Mr. Wheeler. the dredging.] One of the Royal Engineers sent out to investigate, gave the accumulation as being very rapid after the walls were first made, stating that the material travelled through the walls owing to the blocks being laid loosely, but that since the shore had grown up, this had to a certain extent stopped the drift. The matter there, however, was not sand or shingle, but alluvial matter out of the Nile, carried in suspension, not rolled along the bottom, and it could hardly be taken as an instance of tidal drift. While not agreeing with the Paper, Mr. Shelford had brought forward an instance that helped the Author, viz., that of Spurn Point. The shingle went across the Humber, and became detrimental to the navigation; groynes were put in, and they stopped the travel of the shingle. That, therefore, established the fact that the shingle was under control, and that, if proper works were erected, the travel could be stopped.

Correspondence.

Mr. Allen. Mr. G. T. ALLEN considered it was difficult to agree entirely with the views that the operations of nature were now so small that their results were comparatively negligible, and that the effects of former action only had to be dealt with. From his experience in the Island of Sheppey, there had been an enormous amount of material abraded from the cliffs at Warden. In comparing an old chart of the island, of about 1574, with the latest ordnance map of the district, he found there had been an abrasion of about 1,400 yards in width, amounting to a loss of 380,000,000 cubic yards in about 320 years, or considerably over 1,000,000 cubic yards every year. The annual width of the erosion, from the above figures, was over 13 feet, which was about double the rate given in the Paper for the erosion of the coast between Bridlington and the Humber; and this, coupled with the height at Warden, above 100 feet, made the actual rate of erosion five times as great. The material of which the cliffs were composed was clay, which, with the continual washing, was reduced to mud, sand, and shingle, the latter containing innumerable fossils, which denoted that the climate at one time was of a tropical nature.

Mr. Caland. Mr. P. CALAND agreed with the Author that the drift along sea-coasts was not generally derived from the bottom of the sea, but from the erosion of cliffs and strands in high tides and storms, the larger pieces being slowly reduced by the sea and ultimately ground into sand. On the Dutch shores of the North Sea, only sea sand was found, which was easily distinguished from river sand, both by the size of the grains and by its colour. He was quite in accord with the Author, that the travel of the drift was always in the direction of the flood-tide, which he thought arose from the fact that the flood-tide was stronger than the ebb; but he did not believe that the regular and continuous travel of the drift was to be ascribed to wave-motion during the flood, and still less did he believe that it travelled only between high and low water. On the Dutch coast, the motion of the drift was observed, not only between high and low water, but also in depths of 16 feet and more below ordinary low water, as, for example, between the old mouth of the Maas and the new approach channel to Rotterdam; and since the waves could only affect the bottom at these depths during very strong winds, it appeared to him that the movement of the drift along the coast was really to be attributed to the tidal current, the flood-tide carried the drift forwards, and the ebb, being weaker, was unable to move it back again, so that it advanced with each succeeding tide, provided no other cause existed to prevent it. The waves on low coasts had, he considered, no other influence than that they (as the Author also observed, p. 19), with strong off-shore winds, denuded, and, with on-shore winds, accumulated the beach. Mr. Caland.

Mr. A. E. Carey considered the propositions laid down by the Author were certainly not of universal application, and the problem of littoral drift appeared to him more complex than the Paper indicated. The late Sir John Coode, going down in a diving dress, had seen the shingle of the Chesil Bank moving at a depth of 8 fathoms.[1] The phenomena of shifting sandbanks beyond the limit of low water in many estuaries, indicated irregular movements of sand under the action of wind-waves and a consequent deep-water scour along sea-bottoms. How did the Author's theory of tidal action being the proximate cause of littoral drift square with the movements of shingle and sand on coasts where the tidal range was insignificant in extent? A notable instance of a foreshore in which vast movements of sand in suspension extended below low water, was that of the north-east knuckle of the Brazilian coast, immediately south of the line, where a belt of sand-bearing water, several miles in breadth, existed. On reef-sheltered foreshores, the waves not unfrequently could only strike normally to the coast-line, and their action was Mr. Carey.

[1] "Design and Construction of Harbours," T. Stevenson, pp. 19 and 20.

Mr. Carey. concentrated on a given locality. In such cases, the slope of the sea-bottom at that point was steep; and banks of shingle and sand accumulated on either hand, which the tidal action, being neutralized by the run of the waves, was powerless to disturb. The contour of the coast-line, the extent of the tidal range, the proximity of deep water, and the presence of coral or rock reefs near the shore, were conditions modifying the problem of the design of sea-works such as the Author had dealt with. In waters like those of the Persian Gulf, the presence of vast quantities of blown sand was the factor dominating the situation; and each locality had to be studied on its own individuality. Probably in the great majority of instances, solid works commencing at a depth of 3 or 4 fathoms, and channels dredged to that depth, would remain unmolested by drift. Reference was made in the Paper to Newhaven. No shingle had passed the breakwater from the west; but some sand had been deposited within its shelter, which had probably been brought in by easterly gales from the low-lying east foreshore. At Dunkirk attempts to outstrip the accumulations of sand had gone on unsuccessfully for 250 years. Dredging, however, had been vigorously carried on for the last fifteen years, and had produced a channel of a minimum depth of 3 metres. For the last three years the amounts dredged were :—

—	Channel.	Bar.	Foreshore.	Total.
	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.
1893 . . .	61·500	194·575	231·060	487·135
1894 . . .	66·735	47·895	325·730	440·360
1895 . . .	81·520	87·500	285·000	454·020
	209·755	329·970	841·790	1,381·515

The width between the entrance-piers was about 200 feet, but this was now being widened to 135 metres. If the dredging were stopped, the harbour-mouth would infallibly silt up again, owing to the conformation of the coast-line; whilst the nature of the travelling sand and the widening of the entrance would tend to facilitate such action. The extremely fine sand on the Dutch, and portions of the Danish coasts, was very unstable, and when once in suspension was easily transported by feeble currents. Sharp irregular grit, on the contrary, lay closely compacted, and could with difficulty be brought into, or kept in suspension.

In a recent Paper by Professor John Milne, F.R.S., on "Movements of the Earth's Crust,"[1] he demonstrated that variations in

[1] The Geographical Journal, vol. vii. No. 3, March, 1896.

barometrical pressure and in the degrees of evaporation at different points of observation, resulted in earth-movements capable of record. How much more powerful in effect must be the bombardment of a steep sea-slope by the blows of heavy waves, accompanied by rapid changes in atmospheric conditions? In dealing with the motions of the earth's crust in relation to sea-level, Professor Milne gave the close of the palæozoic era and the early tertiary times as the periods of mountain growths and consequent ocean shrinkage, these changes having been synchronous with the formation of coal deposits. On certain portions of the Japanese shores, Professor Milne considered the upheaval of the coast-line and the recession of the sea, now in progress, to be exceedingly rapid; and he gave reasons for considering that a change of level at one spot of 10 feet had been brought about within fifty years; and recent variations over large areas, he thought, amounted to possibly 1 inch per year. In relation to littoral drift, these movements, whether progressive or occasional, were not to be disregarded. Mr. Carey.

Mr. W. DYCE CAY considered the causes of the formation of the alluvial deposits in the sea, as distinguished from the diluvial or boulder clay and stratified beds, were still in operation, that the vast extent of these deposits was due to the accumulated effects of these causes during long ages, and that it was not necessary to refer their production to some cataclysmal epoch. The long continuance of the same causes, and the unchanging nature of the natural phenomena produced a state of equilibrium in their effects on the sea-bed and coasts, and a regime which could be trained, but not safely disturbed without providing an equipoise. Mr. Dyce Cay.

For several years, when he had charge of Aberdeen Harbour, up to 1880, he had dredged 60,000 cubic yards annually of sand and silt brought down by the River Dee, having a basin of only 784 square miles, and deposited by it in the depths of the harbour artificially produced and maintained for navigation. Had it not been for these depths, this detritus would have passed out, and have been deposited on the sea-bed; whereas the dredging plant raised and deposited it well to seaward of the harbour. These figures would amount to 6 million cubic yards per century, or 600 million per 100 centuries, equivalent to a bank 60 feet high, over 7 square miles in area, and equal to a reduction of the level of the catchment surface by about 9 inches. The beach at Westward Ho was similar to the Chesil beach; and its origin and continued formation could easily be traced to the cliffs and rocky shore to the westward; and it was evident that a part of it had been recently rolled bodily landward, ruins of buildings

Mr. Dyce Cay. formerly within it now being left outside it on the foreshore. He attributed these beaches to the land under and behind them being about high-water level, for with a high coast, the shingle would have remained in front till it had been worn to sand by the waves, instead of being thrown over the bank by the sea, and finding shelter on the top and behind. Thus, at the Bay of Nigg, about $\frac{3}{4}$ mile south of Aberdeen Harbour, the granite rocks and boulders were worn down to shingle and sand by the waves; and though he removed the deposit almost entirely in successive years for making concrete for the harbour works, the sea always produced a fresh supply.

The tidal wave along the east coast of Scotland, from Aberdeen to Berwick, passed south during the flood-tide at 70 miles an hour, and so might be taken as 400 miles long from crest to hollow, but it had no similarity to a surface wave. He had often noticed the small wavelets as the tide advanced on a nearly level and dry foreshore, and in particular once in a large culvert at Aberdeen. On that occasion, the fresh water was passing down the culvert at about 4 miles per hour, and he noticed pieces of material, able to float in salt water but sinking in fresh, travelling up-stream with the inflowing tidal water at the bottom by successive impulses. These pulsations he attributed to the rising of the tide through confined and irregular channels, and against the action of surface currents.

Prof. Dawkins. Professor Boyd Dawkins remarked that his enquiry into the origin of the sand and silt in the estuary of the Mersey, undertaken for the Manchester Ship Canal, confirmed the truth of the Author's conclusion, that the deposits in an estuary were not built up of materials swept in from the sea. He had examined the minute composition of the sandbanks in the Mersey, from Stockport inland down to the mouth of the estuary, with the following results. 1. The sand was derived from the angular and subangular glacial sand, forming the surface of the ground in the higher reaches, and differing microscopically from sand battered by the sea. The glacial sand had been washed out of the boulder clay. 2. The sand grains, almost entirely composed of quartz, became more and more rounded by friction in their journey down the stream. 3. In the estuary, and even as low down as the Great Burbo Bank, almost on the sea-front, these were present as more angular elements than the sea sand. 4. They were ultimately delivered into the sea, and contributed to form the ordinary sandbanks of Rhyl, Southport, and Blackpool, in which the rounded grains were more numerous. The silt also in the estuary of the

Mersey had been derived from up-stream, and not from the sea. Prof. Dawkins. The questions raised by the Author relating to groynes were very important. If the shingle, or sand, was intercepted in its drift along the shore by a large groyne, or a pier running into deep water, it was either arrested, or diverted into deep water, in which case it was lost to the shore. Instances of this were to be seen to the east of Brighton, Folkestone, and Dover, where the shore, bared of its shingle and sand, was exposed to the destructive effect of the waves. In his opinion, it was advisable to interfere as little as possible with the natural drift of the littoral deposits. From the experience of Mr. Henry Willett of Brighton, and of the late Mr. H. D. Pochin, it was clear that it was possible, by the use of small movable groynes, to encourage the accumulation of sand and shingle in certain spots, without interfering with the general regime, but they should not project more than about 2 feet above the surface. The disastrous effect of removing shingle from a shore-line was manifested by the rapidity with which the north-western coast of the Isle of Man was disappearing.

Mr. A. F. Fowler did not think the Author's description of the Mr. Fowler. relative transporting power of the flood- and ebb-tides on the Yorkshire coast north of the Humber was accurate; and the alleged movement for a greater distance northwards, against the flood-tide, was not consistent with the statement that "continuous progressive movement is invariably in the direction of the flood-tide." The cliffs were eroded during the first half of the ebb equally with the last half of the flood-tide, and there would be portions of eroded cliff on the beach, to be acted upon by the first of the flood-tide. Moreover percolation through the face of the cliff on the fall of the tide would result in disintegration and falls of material near low water.

After long consideration of the origin of the mud in the Humber, he had come to the conclusion that this silt, known as "warp," was the result of long-continued storm action on the Holderness coast and the north shore of the Humber. The wasted material, in an extremely fine state, was carried by the flood-tide up the Ouse and the Trent, where, being beyond the reach of storm action, it had been gradually deposited, forming the immense estuarine bed between the Ouse and the Trent, extending westward to Selby and southward to Gainsborough. Experiments made by Dr. Parsons of Goole, showed that the warp reached its maximum at Swinefleet, a little below Goole, and was most abundant in dry weather and at spring tides, and least in amount during floods at neap tide and during low water. Samples taken by him of the

Mr. Fowler. Ouse during high floods at York proved that the water was remarkably clear, the suspended matter not exceeding twelve grains per gallon; and, therefore, the mud did not come from above York. During the winter months the Ouse was deep below Naburn weir, the limit of the tidal flow, six miles below York; and the water was clear during both flood and ebb. During a dry summer, silt was deposited in such quantities as to raise the channel 5 feet above its winter depth. This accumulation generally commenced in May, augmenting slowly till the end of July, after which the rate of accretion was much quicker, the river attaining its worst condition about September. The winter rains effected an improvement which went on till April. During a wet summer, the summit of the deposit would be below Wharfe Mouth, 5 miles below Naburn; and in dry summers, the accumulation attained its greatest height about ½ mile below Naburn lock. In the dry summer of 1887, 317,000 cubic yards of material were deposited between Wharfe Mouth and Naburn lock; and during a still drier year, the deposit was so great as to require the floods of several winters to remove it. Between September and April, this bank of silt was washed down to Howden Dyke, 26 miles below Naburn; so that generally the navigation to York was obstructed during the summer by the shoals immediately below Naburn, whereas, in the winter, the chief obstacle was encountered by outward-bound vessels between Howden and Goole. Samples taken by him of the water in the river opposite Goole Docks,

SOLID MATTER HELD IN SUSPENSION IN SAMPLES OF OUSE WATER TAKEN AT GOOLE IN 1885.

Date.	State of Tides.	Low Water.	Half Flood.	High Water.	Half Ebb.
		Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
February 13[1]	Medium	12	4	8	4
,, 18	Spring	48	120	144	64
,, 23	Medium	48	120	88	64
,, 26	Neap	16	16	16	12
May 5	Spring	120	360	128	124

indicated that during the winter the water of both flood and ebb was as clear as in most other rivers. He estimated the quantity carried by spring tides in August and September at from 500 to 600 grains per gallon. In summer, at high water of spring tides, the water at Goole was perceptibly salt.

The clearness of the incoming water at the mouth of the

[1] On the 13th of February there were 2 feet of fresh in the river.

Humber, referred to by the Author, only applied to the summer; for, during winter storms, the flood-tide below Hull was always turbid. The winter condition of the Humber and Ouse was muddiness at the lower end and clearness at the upper limit of the tidal flow. The muddy zone was in constant oscillation; and the river was clear in summer from Spurn Point to Whitton Sands, and in winter from Naburn lock down to Swinefleet, 2 miles below Goole. The muddiness of the water might be attributed in consequence, to the erosion of the Yorkshire coast; the gradual deposition of this wasted matter on the low-lying portions of the Ouse and Trent valleys; reclamation of these accreted lands from time to time without efficient means being taken to protect them; and, lastly, the re-encroachment of the tides, notably on the south side of the Humber above New Holland, coupled with the extreme friableness of the material comprising the bed of the Humber. Wave-action moved both the sand and boulders, of which littoral drift was composed; but while the latter frequently remained where thrown up by one wave until carried higher by the next, the sand was invariably taken back by the under-tow and removed in whatever direction the current might be travelling. A separating action was thus established, which, owing to its long continuance, resulted in the accumulation of isolated boulders, sorted out from immense beds of sand, thrown up towards high-water mark on the coast exposed to the dominant wind, and propelled along the shore by oblique wave-action. Mr. Fowler.

Mr. L. Franzius was of opinion that the movements of the drift along the sea-coast were governed by the action of the waves generated by the wind, and also by the action of the littoral current. The movement of the drift caused by the waves alone might be resolved into two parts, of which one coincided with the direction of the lines of soundings, and the other was normal to this direction. The first component, to which the littoral current had to be added, or else to be deducted if in an opposite direction, produced the continued travel of the sand and shingle along the coast. The second component formed the force which either threw the drift up on the shore, or drew it down into greater depths. With reference to the depth to which the action of waves extended, he was disposed to agree with the opinion expressed by Cialdi and Cornaglia in their books, that the influence of the waves was noticeable in great depths, even down to 650 feet in the open ocean. The examples brought forward by the Author, where sand and shingle were not found at the extremities of moles and the entrances of harbours, could in his opinion be more easily explained Mr. Franzius.

Mr. Franzius. by assuming the movement of drift in great depths, rather than by the complete cessation of the travel of drift when a certain depth was exceeded. He entirely agreed with the Author that experience indicated that moles should always be carried out into an ample depth. He could only advocate the employment of dredging alone for deepening the navigable channel in estuaries, without the help of training works, in cases in which the circumstances were specially favourable. If the formation of a bar at the mouth of a river was due to the splitting up of the channel, it appeared to him more expedient to remove the cause of the formation of the bar by training the channel by spur dykes or longitudinal training-walls, and by the employment of dredging to accelerate the improvement, than to form and maintain a channel across the bar by dredging alone. In every case, considerations of cost must determine the course to be pursued. If the cost of the necessary dredging did not amount to the interest on the capital required for training works, it would be advisable to adopt the more temporary method of improvement.

Mr. Fuller. Mr. GEORGE L. FULLER said that about 2 miles eastward from the Castle Rock at Criccieth, a smaller point jutted out called "Graig Ddu," beyond which the shore surface consisted entirely of sand; though between it and Criccieth, there was a continuous shingle shore intermixed with boulders, the shingle on which appeared simply to travel to and fro. The Esplanade sea-wall, completed in 1884, started from the side of a headland, about 600 feet eastward of the Castle Rock, and about 1,500 feet north of its south point. The wall was 930 feet long, and terminated at its east end, where the beach was lowest, with a concrete return slope, 100 feet long, extending above the highest high-water mark, having a large culvert formed in it, with an outlet in the face of the wall, to provide for floods, and a small stream discharging at that end. The sea-wall reached 10½ feet above ordinary high-water level, and averaged 16 feet in height from the foundations (exclusive of a low parapet afterwards added), 10 feet thick at its base at the east end where the shore was lowest, and 4½ feet thick throughout at the top. The wall was built in sections, of concrete intermixed with boulders, and faced with sharp sand concrete, which, being worn by the action of the sea, was replaced by a stone face up to 4 feet from the top. The foundations were sunk to a minimum depth of 3 feet into the solid substratum of blue clay; and pipe-drains were built through the wall at frequent intervals, at the level of the top of this clay. Since the erection of this wall, a much greater proportion of sand had been deposited on the beach in front of it than previously; though beyond the east return wall, shingle still predominated. A gradual flattening of the clay substratum of the beach had taken place all along in front of the wall, until at its deepest, or east end, the surface had reached a stable inclination of about 1 in 30 from low-water upwards, very similar to that of the same stratum about $\frac{1}{4}$ mile westward of the west end of the Marine Terrace retaining wall, on the west side of the Castle Rock, and nearly $\frac{1}{2}$ mile west of the wall on the east. Even before the Esplanade (behind this last) was finished, one of the storms which occasionally sweep away all loose shingle or sand from its front (to be gradually returned in calmer weather), exposed this under-stratum which exhibited signs of wear. He, therefore, added a false concrete beach under the drainage holes in 1885, 9 feet wide and $1\frac{3}{4}$ foot deep at the face of the wall, laid with a level bottom and tapering down to about 9 inches thick at the toe. During recent years, this false beach had been broken up in places, especially at the east end, by winter storms, and needed repair to secure the foundation of the wall from being undermined by the waves during a severe gale. Mr. Fuller.

Mr. C. F. Gower remarked that the Author was apparently of opinion that matter in suspension was not carried upwards any great distance by the flood-tide in a tidal river. Observations, however, with floats, and in other ways, showed that in the River Thames and in other rivers, matter in suspension might be carried upwards for several miles, the distance varying according to the amount of upland water coming down, and also with the direction and force of the wind. Where the amount of upland water was insignificant, as was the case for the greater part of the year in the River Orwell, the horizontal range of the tide on the flood and ebb was about equal, and floating or suspended matters near the surface were carried upwards as far on the flood as downwards on the ebb-tide. When, however, the wind blew strong from the south or south-east, the lighter matter, such as was discharged from the sewers, was carried a comparatively short distance downwards, and returned on the flood-tide much higher up, nor did the succeeding ebb carry it away. With the wind from the north, or north-west, the ebb-tide had the advantage, and the upper part of the river was kept clear from suspended matter. There was no proof that matter in suspension was carried any greater distance downwards on the ebb than upwards on the flood-tide; it merely oscillated backwards and forwards, in the absence of any preponderating force, from upland water, or of wind-waves; and it Mr. Gower.

Mr. Gower. drifted at last to shore, or was deposited in still water, till a change of tide or some other force again set it in motion.

Mr. Haupt. Mr. LEWIS M. HAUPT thought the scope of the observations and deductions in the Paper was comparatively limited, being restricted to the British Isles and the east coast of the channels as far as Ymuiden, with incidental reference to New York, Madras, and Colombo as to the effect of groynes. The premises did not appear to be sufficiently general, and might, in some cases, lead to erroneous conclusions. For instance, the first proposition as to the cessation of the causes creating deposits should be accepted with limitations. The second, as to the source of material, should be modified, certainly as applied to the extensive cordon of sand flanking the Atlantic coast of the United States, from New York Bay southward, for there were no cliffs to supply the material by their erosion; while the greatest banks, as at Newfoundland, Nantucket, and Hatteras, were at the salient points of the coast, from which the tidal currents set towards the bights of the bays, tending to remove rather than to supply material from these immense deposits. On the North Jersey coast, from Elberon to Long Branch, a clay and gravel bank, about 30 feet in height, had supplied material for the maintenance of Sandy Hook, and the bar obstructing the New York entrance. Such cliffs did supply material, but they were not the only source. The fifth proposition did not conform to his observations, nor would it seem from the context of the Paper to justify the conclusion that the "movement of sand and shingle is limited to the zone lying between high- and low-water mark." Indeed the Author cited a number of instances where breakwaters must extend to a depth of 2½ fathoms before the littoral movement of material could be arrested. The experiments made by placing boxes at various depths under water, as referred to in his Paper on "Harbour Studies,"[1] would seem to demonstrate the active agency of the waves in transporting material at depths considerably below the surface. This proposition was apparently contradicted by the eighth, where the piers were required "to be carried into a sufficient depth of water, and the littoral drift cut off by protective works." The statement in this latter proposition was only true in a limited sense; and serious damages had been incurred by the obstruction to silt-bearing currents in roadsteads, as most strikingly illustrated by the Delaware Breakwater. In his opinion, the silting up of estuaries was due to material brought in from the sea, as well as to that

[1] Library Inst. C.E., Tract 8vo., vol. 410.

carried down by floods from the uplands. He would refer to the changes in tidal rivers, and at Cape Henlopen, Delaware, and Sandy Hook, New York, and especially to the flexure of the mouths of rivers for many miles parallel with the coast, and often in opposition to the ebb movements, caused solely by the currents operating upon them for long periods. Types were furnished by Broadkill Creek, Del. (which debouched about 8 miles north of its natural outlet), and the rivers of the Carolinas, Cape Fear, Great Pee Dee, and others. The harbour of New York was unique in the existence of a resultant force which might have been utilized for the creation of a deep channel over the bar. The peculiar slough, nearly 1 mile long and $\frac{1}{4}$ mile wide, lying along the crest of the bar, athwart the currents, and at the western end of the channel, which had been maintained by the eddy formed by the currents, with depths of 54 feet, was an instance of phenomenal results produced by natural forces which only needed to be utilized to have given an ample passage over the bar.[1] Much of the testimony concerning littoral drift, and the dynamic action of the flood-tide, had been collected by such men as wreckers, light-keepers, and surfmen, whose observations of facts he believed to be reliable. These forced him to the conclusion reached by the Author, that such movements did exist in a direction opposed to prevailing winds, and that the motor was the angular movement of the waves and "breakers," especially during flood-tide. Hence it followed that the resultant direction of movement being known, the proper form and dimensions of breakwaters might be planned to arrest the silt and defend the channel. He might refer to a recent Paper [2] on the unprecedented results already obtained at Aransas Pass, Texas, by the partially completed breakwater he had designed, and which, though only commenced last autumn, had already removed one-half of the bar, at a cost of about £25,000. Information about drift, in addition to that furnished by the Author, would be found in the publications quoted below.[3] Mr. Haupt.

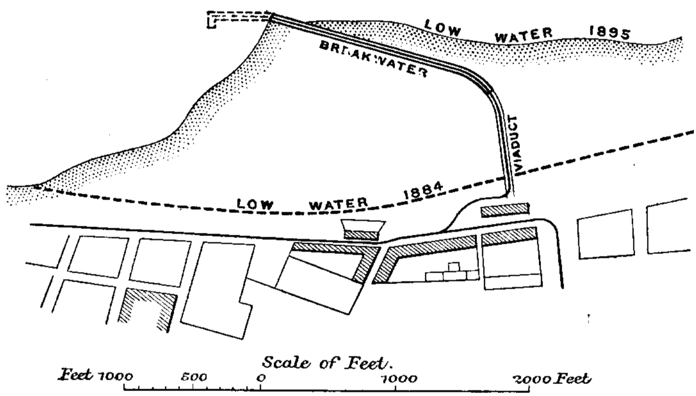
[1] Proceedings of the Engineers' Club of Philadelphia, vol. v. p. 300.

[2] "Commerce and Deep Waterways," The Journal of the Franklin Institute, vol. cxli., 1896, p. 81.

[3] "Harbour Studies," Philadelphia, 1886; "New York Entrance," February 6, 1886; "Delaware Breakwater," February 20, 1886; "The Physical Phenomena of Harbour Entrances," December 17, 1887 (Library Inst. C.E., Tract 8vo., vol. 410); Discussion on the "Dynamic Action of the Ocean in Building Bars," Am. Phil. Soc., March, 1889; "Littoral Movements of the New Jersey Coasts, Beach Protection, and Jetty Reaction," Am. Soc. C.E., September, 1890; "Harbour Bar Improvements," July, 1889; "Jetties for Estuaries," April, 1888; "Improvement of Tidal Rivers," October, 1889; "Law of Deposit of the Flood," Smithsonian Contributions to Knowledge, vol. iii., December, 1851; and sub-references in the above Papers.

Mr. Houston. Mr. J. L. Houston observed that probably the most remarkable instance of littoral drift in the world was on the north coast of Brazil, from Cape San Roque to the mouth of the Amazon. The main South Atlantic current split near the Cape; and the northerly portion, forming the north equatorial current, carried enormous quantities of sand along the coast. The phenomena of this sand-stream were in great measure directly opposed to the propositions the Author sought to establish, except perhaps a modified form of No. 6. (1) Vast deposits of sand were accumulating year by year, the whole coast advancing, and sandhills of considerable height being formed. (2) The sand did not apparently come through the erosion of cliffs or foreshores, but appeared to originate from the

Fig. 9.



CEARA HARBOUR, BRAZIL

bed of the sea. (3) The quantity conveyed by the silt-bearing current was practically limitless, nor could its movement be controlled by practical measures. (4) Its movement was not directed by tidal action, but by the somewhat intermittent action of the trade winds and induced sea, together with the equatorial current. (5) This sand-travel, so far from being confined to the space between high and low water, extended frequently to a belt of several miles seaward, and a considerable distance inland where the drift sand was driven onwards by the wind. (6) The Author's proposition held good in this case, but only to a modified extent, the depth of water must be considerable, and the bottom even then not liable from its contours to assist the formation of banks. (7) Artificial channels through banks, subject to the action of a current of this kind, could not be cut, and still less maintained. (8) Solid piers projected from the shore across a current of this character would certainly result in irretrievable silting. About ten years ago the construction of a harbour was commenced at the port of Cearà, where the phenomena referred to were probably at their worst. The works, designed by the late Sir John Hawkshaw, started from the shore by an open iron viaduct, about 750 feet long, the sheltered harbour area being provided by a solid breakwater, *Fig. 9*. As soon as the solid work had been commenced, silting resulted; and, notwithstanding every device and precaution, steadily followed the construction of the wall, until what should have been harbour space was simply so much dry land. Mr. Houston.

Mr. EDWARD JACKSON thought one of the first considerations "affecting works carried out on the coasts for the benefit of navigation" was littoral drift, and the cause and direction of its movement along-shore: with regard to this, and the zone in which it moved, he was unable to accept the fourth and fifth propositions as giving a complete solution. His experience led him to conclude that the combined action of the wind and waves, and the current set up thereby, were the transporting agents, aided sometimes by the stronger tidal current; and the travel took place, certainly in the case of sand and silt, not only within the zone lying between low and high water, but wherever the action of the waves exerted their influence in disturbing the sea-bed. At Hartlepool, for instance, in constructing the breakwater in a depth of 12 feet at low water, sea-face blocks had to be carried down to the rock, through several feet of boulders and silt filling up a large cavity in the sea-bed. The clearing out of the beds for the blocks could be successfully carried on by divers in calm weather; but when a sea sprang up, and the work was stopped for any time, on resuming operations it was always found that the cavity had completely filled up again with sand and silt to the level of the sea-bed, showing the influence of wave-action. If the small waves, seen in calm weather, described as being given off from the main tidal wave, propelled the drift in the direction of the flood-tide during its flow, when the ebb set in a reaction would take place. Then unless these small waves were generated, as he believed, by the ground swell or rollers which incessantly kept the sea in motion to a greater or lesser extent, and moved in the direction of the prevalent wind, they would break in the opposite direction, on the ebb. The only progressive movement of the drift would be the difference of the propelling force of the flood-tide over the ebb or *vice versâ*. It was Mr. Jackson.

Mr. Jackson. stated, however, that both during flood- and ebb-tide, these small waves broke in the direction of the flood-tide. This indicated that they originated, not from the tidal wave, but from the ceaseless motion of the sea, and the movement of drift, therefore, must be traced to wind-waves. In a tideless sea, this theory of the small waves being given off from the main tidal wave would be untenable. At Madras, during the north-east monsoon, the movement of sand was from north to south, in the direction of the wind at that season of the year, and in opposition to the flood-tide. But during the south-west monsoon, it moved from south to north again in the direction of the wind at that season. Although, in the latter case, the flood-tide was in the same direction, and the movement was therefore much stronger, it was evidently not the flood-tide which was the primary cause of the littoral drift in the Bay of Bengal, but the wind and waves.

The term "prevailing wind" was somewhat ambiguous; and in tropical latitudes, the "set winds" or "constant winds" would better indicate the direction from which the drift would move. On the north coast of Brazil, where the shores were one continuous stretch of sand for miles, backed up with sandhills of varied height, the sand was all travelling westward. In proximity to the harbour of Cearà, close observations of these sand movements showed, that there was a travel of the sand in the direction of the wind and seas, which were practically continuous from the easterly quarters, with the tides and current setting in the same direction. The littoral drift on encountering the opposition presented to its normal movement by the breakwater sheltering Cearà Harbour, *Fig. 9*, p. 68, though minimised by 750 feet of open viaduct, had caused serious shoals in the harbour, necessitating dredging operations and further remedial measures. For the construction of a breakwater on a sandy shore, or where there was considerable littoral drift, it was all-important for the success of the work, that the design should admit of rapid construction, with abundance of materials and labour at hand to enable the breakwater to be pushed forward into a sufficient depth of water to keep the littoral drift in check.

Mr. Mann. Mr. I. J. MANN suggested that it was extremely difficult to generalise in the matters dealt with by the Author, as it was almost impossible to find two harbours identical in all their surrounding conditions. The causes which produced accumulations of sand and shingle on various parts of the coast had been in operation for a very long period. They were still acting, and it was with their present effects that the engineer had to deal. When littoral drift existed in such enormous quantities, that, on a short length of coast, millions of cubic yards of sand and shingle were shifted in a single gale, it would be safer to consider the supply as practically unlimited. He had never seen any wave-action of the flood-tide, which could be traced to the rising of the tide. The wavelets or ripples referred to in the Paper as occurring in calm weather, were not peculiar to the flood-tide, but were equally observable with a falling tide, and appeared to be due to the disturbing effects of distant wind-waves. He could not agree with the Author, that the continuous movement of littoral drift was almost invariably in the direction of the flood-tide, an excellent example to the contrary being furnished by Howth Harbour, referred to in the Paper. This harbour was built by Government for the accommodation of the cross-channel service; its entrance faced north, and the harbour had been so completely filled up by the action of the southerly ebb-tide on the littoral drift, that it was now practically useless. With reference to the eighth proposition, it had hitherto been rightly considered that solid structures built across sandy shores—whether extending into deep water or not—acted like groynes and arrested littoral drift. That the movement of littoral drift was confined to the foreshore between high and low water was not in accordance with his experience, for he had found that the drifting movement took place below low-water mark, to depths to which the disturbing action of the waves extended. The Author's speculations as to the causes which produced littoral drift were interesting; but it seemed rather far-fetched to attribute one of these causes to the occurrence of tides at more frequent intervals in former times, a supposition involving many astronomical complications. Mr. Mann.

Mr. G. Mengin-Lecreulx thought the Author's opinion, that the great submarine banks were due to geological phenomena no longer in action, could not be correct; for the causes which had operated in the past were still in operation, though their action was doubtless slower than was often supposed. It was thus that the great deposits observed within the last fifty years in the upper parts of the Seine estuary, of over 400,000,000 cubic yards, had come straight, not from the Calvados coast, which could not nearly have furnished the amount, but from the submarine accumulation of the Seine bank, stretching in front of the mouth of the river. That bank, however, owing to its extent, had only to be eroded to a depth barely perceptible by soundings, to provide a considerable volume of accretion. By this means, in Mr. Mengin-Lecreulx.

Mr. Mengin-Lecreulx. certain situations, the materials brought in by the sea might lead to more difficulties than could be supposed from the statements in the Paper. The permanence of submarine banks could only be relative, since the causes which produced them were still in operation; but it was especially important to know at what depth below low water this permanence would be ensured, which observations indicated was very variable. At the head of gulfs or bays where the tides, waves, and silt-bearing currents converged and were concentrated, as in the Gulf of Gascony and the Bay of the Seine, the bottom was powerfully disturbed at depths reaching, and possibly exceeding, 33 feet. Hence came the accretion of the Seine estuary in all the parts withdrawn from the influence of the alternating tidal currents. The stability, therefore, referred to in the Paper was subject to restrictions. In the Seine, contrary to the views expressed by the Author, materials from the sea travelled up much farther than the saltness of the water, which practically ceased at Quillebeuf, and this might be due to the rush of the flood-tide.

The theory advanced in the Paper, as to the travel of the drift in the same direction as the tide, appeared to be confirmed by the facts with which he was best acquainted, with the reservation that it related to a general result, and that on any coast, the winds when blowing with force for some time in a certain direction might, as was often observed, for a time reverse the effect. Moreover, whatever might be the cause, experience would show at each place the direction of the littoral drift. The only objection to extending jetties into depths of 3 or 4 fathoms at low tide, to protect harbours from littoral drift, was its practical difficulty, amounting on some shores to almost an impossibility, especially with the necessity of rapid progress. The advice to make the entrance to a harbour large enough to prevent the flood-tide acquiring an increased velocity, followed by a reduction favouring deposit, was good in itself; but it was also necessary to obtain a sheltered area. This question, being governed by the local conditions of shelter, position, and tidal range, did not seem to admit of a general conclusion. The Author's opinion that, owing to the stability of submarine banks, channels deepened by dredging would be permanent, appeared to him to require many reservations. Natural channels generally maintained themselves, because they were the result of permanent causes; whereas artificial channels usually needed more or less maintenance. The most recent experience, however, proved that greater boldness might be exercised in this matter than was formerly supposed; and at the mouths of rivers, there was in addition the ebb and flow of the tide. Especially when, as in the case of the Seine, the river did not discharge much solid matter, there was a permanent and constant longitudinal scour opposing the variable cross-influences of winds, storms, and eddies tending to fill up and alter the channel. He was in accord with the Author in considering that it was possible, at any rate theoretically, to obtain a permanent channel through an estuary by dredging alone, without training walls, by making it regular, sufficiently wide and deep, and in a direction coinciding with the course of influx of the flood-tide, with the object of giving the permanent longitudinal scour a decisive preponderance. The channel in the Seine estuary was a depression, generally winding, of at most $6\frac{1}{2}$ to 10 feet below the banks which it traversed for over 9 miles. The directing action, due to this depression, was wholly inadequate, especially for the flood-tide, and the transverse forces held sway; whilst the materials of the bed, subjected to very strong currents, were in constant movement. According to the Author's views, which he shared on this point, the dredging of a regular and deep channel with sufficient rapidity, would not merely give the navigation a temporary relief, but the regime of the sands would be changed, the shiftings of the channel would cease, and the channel would be maintained at a moderate expense. With the distance, however, to be traversed, the initial formation of the channel would be a heavy task; but the distance was to be reduced by prolonging the training walls, and the improvement would be subsequently carried on in accordance with experience. On the whole, dredging carried out in a movable bottom, was often reproached with only producing temporary results; but the Author arrived at the conclusion that in many cases, on the contrary, the result would be practically permanent, with which he agreed. Nevertheless, even the accomplishment of this initial result would often require great efforts, and the technical problem would also involve a financial problem. Mr. Mengin-Lecreulx.

Mr. Léon Partiot believed the distance which the materials from the sea ascended a river depended upon the slope and fresh-water discharge of the river, in relation to the total volume of water filling the channel, of which the Seine afforded an interesting example. The mean level of the quays at Rouen and at Havre differed only by $4\frac{1}{3}$ inches, which proved that in early times the inclination of the river valley was very small between those points. On the other hand, the channel enlarged greatly below La Mailleraye, $42\frac{3}{4}$ miles above Havre, so that the river discharge had much less influence during the ebb below La Mailleraye than in Mr. Partiot.

Mr. Partiot. the narrower channel above; whilst the tides, which rose $23\frac{2}{3}$ feet at springs at Havre, had a much greater effect. Consequently, the sands from the sea had travelled up to La Mailleraye, where they formed a sort of weir which kept up the level of the Seine nearly $16\frac{1}{2}$ feet above low water of springs at Havre, and which had a gentle slope towards the sea. On this slope, constituting the estuary of the Seine, the main channel of the river was shifting and shallow; whereas above La Mailleraye, it had remained for the most part deep. At Rouen, there was an accumulation of coarse sand brought down from inland; whilst investigations below La Mailleraye showed that the valley was exclusively filled with sea-sand and silt, similar to the materials in the estuary; moreover, the tides deposited sea-shells at the sides of the Seine as far up as Villequier. This instance proved that the distance to which the sands from the sea ascended a river, depended on the highest point at which the flood-tide was stronger than the discharge of the river on the ebb.

Attention had been directed in France to the drift of shingle along the coasts since 1789, by Mr. Lamblardie's memoir [1] on the coasts of Normandy, which he traced to the waves throwing up the shingle and sand on the land in the direction at which they struck the shore. The waves in retreating, having lost their impelling force, flowed down the beach along the line of maximum slope, which generally was at an angle to their original direction. Consequently, the shingle and sand were carried along, at sea-level, to an extent depending on the angle the direction of the waves formed with the shore-line. The direction of travel might coincide with that of the littoral current, or of the flood-tide; but it mainly depended on the direction of the prevalent winds which blew towards the coast. The action of the waves due to the flood-tide was more regular, but these waves were small, and the littoral current had a low velocity, so that both the flood-tide and the littoral current had, in general, less influence than the prevalent winds, of which the coast of Gascony furnished an instance. The sands along that coast did not come from either the Garonne or the Dordogne, the deposits from which were readily recognized on the great bank seawards of Pointe de la Coubre, and could only come from the sea, which had a very flat slope along that coast. Although the flood-tide went from south to north along the shore, the sands travelled from north to south under the action of the prevalent north-westerly winds. Cape Ferret, formed by their advance, which had enclosed Arcachon Bay, had extended nearly 1 mile

[1] Library Inst. C.E., Tract 4to., vol. 22

further south since 1826. He was therefore led to the conclusion that the travel of shingle and sand depended distinctly on the prevalent winds blowing towards the shore, when they continued for an adequate period. Mr. Partiot.

The channels deepened by dredging at the mouths of the Hudson, the Mersey, and the Loire, and in front of Ostend, maintained their depth because they were carried out in the direction of the currents and facilitated discharge. But he considered it should not be concluded, from the success of these works, that continuous dredging should be resorted to for maintaining the access to rivers and ports, without the assurance that the necessary funds would never fail, and that other works would not produce the same improvement more economically. In the first event, there would be the danger of losing the improvements obtained, by the cessation of dredging, at the time when they might perhaps be the most useful, and of having to recommence the work when there might be still difficulty in providing the funds. In the second case, a yearly expenditure would have been undertaken, equivalent to the interest on a larger capital than would have sufficed for the execution of works which would have gained and maintained the requisite depths. The skill of engineers was often exhibited in discerning the requisite works, and in proving their value, so as to avoid burdening posterity indefinitely by works which would require costly maintenance, amounting almost to a perpetual reconstruction, such as certain dredgings in shifting beds.

General F. H. Rundall, R.E., agreed for the most part with the general propositions in the Paper, so far as his experience extended; but he was not sure whether the statement that the transportation of littoral drifts was due to the tidal current, was intended to attribute the movements to that force only, or whether the Author considered the terms tidal and littoral currents as synonymous. There was a littoral current quite independent of the tidal, which within a moderate distance of the shore possessed some transporting power. This was manifest in the Bay of Bengal, with whose coast-line he was the most familiar. In the lower portions of that bay, the tidal range and its consequent transporting power was very small. At Madras, the rise and fall did not ordinarily exceed 3 feet, while there was a considerable movement of sand and drift all along the coast. In the neighbourhood of the estuaries of the great rivers Coleroon, Kistna, Godavery, and Mahanuddy, the alluvium brought down during the flood season was carried out a long distance seawards beyond the influence of tidal action, and was transported by the littoral current for many miles in the direc- General Rundall.

General Rundall. tion in which that current flowed, and which varied at different seasons of the year. From the Kistna northwards, the prevailing direction of that current was shown by the embouchure of their several branches being turned in the same direction. In the lower portion of the bay, where the littoral current must be slight, the mouths of the rivers were deflected southwards, owing probably to the effect of the north-east monsoon. Point Calymere, south of the extremity of the Cauvery delta, and Point Godavery at the northern mouth of that river, were illustrative of the littoral currents in opposite directions on the same coast. At the Sandheads, the mouths of the Ganges and of the Bramaputra had all an easterly trend, while those of the Irrawaddy on the opposite coast trended towards the south-west. The discoloration of the sea, caused by the immense amount of alluvium held in suspension during the floods of those great rivers, extended a long way from the coast; and the littoral currents conveyed it north or south, causing in time a vast extension seawards of the coast-line. In the Godavery, the extension amounted to 2 miles to the eastward and 7 miles to the northward in thirty years. Consequently the Coringa lighthouse, originally built almost at the edge of the surf, was left 2 miles inland; while the soundings decreased so far out to sea that the light had to be raised 15 feet. That alluvial deposit was not, so far as he was aware, ever removed or carried in an opposite direction. In the thirty years which had since elapsed, Point Godavery had been extended several miles farther north; while the Bay of Coringa had become so shallow that the anchorage had been shifted to a corresponding distance, necessitating the construction of an entirely new lighthouse 12 miles farther north. The range of spring tides at that part of the coast did not exceed 6 feet. Owing to the enormous extent of alluvium covering the Sandheads, the tidal water running up the Hooghly carried a large quantity in suspension. The upper portion of the coast canal between Calcutta and Balasore, and thence on to False Point and the Orissa delta rivers, was fed entirely by the tides in the Hooghly. When first opened, the canal was filled by the flood-tide through the locks built at the several river-crossings, so that the canal became quickly choked with silt. To remedy this, a parallel supply-channel had been excavated, into which the flood-tide entered and deposited the greater portion of its silt; and the clear water was then let into the main canal. The stoppage of the navigation was thereby avoided, and the supply-channel could be readily cleared by manual labour. This action in the estuary of the Hooghly, where silt was carried in suspension every flood-tide, was an instance of the transportation of alluvial deposit from the sea covering an area of over 100 square miles of the flats at the Sandheads. General Rundall.

There was a distinct littoral current along the Egyptian coast, occasioned partly by surface evaporation, and partly by the wind blowing right up the Mediterranean, and so raising its level at its eastern end. The accumulation above the outer breakwater at Port Said consisted chiefly of sand, the alluvium of the Nile being only conveyed in flood-time.

An example of the transport of drift by wave-action existed at the Port of Vizagapatam, midway between Madras and Calcutta. That town, in 1844, was threatened with destruction by the sea, which had completely washed away the beach, and was fast eroding the ground on which the town and fort were built. Sir Arthur Cotton erected a series of groynes at intervals along the threatened shore, nearly a mile in length. The groynes were made with large loose blocks of stone quarried from a bluff near the south end of the town. The erosion was lessened as soon as the groynes had been carried out only a few feet from the shore, and sand began immediately to accumulate. When the works were commenced, the beach was very steep, and the space between high- and low-water mark very narrow. By the time the groynes were finished, a long stretch of sand took the place of the steep beach, extending from the shore-line to the groyne heads which alone were visible, all the rest having become buried in the drift-sand. During and after their construction, the action of the waves was very visible, the movement of the sand taking place on the ebb as well as on the flood. The greatest accumulation was always on the weather side of the groynes, and varied with the wind and current at different seasons of the year. During the heavy storms which occurred annually in the Bay of Bengal, there was a considerable degradation of the beach; but the crest of the wave now never reached the shore-line, and the beach resumed its usual shape a few days after the storm had passed. Similar works had been carried out at Madras, Tranquebar, and other places along the coast, with similar results.

Mr. J. Watt Sandeman, from his observation of the causes producing and controlling littoral drift, agreed with all the propositions of the Author, with the exception of the statement in No. 4, that "the regular and continuous travel of the material along the coast is due to the wave-action of the flood-tide." He took exception to this statement, as based upon a new theory, for which evidence was lacking, and contended that no facts had Mr. Sandeman.

Mr. Sandeman. yet been brought forward to confute Sir John Coode's view, quoted near the bottom of p. 16 of the Paper. The Author had attempted to refute the theory that the direction of the littoral drift was determined almost solely by that of the prevailing winds, by stating that, as the prevailing winds in England were from the south-west, the movement of littoral drift should be in the same direction all round the coast, which was not the case, the fact being overlooked that on the north and east coasts, the south-west winds would be off the land, and so could have no action upon littoral drift. He agreed with the Author that on the east, west, and south coasts of Britain, except in certain bays, littoral drift travelled in the same direction as the flood-tide; but it also happened that the heaviest seas on these coasts were from the same direction, so this was not a proof that the flood-tide was the governing agent. Proposition No. 7 (p. 3) was only true when applied to channels in depths beyond the influence of wave-action.

He would suggest the addition of the following propositions, which he considered as now established in regard to harbours on sandy coasts:—(A) In the case of a river harbour upon a sandy coast, if the river mouth were sheltered by piers carried seaward to a depth at which wave-action ceased to affect the contour of the sea-bottom, no bar would form in the harbour entrance so long as the detritus brought down by the river was removed by dredging. If, however, the detritus were allowed to accumulate, it would gradually shoal the river mouth out to the pierheads, until by such shoaling the detritus was brought within the influence of wave-action, when a bar would be formed. (B) In the case of a harbour upon a sandy coast with piers carried seaward to the same depth as in case A, but without a river, no bar would form in the entrance, and no shoaling would occur in the harbour. (C) At all harbours on sandy coasts, where piers were not carried seaward to the depths before-mentioned, dredging would be necessary to prevent the formation of bars; and the amount of dredging required would be increased according as the exposure of the harbour was greater, and the pier-heads were placed in shallower water.

The first principle deduced by the Author for harbours on coasts subject to littoral drift (p. 28) would be almost impossible of attainment, as, where other considerations would allow, pierheads should be placed in alignment with the contour of the sea-bottom, which would, as a rule, be the most favourable position for enabling ships to enter the harbour during storms; but as this would frequently make the two pierheads in line with the tidal current, the piers would of necessity interfere with its main set, and cause an eddy at the harbour mouth. Mr. Sandeman.

Mr. W. SHIELD considered many of the views put forward by the Author tended to endorse rather than refute the opinion which he, in common with many other engineers, held, namely, that the direction of littoral drift was, in the great majority of cases, determined almost solely by that of the prevailing winds. The east coast of England, being sheltered from south-westerly winds and being of very irregular contour, was not a good example from which to draw conclusions. However, on the coast of Aberdeenshire, northward of Peterhead, the prevailing southerly and south-westerly winds were so much affected by the trend of the coast, that the waves set up by them impinged on the shore from the south-east, the result being that the drift travelled in a northerly direction, while the strong flood current, with a velocity of about 3 knots per hour, ran almost due south. There could, in this case, be no doubt about the direction or persistency of the drift, since it pushed the mouth of the River Ugie round to the northward, and kept it there for a great part of the year. With north-easterly winds, however, the drift travelled south, and sometimes blocked the river mouth. He adhered to the opinion that prevailing, rather than dominant winds influenced the direction of littoral drift, if by "dominant" occasional very strong winds were understood. Heavy waves, set up by a strong wind, drew down beach material into comparatively deep water; so that although such a wind might, and almost invariably did, govern the direction of the drift for the time being, the quantity of material moved along the coast was not always so great as might be supposed. Soon after the subsidence of such a gale, the material drawn down was replaced by the action of the waves, and the prevailing wind again controlled the situation; but it was not contended that there were no exceptions to this rule. The Author's proposition "that the drift which travels along a coast is derived from the erosion of cliffs and the wasting of land, and not from the sea-bed" did not seem to be borne out by facts. Mr. Murray had mentioned that shingle and chalk ballast thrown overboard from ships off Sunderland, at 7 to 10 miles from shore, in depths of at least 10 fathoms, were brought ashore in large quantities during violent storms, and cast upon the beach by wave-action.[1] It was ascertained by long-continued observations, that the travel of sand in Algoa Bay, South Africa, extended out to the $3\frac{1}{2}$-fathom line. At present Mr. Shield.

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 670.

Mr. Shield. he was engaged in blasting and removing rock from the bed of the sea, in depths of from 10 to 30 feet below low water of spring tides. A very moderate sea was sufficient to throw up quantities of the smallest of the material thus disturbed upon the adjacent beach. He believed the Author would find that he had been misinformed in regard to the accumulations in Ymuiden Harbour being caused by material discharged from the canal. They took place before the bank across the mouth of the canal was cut through, and were due to sand travelling chiefly from the south, round the ends of the piers which were situated in deep water. The portion of the east coast of Africa referred to by the Author was Port Natal, with which Mr. Shield was well acquainted. The inshore current was the counter-current of the great Mozambique stream, and not a tidal current as the Author supposed. The direction of this current was constant, but that of the drift was not. The direction of the drift was generally from south to north, owing to the angle at which the rollers, produced by the prevailing southerly winds, impinged upon the shore. When the wind was from the north, the direction of the drift along the shore was southerly. This was proved, not only by the banking up of sand against the north pier, but by the fact that materials brought down by the rivers Tugela and Umgani, were on such occasions found scattered along the shore between those rivers and Port Natal. Nevertheless, since the prevailing winds were from the south-east and south-west, the prevailing direction of the drift was northward.

Mr. Vauthier. Mr. L. L. Vauthier remarked that he would only deal with the Author's view, in relation to the oscillating movement caused by the tides in the maritime part of rivers, that the deposits were brought wholly from inland by the freshwater discharge. He agreed with the Author in considering that the amount of alluvium brought in from the sea had often been exaggerated. Nevertheless, he thought the conclusions in the Paper were too absolute, and that particulars of the changes which had occurred in the estuary of the Seine and the adjacent sea-bed, in the last fifty years, might be of value. The physical conditions of the Seine, the training works carried out in the upper part of the estuary, and the changes that had resulted, had been previously described.[1] He would, therefore, confine himself to the changes indicated by the surveys of 1834, 1853, 1875, and 1880, in two zones, one comprising the inner part of the estuary, from a little

[1] Minutes of Proceedings Inst. C.E., vol. lxx. pp. 90–97, and vol. lxxxiv. p. 211.

above Hoc Point for a distance of 7,830 yards seawards, with an area of 30,770 acres, and the other outside the estuary, extending from the first for 5,220 yards further out, and having an area of 40,630 acres. In the nineteen years between 1834 and 1853, accretion to the extent of 120,000,000 cubic yards had occurred in the outer zone, or a shoaling averaging 1 foot 10 inches in height over its whole area, and of 48,000,000 cubic yards in the inner zone, equivalent to a shoaling of 11 inches over its whole area. In 1875, twenty-two years later, 320,000,000 cubic yards of deposit had taken place in the estuary above Hoc Point; and during the same period, scour had occurred in both zones, amounting to a removal of 207,000,000 cubic yards in the outer zone, and 114,000,000 cubic yards in the inner zone, forming together 321,000,000 cubic yards, a remarkable approximation to the accretion in the estuary above, indicating that, in certain cases at any rate, in the action of the sea on beds of sand and silt, a sort of balance was maintained between the accretion in one part and the scour in the adjacent regions. Between 1875 and 1880, a reverse movement took place, resulting in the moderate accretion of 17,000,000 cubic yards over the two zones. Later observations indicated that the inner zone only experienced changes within restricted limits, showing that the changes were becoming regulated. The factors operating in tidal seas on the movements in the bed of the sea near the mouths of rivers, and in their estuaries, were so numerous, so diverse, and so complex, that the establishment of general laws in such matters was of extreme difficulty. The only principle that, in his opinion, could be enunciated on this subject was, that in an ordinary river with an unstable bed, a sort of interdependence existed between the several parts. The same law regulated the still more complex movements in river mouths; and from thence were deduced the rules, to which observation had led, for the improvements in progress on the tidal Seine. The principal of these rules consisted in augmenting to the utmost the flow of tidal water, whilst co-ordinating the discharge of the ebb with the volume introduced by the flood. Besides the enlargement of the lower part of the trained channel, the object aimed at for the improvement of the Seine in the upper part of its estuary, was to harmonise the different portions of the channel, by giving the bed the widths, and the sides the lines best calculated to ensure a free flow in both directions, aided by dredging the shoals which the currents alone could not scour away. Mr. Vauthier.

Mr. L. F. Vernon-Harcourt regarded the Author as somewhat of an advocate, in first stating the propositions which he desired Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. to establish, and then marshalling his facts in support of those propositions, with some important reservations. All harbour engineers understood by the term "prevailing wind," the wind blowing from the most exposed quarter facing the coast on which their works were situated. It was incorrect to state that the prevailing wind on the east coast of England was the south-west, with the object of ascribing the drift to the flood-tide, for in reality the strongest wind which mainly affected that coast was the north-east. The Author desired to attribute all littoral drift "to the wave-action of the flood-tide;" and if this were true, there would be no littoral current or littoral drift in tideless seas. These had, however, been observed in the Mediterranean going towards the west, down to considerable depths, in front of the Rhone delta, and towards the east across the face of the Nile delta, in the Black Sea from north to south across the mouths of the Danube, and in the Gulf of Mexico from east to west in front of the Mississippi delta. The Author had quoted an instance of the accumulation of littoral drift in a tideless sea, on the western side of Port Said Harbour; and it was impossible to suppose that forces which were in active operation in tideless seas should have no influence along the more exposed shores of large tidal seas. Moreover, the Author, when desiring to prove that none of the alluvium eroded from the Holderness coast could enter the Humber from the north on the flood-tide, promptly transferred the preponderating action from the flood-tide to the ebb, and stated "that each tide leaves the material $7\frac{1}{2}$ miles further north than the point from which it started," in direct opposition to the flood-tide. If the flood-tide exercised such an all-powerful influence on littoral drift along the sea-coast, it ought also to manifest its action in large estuaries having a comparatively insignificant fresh-water discharge, such as the Mersey, and should drive the sands from the banks in Liverpool Bay into the inner estuary. Generally, however, a sort of equilibrium was maintained, with occasional fluctuations, which was only disturbed when the construction of training walls in an estuary, by withdrawing the scouring influences from the sides of the estuary, enabled the flood-tide to deposit permanently large volumes of material behind the training walls in the upper part of the estuary, which it had taken up from the sandbanks lower down, as had been observed in the Seine estuary. The muddy alluvium with which the Usk was densely charged was not brought down by the river, as stated in the Paper, but came up with the flood-tide from the Bristol Channel, as he had often noticed. He was surprised at the following statement in the

Mr. Vernon-Harcourt.

Paper: "In the Bay of Bengal, where the monsoon blows continually for several months, there are two movements of sand in opposite directions. During the north-east monsoon, the movement is from north to south, in the same direction as the wind; but as soon as the north-east monsoon ceases, the direction is reversed, and the drift moves in the opposite direction with the set of the flood-tide." The Author appeared to be unaware of the periodical occurrence of the south-west monsoon in the Bay of Bengal, though in the next sentence it was referred to as blowing in the Arabian Sea. The setting in of the stronger south-west monsoon caused the cessation of the north-east monsoon; and the Author, without knowledge of the meteorology of the district, had brought forward an instance, in support of his theory, which only proved that the direction of the drift changed in accordance with the change in the direction of the periodical winds. As the flood-tide was propagated from the ocean, it naturally approached the shore from the most open and exposed quarter, and therefore approximately coincided in direction, in most cases, with the strongest winds causing the greatest wave-action on the coast. In order to prove that the travel of drift along any coast was "due to the wave-action of the flood-tide," it would be necessary to show, first, that there was no wind to which this travel could be ascribed, and, secondly, that this wave-action really existed. The Author had not attempted to establish the first condition, but had contented himself with ascribing any drift coinciding in direction with the flood-tide to that agency, though he had acknowledged in his Paper that "the power of waves in heavy storms breaking on the shore to move material is almost beyond comprehension." The wave-action of the flood-tide depended upon the existence of a continuous series of waves, given off from the main tidal wave, breaking on the shore at an angle of about 45°, and large enough to move shingle along; but no such constant, regular phenomenon was observable on the sea-coast; and when waves rolled in at an angle to the shore, this was due to the oblique direction of the wind. He readily admitted that the flood-tide, in so far as it created a current, had some influence upon the travel of drift; but evidence was wanting of the powerful action along the sea-coast ascribed to it in the Paper. Piers carried out from a coast subject to littoral drift necessarily led to an accumulation of material on their windward side; and though he agreed with the Author, that the amount of drift was often limited, the piers could neither stop the drift towards them, nor prevent its formation, except so far as they protected the coast. The advance of the foreshore was

Mr. Vernon-Harcourt. naturally most marked directly a pier, on being carried out, arrested the drift, as the deposit occurred in shallow water and in the angle formed by the pier with the shore; whereas later on, the accumulation extended over a longer shore-line, and into deeper water. It was impossible to stop the supply of drift brought down by large rivers like the Nile; and he had recently seen the current of muddy alluvium passing across the entrance to Port Said Harbour, and had inspected the accumulation of sand on the foreshore to the west. The sandy portion of the alluvium carried down by the Nile must either accumulate on the western foreshore, or deposit in the entrance channel; but there was a large area to be filled to the west of the harbour, and the deposit in the channel could be removed by dredging.

Mr. Walmisley. Mr. A. T. Walmisley stated that the theories advanced on p. 3 would read better in a report to an authority soliciting the Author's views, than in a Paper presented to the Institution. If *Fig. 2* was drawn to a natural scale, the upper layer of pebbles, "which is subject only to the thin end of the wedge of water," appeared rather steeper than experience indicated. Prior to the building of the Admiralty Pier at Dover, the old reservoir in the South Pier was filled at high water, and subsequently discharged by sluices in the outer end of the reservoir to clear the harbour entrance; but since the Admiralty Pier had been built, not a pebble came into the east bay round the head of this pier. The beach oscillated to and fro in the east bay at various seasons of the year, but gave no cause for anxiety because the groynes were carried up to the parade, and well below low-water level of ordinary tides. Upon the west side of the Admiralty Pier the beach had largely accumulated in recent years, forming a protection to the South Eastern Railway property near the station; indeed, so much had the beach accumulated, that it would be necessary to dredge some of it away, to obviate the stern of the Dover-Calais passenger steamships running into the beach at low water, if the new landing arrangements recommended by the late Sir John Coode, east of the pier, were not decided to be shortly carried into execution. At Dungeness, where there were only groynes to protect the "outfall from damage," the foreshore was continually scoured out from the Hastings side of Dungeness Point and accumulated at the point, the loss of foreshore being an anxiety to the Denge Marsh Level Commissioners.

Mr. Webster. Mr. John J. Webster deemed that the Author's first proposition "that the vast deposits of sand and shingle are due to causes which occurred in the remote ages, and which are no longer in operation," hardly tenable; for whatever the causes, whether they

Mr. Webster.

were glacial action, the transportation of material by melting glaciers and icebergs, oceanic currents, seismic eruptions, or atmospheric disturbances, the same causes were undoubtedly still in operation, imperceptibly, as they were then; for the "last physical great change of conditions," to which the Author referred, was not yet completed. Were it not for the construction of protective and other artificial works, the British coast-line would be considerably altered. The source of the drift was not only the erosion of the cliffs, but also the detritus brought down by great rivers, especially when they discharged into a tideless sea. The Author stated that "it is contrary to all known laws of tidal action in rivers for material to be carried upwards from the sea to any great distance," and gave the Humber and Mersey as instances. Out of numberless observations recorded by engineers and others, the Author was the only one who had not found the incoming water of the Mersey and the Humber heavily charged, with sand in the former case, and alluvial matter in the latter, especially after a storm. The composition of the banks in the estuary of the Mersey was sand, which had undoubtedly come in from the sea, though it was gradually being contaminated by the filth brought down by the rivers from the towns above. The composition of the banks of the Humber was mud, part of which had been brought down by the Ouse and the Trent. But just as the banks in the Mersey were of sand and not alluvial matter, and were consequently not brought down by the rivers, but supplied from the immense banks of sand in Liverpool Bay, so also were the banks in the Humber partly supplied from the immense amount of alluvial matter washed from the east cliffs. In his attempts to disprove this by his oscillation of the tidal-wave theory, the Author entirely ignored the important fact, that in the River Mersey the tide flowed for only five hours, but ebbed for seven and a half hours. Consequently part of the matter brought in by the flood-tide had time to settle during the ebb; and it was thus that the banks were formed in estuaries from sources in the sea. The Author presumably obtained his samples of the "bright and clear" water near the surface; the water, however, was more heavily charged with sand near the bottom. The Author's proposition that "the quantity of drift is limited, and may be either entirely stopped, or its movements controlled," was not supported by the results of many important works which had been carried into deep water for that purpose. For instance, the North Pier at Aberdeen, notwithstanding its extension into deep water, had failed to stop the sand travelling round its head; the bar still existed, and constant dredg-

Mr. Webster. ing was necessary to allow even small vessels to enter the harbour at low water. Although the direction of the drift and of the tidal flow was the same in many places, this could only be regarded as a coincidence, and not as a proof of cause and effect. The direction of the tidal flow on the north coast of France was in many places from east to west, and the Author stated that the drift on that coast was principally from west to east. On the English coast the drift was, in almost every case, in the direction of the wind-waves. The small waves given off from the main tidal wave, as mentioned by the Author, were quite inadequate to account for the movements of the immense masses of shingle on the English coasts: and nothing less than the force of the wind-waves and tidal currents could possibly cause the great changes which were continually taking place. The Author's statement, that the contour of the sea-bed remained in a stable condition, was disproved by the results of deep-sea dredging, and ocean cable-laying, when strong currents—not tidal or due to wind—were found to be sweeping the bed of the ocean. Suction-dredging was an admirable method of removing large quantities of sand, especially with the well-designed plant used on the various works quoted by the Author; but it was decidedly premature to attribute permanency to the channels cut either in the Mersey or at New York, Ostend, and elsewhere, when they had only been completed a few years. The same combination of natural forces, which cut an entirely new channel in the estuary of the Mersey, might remove another one cut by artificial means. Time alone could prove whether channels cut in sandbanks by artificial means would remain permanent or not, without the assistance of constant dredging or protective works. In an estuary like that of the Mersey, where there were thousands of acres of sandbanks exposed at low water, it would be almost impossible to prevent a large amount of sand being blown into the channel during strong winds, which would have to be removed to keep the channel open; and the Author's statement, "that the channels so dredged showed a tendency rather towards deepening than shoaling," required confirmation, for it was said that below a certain depth the opposite action took place.

Mr. Wells. Mr. L. B. Wells was of opinion that the questions raised were of so complex a nature that much more information was required before any general proposition of a reliable character could be laid down. The Author appeared to have made out a good case for rejecting the assumption that "the direction of littoral drift is in the great majority of cases determined almost solely by that of the prevailing winds," which may have been adopted because the prevailing winds and the flood-tide followed the same directions in the English Channel. If, however, the movement was influenced by the flood-tide to so large an extent as suggested in the Paper, then, in and about the Land's End, and to the eastward of harbours on the south coast of England, little or no deposit should be found on the foreshore, owing to the short distance from which detritus could be derived and the hardness of the rocks. Nevertheless, Whitesand Bay, immediately to the north of the Land's End, contained sand; and on the rock-bound coasts between Plymouth and Dartmouth, and of Pembrokeshire, the small coves and large beaches were covered with sand or shingle. The primary rocks rose abruptly from the sea along many miles of that coast, but wherever there was an indent or extended foreshore, it was covered with sand, which was found in the most exposed positions, namely, from Plymouth Sound to "the Start." Shingle was found along the less exposed coast to the east of "the Start;" and the bight of Start Bay was cut off by a beach of shingle, not unlike the Chesil Bank, extending $2\frac{1}{4}$ miles. The sandy bar of Salcombe Harbour, to the west of "the Start," was only just covered at low water of equinoctial springs, and had about 18 feet of water over it at high tide. The estuary inside was of considerable extent, the quantity of fresh water flowing into it being very small. The position of the bar shifted a few hundred yards from year to year, and appeared to be determined by the direction of the storms. The bar was in a state of mobile equilibrium; while the mud-banks, channels, and deeps inside changed but little. Mr. Wells.

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10 March, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The President having referred to the recent death of Mr. James Abernethy, Past-President, read the following resolution, which had been passed by the Council and was concurred in by those present:—

> "That the Council learn with great regret the death of Mr. James Abernethy, Past-President, and desire to convey an expression of their sincere sympathy to Mrs. Abernethy and to the other members of the family."

The discussion upon Mr. Wheeler's Paper on "Littoral Drift" occupied the evening.