confusedly, the vegetation produces tumultuous stirring of the waters, which is eminently favourable to the deposition of sand. In a somewhat similar way, waving reeds and grass stop sand driven by the wind. Planting has succeeded best as a means of stopping the encroachment of blown sand, and our sandy coasts might be similarly protected against sea-attack by sturdy plants with matted or tangled structure, and the habit to withstand salt water at their roots. Such growths appear to be at present unknown much beyond the tropics; nevertheless, this mode of protection from sea-attack might afford scope for interesting experiment in colder climates.

In the fascine dam, withies, and the like, by their yielding and subsequent recovery, reproduce one of the features of protection by a natural wall of matted mangrove or courida.

POSTSCRIPT.

The next paper which I hope to lay before the Society will be upon undulating Waves, a subject upon which I have been engaged for some time past. I endeavour to deal with waves of the sea, of lakes, and rivers; with ripple mark and ripple drift and snow ripples; with gusts of wind, and undulating air-waves and their accompanying cloud forms, with the ridging of hillsides, and with such other rock (and ice) structures as are dynamically related to undulating waves.

I shall be grateful for any help which gentlemen interested in these matters may be kind enough to afford me, particularly—

(1) By suggesting problems for investigation.

(2) By assistance in mathematical treatment.

(3) By the loan of, or reference to, photographs and other illustrations.

Before the reading of the paper, the President said: Mr. Cornish gave us a very interesting paper last year on the formation of sand-dunes, which was followed by an admirable discussion, and I feel sure that the paper he is going to read to us this afternoon will be equally interesting. I will now ask Mr. Cornish to read his paper.

After the reading of the paper, the following discussion took place:—

Dr. BLANFORD: I am afraid I cannot contribute anything of value to the discussion. It is very difficult indeed to discuss papers of this sort, which require a great deal of reading and thinking over before any one can form a judgment upon them. Of course, this paper consists partly of facts, some of which are patent to any one who looks for them, and some are less obvious, and partly of conclusions formed by the observer, and it is not fair to attempt to criticize his views without going very carefully into them. I can only say they are exceedingly interesting, and I am only too happy on this occasion, as on a former one, to bear witness to the interest of the paper.

Mr. A. STRAHAN: England is not very large, and if it were not for its shingle beaches, it would be undoubtedly a great deal smaller. They are the best protection to our shores that we can have, and the subject is therefore of much importance from a national point of view as well as a scientific problem. The application of Mr. Cornish's views to a particular example is of great interest. The example I know best is the Chesil Beach, and it would be difficult to find a better specimen of a graded shingle bank. Mr. Cornish, I hope, will forgive me when I say that I do not entirely agree with him, or perhaps I should express myself more correctly if I say that I think he has not exhausted the subject. There is a copious literature on the Chesil Beach, beginning with a paper by Sir John Coode, and including a very fine piece of work by the late Sir Joseph Prestwich. There are great

difficulties in accounting for several features in the beach. In the first place, where did the material come from? in the second place, how is it now being supplied? and in the third place, why does the beach maintain its curious position at all? The beach extends from Portland to Eype, near Bridport, and is completely hemmed in at either end; nothing but the finest stuff can escape. I think Mr. Cornish will agree with me that only the finest material can escape round Portland, and that nothing but the finest stuff can be fed in, as he says, round the headland at the west end of the beach. The beach, for much of its length, is separated from the mainland by a long lagoon of shallow water 12 miles long, and cannot, therefore, be fed with stones from that part of the mainland. It seems, then, that it is starved at both ends and in the middle, and that some other sources must be found for the stones composing it. The stones themselves consist principally of chalk-flints, though there is no chalk anywhere in the neighbourhood; not anywhere so near, at any rate, as to supply flints. Amongst the stones, moreover, there are some quartzites, which must have come from Budleigh Salterton, a distance of some 20 or 30 miles. The theory formed by Prestwich to account for such stones was that they were washed into the sea from some part of the Devon coast, and brought direct to form the raised beach of Portland; that they were driven thence by storm-waves on the southern end of the Chesil Beach, and travelled in the beach north-westwards. It was supposed, also, that as they were carried they were worn smaller and smaller, and eventually passed almost into sand at the extreme end of the beach. But it always seemed difficult to me to understand how such large pebbles could get across Tor Bay. What could move them when they had got beyond the sphere of the waves? There is, however, an alternative source for these pebbles; the Tertiary strata of the Hampshire basin extend to the neighbourhood, and in a former period not improbably touched the rocks in which these pebbles are *in situ*. At any rate, they contain foreign stones of great variety, derived from that origin. Later than these, though of course altogether pre-historic, there is a set of gravels which once overspread a large part of this area, but which have now been cut by denudation into isolated patches; in those gravels I have myself seen such pebbles embedded. Now the sea is encroaching by slow degrees upon this coast. There still exist two hills on the landward side of the valley of the Fleet occupied by these gravels, and there can be no doubt that before the sea encroached upon the seaward side of that valley, there was there also a corresponding set of gravels, and that they may just as likely have contained these quartzite pebbles as the gravels on the north side. I regard the Chesil Beach, therefore, as having been formed from the sweepings of all the gravels and of the harder residuum of the rocks that once occupied the west bay, heaped up into a ridge. No doubt these stones oscillate, but I consider they are, and always have been, hemmed in effectually at each end, and that the beach is not fed from any other part of Tor Bay, but has been derived solely from the actual region in which it occurs. If the beach were fed from outside, it seems to me inevitable that it should pile itself up towards its eastern end in the direction in which it travels, and that eventually it would assume enormous dimensions. Under such circumstances it would take the form of a series of banks, such as form the promontory of Dungeness, an example of a beach which is continually growing. The only direction in which the beach can persistently travel is towards the shore. In a storm sooner or later waves reach to the top of the bank, and throw the stones on it, or even over it. There is a case on record of a ship having been thrown so high up on the beach that it was decided to launch her into the Portland Roads, as being an easier matter than to launch her into the sea again. Similarly, the stones roll over, and never get back again. They oscillate backwards and forwards with

east and west winds, but once thrown over the ridge they are safe. So that it seems to me that the beach is being rolled over upon itself towards the shore. Further, I think that it is travelling faster at the Portland end than at the Bridport end, and is therefore swinging; and, for this reason, that at its west end it is more or less covered with vegetation, but that at the east end it is completely bare. The raised beach at Portland Bill seems to represent the end of the beach when it extended in a curve 2 or 3 miles further out to sea than it now runs. The application of Mr. Cornish's laws to such a beach as this will be of the highest interest. It is impossible, in a discussion limited to time, to enter into matters of detail, but I feel certain that if he continues his careful investigations in the same spirit as he has commenced them, he will attain results of the highest value.

Sir Erasmus Ommanney asked if Mr. Cornish was acquainted with the accumulation of shingle round the extremity of Dungeness point, because all these sort of projections into the Channel are formed under different influences of tide and weather. According to a measure made from the point to the lighthouse, the shingle beach is advanced at a certain ratio of a few inches every year. Could he account for this accumulation continually going on there?

Prof. George Darwin: Having been one of the first to make experiments on ripple-marks, Mr. Cornish's paper has interested me very much. But, as Dr. Blanford has said, the subject is too large a one to discuss thoroughly after only once reading this elaborate investigation. I should, however, like to ask Mr. Cornish's view on one point to which he refers. On page 640 he gives a figure illustrating the eddies which are supposed to occur at the change of tide on an open coast-line. I should like much to know how these eddies were determined, and what reason there is for believing that there are two sets of eddies, one more seaward than the other; also what evidence there is for the existence of the nodal lines shown in the figure. No doubt he has authority, but the point is so interesting that it will be well worth while to give full details as to how the motion of the water was observed. The wrinkling of hillsides is one of the topics he proposes to take next; it was a subject in which my father, Charles Darwin, was much interested when he was studying earthworms. He was not quite able to make up his mind as to the origin of these longitudinal wrinkles. He concluded, I think, that they were largely, although not entirely, due to the action of sheep grazing sideways; but I do not suppose sheep would be able to make the longitudinal paths, unless the earthworms had given them a friable substance to trample down. If I remember aright, he thought that these wrinkles also appear without the intervention of animals; but it was not possible, in the cases observed, to determine the extent of the several influences which may produce them. In conclusion, I wish to congratulate Mr. Cornish upon his interesting paper, and to wish him success in his future work.

Dr. Mill: I am unable to speak as a specialist upon this question, but I should like to call attention to its national importance. Researches in physical geography have not been made in this country with anything like the frequency and detail that has been devoted to them on the continent, and latterly in the United States of America; and I think this Society should congratulate itself on securing a man like Mr. Cornish, who is prepared to devote his whole time to the study of questions like this. Much of the paper, of course, deals with matters which have been already studied by geologists, and, although the difference between the geological and geographical standpoint is not yet so generally understood in this country as it is, for instance, in Germany or in Austria, nothing can do more to prove the claims of geography to be considered an independent science than such researches, carried on from this point of view.

Captain Wilson Barker: I do not propose to offer any criticism upon the paper, but I should like to call Mr. Cornish's attention to the remarkable reefs on the east coast of Brazil, which are probably due to the action of the wind, and which I think are well worthy of his attention, and of the application of the theories which he has brought before us in this paper. They are commonly reported as coral reefs, but it is well known that they are nothing of the sort, but are formed of mud and sand of different kinds brought down by the rivers. In the trade winds, there is often a shifting of beaches with slight alterations in direction of the wind, so that at one time of the year you get it sandy, and at another time ordinary bare rock. The places I particularly allude to are at the landing-place, Fernando Noronha, and also in the harbour of Bahia, at the entrance. There is a remarkable bank of sand in the island of Gran Canaria, between Las Palmas and Port Luz, which, I believe—quite within ordinary memory—has grown very extensively, and is formed entirely of sand. The island of Gran Canaria is of volcanic formation, and it is difficult to say where the sand comes from. The popular idea is that it has been blown across from the African continent.

Mr. Cornish: I am extremely obliged to Mr. Strahan for giving at this time these further facts with regard to the Chesil Beach. Such a subject cannot be adequately treated from a single standpoint, and although I had read the papers of Coode and Prestwich, and, I think, the greater part of that extensive literature to which Mr. Strahan refers, I did not feel myself competent to analyze the geological evidence in the way he has done. With regard to the amount of the actual difference which there remains between Mr. Strahan and myself, it practically amounts to this: that I have supposed the shingle is travelling, while Mr. Strahan, I think, limits himself to the supposition that the shingle is oscillating on the beach, and that it neither comes nor goes at the two ends. Well, that is a point which I will not labour here, because investigations of the Chesil Beach will no doubt continue, and further evidence will, I hope, show which view is the more correct. In either case, as I have shown in my paper, it is the present and not the past conditions which mainly determines the present mode of grading. Admiral Sir Erasmus Ommaney has asked a question about Dungeness. In a part of the paper which I did not read, this curious accumulation of shingle is dealt with in some detail. I am extremely glad to have heard the remarks of Prof. Darwin, whose paper on "Ripple Marks" greatly helped me when I was struggling with the difficulties of this subject of the movements of incoherent material some two years ago. With regard to Fig. 10, the chief point which I wish to bring out is the *grid* pattern of the probable positions for deposition of sand under the conditions mentioned. The existence of nodal lines approximately at right angles to the shore is commonly recognized; *e.g.* in the case of the tides of the English Channel. With regard to the B nodes, parallel to the shore, I apprehend that these are necessarily established by reflexion, and *seiches* in closed seas and channels probably co-operate with tides (see Forel in 'Le Leman,' vol. ii., on the longitudinal and transverse *seiches* of the Lake of Geneva). A *grid* arrangement of sand formations has been noted by Prof. Osborne Reynolds in a tidal estuary, and by Major MacMahon in a mountain pass in the desert between India and Persia. In the open plains of Sindh the *stripes* (B) and *bars* (A) are not laid down together, but successively as the distance from the coast increases. Such considerations, however, do not enable one to construct a satisfactory figure, and I trust that Prof. Darwin, who commands mathematics, will go more deeply into the matter. With regard to the ridging of hillsides, the Down sheep walk on the flat top, and not on the sheep-sides, and that no doubt accentuates these ridges when once they are formed. But I have seen them equally well in the slopes of the valley at Grindelwald, and I have seen them near Innsbrück, and in other places where

apparently sheep do not go, and I have learned only to-day from one of the gentlemen of the geological survey that this ridging is very noticeable on the quartz screes in the Highlands, and yet other examples have been given me. Therefore, although curious structures may be produced by animals on hillsides, and although the remains of old agricultural workings will sometimes ridge a hillside, yet I think there is a true formation of pressure ridges, which, I may take it, would be analagous to undulating waves, independently of any effect that animals may produce.

Prof. DARWIN: I only meant that my father could not distinguish what part of it was due to the sheep, and what was due to some natural ridging. The difficulty was to eliminate one cause from the other.

Mr. CORNISH: I am much obliged to Captain Barker for pointing out certain interesting formations, and I shall hope to examine into them. In conclusion, I can only thank the gentlemen present for the kind way in which they have received the paper, and to express my gratitude in the usual way by asking for further help in connection with the paper that is coming.

The PRESIDENT: I feel sure that every one present will fully concur in what has been said by Prof. Darwin, Dr. Mill, and the other gentlemen who have joined in the discussion, with regard to the importance and interest which attaches to these investigations, and also with regard to the merit which belongs to Mr. Cornish for the perseverance and ability with which he has conducted them. If Mr. Cornish attaches importance to what he has said about the shingle survey, we shall be happy to report the matter to Admiral Domvile, and I have no doubt he will give it favourable consideration. If the expenses would only consist of the postage, I feel sure that matter would be easily arranged. I now propose a vote of thanks to Mr. Cornish for his valuable paper, and beg to assure him, on the part of the meeting, that we all look forward with great pleasure to hearing the other paper he has promised us.

Mr. CLEMENT REID (writes): I have read with great interest the proof of your paper on "Sea-Beaches and Sandbanks." It contains the explanation of many familiar coastal phenomena, the reason of which I have never clearly understood. There are only two criticisms that I should venture to make, and these may have been taken into account, though the paper is perhaps not quite clear on the point. I would suggest that it might be well to emphasize the fact that, contrary to the ordinary teaching of engineers, large shingle-beaches and sandbanks have not reached an equilibrium. As the last change of sea-level only took place in Neolithic times, and probably only some three thousand years ago, there has not yet been time for such a balance to be attained. The enormous accumulation of beach at Dungeness during the historic period shows that this historic period is no inconsiderable part of the total life of the beach.

The other point is, that the erosion of old gravel deposits at a low level has probably supplied a very large part of the material of some of the beaches analogous to the Chesil beach. In Cley beach, for instance, the accidental preservation of a single outlier of the low-level gravel in the middle of the beach preserves evidence which in a few years will be entirely destroyed. Without this it would be imagined that the whole beach was derived from one of the ends, instead of owing its origin to gravel outliers formerly in the immediate neighbourhood.

In your account of the Chesil beach, you do not allude to the fact that great part of the large pebbles at the eastern end are tough Budleigh Salterton quartzites. I should think that the life of one of these is many times the length of the life of a flint pebble—the one is slowly *rubbed* down, the other wears more rapidly by small conchoidal fractures. The proportion of these quartzites is so large towards Portland, that I suspect the nature of the material has here a good deal to do with the size of the stones.