Mr. COODE stated, that he had used Deane's diving-dress, and had been down in 10, or 11 fathoms of water, for the purpose of examining the bottom, and he had found the line of demarcation between the shingle and the sand to be very clearly defined at their junction. The greatest depth at which the sand and shingle were found to join was 50 feet on the west side of the bank. The bed of the East Bay was of Kimmeridge clay. There was no trace of the East and West Bays ever having been in connexion, even at the most remote period. The earliest notice of the Bank that he had met with, was that by Leland, in 1546. In 1824, an ordnance smack, laden, was carried by the sea right on the Bank, and the easiest way to extricate her was to launch her into the East Bay. With regard to the tide stream, up to Wyke from the Start Point, the tidal currents ran equally, upon flood and ebb, for about 6 hours, and at the rate of $1\frac{1}{2}$ knot each way. The tide in the Race of Portland ran $6\frac{1}{2}$ knots an hour. This was, however, purely local, and was due to two causes, one being the indraught into each Bay, according as the tide was flowing, or ebbing, the other being the rapid deepening of the water from 6 fathoms to upwards of 30 fathoms, this increase of depth taking place in little more than a quarter of a mile. The shingle at Weymouth was derived from the Cliffs to the west of Lulworth, and might be mentioned as a solitary instance of the travel of shingle from east to west.

Mr. BABBAGE thought an inquiry into the form assumed by pebbles under water, under certain circumstances, would lead to useful results, and might throw some light on such formations as the Chesil Bank. At the east end of the Bank, the shingle appeared to be comparatively flat, whilst at the west it assumed almost a spherical form. He believed that the large pebbles would generally be found at the level of low water. The collection of facts recorded in the Paper was so large and important, that both engineers and geologists were equally indebted to the Author.

Mr. BIDDER, V.P., observed, that the Institution was seldom favoured with so good a Paper; and if it reflected credit on the Author, it would also extend the reputation of the Institution. It was not alone valuable for the inferences drawn from the facts which had been brought together, but it evidenced great research and much skill in observation. The facts advanced, in

some cases corroborated his own observations, whilst in others they corrected his opinions. But however acute and scientific the observations might be, on this particular locality, it would not be prudent to receive the conclusions, as applicable to beaches in general; in fact, it would be safer not to generalize upon this, or any other isolated case. The relative positions of the different-sized pebbles on a beach, depended upon the depth of the water, and the force of the waves. On a long shelving shore, like some parts of the coast of Kent, where the waves could only act upon the beach at, or about the time of high water, the larger pebbles were found near the top, after the occurrence of storms; because under such circumstances only, did the waves exert sufficient power to break heavily upon the beach. Under light winds, the force of the waves was expended in the shoal water, before reaching the beach. The Author of the Paper had shown, that the motion of shingle was derived from the wave of translation; and he had confirmed the views previously entertained, as to the effect of on and off-shore winds, and as to the slanting wind causing the wave of translation. The late Mr. H. R. Palmer's observations "On the Motions of Shingle Beaches,"[1] were made upon a very different kind of shore to the Chesil Bank. The great problem to be solved by the engineer, was, the condition under which a harbour could be maintained where there was a travelling beach. He only knew one instance of the kind, and that was at Lowestoft. The works there had been completed between six and seven years, and during that time they had suffered no injury, nor was the entrance to the harbour in any way impeded. But there the circumstances were quite peculiar and accidental. On the north side there was a fine clean sand, and on the south a clean beach, but thin. The conclusion he arrived at from these facts, was, that the travel of the shingle had spent itself at that point. Of the sand, 25,000 tons were annually used, for ballasting the vessels frequenting the port, and about the same quantity was washed up, so that the bank remained the same. Only ten miles off, at Yarmouth, the sand was continually accumulating, and forming a bar. At Aldborough, at the mouth of the River Or, the prevailing wind being from the south, there was a bank,

[1] *Vide* Phil. Trans. Royal Soc. 1834. Part II., p. 567.

somewhat similar to the Chesil Bank, forming an isthmus nine or ten miles long. Here the water deepened gradually, and he had no doubt a careful examination would confirm the Author's opinions. If the project which was before Parliament last year, for forming a harbour at Aldborough, by cutting through the bank beach, had been carried out, it would, he believed, have been filled up again with shingle very speedily.

Sir JOHN RENNIE said, the remarks of Lamblardie, a French engineer, on the movement of shingle on the coast of Normandy,[1] were, perhaps, amongst the earliest of the kind on record. Smeaton and Rennie had also made some observations on the beach at Dover. Lamblardie arrived at much the same conclusions as the Author of the Paper under discussion, and so also had the late Mr. H. R. Palmer, who did not appear to be aware of Lamblardie's pamphlet. These conclusions were, that the shingle was moved, principally, by waves due to the wind, and not to the tide; mere currents were not sufficient; it needed the successive impulse of the waves. Lamblardie also stated, that the waves acting in-shore undermined the cliffs, large masses of which were brought down, and if of chalk, or loose material, were soon dissolved, and the pebbles rounded by attrition; then where the wind struck the shore at an angle of 45°, the beach was moved on. When the waves acted in a direction parallel to the shore, the friction prevented the travel of the beach; the amount of this travel must, of course, at all times depend, on the supply of shingle from the cliffs, and on the direction and power of the wind-waves.

The most important engineering problem was, how and where to make a harbour in a travelling-beach. If the beach could be allowed to move on unmolested, or if it was supplied in such moderate quantities that its removal could be easily insured, the works might succeed; and even if the beach supplied any drift, the works could be extended seawards, so as to be beyond any probable injurious influence, and a dredging-machine could be employed, for removing the alluvial deposit. On the other hand, should the beach be in large quantities, then the case might be different. He recommended that careful observations should be made along the coast, with the view of finding such spots as

[1] Mémoire sur les Côtes de la Haute Normandie. Par M. Lamblardie. Tract 4to.

Lowestoft, where two forces neutralizing each other, rendered it peculiarly favourable for harbour works. Still even in designing them considerable skill was requisite to prevent deposit.

Mr. HAWKSHAW said, the direction of the tidal wave appeared to be nearly identical with that of the prevailing wind-wave. He thought there were certain depths at which the waves would not act upon the shingle, and that by extending the piers into that depth of water, the entrance to a harbour would not be effected by the travel of the beach. No general rule, could, however, be laid down for making harbours in a travelling-beach.

The sea appeared at one time to have washed up to Wyke and Fleet, before there was any such thing as the Chesil Bank. It would be very interesting if the Author of the Paper, in whose views he generally concurred, would devote some attention to the elucidation of the circumstances under which the Bank began to be formed. Viewing the relative position of the geological strata of the coast, to the westward of Portland (Plate 2, Fig. 1), it would be seen that, the series overlying the Devonian rocks were the new red sandstone, the oolite, and the greensand and chalk. Now if we imagined a time when the sea was washing the Devonian rocks, and not reaching to the chalk, it would be evident that no material, such as now constituted the Bank, could be brought down to form it. This state of things might have occurred, as all geologists would admit. As the waves washed away the lower series, those particular pebbles which had since formed the beach would begin to be supplied, and then, when the resistance between the stones just equalled the force of the waves, the Bank would begin to be formed. It was probable, that the extent of chalk exposed to the action of the waves, had, at a former period, been much greater than at present; and that the disintegration of the underlying green-sand, had expedited the fall of the chalk and flints, and thus supplied the material for forming the Bank.

Mr. JOHN MURRAY observed, that the height of the crest of the Chesil Bank being generally about 40 feet above high-water, the materials of which it was formed could not, in his opinion, have been all brought from so small a recess as the West Bay. He thought that the coast westward of it, as far as the Land's End, and the contour of the whole sea between England and

France, must be looked at, to account for that formation which had puzzled both geologists and engineers. The deep wave travelled with greater power and velocity than the shore wave. From the Lizard to the Start Point, and from the Start to Portland, the set of the tidal wave was towards the Chesil Bank. The direction of the wave was changed on entering the West Bay, so that the whole matter in suspension was thrown backwards towards Bridport; naturally, the larger pebbles remained at Chesil, whilst the smaller ones travelled westwards. In calm weather there would be little, or no action; but when accompanied by wind it would be considerable. He had traced the coast, and had found that at Lyme and at Weymouth, the pebbles were moving in different directions.

On the east coast, the shipping which frequented the coal ports, cast out at sea, particularly in fine weather, great quantities of ballast, in water 10 to 20 fathoms deep. The greater part of this ballast was composed of sand and pebbles, dredged from the Thames, with chalk and other matter foreign to the East Coast. After storms the shore between the Tyne and Hartlepool was strewed with these pebbles, which could only have been brought there by the action of the waves at the depths stated.

In the construction of the groynes at Sunderland to arrest the passage of the sand and shingle, the cross action of the waves, influenced by a ledge of rocks, caused the deposit to take place on the opposite sides of the groynes.

Large and small pebbles with sand were, in his opinion, moved at greater depths, under water, than was generally believed. M. Virla, by experiments at Cherbourg, found that the agitation of the waves extended to the bottom of the sea there. M. Vionnois, by observations in the Bay of St. Jean de Luz, ascertained that the agitation during storms had been felt even at the depth of 300 metres. Brémontier stated, that on the sand-bank of Newfoundland, the agitation descended even to 160 metres, and remarked that south of the Cape of Good Hope, the sea was broken, caused by the using of the bottom, where it was upwards of 200 metres in depth.

Mr. Joseph Gibbs could not allow the opportunity to pass, without expressing his dissent from the view of the Author, that large pebbles, when travelling under water, would be

acted upon more easily than small ones, because of the greater surface presented by the former to the action of the waves. Such was not the case. The movement of the beach in question was not so much due to the ordinary flow, as to what might be termed submarine currents, which had the power of carrying pebbles along the shore at great depths until the waves cast them up as shingle.

It was an interesting question to consider, from whence the shingle of the Chesil Bank had been derived, and whether that quantity of beach could have proceeded from the débris of the West Bay. He was certainly inclined to believe, that it was sufficient to produce it. Moreover, its geological character seemed to corroborate this opinion.

The travel of pebbles was alternately up and down a bank, and along with each succeeding wave. The action of the wave, however, was never directly parallel to the bank, but, generally, at a considerable angle to it. It followed, that the shingle would travel in a direction indicated by the oblique action of the wave. The movement of the shingle was influenced, to a certain extent, by the set of the tide along the shore. The fact of the larger pebbles being at the top of a bank, and the smaller ones at the bottom, whilst the foot of the bank was composed of sand only, or the smallest pebbles, might easily be accounted for. It should be borne in mind, that the wave in deep water had only an apparent velocity, which was converted into an absolute velocity when the trough of the wave touched the shore. It was then that the wave mounted up the beach, to a height commensurate with the dimensions of the wave, and above the level of the sea, carrying with it the shingle, stones, and sand. The velocity of the wave was speedily arrested by the gravity of the water, and then its retrocession commenced; but as the velocity and power of the wave of retrocession were not sufficient to carry back all the shingle, the larger pebbles remained on the top of the bank, whilst the sand and small pebbles were drawn to the foot of the bank. A slight obliquity in the oscillation of the wave caused the travel of the beach, from those places where the strata existed, which produced the material of which it was composed.

Mr. RENNIE had some years ago taken sections of the Chesil Bank, when he arrived at the conclusions, that the highest

beach was the result of storms, and that the terraces marked the various states of the tides. He agreed in the opinion, that the most probable source of the beach was the chalk cliffs in the West Bay, and that the cause of the accumulation was the revolving tide from the westward, the wind giving the particular direction. Near Lyme, the beach stretched only to a short distance from the shore; but it became gradually more extensive as it approached Portland. He had great doubts as to whether shingle moved much. He believed the late Mr. H. R. Palmer was correct in the opinion, that the largest shingle was generally to be found at the top of the beach.

Captain Fitzroy, R.N., thought that some consideration should be given to the direction of the currents on this particular part of the coast. In the West Bay, the stream of flood tide set round the bay, to the eastward; the ebb setting straight out of the bay. On the other side of Portland Bill, the tidal stream set in a contrary direction, so that all that was liable to be moved was drifted to the westward. These two streams —the flood on the west, and the ebb on the east—neither of which ran parallel to the main shore, combined to throw up a ridge, to which the projection of the rocky Bill of Portland gave support; and this had led to the formation of the curious Bank, which had been so ably described. The absence of Portland Bill would have permitted the free passage of shingle, but that point checked the travel of beach from each side, and caused the Bank to be formed. That the detritus came from the chalk formation, and not from any great distance, might be shown from other analogous cases along the coast, wherever there was a predominance of chalk, or gravel, in progress of destruction. On referring to Dungeness Point, it would be seen, that it had evidently been carried from Beachy Head. Little, or no shingle was found on a rocky coast; nor was there an instance, on any coast, of great masses of shingle, where they were not derived from the wearing away of some deposit in the immediate vicinity. He did not think that shingle travelled at depths of 40 or 50 fathoms under water. Shingle was never found in deep soundings, but only oaze shells and sand. The beach being supposed to be derived from the immediate neighbourhood, the large and the small together, the impetus of the larger stones would carry them

furthest, where their bulk and weight would cause them to remain, whilst the smaller ones would be partly removed by each receding wave. It certainly was the case that, on all beaches, the largest stones were moved, by water, the greatest distances. Before the Plymouth Breakwater was finished, and during the progress of the works, large blocks of stone were thrown up, and carried over the works to a very great distance; proving that the water had sufficient force to act upon large stones. The tidal rise and fall of the ocean, had no power to move any solid body onwards. The current caused by the tidal-wave might exercise force, but it was the wind-wave that acted most powerfully.

Mr. COODE admitted that, during on-shore winds, the largest pebbles were found at the top of beaches against a cliff, or a wall. In the case of the Chesil Bank, however, and in all cases where the shingle was not so checked, the largest sizes would not be found on the summit, or crest; but with a rising tide, and at those times when the shingle was accumulating, the largest would generally be found at the water line. With the wind at an angle of about 45° with the line of shore, the greatest amount of travel, or onward movement was observed, but the size of the shingle, more especially, was governed by the amount of undulation.

The Chesil Bank was due, he believed, to the bench of Kimmeridge clay, which he had found, (on the east side only,) at 3 feet under low water. The Bank was formed from the detritus of the cliffs to the westward, and it was remarkable that not a chalk flint could be found, from the Bill to Chesil Town. He did not think the shingle could be brought there by a return, or tidal current. The sandy material was quite sharp, and not rounded; but the sharp, shattered flint, noticed by Dean Buckland, and Sir H. De la Beche, would certainly have been rounded if it had been moved. The terraces were formed by the undulation of the wind-wave, the direction of the wind determining their line. The tides along the face of the Bank in the West Bay, up to Wyke, appeared generally to run each way for six hours, and with equal strength in each direction, so that it did not seem possible, that the tide stream could affect the travel of the shingle along the shore.

Professor AIRY, through the SECRETARY, whilst adding his

testimony to the general value of the Paper, said he wished to acknowledge one point as peculiarly valuable, namely, the ascertaining of the existence of the clay bank underneath, which had undoubtedly determined the line of the Bank from Portland. The determining cause of this direction, and of the vacuity of the "Fleet" had now been settled. In a letter to Sir C. Lyell, a year ago, he had suggested that there must be a bank, or at least a shoal enough to make the sea break. He was under the impression, that the Author's examination of the cliffs and quarries was not sufficiently extensive, or close, to enable him to say positively that Portland could not furnish the materials. He remarked on this freely, because it was critical, as regarded the origin of the Bank, and because it appeared to be contradicted by other accounts. For instance, in Conybeare and Phillips' Geology (page 174), there was a complete section from the west side of Portland, in which there were "many layers of flint and stony rubbish 6 feet;" "many layers of flints and unserviceable stones 55 or 60 feet." Until this want of materials in Portland was proved, more certainly than it appeared to be at present, he must retain the opinion, that the Bank had travelled from Portland.[1] There was nothing more remarkable in this, than in the cases of other bays, with cliffy terminating promontories. Thus, at Caswell Bay (where the tide ran rapidly past), after a gale from the west, or south-west, the pebbles from the cliff points were rolled towards the bight of the bay, and were there ground into sand. Although a swell might roll up the centre of the English Channel, yet there was a tendency in all such places, for the direction of the waves to change gradually, as towards the general line of shore, and to roll pebbles that way. He quite agreed in the opinion that very little was ascribable to the action of the tide.

Mr. COODE, through the SECRETARY, remarked, that it was not without a close examination, and an intimate knowledge of all

[1] In a later communication to the Secretary, Professor Airy stated that the evidence adduced by Mr. Coode, as to the mineralogical character of the pebbles, and their original connexion with the strata at the western extremity of the Bank, now appeared quite satisfactory. In consequence, his own opinion had been entirely changed. He regarded the necessary inference, that the large pebbles travelled further than the small ones, without undergoing serious degradation on their journey, as very important.—EDITOR.

the strata in the Island of Portland, that he had ventured to state, that the materials composing the Chesil Bank could not have been derived from that source. The shingle of the Chesil Bank was entirely different in character from any of the strata to be found in Portland. He did not mean to say that there might not be found occasionally a pebble from thence; such were, however, but very rare, and even these were only to be seen within a mile, or so of the south-east, or Portland, end of the Bank. Looking at the great mass of the shingle, it consisted, first, and chiefly, of chalk flints (many with the chalk still remaining in the cavities); next, in point of number, of pebbles from the new red sandstone formation, and many from the neighbourhood of Budleigh Salterton, which had red marks resembling blood-spots, and were very peculiar. There was also a jasper, frequently resembling some of the Devonshire limestones, which though small in proportion, when compared with the chalk flints and sandstone pebbles, yet far outweighed, in point of number, those which were easily distinguished as having been derived from Portland. In a paper "On the Geology of Weymouth and its Neighbourhood," by Dean Buckland and Sir H. De la Beche, read before the Geological Society in 1830,[1] a section was given of the cliff at Blacknore Point, on the west side of Portland, and facing the West Bay. With the exception of some beds of Kimmeridge clay and bituminous shale, found at the north-east end of the island, it represented the whole of the strata in Portland, from the surface down to the sea level. What Conybeare and Phillips had described as "many layers of flint and stony rubbish 6 feet," also "many layers of flints and unserviceable stones, 55 or 60 feet," was called by Buckland and De la Beche "compact and chalky limestone with chert" and "sandy limestone with chert," also "rubbly beds with chert." As there had been many thousands of tons of these beds quarried for the Breakwater, within the last two, or three years, he might perhaps be allowed to say, that the latter was the more exact description of the two. The character of this chert, or flinty matter, which contained vast quantities of shells, and chiefly the "Trigoniæ," was so entirely different from that of chalk flints, that one could

[1] *Vide* Journal of the Geological Society of London.

not be mistaken for the other, even when the former might be found in the shape of rounded nodules, among the shingle on the Chesil Bank. The strata throughout Portland were, with the exceptions before named, the same in character as those shown in the section at Blacknore. There was, however, a difference in the elevation above the sea level. At the north end of the island, the calcareous slate and Portland stone would be found 500 feet in height, and at Blacknore about 350 feet; whereas at 'the Bill' these beds dipped into the sea, the inclination being pretty regular from north to south. Having regard to the geology of Portland, and the character of the shingle of which the Chesil Bank was composed, he was confident that its origin must be looked for elsewhere, than in Portland. Further, he had examined the whole of the surrounding district minutely, and was fully convinced of the accuracy of the views advanced in his Paper on this point.

Mr. RENDEL, President, said, it was evident so much interest had been excited by the Paper, and by the valuable facts laid before the meeting, that he wished other Members would imitate the example of the Author, and transmit to the Institution the results of their observations, on the shores adjoining the works under their charge. By so doing they would not only benefit the Institution, but would advance the best interests of science. It would be found that each part of the coast had certain peculiarities of its own, which required to be studied; and that each demanded special treatment, guided by intelligent observation of those peculiarities, and of the geological character of the cliffs, or shore in the neighbourhood. It was dangerous to generalize too much, or to be too precipitate in drawing inferences.

May 10, 1853.

JAMES MEADOWS RENDEL, President,

in the Chair.

The discussion upon the Paper No. 895—"Description of the Chesil Bank" (Portland), by J. COODE, M. Inst. C.E., being resumed, was extended to such a length, as to preclude the reading of any other communication.