was always pentagonal outside the Trimmingham Chalk he might well have been correct, as I have found only the pentagonal form in the various zones down to *M. cor-testudinarium*, in which it occasionally appears, but in the Trimmingham Chalk it is often tetragonal, and in some specimens passes from the one form to the other.

Dr. Rowe may be right in saying that *Pentacrinus Agassizi* and *Bronni* are very common at Norwich and Sheringham, but I confess I am much surprised at the statement, for I have not found a specimen of either form at either locality, and I have spent much time on the chalk around Sheringham, though comparatively little on that around Norwich.

B. *Chalk between Cromer and Weybourne.*

SPONGIDA.

Porosphæra globularis, Phill. (very large).
Ventriculites impressus, T. Smith.
V. radiatus, T. Smith.

ACTINOZOA.

Axogaster cretacea, Lonsd.
Stephanophyllia Michelini, Lonsd. (common).
Trochosmilia (*laxa* ?).

ECHINODERMATA.

Bourgueticrinus (joints, including one variety very typical at Trimmingham).
Cardiaster sp.
Cidaris.
Cyphosoma (*Königi* ?).
Echinoconus vulgaris, Röm.
Echinocorys vulgaris, Breyn.
Goniaster (ossicles).
Micraster cor-anguinum, Klein (common).

VERMES.

Serpula ampullacea, Sow.
S. canteriata, Hag.
S. carinella (?), Sow.
S. difformis (?), Dix.
S. fluctuata, S. Woodw.
Serpula granulata, Sow.
S. gordialis, Schloth.
S. lituitis, Defr.
S. plexus, Sow.

CIRRHIPEDIA.

Brachylepas cretacea, H. Woodw.
Pollicipes glaber, Röm.
Scalpellum maximum, Sow.

POLYZOA.

Homalostega pavonia, Hag.
Membranipora clathrata, Reuss.
Pachydera grandis, Mares.
Porina filograna, Goldf.
Many others of (at present) unknown zonal significance.

BRACHIOPODA.

Crania Egnabergensis, Retz.
C. Parisiensis, Defr.
Magas pumilus, Sow. (very common).
Rhynchonella limbata, Schloth.
Rh. plicatilis, Sow.
Rh. Reedensis, Eth.
Terebratula carnea, Sow.
T. obesa, Sow.
T. sexradiata, Sow.
Terebratulina striata, Wahl.
Thecidium Wetherelli, Morris.

LAMELLIBRANCHIATA.

Avicula cœrulescens, Nilss.
Inoceramus sp.
Lima granulata, Nilss.
L. pectinata, D'Orb.
Ostrea canaliculata, Sow.
O. inæquicostata (?), S. Woodw.
O. vesicularis, Lam.
Pecten cretosus, Defr.
Pecten pulchellus, Nilss.
P. quinquecostatus, Sow.
P. undulatus, Nilss.
Plicatula sigillina, S. P. Woodw.
Spondylus Dutempleanus, D'Orb.
S. latus, Sow.
S. spinosus, Sow.

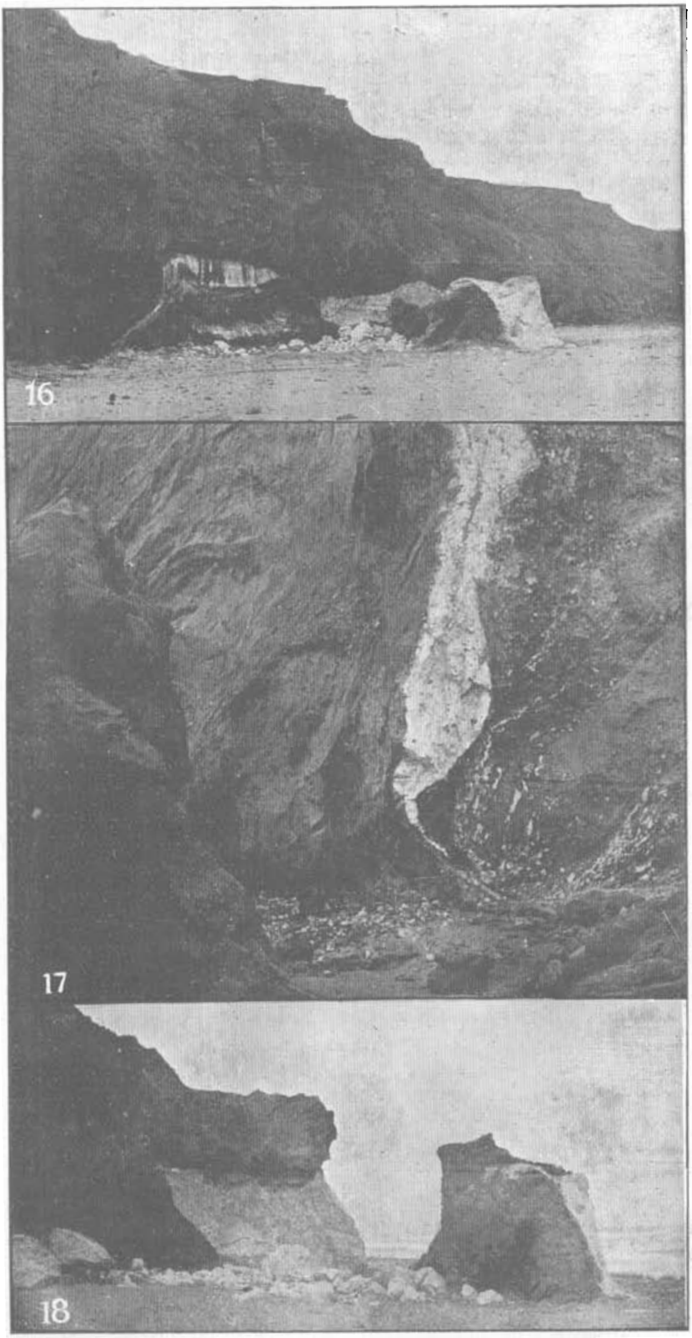
CEPHALOPODA.

Aptychus rugosus, Sharpe.
Belemnitella mucronata, Schloth.

PISCES.

Enchodus sp.

It is perhaps desirable to mention that these fossils come mainly from the western part of this chalk, i.e. about Sheringham and Weybourne. It may be partly owing to the greater facilities for collecting offered by the cliff exposures near Weybourne, but I have no doubt that it is also due to a genuine increase in the abundance of fossils as we get away from Cromer, where the chalk is wonderfully barren. Travelling in this direction, we are, according to Mr. Reid, passing from newer to older chalk, but I have great doubts about this. The only argument he adduces to support this view is that the dip of the chalk in the cliffs near Weybourne is to the east, and may be assumed to continue all the way (there certainly does not appear to be any traceable dip in any direction in the chalk on the foreshore). I have always doubted the existence of this steady eastward dip, and when in 1903 the chalk near Weybourne was exceptionally well exposed after a storm I studied it very carefully. I was able to trace the lines of flint very minutely, and I was absolutely convinced that for nearly three-quarters of a mile from Weybourne Gap the lines of flint are dipping steadily to the west. I have also observed indications that there is a syncline at West Runton, and not very far away a chance hole in the chalk with vertical sides showed a section across a flint line apparently lying in a small anticlinal. I am therefore more inclined to regard this chalk as, at any rate, undulating, if not actually dipping westward on the whole. The fossils of the chalk around Weybourne show a tendency towards the Trimmingham fauna, and it would be remarkable if between that chalk and the Trimmingham Chalk there really lay the very unfossiliferous chalk nearer Cromer.



Views of the Trimmingham Chalk Bluffs, Norfolk Coast.

(To illustrate Mr. R. M. Brydone's paper.)

An Appendix will follow, later on, with figures and descriptions of the Cirripedia and Polyzoa.—R. M. B.

EXPLANATION OF PLATES.

PLATE VIII.

FIG. 13.—North Bluff, seaward aspect; May, 1905.
,, 14.—North Bluff, seaward aspect, showing (but only faintly, owing to shadow) the chalk roof over the clay pinnacle.
,, 15.—October 2nd, 1905, showing the aspect from the head of the south bay the day after the chalk roof was broken through.

PLATE IX.

FIG. 16.—October 2nd, 1905. South bay.
,, 17.—October 2nd, 1905.
,, 18.—October 16th, 1905.

VII.—A METHOD OF CLASSIFYING IGNEOUS ROCKS ACCORDING TO THEIR CHEMICAL COMPOSITION.

By Dr. HUGH WARTH.

(WITH A FOLDING TABLE.)

THE chemical classification of igneous rocks is rendered difficult by the large number of substances which are present in them. H. S. Washington, who based his system of classification upon the composition of standard rock-forming minerals, found it necessary in his great work[1] to divide his 2,880 rocks into no less than 167 final groups in order to ensure a close proximity between the rocks within each group.

The number of rocks in any system of classification must rise so much more rapidly the greater the proximity of the individual rocks to each other. In the case of only a single constituent the deviation of individual rocks from the group average is inversely proportional to the number of groups. A similar law prevails when several constituents are considered at the same time, as will be shown in the following.

Five hundred rock analyses were selected at random for the purpose of classification. The average composition of this whole assembly of rocks was then calculated, and the mean deviation of the several substances was found by deducting the percentage of each substance present from the mean percentage of this substance in the five hundred rocks.

The differences obtained for all the rocks, positive as well as negative, were then added together, and the sum-total divided by 500 gave the mean deviation of each substance. It requires to be noted, however, that for the present purpose some of the substances were taken two and two together, and their combined deviations were thus ascertained. The following is the result:—

500 ROCKS.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
Average composition ...	57·0	15·5	3·9	3·9	4·8	5·8	3·6	2·9
Mean deviation	$\pm$ 9·6	3·0	4·0		7·0		2·6	

[1] H. S. Washington, "Chemical Analyses of Igneous Rocks"; Washington Government Printing Office, 1903.