
Experiments on the Transporting Power of Sea Currents: Discussion

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and the currents keeping up a steady movement from place to place of the finer sand, and matter which has been suspended in the water by wave action.

That fairly rapid currents exist upon the sea-bed in deep water beyond the limits of wave disturbance appears to be established; but their power, unless they are of very great velocity, is probably limited to the transport of fine mud and sand. Of course, given sufficient velocity, a current can move particles of unlimited size, but these remarks are intended to apply only to currents the existence of which we have evidence of at present.

After the paper, the PRESIDENT: We have listened with very great interest to what Dr. Owens has had to tell us. Perhaps Dr. Strahan might open the discussion.

Dr. A. STRAHAN: I think that this paper contains a large number of valuable observations, and I only regret that the author had not more time at this meeting to do justice to his work. One point interests me greatly, and that is the comparative rate of travel of large stones and small. In the case of the Chisel beach, it is well known that at the east end the stones are large, towards the middle they are intermediate in size, while towards the west end of the beach they are small, and it has commonly been stated that this gradation in size is due to attrition of the pebbles in their travel from east to west. In writing the Geological Survey Memoir I had to sum up the theories which had been advanced on the Chisel beach, and I formed a different opinion. I concluded that the larger pebbles were sorted out by wave-action, and that they travelled eastwards and faster than the small, with the result that they assembled at the east end of the beach. One other point seems to me worth mentioning, that is, that when the Channel tunnel was first proposed, a good many years ago now, the French examined the sea-bottom partly by diving, partly by sounding, and were able even to make a geological map of the bottom of Dover strait. They got a sufficient number of specimens to show that the Chalk and the Greensand crop out in the sea-bottom, and were able to indicate the position of the outcrops. It is clear, therefore, that the current is capable of sweeping away all loose material from a large part of the strait.

Mr. LAMPLUGH: The paper contains much of interest to geologists, and the author has attacked the subject in the right way, but I think that the erosive powers of currents has been underrated. In Holderness there is a rapidly receding coast-line, from which boulder clay and other drifts are being removed in very large quantity. If there were not a removal of this material going on below low water, the tidal platform would be continuous from the place where the erosion first began. But instead, the distance between high and low water is comparatively narrow, and it is quite clear that the low-water line is advancing inland proportionally to the advance of the high-water line. The sea deepens steadily from the land, which proves that erosion of the boulder clay is going on much below the level of low water. Moreover, the material that has been removed is not only sand and mud, but also the boulders which were embedded in the drifts, for if these boulders had not been removed they would soon have formed a protecting layer over the whole of the new sea-floor. The character of this bottom shows that the boulders are moved along beneath the sea, accumulating here and there for a time in patches, leaving other patches of bare clay and smooth sand. The result is important geologically, because the encroaching sea produces, not an absolute plain, but a slope, which is no barrier to its further advance.

The author's observations with regard to the rolling of stones along the bottom, will help to account for deposits, such as the Bunter Pebble Beds, in which stones of considerable magnitude sometimes occur scattered, in a comparatively fine-grained

matrix, and not segregated. One sees how such pebbles may have been set rolling upon a smooth sandy floor till they reached a rippled surface, and then brought suddenly to rest and embedded in sand. I mention this only as an example of the usefulness of the author's work to the geologist, and I hope he will give us further results on the same lines.

Dr. VAUGHAN CORNISH: All who are interested in the action of waves and currents will welcome Dr. Owens' addition to the experimental data which we possess as to the connection between velocity of flow and size of stone moved. He finds that ordinary seashore sand is unmoved below a speed of current equal to 0·85 f.p.s.; that between 0·85 f.p.s. and 2·5 f.p.s. the sand moved in the form of the well-known sand-ripples, the depth of water being from 1 to 5 inches; at 2 f.p.s. shingle on the bottom remained at rest; but that at 2·5 f.p.s. the current suddenly acquired the power to move *continuously* stones of nearly 3 inches in diameter and 1·2 lb. in weight, in a stream 3·5 inches deep. My own hitherto unpublished measurements in currents of similar depth on the Dorset and Norfolk coasts yielded results concordant with these observations. I found that in clear streams where the sand was not in the well-known ripples, but only presented small lee-facing cliffs at considerable intervals, the sand was scarcely moved except in a few spots where swirling motion occurred, and that in these streams the velocity was—

<i>Locality.</i>			<i>Velocity.</i>	<i>Average velocity.</i>
Branksome Chine (Dorset.)	...	...	0·54 f.p.s.	} 0·57 f.p.s.
Mundsley-on-Sea (Norfolk)	...	...	0·60 „	

Velocities in streams showing the well-known sand-ripples about 3 inches in wave-length and occurring in long trains were as follows:—

<i>Locality.</i>			<i>Velocity.</i>	<i>Average velocity.</i>
Branksome Chine	1·16 f.p.s.	} 1·475 f.p.s.
Mundsley	...	...	1·49 „
Branksome Chine	...	...	1·50 „
„ „	...	...	1·75 „

The following observations were made in streams in which the ordinary or best-known ripples had been replaced by those which move upstream,* the superincumbent water being moreover turbid owing to sand continuously in suspension. Stones of the beach (smaller, however, than the author's 3-inch pebbles) were often observed to be travelling rapidly on the sandy beds of these streams.

<i>Locality.</i>			<i>Velocity.</i>	<i>Average velocity.</i>
Branksome Chine	...	...	2·00 f.p.s.	} 2·22 f.p.s.
„ „	...	...	2·12 „	
Mundsley	...	...	2·55 „	

The average diameter of the sand-grains at Branksome was $\frac{1}{60}$ of an inch; of Mundsley sand 82 per cent. passed through a mesh of $\frac{1}{48}$ inch, but was stopped by a mesh of $\frac{1}{36}$ inch. It will be noticed that the highest of the above speeds corresponds with that at which Dr. Owens found the sand to travel in a continuous sheet without rippling. I suggest that this effect depends upon a particular state of the current, viz. that it was not fully charged with sand. When saturated it scours, when supersaturated it silts, and when it is picking up just as much as it is dropping it generally maintains some kind of sand-wave.

* *Geographical Journal*, June, 1899. "Kumatology."

In deeper water, certainly, the larger kind of sand-waves, with a wave-length of about 20 feet and height of about 1·5 foot, occur with higher velocities of current; thus at Aberdovey I found these sand-waves were *increased* by a current of 2·93 feet per second in a depth of 3 feet of water.*

Prof. Osborne Reynolds thought that the power of a current to raise sand from the bottom and maintain it in suspension depended on a change from stream-line flow to eddying flow. This, he said, took place suddenly at a critical velocity which was proportional to the dimensions of the channel. Mr. E. C. Thrupp concurred in this opinion, but found that the critical velocity, *i.e.* the commencement of eddying flow, does not set in, in the case of large channels, until a still higher speed is attained than that required by Osborne Reynolds's formula. In large channels, he says, there are innumerable instances where the velocities at the bottom are sufficient, according to mathematical theories, to roll along large cubical boulders, whereas, in fact, they hardly disturb fine sand, and he goes on to say that "No mathematical theories hitherto advanced can account for these critical-point phenomena, because the assumptions upon which they are based have not been ascertained by experiment."

I have now cleared the ground for two suggestions which I desire to make for future experiments: first, I suggest that the rate of settlement through water should be determined for all sand and shingle experimented upon. For the sand at Branksome Chine the rate of settlement was about 2 inches per second. In all the processes of transport by wind or water which are connected with the formation of waves or ripples of granular material the rate of subsidence is the dominant factor, and expresses, better perhaps than any other single quantity or dimension, the specific resistance of the material to transport. The power to transport in suspension is due, or mainly due, to upward swirls. If in a given current these have a velocity of 2 inches per second, sand which settles at that rate in still water would just be maintained in continuous suspension. In the case of shingle travelling in quantity (which it is more important to consider than the case of an isolated large stone being trundled over a comparatively smooth surface † of smaller stones) the effect of the upward swirl is probably of capital importance, and it is, I suppose, on account of its efficacy that the shingle can travel shorewards even when sand is travelling seawards; for the upward swirl made by the forward current of the waves in shallow water is much more powerful than that made by the slower return current of the wave. Hence the heavy shingle is jerked forward just after the passage of the crest of each advancing wave, but remains anchored during the return current until at last the slope of the beach tends to equalize matters. My second suggestion is that systematic observations, such as Dr. Owens has made so well in shallow streams, should now be undertaken with the aid of the diver's dress in deeper water.

In conclusion, I should like to draw attention to some definite measurements of rate of travel on a shingle beach which were taken by my friend Mr. Nelson Richardson (after consultation with me) on the Chesil beach.‡ Some of the half-bricks which he dumped on the beach between tide-marks travelled during twenty-eight hours of fine weather 574 yards, a speed which, if continued, would be sufficient to have carried them the whole length of the beach, viz. 18 miles, in seventy-two days. With regard to this question of the carrying power of currents

* *Geographical Journal*, August, 1901. "Sand-waves in Tidal Currents."

† See remarks in *Q.J.G.S.*, vol. 53 (1897), p. 244.

‡ "An Experiment on the Movements of a Load of Brickbats deposited on the Chesil Beach," *Proc. Dorset Field Club*, 22 (1902), pp. 123-133.

suddenly increasing when you pass from stream-line flow to eddying flow, of course the effect of waves is to impart something of the character of an eddying current, because they produce those sudden upward swirls which raise the material into suspension.

Dr. MILL also spoke.

Dr. EVANS: I should like to call the attention of the committee to the importance of the question which has been raised as to the existence and distribution of currents sufficient to carry shingle from place to place. Recently Prof. Cole and Mr. Crook, who have examined the blocks and pebbles found on the submerged continental shelf off the west coast of Ireland, have shown that the distribution of the different rock types indicates that the material has not, as a rule, been transported any considerable distance by currents, and that it furnishes valuable information as to the geology of the sea-floor. There are many other places at a considerable distance from the coast where banks of shingle occur beneath the sea. In the absence of powerful currents or of transport by ice, these would date back to a time when such localities were in the neighbourhood of the shore-line, and furnish evidence of the depression of the land relatively to the sea. At the same time, as in the area to the west of Ireland, they may in many cases lead to important conclusions as to the solid geology of the sea-bottom.

Captain TIZARD: I should like to say a word. I think it would add very much to the information that has been given if the slope of the bottom was stated in all these experiments. Whether a stone would be moved by a current on a perfectly flat surface in the same way as down an incline is doubtful. In all these experiments the stone has not been moved on a flat surface, but down an incline, for the water would only flow down that incline. With respect to the movement of the larger stones and not the smaller ones, I would suggest that this is due to the friction of the bottom making the water at the bottom move slower than that above. I think the flow might not move small pieces of shingle at the bottom, but might larger pieces above where the power of the water is greater. With respect to the disappearance of boulders, the boulders might disappear from quite another cause. Of the boulders washed off the Holderness coast, some might fall into a soft substance, and I know from practical experience on the east coast, directly an obstruction gets on the sands, the tide hollows out the sand around and the obstruction sinks down. This goes on on the Goodwin sands and in the estuary of the Thames; hence the saying these are quicksands. Of course they are in that way. However, I quite agree with the author's conclusions that it is not the current that erodes the coast; it is the wave-action.

Captain CREAK: Very much to the point has already been said, but I should like to make a remark or two. About three years ago Prof. Herdman, who is engaged in natural history inquiries, asked me a question with regard to the action of waves produced by a cyclone over a plateau of 12 fathoms of water, and whether substances at the bottom would be moved by the waves at that depth. I replied in the negative. I have since thought over the subject, and I remember being at anchor on the open coast of New Zealand during a severe cyclone, when the water broke in 7 fathoms and caused a violent disturbance of the materials at the bottom. You could see the sand moving in remarkable swirls, but I do not think the waves had any action beyond a short distance from those breakers. Hence I believe, if materials are moved at the bottom, it must be due to the current. Some time ago I was staying at Skegness, on the Wash, and I observed there that the beach was continually changing, and the calm water near the shore constantly full of fine *débris* in motion with the tide. Thus currents may carry such *débris* far and wide, but it must be the waves breaking upon a coast which are the cause of the motion of stones and coarse sand.

Mr. G. G. CHISHOLM : With regard to what Captain Creak says as to the power of the waves in moving matters at considerable depth, it may be not uninteresting to call attention to the fact that Sir William Matthews, on the occasion of his recent presidential address before the Institution of Civil Engineers, made some remark on that point. He says, "The depth to which wave-action extends is much greater than was formerly believed to be the case. With reference to the exceptional depths to which wave-disturbance extends, the late Sir James Douglass once mentioned at a meeting here that lobster creels, off the Land's End, lying in from 20 to 30 fathoms, had been found to be filled with sand and shingle on their withdrawal, subsequently to a heavy gale, some of the stones weighing as much as 1 lb., thus showing in that position sea-action had descended to the depth named. I may observe that off the coast of Peterhead and Fraserburgh, there have been similar experiences. Sir James Douglass, at the same meeting, also gave a remarkable instance of coarse sand having been found on the external gallery of the Bishop Rock Lighthouse off Scilly, after a gale, at a height of 120 feet, the depth of water in the vicinity of the rock being 25 fathoms, thereby showing that the sea-bed had been disturbed at that depth, this being the only source from which the sand could have been obtained." It seems to me that these observations have some relevance to the point raised by Mr. Lamplugh, and might explain how the submarine movement took place at Holderness. It might be accounted for by what Dr. Owens has called the interaction of waves and currents. The action of the waves might bring about such an upward swirl in the manner described by Dr. Vaughan Cornish, as to put heavy matter like boulders into such a position as to be dealt with by currents.

The PRESIDENT: I am afraid I must bring a most interesting discussion to an end by calling on Dr. Owens to reply.

Dr. OWENS: With reference to Dr. Strahan's and another gentleman's remarks, I want to make one point quite clear. I did not intend my paper to convey the impression that movement could not take place in deep water. I am aware that movement does take place, due, in my opinion, to the interaction of waves and currents, but the paper referred entirely to currents, and did not take into consideration the effect of waves. I think the second speaker who suggested the conclusion should be modified misunderstood me, because I did not come to the conclusion that movement did not take place, but rather that currents alone, in the absence of waves, had little effect. And I also wish to say that in my mind I limited wave-action to the continental shelf. I think outside that there is no question about the waves not touching bottom, and therefore outside the continental shelf, in deep water, I am of the opinion that the conclusion applies. Dr. Cornish's remarks have been extremely interesting, and I am very glad to see he has confirmed my observations as to the sand-movement. I may say that I have observed the peculiar sand-waves which he referred to, and, roughly speaking—I did not get an accurate measurement—I thought their formation began at about 3 feet per second. The small ordinary ripples were swept away, and suddenly a large wave, of about 3 feet from crest to crest and about 2 inches high, was suddenly formed; and it travelled up against the stream, as distinct from the small ripples, by the transference of sand from the front of one to the back of the other. With reference to the interaction of waves and currents, it appears to me that Dr. Cornish gives a clue to a great many difficulties—that is, that when the waves are rolling over a current you cannot expect that current to be flowing in stream-like motion, consequently we have a state of eddying suspension earlier than if there were no waves. I think the movement of material at Holderness and elsewhere must be looked at entirely from the point of view of the interaction of both waves and

currents. With reference to the suggestions which Dr. Cornish made as to further experiments, I am aware that there are many points which require to be settled. The rate of settlement in water I have worked out theoretically, that is, I found the current which, by an upward velocity, was required to suspend the particles, or the impact of which was equal to the weight of the particles in water. The results compare favourably with any observations I have been able to find. Then again, as to systematic observations in deep water, that I have not done; I have not all the necessary appliances. It is very difficult to *see* what takes place, and difficult to *measure* the current on the bottom in deep water; consequently, it is altogether a more difficult thing to do than the shallow-water observations. A point was referred to which I think I should make clear, that is the slope of the bottom. Now, I did not actually level the bottom, but I feel satisfied that the bottom was in all places, except perhaps one, practically level; also the inference which was drawn from the flow of water I think is incorrect—that is, that the water would not flow unless the bottom was on a slope. The flow of the water depends upon the surface slope of the water itself, and not upon the bed over which it is flowing. Captain Creak mentioned limiting the depth of wave-action to 7 fathoms. It is *very* difficult to say where wave-action ceases. I am disposed to think myself it is somewhere near the edge of the continental shelf, but where I do not know. It is very suspicious to see the continental shelf all strewn with *débris* from the land, and I should not wonder if wave-action takes place at 100 fathoms, and the edge of the shelf was its seaward limit.

The PRESIDENT: I am sure we shall pass a hearty vote of thanks to Dr. Owens for his paper, which has given rise to so interesting a discussion.

A NEW DISTANCE FINDER.*

By E. A. REEVES.

IN geographical and other survey work it is often of great importance to be able to obtain distances rapidly without actual measurement upon the ground, and without having first to set off a known distance as a base, which is necessary with many telemeters and rangefinders. The existing instruments for this purpose depending upon the angle subtended by a short rod, are either too liable to be put out of adjustment for rough exploring work owing to derangement of prisms and change of temperature, or necessitate the sending of an assistant with a rod to the point of which the distance is required. The Bar Subtense instrument, as used by the Survey of India, is of the latter class, and is excellent in its way, but the sending of a man with a rod is often most inconvenient, and naturally *limits its use to accessible positions*. What is wanted is an instrument of this character, strong and simple in construction, not liable to inaccuracies through the derangement of adjustments, and without the necessity of a separate rod, so that distances of inaccessible as well as accessible points can be quickly measured with sufficient accuracy for practical purposes; and I have designed the "Distance Finder" here shown to meet these requirements.

As will be seen from the figure, this instrument consists of a light rod of a certain fixed length, made so that it can be revolved vertically and horizontally upon a tripod, and carrying two telescopes, one at each end of the rod, and connected by a band of "invar." These telescopes can be revolved independently, each

* Research Department, February 21, 1908.