Discussion.

Mr. Vernon-
Harcourt.

Mr. L. F. VERNON-HARCOURT said that the Author had referred to the Mississippi as a case where a bar had formed; but care should be taken in distinguishing between tidal and tideless rivers. The Mississippi, it was known, was really an example of a tideless river, and therefore he did not think it was the case, whatever Messrs. Humphreys and Abbot had said, that the bar at its mouth was due to the tide. It was rather due to the absence of any tide, because its waters brought down a large quantity of alluvium, and deposited it in the slack water, where there was practically no tide to carry it to and fro. Reference had also been made to rivers not silting up; but he thought there were certain rivers, which, although they did not entirely silt up, owing to the fresh water flow, yet were in process of silting up, like some small rivers flowing into the North Sea, which by degrees, partly, possibly, owing to unwise reclamations, but also partly owing to accretion due to sand coming in, had to some extent silted up. He referred to such ports as Calais, Gravelines, Dunkirk, and Nieuport,¹ which originated from the small rivers that flowed into the sea forming creeks. The Author had stated that the outlet-channel of the Seine was always provided with deep water like the Thames, but that was not really quite correct, because it was impossible to navigate the Seine at low-water. Last year, during the excursions of the Congress on the Utilization of River Waters, he had gone to Havre, and went up the Seine, in a small steamer, with the Congress and the French Minister of Public Works; and they had to wait until the tide had risen a certain amount before they were able to enter the estuary, and even then, owing to the change of the channel, they had to go nearly as far as Trouville before entering the channel. He thought the Author had hardly given enough credit to the influence of the fresh water of a river in maintaining its channel. Of course, as compared with the tidal water, in the case of the Thames, Humber, and many other rivers, fresh water had very little influence below, but it had the advantage above of keeping the channel open, and scouring it during the latter part of the ebb. As was well known, floods going down rivers did tend to scour them out. He might

¹ Minutes of Proceedings Inst. C.E., vol. lxx. pp. 3, 5, and 9.

mention the case of the upper tidal portion of the Yorkshire Ouse, which came under his notice last year. The river was continually silting up in the summer, and thereby diminishing greatly in depth from Naburn Lock nearly down to Selby, owing to the deposit, in the absence of fresh water, of the warp that came up from the muddy Humber; but it was scoured out again by the winter floods. Even in the case of the Mersey, the fresh water was of some advantage in scouring out the upper estuary. He thought that the Author agreed with the general view that the ebb-tide from the wide upper Mersey estuary did help in scouring the channel over the bar; and he was not at all sure that the great fret, about which a great deal was heard before some parliamentary committees some years ago, was not an advantage to the estuary of the Mersey, because it carried down the sand and cleared out the upper estuary, increasing its tidal capacity; though possibly, but he did not think that it was proved, some of the sand from the upper estuary did deposit for a time on the bar, which was eventually lowered again by the improved scour from the upper estuary. With regard to the Ribble, last summer he got stranded in mid channel for a short time, near low-water, in a small boat, on one occasion a little above Lytham, and a fortnight later about 4 miles from the bar. The bar there, he thought, was not 12 miles from the trained channel, unless the Author meant the channel which was trained on both sides of the river, because the training-walls extended something like $1\frac{1}{4}$ mile, or even more, below Lytham, and the bar was certainly not more than 6 or 7 miles below the end of the southern training-wall. Then mention was made of Wexford Harbour, which Mr. Vernon-Harcourt knew very well a few years ago. There, undoubtedly, the Author was right in attributing the deterioration of the harbour to large reclamations. It was a kind of lagoon harbour, only partially maintained by the River Slaney. At least half of the lagoon had been brought into culture, and therefore the scouring effect of the sea-water going in and out at each tide had in a great measure been reduced. As to the Author's statement about the improvement by training-works being due to the increased run of the tide, account should also be taken of the area which the tide covered; because really the improvement was due to the increased volume of the tidal flow, and not merely to the increased depth of the channel. If the area could be increased, then the tidal capacity would be improved; but to increase the depth very much below low-water only aided the tide to a small extent in coming up by reducing the friction;

Mr. Vernon-Harcourt. and even harm might be done in some cases by restricting the channel, and diminishing in that way the tidal area, though undoubtedly in almost every case the depth of the trained channel itself would be improved. The Author also mentioned that the loss of area on the Ribble was compensated for by deepening. Mr. Vernon-Harcourt hardly thought that that had really occurred. There had been undoubtedly an increase in the depth of the Ribble in some places above Lytham; but large tracts of the estuary had been practically reclaimed, and, he thought, in a great measure to the injury, if not to the central channel of the river certainly to the channel which went towards the south; and, therefore, it seemed to him, to the injury of Southport. The Author, again, reverted to the Mississippi, as a case proving that training-works might be beneficial to the bar; but Mr. Vernon-Harcourt thought it would be better to separate tidal and tideless rivers entirely, and not to try to prove anything from a case like the Mississippi in dealing with the bars at the mouths of tidal estuaries. The two cases were so very distinct that he did not think there was any good in trying to draw an analogy between them.¹ The Author also mentioned that the water that entered and left an estuary was precisely the same. Of course it was so as far as tidal water was concerned; but there was also fresh water always coming down, which was one of the causes that helped to keep the channel open, because the ebb would otherwise have less power than the flood if it were not for the fresh water. It was well known that creeks on sandy coasts did by degrees silt up, owing to the absence of the help of any fresh water. With regard to the statement of the Author as to the equilibrium of the flood and ebb generally, and as to the trumpet-shaped mouths of estuaries being the best, he was quite in agreement with him; and, indeed, had expressed the same views in very similar language about eight years ago.² He thought it might be interesting to the Institution to see the results of experiments which he had mentioned during the discussion on the previous Paper, on the Liverpool Docks, as having been carried out within the last four years with models of the Seine and the Mersey. The model of the Seine formed the subject of a Paper read last year, which had been printed in the Proceedings of the Royal Society, in which would be found a full description of the method of working of that model, and the results with different schemes of

¹ Minutes of Proceedings Inst. C.E. vol. lxx., p. 19.

² "Rivers and Canals," by L. F. Vernon-Harcourt, pp. 231 and 234.

training-walls.¹ He came to the same conclusion with reference to the training-works on the Seine, that it was an advantage to have a trumpet-shaped outlet, and not to have an outlet which was irregular in form. The diagrams gave instances of the results produced, in a working model, with the principal schemes that had been proposed for the prolongation of the training-works on the Seine by different French engineers. The last one was an attempt of his own to see how far it would be possible to enlarge the width of the trained channel, so as to admit the greatest amount of tidal water; and he thought that the results shown in the diagrams pointed to the conclusion that a trumpet-shaped form was decidedly better than any other. The first diagram showed the results with a proposal of Mr. Partiot; the second diagram indicated the influence of a scheme of the late Mr. Lavoinne, who was Engineer-in-Chief of the tidal Seine; the third exhibited the effect of a scheme proposed by Mr. Vauthier, who had devoted a great deal of consideration to the question; the fourth showed the changes produced by the scheme of a commission appointed by the French Government; and the fifth was not a regular scheme, but simply an experiment of his own.¹ One good result at least had followed from these model-experiments, namely, that the French Engineer-in-Chief of the tidal Seine, Mr. Mengin, contemplated last summer making model-experiments on a larger scale at the cost of the French Government, which probably were now being carried out, with the object of discovering the best arrangement for the prolongation of the training-walls. The upper diagrams showed some model-experiments that were carried out more recently with reference to the Mersey, to ascertain the effect of training-works on the estuary. The first diagram exhibited the extent to which the existing conditions of the Mersey estuary, from Warrington to beyond the bar, could be reproduced in a small scale working model. The second showed the result of introducing the training-works that were proposed for the Manchester Ship-Canal scheme of 1884, effecting the silting up of the upper estuary, and the consequent great reduction in depth of the navigation channel below the "Narrows"; the third showed the introduction of training-works in the outer estuary, without any alteration in the sandbanks; and the fourth showed the result of putting in the same training-walls, and also performing some dredging, by removing a portion of the

¹ "Proceedings of the Royal Society of London," vol. xlv. p. 504; plate 2, scheme A; plate 3, scheme C, and scheme D; and plate 4, scheme E, and scheme F.

Mr. Vernon-Harcourt. sand-banks. The results obtained with the Mersey model had been fully described in a Paper read before the Royal Society on the 30th of January, 1890. The Seine model was made to a scale of $\frac{1}{40,000}$ horizontal, and $\frac{1}{400}$ vertical, affording a rise of tide, by the tipping of a tray, of about $\frac{3}{4}$ inch in the model. It was carried up to the limit of the tidal Seine at Martot. The model of the Mersey was made to a scale of $\frac{1}{30,000}$ horizontal, and $\frac{1}{500}$ vertical, giving a maximum rise of tide of $\frac{3}{4}$ inch in the model. He believed that the model experiments showed that it was possible, by imitating in miniature the action of the tidal ebb and flow and the fresh-water discharge, to produce in a small model, with a bed of very fine sand, results fairly approximate to the actual conditions of an exposed estuary, indicating that these forces exercised the main influence in shaping the channels of an estuary out to the open sea. Moreover, the actual influence of existing training-walls had been reproduced in the Seine model; and, by analogy, the results exhibited in the diagrams might be regarded as those which would be produced by the various schemes, if carried out. Engineers would by this means be enabled to ascertain beforehand the probable effects of any system of training-works, and thus avoid schemes leading to injurious results, such as those exhibited in the second Mersey diagram, and to select the lines of training-walls most advantageous for any particular estuary. In conclusion, he would only add that he should feel that the time, trouble, and money devoted to these model-experiments had not been expended in vain, if these experiments led engineers to learn from nature the effects of training-walls on a small scale before introducing them into estuaries; if they removed the divergences of opinion as to the effects of training-walls under certain conditions; and if they resulted in the establishment of correct general principles for guidance in the designing of training-works through tidal sandy estuaries.

Mr. Kinipple. Mr. W. R. KINIPPLE noticed that the Author ascribed the formation of bars to the action of waves, and he also observed that Mr. Vernon-Harcourt coincided with that view; but he thought it was not altogether so. He had himself made some experiments in quiet water with small models, and a bar was formed each time possessing the same characteristics. He thought it was not necessary for waves to be driven along the shore, or to have the action of any waves whatever, to form a bar. Waves, acting in opposition to outflowing currents, did unquestionably give fantastic and unaccountable shapes to bars; but this was different from ascribing the formation of bars to the action of waves alone. In the case of

entrances to small rivers, where there was a bar, very frequently Mr. Kinipple. they were sheltered from winds and waves; especially in inland waters, which were free of tides. Even debris forced into a heap at a mill-tail was nothing more or less than a bar. There were bars formed almost solely by waves and currents, but these were generally well out to sea, at the ends of channels, and partook more of the character of low sandbanks than of bars as generally understood. In Aberdeen, there was a bar just inside the north pier, where the exposure was to the north and north-east. During heavy weather, and strong gales from the north-east, that bar was driven up into the harbour. If there happened to be a dry season, it was driven further up the harbour; but should there be fine weather outside, and a heavy spate inside, it was shifted down nearer the sea. That was a case in point, where a bar was moved either inwards by seas, or outwards by the outflowing waters, and which had to be kept down by dredging. In February, 1868, he was engaged in laying down river-lines on the Clyde from Greenock up towards Port Glasgow. His object at that time was to carry the future Greenock Harbour Works out to those lines. These lines, with his recommendation for dredging a central channel of 200 feet in width by 23 feet in depth at low-water, and a depth of 18 feet along the sides thereof, were ultimately adopted with very slight modification by a Committee of the House of Lords, in 1880. In March 1870, he was inclined to fall in with the views of some of the authorities in Glasgow who wanted to cut through the Greenock bank, and he said:—"By all means cut through that bank, but he only expressed his approval of this, if it were done in such a way that a large bay, or tidal harbour, might be enclosed, and given to Greenock in front of the town, similar to the great harbour which he proposed and had since enclosed at Ladyburn, east of Garvel Point." The Leven and Clyde converged at Dumbarton, and from there to the tail of the Greenock bank, along the whole length of the north side, and some portions of the south side of the channel, he proposed to train or harden the margins of the channel. These banks were to be about 2 feet above low-water level, or up to the tops of the Pillar, Cockle, and Greenock banks. They were not to be training-banks as commonly formed, but simply composed of boulder-clay, or broken stone, so as to pen in the last of the ebb waters southward of such banks, and allow the flood coming in from the north side to have free swing over them into the channel. At Port Glasgow it was sometimes flood nearly half an hour earlier than at Greenock. The last of the ebb-tide came down

Mr. Kinipple. with considerable force, and was confined almost wholly to the south side of the estuary below Dumbarton. At the present time, if there was a bar at all on the Clyde, it was just above Port Glasgow, or opposite to Cardross. Fortunately for Greenock, the Clyde Navigation Trustees had kept more or less, for some twenty years in that locality, a dredger to pick up the travelling material, which otherwise would have found its way down into the Bay of Greenock; and no doubt this had effected a considerable saving to the Clyde Lighthouse Trust in dredging operations in front of Greenock, and, further, would most likely reduce the rate of growth of the Greenock bank. This bank was the property of the Greenock Harbour Trust, and it was not at all improbable that in future it might be materially reduced. Garvel Point was cut off some fifteen years ago to the extent of about 120 feet in width by 14 feet in depth in the first instance, and subsequently to 18 feet in depth and to a greater width, with a view of improving the lower part of the channel. There was before commencing operations a sectional area of about 600 feet by 18 feet in depth at low-water; and that had been the normal condition of things, taking the average section all the year round, for one hundred and fifty years. He was instructed to take off that point, and did so. It was chiefly composed of hard boulder-clay. At that time he reported, that it was of very little use spending money on its removal, except for straightening the channel; because, as the point was removed on the south side, so would the sand come in on the opposite side of the channel. After a year or two, sections were taken in the spring of 1876, verified by Messrs. Stevenson in August of the same year, and these showed that precisely what he had predicted had then taken place; for in regard to sectional area there had been no improvement. These facts were officially recorded at the time; but the present section of the channel, after more than thirteen years of dredging operations in the locality and above and below the point, might have increased its original normal section. As the Clyde Lighthouses Trust had been dredging in front of Greenock since 1876, it would be interesting to know what were the depths in the channel at the present time as compared with those of 1872, that was before any dredgings were commenced, when a survey of the channel was made. His impression was that a large amount of material along the frontage of Greenock had been dredged beyond what was necessary to obtain the agreed upon depths and widths, sanctioned by Parliament in 1880, unless the almost constant dredging by the Clyde Navigation Trust, just above Newark Castle, since 1872, had prevented the travelling silt from

being carried down the river into the embayed area in front of Mr. Kinipple. Greenock. In a river like the Clyde it would be a mistake to keep training-banks high. The last of the ebb should not go by the north side to the sea, and the banks should be so trained as to give the fullest width of channel capable of being kept open by scour. In that way he believed the Clyde would have a fair channel, capable of keeping itself open naturally, and so the present expensive operation of dredging might to a great extent be dispensed with. In 1870 he estimated that more than 50 per cent. of the last of the ebb-water was lost by escaping to sea through the swashways between the Pillar and Cockle, and the Cockle and Greenock banks, and therefore these should have been blocked up. About three years ago he had reported on the bar at the mouth of the small harbour of Irvine. The question was whether the bar should be removed by dredging, or by extending the training-banks. He advocated both plans; and, while wishing as much training as possible to be done, suggested that if sufficient improvement could not be effected by training alone, dredging might be adopted later on. He thought that where bars were likely to form very rapidly, it was not altogether wise to resort to, or rely wholly upon, dredging. A harbourmaster might one day report that there was a depth over the bar of, say, 16 feet of water, and some vessel might go out after a gale, and find perhaps only 14 feet. He certainly considered it dangerous to rely solely upon dredging, although almost anything could now be done with powerful dredging plant in keeping down bars, especially by suction trailing hopper-dredgers, which received the coarser particles of sand into their hoppers, and allowed the finer held in suspension to flow overboard, and thus by the ebb to be carried harmlessly away far out to sea; but, after all, dredging was expensive and uncertain in its operations, and to be of service must be continued at a rate equal to that of deposit, which, in some cases, was very great indeed; and therefore to train first, and remove by dredging that which could not be displaced by scour, would appear to be the safer and more economical course to pursue. At Irvine the ebb was almost equal to the flood, and the prevalent gales were from the westward. To improve the bar he reported in favour of low training-banks, following practically the sides of the bed of the channel. It was true the bar would shift further out, with the extension of the training-banks; still it was neither difficult nor costly to follow it out to deep water. It would have been unadvisable to have adopted very high training-banks, so they were to have been kept low enough not to be much affected by the waves.

Mr. Kinipple. Another case to which he referred was at Girvan, where there were two short old piers of rubble. The ebb was from the north, and was much stronger than the flood from the south, and the heaviest gales were generally from the westward. The engineer who preceded him had proposed to build a couple of piers parallel with each other in extension of the old works. The bar was immediately in front of the entrance, and could only be removed by dredging. The new south pier, 450 feet long, went straight out; but the north pier, 750 feet long, was laid diagonally, with the result that the alongshore ebb was trained by it, and meeting the river ebb at the entrance, shifted the bar to the south side, leaving ample room for a fair line of entry to the harbour. As a portion of the bar was composed of boulder-clay, it had to be dredged. Since the construction of these piers, about seven years ago, he had not heard anything more about the bar. Another case to which he might refer was Yarmouth. In the year 1030 the entrance to the Yare was $1\frac{1}{2}$ mile to the north of the town of Yarmouth; now it was about $2\frac{1}{2}$ miles south of it. In almost every case where he had been consulted the local authorities had advocated a pier, or extension of a pier, on the side of the entrance from which the shingle or sand travelled, in the belief that by arresting the travel the entrance would be saved from being blocked up. Under any circumstances such works could only be regarded as temporary checks, for as soon as the shingle or sand had been heaped up to the top of the pier, it was either tumbled over into the entrance, or driven round the pier-head, there to block up the direct or fair line of entry to the harbour, and commence anew another spit like that at Yarmouth, which had travelled southward until stopped by a Dutch engineer, Joas Johnson, who, in the year 1560, cut a new channel through the shingle spit, and erected on the opposite side to the travel of the sand the present south pier. The entrance to Poole Harbour afforded another example. Here, all that was necessary for the removal of the bar was to lay down a submerged groyne, or mole, of heavy blocks of concrete, founded on a base of large-sized rubble carried up to, and through, the bar on the opposite side of the entrance-channel to that from which the sand travelled. Again, at New Quay, Cardiganshire, the head of a pier was washed down, and the debris was strewn groyne-fashion at about right-angles with the inside face of the pier. There the heaviest seas worked round the bay, and carried with them a considerable amount of sand. The mound formed by the debris from the ruined head, for its full length, arrested the sand,

and thus the harbour was in a very short time blocked up; and Mr. Kinipple, obviously, to open up the harbour again, it was only necessary to remove the debris, and allow the sand to drift as it did formerly past the base of the old head. Since 1880 he had been engaged in training the channels of the Burry Inlet in South Wales. In August 1883, about a year after the main training-works were commenced, a broad travelling spit, which had worked its way up the estuary for many years from Burry Port, a distance of nearly 4 miles, crossed the entrance to Llanelly Harbour, and travelled $\frac{3}{4}$ mile beyond towards Carreg-fach; this blocked up the fair line of entry to the harbour to nearly half-tide level. Had the growth of this spit not been arrested, Llanelly, with its thirty thousand inhabitants, and export-tonnage of nearly a quarter of a million, would have been so sanded up as to have ceased to be a port of any consequence. The harbour scour-water at Llanelly, however, during this unsatisfactory state of things kept open a small back or scour-channel along the inside of the spit towards Carreg-fach, then by a curve to the south, and which finally joined the low-water channel at about $\frac{1}{2}$ mile out from the harbour. Here was a close resemblance to the conditions that existed at Yarmouth prior to the erection of the south pier by the Dutch engineer. He hardly knew of a more serious case than that at Llanelly. A spit of about $\frac{1}{3}$ mile in width, by about 13 feet in height in places, travelling past the harbour-mouth, with a certainty of blocking it up within a short time. To arrest and remove this spit, of nearly 5 miles in length, extending along the shore from Carreg-fach to Burry Port, was a matter for anxious thought. The local authorities tried, by the use of a necklace of wobblers, and also by balks of timber held by chains, to open a channel through the spit, but without avail, for some of the wobblers were soon buried. The first step he took to relieve the congested state of the harbour entrance, was to block up with slag the scour-channel, although it was then the only course left open for access to the sea. At the time there were several vessels in the harbour, and the risks of blocking up this channel appeared very great; but he felt sure of success, as there were ready and willing hands, who rapidly raised the slag-bank until it was as high, if not higher, than the crest of the spit in front of the harbour. When the sluices were opened, the scour-water slightly raised the pent-up water inside the harbour, until it began to trickle over the crest of the spit, and, by the aid of shovels, a small water-course was opened up, and in a short time the spit of sand was burst through, and thus within a few days a channel of

Mr. Kinipple. nearly 100 yards in width by 500 in length was formed, and the scour-water made its way from the end of the new channel through the sands to the low-water channel, which was then about $\frac{1}{2}$ mile out from the entrance to the harbour. This newly-made channel, to be of use until the main training-bank was completed, had to be kept open by a training-bank of nearly 600 yards in length, which was laid down on the opposite side of the channel to that from which the sand travelled. As the main training-bank was now nearly completed, this bank would be removed. Having opened a new channel through the spit, next came the important question of driving this enormous spit back to sea, or to any other resting-place outside the course of the new sea-channel, and of restoring to Llanelly Harbour and Burry Port the former depths of over 25 feet at high-water of spring-tides. The main training-bank was commenced in 1882 at Salthouse, and had been extended up to Penclawdd and down to Llanelly Harbour to a point at about $\frac{1}{2}$ mile out therefrom. Up to the present time some 20 or 30 million tons of sand had been scoured from the course of the new channel. The main training-bank works had been instrumental in removing the sand-spit for its whole length within a few years, and there was now a good and safe channel, from the entrance to the harbour out to sea, of more than 25 feet at high-water, or double the depth there was in 1883, with about 33 feet over the bar at the mouth of the estuary. These examples of river, bar, and estuary work under his immediate direction would, he thought, suffice to support some of the conclusions at which he had arrived, and to show that very careful consideration should be given to questions relating to any proposed improvements of rivers and estuaries prior to the commencement of dredging, or the laying down of permanent training-banks. He concurred generally with the Author's conclusions as to estuaries having natural deep-water channels; but if *Fig. 1* was intended to illustrate an example of a well-trained estuary, to be followed generally by engineers, then he did not altogether agree with him, for the mouth of the river as shown had a somewhat wandering and uncertain appearance; and if the method there illustrated was closely analyzed, he believed it would be found that the river should have been trained by a right-hand bank only, having an easy curve from the head of the estuary passing near the upper letter D down to the left-hand headland, where its outlet to the sea should have been placed, and where, also, a pier or mole should have been run out, having a slightly concave face, against which the trained ebb-current, on leaving the outer end of the main

training-bank, should have been made to impinge: this aided by Mr. Kinipple. the outside ebb, and heaviest gales striking the outflowing river ebb-current at an angle of about 100° , should keep an entrance so designed open and free from bars. Of course these remarks were based upon the assumption that all the conditions were as he described. To illustrate further what he meant, he would take a like-sided, bell-mouthed estuary, having a rivulet at its head, a straight foreshore line between the two headlands, the strength and duration of the ebb from left to right being somewhat greater than those of the flood from the opposite direction; and the heaviest seas at right-angles to the foreshore, driving directly up the estuary. Under these conditions, he ventured to say that if an inexperienced engineer were called in to open up a new channel or waterway from the rivulet at the head of the estuary out to sea, most likely he would train a channel down the very centre of the estuary directly in opposition to the heaviest gales, using two training-banks, instead of one bank, and gradually increasing the width between them until the sea was reached. On the other hand, an experienced engineer would most probably have trained a channel somewhat diagonally; that was, by commencing at the top left-hand corner with one bank only, and running it across the estuary in the direction of the right-hand headland, where he would construct a pier, as before described, against which the outflowing ebb would impinge. The inexperienced engineer, however, by his action would first create a bar outside, then perhaps one or two bars inside, and ultimately, if dredging were not resorted to, the bar, being worked up by the river and sea forces, would, aided by the constant supply of debris sent down by the upland water, ultimately lose its character as a bar and become an ordinary delta; and so the debris deposited at the mouths of the minor channels along the margins of the delta would by the heavy on-shore seas, striking the sides of the delta, be deflected and caused to travel towards each headland. At this stage the mouth of the main channel would gradually close up; minor channels would be created, and ultimately there would be formed two tolerably well-defined outfalls, by the river having bifurcated some distance up from the original line of foreshore, each being driven in the direction of the nearest headland, and to prevent which most likely he would repeat the act of the engineer who ran out a pier on the travel side of the channel and diverted the mouth of the River Yare, 4 miles to the southward of its original position. Thus one engineer would so place an entrance to a river that a bar, delta and spit would be formed; while another engineer would so place

Mr. Kinipple. it as to free itself from such obstructions. Generally, to avoid bars on the west coast of England, the mouth of a trained river should be on the northern side of an estuary, and trained in a north-west to northerly direction against a pier or promontory. That was, the outfall should be on the opposite side to that from which the sand or shingle travelled, and from which the prevalent gales came. On the east coast an outfall should be on the southern side of an estuary, and trained in a south-easterly to southerly direction. The outfalls of the rivers in the Dee, Mersey, and Ribble estuaries could be easily, economically, and successfully dealt with. The reclamation of saltings, which were perhaps only covered a few times each spring-tide, in his judgment was bad in practice, no matter where they were situated; for reclamation simply induced further accretion, and so the process went on until the top water of high-water of spring-tides was ultimately shut out, and the surfaces of the higher portions of the bed estuary were robbed of the beneficial washing down of the film of sediment which usually took place in estuaries as the tides fell off towards the neaps. From the small models he had used, he was sure tolerably trustworthy results could be obtained, and especially by one 6 feet in diameter, having sides 3 or 4 inches high, a glass bottom, radial arms 3 feet across, driven by clock-work from a centre-pin, at a speed sufficient to move fine silver sand, and capable of being worked from the right or left, to represent ebb-tide and flood-tide; also a wave-maker, likewise driven by clock-work, and mounted in such a manner that any angle could be obtained. And if small models of piers, groynes, training-banks, mouths of rivers, narrows, estuaries, &c., were made of cast-tin and placed on the glass in proper relative positions to the currents and waves, and fine sand was dropped into the water, the gradual formation of banks, bars, the deepening at concave faces, and of narrows, arresting of the travel of sand by groynes, formation of spits, &c., could be pictorially displayed, and watched with interest, especially if observed in a dark room, with a light beneath the model.

Mr. Hayter. Mr. HARRISON HAYTER, Vice President, with respect to the forces in operation in the formation of a bar in a tidal sea, took as an illustration the case of what might be regarded practically as the creation of a new river with an outfall into the sea. He alluded to the Amsterdam Ship Canal,¹ which entered the North Sea on the Dutch coast, the mouth being protected by two sea-piers or breakwaters, each about 1 mile long. The coast and the

¹ Minutes of Proceedings, Inst. C.E., vol. lxii. p. 1.

foreshore were sandy, not only at the site of the piers, but for miles northward and southward. In 1880, the date of his Paper on this work, the sea-piers had not been completed sufficiently long to enable conclusions to be drawn as to the effect they would produce on the surrounding regime. Now, however, what had taken place was illustrated by *Fig. 2*. The continuous contour lines showed their general direction before the piers were begun. The coast-line being regular, these contour lines were more or less regular also, and parallel to the coast. The interposition of the piers broke the continuity of the contour lines,

Fig. 2.

and it was not very material whether this was done by piers or by land or tidal waters, as the result would be generally the same. The dotted contour lines showed the manner in which sand was accumulating behind the piers by the winds and currents, the accumulation being greater behind the south pier than behind the north, because in the former case the operating forces were the stronger. Another disturbance in progress was due to the diversion of the sea currents. Before the piers were begun the direction of the current was generally parallel to the coast, and the velocity from 2 knots to $2\frac{1}{2}$ knots an hour. Now, however, the current was deflected, as shown by the arrows, and

Mr. Hayter. the velocity at the end of the piers increased to from 3 to 4 knots an hour, dependent on the direction and force of the wind, and there was a resulting eddying current which entered the harbour setting over towards the south pier at and near the end, and creating a sandbank under the lee of the north pier at X. If these accumulations outside and inside were allowed to go on uninterruptedly (and the case would be the same everywhere under similar conditions), the piers would in the course of years be high and dry. How long this would take in the absence of preventive measures it was of course impossible to say. These measures consisted of scour and dredging. Scour was obtained by means of water from the canal as well as from the tide. About $\frac{3}{4}$ mile inland from the coast there were locks and large sluices, and there was almost always water to run off from the canal, and generally a large surplus to be pumped by powerful pumping-machinery, discharging into the Zuider Zee. The land water sent through the sluices, in conjunction with the tidal water which filled the area between the piers and the widened channel or inner harbour between the coast and the sluices, scoured the entrance to the canal to some extent, directed as these waters were by low interior moles. The rise of the tide, however, was only from 7 to 10 feet, and the scour had to be supplemented largely by dredging. All engineering works needed maintenance, and the annual cost of the dredging was considerable, although it could not be regarded as excessive when compared with the value of the canal, to the city of Amsterdam in particular and to Holland in general, and was not more than might be expected, considering the conditions. He referred to this case because it was an apt and suggestive illustration. A new river, as it were, had been called into existence. A bar was in process of formation by the winds and currents, and systematic observations showed the accumulations and successive encroachments. The study was an instructive one, and illustrated exactly the way most bars were formed in tidal seas. He could only say that, whatever theories there might be as to the formation of bars, the state of things he had described was doubtless due to the prevalent winds and resulting waves, and to the littoral currents in a tidal sea, the injurious influences which would arise therefrom being checked by counteracting measures—that was to say, by scour and dredging. If the sea were tideless and without currents, then the formation of a bar must, as a rule, be sought for by matter in suspension brought down by a river being deposited where the velocity of the river water was checked by mingling with the sea.

Mr. W. SHELFORD said that the Author had undertaken a difficult task, and he thought it was not too much to say that those who understood the subject best would thoroughly appreciate the ability which he had shown and the pains he had taken in executing it. He might be permitted in the first place to refer to some remarks of Mr. Kinipple with reference to the Clyde, a river in which he had taken some interest as long ago as 1873, when a Paper was read respecting it by the engineer of the river, and Mr. Shelford took part in the discussion.¹ With respect to Garvel Point, it was stated that as fast as the point was cut off, the sand accumulated upon the other side of the channel, and no improvement was effected. Whether or not such a silting would occur in a broad estuary, having separate flood channels and ebb channels, was a matter of importance because of its general application. Mr. Shelford had received a communication from Mr. David Alan Stevenson, who represented the firm of Messrs. Stevenson, in which he stated, "The line of the river channel was fixed by Messrs. Stevenson, representing the Clyde Lighthouses Trust, and Sir John Hawkshaw, representing the Greenock Harbour Trust, and if that particular part of the river channel line coincided with what Mr. Kinipple recommended in 1868, he was not aware of it. Garvel Point was cut off under the directions of Messrs. Stevenson, and 240 feet was taken off, the object being the straightening of the channel, and bringing the scour of the flood and ebb-tides closer to the Greenock Harbour. Up to this time there is no appearance of any appreciable amount of silting having taken place in any part of the new channel. The works are nearly completed, and have proved entirely successful, and ship-masters and owners are quite satisfied with the results that have been attained. The depths of 18 feet and 23 feet, at low-water, provided by the Act, have been procured, and the channel widened and straightened. The dredging operations at Greenock during ten years have extended over 4 miles of channel, much of which was in hard boulder-clay. The channel opposite Greenock has now a uniform depth of 23 feet at low-water, in place of a ruling depth of about 20 feet." The point in which he was particularly interested, namely, whether one of the channels in an estuary, when excavated on one side, would necessarily fill up on the other, was therefore entirely in dispute and as unsettled as ever, Mr. Kinipple having maintained that it was so, and Mr. Stevenson saying that it was just the other way.

¹ Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 188.

Mr. Shelford. More than half of the Paper was taken up with an investigation into the causes of bars, and properly so, because it was obviously useless to attempt to remedy a bar unless the exact cause of it was known. The Author went as far back as two centuries, and referred to what the Abbot Castelli then said about bars in a tideless sea: "The Abbot Castelli expressed the opinion that the obstruction to the entrance to the ports in the Mediterranean proceeded from the violence of the sea, which threw up a body of sand of the shape of a half-moon at the place where the river fell into the sea." It might be well for a moment to consider a bar in its most elementary form. When a stream discharging into a basin of still water, and carrying in suspension a large quantity of detritus reached the coast line, it commenced to deposit sediment, and the deposit took the shape of a half-moon or horse-shoe. Owing to the velocity at the sides of the stream being less than the velocity at the centre, the stream first deposited upon each side, while the centre particles were carried further forward, and in that way the horse-shoe or half-moon shape was obtained. But not only had the centre of the stream a greater velocity, but a greater volume, and therefore carried a larger quantity of silt, depositing much more in front than upon the sides, so that a heap or shoal was formed in front; and, supposing the water to be still and everything accurately balanced, there would be a stream discharging on the one side and on the other. He thought that in that way rivers discharging into tideless seas, like the Nile, the Danube, the Rhone, and many others, might, apart from other causes, have formed for themselves several mouths. But if there was the slightest disturbing cause outside, the balance was at once altered, and there was a discharge from one side only. With a prevailing wind from one direction and the sea breaking upon the coast, one side of the bar would be lower than the other, and there would then be only one channel of discharge. In proof of that he would refer to a chart of the Tiber mouth made from the Admiralty official chart published in Italy, which was produced at the Institution in connection with a Paper, which he read in 1885 upon rivers discharging into tideless seas.¹ The chart showed a horse-shoe bar with a shoal on its centre. The prevailing wind was from the south-west, and it broke upon the bar, making the greatest depth 6 feet 6 inches on that side, while on the other the depth was 2 feet 6 inches; and the Tiber had only one natural mouth, the smaller one being artificial. Accurate records had been

¹ Minutes of Proceedings Inst. C.E., vol. lxxxii. Plate I.

kept for centuries, and it appeared that the accumulations of the delta on one side of the river had been 50 per cent. more than upon the other side during the last three hundred years. There was therefore an outside cause in the case of the Tiber which had upset the ordinary action of its most simple and elementary bar. The conclusion he drew was that any river discharging detritus into a tideless sea would naturally have a horse-shoe bar, and the fact of a horse-shoe bar existing proved that the down-stream was the cause of it, and that it was not caused, though it might be modified, by the sea. In the case of Liverpool there was also a horse-shoe bar, and from its shape no one could suppose that it had been formed otherwise than by the ebb-tide, and yet, having a ridge of 5 miles in length, and being virtually an enormous bank, it was impossible to conceive that it was supplied with material for its maintenance from the small water-sheds of the two rivers, the Mersey and the Weaver; and there must therefore be some other cause. He had pointed out in connection with the Paper by Mr. Lyster on "Recent Dock Extensions at Liverpool" that the flood-tide and the prevailing wind drove the sands from the west into the main channel of the Mersey. If that were so the channel must of necessity fill up unless the sand was removed. But it was not filled up, and therefore the ebb-tide, which was very powerful in the channel coming from Liverpool, must roll the sand along the bottom, and deposit it in water of low velocity, thus forming the bar. That was further proof that the bar was caused, or rather maintained, by the ebb-tide. It was not a new idea. Admiral Spratt, then Acting Conservator of the Mersey, some years ago prepared a map and report, in which he showed from the analogy of another place, which he had carefully studied, that there was what he called a circulation of sand always going on, the sand being constantly thrown up into the channel, and being carried down again, and deposited on the bar. He would suggest to the Author that this was also the probable cause of the Boston bar. He knew the Wash and Boston, but not in sufficient detail to be prepared to say that it was the cause, and he suggested that the Author, who had charge of a great part of that estuary, should consider that point. The main set of the tides and winds, especially the winds, was across from east to west, so that when the waves broke on the Long Sand they would drive it into the Boston Deep, which would therefore be filled up were it not for the action of which he had spoken—the ebb-tide rolling the sand back again to still water where it formed the bar.

He wished now to call attention to his model of the River

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Mr. Shelford. Humber, made many years ago, which illustrated the action of the tides within that estuary. There was no bar at the mouth of the Humber. There was deep water instead at low-water from 72 to 108 feet between the mouth and the open sea. The Humber contained an enormous quantity of alluvial matter, finely comminuted, which rested nowhere but in still water. There was no material carried down by the river of sufficient size to stand the action of the sea, consequently what was discharged from the Humber was found in the shape of mud in places where there was slack water only, especially off Cleethorpes and Saltfleet, where there was an area of slack water which escaped both the ebb-current from the Humber and the ebb-current from the Wash going northwards. The reason why the Humber was so very muddy was probably that there were great embayments upon it. The formation of the mouth was remarkable, there being a natural groyne (Spurn Point) formed by the action of the waves. Inside that groyne there were thousands of acres of land where mud was deposited by the ebb-tide, and returned by the succeeding flood. He thought the reason why the Humber was so muddy was that the mud did not escape so freely as from trumpet-mouthed rivers, but the mud did not tend to form a bar. On the other hand there was an action going on outside which was very important. For 30 miles north of Spurn Point the coast was diluvial clay, which contained shingle, and this was carried forward by prevailing winds and the flood-tide to Spurn Point (where the President had trapped a great quantity of it and so had preserved the Point). That shingle, supposing it to be strong enough to overcome the tide, would close the river, and had already diverted it southward. On the east coast almost all the rivers were diverted by a similar travel of shingle southward. The Yare, for example, had been diverted for miles at Yarmouth, and so with other smaller rivers, and in some cases there were bars. Why there was no bar in the Humber was a very interesting question. He could only account for it in this way; that the ebb-tide was sufficiently strong to maintain a deep channel for about 8 or 10 miles beyond Spurn Point where deep water was reached, and a strong littoral ebb-current was running northward which dispersed the detritus.

Those were one or two examples of rivers, with and without bars, that had come under his own professional observation. It was dangerous to generalize, and he would rather not do so; but he should like to say that he entirely agreed with one of the conclusions at which the Author had arrived, namely, that the causes which

operated in maintaining the existence of bars in tidal estuaries came from the sea and were not due to the inland water. But he would add that that did not apply to bars at the mouths of rivers flowing into tideless seas. Mr. Shelford.

Captain W. J. L. WHARTON, R.N., said it was with diffidence that he rose to make any remarks upon a professional subject before a professional society; but he might be permitted to state the view of a sailor who had always taken interest in such matters, and had seen a good many bars. He had listened with great pleasure to the Paper, as the Author's opinions agreed entirely with those that he himself had formed. He was also glad to find his old fellow-officer, Captain Calver, quoted as an authority upon the subject. Captain Calver had written a very able book nearly forty years ago, and had had the satisfaction of living to see many of his views therein expressed, especially in regard to the treatment of bars, confirmed. He had made many reports to the Admiralty, and the correctness of his views had been thoroughly proved. Captain Calver attributed the formation of bars in most instances to what he called the stroke of the sea, and he understood the Author to agree with that view, in which he also concurred. He was not, of course, prepared to say that a bar was caused by one force alone; like other things in nature it was the result of a combination of several forces; but he was convinced that the powerful factor in the formation of such bars as the Author had referred to was the sea. He understood the stroke of the sea to be a violent forward movement of a considerable body of water, whether caused by a breaking sea, or by the horizontal motion into which a wave motion was transformed in shallow water, meeting a considerable outflow of river or tidal water more or less at one spot. He was speaking of a bar as defined in the Paper namely, a more or less narrow ridge, with deep water on both sides of it. To his mind an estuary like the Thames went very far towards proving this. The Author had stated that an estuary gradually widening and deepening was one in which no bar was formed; but he had not gone further than that, and given the reason. In the case of the Thames, if there was a bar, it would probably be at Southend, where the river ended; but the mouth of the Thames was encumbered with many sands, and the sea could not get in there. There was not sufficient sea to move the sand at one particular point; and its force was distributed. There might be bars again at the entrance of the channels between the great sands which were a prolongation of the river, as the Black Deep, but there the estuaries gradually deepened to 15 or 16 Captain Wharton.

Captain Wharton. fathoms. The sea was not very heavy; it had not what sailors called a fetch, a deep undulation; there was not sufficient sea to move the sand and push it forward in opposition to the current. It was different in the case of the Tay. The estuary of that river was not exactly the same formation as the Thames; but the sand had formed, instead of a number of individual sands with deep channels between them, one large sand, crossing the entrance, so that the river was practically prolonged until it met the sea, and the consequence was there was a bar there, the sea being sufficiently shallow. At present, however, he believed it was better than it had been for many years. The Author had used an expression, which he did not quite follow, about a shallow sea aiding the formation of bars. If by that was meant that the estuary of the sea immediately outside where the bar was formed must be shallow, he agreed with him; but if he meant that the sea outside should be shallow also, he failed to follow the argument. It appeared to him that there were many cases where there was a deep sea outside, and consequently a very heavy fetch, beating on a shallow coast, and there would be a bar, just as in the case of the Zambesi, where there was a heavy sea and comparatively deep water outside; indeed, there were no worse bars anywhere than in the Zambesi. There was another little point to which he must demur, namely, that a bar, such as the Tyne formerly had, was no impediment to navigation because the river was shallow inside it. That was scarcely correct; because it was a different thing to cross a bar and to force a way up a shallow river; one thing could be done, but not the other on account of the sea on the bar. He should be glad to know whether the theory advanced as to the bars of the Danube and Mississippi met the Author's approval. He thought they were both unsatisfactory; in both cases the sea had a very large part to play. There was a continual easterly wind at the mouth of the Danube, and he imagined that that must have a great deal to do with the formation of the bar. Supposing there were no sea, the stream running out into a tideless and smooth sheet of water, he could not see that a bar would be formed of the kind mentioned. There would be a great conflict; but the force of the river running into the still water would set up a current which would be carried out a great distance, as was well known in the mouths of great rivers; and the water could hardly be called still. Of course it did not require water to be perfectly motionless to deposit material in suspension; but it needed a very considerable diminution of its velocity, and he could not think that deposition in one spot would

occur unless there was some opposing force, which he believed to be the stroke of the sea.

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Wharton.

Mr. J. C. STEVENSON, M.P., said he could only give his own impressions from an entirely non-professional point of view of what the situation was on the Tyne before any improvement took place. Having lived there during the whole period from the commencement of the improvements, and knowing what the state of matters had been, his description would be this, that the bar was not a piling or heaping up of sand beyond the natural level, but it was very much the depth of the ocean, along each particular contour line which would have existed if the river had not been there. The contour lines on the Admiralty charts, previous to any works being undertaken in the way of piers or dredging, were scarcely at all thrown out opposite the Tyne entrance, as they ran north and south. The Author had stated that the Tyne was a case where the bar did not affect the navigation. He understood his meaning to be that it did not diminish the depth of water at the place which would have existed if the river had not been there at all. The promontory on which Tynemouth Castle stood, which acted as a natural pier, controlling the direction of the ebb-tide before it joined the sea, no doubt caused a deepening along the line of the promontory, giving deeper water inside what was called the bar than there was at the bar itself. In the same way the contraction of the river in Shields Harbour gave the deep water in that harbour, which formed an anchorage along the concave sides before the recent improvements were adopted. He considered the improvement in the Tyne to be mainly cutting away the sands by dredging, and then, by means of piers running out into 30 feet at low-water, protecting the dredged part so that the waves at that depth had no action at the bottom. It was different where the piers ran across shallow sands, where the channel was apt to be levelled up by the action of the sea. There, the piers protected the bottom from being disturbed, so that the bar so-called having been once dredged away did not re-form finally. It did re-form several times, through the sands which were enclosed by the piers, leaving many acres dry at low-water, being scoured into the channel by the action of the waves. The sands were now scoured away by the waves to what might be their natural equilibrium, having been dragged down into the channel from either side of the large area within the piers. The sands to the south were washed away into the dredged channel, and had to be picked up again. Those sands had been very much diminished in level, and were not so high at low-water as they used to be.

Mr. Stevenson.

Mr. Stevenson. He remembered a prediction made by an eminent Admiral who was present at a meeting of the British Association in Newcastle, just after the improvements were commenced and the piers designed; the prediction was to the effect that there would be a silting up inside of the piers, and he traced with his pointer the line at which he predicted the silting would take place. But the opposite result followed, the heavy sea there having washed the sands away. He thought, therefore, that the great improvements in the Tyne were due mainly to the extensive dredging which had been carried on, not only at the entrance, and up to Shields Harbour, but to the head of the navigation. With regard to the action of the waves, he could not speak with any confidence; he would only say that the action of the waves at that point of the coast was very severe. There was an unlimited fetch from the North Pole down to Tynemouth Castle, and comparisons could not be fairly drawn between the action of the waves on a coast situated like that, and the action of waves on a shallow coast like the Dutch coast or that of the English Channel.

Mr. Redman. Mr. J. B. REDMAN considered the Institution was indebted to the Author for bringing forward a subject of much interest to large numbers of the profession, and which must be of the greatest importance to an insular and commercial people like the English. The opinions held in reference to the formation of bars had been as divergent and opposite as was the natural physiography of tidal estuaries and outfalls. A galaxy of eminent names might be quoted of persons who had written largely on the subject of the formation of bars—De la Bêche, Hutton, Playfair, Rennel, and many others. The effect produced by reading their works was a belief that the cause of harbour bars came from inland. He thought that experience would endorse one of the conclusions of the Author, that the causes of bars at the entrance of tidal harbours, at least, were oceanic or marine. In pursuing the subject, engineers were apt to imagine, innocently enough, that their views were more original than they really were, forgetting, ignoring, or not being aware of what many pioneers had essayed in the same direction. About half a century ago a very elaborate report was written and published by Mr. W. B. Prichard on Shoreham Harbour, and it was in the Library of the Institution. Mr. Prichard was in antagonism with Mr. Chapman, one of the leading hydraulic engineers of that period. A few years afterwards he published a work, known as “Prichard on Bar Harbours,” A.D. 1844. He had not seen it for many years; but, judging from the tenor of the report on Shoreham Harbour, the writer would probably have

endorsed the Author's conclusions as to the origin of those forma- Mr. Redman.
tions. About a decade after the publication of the book Mr. Redman contributed a Paper to the Institution on the South Coast of England,¹ and eight or ten years subsequently another Paper on the East Coast of England.² He would not go over well-trodden ground, but would simply remark that the tidal outfalls along the whole stretch of coast, from Portland to the Wash, showed indubitably that, of the forces producing the bars, the prime motors were the winds and their attendant waves. All the harbour outlets on the southern coast trended up channel to the eastward, owing to the prevailing south-westerly winds; and all the outfalls on the eastern coast were deflected southward, being open more especially to north-eastern gales. Without going much into detail, he would point to four examples on that stretch of coast directly illustrating that position—Yarmouth and Harwich on the eastern coast, and Folkestone and Newhaven on the southern. The town of Yarmouth and its parish church, St. Nicholas (said to be the largest in England), stood upon an ocean bar; and in the graveyard it was necessary to timber the graves in burying the defunct inhabitants. The harbour had had something like six outfalls, and it was not until the Elizabethan period that the outfall became permanently directed at the Gorleston end by Dutch engineers. In more modern times the attempt had been made to maintain that outlet. The endeavour of the effluent waters had always been to creep down to the south, and on one occasion the water did effect an outlet as low down as Corton. The President was perhaps better acquainted than any member present with the modern efforts to maintain the channel, having been professionally connected with the harbour for some years. Harwich told the same tale. At one time it almost shared the same fate as Yarmouth during the Edwardian period, being almost filled up by the travelling shingle across the mouth, so much so that the high light and low light that had been in use for many years were disestablished, and a new high light erected southward of Harwich, and a light on the point. The low stone breakwater or groyne running out from Beacon Cliff was erected forty years ago, pointing towards Landguard Point. Its object was to confine the effluent waters upon the ebb, and direct them towards Landguard Point, with a view of checking its advance. The work had no influence on the Point; it still went forward to the

¹ Minutes of Proceedings Inst. C.E., vol. xi. p. 162.

² *Ibid.*, vol. xxiii. p. 186.

Mr. Redman. southward and the westward, and appearances seemed to indicate that the harbour would eventually be choked up. Subsequently a timber groyne was erected on the Felixstowe side to the northward by Mr. Brough, and the effect of it had been to prevent the travel of the shingle to the southward, arresting it before arriving at Beacon Cliff; and that, coupled with dredging, had maintained the channel. The harbour in the time of Henry VIII. was a Royal dockyard; it was never accounted of any great importance even at that period, and had now only 13 or 14 feet at low-water. Those, he thought, were samples that endorsed the position that the origin of the formations in question was oceanic. Five years ago a committee was appointed by the British Association to report upon the erosion of the shores of England and Wales, and whether it was checked or hastened or influenced in any way by artificial works. The Admiralty Hydrographer, Captain Wharton, was a member of that committee, and for the first two years Mr. Redman was a working member. Recently, however, the existence of the committee had been rather mythical—they now never met, and the work had been mainly done by the acting secretary, Mr. W. Topley. Two or three reports had been issued and a large amount of information collected, and the results of the inquiries made had been to endorse the position that the origin of bars in tidal harbours and estuaries was oceanic. It would be a bold attempt to lay down any definite plan for dealing with bars along the shores; but it was clear that where there was a large fetch of sea into a tidal river, parallel piers conducting the effluent waters presented many arguments in their favour. Where, on the other hand, there was no back-water, piers like those of the Liffey, the Tees and the Tyne, the wide part next the shore converging towards the outlet appeared to be the form most likely to deepen a channel, assuming that the piers went into deep water free from deposit. But there were a large number of harbours, such as those of which the Author had special knowledge in the estuaries of the Wash and other localities of that description, where the trade would hardly warrant such an outlay. Where the foreshores were of a different character, composed of sand and ooze, guiding-banks, which would allow the tidal water to flow from the foreshore into the channel, appeared to be the most desirable mode of treatment. In regard to training-banks a large amount of work had been carried on by American engineers, respecting which there was a very great difference of opinion. He would refer to a paper published two years ago by Professor L. M. Haupt, an American engineer, on "Harbor Entrances," and the allegation made by him

and other critics was, that, with many of those training-works, Mr. Redman. there was an enormous amount of accumulation on the windward side, and a corresponding gulling out or deepening on the lee side, with shoals beyond their terminals where their influence ceased, and in some of the roadsteads where those training-works had been executed, the harbours generally carried less water than they did before their inception.

Mr. A. GILES, M.P., Vice President, agreed with the Author Mr. Giles. generally as to the causes of bars. It had been stated in the Paper that they were not so often caused by the fresh water of rivers as they were by the action of the sea; and he had an instance in his mind where one side of the bar was composed of silt brought down by the river, and the other side was composed of sand brought up from the sea. But one thing seemed to be difficult to understand. Why was it that the seaward slopes of the bars of the Mersey and the Ribble and the landward slope were steeper than the natural slope of the soil? He should be glad if the Author would state whether he knew any cause to which that could be attributed. He quite agreed that a funnel-shaped estuary of a river like that of the Severn and the Thames was more likely to be free from bars than other rivers. He had given very good instances showing that it was not always detrimental to the bar of a tidal river to cut off the sinuosities and bays; but he agreed with the general principle that the more water admitted into a tidal river, and the more water let out, the better chance there was for keeping the channel open. At the same time he admitted that the water coming over sandbanks at a level far above low-water had little effect in keeping the channel clear. There were many instances of regulated rivers. He might instance the Tyne, which he remembered when there was not more than 6 or 7 feet depth of water over the bar. But it had now been increased to a depth available for large steamers, principally by regulating and dredging. The Tees was another example of the same kind. The Author and he had also been engaged in the investigation of another river—the Ribble—where they hoped the same result would follow. But where the tide rose, as in the Ribble and the Mersey, to something like 30 feet, vessels were rather independent of bars, because if they could have 6 or 9 feet, as in the Mersey, over the bar at low-water with 30 feet of tide, they were pretty safe to get into the dock entrances. Another suggestion of the Author's was, that no good could be done by constructing piers to regulate or improve bars, unless they were carried into deep water. There was pretty good evidence of that in the case of

Mr. Giles. Yarmouth and Lowestoft. There the set of the shingle had driven the mouth of the river Yare 2 or 3 miles south of the direct line in which it would have naturally come; the discharge at Lowestoft had not gone to that extent, because a pier had been constructed to stop the shingle, and allow the water to go out in its proper course; but the water at the back of that pier was gradually shoaling, and the pier would have to be extended into deep water before any permanent good could be done. He had an instance before him in his own practice, in which he thought it desirable to widen a river. It was found after long experience that there was just sufficient water to keep the old river open without deposit; but when he widened the river 50 feet, and made a quay for the purpose of benefiting the navigation without obstructing the other part of the river, he had found that the consequence of the widening was, that there was a deposit alongside the quay, which had never occurred before in the river. That, he thought, was a proof that a river would to a certain width maintain its regular depth; but if an attempt were made to widen it without increasing the volume of water going through the channel no good would be done.

Mr. Hurtzig. Mr. A. C. HURTZIG observed that although a good deal had been said on the subject, he might be permitted to make a few remarks, having been for eight or ten years engaged in the construction of large works in the Humber estuary, and having studied tidal questions to a greater or less extent. He thought the abstract question whether bars were due to causes which arose in the sea, or to causes arising in the river, was not of serious import to engineers, provided they were able to determine the causes which tended to their continuance, and were able to design works which would counteract those causes. The Paper had given a good deal of food for reflection on the question of bars, but he would confine his remarks within narrow limits, which would have a greater bearing on the Mersey, perhaps, than on other bars. The Author stated that a sandy bar, in a tidal estuary, owed its shape to causes arising from the meeting of the ebb and the flood currents at a point where their effect was at a maximum. He could not understand that statement. In a tidal estuary, such as the Mersey, there was no particular point where the ebb and the flood current met any more than at other points, every point from end to end of the tidal compartment was successively a point of meeting of the flood-tides and ebb-tides. The only places that he knew of where there was really such a meeting of tides and conflicting currents were such as that described by Admiral Beechey, in the Irish Sea,

where two main branches of the ocean tide came round the north Mr. Hurtzig. and the south coasts, meeting between the Isle of Man and the coast of Ireland. There was a place where there was absolutely slack water, and the bottom of the sea was covered with soft mud, slack water being due to the conflicting effect of the two flood currents; yet close by, in the narrow pass between the Irish Coast and the Mull of Cantire, there was a channel 140 fathoms deep, scoured out by the flood-tides and the ebb-tides passing through at a high velocity. Taking the case of the bar at the Mersey; the very existence of a bar indicated that there was a permanency of slack water, not temporary slack water at the turn of the tide. It was well known that a tidal current of 3 feet per second, equivalent to 2 miles an hour, would move shingle; and therefore a sandy bar like that of the Mersey, with 9 feet of water upon it, could not exist unless there was permanent slack water. Such slack water could only be due, he thought, to two causes, either to a continuous undercurrent which was always opposing both the flood-tide and the ebb-tide throughout its normal progress in and out of the estuary (which was hardly conceivable), or to the dispersal of the water into larger and larger channels, which dispersal left the water passing over the bar to pass in and out at a slow and almost constant rate. He had taken the Admiralty Chart of the Mersey to see to what extent that view could be borne out by facts, and he had taken some sections of the various approach-channels to the Mersey. He found that the gross area of the low-water channels passing through the banks into the Mersey estuary was about 150,000 square feet, of which about one-half, or 80,000 feet, received water which passed over the bar. An hour and a half after low-water, when the tide had risen 6 feet, the area of the channels which fed the Mersey was about 300,000 square feet, and the water which passed over the bar was only $\frac{1}{2}$ of the total instead of $\frac{1}{2}$, as in the previous case. That showed that there was a dispersal of the water, and that the flood-tide which fed the estuary did not necessarily pass over the bar at an increasing velocity; and the rate of 4 or 5 miles an hour in the inner estuary could not, over the bar, be more than such as would leave a sandy bed unmoved. If that view were correct, he thought that the works of the engineer to counteract that force, which tended to the continuance of a bar, should be such as to increase the velocity over the bar, by closing the subsidiary channels and preventing the dispersal of the water to which he had referred; and he also thought that the various improvements carried out on the bars of the Tyne and the Tees, and on other

Mr. Hurtzig. sandy foreshores, were due largely to the appreciation of that fact.

Mr. Wheeler. Mr. W. H. WHEELER, in reply to the discussion, said that the point raised by Mr. Hurtzig was a mere difference of words. He had laid down clearly enough that the way to remove bars was by concentrating the ebb current and strengthening its force by training-works or otherwise, and that appeared to him the conclusion that Mr. Hurtzig had arrived at. Mr. Hurtzig objected to the statement that the actual shape of a bar was due to the contending forces of the ebb and the flood currents when they were at their maximum. If it was not due to that he was at a loss to account for the shape of the bar. Mr. Giles had also asked why the bar should be of the peculiar shape referred to. Mr. Wheeler had studied the subject and had tried to find out a cause for this. In order to watch the action of water on sand, he had a model constructed in which he let a stream of water continuously run down carrying sand with it, and he had also closely observed the models of the Mersey which Professor Osborne Reynolds had made some time ago, and watched the action of the water. The only conclusion he could arrive at was that when the two contending forces, the ebb and the flood, met, as in the case of a collision of railway-carriages, they telescoped. There was a continual rotary action of the water working upwards which drove the sands up and held them in the peculiar position which they had in a bar. He could not see any other way of accounting for it. When sand was being moved along a channel, it was not carried by the water in a thin film spread over the bottom, but assumed the form of a series of long slopes on the upper side, or that from which the current was coming, with steep faces on the lower side, something in the form shown in *Fig. 3*. Over this face, or tip, the particles of sand were rolled, the crest gradually advancing forward. In a tidal channel, where the current was continually reversed, the position of the faces varied with the direction of the tide. At the junction of the channel of an estuary with the sea, where the conflict between the ebb-tide and flood-tide took place over the sand being rolled into the channel by the littoral current and the bar was maintained, a somewhat similar action went on. The particles of water of the flood-tide or ebb-tide on coming in contact with the ridge of sand lying across the channel were deflected upwards, as shown by *Fig. 4*, and carried the moving sand over the top of the ridge. A rotary or screwing motion was also set up, which whirled the sand round the bottom of the hollow at the foot of the ridge, continually scouring it deeper, *Fig. 5*. The particles of water which passed

over the ridge and down the other side in like manner whirled round Mr. Wheeler. the sand at the inner foot. It was owing to this rotary action that the ridge and also the depression which was always found on either side of a bar were maintained. It was also due to this action that the pools in rivers and the deeps, such as the Sloyne in the Mersey, or Lune Deep in the Irish Sea, were kept from being filled up by detritus. Captain Wharton had also asked him

Fig. 3. *Fig. 4.* *Fig. 5.*

a question with regard to such rivers as the Danube. The distinction he had drawn in the Paper was that, in a river like the Danube, the material of which the bar was composed came from the land, and not from the sea; but in a tidal river the matter came from the sea and not from the land. The material of which a tidal bar was composed was pure sand and not diluvial matter. Mr. Shelford had stated that he thought the cause of the bar at Boston Deep was the tide setting over the Long Sand and washing

Mr. Wheeler. the sand into the channel which was carried by the ebb. That, no doubt, was correct. The tide did set over the Long Sand, and in setting over it carried some sand into the channel. If this sand was not fed from somewhere it would have long since disappeared, and the feeding material came from the sea. Mr. Vernon-Harcourt's criticisms, he thought, had rather confirmed what he had stated. He seemed to think that sufficient importance had not been given to the value of fresh water, and the case of the Ouse was instanced, where deposit had taken place in the summer, and it was removed in the winter. That was a valuable illustration, confirming what he had stated in the Paper, and showed the service which fresh water rendered in maintaining a tidal river. Mr. Vernon-Harcourt had also challenged the statement as to the effect of applying training-works in the upper estuary of the Mersey, and the remark made in the Paper that the bar of the Mersey deteriorated with the freshets that took place in the upper Mersey. The estuary of the upper Mersey consisted of a large quantity of pure sand, similar material to that of which the bar was composed; and it was a singular fact that the bar of the Mersey deteriorated whenever there had been heavy freshets down the Irwell, or the Mersey. He had prepared a Table commencing with 1864, showing the depth of water on the bar, and the rainfall.

Year.	—	Depth on Bar.		Rainfall.	—
		Ft.	In.		
1864	{ Victoria } Channel	15	0	30·64	{ A great fret began about 1860 and continued to 1869.
1865	Do.	13	0	28·39	
1866	Do.	12	0	43·17	Great flood in Irwell.
1867	{ Queen's } Channel	10	0	34·58	
1868	Do.	10	0	32·23	{ Great fret off Stanlow Point; 5,800,000 cubic yards carried out of the estuary.
1869	Do.	9	0	35·45	
1870	Do.	9	0	27·55	
1871	Do.	9	0	33·23	
1872	Do.	8	0	50·69	
1873	Do.	7	0	28·82	
1874	Do.	7	0	30·10	
1875	Do.	8	0	35·49	
1876	Do.	8	0	36·96	
1877	Do.	9	0	41·63	
1878-82	Do.	9	0		
1883-89	Do.	10	0		

It would be seen that in 1864 there was a depth of 15 feet of water on the bar; in 1866, when there were very heavy floods down the Irwell, the depth had decreased to 12 feet. Between

1866 and 1870 there was another great change in the channels, Mr. Wheeler. followed by a further decrease on the bar to 9 feet in 1869. In 1872 there was a very heavy rainfall, and a very great disturbance of the sand in the upper estuary—what was termed the great fret. That continued until 1873; and it resulted in the removal of a large amount of sand from the upper estuary. The depth at the bar still decreased, until in 1873 there was only 7 feet depth of water upon it. Since that time there had been dry seasons, and few floods down the Irwell or the Mersey, so that the depth gradually increased until at the present time it was 10 feet. He thought that this justified the conclusion arrived at in the Paper, that if the sands in the upper estuary were fixed, and not allowed to roll about and wash down to the bar, there would be an advantage. Mr. Vernon-Harcourt had also referred to the Ribble. He was glad to have Mr. Vernon-Harcourt's testimony to the fact that the training-works carried down the estuary had resulted in deepening the main navigable channel. The objection he raised was that they might probably result in damage to some of the inferior channels in the estuary. Mr. Wheeler thought that that was a matter of very little importance. If by training-walls the main navigable channel up which the ships went could be deepened it mattered very little what happened to the smaller channels. Mr. Kinipple objected to a statement in the Paper, that the material on the bar came from the sea and not from the land, and in support of that he quoted certain experiments that he had made with a pail of water and a little sand, which he had poured down a trough. He thought that was rather like a storm in a teacup, comparing a few buckets of water poured down an artificial trough with what would happen in an open sea. He was not disposed to give up what he had stated on the results of an experiment of so small a character. He thought he might fairly congratulate himself that the conclusions at which he had arrived had been generally supported by the members of the Institution.

Sir JOHN COODE, President, said he was sure the members would agree with him that the Paper had been one of the most exhaustive character, and that it indicated an amount of reading and study on the question of the formation of bars at the entrance of tidal estuaries, of which very little idea could be formed by those who had not gone into the subject. The Author had in his Paper condensed a very great amount of information. Sir John Coode could not agree with the speakers who had laid so much stress upon the results of experiments by means of models, because they almost altogether ignored the all-important factors of

Sir John
Coode.

Sir John
Coode.

floods from the uplands, and gales from the sea. The floods, of course, all operated in one direction—down the estuary. But what happened within an estuary during gales of wind? There might be a flood or not; there might be a gale blowing strongly up the estuary, or down the estuary, and of course it required no great stretch of imagination to see that those two conditions would bring about very different results. There might be gales blowing transversely directly across the estuary from left to right, or from right to left, or there might be gales blowing obliquely at all sorts of angles. How the experiments referred to with regard to estuaries were to be taken as indications of what might be expected in nature, he for one was at a loss to understand. Then, going seaward, there were gales off shore and gales along shore, gales of short continuance, and gales of long continuance. It was not necessary to go further back than a month for an example of the latter. In January continuous gales had been blowing night and day for a fortnight. He did not know how those conditions were to be indicated by the models of which so much had been said. Those varying conditions did not come into play in the models at all. While he congratulated the Author on his Paper, he desired to comment upon one or two points in it. The Author appeared to adopt the view of Messrs. Humphreys and Abbot with regard to the Mississippi, and he had stated that “The current is able to roll the detritus along the bottom, until the river water begins to ascend upon the salt-water of the gulf, when the rolled material is left upon the bottom in the dead angle of the salt-water. A deposit is thus formed which produces the bar.” He had recently met with a somewhat important Paper written by the late Captain Eads, who traversed both those statements as being founded on fallacies. With regard to sand being rolled or pushed along the bottom; he said he had gone down to the bed of the Mississippi in a diving-bell when the current was so strong that it was very difficult to get the bell down at all, and so far from finding the matter being rolled along the bottom, he could only compare it to flakes in a snowstorm. The “dead angle” was not a very apt expression. The reference was to a triangle, a wedge-shaped figure supposed to be found outside the bar. Captain Eads demolished that argument, because he gave from the appendix to the very same report of Messrs. Humphreys and Abbot the results of ten or twelve experiments; and the velocity along the sea front in those experiments indicated an average of $1\frac{3}{4}$ foot per second—more than three times the velocity necessary to move sand. It was remarkable (he said somewhat

satirically) to find a dead angle of water which was supposed to underlie the current of a mighty river. Sir John Coode hoped that the members quite understood what he was referring to. The contention of Messrs. Humphreys and Abbot was that under the bar there was a dead angle of water. Their argument was founded upon two so-called facts, which Captain Eads called fallacies: first, that the material was pushed along the bottom; and secondly, that there was a dead angle in front of the bar. There was no such dead angle of still water, because the lowest velocity indicated in the experiments was about 0.92 foot per second, and in some cases it ran up to 3 feet per second. The Author had spoken of the material composing the bar travelling along the beach. That hardly agreed with the Abbot Castelli, who said distinctly that the principal cause of the bar was the violence of the sea; and there Sir John Coode entirely agreed with him. It had been his view, for many years, that the most important factor in the formation of bars was the power of the waves which might be exerted either in heaping up or throwing down material practically at right-angles or normal to the line of the coast. He based that statement upon what he thought was a very noteworthy fact. It might seem like ancient history, but in the year 1853 he presented a Paper to the Institution on the subject of the Chesil Bank,¹ at the end of which he gave some remarkable facts indicating the clawing down in a single night of an enormous quantity of shingle, amounting to millions of tons by actual measurement, extending over a length of about 8 miles of coast. He would take that as the basis of the figures he was about to give. He would assume a bar which was just 200 yards across from side to side, not a very large bar. And what happened? Taking the actual observations on the Chesil Bank for a length equivalent to 200 yards along the front of the beach, there were 63,000 tons moved in one night, and at the next spring-tide 45,000 tons were thrown upon the beach again. If that was not an indication of the forces of the sea in heaping up and throwing down material, he did not know what was. But there was a still more striking fact, that in a month afterwards, December, the quantity which was thrown down by the sea, in that length of 200 yards, was no less than 76,000 tons. In five days from that time the quantity heaped up was 60,000 tons. He thought that in the face of those facts the members might

¹ Minutes of Proceedings Inst. C.E., vol. xii. p. 520.

Sir John Coode. form some idea of what the power of the sea was in dealing with material of that kind.

Mr. Wheeler. Mr. W. H. WHEELER said he did not understand Messrs. Humphreys and Abbot's contention in the way indicated by Sir John Coode. If he had done so he should not have endorsed it. It did not mean that there was dead water at the back of the bar—simply that it was a slackening of the current due to the action of the salt-water in forcing a way under the fresh water at that point.

Sir John Coode. Sir JOHN COODE, President, said it appeared to him that the contention of Messrs. Humphreys and Abbot was as he had stated it.

Correspondence.

Mr. Baensch. Mr. BAENSCH found that the Author's treatment of the subject, and the conclusions at which he arrived, corresponded entirely with the views of German engineers who had made the subject a matter of special study. The Baltic was an example of a sea with a very small range of tide; and under these conditions the only factors in the formation of bars at the mouths of estuaries and harbours were the littoral current, which conveyed the abraded and suspended material, and the wave-movement, which deposited it upon the shore, while the counteracting agents were the outflow of fresh water and the small tidal ebb. The littoral current in the Baltic, depending upon the prevailing westerly winds, caused shoals to be deposited generally from west to east, while where the coast was sheltered from the west the usual formation was from north to south. There were few examples of fresh-water shoals, as most of the alluvial deposits from inland sources were dredged away before reaching the coast, or the current was strengthened by improvements in the channel, while in the larger harbours, such as Swinemünde, Pillau, and, above all, Memel, the deposit was effectually checked by the inner lake. In the North Sea, where there was a greater range of tide, the ebb and flow came into greater prominence as factors in the case. Outlets to the sea might be divided into two classes: first, river estuaries, such as the Weser, Ems, Elbe, and Eider, where the discharge of fresh water had to be added to the ebb-tide; and second, inlets in the coast, lagoons or meres, such as the Jahde, North and South Diep, Hever, Schmaltief, Ruytergatt, Vortrapptief, and Listertief, where, in the absence of back-water, there was only the effect of the rising