THE

BOTTOM-DEPOSITS OF THE ENGLISH CHANNEL FROM THE EDDYSTONE TO START POINT, NEAR THE THIRTY-FATHOM LINE.

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(Read at Great Torrington, August, 1899.)

In 1895 Mr. E. J. Allen, B.Sc., Director of the Marine Biological Laboratory at Plymouth, commenced an investigation into the fauna and bottom-deposits near the thirty-fathom line from the Eddystone grounds to Start Point. In June of the present year Mr. Allen published his results. (Vol. v. No. 4, June, 1899, *Journal of the Marine Biological Association of the United Kingdom.*) A feature of the method pursued was the care taken to obtain samples of the bottom-deposit, with the object of acquiring information as to the influence of its texture and nature on life at the sea-bottom. In 1898, when the results were being collated, the present writer became associated with the inquiry.

Although the investigation was undertaken for purely biological purposes, a great deal of information was obtained of interest geologically. The manner in which samples were taken and their subsequent treatment both lent themselves to geological inquiry, although in certain cases the points at which dredgings were taken were not equally well adapted to those purposes.

The features which can be satisfactorily considered are:—

(*a*) The "texture" of the bottom-deposits.

(*b*) The rock fragments constituting the gravels and sands.

(*c*) The rock fragments of considerable comparative dimensions occasionally obtained.

(*d*) Deductions as to the underlying strata based on *a*, *b*, *c*.

(*e*) The extent of wave-action at the bottom, as evidenced by the condition of the bottom-deposits and by the fauna found thereon.

(*f*) A consideration of the deposit as a recent formation, from which reasonable deductions may be drawn as to the conditions under which similar clastic deposits, now indurated into definite rock-beds, may have been formed.

These matters (with the exception of *e*) were necessarily of secondary importance in the biological investigation, and the notes thereon, which are incorporated in Mr. Allen's paper, were restricted in range accordingly.

The writer has to express his thanks and great indebtedness to the Director of the Marine Biological Laboratory for the opportunity of examining the various samples, and for permission to use the results obtained for purposes outside the intent of the original inquiry.

(*a*) The Texture of the Bottom-Deposits.

Each dredged sample was divided into a series of grades by the use of sieves having circular perforations of known diameter.

Eight grades were constituted, numbered, and named as under :—

I. Stones. All inorganic material which will not pass through sieve with 15 mm. perforation.
II. Coarse gravel. Material left on sieve with 5 mm. perforation.
III. Medium gravel. Material left on sieve with 2·5 mm. perforation.
IV. Fine gravel. Material left on sieve with 1·5 mm.
V. Coarse sand. Material left on sieve with 1 mm. perforation.
VI. Medium sand. Material left on sieve with 0·5 mm. perforation.
VII. Fine sand. Material which passes through 0·5 mm. sieve, and when stirred up in sea-water settles in one minute.
VIII. Silt. Remains in suspension at the end of one minute.

The terms "medium gravel," "fine sand," etc., suit well the grades to which they have been applied, and the system as a whole has been found to work excellently, both for biological and geological purposes. For instance, all of the larger foraminifera will be found in Grades VI. and VII., while the smaller foraminifera, together with the diatoms and coccoliths, are practically confined to Grade VIII. In a similar way all rock fragments identifiable to the unaided eye will be found in Grades I., II., and III. Much information is afforded by the determination of organic carbonate of lime in each grade of each sample; and accurate conclusions as to wave-action may be formed by studying the percentage of each sample afforded by the various grades. More than this, and most important biologically, it is found that the texture of the bottom-deposit largely influences the nature of the fauna.

The system was devised by Mr. Allen, and has proved so satisfactory that it is to be hoped future workers will adopt it in its entirety, and thus assign a known value to such indefinite terms as "fine sand," "silt," etc.

For close comparison between any two or more dredgings the whole details of the textures must be studied; a readier method should, however, be available for general purposes. This the present writer has sought to supply in the following manner:—

The purely conventional figures I., II., III., etc., having reference to material left in sieves of 15 mm., 5 mm., 2·5 mm., etc., are adopted for the purpose of shortly stating the average grade of each sample. The percentage of each grade of the sample is multiplied by its conventional number, the figures so obtained are summed together, and the total divided by 100, the result being described as the "average grade" of the sample.

As an instance of the method the determination of the "average grade" of sample 83 is appended.

	Per Cent.
I. Stones . . .	$0{\cdot}00 \times 1 = 0{\cdot}0$
II. Coarse gravel . .	$27{\cdot}9 \times 2 = 55{\cdot}8$
III. Medium gravel . .	$28{\cdot}3 \times 3 = 84{\cdot}9$
IV. Fine gravel . .	$14{\cdot}1 \times 4 = 56{\cdot}4$
V. Coarse sand . .	$6{\cdot}0 \times 5 = 30{\cdot}0$
VI. Medium sand . .	$7{\cdot}3 \times 6 = 43{\cdot}8$
VII. Fine sand . .	$8{\cdot}3 \times 7 = 58{\cdot}1$
VIII. Silt . . .	$8{\cdot}2 \times 8 = 65{\cdot}6$
	$394{\cdot}6 \div 100$

$= 3{\cdot}946$ the "average grade" of sample 83.

It must be repeated that this figure only gives limited information, and should be read together with the details.

The fine sand, Grade VII., differs widely in the samples. Alone of all the gravels and sands it possesses great possibilities of variation; its coarsest grains may attain a diameter of 0·5 mm., its finest need only be heavy enough to settle through six inches of sea-water in one minute. Closer classification would not, however, serve any useful purpose, and hence it follows that in some samples VII. consists almost exclusively of grains approximating to the maximum diameter of 0·5 mm., in others Grade VII. consists of very fine material little removed from the coarser particles in the silt. It will still be found even in these latter cases that the silt retains its distinctions from VII.

Out of some 112 hauls, samples of the bottom-deposit have been graded from 17, representing sixteen defined zoological grounds. In addition to these, samples have been obtained from various stony grounds, in which cases grading was not necessary. The information is not continuous from the Eddystone to the Start; an uninvestigated area lies east and north of the Eddystone, and a much larger hiatus occurs south of the East Rutts.

In the *Journal of the Marine Biological Association*, New Series, Vol. v. No. 4, will be found tables on pages 525–7 with full details of the percentage weights of each grade of gravel and sand found in the samples of bottom-deposit, and of the percentages of carbonate of lime (or where distinguishable, shell) in each grade of gravel or sand in the samples of bottom-deposit. These are more elaborate than the present paper requires, although reference may hereafter be made to some of the details. The following table may, however, be reproduced with advantage:—

TABLE I.

Showing the samples of bottom-deposit arranged according to average grade of texture and the total percentage of organic carbonate of lime in each.

No. of Samples.	Average Grade.	Percentage $CaCo_3$.
94	3·66	17·71
84	3·704	34·66
106	3·803	52·77
83	3·946	40·74
96	4·081	33·18
87	4·151	72·25
97	4·471	46·68
105	4·498	47·26
85	4·597	27·87
103	4·638	61·18
89B	6·386	48·61
90	6·561	22·91
109	6·749	30·15
91	6·814	14·13
102	6·849	14·86
92	6·971	17·41
104	6·998	15·80

A sample as a whole does not necessarily take its description from its average grade. For instance, samples between 3·5 and 4·5 average grade cannot in many cases be called medium gravel with any degree of accuracy; the question of which grade actually preponderates must also be considered. The following are the correct descriptions of the above samples:—

94. Coarse gravel with sand and mud, the latter being present in considerable quantity, but there is not enough to mask the gravel. 84. The same. 83. Medium gravel, sand, and mud. These three samples lie to the north of a line due west of the Eddystone, and extend to a little north of and on the east side of the Hand Deeps. Between this ground and the Eddystone lies 85, fine gravel, and 87, medium, shelly gravel, the latter fringing the western side of the Eddystone reef. North of 85 and 87 lies 89B, which is fine sand. South of 85 and 87 lies 109, which again is fine sand, and 102, almost due south of the Eddystone, is even finer sand. 103, south-east of the Eddystone, is medium gravel with sand and mud; the silt is exceptional, forming 17·1 per cent. of the whole. 97 flanks 103 to the eastward, and is fine gravel very uniformly divided among Grades II., III., IV., V., and VI. Hauls 90, 91, 92, and 104 spread over a very extensive area to the east of the Eddystone and are all fine sands; between these and 97 lies an unexplored region. South of the East Rutts is another unexplored region, and then south of Bolt Head we have 105 and 106, both coarse, shelly gravel, and between the Prawle and the Start a stony ground. Stony grounds also occur at the Hand Deeps and scattered in small patches round the Eddystone at the following points: Half a mile N.W. by N. of the lighthouse; one mile W.S.W. of the same point; two miles S.W.; one and a quarter miles S.W.; one and a half miles S. ½ E., possibly rock; while a patch of rock extends over the bottom from one mile S. of the lighthouse to one and a half miles S.W. of the same, its exact boundary being unknown.

Stony ground is also found at the East Rutts, and there is probably coarse gravel south of that point.

The chart accompanying this paper shows the known extent of each area of bottom-deposit, the nature of each area, the position of each of the dredgings above referred to, the average grade, and percentage of $CaCo_3$ in most cases. Each dredging is indicated by a number within a circle; the figures in vertical type below this give the

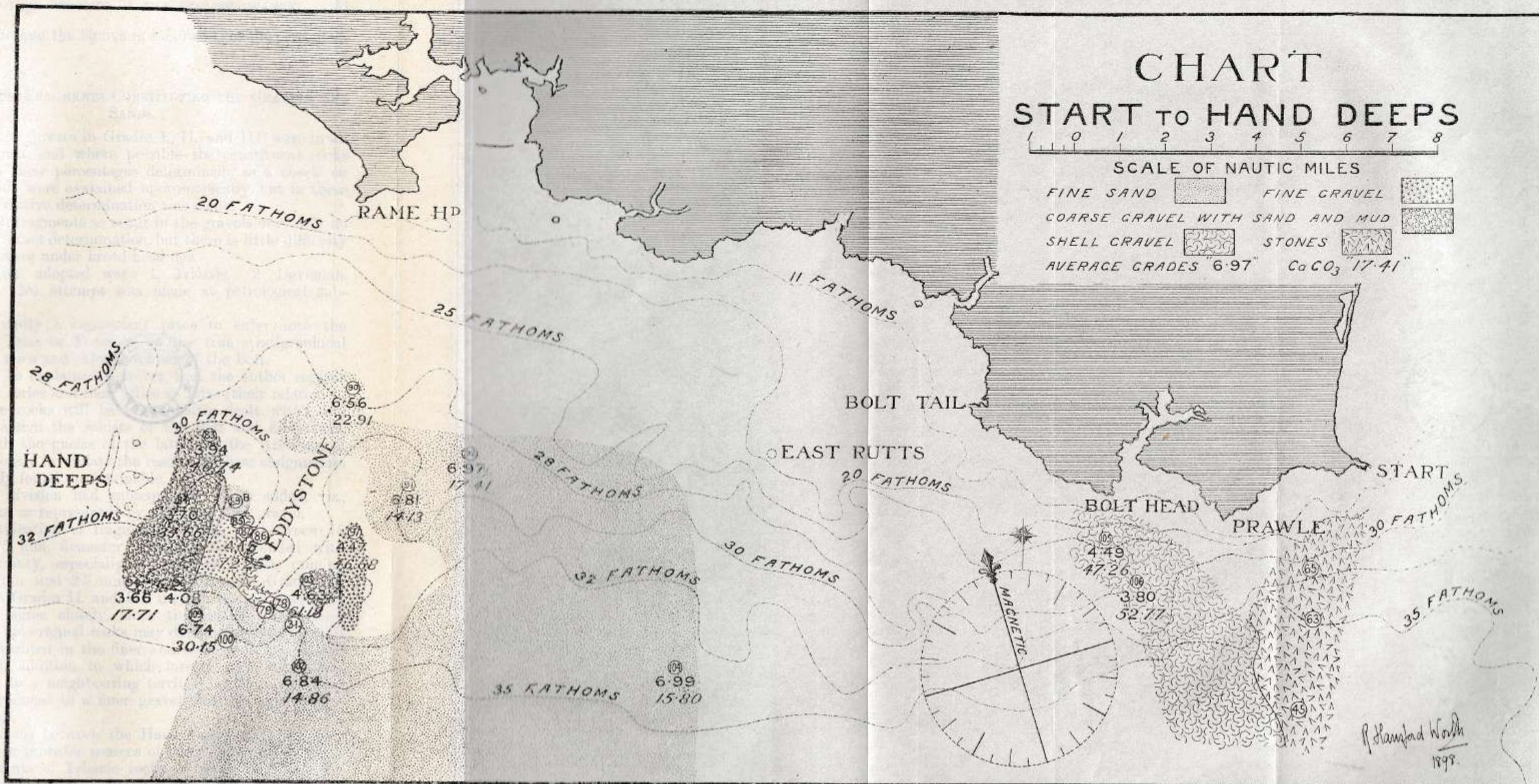


CHART
START TO HAND DEEPS
1 0 1 2 3 4 5 6 7 8
SCALE OF NAUTIC MILES
FINE SAND
FINE GRAVEL
COARSE GRAVEL WITH SAND AND MUD
SHELL GRAVEL
STONES
AVERAGE GRADES "6·97"
$CaCO_3$ "17·41"
RAME HD
20 FATHOMS
11 FATHOMS
25 FATHOMS
28 FATHOMS
30 FATHOMS
HAND DEEPS
32 FATHOMS
EDDYSTONE
BOLT TAIL
EAST RUTTS
20 FATHOMS
28 FATHOMS
30 FATHOMS
32 FATHOMS
35 FATHOMS
BOLT HEAD
PRAWLE
START
30 FATHOMS
35 FATHOMS
MAGNETIC
6·56
22·91
6·97
17·41
6·81
14·13
4·47
3·66
17·71
4·03
6·74
30·15
6·84
14·86
6·99
15·80
4·49
47·26
3·80
52·77
R. Hansford Worth
1898.

average grade, and the figures in inclined type the percentage of $CaCo_3$.

(*b*) The Rock Fragments Constituting the Gravels and Sands.

The rock fragments in Grades I., II., and III. were in all cases examined, and where possible the constituent rocks isolated and their percentages determined; as a check on this the sands were examined microscopically, but in these cases no quantitive determination was made.

Such small fragments as occur in the gravels obviously do not admit of exact determination, but there is little difficulty in bringing them under broad headings.

The division adopted was: 1. Triassic. 2. Devonian. 3. Archean. No attempt was made at petrological subdivision.

This is hardly a convenient place to enter into the question of Trias or Permian, or the true stratigraphical place of the mica and chlorite schists of the Bolt.

It should be explained, however, that the author regards the red rock series and their allies as Trias (their relation to known shore rocks will be subsequently dealt with), and inclines to assign the schists of the Bolt and Eddystone, together with the gneiss of the latter, to the Archean; it will not seriously invalidate the results if these assignments are ultimately found unsustainable.

A fourth division had subsequently to be added, viz., 4. Cretaceous, as represented by flints and flint gravel.

The identification of fragments of rock of between 15 mm. and 2·5 mm. diameter is necessarily attended with some uncertainty, especially as regarding those ranging between 5 mm. and 2·5 mm. which constitute Grade III. Results from Grades II. and III. in each sample cannot be expected to agree closely, since the relative degrees of friability of the original rocks may determine that one shall be best represented in the finer and another in the coarser material. In addition to which foreign rock, which has travelled on to a neighbouring territory, must be expected to be found reduced to a finer gravel than the rock of that territory itself.

In the gravels between the Hand Deeps and the East Rutts the most probable sources of error are the liability to assign fragments of Triassic rocks of other than the distinctive red colour to the Devonian, and the further liability to similarly falsely identify non-micaceous fragments of the Archean.

A little uncertainty attends small particles of much decomposed flint which simulate buff-coloured Triassic rocks, and an ambiguity arises from the known occurrence of calcedonic veins in the Trias itself. None of these possible sources of error are such as to seriously affect results; and none apply to samples 90, 105, 106. The following table gives the classification into percentages of the rock fragments in the gravels, all organic matter having first been removed (the figures show the percentage composition by weight).

TABLE II.

Classification of Rock Constituents of Gravels.

	II.			III.		
Distinguishing No. of Sample.	Triassic.	Devonian.	Archean.	Triassic.	Devonian.	Archean.
83	92	Trace	8	72	10	18
85	63	5	32	69	6	25
87	—	—	100	26	—	74
90	—	100	—	19	81	—
94	75	16	9	68	14	18
96	77	10	13	81	3	16
97	92	2	6	75	8	17
102	100	—	—	85	15	—
103	79	4	17	74	—	26

In samples 104 and 109 the large bulk of the material is fine sand, and no reliable results can be obtained.

In samples 91 and 92 no trustworthy numerical results could be obtained. In 91, IV., there is more Devonian than Trias, and in 92, IV., more Trias than Devonian. Amorphous silica occurs in small quantity in most of the above-named samples except 90. Sample 105, Grade II., taken one mile S.S.W. of Bolt Head, was analysed as follows: Archean (chiefly mica schists), 79 per cent.; Flint, 13 per cent.; Trias, 8 per cent. And 106, II., taken two miles south of Bolt Head: Archean, 89 per cent.; Flint, 40 per cent.; Trias, 11 per cent.

(c) The Rock Fragments of Considerable Comparative Dimensions Occasionally Obtained.

From 107 on the Bolt shell gravel a haul of the larger rock fragments was taken in a wide-mesh dredge. The result seems to indicate the presence of more flint than at 105, although this apparent excess might arise from the manner in which the sample was taken, since the flints being above the average size of the other stones would be more easily retained in the net. This is not the full explanation, however, for a sample taken in the ordinary way at 106, a little nearer 105, also contains a higher percentage of flint.

Of eight stones brought up in the dredge from 63, three miles S.S.E.½E. from the Prawle, on the Prawle stony grounds, all were either Archean mica schist, or fragments from quartz veins in the same. The schist from this point is comparatively speaking fine-grained, that is to say, in comparison with the mica schists bordering the Eddystone gneiss; similar rock occurs on the adjacent shores.

A specimen of mica schist closely resembling the above was dredged from 45—four to five miles S.½E. of Prawle Point. A fragment from a quartz vein in apparently the same rock was obtained from 65, from two to two and a half miles S.E. of Prawle Point. From the western side of the East Rutts was obtained a piece of massive quartzite weighing a little over two pounds; here and there it showed traces of a light brown gneiss on its surface. A small piece of rock corresponding to these traces was taken in the same dredging; the mica is practically white, the body of the rock is the colour of limonite, and the foliations bend around "eyes" of colourless quartz.

No rock specimens were retained from hauls 78, 79, and 31, but of these 78 and 31 are known to have been on rock, and 79 yielded "red stones," undoubtedly Trias. Haul No. 100, two miles S.W. of Eddystone, gave large stones and sand; the stones were preserved and included a thin slab of variegated sandstone, red and grey, a specimen of buff sandstone almost salmon coloured, and a compact red sandstone, sub-jaspideous. All the stones were more or less thin slabs, very little waterworn and in some cases very fresh and angular; none can have travelled far from their original site; all are Triassic in character.

One large stone was raised in haul 86, one-half mile N.W. by N. from the Eddystone. This proved to be a grey-green foliated rock with plates of brown mica, and garnets just distinguishable in hand specimens; quartz shows but is not prominent, except where it occurs filling thin joints which form planes at right angles to the plane of foliation.

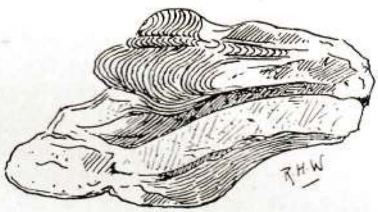
Pink garnets of varying sizes up to 1·5 or even 1·75 mm. in diameter are frequent and form a characteristic feature of the rock; a well-defined eye structure is developed around each garnet, and gives an undulating surface to the hand specimens. The most prominent mineral is hornblende, the prisms of which lie with their long axes wrapping or flowing round and partly tangential to the garnets. Quartz lies between the prisms of the hornblende. Water-white felspar is present in considerable quantity, and shows the lamellar Twinning of plagioclase. The hornblende is chiefly actinolite.

Brown mica is more prominent on the surfaces of schistose cleavage than in the section, and from its mode of occurrence appears to constitute a greater portion of the body of the rock than is the fact. The rock is a hornblende gneiss.

This specimen was in reality a small boulder, the edges were sharp and some of the surfaces fresh; it cannot have travelled far from its point of origin.

The only other considerable fragments were obtained from the slopes of the Hand Deeps. A little uncertainty exists as to the exact point at which the rocks were dredged in this case, but the one certain fact is that they came from the verge of the Hand Deeps reef and represent the material of which it is composed. Further dredgings are intended in this locality, which will give more exact information.

The rocks obtained included a red felsite of the Triassic series, the principal minerals being quartz and felspar, both porphyritic at places, the rock showed spherulitic structure in parts; a red Triassic conglomerate associated with a coarse red micaceous sandstone; and a variegated felspathic Trap, yellow, red and purple, bearing a close resemblance to other Traps known to be associated with the Trias. The Trias apparently surrounds this reef, which itself consists of Archean rocks; of them the most prominent is a mica schist in which micaceous layers greatly contorted and convoluted alternate with granular layers of quartz and garnet. (Fig. 1 below.) This schist has not been microscopically examined and may prove to be a gneiss. A single stone was obtained which at first sight closely resembled the hornblende gneiss found at the Eddystone reef, and indeed the main part of the specimen is closely allied to this, the chief variation



Sketch of Mica Schist Rock from Hand Deeps.

being the presence of a little more mica, and at one place a development of red felspar in crystals from 2 to 4 mm. in length and up to 1·5 mm. in breadth. The rock is a hornblende gneiss with porphyritic felspar; the curiously local development of porphyritic felspar may serve as a warning against conclusions drawn from isolated specimens. Apparently a certain amount of chlorite is also present.

(*d*) Deductions as to the Underlying Strata based on (*a*), (*b*), and (*c*).

In the vicinity of the Eddystone and the Hand Deeps Triassic rocks are found *in situ*, and form the general sea-bed (wherever rock is exposed), through which protrude the reefs. The variety of these rocks is considerable, including conglomerates, coarse red micaceous sandstones, fine red jaspideous sandstone, mottled sandstone, and salmon-drab sandstone, as well as a red felsite, and a variegated felspathic Trap.

The nearest point on shore at which the mottled sandstone can be matched is Oddicombe, St. Mary Church; the conglomerate is very similar in structure but not in included rock fragments to the patch at the Bolt.

The whole of the series presents a great likeness to the Trias rocks trawled off the Lizard and Dodman, except that the coarse red micaceous sandstone is not there exactly represented.

The Trias off the Lizard was first reported by the late R. N. Worth in the *Quarterly Journal of the Geological Society* for August, 1886. In that report there is mentioned a light salmon-tinted drab calcareous sandstone, the Triassic nature of which is rather suggested than affirmed; among the present series from the Eddystone grounds a precisely similar sandstone occurs. From this second instance of its association with the Trias there should no longer be doubt that it is one of that series.

The extent of the Trias eastward from the Lizard is defined up to the present by a rock dredged seven miles south of the Dodman. It is very improbable, however, that this is the real limit. Its extent westward of the Eddystone is not yet known, beyond the fact that it passes the Hand Deeps. Further dredgings are to be made to the westward.

Eastward of the Eddystone the Trias is probably continuous to the Bolt.

Gravels and sands of unknown depth intervene between the Eddystone and Bolt with no known rocky patches, but in none of these sands does the Trias fail to constitute the great mass of the rock fragments, and there is strong evidence for Trias formations occurring somewhere south of haul 106 which contained 11 per cent. It may well be that from the Hand Deeps to the patch of Trias near Thurlestone there is a continuous series of rocks of that formation.

Northward the known shore-limits are Cawsand Bay and Bovisand Bay. There is no information as to whether there is a continuous series between the Eddystone and these points.

At 90, about four miles north-east from the Eddystone, there can be no doubt that we are on or near the Devonian, for in Grade II. Devonian rocks constitute 100 per cent., and in Grade III. 81 per cent. of the total.

It is certain that somewhere south of the Bolt there is a patch of cretaceous; the exact location is as yet in doubt.

The Bolt and Prawle schists extend southward from those headlands on the sea-bottom, but the limit is not known. The more southerly specimens show a closer approximation to some of the Eddystone series.

Westward the East Rutts have proved to be a reef of gneiss; this carries the formation some four miles nearer the Eddystone.

The gneiss and schists of the Eddystone reef prove to be practically limited in area of exposure to the summit and sloping sides of the reef itself. There is only one dredging in which the Archean predominates over all other rock constituents, and that is 87, three-quarters of a mile N.W. by N. of the lighthouse. It is surprising how little Eddystone reef material was found in any other gravel dredging.

From 86, one-half mile N.W. by N. of the lighthouse, came the large block of hornblende gneiss elsewhere described. This rock is new from the locality, and the writer knows no exact counterpart in Devon or Cornwall.

The Hand Deeps prove to be a similar reef to the Eddystone, rising like it through and above Triassic strata, and, like it, composed of Archean gneiss and schists. The hornblende gneiss, elsewhere described as derived from this reef, is unlike any rock the author knows from Devon or Cornwall. There are, however, strong suggestions of kinship to the Lizard Rocks.

It will be seen that the operations of the Marine Biological Association have added greatly to our knowledge of the Channel geology off Plymouth. These operations are to be continued westward, and further information will probably be obtained.

(*e*) The Extent of Wave-Action at the Bottom as Evidenced by the Condition of the Bottom-Deposits, and the Fauna Found Thereon.

It is well known to engineers that a comparatively small depth of water is a good protection to foundations against wave-action, but it has already been pointed out by Mr. A. Roope Hunt that the action of surface waves may make itself felt, at least to some slight extent, to considerable depths.

A complete wave, as represented by the mass of water between the centres of two succeeding troughs, forms a rolling load whose constant tendency is to displace the water immediately beneath it, and by raising a portion of that water as well as lowering its own level arrive at a condition of static equilibrium. It is largely due to this tendency, added to the viscosity of the water, that a wave diminishes rapidly in height as it travels from its point of origin. This diminution in height does not take place in the ordinary Channel wave, since the wind, to which it owes its origin, continues to support and even enhance it. Once, however, let the wind fall or change its direction, and the rollers begin to diminish.

Were a series of rolling loads equivalent to these waves caused to travel across an iron bridge, their effect would be that of a series of blows, causing a strain much in excess of a dead load of the same mean depth of water. Added to which their periodicity might further produce excessive vibration. It matters not that in the case of the wave in deep water no considerable body of liquid is ever carried far forward; the reciprocating motion, nevertheless, induces a load which constantly advances, and which is replaced at fairly regular intervals.

Such forces applied to a mobile and at the same time practically incompressible fluid must cause numerous eddy currents to a considerable depth, which currents, owing to the periodicity of the load, may in some instances tend to become fixed in direction, although varying in force, for a given fixed direction of surface wave. Little is known of the actual magnitude of the transmitted wave-motion on the Channel bed; the mathematical theory is well defined, but the effect of disturbing influences cannot be argued with certainty.

This much, however, may be clearly foreseen, that any variations in the bottom level will tend to intensify the bottom disturbance—even a uniform gradient will produce this effect. If in place of a gradual change of level the sea-bottom abruptly rises the currents will be greatly intensified, and if it rise to a reef visible above low-water the back-wash will extend down the face of the reef into deep water. The reciprocating action of the surface wave is then destroyed, the pressure due to its height above the mean is no longer distributed equally in all directions to a yielding body, but meets a rigid resistance to movement in one direction. The waves themselves cease to be waves of oscillation, and on meeting the reef rise to much more than usual height.

The sands and gravels dredged in the course of this investigation afford interesting evidence of the effect of the bottom contour on the intensity of wave-induced currents.

A coarse gravel deposit may either arise from the presence of a large percentage of considerable rock fragments or from the absence of all small sand. Similarly a fine sand deposit may exist, either as a consequence of the absence of all larger fragments, or of a preponderating supply of small sand, or in each case the two causes may act in conjunction. This may read as "a most ingenious paradox," but has an underlying meaning.

Assuming the conditions to be such that both gravel and sand can settle and make good their standing, the grade of the deposit will depend on the relative supply of each material; and unless the gravel is constantly recruited from the detritus of an adjacent rock surface, the deposit will constantly tend to assume a finer grade by the mere degradation of its coarser particles.

If there is a supply of silt, and the conditions are such that it can at times settle, the whole deposit will be more stable under the occasional action of wave disturbance. Any deposit in which the various grades of material are all present, and in approximately such quantity that each helps to effectively fill the interstitial spaces of the next coarser particles, will as a whole much more effectively resist moving water than would a coarser gravel in which the spaces between the small stones were unfilled. Hence those surfaces which are longest left quiescent will more readily resist occasional violence; it being the nature of the gravels and sands thus to emphasise the local variations in wave-action.

The dredgings in the Eddystone neighbourhood are not so numerous as might be desired, but it is interesting to note the relative positions of fine and coarse textures.

With one exception the fine textures occur at some considerable distance from the reef, while the coarse textures are clustered around the reef or around the Hand Deeps. The exception as to a fine texture occurring near the reef is in the case of dredging 89B taken from the centre of the channel between the Hand Deeps and the Eddystone reef.

Between the reef and the Hand Deeps lies a channel of over thirty fathoms in depth, and again on the eastern side of the reef is found a similar but smaller channel. The western side of the Hand Deeps shows the formation of another incurve in the thirty-fathom line. The embayment of the thirty-fathom line between the two reefs is no less than three miles.

To account in part at least for the formation, and for the entire burden of the maintenance of such a depression, we have wave-action as an only possible cause. The Eddystone reef, rising above low-water, meets and breaks the great Channel rollers, and this certainly cannot be effected without the creation of relatively intense currents in the neighbouring depths.

Dredging 85 gives additional evidence for the existence of such currents. It is remarkable for the manner in which the quartz grains have been rounded and polished, and also for the extremely coarse texture of the fine sand VII. As has been pointed out, this grade may either have a maximum coarseness, in which all grains are of such size as to barely pass through the 0·5 mm. aperture, or it may approximate to silt. In the present case the maximum coarseness is closely attained, while the actual silt only forms 0·6 per cent. of the whole sample.

The greater portion of the sample is almost uniformly distributed between III., IV., V., and VI., a feature which occurs in this dredging only. The average grade is 4·597, or nearly a mean between IV. and V.

The conditions at this point are therefore unfavourable to the existence of either coarse gravel or fine sand; of the first because the strong wave-action breaks up all large particles, of the second because the same action will not allow fine particles to permanently settle. Add to this the rounded and polished sand grains, rounded as they are rarely found in number on any beach, and almost every individual grain so polished, and the inevitable conclusion is that here we have a centre of wave-action which, lying as it does below the thirty-fathom line, proves the great effect produced by the reef in breaking or deflecting surface waves and creating bottom currents.

The sand grains of 87 show a similar but less complete polish, and well-rounded quartz gravel occurs around the southern slopes of the Hand Deeps.

The action which has rounded these sand grains undoubtedly lies dormant for considerable intervals, and its periods of greatest activity occur at still longer intervals, since both *Rotalia beccarii* and *Miliolina seminulum* are by no means infrequent in the sand from 85, although the more delicate foraminifera are practically absent. In 87 VII. there are 81 foraminifera to 13 cgrms. by weight. The skeletons of these delicate organisms could not long survive any storm-wash calculated to polish quartz grains.

There is little doubt that around the Eddystone the tidal currents materially affect the wave-action, probably not so much by adding the velocity of their flow to the bottom currents as by inducing a heavier sea at the surface. Of the actual velocity of tidal streams at any depth below the surface little or nothing is known.

In a similar manner the tide race off the coast from Prawle to Start is probably the cause of the exceptional absence of fine material from the sea-bottom; the contour of the thirty-five-fathom line suggests the existence of a deeply submerged reef, and this, too, may help to make and maintain the Prawle stony grounds.

The finer deposits are all in more quiescent localities, with no abrupt changes in the levels of the bottom to reflect the surface waves.

One notable exception to this last statement should be remarked—the deposit at 89B. This consists of the finer detrital matter from the Eddystone gravels; it lies in mid-channel between the Eddystone and Hand Deeps, and at the quietest spot. Fine sand rises as high as 56·8 per cent. in this dredging, but this will not compare with 92, which lies well clear of the reef, and has 90·9 per cent. fine sand; nor with any other fine texture deposit except 90, which is similarly situate at the head of the eastern Eddystone channel, and has 68·8 per cent. fine sand. Dredging 89B also differs from all the other fine texture sands in having a a large percentage (29·2 per cent.) of medium sand, in addition to which its very high percentage of $CaCO_3$ (48·61 per cent., the highest of all the fine textures) betrays its origin from the Eddystone shell gravel.

Mr. Allen remarks the scarcity of hydroids on Ground XIV., which surrounds dredging 85, and suggests as an explanation the periodical wave-action evidenced by the polished quartz grains.

In Mr. Allen's paper, on page 457 *et seq.*, will be found an interesting discussion on the distribution of *Alcyonium digitatum* (one of the Actinozoa). Large colonies of *Alcyonium* are found attached to shells of *Pecten opercularis* and *Cardium echinatum* in depths below thirty-four to thirty-five fathoms, but in less depths large colonies are only found in sheltered situations attached to rocks or solid structures; the species is found up to within a few feet of low-water, or even exposed on the sheltered parts of the Eddystone reef, hence the depth of water is not directly necessary to its existence.

Since, however, "a large colony of *Alcyonium* when fully expanded offers a very considerable surface to any movement of the water, when such a colony is attached to a shell of the size of *Pecten opercularis* or *Cardium echinatum* a very slight movement will be sufficient to overturn it. At a depth of thirty to thirty-five fathoms," Mr. Allen concludes, "we are probably approaching the limit at which wave-action is seriously felt on the sea-bottom in this portion of the Channel." The author would add "except in the immediate neighbourhood of reefs or other abrupt changes in the Channel bed."

(*f*) A Consideration of the Deposit as a Recent Formation.

The most striking feature in the whole of the deposits is the absence of any rock fragments which must of necessity, or even probably, have been derived from the adjacent shores. Off Prawle and the Bolt it is true that schists similar to those found on the shore constitute the greater part of the bottom-deposit, but even here the similarity does not amount to identity.

The Eddystone reef is a little over nine miles from the nearest land at Rame Head; 90, the most northerly dredging taken, is about four miles from land; north of this again dredgings would probably give misleading results, in consequence of the large amount of material which has been deposited from the deepening of Hamoaze and Plymouth Sound. Notwithstanding that quantities of dredged material have been deposited to the north of the grounds examined, none of it has yet apparently spread on to these.

The silt brought down by the rivers Tamar, Tavy, and Yealm, apparently deposits near shore, or if it is carried as far as the sites of the various dredgings, is met by the Channel tides, and distributed over a large area, becoming unimportant as compared with the silt from the organic waste and the pulverised rock of the immediate neighbourhood. In this connection it is interesting to note that no fresh-water diatoms have yet been detected in the silts; some of the species common in the rivers have very distinctive forms, but careful search has failed to give a single specimen. This is negative evidence, and only acquires value from the vast numerical developments of diatoms in our rivers. The dredgings from off Salcombe have not yet been carefully examined in this connection.

The deposits brought down by the rivers have an entirely different texture from those dredged in the Channel. This can be best seen by referring to Table II. in Mr. Allen's paper. All the dredged samples which are rich in Grade VII. (fine sand) are poor in Grade VIII. (silt). The one deposit, 103, which contains any fair proportion of silt (17·1 per cent.), is a medium gravel. Mud from the Sound contains 69·8 per cent. of fine sand, and 24·4 per cent. of silt.

Three silts recovered from samples 83, 94, and 103 were analysed. The results were as follows, and should be accurate to the nearest 0·25 per cent.

The analysis of a silt from the deposit in Plymouth Sound is added for comparison.

ANALYSIS OF SILTS.

	83		94		103	
Loss on Ignition—						
Bunsen	11·50	20·50	12·00	20·50	12·50	21·00
Blowpipe	9·00		8·50		8·50	
SiO_2		42·35		35·42		41·56
Al_2O_3		10·18		9·64		7·53
Fe_2O_3		9·29		7·70		8·00
CaO		13·67		17·60		12·69
MgO		Heavy trace		Heavy trace		Heavy trace
Undetermined		4·01		9·14		9·22

PLYMOUTH SOUND.

Loss on Ignition—

Bunsen	8·275	13·975
Blowpipe	5·700	
SiO_2		45·00
Al_2O_3		20·25
Fe_2O_3		10·00
CaO		7·00
MgO		A trace
Undetermined		3·775

The loss on ignition over bunsen gives with fair accuracy the more volatile substances and organic matter; the further loss over blowpipe is practically confined to CO_2 in carbonates.

Under the head of "undetermined" must be classed the alkalies, any slight traces of metallic oxides, and a small residue of CO_2 left after ignition.

All samples were fairly thoroughly washed before analysis to remove salts derived from sea-water, and were desiccated before ignition.

A comparison of these analyses shows a considerably greater percentage of alumina in the silt from Plymouth Sound, amounting to more than twice the average percentage present in silts from the Eddystone, and a much less percentage of lime, amounting to less than one-half the average percentage present in the silts from the Eddystone.

The loss on ignition is also less; this, however, is partly accounted for by the low percentage of $CaCO_3$, and not wholly by the absence of organic matter.

Much of the silica is in combination with the alumina as clay.

The presence of a considerable percentage of alumina is good evidence of detrital matter from the rivers, especially where no aluminous rock is exposed in the neighbourhood from which the sample is taken, and its relatively small proportion in the Eddystone silts is evidence of the fact that detrital matters from the mainland do not reach as far in any quantity.

It is fairly evident, therefore, that river-borne detrital matters from the land are not carried far to sea, at least in recognisable quantities, under the conditions now prevailing off the mouths of the Tamar, Plym, Yealm, Erme, and Avon.

The lighthouse on the Eddystone is not probably situate over the centre of the Archean rock mass constituting the reef, but it forms a convenient point of reference. In the following table are given the numbers of a series of dredgings round the reef, their bearings and distances from the Eddystone light, and the percentages of the Archean to the total rock fragments in Grades II. and III.; the results for III. are the more reliable, as founded in each case on a larger total. The dredgings are placed in order from N.W. by N. to W., S., and E., and where two dredgings fall on the same bearing that nearer the lighthouse is set first.

Distinguishing No. of Sample.	Bearing from Eddystone Light.	Distance from Eddystone Light.	Archean as Percentage of Total Rock Fragments. Grades.	
		Miles.	II.	III.
87	N.W. by N.	$\frac{3}{4}$	100	74
85	N.W. by N.	1	32	25
94	W. $\frac{1}{2}$ N.	3	9	18
96	W.	2	13	16
102	S.	$2\frac{1}{2}$	None	None
103	S.E.	1	4	26
97	E.	2	6	17

It will be seen that distance exercises a considerable influence. Two features are especially notable: the great fall in frequency of Archean between 87 and 85, due to a distance of one-quarter of a mile only, and the total absence of Archean in 102, due to a distance of $2\frac{1}{2}$ miles. No. 94, at 3 miles, is evidently nearer the centre of the Archean mass; it is but $2\frac{1}{2}$ miles from the Hand Deeps, which are also Archean, while 102 is $5\frac{1}{2}$ miles from the Hand Deeps.

It should be noted that even at 78 and 99, not much more than a mile to the S. and S.W. of the Eddystone respectively, none but Triassic rocks were dredged from the stony bottom.

These facts point to the Archean being confined to a comparatively small area, probably only the summits and submerged cliffs of the Eddystone reef and Hand Deeps. They also prove that, although the wave-action suffices to polish quartz grains, it does not convey rock fragments, even so small as between 2·5 mm. and 5 mm. in diameter, to any considerable distance, although the course of these fragments from their points of origin on the reef would in every case be downhill to below the thirty-fathom line.

Another conclusion from the examination of the samples dredged is that materials may be derived from the subaqueous disintegration of rock masses in from 28 to 35 fathoms of water, which, if indurated, would form a conglomerate in which many of the smaller grains would be beautifully rounded and polished, medium materials would be subangular, and coarse materials, above 5 mm. in diameter, would be largely angular. To the geologist examining such a conglomerate it might appear necessary to assign to each class of materials a different origin. Side by side with the rounded sand would be found glauconite casts of delicate foraminifera, and the percentage of carbonate of lime in the conglomerate might range from 72 to 17. All these varied forms and constitutions characterise the Eddystone gravels of to-day, which have been forming for long years, and still are forming under practically unchanging circumstances.

To add to the troubles of our problematic geologist of the future, he will find associated in the same horizon with the conglomerates a series of fine-grained sandstones, in which the quartz granules will be mostly angular and sharp, while the percentage of carbonate of lime will probably be about 15.

A warning should be issued to all geologists who regard *Coccoliths* among the algæ, *Hyalodiscus* among the diatoms, and *Globigerina bulloides* among the foraminifera, as essentially defining the rocks in which they are found as deep-sea deposits; all these are present in number in the Eddystone dredgings. Their presence in coastal waters is no new discovery, but their great frequency in the silts was unexpected by the author.

Although no "ooze" was found, it is by no means certain that under conceivable conditions some of the very fine sands might not indurate to successfully simulate rocks at present regarded by some as of oceanic origin.