

(Paper No. 3602.)

“The Harbours of South Africa ; with Special Reference to the Causes and Treatment of Sand-Bars.”

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THE subject of this Paper is one with which the Author has been closely identified in South Africa during a period of 17 years since 1888. For the first 7 years of that period (1888–95) he was in charge of the Natal Harbour Works at Durban as Engineer-in-Chief. Subsequent events led to his examining and reporting upon practically the whole of the harbours on the South-East African coast, from the Cape to Delagoa Bay ; and he ventures to hope that the following information in regard to these harbours so far as already developed, and to some which are still in their natural condition but whose possibilities he has had to investigate, may be of interest to the Institution. Owing to the wide scope of the subject, the Author must confine his remarks principally to the physical features affecting the harbours referred to, and to some of the problems that arise in dealing with the bars which so seriously obstruct nearly all the harbours on this sandy coast. Special reference will be made to the harbour of Durban in Natal, as an example of what it is possible to achieve by working on natural lines, and of the difficulties which beset all attempts to coerce Nature.

The construction of harbours, under the almost insuperable difficulties which often present themselves on the exposed sandy coast of South-East Africa, is of supreme importance to the country, which possesses very few naturally sheltered sites capable of being utilized.

THE SOUTH-EAST AFRICAN LITTORAL.

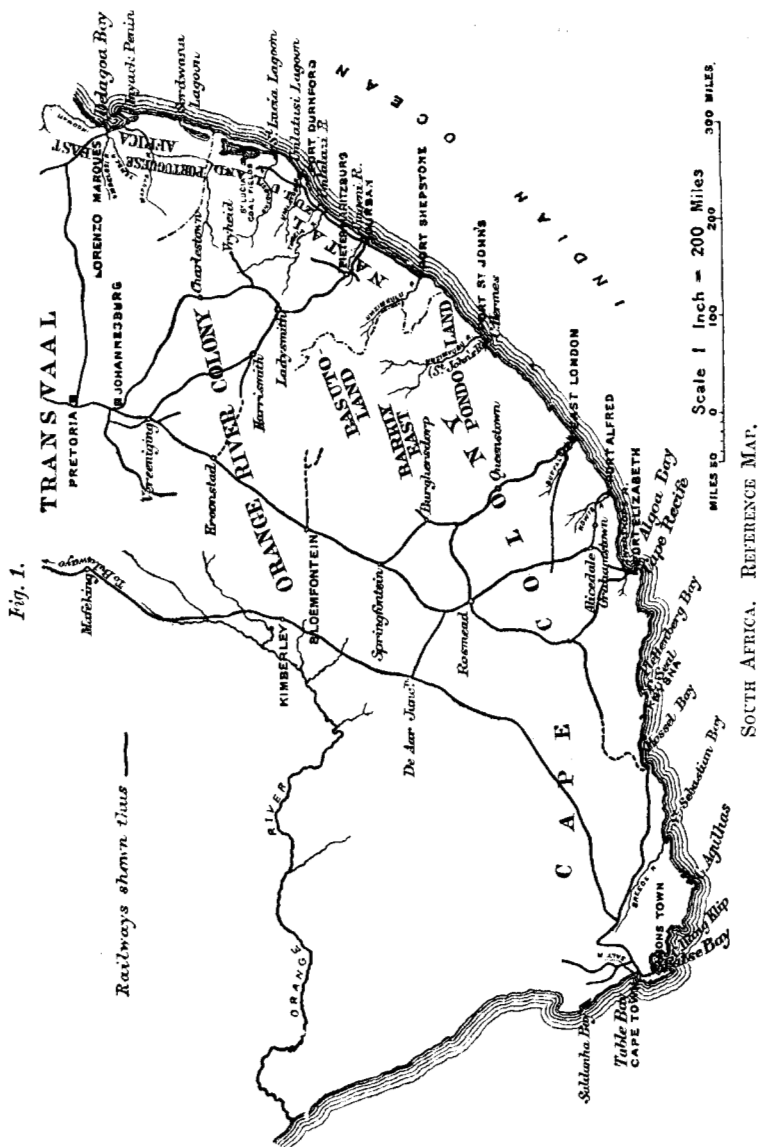
In connection with the following description of the littoral between Cape Town and Delagoa Bay the Author is indebted to Mr. William Anderson, the Government geologist in Natal, for some valuable information. One remarkable feature is the absence along the South-

East African coast, between Cape Town and Delagoa Bay, of deep-water indentations forming natural sheltered harbours. Such embayments as do exist lie between False Bay and Algoa Bay. North of this, although there are small rivers and some lagoons, presenting certain possibilities as harbours—only to be realized, however, by considerable expenditure—there is not a single well-sheltered deep-water indentation on the coast-line the whole way to Delagoa Bay. Even False Bay, which faces nearly south and is almost square in form, has an entrance between the Cape of Good Hope and Cape Hang Klip about 25 miles wide; and as the depth of the indentation is about the same, and the width is practically uniform all the way in, heavy seas run into it. The only comparatively sheltered spot in False Bay is Simon's Bay, where the Admiralty docks are in course of construction. Going eastward along the coast, a striking feature is that every bay has a rocky promontory on its western side (*Fig. 1*): it is only immediately under these promontories that any shelter exists, and there only from south-westerly gales. There are apparently two main reasons for this, and for the absence of depth both of indentation and of water. The first is that the hard quartzite rocks which now protrude on the western sides of these embayments, and which resist marine erosion fairly well, cover softer rocks below, which to the east are more exposed to erosion by south-easterly seas, which scoop out the bays in the form shown on the map. The second reason is that, unlike some other parts of the world, where gradual sinking of the coast has submerged deeply-eroded valleys, thus forming deep and sheltered natural harbours, there is clear proof that, within recent geological times, the coast of South-East Africa had been gradually rising.

The effect of marine denudation in producing irregularities in the sea-bed is much more limited than that of atmospheric denudation. It is therefore only, under very exceptional circumstances that depressions occur in the sea-bed which are sufficiently extensive and enclosed to become good natural harbours. This is no doubt one of the reasons why, on a rising coast-line, deep depressions which would form good natural harbours are rarely met with; and the Author thinks that, with the exception of Cape Town, Durban, and Delagoa Bay, and possibly Port Elizabeth in Algoa Bay, South-East Africa will have to look for her harbours chiefly to the rivers. Many of these, with the lagoons generally found at their mouths, have features which modern engineering can deal with efficiently, though unfortunately, in every case with which the Author is acquainted, they are such as to involve constant dredging.

Northwards of Algoa Bay the coast becomes less precipitous and

rocky, and long stretches of sandy beach and dunes occur. At



St. John's River, the Table Mountain sandstones are again met with, and form the rocks of this district. The extremely picturesque

chasm through which the river enters the sea is probably due largely to the presence of faults in these sandstones, its sides forming two great walls, which rise to a height of about 1,200 feet.

The southern coast of Natal is equally destitute of deep-water sheltered inlets; and the first possible harbour is the mouth of the Umzimkulu River, known as Port Shepstone. Between this point and Durban the rocks of the coast consist of a series of small outlying spurs of Table Mountain sandstones, granites, Ecca shales, and glacial conglomerate, with a fossiliferous calcareous sandstone from Isipingo to the bluff at Durban, the age of which is not certain, which is also met with at Algoa Bay, and elsewhere along the coast. All along the Natal coast there are immense stretches of sandy beach and dunes, with small rivers at frequent intervals, and up to the Umlalazi River, about 18 miles north of the Tugela, where the whole aspect and the physical geology of the coast change entirely. The littoral becomes slightly undulating, covered with great depths of sand, and fringed along the coast-line by ranges of dunes, often several hundred feet in height. The older rocks inland are not exposed nearer to the coast-line than about 5 miles, at Port Durnford, increasing to 50 miles on the Portuguese border. This immense area contains many large lakes and lagoons, some salt and some fresh. St. Lucia Lake is about 50 miles in length, including its outlet, by 10 miles in width, and has an average depth of only 4 to 10 feet. It is separated from the sea by a long strip of land, consisting chiefly of dunes covered with vegetation and bush, 2 to 4 miles in width.

Wherever rocks are exposed, either on the coast, at the margins of the lakes or lagoons, or elsewhere, they are in all cases of upper cretaceous or later age, affording conclusive proof of the geologically recent elevation of the coast. It is the old sea-bottom, raised gradually into its present position as a land surface: during its elevation it was not perfectly level, and the hollows were subsequently occupied by the present lakes and lagoons. These as a rule are at or near the mouths of the rivers, and therefore either among or just inside the dunes of the coast-line. Among them are the lagoons at the mouth of the Umlalazi River, the outlet from St. Lucia Lake, and the Sordwana lagoon. About 60 miles north of this latter point Delagoa Bay is situated. Further evidence of the gradual elevation of the littoral, even along the rocky coast-line between Port Elizabeth and Cape Town, is afforded by the raised beaches found at considerable elevations, as for instance at, and in the neighbourhood of, Mossel Bay. There is also a very well-marked beach at the end of the bluff at Durban, about 20 feet above the level of high water, the

mollusca of which show that its elevation has taken place within geologically recent times.

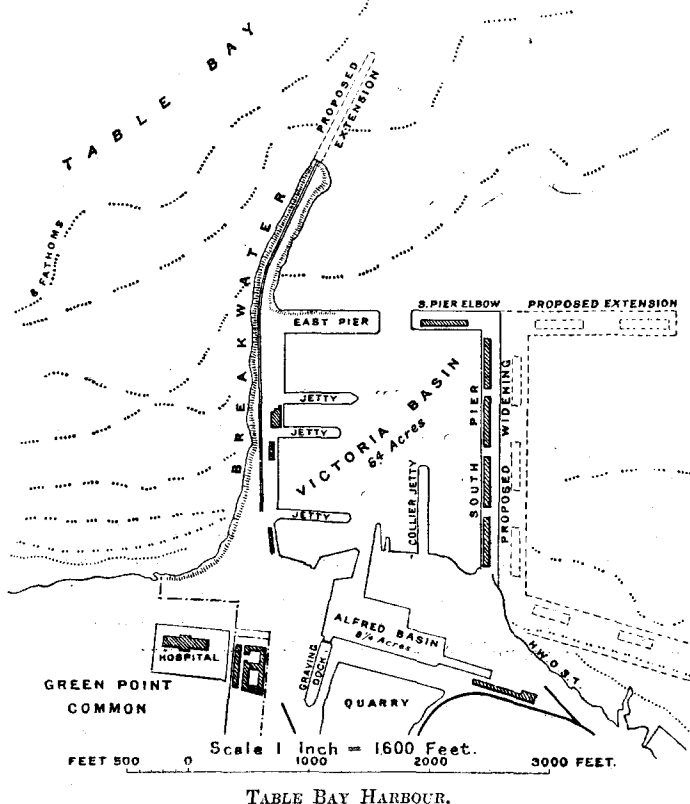
Table Bay.—The breakwater sheltering the harbour of Table Bay, Cape Town, which was designed by the late Sir John Coode, Past-President Inst. C.E., and begun in 1860, is now about 3,600 feet in length, and consists of a rubble mound, to which a concrete superstructure is now being added. It affords shelter from the north-westerly seas, which, entering the wide opening of the bay, about 20 miles across, would render its southern recess, where Cape Town stands, quite unsafe for shipping without this protection (*Fig. 2*). It has not been practicable to obtain dynamometer records here of the force of the waves, on account of the sea-slope of the rubble mound having assumed a varying inclination of 1 in $2\frac{1}{2}$ above high water, 1 in 5 to 1 in 7 to 15 feet below low water, and 1 in $1\frac{1}{2}$ lower down. This causes the seas to break so far back that it is of no use to place an instrument there. Waves, which were estimated to be 25 to 30 feet high from trough to crest, have, however, been observed passing under the breakwater staging.

The two existing docks, one of 64 acres with jetties projecting into it, and the other of $8\frac{1}{2}$ acres, are situated immediately under the lee of the breakwater. In order to afford more complete shelter to the entrance to the main dock, a slight southerly bend was given to the last 1,300 feet of the breakwater (*Fig. 2*). With the growing requirements of traffic the present docks have become insufficient, and still more shelter is required. Having been invited by the Government, in 1902, to visit Cape Town for the purpose of reporting to them on the reclamation of the foreshore of Table Bay between the docks and the mouth of the Salt River, a distance of nearly 3 miles, the Author was requested by the Harbour Board to consider, at the same time, and to report, in conjunction with the Board's General Manager and Chief Engineer, Mr. Hammersley Heenan, M. Inst. C.E., on the question of future dock-extension. This led to an extensive scheme, which consists mainly of the doubling of the south pier of the present docks; the extension of the south pier elbow southward to the new entrance (*Fig. 2*), between which and Craig's Battery, on the south-east side of the bay, it is proposed to construct a concrete-block mole about 7,000 feet in length, thus enclosing about 431 acres of the bay immediately in front of Cape Town; and the construction of a central jetty opposite the foot of Adderley Street, about 2,700 feet long and 375 feet wide. The main object of constructing this jetty is, that owing to its central position, it will afford shelter from the strong south-east winds, peculiar to Cape Town, to the whole of the enclosed harbour lying between it and the south

pier, where further jetties can be constructed as required, each with its separate railway-sidings.

In 1883 the late Sir John Coode recommended an extension of the breakwater, as indicated in *Fig. 2*; and this recommendation was endorsed by Messrs. Coode, Son and Matthews in 1895.¹ The Author and Mr. Hammersley Heenan have also recommended the

Fig. 2.



extension of the breakwater on its present line for 1,000 feet, to afford more shelter, both to the present dock-entrance, and to the entrance to the proposed main harbour within the mole. The cost

¹ Table Bay Harbour. Report by Messrs. Coode, Son and Matthews on the Existing and Proposed Works, Cape Town, 1895. (Copy in the Institution Library.)

of this scheme, including the reclamation of the foreshore between a point 1,300 feet south of the proposed Adderley Street pier and the present docks, but without the intervening jetties, is estimated at £3,561,757. This also includes the construction of a quay-wall along the face of the reclamation, to give berthage 20 feet deep at low water. It was decided to give this shallow-draught berthage along this line, on account of the underlying rock which fringes this shore of the bay, the vessels of deeper draught lying farther out alongside the jetties or the south pier. Portions of this scheme are now in progress. With the vast territory which is now thrown open for development, and for trade with other parts of the world, and considering the somewhat limited capacity of the other Cape ports and of the railways which serve them, it may be confidently predicted that, even with all the disadvantages of geographical position as regards the Transvaal Colony and Rhodesia, Cape Town will command for many years a large inland trade; and, as a port of call, it must steadily grow in importance as commercial relations between the Cape and Australia extend.

The following statistics illustrate its growth, even within a few years.

Cape Town.	Customs Revenue.	Imports.	Exports.
Year.	£		£
1895	577,605	3,343,105	8,482,441
1904	976,493	8,080,558	16,745,470

EMBAYMENTS OF SOUTH-EAST LITTORAL.

Reference has already been made to the remarkable absence of deep, sheltered bays on the south-east coast of Africa. The bays which do exist, though partly protected by their western headlands from south-westerly seas, are fully exposed to seas from south to south-east. For this reason, and also because the back country in their neighbourhood has not yet attained such a condition of development as to warrant the heavy expenditure necessary to create ports in such situations, only Mossel Bay and Algoa Bay have so far been utilized to any extent. It appears probable from the Admiralty chart that the construction of a harbour at the embouchure of the Breede River in St. Sebastian Bay might not be found impracticable, though the situation is very exposed. At the present time, however,

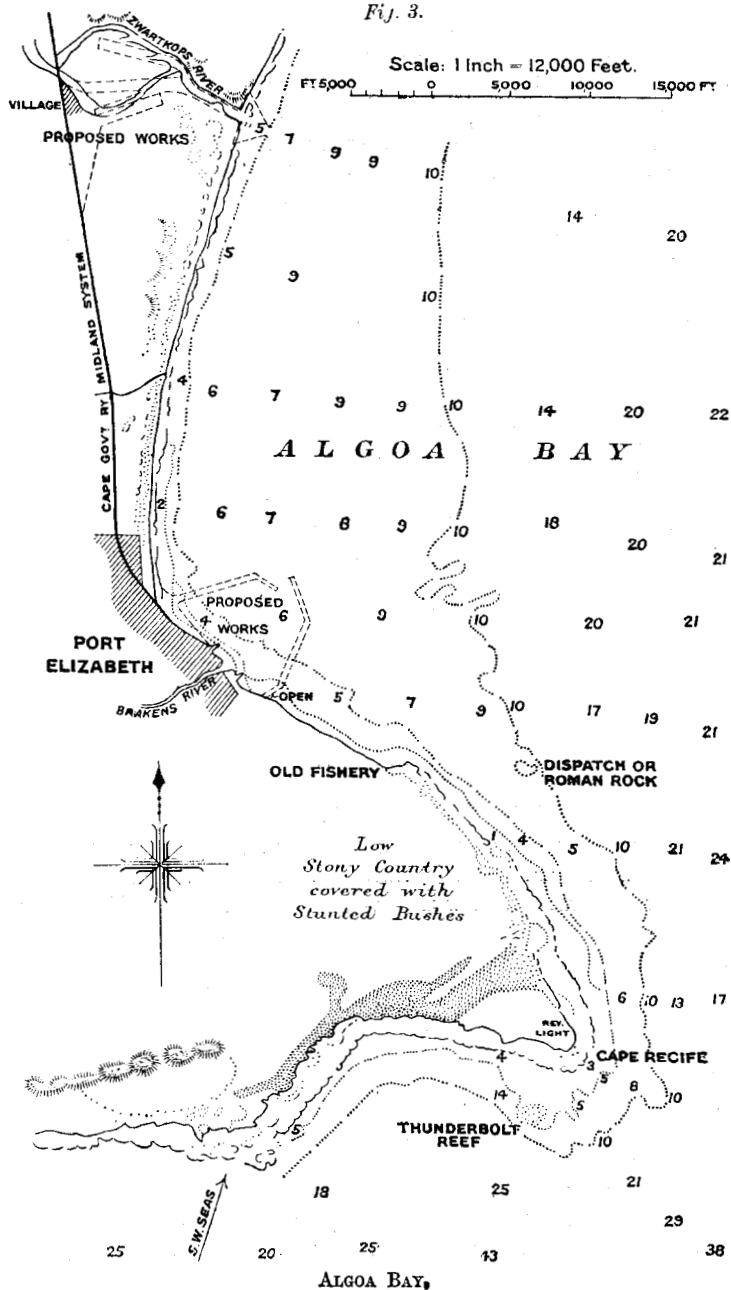
on the stretch of coast so exposed to severe storms between Cape Town and Delagoa Bay, a distance of about 1,200 miles, no harbour of refuge exists for which a vessel can make in stress of weather with the assurance of a safe entry—a thing which, with a very large and constantly increasing ocean traffic, is more and more needed.

Plettenberg Bay was examined by the late Sir John Coode in 1876. In reporting upon it, he stated that it had been frequently spoken about as a harbour of refuge, being naturally protected against all winds between south-east and south-west, and that its peculiar configuration, owing to the deep indentation caused by the promontory, 2 miles in length, terminating at Cape Seal, and the good depths and anchorage to the north of this projection, rendered it well adapted for such a harbour; whilst there was abundance of good material on the spot. On the other hand, he pointed out that its geographical position is by no means as favourable as that of Mossel Bay, which he stated was much more resorted to by sailing vessels for shelter when met by heavy westerly and north-westerly winds in trying to get round Cape Agulhas, a difficulty by no means uncommon in the winter season. Gales along this coast are almost invariably more from the eastward than southward of south-east; and therefore, unless actually embayed, no vessel need go on shore in such gales anywhere west of Cape Recife at Port Elizabeth.

At Mossel Bay Sir John Coode found that the bottom was subject to considerable changes by shoaling and deepening, and that great caution would be necessary in laying down any sheltering works. The Author visited this bay in July, 1902, in order to report to the Government on certain works which had been executed and were in progress. While it would be possible to construct works there, which would form a harbour of considerable capabilities, its serious exposure to heavy rollers from the south-east, and its general contour, do not, in his opinion, recommend it as a good site for a harbour of refuge. There is a thriving community at Mossel Bay, and about 6,500 square miles of rich agricultural country to be served at the back of the port (equal to nearly twice the area of Wales), which would probably be doubled if the railway were extended to Oudtshoorn and Nels Poort.

Algoa Bay.—The last of this series of embayments, proceeding north-east, is Algoa Bay or Port Elizabeth (*Fig. 3*), which in 1820 was a small fishing-village with a military post, and to-day is one of the most important ports of Cape Colony, with a population of 46,626 persons, of whom 23,782 are Europeans. The shelter afforded by Cape Recife from southerly to south-westerly seas is very con-

Fig. 3.



siderable ; but the bay is open to south-easterly gales, which frequently blow with great violence, and have more than once caused serious casualties to shipping at anchor in the roadstead. Yet in spite of all these difficulties, and often in the face of very rough weather, the whole of the landing of goods at Port Elizabeth has been carried on in the earlier days by means of surf-boats and sailing barges landing on the beach, and later by a system of lighterage between the vessels in the open roadstead and iron jetties projected from the shore and furnished with railway-communication and hydraulic cranes. The remarkable strides in commercial prosperity which this port has made, in spite of the landing-difficulties, are shown by the fact that in 1893 the customs revenue was £1,097,193, and in 1904 the value of the imports was £6,855,729 and of the exports £2,044,508.

Many proposals have been made with a view to remedy the want of sufficient shelter from the south-east. Before 1870, and therefore before the days of the larger aspirations which now prevail, a small breakwater of timber and rubble stone was erected at the mouth of Baaken's River, an insignificant stream entering the bay through a deep cleft at the western end of the present town. The immediate result of this work, placed at right angles to the shore, was to act as a groyne, arrest the travel of sand from east to west due to the surf-currents, and threaten a serious accumulation of sand on the part of the beach where landing- and loading-operations were carried on by means of surf-boats. In consequence, the work had to be removed ; but it has left behind it a valuable record of the danger of running out solid works at right angles to the coast, without due consideration of their effect in arresting the in-shore drift, and of the means of dealing with it, if such a work is essential.

The open jetties on iron piles which were advocated and carried out under the advice of the late Sir John Coode have the advantage of presenting no obstacle to the free passage of sand between the piles ; so that three of these jetties have now been used for a number of years, without producing any change in the foreshore in front of the town : but it is impossible for any but very small vessels to lie alongside them, and then only in quite calm weather. Sir John Coode also made a proposition which was novel at the time, and was specially designed to meet the necessity of non-interference with littoral sand-travel, namely, to construct an open iron viaduct from the shore seaward, for a distance of about 3,000 feet, terminating in a solid breakwater nearly at right angles to it, and about 2,000 feet in length, with jetties projecting shoreward from it under its lee, at which vessels were intended to lie. This work

was fortunately never carried out, for, though the idea was an ingenious one, it is practically certain that vessels could not have lain alongside such a breakwater or jetties except in the smoothest weather. As the trade of the port grew, the necessity for complete shelter of some kind made itself more and more apparent, until it has now become an absolute necessity, if Port Elizabeth is to hold her own with other ports on the coast, where vessels can lie in security alongside sheltered wharves. Two important schemes are therefore now under consideration (*Fig. 3*): one to enclose a large harbour of 800 acres by means of two great breakwaters projected from the shore; and the other to open up the Zwartkops River, which runs into Algoa Bay about $5\frac{1}{2}$ miles to the north of the railway-terminus in the centre of the town, thus providing a sheltered harbour furnished with the ordinary wharves, sheds, etc., and providing room for indefinite extension in the future. The first of these schemes was proposed in February, 1897, by Messrs. Coode, Son and Matthews, and subsequently formed the subject of a Report¹ by Sir John Wolfe Barry, K.C.B., Past-President Inst. C.E., Mr. Wm. Matthews, C.M.G., Vice-President Inst. C.E., and Mr. A. G. Lyster, M.Inst. C.E., in 1905, the cost being estimated by them at about £3,100,000.

The opening up of the Zwartkops River, upon which the Author was asked to report, would provide Port Elizabeth with a completely sheltered harbour, free from the serious problems involved in the other scheme, and at a cost which, to begin with, need not exceed £1,500,000, while it would be capable of indefinite internal extension. There are, however, important questions in connection with it, as to the disturbance of vested interests in Port Elizabeth; and this proposal is, like the other, under consideration.

The Zwartkops River is tidal for some miles, and has a tidal volume, as ascertained by careful tachometer measurements, of about 4,500,000 tons, which would be somewhat increased with the opening up of the river-mouth by dredging and works. The river is barred by sand just outside its mouth; and the minimum depths on the bar are only 6 inches to 2 feet at low water of spring-tides, which have a range of 5 feet 5 inches. The railway crosses the river about $2\frac{1}{2}$ miles above its mouth. On the north bank, between the railway-bridge and the sea, is the sandy range of low-lying hills, known as the Zwartkops, descending abruptly to the river-bank, and leaving little room for quayage on that side, except for about a mile below the railway.

¹ See "Port Elizabeth, Algoa Bay: Proposed Harbour Improvements. Report of Commission of Engineers, 1904-5." (Copy in the Institution Library.)

Between the subsidiary channel, or backwater, on this side, and the main or southern channel of the river, there lies a considerable area of slob land, intersected by small channels, and overflowed 6 to 9 inches by high water of spring-tides. On the south side of the river, the slob lands are of very considerable extent, and lie at a general level of about 9 inches below high water. These slob lands would form a very valuable area for reclamation with the spoil dredged from the river, and afterwards for quayage. Extensive borings and probings have proved that there is no obstruction of rock in the bed of the river, and that an outcrop of calcareous sandstone, on the north side of the entrance near the bar, dips rapidly to the southward and disappears. It is not anticipated, therefore, that any obstacle will be presented to dredging on the bar.

There are no shingle beaches along the coast of South-East Africa between Cape Town and Delagoa Bay, though at a few spots there are accumulations of gravel, sand, and shells. The entire coast-line, where not precipitous and rocky, is sandy; and, so far as the Author knows, the sea-bottom off the coast is for the most part also sand. Between what is brought down by the river in flood during the heavy sub-tropical rains, washed in from the sea-bottom, and eroded both by the sea and by the winds from the vast accumulation of dunes which line the seaboard, the sand-supply is continuous and on a vast scale. The variations in its movements, also, are infinite, depending mainly on the direction and strength of the seas, and on local conditions. The Author found the travel of sand in Natal and elsewhere to be, as a rule, from south to north, the prevailing seas acting obliquely to the coast-line in that direction. There is also on the Natal coast a northerly littoral current, counter to the Mozambique current, which flows southward 5 to 10 miles out at sea. This littoral current has not generally sufficient velocity to transport sand of itself, unless in suspension; and the main cause of the almost continuous travel of sand along the exposed parts of the coast is the action of the seas, especially between low- and high-water marks, and the currents set up between the same limits, and for some distance seaward of them, by the heavy surf which constantly sets in upon these shores. That the movement of sand by the waves is effected at considerable depths is proved by the fact that in 1891 the Author found that sand from the inner bay or lagoon at Durban, deposited by the dredgers about $1\frac{1}{2}$ mile out to sea, and in 60 feet of water, was washed ashore in large quantities in the neighbourhood of the Durban breakwater. Sometimes, during the continuance of off-shore winds, vast sand-accumulations take place along some parts

of the coast, which, on the occurrence of a heavy easterly sea, are cut out by the waves, and drawn back into the bed of the ocean, to be later on largely returned. During such on-shore seas, should the littoral current be running strongly, sand held in suspension by the action of the breakers can be observed travelling northwards in large quantities well seaward of low-water mark; and this sand-travel becomes even more marked if the seas become more southerly, and therefore more oblique to the coast-line. During such periods of heavy littoral drift, large quantities of sand were conveyed by the littoral and surf currents round the end of the Durban breakwater, and deposited in the area under its lee, where, owing to the shortness at that time of the northern work, there was comparatively slack water. The accumulation then rapidly extended across the entrance, blocking it up, and forcing the tide over to the north.

Another important phase of littoral drift, on the South-East African coast, is that due to the wind, which lifts the finer sand from the slopes of the dunes along the upper side of the beaches, and sometimes from sand-flats behind them. This was well exemplified at Port Elizabeth, where a great sand-drift on the Recife peninsula proved a serious source of trouble to Algoa Bay, during the prevailing westerly and south-westerly winds. Planting, however, was resorted to, after spreading town refuse over the sand; and the result has been very satisfactory, as described by Mr. Hammersley Heenan in a Paper¹ on the Harbour of Algoa Bay.

At the request of the Port Elizabeth Harbour Board, a very extended investigation of the movements of sand was made by the late Mr. Allan Brebner, M. Inst. C.E., in 1899, on the shore of Algoa Bay, between the Zwartkops River and Cape Recife, in order to ascertain to what extent this might be likely to interfere with the works which it was proposed to project into the bay in front of Port Elizabeth. Up to that time the extent of any such sand-travel was purely a matter of conjecture. The work was begun by Mr. Brebner in June, 1899, and was carried on continuously over a period of 1 year and 8 months. After his investigations Mr. Brebner expressed the opinion that, though there was a tendency for drift-sand to move northwards along the west shore of Algoa Bay, there was no continuous or regular travel or drift of sand in that direction, either from wave-action or from wind, so as to cause an accumulation of sand on the south side of a breakwater built on the west shore of the bay, beginning above high-water mark, and extending seaward at any angle convenient for the formation of shelter within it. He

¹ Minutes of Proceedings Inst. C.E., vol. cxxx, p. 263.

also held that in a harbour enclosed by two such breakwaters, one of which was left open, at its shore end, by constructing a viaduct about 1,000 feet long, the sand carried into the harbour in suspension in the breakers would not exceed about $\frac{3}{8}$ inch per annum. He also came to the conclusion that there were no littoral currents in the bay to interfere with the construction of works there. Sections, taken periodically, also appear, he says, to have shown that sand is "moved and stirred" by the waves at depths of 30 feet; that between depths of 4 feet 6 inches and 10 feet at high water, variations occur in the bottom, over a period of 8 months, to the extent of 5 feet 6 inches; and that the zone of maximum disturbance of the sand on the bottom is at low-water level. If Mr. Brebner is right in these conclusions, then any works at Port Elizabeth will be free from one great engineering difficulty; but the Author holds strong opinions as to the danger of sand-accumulations outside works of this nature, and on such a scale, built across the littoral drift on this coast, even if the precaution be taken of making an open viaduct connection with the shore: and especially is there danger if, as is proposed in this case, the northern arm were a solid work.

The principal subject with which the Author has to deal in the present Paper is the sand-barred harbours on this coast; and the Zwartkops is the first river met with, going northwards from the Cape, where this difficulty has been fully investigated. Between here and Delagoa Bay there is no harbour—nor any site proposed for a harbour—which has not, in its natural state, either a sand-bar, or a solid beach across its mouth. Before describing some of these river-mouths, and what has been done to open them permanently, the causes of the formation of these bars must be made clear.

Formation and Treatment of Bars.—Great differences of opinion have always existed as to the precise cause of the areas of shallow water which are so often found at the mouths of rivers in this and other countries, and which, forming a serious obstacle to their navigation, have been termed bars. They may be formed under a great variety of circumstances, and many theories have been propounded to account for the phenomenon: *e.g.*, a deposition of material where the outgoing ebb-tide meets the incoming flood; the deposition of material brought down by the river, where the velocity of its current is checked by the seas or tide, or by its entry into the larger area of the ocean, or by the inflowing tidal water, which, on account of its higher specific gravity, meets and checks the lower stratum of the outflowing fresh water of the river and causes deposition; or the want of a sufficient volume of backwater, and therefore of scouring-power. There are also bars composed of various materials, such as

alluvial deposit brought down by the river from the uplands, shingle, sand, clay, or even rock, for the existence of which there may be a variety of reasons.

On the south-east coast of Africa, every river and lagoon that the Author has examined is barred by sand, which is usually of a loose, free character, and is sometimes very light on account of the presence of large quantities of finely comminuted shelly matter. In most of the small rivers this sand accumulates during the absence of floods, until it forms a beach across, and entirely closing, the river-mouth: here it remains until broken through and swept away by the next flood, after which it again accumulates rapidly. Such is generally the case when the tidal compartment of the river is of small extent. Where the tidal compartment, often in the form of a lagoon, is of sufficient extent, the inflowing and outflowing tidal waters frequently afford a scour strong enough to prevent the entire closing of the mouth; but in all cases the depth over the shallowest part of the bar, or partially submerged beach, is very small—frequently not more than a few inches at low water. A characteristic feature of many of the rivers is that often 3 to 15 miles up from the mouth, as in the case of the Kowie River, Port Alfred, the Buffalo River, East London, and the Umzimvubu River, Port St. John's, a tidal compartment is found, varying in width up to perhaps 800 or 1,000 feet, or even more in parts, and narrowing sharply at its upper end. Here it generally receives a rapid, clear stream, often of quite insignificant proportions, except in times of flood, when, owing to the quick rise of the back country, and the occasional heavy sub-tropical rains, sudden and heavy floods come down. The result of these floods is usually to clear out any deposit of sand brought within the mouth by the seas and tides, and to sweep away the bar for a time. This often occurs, especially in the case of the Umzimvubu River, to a considerable depth. A gradual silting-up, or re-formation of the bar, then takes place, at a rate depending on such circumstances as weather, etc. Little change takes place, as a rule, in the tidal compartment itself from these occasional floods. The matter brought down in suspension is rapidly swept out to sea; and practically no detritus or silt is brought down by the rivers at any other time. In the event of the opening up of the rivers for harbour purposes, and the consequent enlargement of the normal sectional area of the tidal compartment, there is little tendency to silt up again, except in the immediate neighbourhood of the bar, where shoaling frequently occurs by the deposition of sand from outside.

Since 1888 the Author has closely studied the river-mouths on this coast, and he has no hesitation in ascribing the bars which

obstruct them to the action of the waves on the sandy bottom of the ocean immediately in front, and on the accumulations of sand along the beaches on one side or the other. These, with the aid of the surf-currents, provide a constant supply for the seas to act upon and heap up. There are, in fact, two principal factors at work; the seas which constantly endeavour, by sweeping in sand, to form a beach across the mouth; and the outflowing tidal waters, sometimes greatly augmented in time of flood, which strive to counteract this by scouring away the deposit. In the case of the smaller rivers, this usually ends in a triumph for the sea. In the case of the larger rivers, the beach remains partly submerged, with only a narrow channel—or at all events a very shallow and unstable one—through or over it at low water. The form assumed by these bars is sometimes roughly an arc of a circle, which may become distorted, and approach nearer to the shape of a horse-shoe, with its apex to one side or other of the entrance. This is generally the result of special circumstances, *e.g.*, a somewhat oblique direction of the seas to the mouth, the existence of a rocky projection causing a deflection of the outflowing tide which finds its level in the ocean by the line of least resistance, or the littoral currents.

At the London International Maritime Congress in 1893, Mr. A. G. Lyster, the Engineer-in-Chief to the Mersey Docks and Harbour Board, gave a very clear description of the primary cause of the curved form assumed by sand-bars.¹ Supposing the volume of water in the river-channel to be constant as far as its outlet, immediately it passes into the sea it spreads out laterally, causing a decrease in volume and velocity directly in front of the outlet, which produces a gradual rise in the bottom seaward, and also at the sides. This results in the formation of a ridge or mound along the curved line forming the intersection of the side slopes of the channel with the outer slope of the bank, which constitutes a river-bar. Such a bar occurring on the sloping sea-bottom at the mouth of a river is liable to great distortion, depending on the various factors at work which tend to effect it, such as the conformation of the outlet of the river, the existence of promontories on either side, waves, littoral and surf currents, etc.: but the general curved form can often be traced.

Lagoons.—The same formation usually occurs at the outlets of lagoon harbours, though in these cases there is generally a variation in the circumstances leading to the formation of the bar. In the larger lagoons on this coast which the Author has investigated

¹ "International Maritime Congress, London, 1893, Section I, Harbours and Breakwaters," p. 62.

with the view of determining their adaptability as harbours, such as the Umlatusi lagoon and that at the mouth of the St. Lucia and Umvolosi rivers in Zululand, where everything is still in its wild, natural condition, the mouths or outlets to the sea are liable to, and frequently undergo, complete changes in position; and the outlet which may be here to-day, in a few months' time, or even much less, may be a mile farther along the coast, in either direction. No doubt such changes occurred at one time in the lagoon now forming the Port of Durban.

It is to the class of river already described, and to lagoons, that South Africa will have to look for many of its harbours in the future. Indeed, in 1903 the Author recommended the Umlatusi lagoon in Zululand to the Government of Natal, as the most promising site for a port on the Zululand coast. It is typical of the lagoons of the country, and is situated about 45 miles northward of the mouth of the Tugela River. The lagoon at Durban, known as Durban Bay, in its original state, before the construction of any engineering works, and that at the mouth of the St. Lucia River in Zululand, are examples of the same type, as are also, on a much smaller scale, the lagoons within the mouths of several of the smaller rivers along the coast. The area of the Umlatusi lagoon at high water is 7,788 acres. It lies amidst an extensive area of flat, swampy land; so that when a permanent channel between it and the sea is opened up, of sufficient sectional area to admit of the free inflow of the tide, this area will be increased to probably not less than 10,300 acres, or more than twice the high-water area of Durban Bay. It has also the advantage over Durban Bay that, whereas in the latter the proportion of sandbanks above the level of low water of spring-tides is about 3,830 cubic yards per acre, in the case of the Umlatusi lagoon it is only about 450 cubic yards per acre. In other words, owing to the height of the sandbanks in Durban Bay above low-water level, the loss of tidal volume at high water of spring-tides is about 3,000 tons per acre; whereas at Umlatusi this only amounts to 347 tons per acre. Owing to the small low-water sectional area of its outlet to the sea, the lagoon never fills to high-water level. It also never empties itself before the rising tide again partially raises its level. The bottom of the lagoon is 1 to 2 feet below low water of spring-tides, with the exception of a few banks here and there. At neap-tides, there is hardly any variation in the water-level of the lagoon; though a heaping up of the water at one end or the other is often observable during strong winds. Simultaneous observations, by means of tide-gauges set at different points of the lagoon, showed that at high water of ordinary spring-

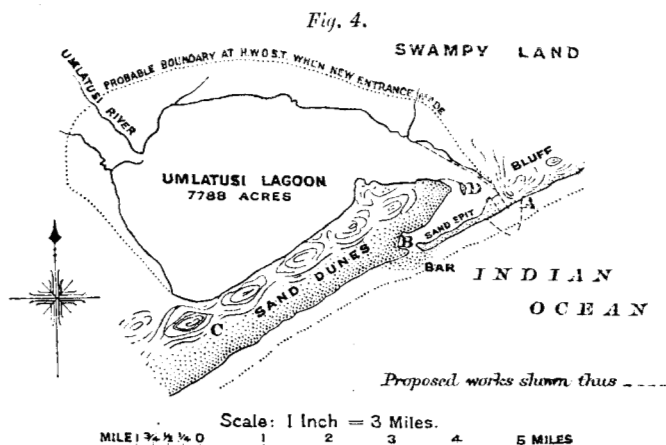
tides, the present tidal volume of the lagoon does not exceed 4,500,000 tons, or about one-fifth of the original tidal volume of the lagoon at Durban. If, however, a new permanent entrance is formed, of sufficient width and depth to allow of the unrestricted ebb and flow of the tide over its full range of about 6 feet, the tidal volume at Umlatusi will be increased to probably not less than 61,000,000 tons, or about $2\frac{1}{2}$ times the original tidal volume at Durban. This, when works are constructed, will be of the greatest value as a natural agent in maintaining any future entrance-channel, with such assistance by dredging as may be found necessary. According to the survey the Author made in 1892 of the Durban lagoon, the cubic contents of the sandbanks above the level of low water of spring-tides was about $18\frac{1}{2}$ million cubic yards, whereas at the Umlatusi lagoon they are approximately only $3\frac{1}{2}$ million cubic yards: which shows the comparative loss of tidal volume due to this cause.

The formation of these lagoons is very well described by Mr. Anderson in his "First report of the geological survey of Natal and Zululand." He says: "Although there are numbers of large rivers which debouch on to the littoral of this coast as permanently strong flowing streams, there is in all cases a bar of sand thrown up by the sea across their mouths. These sandy bars dam back the river-water, until often for miles inland from the mouths it forms deep and often broad waterways, which, but for the presence of the bars, would have formed splendid harbours and waterways for small craft. In many instances large lagoons intervene between the river and its exit into the ocean; but in these cases also a similar and unfortunate sand-bar exists." No doubt in using the term "bars" Mr. Anderson also includes the sand-spits which are found in all cases to lie between such lagoons and the sea, and which, by the joint and persistent action of the waves and the winds, are gradually widened and heightened, until in some cases they become broad and permanent belts of land, covered with sand-hills and eventually by bush and grass, like that lying between Lake St. Lucia and the sea, 1 to 4 miles in breadth, with bush-clad dunes next the sea, frequently attaining a height of several hundred feet.

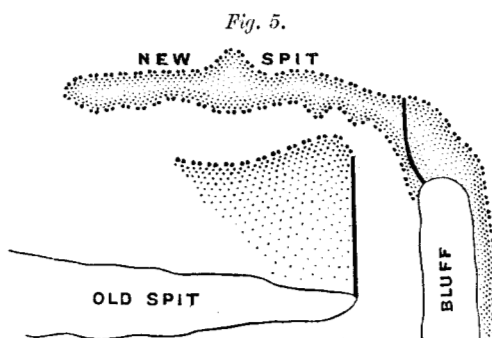
The sand-spit at Umlatusi lagoon, of much smaller dimensions and more recent growth, extends from the foot of the bluff at A (*Fig. 4*), which is about 100 feet high and of the usual æolian formation, to the point B, where the entrance was at the time of the Author's visit, a distance of about $1\frac{1}{2}$ mile. The growth of this spit, as shown both by its tapering form, and its greater height at the foot of the bluff, as well as by the older vegetation at that end, has been evidently from A towards B. It is almost certain that a

former spit existed between C and D, with the entrance between D and the bluff, and with a bar opposite that entrance in about the position of the root of the present spit, forming the nucleus from which that spit has since grown.

These changes on the South-East African coast, owing to its being



in parts surcharged with immense masses of free sand, occur in extraordinarily short periods of time. The Author has, indeed, seen growths of an exactly similar nature, although in a more or less embryo form, make themselves quite apparent opposite the entrance



to Durban Bay, before the completion of the present works (*Fig. 5*); and they are recorded on surveys both before and during the earlier stages of those works, as the bluff was practically lengthened by the construction of the southern breakwater.

RIVER HARBOURS ON THE SOUTH-EAST AFRICAN COAST.

Port Alfred.—The mouth of the Kowie River, generally known as Port Alfred, lies about halfway between Port Elizabeth and East London (*Fig. 1*). It has a tidal compartment about 12 miles in length, and varying in width between 250 and 500 feet, with depths of 5 to 10 feet; but in parts it is much deeper. The shores on either side of its mouth are surcharged in immense quantities with loose, free sand, which is easily blown about by the winds. The upper part of the beach, therefore, especially to the west of the river, is lined with dunes of great size; and others are constantly forming along the beach lower down, and shifting their forms and positions. The mouth of the river is fully exposed to gales from south-west round to east. There are no projecting headlands affording shelter of any description; although there is a reef to the south-east of the entrance, known as the Fountain Rocks, which gives a little shelter from easterly to south-easterly gales.

In 1856 the late Mr. James M. Rendel, Past-President Inst. C.E., laid down a plan of training-walls and breakwaters, giving an entrance about 250 feet in width. Mr. Rendel's plan was seriously deviated from, and the entrance was reduced to 170 feet—an unworkable width for any but very small craft. The late Sir John Coode in 1870 advised extensions of the piers at the entrance, which, however, still preserved the old narrow width. In 1877 the trade of the port was increasing, the customs revenue having risen from £3,200 per annum in 1871 to about £30,000 in 1876. It was impossible, however, to realize the depth on the bar anticipated by Sir John Coode, namely, 12 feet at low water; owing to this want of depth, and competition with Port Elizabeth, the trade diminished, and eventually disappeared; and the works, which had cost £250,000, were practically abandoned. In 1900 the Author was requested to examine this river with a view to see what could be done to remedy the then existing state of matters, utilizing the works already constructed to the utmost extent possible. These works, having been constructed with concrete blocks, were in fair condition, though repairs were necessary; but sand had accumulated on the beach southward of the works, until it had entirely buried the western pier for a considerable length under a great slope running down into the channel. A survey showed that the depth just within the piers was only 5 to 6 feet at low water, while just seaward of the piers the depth was 12 to 18 feet at low water. This was very similar to the original condition of the mouth of the Buffalo River at East London after the construction of works, but before the introduction of the sand-pump dredger. The

remedy, namely, dredging, would be the same at Port Alfred were the entrance of sufficient width to admit of the safe working of a powerful plant; but this is not the case. The Author therefore decided that the proper course, so as to utilize the old works, would be to extend the west pier as a curved breakwater sufficiently to cover a new entrance to the east of the existing east pier; to run out a converging east breakwater, starting about 1,000 feet beyond the east pier; and to excavate and dredge a new channel joining the old channel about $\frac{1}{2}$ mile inland. This would give an entrance superior to that at East London, and wide enough to enable powerful dredging-plant to work with safety; while the old channel, and the triangular area enclosed by the new east breakwater, would form efficient wave-traps to reduce the swell entering the harbour.

The port has the great advantage of a large area of flat slob lands lying on both sides. These would be very useful for the excavation of tidal basins—an advantage not enjoyed at East London, where the banks are precipitous.

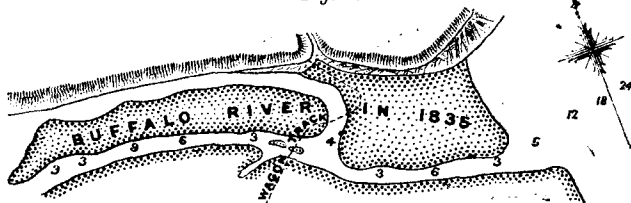
Port Alfred is connected by rail not only with Grahamstown but also with Alicedale, the junction with the main lines leading thence to Kimberley and Bulawayo, and through the Orange River and Transvaal colonies. The distance from Port Elizabeth to Alicedale is the same as from Port Alfred; and therefore, so far as railway communication with the interior is concerned, they are on an equal footing. On the other hand, Port Alfred is 55 miles nearer De Aar Junction than East London, and East London is 55 miles nearer Springfontein than Port Alfred (*Fig. 1*). As compared, therefore, with East London also, Port Alfred is favourably situated, and is in a position, so far as railway-communication is concerned, to compete for a fair share of the inland trade.

The west breakwater at Port Alfred is a concrete-block mound, surmounted by a block superstructure and parapet, and the east breakwater is a rubble mound with a block superstructure. As the seas, even from the south-west, wheel round as their shore-ends are retarded in the shallower water, they approach the works nearly end on, and consequently the works are not so heavily tried as are longer works in deeper water and broadside on to the seas. In nearly all cases, however, on this sandy coast, especially where the works are short, the advance of the contour-lines of deep water caused by their groyne-like action, and the accumulation of sand which, consequently, takes place in the external angle of the work with the shore, cause the waves to break well back from the works, and to become waves of translation long before they reach them; so that the impact of the waves is much less than in cases where oscillatory waves break

suddenly in deep water right on to the works on meeting the abrupt decrease in depth due to the foundation mound.

East London.—The Buffalo River, at whose mouth is the port of East London, is of the same type as the Kowie River, and is exposed to very heavy seas. No accurate observations have been made of the height of the seas in heavy gales; but they have been estimated at 18 to 20 feet from trough to crest. Its tidal compartment is broader, but much shorter than that of the Kowie; and its tidal volume at high water of spring-tides has been calculated to be only a little over 1,000,000 tons. Its mouth, prior to the construction of works, was encumbered by sandbanks dry at low water for a considerable distance inland. Only a narrow channel 2 to 3 feet in depth traversed these banks at low water. In fact, in 1835, and for many years afterwards, there was a wagon-track across the river, as shown in *Fig. 6*, where it is now navigable for large steamships. At the mouth of this river, as at all other river-mouths on this coast,

Fig. 6.

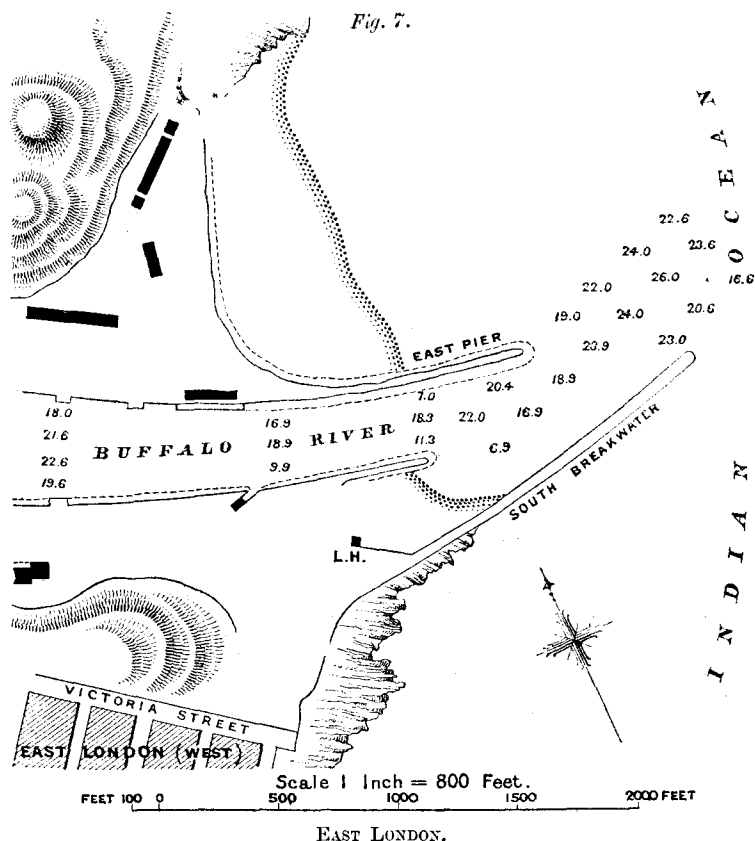


a heavy surf constantly prevails until works are constructed and deepening is effected.

The first serious attempt to improve the river was made about 1870, when the late Sir John Coode examined and reported on it. Some training-walls were constructed shortly after; but it was not until the year 1884 that the present outer piers were completed (*Fig. 7*). These works alone proved insufficient to give the depth of 15 to 18 feet at low water which it was expected to attain over the bar, as the tidal volume was much too small; and a survey made in 1885 shows that the entrance was still so encumbered by shoals that there was a depth of only 2 to 3 feet at low water between the piers. The mistake of the Kowie River was repeated so far that it again proved impossible to gain, in a position exposed to sanding up from outside causes, a depth which the tidal volume could not naturally maintain inside under shelter and through similar material. Too much reliance was also placed on the recurrence of heavy freshets, which used to come down with considerable frequency at one time, but which, for some unexplained cause, ceased almost entirely in

their former volume. One of these freshets, in 1874, swept the inner shoals entirely away, forming depths varying between 14 and 25 feet, the shallower depths being naturally in the broader portions of the tidal compartment; but the outlet soon shoaled up again.

Fortunately, about this time the sand-pump dredger, though invented long before, was brought into prominence by the excellent work achieved by it in Holland; and this appliance has rendered



practicable the opening up of harbours in positions such as those referred to, where previously the attempt would have been hopeless. The "Lucy," a 500-ton sand-pump dredger, was obtained, and, though of comparatively light draught, she cut her way inwards through the shoal water, and afterwards maintained the depths until assisted by more powerful craft.

In 1885, just outside the entrance, there were depths of 15 to 20 feet at low water of springs. Directly the inner shoals were removed by dredging to a depth greater than outside, the bar was practically transferred from just within the piers to the area outside. For a long time the depths there remained about the same, with fluctuations according to weather and to the extent of the sand-accumulations occurring to the west of the breakwater.

During recent years the progress achieved in dredging with powerful plant in an open seaway has enabled the depths outside to be increased to about 20 feet at low water of spring-tides; and East London, with her shipping of to-day, stands, in spite of certain drawbacks as regards the disposition of the entrance-works, a triumph of engineering skill over exceptional difficulties, as well as a credit to the Government of the colony and to the eminent engineer who initiated the works (*Fig. 7*).

The difficulty in the navigation of the entrance, due to the unfortunate position of the east pier, and the contraction of the entrance some little distance within it, is one which will be remedied in course of time. Proposals for its improvement, both by Messrs. Coode, Son and Matthews, consulting engineers to the Harbour Board, and by the Author, are under consideration. Meanwhile a great development of the internal resources of the port is taking place. The western bank is being utilized for additional wharfage; and a high-level bridge is in course of construction, to provide the necessary railway-communication across the river. The Author knows of no other port, situated like East London on a sandy foreshore, exposed to tremendous seas on an open seaboard without any shelter, and hampered within by precipitous rocky slopes on each side, and consequent want of space, where difficulties of so unusual a nature have been successfully overcome.

A powerful sand-pump dredger has now been obtained, with a hopper-capacity of 2,000 tons, and of 1,100 I.H.P. Her suction-pipe is 4 feet in diameter; and a good average day's work is the raising, conveyance, and depositing well out at sea, of 8,350 cubic yards of sand. Her shortest time for filling her hopper with 2,000 tons is 30 minutes; and she is able to work in waves 5 to 6 feet in height. The commercial progress of the port is demonstrated by the following figures:—

	East London.	Customs Revenue.	Imports.	Exports.
Year.		£	£	£
1895		275,153	2,890,021	760,279
1904		505,558	4,344,315	1,165,938

Port St. John's.—Port St. John's at the mouth of the Umzimvubu River, is a very different case, although here also the precipitous nature of the river-banks, and the extremely broken country to the westward, will present some problems in railway-engineering. St. John's is situated about halfway between East London and Durban, 150 miles south of the latter (*Fig. 1*). The river has a greater discharge than any other on this part of the coast, a course of about 150 miles, and a watershed of 7,375 square miles; whereas the watershed of the Buffalo River is only 580 square miles. The St. John's River enters the sea through a great rift in the high plateau on each side of it; and its banks are therefore precipitous, rising 1,000 to 1,200 feet above sea-level, and are thickly clothed with magnificent native bush. There is only just room for the main road to Umtata along the foot of the west bank. The mouth of the river at Porpoise rock is well sheltered from southerly to south-westerly seas by Cape Hermes, which extends 4,600 feet seaward on its western side, and rises to a height of 433 feet above sea-level.

A survey of this river which the Author made in 1897, for the purpose of reporting to the Cape Government on its suitability for a harbour, showed the mouth to be heavily barred by sand, the depth on the crest of the bar, which extended almost straight across the entrance, being only 6 to 7 feet at low water of springs. As the rise of tide at St. John's is only 5 feet, this gave a depth of 11 to 12 feet on the bar at high water of spring-tides—only just enough to admit small coasting craft and tugs. This bar, also, is due entirely to the action of the sea, and not to any deposit from the upland waters. At its eastern end the bar springs from "White's Hill," and at its western end it joins the beach which runs along the west side of Gordon Bay.

One of the conditions present at St. John's, and which in some other cases as well is largely responsible for the very shallow character of the bars, is a projecting headland on the south-western side. The littoral drift of sand takes place, as a rule, in the direction of the littoral current and prevailing seas, which at this part of the coast is from south-west to north-east. Any projection of this kind, therefore, acts to a certain extent like a groyne on the foreshore under its lee, and beyond which it projects. In a less marked degree than at Durban, where at one time the works themselves caused an aggravation of this formation, the same effect is distinctly noticeable under the lee of Cape Hermes; and it is practically certain that if St. John's River entered the sea on a straight line of coast, without any headland on either side of it, the

deep water would be even closer in towards the mouth, and the bar would be more in the form of sandbanks heaped up by the seas within the jaws of the entrance. The projecting Cape Hermes, however, keeps the 30-foot line of soundings at low water nearly $\frac{1}{2}$ mile away from the mouth of the river; whereas it is comparatively close in-shore to the west and east of the bay. This influence, underlying the ordinary bar-formation by the action of the waves, sometimes creates a very formidable obstruction in front of an entrance, which is all attributed to the seas, when it may be due very largely to a faulty disposition of the entrance-works. At Durban, it was first due to the projection of the bluff on the south side of the entrance, and afterwards both to this and to too great a projection of the south in relation to the north entrance-work.

The tidal compartment of St. John's River extends inland for about 15 miles. The lower portion of it, for 2 or 3 miles up, has depths of 10 to 15 feet at low water, and more just within the bar. The tidal volume at springs is about 5,250,000 tons. In the dry season, the river above the tidal compartment is a fine clear stream of considerable width, which brings down no detritus or alluvial matter, unless in flood. For a short distance inland from its mouth the tidal compartment is about 300 yards wide; and farther up it is, in parts, even wider. Owing to its extensive watershed, it is seldom that a year passes without freshets of greater or less magnitude in the St. John's River. One flood is stated to have reached a height of 27 feet above low water of spring-tides $6\frac{1}{4}$ miles above the mouth. At the mouth of the river, it rose 9 feet 6 inches above low water. This flood is said to have swept away the entire bar and westerly beach, forming a depth of 30 feet. Although this flood was no doubt abnormal, such occurrences have to be taken into serious consideration in providing for shipping. For that reason the Author proposed a large tidal basin, extending from the west side of the entrance to the river immediately in front of the site of the township, which would have ample room to spread westwards over the flat ground in this locality, and up the valleys running back into the higher lands to the west.

The main sheltering works proposed under this scheme are an eastern breakwater, and possibly a shorter one at the point of Cape Hermes, where a reef of rocks running out into deep water partially lends itself for a foundation. This, however, from its great exposure nearly square on to the heaviest seas, would be a very expensive work in proportion to its length. After the deepening of the bar by a freshet, it takes a considerable time at St. John's for the bar to

make up again ; and it is probable that nearly the whole of the sand which is scoured away by such freshets is deposited farther out in Gordon Bay, and gradually works in again to re-form the bar. The coast-line immediately west of St. John's is very rocky and precipitous, with deep water close in, and with few accumulations of sand along it of any importance ; and any littoral current, if it exists at all near the breakers, is so slight that it is of no account as a transporter of sand. There is no doubt, therefore, that the bar at St. John's River exists under conditions which will go far in enabling dredging for its removal to be carried on with economy and success, and that as the area in front of it becomes deepened and denuded of sand, there will be, when the proposed eastern breakwater is carried out, little difficulty in maintaining good navigable depths. In fact, the conditions of this river-mouth are such that the Author felt justified in recommending to the Cape Government the commencement of dredging at the entrance, working in the first instance inwards from the sea to the deeper water within the bar, without waiting for the completion of the eastern breakwater. Where powerful dredging-plant, capable of working among waves 5 to 6 feet in height, can be employed, experience leads the Author to the opinion that much might be done in opening up some of these sand-barred harbours by dredging alone, and without more in the way of works than is necessary to improve the internal regime of the river and concentrate and direct any available scour at the entrance ; bearing in mind that the projection of long outer works into the sea is almost invariably attended by a corresponding advance of the shoal-water or bar in front, and that whatever the projecting works, open-sea dredging outside them is almost sure to be a concomitant requirement.

The width of the entrance between the end of the proposed eastern breakwater and the end of the proposed breakwater at Cape Hermes would be 2,200 feet, so that this port would be easily accessible in almost any weather. St. John's is the natural port for Eastern and Western Pondoland, Griqualand East, and the districts of Barkley East, Basutoland, and Maclear. Eastern Pondoland is said to be rich in minerals, and possesses extensive forests at Ekossa, only 20 miles from St. John's. The lands in the neighbourhood of the port are exceedingly rich, and well adapted for the cultivation of all kinds of semi-tropical and other produce. At present, communication between St. John's and the districts mentioned is by road only. The value of the imports to St. John's in 1895 was £6,013, and in 1904 it was £23,185, though hardly anything has been done in the way of works.

Port Shepstone, Natal.—On the coast of Natal there are about twenty-five rivers of various sizes, none of which are navigable. The smaller ones are generally blocked by the extension of the beach across their mouths for the greater part of the year, except when in flood; and all the larger ones have either sandbanks or shallow bars across the outflow of their tidal compartments, or lagoons, into the sea. At one of these rivers, the Umzimkulu, at Port Shepstone, works have been in progress for some years to improve the entrance, and to open the river to the small coasting craft which sometimes make precarious visits to it during periods when the condition of the entrance is favourable. Hitherto, however, they cannot be said to have produced much benefit. So far as its physical features are known to the Author, the river is one which, like the Buffalo River at East London, would be susceptible of great improvement, probably as a fishing-port in the first instance, but capable of development into a harbour of much greater importance when the trade of the districts it serves warrants the necessary expenditure.

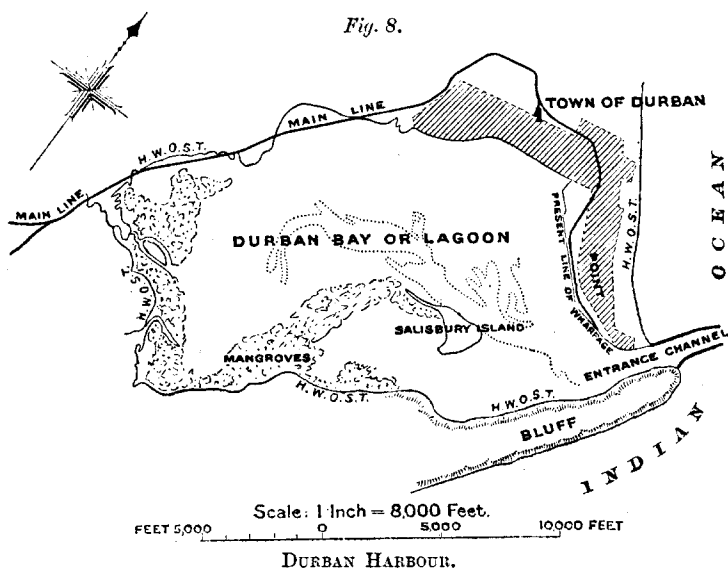
To be successful, however, schemes of this nature, at any of the rivers on the South-East African coast, require, in the first instance, the most careful investigation into their physical characteristics, and the fullest recognition of the ultimate expense involved in carrying out the necessary works. Any attempts to carry out works piecemeal and in a tentative fashion, are almost certain to end in disappointment and failure. Even if only small results are desired to begin with, it is always advisable that the works to attain such results should form part of a well-considered and more comprehensive scheme, which aims at the utmost results of which the river in question is found to be economically capable. Not only is this highly necessary from an engineering point of view, but in a new country like South Africa, with possible developments which no one can foresee, it is highly advisable for commercial reasons. When larger views come to be held of the necessities of a growing port, it is always objectionable and expensive to have to sweep away older works, which, conceived under less propitious circumstances, and perhaps without sufficient forethought and experience, stand in the way of the more extensive works for which need has then arisen.

Durban.—The only break of importance on the whole coast-line of Natal is that formed by the inner bay or lagoon of Durban; and this site has therefore been for a long period the harbour of the colony, and the gateway through which a large trade is carried on, not only with Natal, but with the Orange River and Transvaal colonies. Geographically, in fact, Port Natal or Durban

is the natural port for a large portion of both these colonies (*Fig. 1*). The following statistics show the commercial prosperity already achieved by this port :—

Year.	Ships Entering.	Registered Tonnage inwards	Value of Imports.	Value of Exports.	Customs Revenue.
1846	No.	Tons.	£	£	£
1880	362	198,630	41,958	17,142	3,510
1904	912	2,108,658	2,336,584	890,874	250,740
			10,991,302	9,010,389	981,888

During 1904, 395,578 tons of coal were bunkered and exported.



Durban Harbour is a lagoon harbour of a somewhat similar class to those of Malamocco (Venice) and Karachi. The lagoon, which provides a large and valuable backwater, is about $7\frac{1}{2}$ square miles in area. With the exception of a few channels intersecting it, and connecting the mouths of the two small rivers which enter it with the deeper parts near the outflow to the sea, it used to be extremely shallow over nearly its entire area, the bottom being, in fact, a stretch of sand and mud-flats, or banks, which were, and for the greater part are still, covered with about 2 to 3 feet of water at high water of spring-tides (*Fig. 8*). At the south-east side there are some islands which are slightly above high-water level, and are covered by man-

groves and other trees and shrubs similar to those fringing the head of the lagoon. These islands are being gradually and naturally reclaimed by the silting-up of the lagoon by debris and alluvial matter brought into it by the rivers, and by the almost imperceptible elevation of the coast which is going on. The same process accounts for the flats upon which the town of Durban is situated. The Umgeni River, which now enters the sea 3 miles north of Durban, undoubtedly at one time flowed southward within a sandspit between it and the sea, until it met the impenetrable barrier of the bluff rocks and was turned abruptly into the ocean. Its shallow lagoon, long since silted up, must then have occupied the position of the western Vlei along which Durban is now extending. Indeed, it was only in 1856 that, during a high flood, this river, being barred by an accumulation of sand at its mouth, turned southward and flowed over the Vlei, through a portion of the town, and into the lagoon at Durban, or "Durban Bay" as it will hereinafter be termed. It was even proposed at one time to divert this river permanently into the bay, in order that its waters might increase the scour at the entrance of the harbour, a scheme which was fortunately never carried out, as the whole of the detritus brought down would have been deposited in the bay and caused serious silting up.

The rise of the tide at springs is 6 feet; and the tidal volume available for the purposes of tidal scour in assisting to keep the port open, was calculated from the detailed survey made by the Author in 1892, to be about 28,327,972 cubic yards. Since then dredging-operations, where they have removed material above the level of low water, have somewhat increased this. The range of tide at neaps is not more than 3 feet, and occasionally only 9 inches to 1 foot. The tidal volume, therefore, during these tides is very much less than during springs; and the most valuable period of scour is during the first half of the ebb-tide of both springs and neaps, as after that there is little tidal water left to run out, beyond what is contained in the channels. The entrance to the lagoon is between a low-lying sandy spit on the north side, originally, and still largely, consisting of dunes, and a promontory about 200 feet in height on the south side, known as "The Bluff." Its geological structure is described in Mr. Anderson's second report on the geological survey of Natal, as "different from anything else we have on the coast, from the cretaceous rocks of St. John's River to the cretaceous rocks to the north of the Umlatusi lagoon in Zululand. In fact, the rock which forms at the surface the backbone of the bluff, and a portion of the ridge connecting it to the mainland, is certainly younger than anything exposed between the above limits.

It is a calcareous sandstone showing false bedding, and probably forms some part of the cretaceous series." This cretaceous rock cropped out in several parts of the bluff channel, and had to be removed by the Author.

The deposits forming the Durban flats, including the bay, are the same as those still being deposited in the bay, and consist chiefly of sand, clay, and beds of shelly marl, which occasionally give trouble to the sand-pump dredgers. The estuarine deposits of mud and clay on the surface render these flats agriculturally highly reproductive, a characteristic which is recognized to the full by the many Indian settlers upon them. They are, in fact, very similar in this respect to the estuarine deposits in the neighbourhood of the Tay, the Thames, the Humber, etc., and to the well-known fertile Dutch polders in the Netherlands.

The bar at the entrance to the lagoon, immediately under the lee of the bluff, was one of the most persistent and difficult to deal with known to the Author. Owing to the enormous accumulation of free sand along the coast, to the south of the entrance, for at least 100 miles, and its constant movement, due to both sea and wind, the depths on the bar were always very variable. Before the commencement of the present works, the average low-water depth has been generally assumed to be 6 feet, though occasionally it was much less. In February, 1860, there is a record of only 12 inches on the bar, and in July of the same year, 2 feet. The early records of the port are meagre and unreliable; but it is evident that the condition of matters at the entrance was very similar in some respects to what the Author found opposite the mouth of the Umlatusi lagoon, except that it was aggravated by the accumulations of sand which took place under the lee of the projecting end of the bluff, acting as a groyne in relation to the coast-line northward of it. The following notice in the Dessimian Collection of Manuscripts in Cape Town public library, dating from about 1685, seems to bear out the above assumption. "The East India Company would have taken possession of this fertile land (Terra de Natal) years past, but for seeing at the mouth of the Port a reef or sandbank that no galliot without touching could get over without danger; so that a small vessel could not safely go in there."

The form of this bar before any works were undertaken is shown in *Fig. 9*; and the influence of the projection of the bluff is very clearly observable in the accumulation of sand under its lee. The position of the bar has been recorded by the Author by indicating all the shoal water under 2 fathoms in depth.

Before the Author took charge of the Durban Harbour works in 1888, many proposals for rendering the entrance navigable had

Fig. 11.

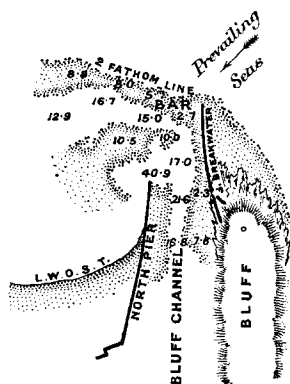
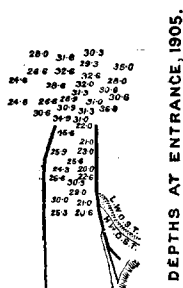


Fig. 14.



DEPTHS AT ENTRANCE, 1905.

Fig. 10.

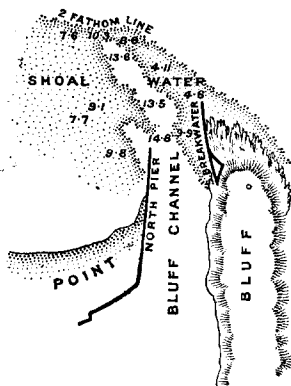
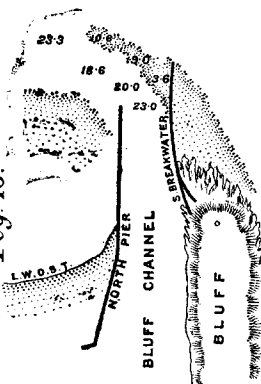


Fig. 13.



Scale: 1 Inch = 3000 Feet.
1500 3000 4500 6000 FEET

ENTRANCE TO DURBAN HARBOUR.

Fig. 9.

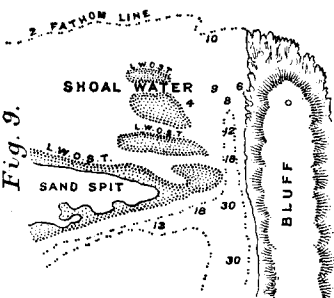
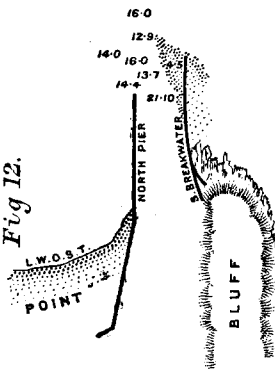


Fig. 12.



been made by various eminent engineers, including Mr. James Abernethy, Past-President Inst. C.E., and Sir John Coode. Certain works had been carried out under Mr. Abernethy's advice, but they proved unsuccessful, and were, indeed, broken up by the seas; and a northern work of considerable extent, executed under the advice of Captain Vetch, R.E., was abandoned, and afterwards partly removed for the sake of the stone it contained. The main work in progress on the Author's arrival at the port was the south breakwater. A north pier had been commenced under the advice of Mr. J. Milne, and was continued under the late Mr. E. A. R. Innes, Assoc. M. Inst. C.E., but was temporarily abandoned by him before the Author's arrival. Mr. Innes also designed and carried out the earlier portion of the south breakwater, which by 1888 had been carried out 900 feet in advance of the north pier. These works, so far, had increased depth over the bar at low water to 10 feet 7 inches in 1887, and 11 feet 7 inches in 1888; and the bar had assumed the form shown in *Fig. 10*. The works had not been extended nearly far enough to place them in a proper position relatively to the coast-line; and the north pier had been left lagging behind as if it were of no account, leaving the flood- and ebb-tides free to work round its end and form a tortuous northerly channel. The breakwater alone was being pushed on, practically extending the natural projection of the bluff on the south side of the entrance, and tending to close the entrance by causing additional accumulations of sand under its lee, and between it and the beach on the north side of the entrance.

There was no dredging-plant at the port, except an old bucket-dredger and a small stationary sand-pump dredger for reclamation purposes inside the bay. Before leaving England for Natal in 1888, however, the Author visited Holland; and after inspecting the work of dredging on the River Maas, he ordered, on behalf of the Government, a sand-pump dredger, of what were then considered large dimensions, from Messrs. Simons and Co. of Renfrew, as well as a powerful bucket-dredger for the harder material which had to be dealt with in the bluff channel and elsewhere. The sand-pump dredger had a hopper-capacity of 500 to 600 tons, and two suction-pipes, one on each side, 15 inches in diameter. She afterwards did good work, both on the bar and inside the harbour, for which latter she was more suitable.

After mature consideration of all the facts ascertained during a protracted period of investigation, the Author recommended that the north pier should be extended until it was abreast of the breakwater, and that dredging should be resorted to on the bar to supple-

ment the scour then induced by the works; pointing out the great burden on the port which continuous dredging would create, and the consequent necessity for minimizing it by utilizing to the utmost the tidal scour available from the bay. He also made provision for a further extension of both works on a slight northerly curve for 600 feet, should this be found necessary after the extension of the north pier; but the authorities strongly opposed any further extension of this work. As the breakwater advanced farther ahead of the north pier, thus increasing the projection on the south side of the entrance, the bar, or rather the area of shoal water which formed under its lee and across the entrance, progressed with it. When the breakwater went ahead rapidly, the ridge of the bar occasionally came just within its end, being beaten inwards by the heavy seas; but in a very short time it again headed the work before any further extension of the northerly pier was begun, and also during and after its construction out to the point it reached in the period during which the Author had charge of the works. The form the bar usually took is shown in *Fig. 11*, which is taken from a survey made just before the commencement of the north pier extension, and when that work was 1,300 feet behind the breakwater. The dotted areas show the sand accumulations, or shoal water less than 12 feet in depth. Under these conditions, the scour from the ebb-tide was dissipated to the north round the head of the shorter work, the waters finding their level in the ocean outside by the shortest route. It was therefore necessary, for the navigation, to train the tides as far as possible on the line of the axis of the bluff channel. This was also the only practicable line on which dredging could be carried out; for dredging in a more northerly direction would have brought the craft broadside on to the seas.

An endeavour was being made, before the Author took charge of the works, to cut off the sand-supply by the extension of the south breakwater only; but the Author pointed out that this was absolutely impracticable. The only result the work had, by itself, was to cause accumulations of sand under its lee and across the entrance. A sufficient extension of it would have caused the entrance to become blocked altogether, by lengthening the base on which the accumulations rested. As, however, it was a necessary work in conjunction with the north pier, and, from its greater exposure to the prevailing seas, had to be made much stronger, its progress was slower than that of the north pier, so that it was continued while the latter work was being brought up to overtake it. Before this could be done, however, its increasing overlap diminished the average depth over the bar to 10 feet 1 inch. The effect of the extension of

the north pier was not only to train the ebb-tide, but also to narrow the width of the entrance from 900 feet to 800 feet, and so increase the scour from the bay. The scour, however, was quite unable to maintain the necessary navigable depth in so wide a sectional area as that of the bluff channel; and in 1890 the Author pointed out that the width might have to be still further reduced, which has since been done. As the immediate result of the extension of the north pier to a point 700 feet short of that which the breakwater had reached, the depth of 10 feet 1 inch in 1890 was increased to 13 feet 8 inches in 1892. In March, 1893, the depth on the bar averaged about 13 feet 6 inches, though no dredging had been done on it since October, 1891. This was a remarkably good increase of depth in so short a time; but it was followed by a gradual reduction to 12 feet 1 inch in 1895, even although during these years every effort was made, with the available dredging-plant, to maintain and increase the depth.

It was not until 1894 that the Author was able to order a powerful dredger for open-sea work on the bar, in accordance with a specification which he had prepared several years before, and for which he repeatedly made application. For this dredger, the "Octopus," he partly took as a model the "Brancker," the well-known pioneer of this powerful class of craft on the Mersey bar. Her hopper-capacity was fixed at 1,200 tons, as it was then considered by the port-authorities that this would be as large a craft as could be handled with safety on the bar, and exposed to heavy seas. Subsequent experience has shown the practicability and advantage of working considerably larger craft in this situation. The main suction-pipe of the "Octopus" was 42 inches in diameter, and placed in a central well, and it was of sufficient length to enable the vessel to dredge considerably below the depth required for navigation when at an angle of only 45°. She had separate pumping-engines, in addition to her propelling-engines, and two large centrifugal pumps with 24-inch suction- and discharge-pipes working out of the main suction-pipe. The plan of dredging well below the required navigable depth outside the entrance, and thus making allowance for any shoaling during rough weather, the Author saw in use in Holland in 1888, where it was regularly practised by the Dutch, who at that time were considerably ahead of English engineers in sand-pump dredging. The contract dredging-capacity of the "Octopus" was 3,000 tons of sand per hour; but her record time in filling her hopper with 1,200 tons of sand was about 13 minutes, or nearly 100 tons of sand per minute. This vessel, which was the first of the present fleet of these powerful dredgers at Durban, did not arrive until 1895; and the

Author pointed out to the Legislature that with her advent would commence "greater experiments of outer-sea dredging than had probably been tried in any other part of the world." He thinks it may safely be said that this prediction has been verified.

Reverting to the outer works, in 1892, in spite of his most urgent appeals, the Author found it impossible to obtain sanction for the further extension of the north pier. He therefore decided to stop any further projection of the breakwater until the north pier was brought up abreast of it; and it has not been extended since. These works, therefore, remained as they were for some years, with the end of the south breakwater about 700 feet ahead of the north pier.

The changes on the bar during this time are shown in *Figs. 12 and 13*. The original overlap of the bluff beyond the sand-spit on the north side of the entrance, now known as "The Point," and before any works were begun, was the governing factor as regarded the area of the shoaling which then took place to the north of it, for it acted as a huge groyne in relation to the coast-line to the north, and induced shoaling under its lee, as shown in *Fig. 9*. After the extension of the north pier to within 700 feet of the breakwater end, the same formation, which for a time was broken through, reappeared in the form shown in *Figs. 12 and 13*.

It was then quite apparent that the reduction of depths between 1893 and 1895 was due entirely to the overlap of the work on the south or weather side, the side from which the heaviest seas, the littoral current, and the sand-travel came. To dredge under such conditions was to preserve a state of affairs which was equivalent to putting sand in front of the entrance with one hand in order that it might be taken away with the other. While the tide ran in and out round the head of the north pier, it only tended to form a northern channel there; and the dredgers were employed in forming one on the axis of the bluff channel. In fact, Nature was being pitted against the artificial power of dredging, and if she did not win, the only result would be to greatly increase the annual cost of dredging, instead of reducing it to a minimum by bringing forward the north pier abreast of the breakwater, and inducing the two powers to work together. These views were constantly insisted upon by the Author, but without avail; and in 1895 his professional connection with these works ceased.

Some time before this, the Author suggested to the Government that independent opinion on the subject should be sought; but it was only subsequently arranged that Sir Charles Hartley, K.C.M.G., M. Inst. C.E., should visit Durban in 1896. Sir John Wolfe Barry was also retained to act with Sir Charles Hartley in advising the

Government; and in 1897 they advised, in an able report,¹ the immediate extension of the north pier until its end was abreast of that of the south breakwater, and a still further narrowing of the entrance to 600 feet, in order to increase the scour from the bay. In addition, they advised persistent dredging on the bar in the open sea. The north pier was then extended until its end was abreast of that of the breakwater, and at a slight angle, so as to narrow the entrance; and dredging with the "Octopus" and her sister craft was carried on in addition. The scour, induced and trained by the extension of the north pier, was brought to bear in assisting and maintaining the work of the dredgers. The result has been that the average depth at low water on the bar in 1902 was 18 feet 5½ inches; in 1903 it was 21 feet 3½ inches; in 1904 it was 25 feet 9 inches; in the earlier part of 1905, 27 feet 6 inches; and in October 1905, 30 feet (*Fig. 14*). Since June, 1904, the largest mail-steamers have entered and left the harbour in perfect safety.

The following figures show the quantities dredged outside the works, and for a distance of about 700 feet inwards from their ends, that is, on, and in the neighbourhood of, the bar:—

Year.	Dredging. Tons.	Average Depth at Low Water Feet. Inches.
1897	567,700	17 3
1898	775,800	18 7
1899	353,700	19 7½
1900	377,250	19 8½
1901	684,550	19 1½
1902	711,400	18 5
1903	1,123,650	21 3½
1904	1,021,000	25 9

The north pier extension was completed at the end of 1900.

From the above figures it will be seen that the increase in the depth over the bar is by no means in exact proportion to the amount of dredging. In 1898, though 775,800 tons were dredged, the average depth over the bar was 18 feet 7 inches. On the other hand, though little more than half that amount of dredging was done in each of the years 1899 and 1900, the average depth increased to 19 feet 7½ inches, and 19 feet 8½ inches in these years respectively. During these years, however, the north pier was being extended, and was made fully effective at the end of 1900. The depths then fluctuated between 19 feet 1½ inch and 18 feet 5 inches in 1902, a decrease, though the dredging was nearly doubled.

¹ "Port Natal: Report on the Existing Works, with Proposals for Further Improvements of the Harbour." London, 1897. (Copy in the Institution Library.)

The dredging was then increased to 1,123,650 tons in 1903, an increase of 412,250 tons; and the depth increased to 21 feet $3\frac{1}{2}$ inches. But in the following year, 1904, the dredging was less by 102,650 tons; while the depth increased to 25 feet 9 inches. Such are the uncertainties of weather, and the consequent movement and deposition of sand, that it is unsatisfactory and misleading to draw any conclusions from comparison of the results of one year with the following. In such cases considerably longer periods are necessary; and thus it is found that in 1904 the amount dredged on, and in the neighbourhood of, the bar, was greater by about $31\frac{1}{2}$ per cent. than that dredged in 1898, before the extension of the north pier was far enough advanced to be effective; but the increase of depth in 1904, after the completion of the north pier in 1900, was about $38\frac{1}{2}$ per cent., namely, from 18 feet 7 inches to 25 feet 9 inches at low water.

This splendid result is undoubtedly due to the proper training and increase of the tidal scour, coupled with the dredging-operations. In fact, there can be no doubt that, before the extension of the north pier, the natural tidal scour and the dredging were largely opposed to each other; and the liability of the bar to the sudden shoalings which frequently took place during very short spells of bad weather—sometimes lasting not more than about 24 to 48 hours—reducing the depth much below the loaded draught of the dredgers, made it impossible to work these effectively, or with any hope that their work would be maintained.

The dredging-fleet at Durban now consists of twelve dredgers, several of them large hopper-dredgers provided with powerful sand-pumps of the "Octopus" class, with central well and separate pumping engines, and with a combined dredging-power of not less than 7,000,000 tons of sand per annum; but when it is borne in mind that not only have constant operations to be carried on on the bar at the entrance, but that a great work of deepening in the shallow bay, and of land-reclamation round its margins, has also to be carried out, the plant is not excessive, though it is very large in proportion to the revenue of the port. The cost of dredging in free sand varies according to the site between a little more than 1*d.* per ton and 3*d.* per ton, the cheaper work being done by the dredgers of larger hopper-capacity.

With respect to the outer works, and the minimizing of dredging at the entrance, in the Author's opinion everything has not yet been done that is possible in this direction. It is of great importance in all cases of this kind that the termination of the works should be placed in proper relation to the coast-line, so as to be, if possible, beyond

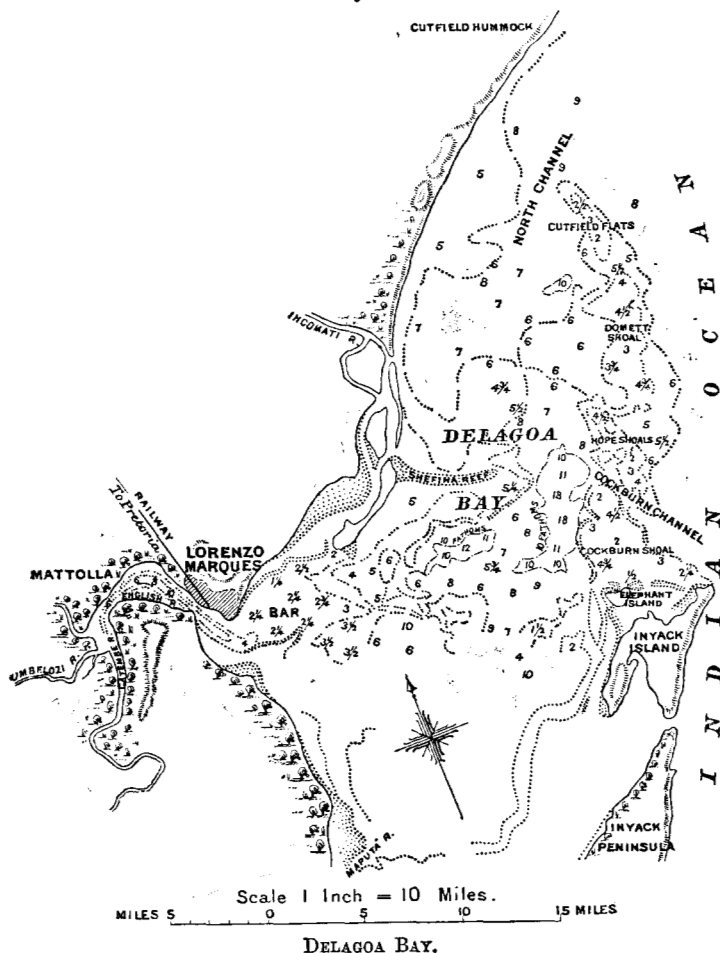
the influence of any peculiarity in its contour which might cause deposition about the entrance. There is an interesting indication among the earlier surveys of the Durban bar that this has not been quite reached, and that, if it were, the result might be undiminished depth, and at the same time considerable decrease in the annual cost of dredging the bar. The bluff does not taper at its seaward end to a fine point (*Fig. 13*); and in consequence of this, and of the direction of the seas and the littoral current up the coast, a sand-spit, with 12 feet in depth at low water of springs, formed in 1885, and again in 1887, springing from the broad end of the bluff as a base, and between the seas and littoral current on the south side, and the out-flowing and inflowing tide on the north side. Had the end of the bluff been wider, thus forming a wider base for the spit, the latter would have been longer. It is clearly visible on several of the surveys, and is a certain indication that the south breakwater, the end of which is short of the length of that spit, is still within the influence of shoal water so caused. This natural indication, so clearly and repeatedly shown by the surveys, was taken by the Author as a guide in determining the length to which it might ultimately be advisable to extend the works, in case, after the north pier had been brought up abreast of the breakwater, it were found necessary to go farther. As there is, however, the interest to be reckoned on the cost of the additional works, it is difficult to determine whether any saving in dredging would more than counterbalance this. The point is nevertheless of interest, as an instance of the indications which Nature sometimes gives the engineer as to the proper course to follow.

In the treatment of bars on sandy coasts, the great development of the sand-pump dredger has come to the engineer's assistance, and has made it possible to deal with cases which it would have been hopeless to attempt before; but it must not be imagined on that account that it has made these problems any easier to solve. Heavy dredging when, unfortunately, it is necessary to supplement the natural forces, is very costly, and has to go on for all time: it thus becomes a millstone around the neck of any engineering and commercial enterprise depending on it. It is therefore the first duty of the engineer to see that, in the disposition of the works, he utilizes to the utmost degree, and in the most effective and economical manner, any natural forces available, so as to minimize the amount of dredging necessary: and it is here that the problem is as great as ever.

Delagoa Bay.—Delagoa Bay, though not a British port, ranks not only as one of the principal ports of South Africa, but also as one of the great natural harbours of the world, more, indeed, by reason

of its possibilities than owing to its present state of development. Although a bay in one sense, it appears from *Fig. 15* to be in a state of transition between a bay and a lagoon on a gigantic scale. It receives four main rivers, namely, the Tembe and Umbelosi,

Fig. 15.



flowing with the smaller Mattolla River into the inner lagoon, called sometimes the "English River," the Maputa flowing into the so-called bay at the back of Inyack Peninsula, and the Incomati flowing in at Shefina reef.

The distance across the mouth of the bay proper, from the north end of Inyack Island to the mainland at Cutfield Hummock, is about 35 miles; and the width across from this line westwards to Reuben Point at Lorenzo Marques is about 23 miles.

The deep-water entrance to the bay is between the points of Shefina reef and the Cockburn shoal, which extends about 5 miles northwards from Inyack, with depths of only $\frac{1}{2}$ fathom to 3 fathoms on it. This entrance is 60 to 72 feet in depth, and about 3 miles wide; and it has a bar at its outlet, which, though it has varying depths over it of 3 to 7 fathoms, is, nevertheless, a bar in relation to the much greater depths immediately within it. Owing to the uncertainty and variability of these depths, it also constitutes a very real bar to the larger class of vessels entering the port. There are, in fact, only two highways for large vessels into the bay, one from the north within the shoal referred to, and the other, and more generally used one, by the Cockburn channel round the point of Inyack.

The submerged spit, formed by the "Cockburn," "Hope," and "Domett" shoals, with the "Cutfield flats" at their northern point, resembles on a very large scale the form of the sandspits which exist between all the smaller lagoons previously referred to and the sea. Again, on examining the northerly deflection of the deep-water entrance between the Shefina reef and Cockburn shoal, the curved bar-formation encircling the entrance is very apparent.

The Author has heard expression frequently given to the mistaken idea that Delagoa Bay, or its harbour at Lorenzo Marques, is accessible to the largest vessels at all states of the tide. The plan shows, on the contrary, that outside the entrance to the English River, or inner lagoon, there is a very extensive bar. This bar, which has depths over it of only $2\frac{1}{4}$ to 3 fathoms, with a governing depth of $2\frac{1}{4}$ fathoms, is slightly over 4 miles wide. It is clearly not of the usual bar-formation, previously referred to as being due to the action of the waves on the sand. There are, in fact, never any heavy seas at this part of the bay, as they are broken up by the outside shoals when they come from the east; and when coming from south-east, the peninsula and island of Inyack stop them. This bar is caused by the deposition of matter brought down in suspension by the rivers entering the inner lagoon. As soon as the river and tidal waters emerge from the narrow outlet opposite Lorenzo Marques into the rapidly widening area of the outer bay, the current slackens, and deposition occurs. There is a rise of tide, however, at Lorenzo Marques of 12 to 13 feet at springs, so

that at high water vessels of considerable draught can cross the bar to the deeper water inside.

To dredge a channel 18 feet in depth at low water of springs through this bar would involve about $4\frac{1}{2}$ miles of dredging; a channel 24 feet deep would involve $5\frac{1}{2}$ miles of dredging; and a channel 30 feet deep would necessitate about 8 miles. No doubt these extensive operations will be undertaken some day. The deposit forming this bar must have occupied an immense period in accumulating; and in such a situation the effect of dredging may be regarded as practically permanent, when once the side slopes have taken their natural angle of repose. At all events it is probable that once the channel is dredged, its maintenance will be no more serious than are similar operations carried on in the Mersey estuary or at New York. The ultimate fate of the Cockburn channel in such an exposed position is not easy to predict: it is probable that dredging difficulties may have to be faced here—possibly in the far future—which may tax the best energies of the engineers of that day; but no doubt they will be overcome.

The possibilities as regards the development of the harbour are limitless, and depend upon the development of the immense tract of country behind it, of which it is the natural port. It is to be hoped that what is done towards that end will be begun upon a well-considered general plan, far in advance of the times, and not built up in a haphazard way.

The Paper is illustrated by twenty tracings, from some of which the Figures in the text have been prepared.