HALLSANDS AND START BAY.

BY R. HANSFORD WORTH, F.G.S.

(Read at Teignmouth, July, 1904.)

START BAY.

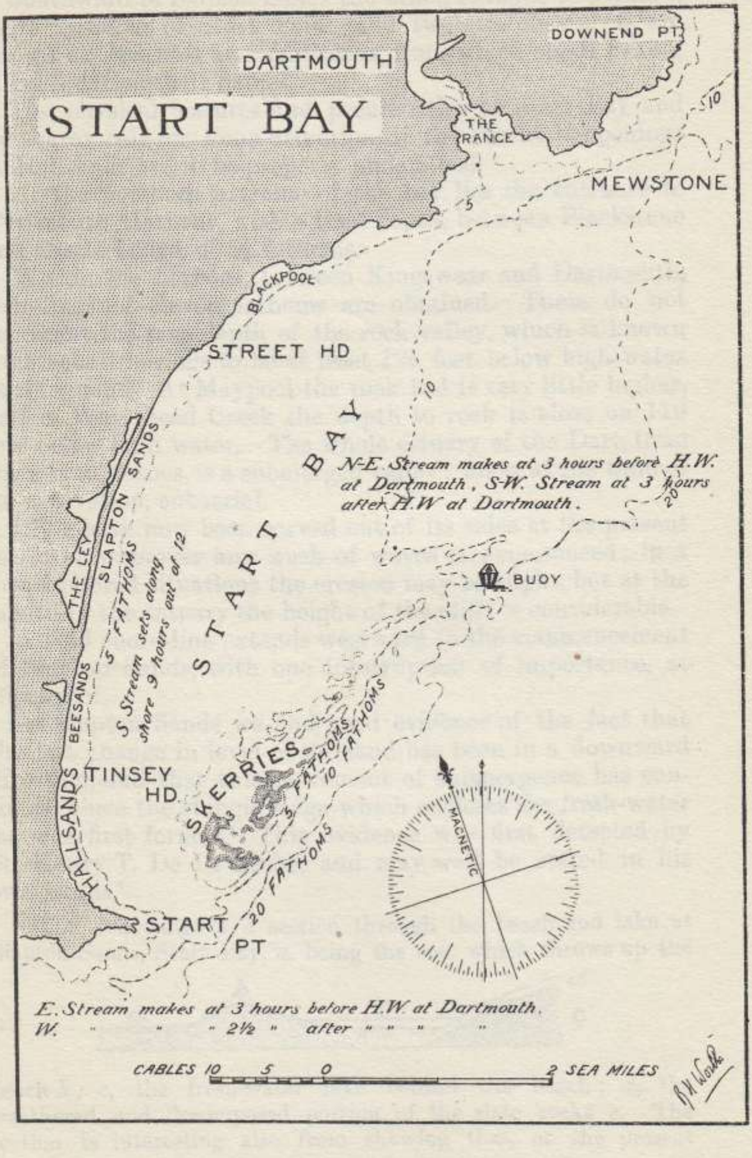
THE south coast of Devon turns practically through a right angle at Start Point; and while from Plymouth Sound to the Start its trend is easterly, with an inclination toward the south, from Start Point to Exmouth its direction is northerly, with an inclination toward the east.

Start Point itself juts out for some short distance in an easterly direction, and between it and the Mewstone off Dartmouth lies Start Bay. The extreme embayment, as measured shoreward from a line joining the two points just mentioned, is slightly over two miles. (See Chart.)

The greatest depth of water anywhere, except very locally or at the north end of the bay, is nine fathoms. The same line, which bounds the bay seaward, forms also the shoreward limit of the great Skerries Bank, which has but nine feet of water over its southern extreme, and two to four fathoms over it in other parts. The bank, if taken as outlined by the five-fathom contour, is about three and a half miles in length.

The shore of Start Bay is noteworthy for its large deposit of beach material, of which the stretch now known as Slapton Sands, separating the fresh water of Slapton Lea from the salt water of the bay, is probably the best known to most persons.

Tristram Risdon's description of the locality is sufficiently quaint, and in some manner informative, to be quoted. He writes:—" STOKENHAM standeth where the shore shrinking back is made in manner a bay; and thereby a spacious pool, which the Britons call *Llyn*, the Irish *Lough*, we the *Ley*, seperated from the sea by a ridge of chesell sand and gravel,



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called by some *Longsand*. This mere is fed by rills of fresh water, wherein stores of fish (as I have heard) are taken."

Southward of *Slapton Sands* the beach extends to within a short distance of Start Point, and two stretches of it are known as *Beesands* and *Hallsands*, from which small fishing villages derive their names.

The physical features and peculiarities of Start Bay and its shores call for some attention, if the recent happenings at Hallsands are to be properly understood.

At the northern extreme of the bay lies the entrance to Dartmouth Harbour, with a least depth, between Blackstone and Castle Ledge, of 5¼ fathoms.

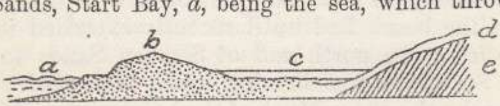
Within the harbour, between Kingswear and Dartmouth, soundings of eleven fathoms are obtained. These do not represent the true depth of the rock valley, which is known from actual borings to be at least 125 feet below high water at this point. At Maypool the rock bed is very little higher, and in Waterhead Creek the depth to rock is close on 110 feet below high water. The whole estuary of the Dart, from the sea to Totnes, is a submerged valley; once, at the time of its excavation, subaerial.

Cliffs have now been carved out of its sides at the present sea-level wherever any wash of waves is experienced; in a few sheltered situations the erosion may be slight, but at the mouth of the estuary the height of the cliffs is considerable.

A bold shore-line extends westward to the commencement of Slapton Sands, with one interruption of importance, at Blackpool.

At Slapton Sands we find good evidence of the fact that the last change in level of the land has been in a downward direction, and that this movement of submergence has continued since the shingle ridge which encloses the fresh-water lea was first formed. This evidence was first detected by Sir Henry T. De La Beche, and may well be stated in his own words.[1]

"The following is a section through the beach and lake at Slapton Sands, Start Bay, *a*, being the sea, which throws up the



beach *b*; *c*, the fresh-water lake behind the beach; *d*, the weathered and decomposed portion of the slate rocks *e*. The section is interesting also from showing that, at the present

[1] *Geological Observer*, second edition, 1853, p. 56.

relative levels of sea and land in that locality, the sea has not acted on the hill *d e*, since the loose incoherent substance of *d* would have been readily removed by the breakers.

"The Chesil Bank, on the coast of Dorsetshire, ... in this case also we seem to have an example of the Atlantic breakers not having reached the land behind, since the relative levels of sea and land were such as we now find them. A gradual sinking of the coast would appear to afford an explanation of the phenomena observed, and is a supposition harmonizing with the facts previously noticed at Slapton Sands."

The submerged forest at Blackpool[1] is further evidence of the subsidence of the land in this neighbourhood at a recent geological time.

For present purposes, however, the point of interest is that a beach existed at Slapton prior to the completion of the last downward movement of the land (if indeed such movement is even now absolutely complete), which has continued to exist to the present time, and has uninterruptedly protected the shore-line behind it from the attack of the Channel waves.

Passing westward and southward we find a continuous beach extending to within a short distance of Start Point. Where it crosses the mouths of valleys entering the sea it has barred the access of the waves, and protected the land from their attack. It is true that no natural leas have been formed, but this is largely in consequence of the relatively small streams which occupy these valleys, in comparison with the several sources of fresh-water supply which have been in action at Slapton. (Perhaps small leas may have existed and have been silted up.)

The beach, except where it crosses these valleys, is bounded on the landward from Torcross to Start Point by considerable cliffs. These mark positions where the steeper spurs of hills have been submerged, forming, at one time, small capes jutting seaward beyond the protection of the beach; now, however, when by the continued action of the breakers these capes have been cut back to a fairly uniform coast-line, the beach had until recently extended itself continuously from the north end of Slapton Sands to a point near the Start, and was bearing nearly the whole brunt of the erosion by the sea. Much of the beach material had been driven above high-water level, and every slight recess in the

[1] "On the Submerged Forest at Blackpool, near Dartmouth, South Devon," by W. Pengelly, F.R.G.S., F.G.S., *Trans. Devon. Assoc.*, vol. iii., 1869, p. 127; and A. R. Hunt, *Trans. Devon. Assoc.*, vol. xiii., 1881, p. 344.

shore-line held between high water and the cliff its expanse of shingle.

So long, prior to recent happenings, had the shingle immediately below the surface and touching the cliffs been undisturbed, that at Hallsands masses of natural concrete adherent to the cliffs have been formed. In this concrete lime is the cementing material, and carried in minute quantities by water oozing from the main joints of the metamorphic rock, it has bound together the shingle of the beach, thoroughly filling the interstices between the constituent pebbles.

Such concrete could not have been formed had the shingle in contact with the cliffs been subject to even occasional disturbance of wave-action. And its existence as recently revealed is proof of the previous long continuance of stable conditions in the higher levels of Hallsands beach.

Just north of Hallsands, at Greenstraight, is one of the valleys from which the beach has barred the sea.

The Physical conditions thus give every evidence of the long existence and maintenance of the shingle beaches of Start Bay. . . . (1).

We may now, with advantage, consider the lithological composition of the beaches.

Mr. A. R. Hunt has already directed attention[1] to the fact, that in Start Bay "its beaches are permanently composed, among other constituents, of material foreign to the coast-line, viz. flint shingle."

Mr. Hunt has also determined the presence of quartz sand of Dartmoor origin.

The late R. N. Worth[2] reported the existence of felsitic and granitic pebbles on Slapton Sands.

Recent examination of the beach at Hallsands has disclosed the presence of very numerous pebbles of Dartmoor origin, many of which are of rocks identical with those still to be found *in situ* in the moorland valley of the Dart. Best represented are the variants of "Felsite A";[3] following this we find, but in much less quantity, fine-grained granite highly charged with schorl; and in still less prominence grey and buff granular felsites, and fragments of true schorl rock.

There is not a square yard of beach from which these Dartmoor materials cannot be obtained.

[1] "The Wearing of Fine Sands by Waves," *Trans. Devon. Assoc.*, vol. xix., 1887, p. 511.

[2] "Materials for a Census of Devonian Granites and Felsites," *Trans. Devon. Assoc.*, vol. xxiv., 1892, pp. 203 *et seq.*

[3] "The Petrography of Dartmoor and its Borders," *Trans. Dev. Assoc.*, vol. xxxiv.

Approximately the shingle may be stated to be composed: In the first place, of flint pebbles; these preponderate over all the other constituents taken together. In the second place, of quartz pebbles, many of which may be derived from the Hallsands cliffs. In the third place, of Dartmoor felsites and some granites. Finally, a very small quantity of undoubtedly local rock is represented by fragments of mica and chlorite-schists (it requires careful search to find any), and there are also occasional pebbles of Permian or Triassic sandstones and conglomerates.

Take away the material of undoubtedly foreign origin that is not derivable from the adjacent cliffs, and for all practical purposes no beach would remain. The cliffs, it may be emphasised, can only supply mica and chlorite-schists, Devonian slates, and fragments of quartz derivable from the same.

There is no present source from which the foreign constituents of the beach can be recruited. We shall see later how true this is of the flint gravel, but we may at once consider the matter of the Dartmoor rocks. If these are to reach or to attempt to reach this coast they must first run the gauntlet of the whole estuary of the Dart. In the course of their travels they would have to pass along a channel sixty-six feet deep off Kingswear and Dartmouth, and then climb over a submerged bar with about thirty-two feet of water on it between the Range and Blackstones. A much more perfect trap for any but mere sand grains could not be devised. If it is objected that these pebbles might choose to keep in shallower inshore waters, or on the foreshore of the estuary, it can only be said at once that this attempt would be fatal to their future freedom, as the silt would stop them, and further, their course would then be open to actual observation, as a result of which we are in a position to state definitely that they do not travel in this manner.

Even if landed on the submerged bar of the Range, pebbles of any size would be lost for ever to the neighbouring beaches, the depth of water being too great to admit their transference to the shore. It may be added that according to the Admiralty chart the sea-bed of the Range is not shingle but sand, and this one fact effectually disposes of all question as to whether or no pebbles could travel over this area; if they could and did, they would be found there.

Granted, then, that Dartmoor rocks can no longer approach the beach by this channel, it remains that an explanation should be found for their presence. Here again we are dependent upon our knowledge of the previous relative levels of land and sea. The difficulties of transit which now exist were absent when the present harbour of Dartmouth was a subaerial valley. Lift the land some 130 or 140 feet, and a constant supply of felsite and granite would once more be available.

We must retire to the period when the harbour of Dartmouth was a land valley, at the bottom of which ran the fresh water of the Dart, if we would account for the presence of the felsites at Hallsands. The evidence would be conclusive even if this were an isolated case; but, in fact, the conditions can be paralleled at the Yealm: here, too, Dartmoor pebbles are found on the sea-beaches, but none within the estuary, the depth of water in which prevents any further supply reaching the open shore.

A considerable amount of the beach material in Start Bay is thus shown to be of great age. And if the granites and felsites have seen long service, we cannot attribute any less antiquity to the flint. From the point where the entrance channel to Dartmouth presents an impenetrable barrier there is nowhere westward any land deposit of flint which might feed this beach. A marine origin for the flints, from somewhere beneath the waters of the bay, has been suggested, but this, which has not appeared in any published paper, will presently be proved to be erroneous.

Subject to such proof being forthcoming, we may say that: *The lithology of the beach gives additional evidence of its great age; and further, shows that any loss caused by the removal of a portion of the shingle must under present conditions be permanent. . . .* (2).

Combining conclusions (1) and (2), we deduce that not only has a beach existed in Start Bay for a long period, and afforded throughout its existence a great protection to the lands shoreward of it, but that it has also throughout that period consisted of similar materials, and even of the same identical materials, stone for stone, and has borne the brunt of the wear and tear of the waves, with no recruited stock to replace loss, except some small quantity derived from the cliffs.

We have already adduced evidence that the beach was in existence before the last downward movement of the land. The mere presence of such an accumulation on a sinking shore-line is in itself suggestive of age, if Professor Bonney is right in holding that "a sinking or sunken land seems to be unfavourable to the formation of pebble beds (beaches). Thus there are few pebble beaches along the coast of Norway, partly, perhaps, because much of it is protected by outlying islands, and partly because the deep fiords prevent the rivers from carrying pebbles into the open sea."[1]

Has the beach been derived, or is it being recruited, from deposits now existing under the waters of Start Bay? That to some extent it was originally derived from deposits which once occupied the area now known as Start Bay seems almost certain. As the land has settled downward the advancing waves have driven the beach before them, and must have taken materials from the land surface which they transgressed and added these to the beach. But no further accession of material may be derived from that source. The bed of the bay now consists of sands of varying degrees of fineness, and none of the beaches in the bay are wholly, or even largely, sand. If we except Blackpool, we may assert that none but shingle beaches can exist in Start Bay, and hence no quantity of sand on the adjacent sea-bottom is of any avail for their maintenance.

It is true that off Blackpool flint pebbles have been found in five fathoms of water. Dr. H. M. Kyle has written:—[2]

> "A dredging obtained off Blackpool, where the beach is sand, showed that other materials were present in the deeper water. It is well known that the sand of the beach rests on a clay bottom, which is frequently uncovered by storms. At the eastern corner, in five fathoms of water, this clay was found free of sand, but contained small pebbles similar to those on the beach at Hallsands. These pebbles were well rounded, showing that they must have travelled about a good deal until trapped in the clay."

The statement that the sand on the beach is frequently stripped by storms can hardly be accepted. Mr. Pengelly gives 1802, a date some fifty years later, and 1869 as the years in which this stripping had been known to occur, and we then have an interval of sixteen years to 1881, Mr. Hunt's record. But the presence of flint pebbles in five fathoms of water, off Blackpool, is undoubted, and Dr. Kyle correctly describes them as "trapped in the clay."

The probability is that these pebbles were caught and held by the clay as the beach moved upward over it, when

[1] *The Building of the British Isles*, A. J. Jukes-Browne, 1892, p. 8, footnote.

[2] "Notes on the Physical Conditions existing within the Line from Start Point to Portland," by H. M. Kyle, D.SC., *Journal of the Marine Biological Association*, vol. vi. p. 536.

the land was sinking, and once caught, they have ever since been held.

It has been suggested that in these and similar pebbles (if such exist elsewhere) we are to recognise the future recruits of the beaches. There is no remote probability, however, that any of them will ever reach the shore. The sea-bottom is admittedly disturbed by wave-action to a depth of at least thirty fathoms, but in much less depths materials are not transported on it.

At Port Elizabeth, in South Africa, the movement of sand from the beach seaward terminates in three and a half fathoms,[1] and at Madras the movement of sand during the monsoon extends to five fathoms only where artificial obstructions cause eddies.[2] It seems fairly certain, therefore, that on our coasts any gravels which exist at a greater depth than five fathoms on an uniformly sloping sea-bottom are free from all danger of being cast ashore.

It may be convenient to reproduce from Dr. Kyle's paper the following tables:—[3]

I. SAMPLES OF BOTTOM SOIL SHOWING THE PROPORTIONS OF THE DIFFERENT KINDS OF SAND.

Grade.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
I. Stones . . .	—	—	—	—	—	—	—	—	—	—
II. Coarse Gravel .	—	0·50	0·58	0·70	4·30	0·37	0·25	Trace	3·20	
III. Medium Gravel .	1·35	2·60	3·10	2·40	15·60	2·71	0·10	0·42	5·50	1·4
IV. Fine Gravel . .	3·50	4·00	7·92	4·50	21·00	4·61	0·20	1·65	11·20	0·68
V. Coarse Sand . .	4·45	5·80	10·25	5·30	19·20	6·30	0·25	2·37	12·30	0·78
VI. Medium Sand .	59·70	80·30	71·85	70·50	38·20	56·00	11·05	61·14	50·50	16·0
VII. Fine Sand . .	—	6·80	6·30	16·60	1·70	30·01	87·80	34·41	17·30	74·0
VIII. Silt . . .	—	Trace	—	—	Trace	Trace	0·35	Trace	Trace	7·2

II. GROUND WHERE SAMPLES WERE OBTAINED AND AVERAGE CONDITION OF SAMPLES.

No.	Ground, Depth, and Date.	Average.
I.	Close to Skerries Buoy on inner side; $11\frac{1}{2}$ fathoms; January 30, 1902 . . .	6·22
II.	Close to Skerries Buoy on inner side, after easterly gale; February 4, 1902 . .	5·83
III.	Close to Skerries Buoy on outer side; 15 fathoms; February 4, 1902 . . .	5·686
IV.	On line Skerries Buoy to Start Lighthouse ($\frac{1}{2}$ mile); 10 fathoms; February 4, 1902 .	5·923
V.	On line Skerries Buoy to Lighthouse (half-way); 10 fathoms; February 4, 1902 . .	4·760

[1] *Minutes Inst. C.E.*, Sir John Coode, lxx. 44.
[2] *Ibid.*, Mr. W. F. Thorowgood, lxx. 37.
[3] *Op. cit.*, p. 540.

No.	Ground, Depth, and Date.	Average.
VI.	South-west corner of Skerries Bank, opposite Hallsands, on line Buoy to Lighthouse; 10 fathoms; February 4, 1902 . . .	6·049
VII.	Midway between Hallsands and Beesands (½ mile offshore); 9½ fathoms; February 4, 1902	6·86
VIII.	Off Torcross (2 miles); 7½ fathoms; February 4, 1902	6·274
IX.	On line Skerries Buoy to Lighthouse (¾ mile); 16 fathoms; February 4, 1902 . .	5·513
X.	Four miles off Berry Head (E. ½ S.); 24 fathoms; April 16, 1902 . . .	6·82

The whole of these samples were obtained by Dr. Kyle; the writer worked out the details of II. to VIII. inclusive.

The division into grades is that adopted by Dr. Allen, and subsequently utilised by the writer in a previous paper in these *Transactions*. It may, however, be repeated here. The terms "stones" and "gravel" are not used in strict accordance with common acceptance.

I. *Stones.* All inorganic material which will not pass through sieve with 15 mm. perforation.

II. *Coarse gravel.* Material left on sieve with 5 mm. perforation.

III. *Medium gravel.* Material left on sieve with 2·5 mm. perforation.

IV. *Fine gravel.* Material left on sieve with 1·5 mm. perforation.

V. *Coarse sand.* Material left on sieve with 1 mm. perforation.

VI. *Medium sand.* Material left on sieve with 0·5 mm. perforation.

VII. *Fine sand.* Material which passes through 0·5 mm. sieve, and when stirred up in sea-water settles in one minute.

VIII. *Silt.* Remains in suspension at the end of one minute.

With a knowledge of the result of these dredgings we may safely conclude that *the beaches have no possible recruiting ground on the adjacent sea-bottom* . . . . (3).

Abandoning for the moment all special local features, it becomes necessary to recall a few of the characteristics of beaches in general. It is a mere truism to state that beaches are littoral accumulations, but one probably enters on ground which will to some prove debatable in adding, "and are of littoral or inland origin." And yet nothing seems more certain, after exhaustive inquiry, than that all the inorganic materials of our beaches have been derived, either from the wear of the coast by the sea, or from the denudation of the land by subaerial agents, and the transmission of material by rivers. Beach material need not be found at the place at which it first originated, or where it was first discharged on the shore by rivers, for littoral drift can and does distribute shingle and sand along a coast. Or, when a coast-line is sinking, the beach may largely have derived from strata now lying below tide-marks.

No beach can long remain in any situation subject to littoral drift unless either a constant supply of fresh sand or pebble is available to make good the loss, or the drift reciprocates, being at one time in one direction and at another time opposed to that direction, with no material prevalence of either.

Hence in most instances where beaches now exist the nature of their contents is very uniform over long periods, for if the loss is constantly made good by fresh accessions, those accessions are derived from the same source as that they replace, or, if the drift reciprocates, the same material is constantly present.

Again omitting organic substance, the sea-bottom is covered by deposits derived from the land, or from itself when land, and does not at least yield its own substance to form beaches for the protection of the shore. There is no greater fallacy than to hold that if a beach be artificially denuded the adjacent sea-bed will move in to replace the loss. The waves may, and in many cases do, move down material from the higher levels of a beach to low-water mark and a little below that level, and may and do subsequently return that material to the higher levels of the beach. But what they once succeed in taking out to beyond the line of four or five fathoms they rarely, if ever, return.

It is a corollary that, in the words of the late Mr. D. Pidgeon, "there is nothing more intensely local than the materials of a beach and its contents,"[1] and Mr. Pidgeon's remark has, I believe, the endorsement of Mr. A. R. Hunt. This localisation extends in a less degree to the bottom deposits, as the writer first pointed out in a recent paper,[2]

[1] "Notes and Comments on the Raised Beaches of Torbay and Sharkham Point," by A. R. Hunt, F.G.S, *Trans. Devon. Assoc.*, vol. xxxv. p. 321.

[2] "Bottom Deposits of the English Channel," *Trans. Devon. Assoc.*, vol. xxxi.

in which he is confirmed by Professor Grenville A. J. Cole, who writes: "I am glad you found it possible, as we have done, to map out the sea-floor to some extent by the stones dredged up. These are by no means so mixed as one might suppose."

It is a constant feature in shingle beaches that the larger pebbles are found at and above high-water mark, and the materials become gradually smaller in grain as low-water mark is approached. A little below low-water mark the shingle often gives place to extremely fine sand, and in yet a little deeper water the sand becomes somewhat coarser.

If there is anything like a high-water bank of steeper gradient than the general surface of the beach, it is there that the greatest difference in size of the pebbles will be apparent in the shortest distance, and such a high-water bank will have a constantly steeper gradient until its crest is reached.

There are two separate causes involved in this grading of beach material. In the first place every wind-driven wave which breaks upon a shingle shore does in fact become a mass of water in translation, and reaches up the beach to a level above that to which a calm sea at the same height of tide would attain. When it has ended its landward journey its whole kinetic energy has been utilised: firstly, in raising itself to a certain height; and secondly, in friction on the beach. The friction on the beach causes a general landward movement of the surface pebbles. Arrived at its shoreward limit, the remnant of the wave has no longer any velocity, but only potential energy due to its position, and this potential energy is less than the original kinetic energy by the measure of the amount of work expended in driving shingle up the beach, and the work expended in surface friction and eddy formation. The backwash of the water towards the sea is thus less forcible than its inrush on the shore; the wind itself further aids to check the velocity of the retiring wave. The depth of water of a retreating breaker is less than its depth in advance, hence its pressure is less. And each pebble during the advance of the wave has acquired a forward velocity of its own which has aided its rise on the shore after the wave itself had fallen to a magnitude incapable of moving it from rest.

Now Wilfred Airy[1] and Law[2] have shown that the transporting power of a current varies as the sixth power of its

[1] *Minutes Inst. C.E.*, Mr. Wilfred Airy, lxxxii. 25.
[2] *Ibid.*, Mr. Henry Law, lxxxii. 29.

velocity; hence a very small change in the velocity involves a great change in the size of the particle that a current or a wave can move. We see, therefore, that pebbles easily carried forward by the incoming wave will be left stranded when the wave retreats, and that the larger the pebble the more certain it is that the velocity of the retreating wave will not be sufficient to draw it back with itself. By a constant repetition of this selective action the larger pebbles are driven to the higher levels of the beach and there stranded, the smaller pebbles are equally driven forward, but are readily carried back again. The actual difference in size between those driven forward and there left and those driven forward and again carried back, is reduced by the fact that the incoming wave has to work against the incline of the beach, while the outgoing wave has the assistance of that incline.

The formation of a high-water bank with much steeper gradients than the general slope of the beach is thus explained. It is probably within the experience of all, and outside the necessity of mathematical demonstration, that coarser-grained, fragmentary materials can be piled to stand at a steeper angle than those of finer grain; for example, a heap of stones will stand with a steeper slope than a pile of sand, boulders will take a steeper angle than stones, and hour-glass sand a less angle than builder's sand, measuring in every case from the horizontal. The angle of rest under wave-action is usually less than the angle of undisturbed repose, but the differences due to the size of the particles remain.

Now the larger pebbles driven forward to high-water mark take a steep angle of repose, the coarse materials—not actually the largest—still take a high angle, and these together constitute the high-water bank; the remainder of the beach between tide marks will usually consist of smaller material, and thus lies at a less gradient, frequently very uniform, down to low water.

A little below low water will be found the finest materials absolutely rejected by the beach, and these on a shingle beach may be very fine sands. In still deeper water these again may be replaced by coarser sand. There are two reasons why the sand should be finer immediately bounding the shingle. In the first place, the waves naturally select from the sea-bottom within reach of their disturbing action the smaller particles, and carry them forward until checked by the incline of the beach; or perhaps this would better be stated that the sea at times of disturbance is more fully charged with fine than with coarse sand-particles; secondly, even coarse particles which have been thrown on the beach and rejected by it are liable to be materially reduced in size in the process, and this remark especially applies to shell fragments.

Although fine sands are frequently found bounding shingle beaches and rocky shores, silts rarely, if ever, occur in such situations; the wave-action sufficient to reject sand from the beach, or to prevent the formation of a beach, is sufficient also to prevent silt settling in shallow water.

As regarding the littoral drift of a beach, the chief agent is wave-action; indeed, this may be said to be practically the sole force at work. Years ago De la Beche expressed himself as opposed to the idea that tidal currents had much share in the abrasion of coasts, and wrote further:—

"We have frequently watched on the shores of the district in calm weather, and during spring-tides, for the power of the tidal stream to move the small shingle and sand where breakers pile them up; but, as such places are necessarily at the bottoms of bays or creeks, where the tidal current is so weak as to be scarcely appreciable, except by the direction of the long seaweed, or some floating body on its surface, we have rarely seen even the grains of sand moved by it."[1]

In this connection it may be stated that from experiment it has been found to take a current of over $1\frac{1}{2}$ knots to move a flint of 1·95 cubic inches resting on a smooth surface, from which it is arguable that a particle of one-tenth inch side would require a current of $\frac{1}{2}$ knot to move it; but if either the flint or the smaller particle formed part of a beach, a much greater velocity of current would be required to set it in motion. Tidal currents may assist transport when once fine particles have been placed in suspension by wave-action. But shingle is only acted upon by the wave itself, the tidal currents having little or no force within the actual area of disturbance on the beach.

Breakers striking a beach obliquely attribute a movement to the shingle which may be resolved along two directions at right angles to each other. The one direction perpendicular and the other parallel to the water-line. Movement in the latter direction constitutes littoral drift. If there is a prevalence of breakers from any one oblique direction on a coast, the beach material will constantly drift before them,

[1] *Report on the Geology of Cornwall, Devon, and West Somerset*, p. 437.

occasional storms from other quarters only partially undoing the work of the prevalent waves.

Further, if the prevalent breakers are more forcible, as well as more frequent, than those from other quarters, the larger constituents of the beach will always be liable to be found at the far end toward which the waves drive, and the finer materials at that end from which they drive and which they first strike. The lighter materials will more easily be returned from time to time by the occasional countervailing drift, while the heavier materials may even be beyond the power of the lesser waves to move, *e.g.* if the waves move from east to west the western end of the beach will show the largest pebbles.

The prevalent breakers may not coincide with the prevalent winds, or the larger waves with the greater storms, since the configuration of the coast may afford shelter to the beach from that quarter from which the most frequent and heaviest gales are experienced.

To a great extent the size of pebble which will be found occupying any beach is determined by the movement normal to the coast-line, and not by littoral drift.

Direct onshore winds, of greater than a certain strength, have a tendency to bring up sand over a shingle beach, especially on its lower slopes. Absolute calm, or offshore breezes, or most breezes oblique to the shore, have an equal tendency to remove sand and to leave clean shingle. It follows that the most sheltered portion of a beach may often show the coarsest average grade of material. In such instances the finer material is not usually far off, having merely retired below low-water mark.

Since writing the above the author has reperused Mr. A. R. Hunt's paper on "Denudation and Deposition by the Agency of Sea-waves."[1] The valuable experimental research set forth in that paper may seem in some respects opposed to the conclusions already reached. Thus Mr. Hunt is very definite in his statement that no wave of oscillation becomes converted into one of translation by its arrival on a sloping beach. In a certain sense the writer agrees with him, and yet a portion of every such wave must proceed up a beach as a mass of water in translation. The particles in the crest of each wave striking a beach have a forward movement which, in the open sea, would presently be converted into a reciprocal backward movement; but once arrived at the beach the whole of that forward movement has to be utilised

[1] British Association, Birmingham, 1886.

in flow up the incline. The circular movement ceases when the circular path becomes impossible, and the water, by its momentum, and in consequence of its energy of position, runs up the beach, and by gravity is drawn back to the sea. The accuracy of this statement is not affected by the fact that on a long incline the water never flows forward to the height of the crest of the free waves; friction on the beach and the retardation caused by the returning waters of the previous wave are sufficient to prevent this.

The writer is forced to dissent from Mr. Hunt's view that "the key to the curves of beaches is the amount of porosity in the beach material, whereby the wave flow beyond the water margin sinks into the beach, and the recoil is thereby more or less destroyed. Thus the wave builds up faster than it pulls down." In point of fact, porosity in a beach may aid its denudation, since each particle is apt to be surrounded by water and its weight reduced by the amount equal to that of the water displaced. The whole key to the curves of beaches lies in the greater angle of repose of a mass of large particles, and the less angle of repose in a mass of small particles, taken into consideration with the greater velocity of current required to move the larger particle.

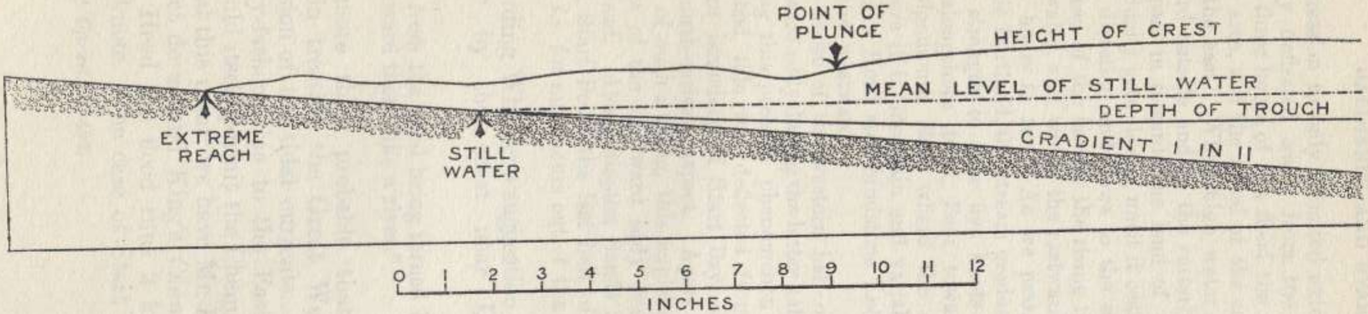
Mr. Hunt's observations as to the importance of the position of the line of plunge of breakers is entirely borne out by observation; with certain wave-periods and wave-heights the sand outside Hallsands beach is liable to be brought forward on to the beach; with other wave-periods it is drawn back, the direction of the waves having also an influence.

We can now return to a consideration of the physical conditions existing in Start Bay. Dr. Kyle's paper already cited is the most recent dealing with this subject, and Mr. Hunt's paper on "Start Point to Petitor, and the Drifting of Shingle," contains much important detail.[1]

Writing of the tides in the Great West Bay, Dr. Kyle states:—[2]

"At the two extreme corners [Portland and Start.—R. H. W.] the currents rush in and out with great velocity. The latter phenomenon is associated with, and partly the result of, the heaping up of the waters within a confined area. When the flood tide passes round the Start it has to contend against not merely the rising ground, but also a sheet of water which will

[1] *Trans. Devon. Assoc.*, vol. xxxiv. pp. 482 *et seq.*
[2] *Op. cit.*, p. 531.



MR. A. R. HUNT'S EXPERIMENTAL TANK RESULTS.

Experiment to show persistence of trough of wave below mean level of undisturbed water. The diagram does not show the *exact* relation of height of crest to depth of trough, as slight irregularities in starting and stopping the wave-producing apparatus may have affected this.

The incoming wave plunges seaward of the margin of repose, and its extreme reach does not attain the level of the crest of the wave prior to its plunge. With a beach gradient of 1 in 11, and wave length 24 inches, the wave plunged $7\frac{1}{2}''$ seawards of the margin of repose, and ran forward $5\frac{3}{4}''$ beyond the margin of repose, reaching a height on beach $\frac{1}{2}''$ lower than its own crest.

To face p. 316.

stand compression to only a limited extent. The main stream is consequently deflected away from the bay towards Portland. In the first three hours of the flood the water-level steadily rises all over the area, and the trend of the current all along the shore is towards the east. When high water is reached the current is still eastward outside and in the easterly portion of Lyme Bay; but as we pass in towards the land of the westerly portion the current gradually gets slower, until it ceases altogether, and finally changes its direction and flows to the west. The waters heaped up at the head of the bay by the rising tide must find some outlet after high water, and whilst the eastward current outside still has some three hours to run. As we pass, on the one hand, from Beer towards Portland, the stream gradually increases from almost nothing in strength to over five knots per hour. As we pass backward alongshore from Beer towards the Start, we pass through Teignmouth Bay, where the current is scarcely felt, Torbay, where it is uncertain and variable in direction, until we come to Berry Head and Mudstone Ledge, where the current is setting to the westward.

"On the shore of the western half of the area there is therefore a backward eddy during the latter half of flood tide. Wheeler, in describing this peculiar phenomenon for Start Bay, imagined that the flood tide was deflected from the cliffs forming the north-eastern boundary of Start Bay, and thus entered the bay from its north-eastern aspect. Apart from the inherent improbability of such a thing, this explanation leaves out of count the presence of the backward eddy over Mudstone Ledge, close to Berry Head. Along Slapton Sands in Start Bay, the current sets toward Start Point the last half of the flood and the whole of the ebb, *i.e.* for nine hours out of the twelve."

As regarding Wheeler's suggestion of the deflection of the flood tide by the coast near Dartmouth, Mr. Hunt writes:—[1]

"So far from the flood being turned back by this projection, it sweeps eastward there like a river."

It is more than probable that Dr. Kyle has made an error in treating the Great West Bay as a whole in his discussion of the tidal currents. The close approach of the twenty-fathom line to the East Blackstone off Dartmouth would itself permit the Channel flood to impinge on the coast at this point; we have Mr. Hunt's statement that it does in fact do so, and King's *Channel Pilot* [2] is clear that off Berry Head the flood runs 2 knots, and off Downend Point 2½ knots. The case of Start Bay must therefore be

[1] *Op. cit.*, p. 493. [2] p. 48, 1893 ed.

considered on its own merits. The main stream of flood after passing Start Point is not "deflected away from the bay toward Portland," but only toward Downend Point. It is incorrect to speak of the waters as "heaped up at the head of the bay by the rising tide," whether we are dealing with the Great West Bay or the Start Bay.

At St. Malo, on the French coast, such a "heaping up" does occur, with the result that springs rise 36¼ feet and neaps 25¾ feet.

But throughout the Great West Bay the rise of tide diminishes from west to east, as the following figures will show:—

Place.	High Water Full and Change.	Rise. Springs.	Rise. Neaps.
Start Point	5.41	15	11½
Dartmouth	6.16	14¼	10½
Torbay	6.0	13½	10
Teignmouth	6.0	13	9¼
Exmouth	6.27	11	8½
Lyme Regis	7.21	11½	8½
Bridport	6.5	11¼	7¾
Chesilton, W. Bay	6.13	10¼	7
Portland, Bill of	6.35	9	6½

The figures are taken from the last edition of the *Admiralty Tide Tables*. There is nothing in the heights of the tides there shown to account for any general system of eddies in the Great West Bay. Bridport and Lyme Regis certainly show a slight "heaping" in Lyme Bay itself, but the matter is minute.

In discussing any question of tides and tidal currents, it is well to observe Dr. Whewell's warning:—[1]

"We must take care not to confound the time of the *turn of the tide stream* with the time of high water. Mistakes and errors have often been produced in tide observations by supposing that the turn of the tide stream is the time of high water. But this is not so. The turn of the stream generally takes place at a different time from high water, except at the head of a bay or creek. The stream of flood commonly runs for some time, often for hours, after the time of high water; in the same way the stream of ebb runs for some time after low water."

Now at Start Point the eastern or Channel flood stream makes at three hours before high water at Dartmouth, so that it is already half-tide at Dartmouth before the Channel flood stream commences to run. The western or Channel ebb

[1] *Admiralty Tide Tables*, 1904, p. 13, sec. 32.

stream makes at Start Point at $2\frac{1}{2}$ hours after high tide at Dartmouth, so that the tide is falling at Dartmouth for $2\frac{1}{2}$ hours before the tidal stream at Start Point has taken its ebb direction.

In the bay, at a point two miles south-west from Street Head, the north-eastern or flood stream makes at three hours before high water at Dartmouth, and the south-western or ebb stream at three hours after high water at Dartmouth; here, according to the Admiralty chart, the flood and ebb streams are of equal duration.

This agrees fairly well with Mr. W. Diamond's statement as quoted by Mr. Hunt, that "the ebb tide at Strete makes alongshore at two hours after high water, and the flood tide runs up until two hours after high water." The difference in time between inshore and offshore streams is not unusual, the point to be noted being that both inshore and offshore streams agree in flowing an equal period each way across a line drawn south-west from Street Head. No eddy exists therefore at this part of Start Bay, a fact which not only disposes of Wheeler's deflection of the flood stream, but is also out of agreement with Dr. Kyle's views. Dr. Kyle's statement that a westerly eddy exists at Berry Head and Mudstone Ledge is given without any cited authority, possibly on his own observation, and no confirmation has been obtained. It is very probable, however, that an inshore eddy exists purely as a local and restricted phenomenon.

As regarding the southern end of Start Bay, between the Skerries and the land, the description of the currents given by the Admiralty chart is as follows:—"Tides here are weak and irregular, but generally set alongshore to the southward nine hours out of twelve." This agrees well with the evidence of the local fishermen, with the writer's own observations, and with Mr. W. Diamond's statement. Dr. Kyle is in practical agreement, but appears to overestimate the normal strength of the currents.

If then we abandon Dr. Kyle's attempt to deal with the tidal phenomena as due to the configuration of the Great West Bay as a whole, and dismiss Wheeler's suggested deflection of the flood stream by the cliffs near Dartmouth—and neither of these will bear critical examination—have we an alternative explanation of the inshore southerly current of nine hours out of twelve in the southern half of Start Bay?

In fact, there is no real difficulty involved. Start Bay is open to the westward stream of the Channel ebb which sweeps into it, passing out in part over the Skerries, in part through the channel between the Skerries and the land, and flowing along the western shore of the bay, causes during the six hours' duration of the Channel ebb a southerly current along the shore from Torcross to Hallsands and Start Point.

But Start Bay is closed to the eastward and north-eastward stream of the Channel flood. In the first place, that stream passing Start Point has a direction away from the west coast of the bay almost at right angles, but later it bends more toward Dartmouth, partly no doubt from the indraught of the bay, partly from the form of the sea-bottom, and even more from the indraught of the Great West Bay. The distinct easterly extension of Start Point aids to exclude the Channel stream.

Now the Channel flood stream does not commence to flow at Start Point until it is already half-tide on the shore, and from that moment until it is high tide there may be said to be no currents in Start Bay. (This agrees with Mr. Diamond's statement that the ebb tide at Torcross runs down until it is half-flood by the shore.) At high tide by the shore the Channel flood still has three hours to run, but the water-level at Start Point begins to fall, and thirty-six minutes later it commences falling at Dartmouth. The water in the southern half of Start Bay naturally flows toward the lowest point of its surface, which is at Start Point. Some little will pass out over the Skerries, but a great part follows the channel between the Skerries and Hallsands, Beesands, and Torcross. Thus a southerly stream along the western shore of the bay sets in shortly after the tide commences to fall at Start Point.

It is possible, too, that there may be some very slight induced current set up by the last half of the Channel flood running past the Start. Thus we obtain three hours' southerly current, caused mainly by the variation in level of the surface of the sea, and in no way but the slightest to be described as a true eddy of the flood stream.

To summarise, the Channel ebb having full access to the bay is able to maintain a constant southerly current although the water is rising during part of the time at Start Point; the Channel flood, on the other hand, being excluded from the bay, and indeed "trained" past its entrance by the form and direction of the coast, is unable to interfere with the currents naturally arising from the fact that the tide is falling at the Start. Still, at the extreme southern part of the bay the actual rise of tide at Start Point does sometimes avail to cause a slight northerly current shortly after low water, and this is referred to by Mr. Diamond.

The prevalent southerly inshore current being admitted on all hands, it remains to discuss its effect on the beaches and the adjacent sea-bottom.

Broadly speaking, there is more sand mixed with the shingle of the beaches at the north end of Start Bay than at the south, and on the whole the shingle itself is coarser at the south end. As regards the amount of sand mixed with the shingle, this statement must be understood to apply to the surface and some slight depth of the beach only; at a few feet at the most in depth the interstices of the shingle beach are everywhere filled with sand. An isolated beach at Blackpool, to the north of the bay, consists of sand and fine gravel. Dr. Kyle writes of it as "medium sand," which, read with the context of his paper, would suggest that the great number of the particles would pass a 1 mm. perforation but fail to pass a $\frac{1}{2}$ mm. This would be inaccurate in the extreme, and probably the context was not in his mind as he wrote.

Dr. Kyle's version of the action of the southerly current on the beach may be given in his own words:—[1]

> "Along the beach from Slapton to Hallsands we have the Chesil beach reproduced on a smaller scale. The finer sand mixed with stones and gravel is found on Slapton Sands, whereas at Hallsands there is practically nothing but pebbles. The theory of Cornish seems to apply equally well here. The eddy and the ebb together being in excess of the flood, carry all materials down the bay. The heavier stuff comes to rest sooner under the lee of the projecting promontory of Start Point, and is thus deposited on the beach at Hallsands, whilst the lighter sand is carried onwards and deposited on the Skerries."

Mr. Hunt attributes some importance to the southerly current, but recognises another factor. He writes:—[2]

> "The travel of shingle in Start Bay, as evidenced by the larger pebbles at Hallsands (now removed), is to the southward and westward in the direction of the most effective winds (easterly) and of the ebb-tide current."

The writer doubts whether the current has much effect in grading the shingle, or in any way really accounts for the general absence of sand from the beach surface at Hallsands. Sand is always liable to appear on this beach, granted waves of the right period and direction, and always disappears

[1] *Op. cit.*, p. 539. [2] "Start Point to Petitor," *op. cit.*, p. 494.

when waves of different period or direction are in action, the current remaining much the same. And the sand is not carried away to the Skerries, except in most minute quantities. It can always be found a little outside low water. This "ebb sand," as it is termed by the fishermen, is remarkably fine; if we exclude a little organic matter it falls wholly within or under Grade vii. (passes a $\frac{1}{2}$ mm. perforation); $22\frac{1}{2}$ per cent. of it is shell, and the remainder clean, sharp quartz, with very little other mineral. The colour of the mass when free from shell is a warm grey. Outside the "ebb sand," in about 25 feet of water at low water, we meet another deposit, the average grade of which is 4·77, and which contains $21\frac{1}{2}$ per cent. of shell, the remainder being largely small flat particles of local rocks.

A current which will allow these sands to collect and remain just off shore, where it runs the strongest, stronger far than on the beach, can have little effect toward grading large shingle.

The greatest recorded speed of this southerly current off Hallsands, on the ebb, with a strong gale to help it, has been 1·6 knots, and this was largely surface velocity due to the breeze.

The "ebb sand" and outer sand are always present, and Dr. Kyle is mistaken when he suggests that easterly breezes take fine sand from the top of the Skerries and place it within the bay near the shore.

There is a great difference between Skerries sand and the inshore material. The Skerries Bank is a very ancient accumulation, and its individual grains, speaking from the examination of many samples, are even more completely rounded by long attrition than Mr. Hunt has reported. The shore sands are comparatively sharp and angular.

The Skerries have probably derived much more of their material from the Prawle coast-line than from Hallsands, but they call somewhat on the whole neighbourhood for their support. This, however, is no great matter, the wear and tear being slight.

The grading of the shingle beach in Start Bay is due to the fact that the south end is the most sheltered from direct wave-action, and more liable to the attacks of breakers oblique to the shore; partly also, perhaps, to the fact that when a southerly drift does prevail it is stronger than the more frequent northerly drifts, and moves southward pebbles which the latter cannot return.

Beyond doubt the littoral drifts in this bay are very evenly balanced, otherwise the beach material would long ago have been lost by passing one horn or other of the coast. . . . . (4).

The beach does not reach the extreme of the Start, the easterly trend of the latter rendering winds from that quarter extremely effective in driving straggling material back into the embayment. For a similar reason the beach dies out northward at Street Head, Blackpool being an isolated bay.

That some of the shingle reached Hallsands in the first place in consequence of a southerly drift seems almost certain from the large quantity of Dartmoor felsite to be found there, but that once arrived it fell into a state of reciprocating equilibrium is equally certain from the fact that the felsites are still at Hallsands.

The Skerries Bank had its origin in the shelter which Start Point affords the area it occupies from the direct attack of the flood stream, and the channel between the Skerries and the land has been maintained by the action of the ebb stream and the ebb tide from the bay. In some parts this channel has a rock bottom, not probably because the sand has been scoured away, but because it has never been permitted to accumulate.

HALLSANDS.

The village of Hallsands in Start Bay lies a little over a mile north of Start Point. In happier days it comprised thirty-seven houses and had a population of about 126 persons (excluding in each case the coastguard station).

The date of its foundation is unknown; its appearance gives evidence of antiquity, and one would think that some information should be obtainable from private records. The parish registers yield no assistance; the only reference to the locality is as follows:—

"Henrie Muge a pirat of the sea, was hanged in chains upon Stert, the 28th daye of Septembre in the yeare of our Lord God 1581, the 23rd yeare of the Queens Mates reigne."

The title-deeds of the London Inn make it clear that there was already a building (probably the same as now) on that site 120 years ago.

Originally the site of Hallsands was a wide beach, much of which lay well above high-water mark. The cliff sent out numerous spurs of rock into this beach, two only of which extended well into the area between high and low water, and both these were isolated from the cliff itself. Some of the rock spurs had flat crests at or about beach level, some stood slightly above that level, and some were hidden by the beach. Against the cliff the shingle had been covered by wind-drifted sand, the finest material which at times appears on the shore, and thus the general level at the foot of the cliff had been materially raised. The talus of the rock-face had also added its share to the lands above high water; doubtless some rough vegetation bound the whole together. From high-water mark to the foot of the rock was a distance of at least 150 feet; of this width at least 60 feet lay between 9 and 14 feet above high-water level. (See Plan.)

So the land stood, a series of little coves, filled and levelled by the action of the sea and wind, with a cliff 100 feet in height behind and the sea in front.

On the little tablelands of rock, where these showed through the rough grass, the first houses may possibly have been erected. But many of the earliest houses were founded directly on the compacted blown sand, which yields a sufficient and firm foundation. The houses which are farthest seaward in many cases conform closely to the exact shape and dimensions of the rock on which they stand. The remaining portion of the London Inn, for example, is on the verge of a large mass, while the most northerly house of the village is wonderfully dovetailed into the spur on which it is built, the doorway being formed in the rock itself. In one sense the last-named building seems the remaining relic of the first order of things; its only approach is from the beach, and it abuts on no road whatever.

Buildings under the cliff and nearer its base were erected without thought as to the exact nature of their foundation; the half a house will be on rock, the other half on sand.

As the houses grew in numbers, and sites for more were desired, short walls of primitive construction were thrown across from rock to rock parallel to the high-water mark, but well behind it; and the spaces so enclosed were levelled with shingle. From time to time fresh walls were built, some in front of the first structures, and more land was taken from the beach. One of the most important of these walls was constructed in 1841, as attested by a stone bearing that date and the initials "C. P." (Caleb Pipperill); it stood secure until March of 1903.

So the village grew, and we can speak confidently of the manner of its growth from the knowledge acquired as it has since been slowly dissected by the sea. And so it became a village, with a narrow road running its whole length, and its feeble sea-wall successfully protecting both road and houses.

The beach, which had nursed it into existence and cherished its growth, became the cause of its destruction, and Hallsands, torn from its peaceful obscurity, found itself famous by its misfortunes. If the frequent formula as to the cradle of our navy is in any sense true, it fits well with the irony of circumstance that the navy's extension should have involved the homes of fisherfolk in ruin.

There came a time when it was advisable to enlarge the Dockyard at Keyham; the process of enlargement necessitated the use of large quantities of concrete, which in turn demanded much broken stone or shingle, while on the beach in Start Bay lay shingle superb in quality, easily and cheaply procurable, and, some seem to have thought, with fatal error, inexhaustible in quantity. In the result the beach went to Keyham and the houses to the sea.

The whole story of the Hallsands disaster can be graphically summarised. Plates I. and II. exhibit the village before and after the dredgings. Plate I. is a copy of photograph 20,891 of Messrs. Valentine and Son's series, and is from a negative taken on the 28th day of June, 1894. Plate II. is from a negative taken by the author on the 28th day of November, 1903. Precisely the same point of view was occupied by the camera in each case, and the tide was an inch or more lower when Plate II. was taken. The difference in height of tide is very slight, and it may be assumed with sufficient accuracy that in each instance the sea was 1 foot 3 inches below the level of an ordinary high water, that is, of such a high water as lies midway between the springs and neaps.

Considering first the houses of the village. In Plate I., on the extreme left, is seen the front of a house which is not in Plate II., having been entirely removed by the sea in the interval. The next house, to the right, is intact in Plate I., but in Plate II. its end is seen to have been removed; this was taken down and rebuilt because it had become unsafe. Other properties had been damaged prior to November 28th, 1903; for instance, portions of the London Inn had been washed away, but unfortunately these ruins are hidden by other buildings.

The sea-walls, which in Plate I. are the old structures, and in Plate II. the new concrete walls, may now be compared.

It will be seen that in Plate II. the whole wall in front of the house which has disappeared has gone with it. The new walls, where erected, show of much greater height than their predecessors, although the copings were set at the same levels. The relative widths of beach require no comment, except that it should be clearly understood that as regards both this and the height of the walls Plate II. does not show the beach at its lowest.

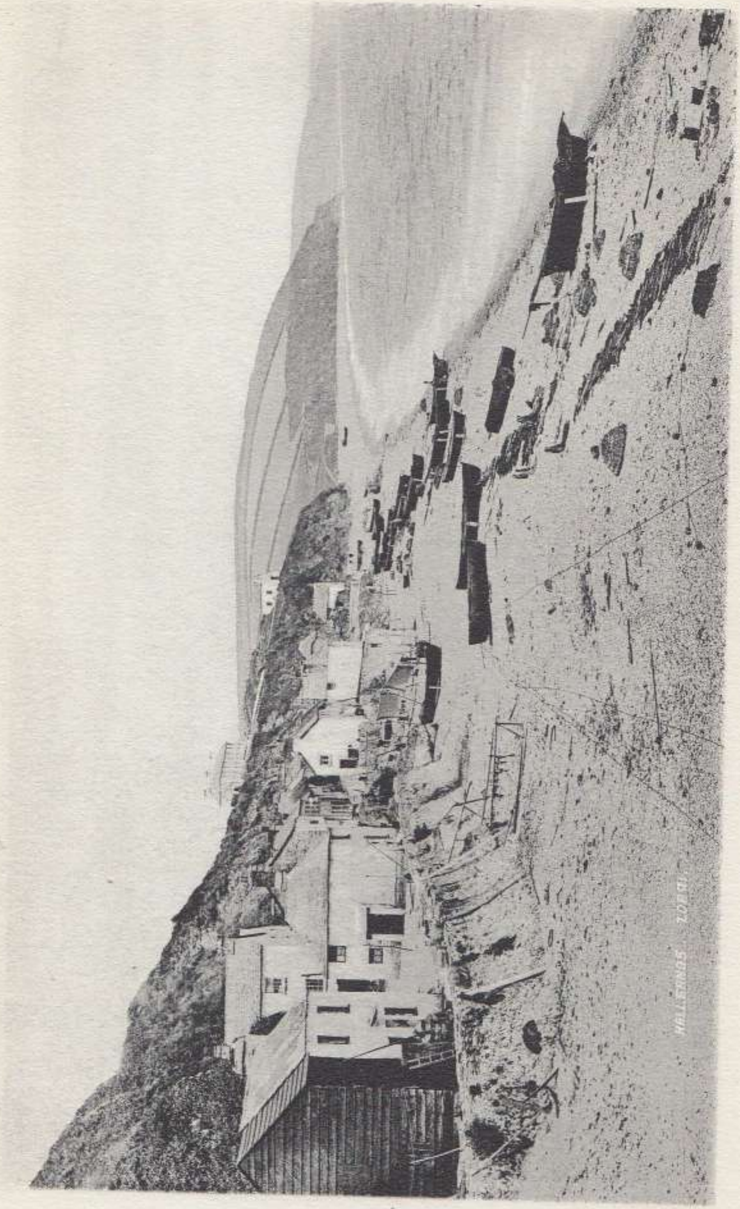
In the foreground of Plate II. two rocks, their base just awash, will be seen; these stand from eleven to twelve feet high, and in 1894 the beach entirely covered them. Further north on the beach an isolated rock (Wilson's Rock) stands out of the sea; in 1894 this rock rose out of beach at the same tide and showed but little height. Both photographs are taken with the lens looking northward.

The history of the disaster is as follows.

By an agreement dated the 10th of November, 1896, and made between the Board of Trade of the one part and Sir John Jackson of the other part, the Board of Trade, acting under the powers vested in them by the provisions of the Crown Lands Act, 1866, granted the said Sir John Jackson licence to dredge and carry away sand, shingle, gravel, and other material from that portion of the bed of the sea below low-water mark at Start Bay and opposite Hallsands and Beeson Sands which lay within an area more particularly delineated on a plan attached to the licence. It was a term of the licence that should the Board of Trade be of opinion that any such operations might in any way damage the foreshore defences of the adjacent district, or become injurious to the interests of navigation, then the licence could forthwith be cancelled.

By an indenture dated the 10th of December, 1896, and made between the Queen's Most Excellent Majesty of the first part, John Francis Fortescue Homer, a Commissioner of Woods, of the second part, and Sir John Jackson of the third part, after reciting that Sir John Jackson had contracted with the Admiralty for the execution of certain works for the extension of Keyham Dockyard, Devonport, and that for the purpose of such works he would require a large amount of sand and shingle, the said John Francis Fortescue Homer granted unto Sir John Jackson, his executors or administrators, liberty, power, and authority to dig, dredge, and carry away sand and shingle within, under, or upon the foreshore of the sea between high- and low-water marks at and opposite Hallsands and Beeson Sands;

PLATE I.



HALLSANDS, 1894.

PLATE II.

HALLSANDS, 1904.

and by a clause of the said grant it was expressly provided that in dredging or carrying away the sand and shingle it must be done in such a manner as not to expose the land above high-water mark to the encroachment of the sea and as not to leave dangerous holes and otherwise to cause a nuisance or danger to persons using the foreshore, or to the owners of the land above high-water mark.

In or about the month of April, 1897, Sir John Jackson commenced his dredging operations on the beaches of Start Bay, at first using a bucket-ladder dredger, which was subsequently replaced by two suction-pump dredges.

The owners and fishermen of Hallsands at once took exception to the operations, and on their behalf Mr. F. B. Mildmay, M.P. for the division, asked a question in the House of Commons. The Board of Trade, as a result, sent down an inspector (the Honourable Captain Vereker, R.N., since deceased), who in June, 1897, held an inquiry at the Coastguard Station at Hallsands. Mr. Edward Windeatt, of Totnes, attended on behalf of the fishermen, who were also represented by three of their number; Sir John Jackson was represented, and among others the coastguards gave evidence.

Mr. Windeatt's representation to the inspector was, that if the shingle were taken away it would mean bringing down the houses at Hallsands, and he gave as reason for this that when the wind blew from the south-east the wash upon the beach at Hallsands would carry the shingle into the excavations made by the dredging.

It is understood that Sir John Jackson's agent urged that the sand would come in and fill up the excavations made by the dredging, and no damage would arise to the village. To which one of the fishermen very pertinently replied, "What Sir John Jackson takes down to Devonport can never come back again."

In the result the Board of Trade informed Mr. Mildmay that they would not withdraw the licence.

In August, 1897, through the intermediary of Mr. Windeatt, agreements were arrived at by which Sir John Jackson undertook to pay to the fishermen of Hallsands the sum of £125 a year during the continuance of the dredging, as compensation for interference with their fishing, and to the fishermen of Beesands the sum of £48 a year. Sir John subsequently added Christmas gratuities of £20 and £10 to each of the villages respectively.

This payment amounted to about £4 per annum per head to the fishermen of Hallsands, and £1 10*s.* per annum per head to the fishermen of Beesands.

The licence not having been revoked, the dredging proceeded busily. The dredging was carried on north of the village of Hallsands, from just below the Bible Christian Chapel (450 feet north of nearest ruined house) to Tinsey Head, a length of about 3,500 feet. As the shingle was confined to the beach above low-water mark, and the dredgers did not wish to secure sand, at low water the dredger would lie off idle, but as the tide began to flow it was hauled in, and dredging commenced; it continued until the tide began to go back again, when the dredger worked back with it.

The suction dredgers had a draught of about four feet forward and eight feet aft, and the barges into which the shingle was loaded had a capacity of about 1,100 tons each. Two hopper barges could be filled on one tide, but this was rarely done. It is stated that on an average about seventeen barges were loaded in ten days. When two dredgers were working, twice this amount could be loaded. In fact the dredgers ultimately worked their way in to inside the original high-water mark of the beach.

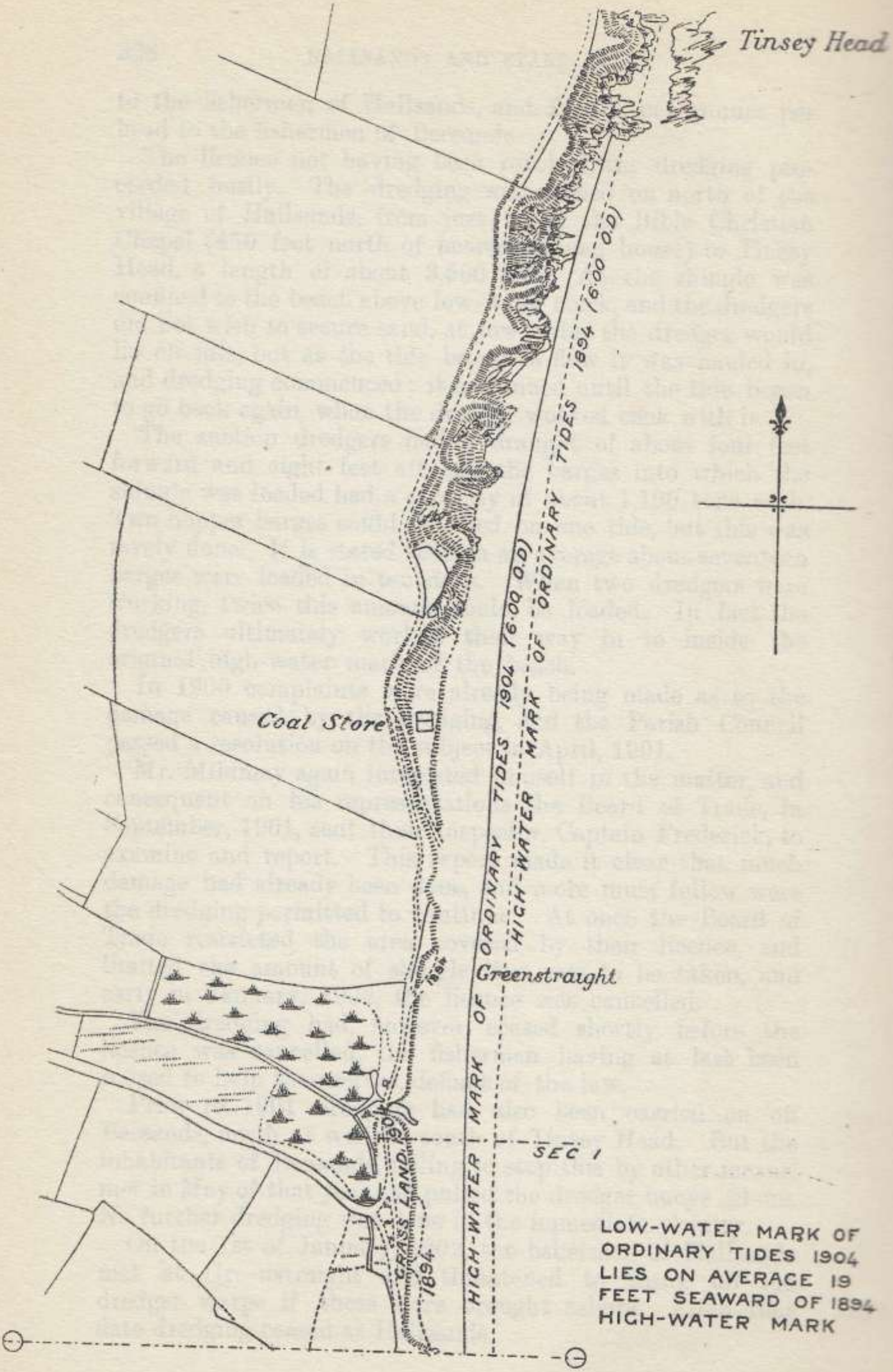
In 1900 complaints were already being made as to the damage caused by the dredging, and the Parish Council passed a resolution on the subject in April, 1901.

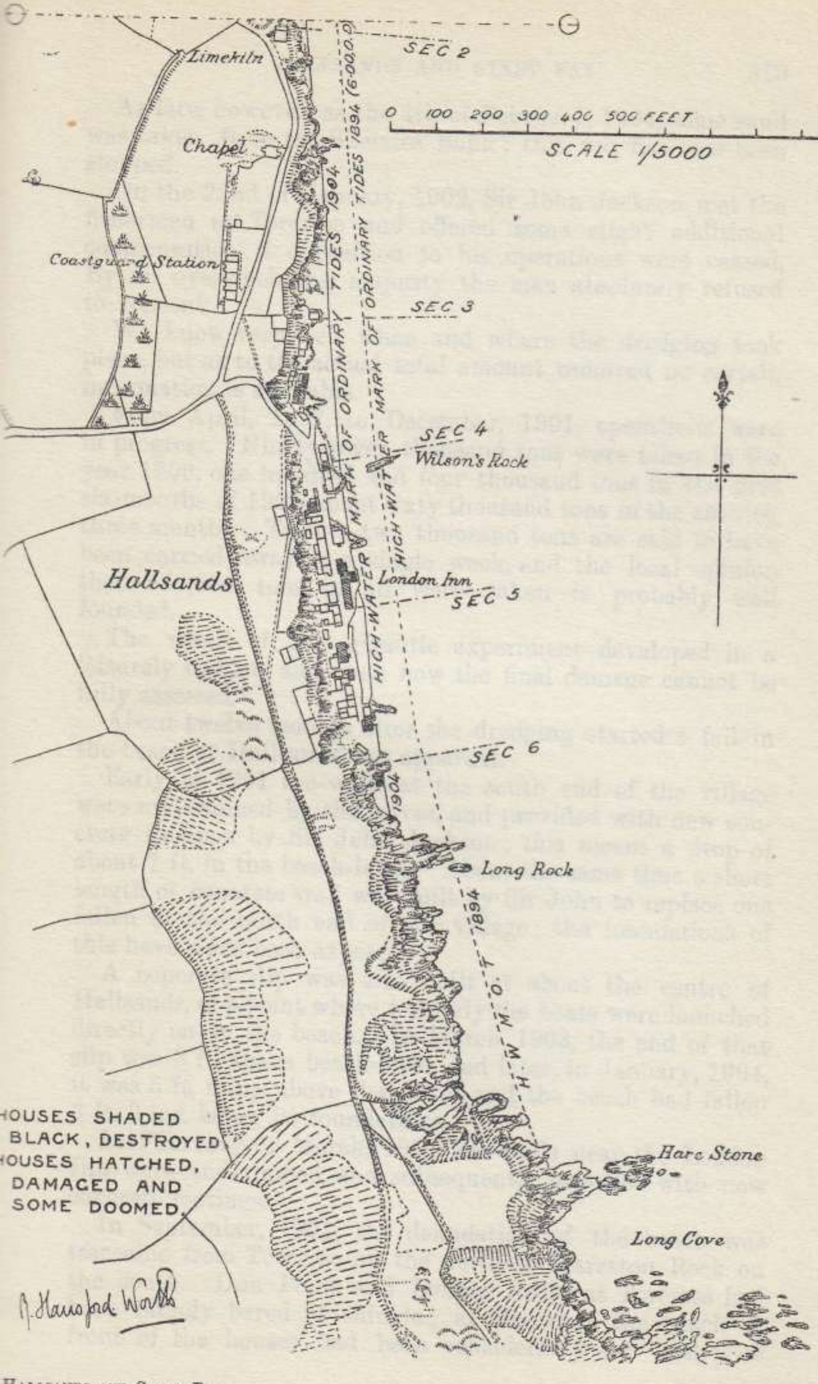
Mr. Mildmay again interested himself in the matter, and consequent on his representations the Board of Trade, in September, 1901, sent their inspector, Captain Frederick, to examine and report. This report made it clear that much damage had already been done, and more must follow were the dredging permitted to continue. At once the Board of Trade restricted the area covered by their licence, and limited the amount of shingle that was to be taken, and early in January, 1902, the licence was cancelled.

The dredging had, however, ceased shortly before the licence was cancelled, the fishermen having at last been roused to help themselves, defiant of the law.

Prior to 1901 dredging had also been carried on off Beesands, north as well as south of Tinsey Head. But the inhabitants of Beesands, failing to stop this by other means, met in May of that year and pulled the dredger buoys ashore. No further dredging was done in the immediate vicinity.

On the 1st of January, 1902, the fishermen of Hallsands met at Greenstraight and threatened to throw off the dredger warps if these were brought ashore. From that date dredging ceased at Hallsands.


Tinsey Head
Coal Store
Greenstraight
HIGH-WATER MARK OF ORDINARY TIDES 1904 (6.00 O.D)
HIGH-WATER MARK OF ORDINARY TIDES 1894 (6.00 O.D)
HIGH-WATER MARK OF ORDINARY TIDES
GRASS LAND
1894
SEC 1
LOW-WATER MARK OF
ORDINARY TIDES 1904
LIES ON AVERAGE 19
FEET SEAWARD OF 1894
HIGH-WATER MARK



HALLSANDS AND START BAY.

Between pp. 328, 329.

As late, however, as the 4th of February, 1904, some sand was taken from the Skerries Bank; this, too, has now been stopped.

On the 22nd of January, 1902, Sir John Jackson met the fishermen at Torcross and offered some slight additional compensation if opposition to his operations were ceased. By an overwhelming majority the men absolutely refused to consent.

We know very well when and where the dredging took place, but as to the actual total amount removed no certain information is available.

From April, 1897, to December, 1901, operations were in progress. Ninety-seven thousand tons were taken in the year 1900, one hundred and four thousand tons in the first six months of 1901, about sixty thousand tons in the ensuing three months. Twenty-two thousand tons are said to have been carried away in a single week, and the local opinion that 650,000 tons in all were taken is probably well founded.

The result of this gigantic experiment developed in a leisurely fashion, and even now the final damage cannot be fully assessed.

About twelve months after the dredging started a fall in the beach at Hallsands was apparent.

Early in 1901 sea-walls at the south end of the village were undermined by the waves, and provided with new concrete footings by Sir John Jackson; this meant a drop of about 7 ft. in the beach-level. About the same time a short length of concrete wall was built by Sir John to replace one fallen at the north end of the village; the foundations of this have since been exposed.

A concrete slip was also built at about the centre of Hallsands, at a point where formerly the boats were launched directly on to the beach. In March, 1903, the end of that slip was 3 ft. above beach-level, and later, in January, 1904, it was 6 ft. 6 ins. above that level, and the beach had fallen 3 ft. 3 ins. below its foundations.

In February or March, 1901, sea-walls near the London Inn were undermined, and subsequently provided with new concrete footings.

In September, 1901, the denudation of the beach was traceable from Torcross on the north to Hareston Rock on the south. Dun Point and Limpet Rocks at Torcross had been largely bared of shingle; at Beesands the beach in front of the houses had been considerably cut back; at

Tinsey Head 30 ft. of shingle which had formerly existed between the rocks and the sea had disappeared; opposite the coal store at Greenstraight the beach had been cut back to within 30 ft. of the building; at Greenstraight itself rocks and stones were showing through the lower levels of the beach, and Sir John Jackson had to keep a man breaking the latter to prevent injury to his suction dredgers; the appearance of such stone was itself evidence that the depths of the shingle were being reached; at the limekiln the seaward edge of the grass-land was only 25 ft. away from the road—it is now only 1 ft. distant; at Hallsands, against the cliffs and walls, the beach had lowered 7 ft., and at Wilson's Rock about 12 ft. The high water of spring tides was 30 ft. from the outside of the rocks at the village of Hallsands; the distance had been 70 or 80 ft. An undercliff road, at the north end of Greenstraight, formerly passable at all times of tide, had been washed away, and in its place a ridge of rocks appeared.

The winter of 1901–2 passed without much incident. A portion of sea-wall at the London Inn fell in March, 1902, and was rebuilt.

By August, 1902, the beach appeared to have recovered somewhat, but this was mainly the effect of a general movement of shingle from low-water mark shoreward. Against the quays and rocks the beach was still from 5 ft. 6 ins. to 6 ft. low; the greatest apparent recovery being at Wilson's Rock, in the centre of the beach, where 5 ft. or a little less of sand and shingle had collected and the fall in the beach had been reduced from 12 ft. in September, 1901, to 7 ft. Circumstances about this time greatly favoured the deposit of sand, and this material gave a spurious air of recovery, whereas the first slight scour removed it all.

It was reserved to the winter of 1902–3 to first exhibit the true extent of the threatened damage.

In December the wall which had been rebuilt at the London Inn required repair.

On the night of 27th February, 1903, the straight length of sea-wall in front of the inn slipped forward and downward, and admitted the seas behind it, by the action of which the filling at the back of the wall was removed and a conservatory undermined.

Either at the same time, or during the following week, the southernmost house of the village was partially wrecked, the sea-wall in front of it destroyed, and a gap torn in the road leading to it, where a deep cove suddenly appeared in place of the highway. The longest sea-wall in the village was undermined and slipped down (this was the wall built in 1841), and a boat slip adjoining it was partially removed. Every sea-wall with one slight exception was damaged. The centre house of a row of three opposite Wilson's Rock was undermined and rendered uninhabitable.

Following this, the writer was called in to report and advise as to the condition of the village, its cause, and the best remedial measures. He visited Hallsands on the 13th March, 1903, and from that date to the present has acted as honorary engineering adviser to the fishermen and those interested in their case. The report made, pursuant of the inspection of March, 1903, set forth that on the average the beach had dropped eleven feet over its whole area in front of Hallsands, and the worst had not yet come. Evidence of the former level of the beach was adduced from the appearance of the rock-surfaces recently bared, from the fact that clothes lines extending from Wilson's Rock to the shore were then 17 ft. 6 ins. above the shingle, from stranded portions of beach adherent to rocks and walls, from Sir John Jackson's dredger holdfasts left 11 and 12 ft. up the cliffs, and from certain portions of wall which in the old days had been plastered down to beach-level, thus giving points for direct comparison.

A photograph of Hallsands before the disaster, taken by Mr. Bryan Hook, also afforded valuable information.

The report ran:—

"The loss of the beach has already caused great destruction, and imperilled the mere existence of the village. Unless some properly considered measures are promptly taken, houses and road alike must fall, with the exception of the houses founded entirely on rock, and even these will be left without means of access.

"There is no part of the quay-wall which is not damaged; parts are destroyed, other parts are on the eve of destruction and slipping hourly towards their collapse. Such efforts as the inhabitants can make are entirely inadequate to prevent the end, and that end is certainly very near. Sir John Jackson has expended a few bags of cement from time to time in the effort to check immediate disaster, but has never apparently recognised that the worst has yet to come.

"Every wall is undermined, the few concrete footings, for which Sir John provided a little cement, are failing. The slip he built ends 3 ft. 6 ins. above beach-level, and its foundation on the shingle beach is only 9 ins. below the surface.

"There is ample evidence of the progress of the damage, and attempts were, from time to time, made by the inhabitants to check it; but the recession of the beach has been continued, and I doubt it has yet reached its worst. There are many places where the beach has dropped 4 ft. and more since the first repairs to the wall and slips were executed. One house has fallen, at least two have had to be deserted. With the collapse of the tottering sea-wall, other houses are threatened. Worst of all, those inexpensive structures, which served so well to protect the village while its natural rampart existed, are now wholly inadequate if repaired. The matter has passed beyond the power of the inhabitants to deal with. They can but stand by and watch, with slight attempts at delaying the inevitable."

The report was correct in that the worst had not yet come. Although in July, 1903, the erection of new sea-walls was commenced, the following further damages have occurred:—

"24th Aug., 1903. South-east wind and bad sea, breaking over top of old wall at south end of village. Small hole made in base of same.

"20th Sept., 1903. Easterly storm. Kitchen, beer cellar, bedroom, and conservatory of London Inn washed away, despite all efforts to save same. Wooden boat slip at north end of village washed away. Nearly all timber broken adrift from works for short new wall opposite Wilson's Rock.

"24th Sept., 1903. Wall of cellar and part of kitchen, which had been left standing at London Inn, fell, taking with it part of road.

"7th Dec., 1903. Wind from S.E. Curved sea-wall at London Inn, rebuilt in 1902, cracked.

"10th Dec., 1903. Very strong wind from W. Last-named wall fell.

"11th Dec., 1903. Foundations of northernmost old sea-wall of village (built 30 years ago) exposed.

"12th Dec., 1903. Wind S.E. Sea very rough. About 10.30 a.m. the last-named wall broke in half, and southern end slipped down eight feet, followed by other portion about an hour later. Sea took road away to within three feet of corner of house. Inhabitants departed, furniture and all. 11.30 p.m. (H.W. 12.0), end of lowest house completely gone.

"13th Dec., 1903. 2 a.m. Sea fearful. Every sea coming in solid over the sea-walls. At 8 a.m. end house at north end had practically gone, and nearly all front of next house with it. Two more houses on the verge.

"2nd Feb., 1904. Water flying in air 30 and 40 ft.; hole made in wall of road adjoining Jackson's slip, just north of London Inn.

"12th Feb., 1904. Last-named wall slipped down.

"16th Feb., 1904. Wall collapsed, chasm in road back to front of house abutting on same.

"Hole broken in wall by new slip, and pit in road excavated by sea to a depth of 6 ft.

"5th March, 1904. Last-named wall badly breached. London Inn roof and front badly damaged (the portion founded on rock and still left standing). All houses along the front badly served by waves and shingle, sea washing over walls and houses alike, and filling the latter. Brick porch washed away behind new sea-wall. Many windows broken. Front of house by Jackson's slip fell in evening."

These notes are taken from the works log; to properly appreciate them it must be remembered that the old walls which are not reported as having fallen were those which had been replaced by new concrete structures. There are only a few feet of old sea-wall now left in the village, and that lies behind a new slip.

The beach this past winter (1903–4) has been twelve feet low in general, and in places as much as nineteen feet below its original level against the walls, at times after storms.

It might hardly seem necessary to urge the fact that every evidence points to the direct connection between the dredging in Start Bay and the fall of the beach at Hallsands as between cause and effect. But even recently the Board of Trade wrote to the Kingsbridge Rural District Council, stating that the condition of the village was largely attributable to natural causes; and Sir John Jackson at Devonport repeated this statement, with the addition that he presumed ninety-nine persons out of every hundred would find it difficult of belief.

Assuming that 600,000 tons of shingle has been dredged from the beach, this is the equivalent of 500,000 cubic yards. Now take it that the beach averaged ninety yards in width in its original condition, which is a very close approximation to the truth, erring somewhat in excess. From Tinsey Head, on the north, to Harestone, on the south, is a distance of 1,800 yards, and the abstraction of 500,000 cubic yards of shingle, if precisely distributed over that area, would mean a loss of 9 ft. 3 ins. to the height of the beach. The actual loss at Hallsands has been twelve feet; in part that must be explained by the fact that Greenstraight is now better able to rebuild its beach than Hallsands, although formerly both were equally circumstanced. For at Greenstraight the seas still run up and die out on the shingle slope, but at Hallsands the seas now rebound from the walls and cliffs, which formerly they could not reach, and the rebound materially aids the denudation. The actual figures, too, are not exactly known, but the correspondence between the estimate and the fact is sufficiently close.

North of Tinsey Head the shingle is practically shut off from Greenstraight, and the area mostly dredged, by a reef of rocks which now extends eastward from that headland; hence little relief has come from that quarter, but practically the whole amount of material to refill the dredging has been derived by littoral drift from Hallsands and from the higher levels of Greenstraight beach.

It should be noted that from the Long Rock to Harestone the whole depth of shingle was not great, and this part of the beach could not contribute its fair quota.

The damage has been slow in its development because the material had to be moved northward by the drift, and drift is slow on this beach. It is interesting that the prevailing southerly stream has not sufficed to prevent this northerly drift. The pit formed by the dredgers appears now to be filled.

Repeating the conclusions stated in the early part of this paper—

(1) The physical conditions give every evidence of the long existence and maintenance of the shingle beaches of Start Bay.

(2) The lithology of the beach gives additional evidence of its great age; and further shows that any loss, caused by the removal of a portion of the shingle, must under present conditions be permanent.

(3) The beaches have no possible recruiting ground on the adjacent sea-bottom.

(4) Beyond doubt the littoral drifts in this bay are very evenly balanced, otherwise the beach material would long ago have been lost by passing one horn or other of the coast.

Add the facts of the case—

(*a*) A large quantity of shingle has been taken from the beach immediately north of Hallsands, from above low-water mark. The amount is believed to have been 650,000 tons.

(*b*) A reef of rocks at Tinsey Head practically excludes all southerly drift.

(*c*) The beach at Hallsands has fallen 12 ft.

And it is difficult to see how any other relation between the removal of the shingle and the fall of the beach than that of cause and effect can be seriously suggested.

We have the further evidence that structures 120 years old, 60 years old, and 30 years old have successfully resisted

PLATE III.

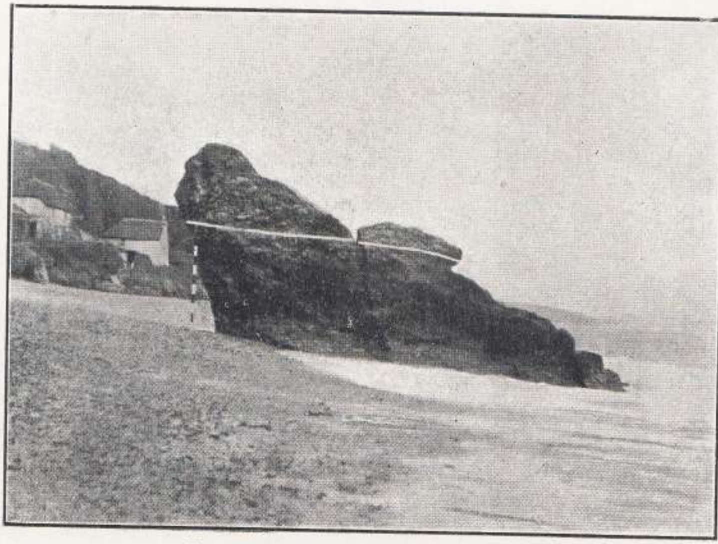


FIG. 1. WILSON'S ROCK (17th March, 1904).

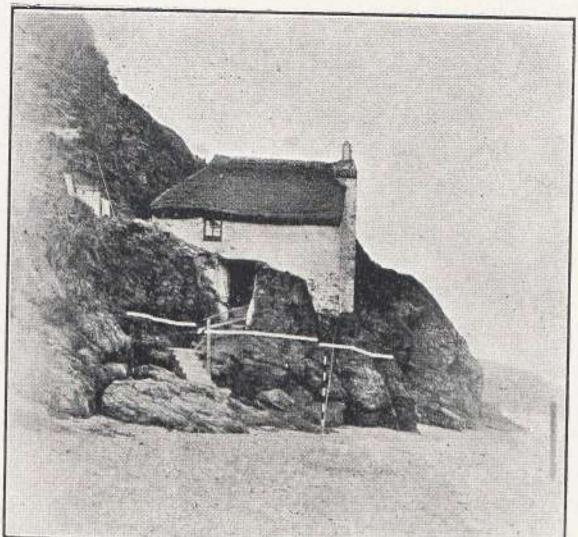


FIG. 2. NORTHERNMOST HOUSE (17th March, 1904).
White lines indicate beach level in 1894.

all storms, including those of 1881 and 1891, until recently, but that subsequent to the dredging their destruction came.

There is natural concrete adherent in masses to the sea-cliffs, formerly below beach-level, now exposed and rapidly eroding.

Such concrete, the cementing material of which is lime brought by waters weeping from the cliff, can only be formed in the tranquil depths of a beach, and where found it is proof that not even transient disturbance has taken place.

If for 120 years, or the much greater period required for the formation of the natural concrete, the condition of affairs has been stable, and then, following an artificial interference, the equilibrium is violently disturbed, most unprejudiced persons would agree with one of the sufferers, who when told by a representative of Sir John Jackson that he attributed the damage done to the beach solely to natural agency, replied, "Nature has been extremely well assisted."

The more clearly to demonstrate what has happened, Figs. 1 and 2, Plate III., have been prepared. Fig. 1 exhibits Wilson's Rock as it now stands, and the white line shows the beach-level in 1894; Fig. 2 shows the northernmost house of the village as it now is, while the white line exhibits the beach-level in 1894. Both are copies of photographs, and the former beach-levels are taken from Valentine's photograph of 1894.

In Plate IV., Fig. 1 gives the London Inn prior to the dredging, Fig. 2 the London Inn after the dredging; the first taken at high, and the second at low tide, the relative position of the beach is especially to be noted. Fig. 1 is from a photograph the use of which Mr. E. G. Hawkings, of Plymouth, has kindly permitted. Many similar photographs exist, but these will serve to represent this class of evidence.

Plates V. and VI. are photographs of some of the ruins, etc.

Largely in consequence of Mr. Mildmay's efforts, the sum of £1,000 was offered by the Board of Trade and Sir John Jackson jointly as compensation to all those who had suffered damage from the fall of the beach at Hallsands. This offer was made in 1903 in April, and on Wednesday, 29th of that month, it was accepted by the majority of owners and inhabitants present at a meeting in the village. Conditions were attached to the offer that the recipients should give a receipt in full and final settlement of all claims, and that no legal liability was admitted by the donors. Signatures of the majority of those interested were obtained, but before all the owners had signed the damage had materially increased, and it was found that the amount would be wholly inadequate.

Consequent on Mr. Mildmay's further efforts, the offer was increased to £1,750, and as recently as June last to £3,250, to which Mr. Mildmay generously added £250. Meanwhile the owner of the London Inn had instituted legal proceedings against Sir John Jackson Limited, and to cover the possibilities thus arising the offer was reduced by £250.

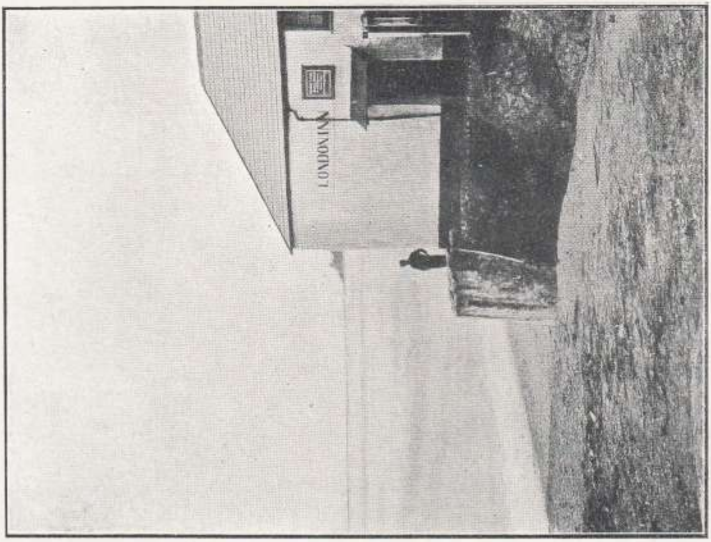
Subsequently an arrangement was arrived at and the threatened proceedings abandoned, the plaintiff having obtained terms which were entirely satisfactory. The reduced sum of £3,250 has now been accepted, and the owners of property have signed the required receipt and indemnity, which runs as follows:—

"We, the undersigned owners of house property at Hallsands, agree to accept the sum of £3,250 from Sir John Jackson and others as a full and final payment of all claims direct or indirect against him or any Government Department for any damage past present or prospective which might be said to be attributable to dredging operations by the said Sir John Jackson in Start Bay to this date and for any consequential expenditure on defensive works. They admit that it is a condition of this payment being made that it is not to be regarded as a recognition in any way by him of legal liability on his part or that of any Government Department and they agree to accept payment of such amount and acknowledge that as far as Sir John Jackson is concerned it is given purely as a matter of good feeling towards men with whom his firm in carrying out work in the district have been brought in contact. They authorise payment of this said sum of £3,250 to Francis Bingham Mildmay, Esq., M.P., whose receipt for the same shall be conclusive and binding on them and each and every one of them."

It should be stated that the Devon County Council and Devon Sea Fisheries Committee have throughout given every assistance in their power, and that in addition to Mr. Mildmay, other gentlemen, notably the Rev. C. W. E. Finzel, Mr. Holdsworth, and Mr. E. Windeatt, have made their best endeavours to assist the fishermen.

The *Western Morning News*, recognising that any compensation likely to be obtained must still leave many families homeless, started a public subscription, which, in consequence of their advocacy, reached the total of £650, and this sum having been vested in trustees, is to be expended in erecting new cottages well beyond the reach of the sea.

PLATE IV.



LONDON INN (21st October, 1903).

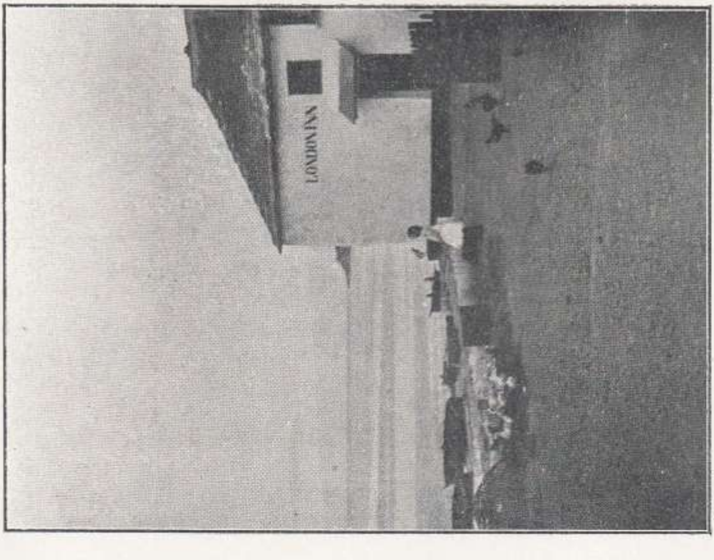


Photo by] *[E. G. Hawkings.*

LONDON INN (prior to dredging).

PLATE V.

LONDON INN (21st September, 1903).

LOGAN'S HOUSE (17th March, 1904).

Meanwhile had matters been left to the slow process of Government departmental determination, there would have been no village of Hallsands now in existence.

Following the first offer of £1,000, it was determined to proceed with the erection of new sea-walls for the protection of the road and houses, and here again Mr. Mildmay's interest was shown, for had it not been that when funds seemed unprocurable he stepped forward with a personal guarantee of £1,500, the protective works could never have been carried into being in time to be of any practical use.

Even as it has been the sea has succeeded in doing considerable damage during the progress of these works. Rigid economy and marine engineering do not go well hand in hand; an ever-ready sea requiring to be met by an unrestricted purse.

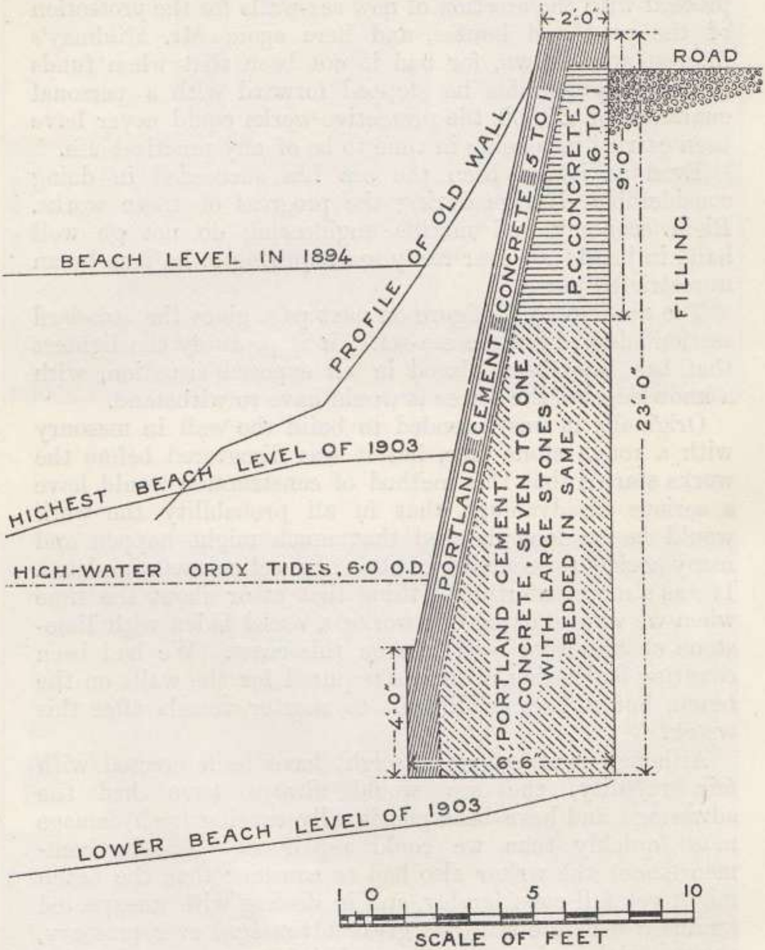
The accompanying figure on next page gives the standard section adopted for the sea-wall; it is probably the lightest that has ever been placed in an exposed situation, with a knowledge of the forces it would have to withstand.

Originally it was intended to build the wall in masonry with a rough stone face, but it was discovered before the works started that this method of construction would have a serious disadvantage, that in all probability the work would be so long delayed that much might happen and many accidents occur before even one section was completed. It was a most unfortunate thing that at or about the time when we were starting our works, a vessel laden with limestone should have been lost on this coast. We had been counting on landing materials required for the walls on the beach, but it became difficult to charter vessels after this wreck.

Although masonry walls might have been erected with fair rapidity, the sea would always have had the advantage, and have been continually causing fresh damage more quickly than we could repair it. At the commencement the writer also had to consider that the beach might yet fall considerably, and in dealing with unexpected strains a concrete wall has great advantages over masonry, the material having some strength in tension as well as in compression.

By the use of concrete we gained speed in execution, additional strength, and the certainty that in case easterly breezes prevented the landing of materials on the beach the work need not necessarily be stopped.

The concrete used was formed of shingle and sand from the beach mixed with the best Portland cement. The main body of the wall was formed of concrete consisting of seven parts of shingle to one part of cement, and in this large stones were embedded, no stone being nearer



another stone on the back of the wall than 5 ins. From the point where the total thickness of the wall reduced to 4 ft. upwards 6 to 1 concrete was used. The face for a thickness of 1 ft. was first formed in 5 to 1 concrete without large stones, but subsequently 3 to 1, and even 2 to 1, was used here. The face of the wall batters or slopes back 1 in $4\frac{1}{2}$, except for 4 ft. from the foundation, where it is vertical. The thickness at the top is 2 ft.; 9 ft. down from the top the thickness is 4 ft., and here in some sections it is increased to 4 ft. 6 ins. by a set-off on the back of the wall. There were slight variations from the standard, but the strength was always the same.

It will be seen that as regarding the top portion, from the coping 15 ft. downward, the structure is a retaining wall of moderate section, while as each additional foot of height is exposed by the fall of the beach the relative stability is considerably reduced.

None the less, if used only for the purpose of holding up filling, there would be no doubt as to the permanence of the wall, the filling employed having a high angle of repose.

But as against the advisability or justification of the attempt to resist the beat of the open sea with a wall of any such section a great deal may very properly be urged, and the writer feels a certain amount of sympathy with the journalist who wrote of the "utterly inadequate sea-walls" as "the most ludicrously flimsy protection against the sea" he had ever known; at least his intentions were good, although his technical knowledge was adrift, as proved by a subsequent suggestion that "groins" were the proper cure for the evil.

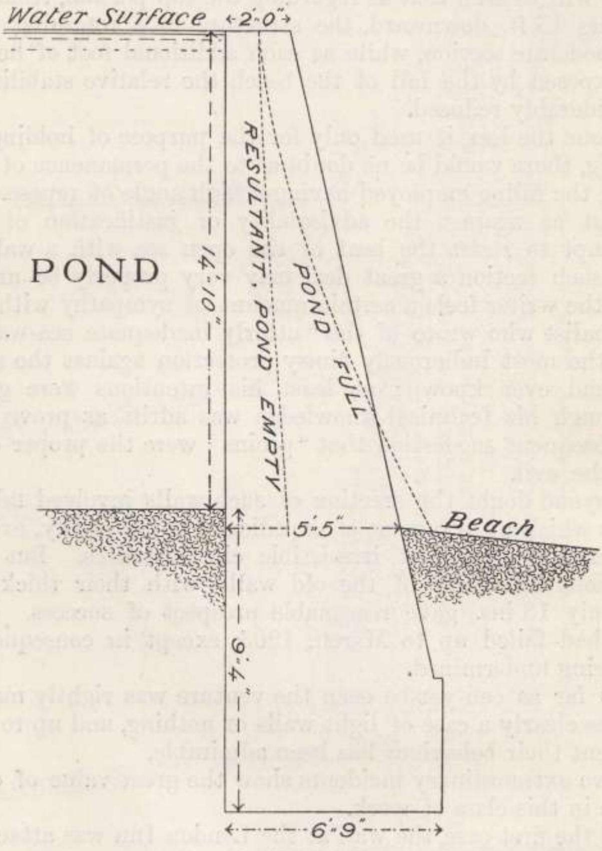
Beyond doubt the erection of such walls involved taking risks which no argument of expediency would justify, except under the control of irresistible circumstances. But the previous behaviour of the old walls, with their thickness of only 18 ins., gave reasonable prospect of success. Not one had failed up to March, 1903, except in consequence of being undermined.

So far as can yet be seen the venture was rightly made; it was clearly a case of light walls or nothing, and up to the present their behaviour has been admirable.

Two extraordinary incidents show the great value of concrete in this class of work.

In the first case, the wall at the London Inn was attacked by heavy seas within a month of its completion, and before the chasm behind it had been filled with rubble. The length of this wall is 28 ft., and at each end it abuts on solid rock; its total height is 24 ft., and at the time of the storm it stood 15 ft. 4 ins. above beach-level. The foundation is on rock and large boulders. The top of the wall is 15 ft. 6 ins. above high water of exceptional spring tides, and the beach on its sea-face was at about the level of such tides.

Seas broke on and against the wall, shot over it, and converted the chasm behind it into a miniature lake, having about 15 ft. depth of water. The seas even continued their career over the surface of this lake and attacked the roadway behind. Now in reservoir dams it is a maxim that for absolute safety the line of resultant pressure of water



thrust and weight of wall shall fall within the middle third of the dam, while for mere security against overturning the resultant must fall within the base of the wall.

The accompanying diagram shows the line of resultant thrust, "pond empty," and the line of resultant thrust, "pond full"; the latter falls 11 ins. outside the base of the wall at beach-level. To add to the severity of the strain the large stones exposed on the beach cut the face to a depth of some 4 ins. or 5 ins., while the alternate rise and fall of the waves converted the stress into live loads. The wall survived, uncracked even, although its base at beach-level was only 5 ft. 5½ ins., where, with merely the thrust of the water in the pond, it should have been 10 ft. 8 ins.

The second exceptional test affected a portion of the "Long Wall," 23 ft. in total height and 7 ft. wide at the base, where for a length of 12 ft. the foundation was undermined, and the filling at the back washed out from under. The foundation in this case was on shingle, and as a result of this treatment the wall developed a crack which is barely discernible. Its strength remains unimpaired, and it has now been underpinned to rock.

The inhabitants of the village were at first somewhat critical of the extravagance which made walls 23 ft. in height, 6 ft. 6 ins. in thickness at the base, and set that base 10 ft. below beach-level. But, after the sea had exhibited its ability to entirely uncover the foundations, their views were modified.

All the new walls now rest for the greater part of their length on rock.

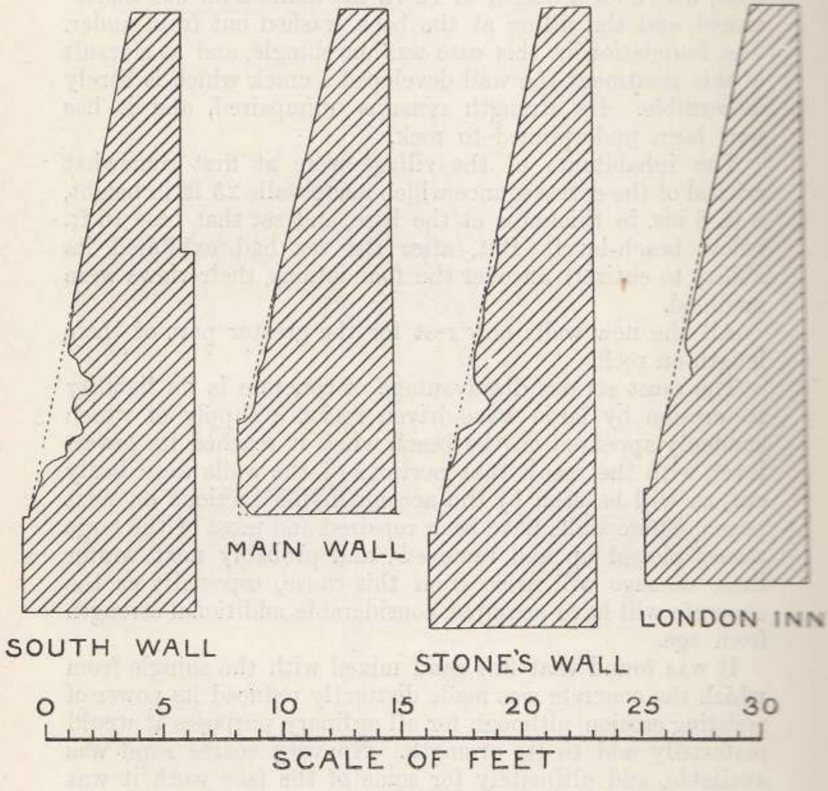
The most serious disadvantage of concrete is its liability to erosion by large wave-driven rocks, a supply of which suddenly appeared on the beach when it reached its lowest level, with the result that portions of the walls were badly cut, as will be seen by the accompanying sections on next page. These walls have been repaired and most of the large stones picked up and removed; and probably next winter little damage will arise from this cause, especially as the concrete will have acquired considerable additional strength from age.

It was found that fine sand mixed with the shingle from which the concrete was made distinctly reduced its power of resisting erosion, although for all ordinary purposes it would materially add to its strength. No very coarse sand was available, and ultimately for some of the face work it was altogether omitted.

No filling for placing behind the walls has been taken from the beach, but all from the talus of the cliff or from excavations undertaken for the purpose.

It may at some time be of use to others to know that a boat-slip with a rough stone pitched surface is just conveniently usable when it has an incline of 1 in 4, but should not be steeper.

A very fair criticism of the new sea-walls would be that they have no outward curve or overhang at the top, such as would fling back the wash of the waves. This was omitted from motives of economy; its presence would have involved much additional strain, to meet which the walls would certainly have had to be 50 per. cent. heavier. If the beach had not so materially fallen during last winter, the overhang of the wall would probably have been little missed. But at



places it fell 10 ft. and more below its previous record, making a total of 19 ft. at one point. No doubt the wall itself has helped to scour the beach in its immediate neighbourhood; had it been provided with a curved top it would still further have lowered it.

High water of ordinary tides has not only reached some of the walls, but has been 3 ft. and 4 ft. deep against them, and the increased wash arising from this cause has been immense.

As one of the inhabitants has described it:—

"The sea, on the occasion of strong winds from between north-east and south-east to east, has on several occasions washed over the wall and houses, across the street, and into houses on the other side of the street. This has happened to the house in which I live, besides others. No such thing occurred before the dredging operations, although there had been much stronger gales, particularly in 1881 and 1891, than have been experienced since such dredging commenced."

It has been mentioned that the sea-wall is a structure in the design of which economy has exercised a controlling influence. The average cost per yard in length of standard wall has been £7 2*s.* 1*d.*, and Mr. J. C. Lang, of Liskeard, was the contractor who executed the work.

The total amount so far (June, 1904) expended in various works of defence and reconstruction has been £1,540, including all management expenses. No fees of any sort have been paid, the resident engineer, Mr. G. F. Evans, having been a pupil in the writer's office.

One of Mr. Evans' duties has been to take accurate sections of the beach from time to time, and to take daily measurements of its height at specified points.

The whole of the statements as to the beach movements given in the earlier part of this paper are either founded on such information or on the direct personal observation of the author.

At low-water mark of ordinary tides the beach is least subject to variation in level; at high-water mark of ordinary tides it is most liable to vary.

The natural incline of the shingle at low-water mark of ordinary tides and for some little distance above it is from 1 in 9 to 1 in 11, according to recent conditions of weather and sea. From mean sea-level to near the high-water bank it is often as steep as 1 in 8. The high-water bank itself is approached by a short length of increasing gradients, and reaches 1 in 3, with small portions even steeper. But sometimes on parts of the beach there is no true high-water bank, and the general slope is then about 1 in 10.

Plate VII. gives some recent sections which may in future enable comparison to be made with the conditions prevailing immediately after the worst effect of the dredging was felt. These sections represent fair average conditions of to-day; so far there having being no signs of recovery.

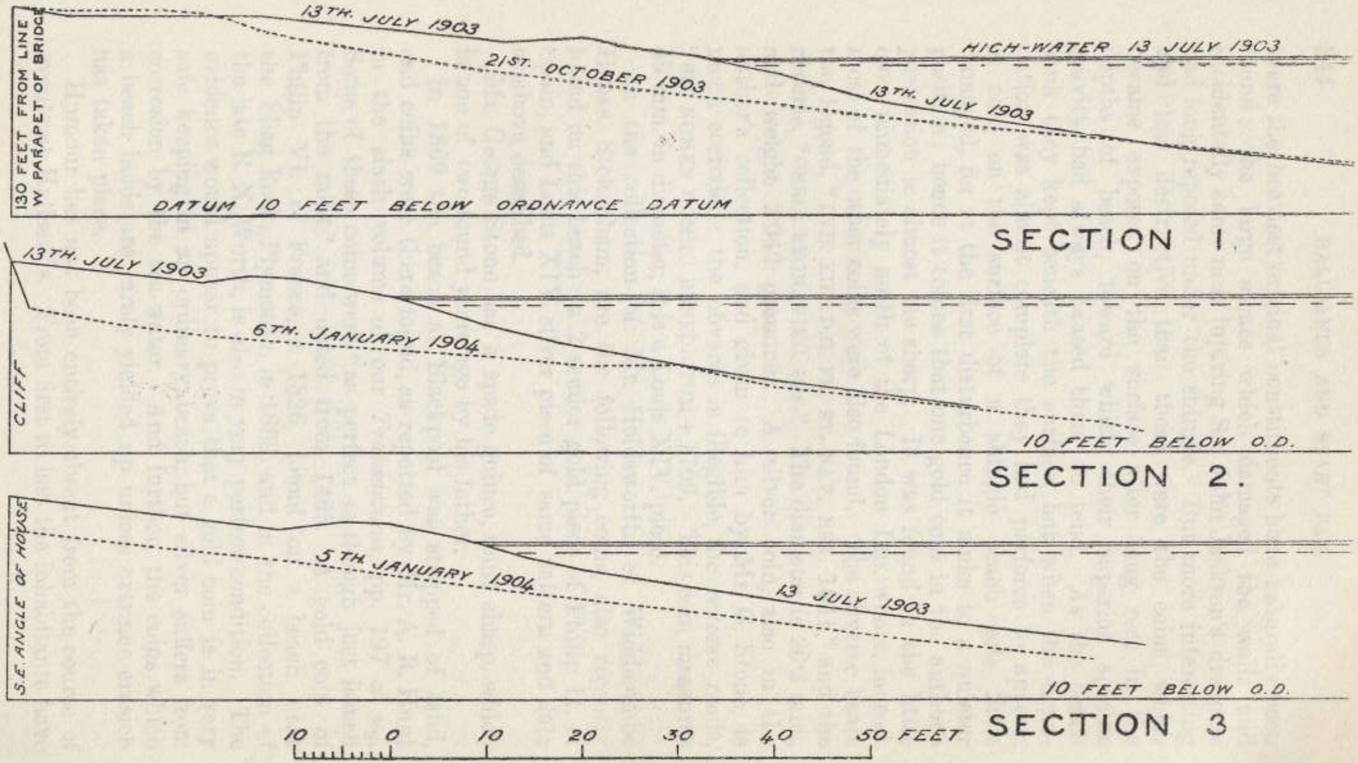
The lowest levels of the beach have been reached, and there the heaviest original constituents have naturally been found; the large stones which damaged the walls and incidentally came near injuring Sir John Jackson's dredgers had long reposed under the shingle. But more interesting and less destructive than these were the coins which became exposed on the surface after long rest in the depths of beach, toward which their superior specific gravity had always caused them to tend. As the beach sank they kept beneath the surface, but when the denudation was almost complete they had perforce to appear. A coin on the surface of a shingle beach gets little damaged, for at the first disturbance it sinks to a quieter position; hence it comes that one gold coin in the author's possession is almost die sharp. It was found in the little cove immediately north of the London Inn, where, indeed, most of the other coins were also found. The obverse bears the legend, "LVD. XIII. D.G. FR. ET. NAV. REX. 1641," and the reverse, "CHRIS. REGN. VINC. IMP." The diameter is 20·3 mm., and weight 2·042 grammes. A silver coin, also in the author's collection, and given to him by Mr. G. Stone, is much corroded: the obverse is illegible, the reverse reads, "SIT NOMEN DOMINI BENEDICTUM + 1709. This coin measures 40 mm. in diameter, it is a Louis XIV. piece.

In the collection of Mr. Holdsworth, of Widdicombe House, Stokenham, are the following coins, also recently found on this beach: a 2 scudor gold piece of Philip II. of Spain, and Louis XIV. silver piece of same pattern and date as above described.

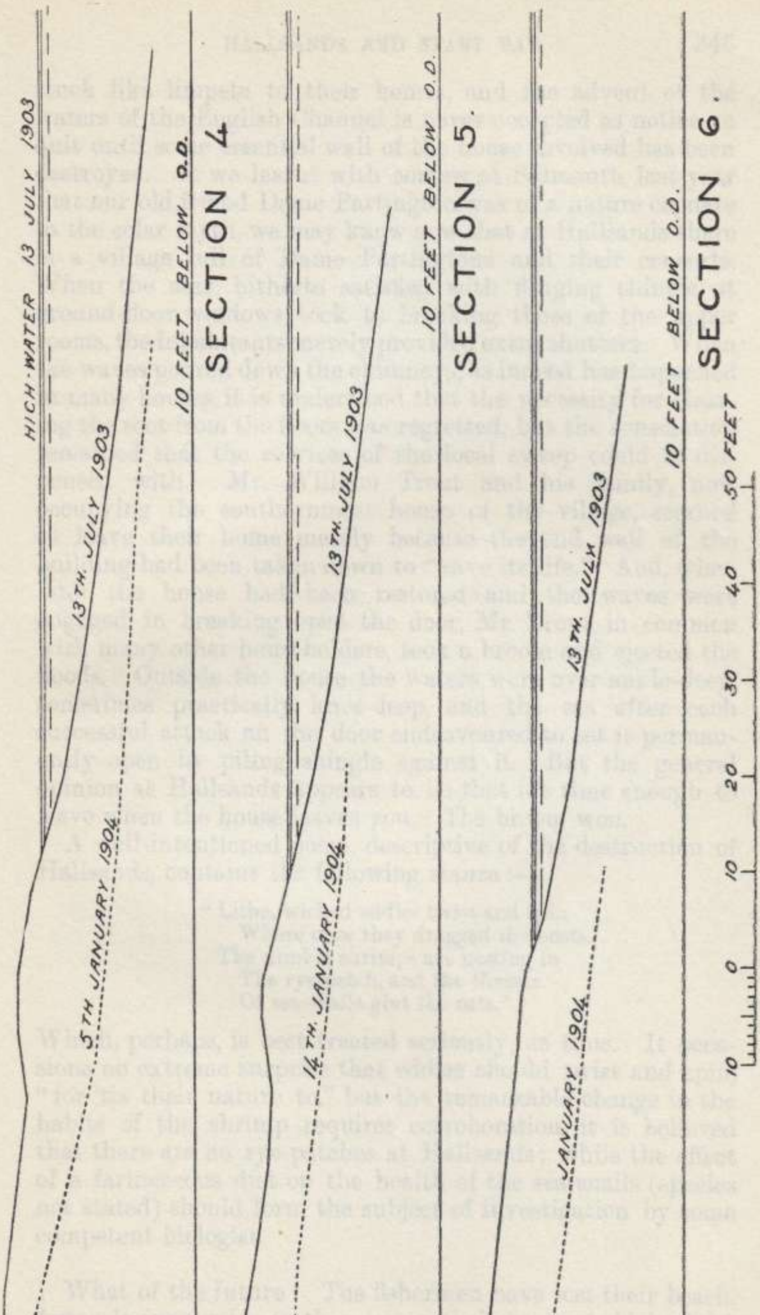
Mr. George Stone has a spade guinea, mint sharp, which is one of two found years ago by his father.

In 1869 the beach at Blackpool was stripped of sand, and coins were there found, as reported by Mr. A. R. Hunt in the sixth volume of our *Transactions*, pp. 197 *et seq.* Some of these coins were "as perfect as though just issued from the mint," and dated from 1465. A gold coin of Philip VI. of France, *c.* 1326, found on a beach near the Shag Rock, Plymouth, in 1888, and in the collection of the late R. N. Worth, is also in very perfect condition. The evidence would appear to prove that a gold coin is in very safe keeping in an ordinary beach, but silver suffers from corrosion by the sea-water. And further, the coins which a beach holds are rarely yielded up unless extreme erosion has taken place.

Humour has not been entirely absent from the course of events at Hallsands. From first to last the inhabitants have



130 FEET FROM LINE
W PARAPET OF BRIDGE
13TH. JULY 1903
HIGH-WATER 13 JULY 1903
21ST. OCTOBER 1903
13TH. JULY 1903
DATUM 10 FEET BELOW ORDNANCE DATUM
SECTION 1.
CLIFF
13TH. JULY 1903
6TH. JANUARY 1904
10 FEET BELOW O.D.
SECTION 2.
S.E. ANGLE OF HOUSE
5TH. JANUARY 1904
13 JULY 1903
10 FEET BELOW O.D.
SECTION 3
10 0 10 20 30 40 50 FEET


SECTION 4
HIGH·WATER 13 JULY 1903
13TH. JULY 1903
5TH JANUARY 1904
10 FEET BELOW O.D.
FACE OF HOUSE
SECTION 5.
10 FEET BELOW O.D.
13TH. JULY 1903
14 TH. JANUARY 1904
SEA WALL
SECTION 6.
10 FEET BELOW O.D.
13TH. JULY 1903
JANUARY 1904
LINE OF NEW WALL
50 FEET
40
30
20
10
0
10

stuck like limpets to their homes, and the advent of the waters of the English Channel is never accepted as notice to quit until some essential wall of the house involved has been destroyed. If we learnt with sorrow at Sidmouth last year that our old friend Dame Partington was of a nature cognate to the solar myth, we may know now that at Hallsands there is a village full of Dame Partingtons and their consorts. When the seas, hitherto satisfied with flinging shingle at ground-floor windows, took to breaking those of the upper rooms, the inhabitants merely provided extra shutters. When the waves poured down the chimneys, as indeed has happened in many houses, it is understood that the necessity for clearing the soot from the floors was regretted, but the consolation remained that the services of the local sweep could be dispensed with. Mr. William Trout and his family, now occupying the southernmost house of the village, scorned to leave their home merely because the end wall of the building had been taken down to "save its life." And, when later the house had been restored and the waves were engaged in breaking open the door, Mr. Trout, in common with many other householders, took a broom and ejected the floods. Outside the house the waters were over ankle-deep, sometimes practically knee-deep, and the sea after each successful attack on the door endeavoured to set it permanently open by piling shingle against it. But the general opinion at Hallsands appears to be that it's time enough to leave when the house leaves you. The broom won.

A well-intentioned poem, descriptive of the destruction of Hallsands, contains the following stanza:—

"Lithe, wicked eddies twist and spin
Where once they dragged the boats.
The nimble shrimps are nesting in
The rye-patch, and the throats
Of sea-snails glut the oats."

Which, perhaps, is best treated seriously, as thus. It occasions no extreme surprise that eddies should twist and spin, "for 'tis their nature to," but the remarkable change in the habits of the shrimp requires corroboration, it is believed that there are no rye-patches at Hallsands; while the effect of a farinaceous diet on the health of the sea-snails (species not stated) should form the subject of investigation by some competent biologist.

What of the future? The fishermen have lost their beach, formerly invaluable to them, since their boats could be kept there in all but times of real storm; they are seriously hampered in the use of their nets by the numerous rocks which have now appeared through the shingle; many of their houses are gone, others are practically uninhabitable in bad weather. True, some measure of compensation is available, but the annual loss from the injury to the net-fishing alone would far more than absorb the interest on that sum. Is there any prospect of conditions bettering?

So long as the sea-walls stand—and they seem secure—some of the houses are safe. But any gale of severity equal to the 1891 blizzard will probably remove several houses from behind the sea-wall. Ultimately we must believe that the loss of shingle will be distributed over the whole length of beach from Street to Hallsands; this will be greatly delayed by the reef of rocks at Tinsey Head, and would in any case be the work of very many years.

The injury inflicted will prove long enduring, and nothing but a long succession of favourable winters will prevent its extending, to some degree.

As from a scientific experiment, a great deal of exact knowledge will be derivable, provided the future of this beach is carefully watched. Meanwhile it is to be hoped that the authorities have thoroughly learnt the immediate lesson, that littoral accumulations should not be incautiously disturbed, and the disaster to Hallsands may prove of benefit to other places similarly threatened.

PLATE VI.

NORTH END, LOOKING SOUTH (23rd December, 1903).

LONDON INN (17th March, 1904).

NORTH END, LOOKING NORTH
(23rd December, 1903).

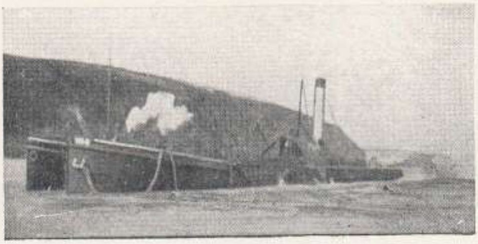


Photo by] [*E. G. Hawkings.*

DREDGER AT WORK.