XXVII. *Observations on the Motions of Shingle Beaches.* *By* Henry R. Palmer, *Esq. F.R.S. Civil Engineer.*

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THE extraordinary prevalence of tempestuous weather during the last autumn having occasioned numerous disasters on our coast, the public attention was directed in an unusual degree to the imperfections of many of the harbours, and more particularly to those which are encumbered with accumulations of shingle. The access to harbours thus circumstanced is generally uncertain, and in tempestuous weather is frequently dangerous, or even impossible.

The action of the sea, which gives motion to the shingles and produces the evils complained of, has long been a subject of speculation; but I have not found that it has been systematically investigated. Indeed, the contrariety of opinions advanced upon the subject, sufficiently indicates an entire absence of that satisfactory mode of inquiry which is essential to the foundation of a safe and practical deduction.

Very little has been written upon the subject; and such facts as have been mentioned have only been referred to incidentally, or with a view to geological science. My present object is exclusively practical in its nature, and my observations have been limited to such facts as would assist in establishing certain and fixed rules for controuling the motions of the beach, so far as to enable us to preserve a clear channel through it in all seasons, and in every variety of weather; and to accumulate and preserve the shingles, where it is needful to do so.

The subject at first sight appears greatly complicated; and were it necessary to discuss minutely all the modifications arising from the variety of forms and local circumstances, it would perhaps be too much so for general description. I have, however, limited my investigation to those simple and unvarying laws to which nature always adheres; and therefore the following observations must be considered as restricted only to certain general principles, subject to a variety of modifications.

The principles which I propose to illustrate will (under similar circumstances) at all times exhibit the same phenomena, but for the sake of perspicuity I shall now only refer to the coasts of Kent and Sussex.

Section 1.

That the pebbles which compose the shingle beaches on these coasts are kept in continual motion by the action of the sea, and that their ultimate progress is in an easterly direction, are facts long known and commonly observed. The following

observations are chiefly directed to the particular manner in which the motions are produced.

From a general view of the effects that I have noticed, it appears that the actions of the sea upon the loose pebbles are of three kinds: the first heaps up, or accumulates the pebbles against the shore; the second disturbs, or breaks down the accumulations previously made; and the third removes, or carries forward the pebbles in a horizontal direction.

For convenience I propose to distinguish these by the following terms, viz. the first, the accumulative action; the second, the destructive action; the third, the progressive action.

All the consequences resulting from these various actions are exclusively referrible to two causes. The one is to the current, or the motion of the general body of the water in the ebbing and flowing of the tides; the other to the waves, or that undulating motion given to the water by the action of the winds upon it; and it is of considerable importance to the present inquiry that the effects resulting from each specific cause be separately considered.

The motion of the shingles along the shore is commonly attributed to the currents, the action of the waves being considered only as a disturbing force. That such a notion is erroneous will, I apprehend, presently appear; although I have to regret that I have not had the opportunity of obtaining such satisfactory information relating to the velocities of the currents in the channel as would have enabled me to include every form of argument upon the subject. The absence of such information has also prevented me from deciding satisfactorily as to the sources from whence the whole body of shingle is derived, which, although not necessary for the practical purposes I have in view, would have given more interest to the subject, and would have rendered the elucidation more complete. I must, therefore, for the present, be content to pursue the motions of the beach after it is found lying along or near the shore; observing only that the materials of which it is composed are those of the various strata in the vicinity of the coasts, together with the ordinary sea sand, and such small particles as may have been brought to the shore by the floods of the various rivers.

That the current is not the force which moves the pebbles along the coast, will appear from the following reasons:

1st. If it were so, the direction of the motion of the pebbles would be determined by that of the currents; but while the direction of the currents will vary with the changes of the tides, we find that the direction of the pebbles may remain unaltered; and also that the motion of the pebbles is continued where no current exists.

2nd. Although the velocities of the currents may not have been ascertained with precision, yet it is known that the velocities generally along this coast, which can possibly act on the shingles, are not sufficient to give motion to pebbles of every dimension, which are in fact carried forward.

Fig. 1.

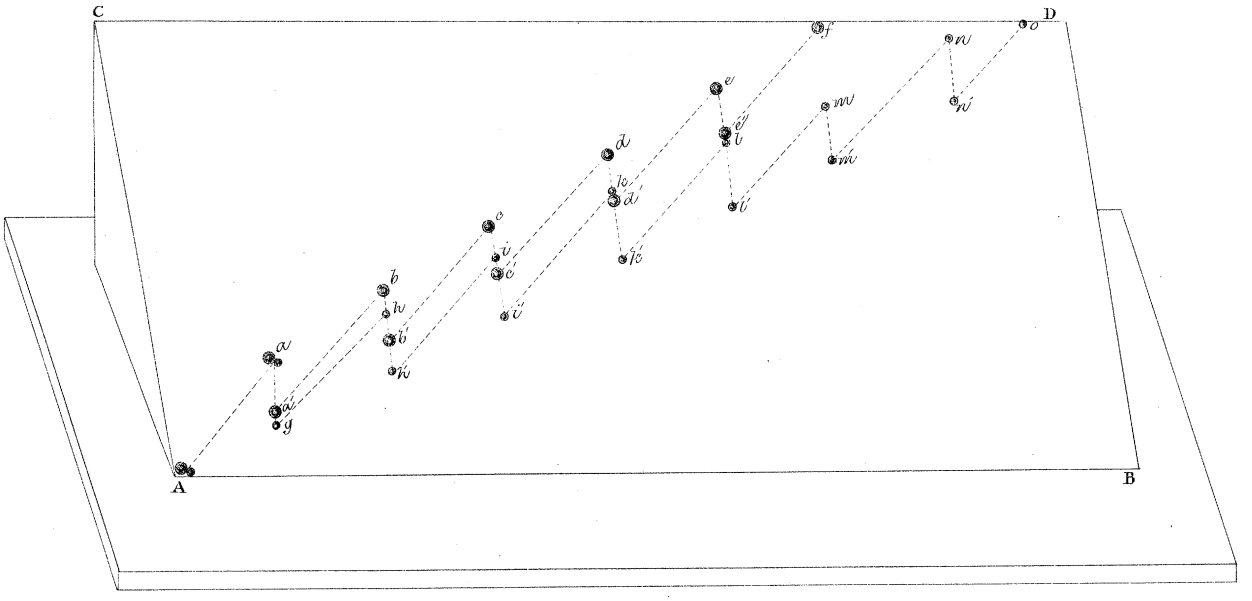
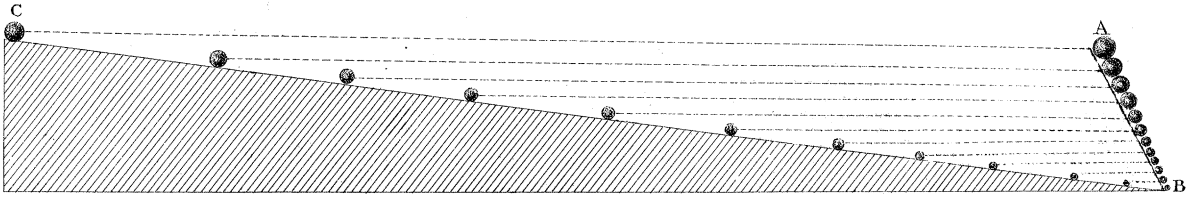


Fig. 2.



3rd. The motion of a current will not produce that order in which the pebbles are found to lie, which order (as will be hereafter shown) may easily be distinguished as the effect of the motion of the waves only.

The direction of the waves is determined principally by the wind, the prevailing direction of which on the coasts referred to is from the westward. Every breaker is seen to drive before it the loose materials which it meets; these are thrown up the inclined plane on which they rest, and in a direction corresponding generally with that of the breaker. In all cases we observe that the finer particles descend the whole distance with the returning breaker, unless accidentally deposited in some interstices; but we perceive that the larger pebbles return only a part of the distance; and upon further inspection we find that the distance to which each pebble returns bears some relation to its dimensions. This process is an indication of the accumulative action.

But under some circumstances, depending on the wind, it is found that pebbles of every dimension return with the breakers that forced them up the plane, and that these are accompanied also by others, which had been previously deposited, but which are in such cases disturbed by the waves; and by a continued repetition of the breakers acting in this manner, the whole of the shingle previously accumulated is immersed below the surface of the water. This process is an indication of the destructive action.

The particulars of the accumulative action, *combined with that of progression*, are explained as follows. (See Plate XXVI. fig. 1.)

Let A B C D be an inclined plane, representing that on which the loose pebbles move. Suppose the wind to blow in such a direction as to cause a wave to strike a pebble at A, in the direction of A *a*, and to the distance (*a*) up the plane, that point being the extent to which the force can reach. Now here the wave breaks partly into spray, and is dispersed in all directions; is partly absorbed, and descends in a shallow form, which rapidly diminishes in its depth, so that the pebble is soon left exposed, and therefore does not return the whole distance with the water, but is left at rest at (*a'*), being at a higher level than that from whence its motion commenced.

With the rise of the tide the striking force is also elevated; and by the repetition of the operation described through the different heights in succession, the further motion of the pebble will be represented by *a' b' b' b'*, &c., the distance in each step of its descent being something less than in that of its ascent, until it has reached the summit (*f*) determined by the height of the tide. Now if we suppose a pebble of less dimensions than the former to be struck from the same point, we shall find it raised as before; but because its surface is greater in proportion to its weight, and because from its less bulk it remains longer immersed in the declining wave, it will descend further, and follow the line (*a g*, &c.), and will not be left at rest till it has reached (*o*).

If, then, we suppose a pebble whose dimensions are less than either of the former, it will be evident that the point at which that will arrive on the highest level will be

more distant still; hence it follows that the distance travelled horizontally by the pebbles during a tide will be in some proportion to their bulk, the specific gravities being the same.

(The pebbles do not in reality move in straight lines, but in a succession of curves; the straight lines are assumed here, and in other parts of this paper, to simplify the description.)

I trust it is only necessary to remark, that if the wind continue to blow in the same direction during the ebbing of the tide as through the flowing of it, the direction in which the waves will strike the shore will be nearly the same, and the progress of the pebbles will be urged by a similar action, and therefore their direction will also be the same.

In this action we observe a constant tendency to heap up and accumulate the shingles; and it is an interesting fact, that when the action has continued equally through a tide, the pebbles are left *in regular order, according to their dimensions*, the largest being uppermost, and the smallest at the bottom of the plane. I do not mean to state that all the largest are at the top, or that all the smallest are at the bottom, for it is evident that some of every size will be found at every level; but that if an equal measure (say half a peck) be taken from the different levels, the average of each specimen will exhibit in regular order the various dimensions.

The order in which the pebbles are thus found is, then, that by which the effect of the waves is distinguished from that of a current, the effect of the latter consisting only in its influence on the direction of the impinging and recoiling motions of the waves, by which the motion of the beach may in a small degree be accelerated or retarded.

Section 2.

In the illustration of that action of the sea which breaks down and removes an accumulation, I propose referring to my observations in the order in which they were made. My attention was first directed to this part of the subject in the neighbourhood of Sandgate in October last.

The accumulative action had been continued for a considerable time. The numerous groins erected near Folkestone to impede the progress of the beach, for the protection of the cliffs, had collected a bank of pebbles, which in some parts was five feet in height. The wind had so much abated as to be scarcely perceptible, but the sea had a motion denominated a *ground swell.*

The waves approached the shore nearly at right angles with it; but although in rapid succession, their forces were very moderate. These circumstances continued through five tides, by which time nearly the whole of the loose shingle had disappeared, including all that had been collected by the groins at Folkestone. The water being particularly clear, I was enabled to perceive distinctly the action upon the pebbles, and their motion downwards. I observed, that although every wave

became broken and dispersed as usual, yet they followed in such rapid succession, that each wave rode over its predecessor while on its return, and thus produced a continual downward current, which carried with it the pebbles that were disturbed. That the pebbles were not removed far from the line of low water, would appear from the fact, that on the subsiding of the swell, it being succeeded by a light breeze of wind from the westward, the accumulation immediately commenced, and was restored to its former quantity by the action of four tides. I have subsequently had some favourable opportunities for making other observations on the effects produced by different rates of succession of the waves, and particularly at Dover, during the late gales, where the same actions were noticed. There I watched for an opportunity of witnessing that rate of succession which exhibited the destructive and accumulative actions in their smallest degrees; and I observed, that when ten breakers arrived in one minute, the destructive action was but just evinced; and that when only eight breakers arrived in the same period, the pebbles began to accumulate; which facts harmonized with my observations made at Sandgate and Folkestone, viz. *that the difference between the two actions was determined by the rapidity in succession of the waves upon the shore.*

In the description of the accumulative action, I have assumed the forces to be directed obliquely with the line of coast, and have therefore necessarily included the progressive motion; but it remains to be explained in what manner the shingles are carried forward while the destructive action is going on.

It is known that the action and reaction of the waves give to the whole body of the water, within a certain distance from the shore, an undulating motion. The direction of this motion, when approaching the shore, will, to a certain degree, correspond with that of the waves upon the surface, and the direction of the recoil will also be affected in like manner; therefore the pebbles that have been carried down by the destructive action are moved forward through an angular course *beneath the water*, until, by the excess of the impinging forces over those of the recoil, they are again raised by the action of the water, and deposited where the destructive action has ceased, or where, from local circumstances, it cannot occur. The circumstances which are most unfavourable to the destructive action are those which least admit of the constant downward under-current,—an inlet, or narrow arm of the sea, for example. If we suppose a wave rolling through the mouth of an inlet, carrying with it a charge of shingles, it does not break as upon an inclined plane, but is dispersed in the general body of the water, which is comparatively quiescent; and there being no returning force, the shingle becomes deposited, and a bank is formed: and although the destructive process would act upon that bank if it could attain a certain height, yet the attainment of that height is prevented by the waves passing over it, and carrying with them, in succession, the shingles with which they are charged.

Section 3.

In Plate XXVII. is represented a section of the beach formed along the outside of Folkestone Harbour. This section was taken with great accuracy, after the ground swell before referred to had removed most of the loose pebbles from it; so that the section may be considered as representing the plane upon which the progressive motion of the pebbles is carried on. Its slope is in the proportion of 1 to 9, nearly, and (with the exception of that part near the summit where there remained a bank of pebbles beyond the reach of the previous tides,) the surface of the plane corresponds very nearly with a straight line, which, considering that it is a natural formation, is a fact worthy of notice.

I think this plane may be considered as representing the average dimensions and inclinations of the surfaces over which the beach travels along this coast, and I have therefore generally assumed such an one for the present purposes. Upon such an inclination, the loose pebbles are in contact with each other; and although their depth upon the plane is constantly varying, yet, for the sake of conveying a general idea, we may assume the average to be about six inches, extending between high- and low-water marks. When, however, the plane is less inclined, the same quantity of beach is spread over a larger surface, and its depth is diminished; and the pebbles are in some places so far separated as to exhibit the appearance of a diminished quantity. In Plate XXVI. fig. 2. this is illustrated geometrically.

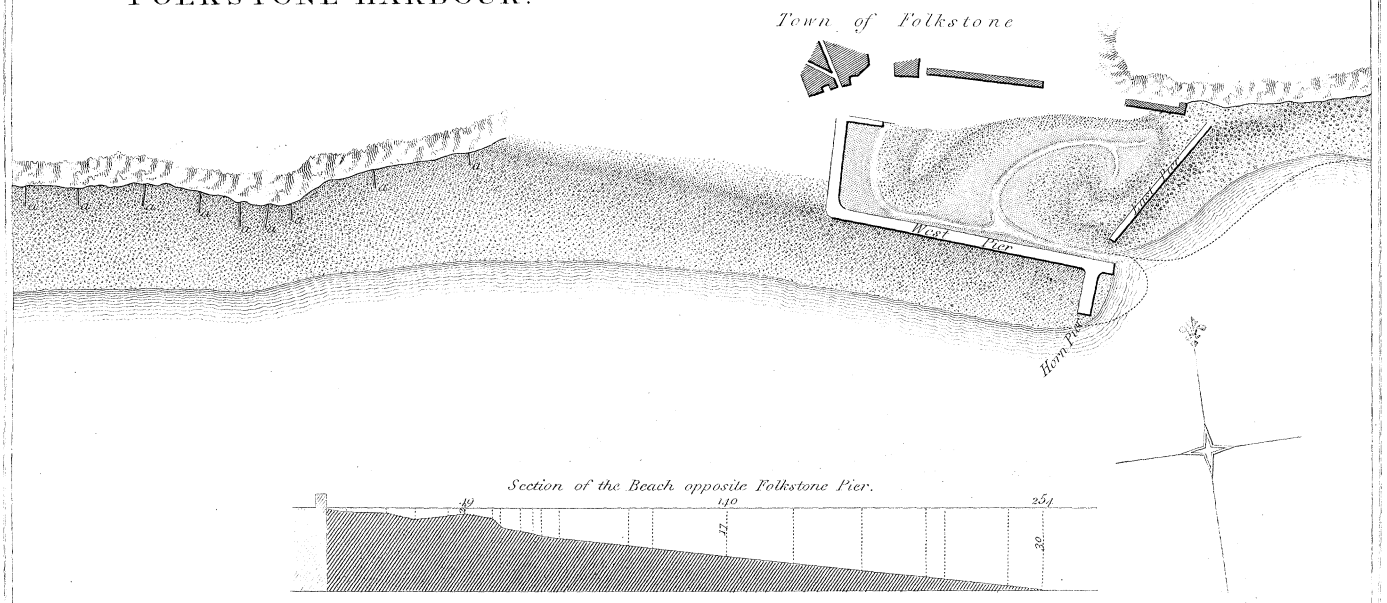
Let A B represent a plane on which all the pebbles are in contact, C B a plane considerably more inclined. If, from the centre of each pebble on the plane A B, a horizontal line be drawn to the plane C B, the position of the pebbles on the latter will be respectively at the various points of intersection.

Section 4.

There are numerous points on the coast at which the line of beach is apparently intercepted and its continuity destroyed, and the rock washed bare. Having sufficient evidence that the motion of the beach was continuous, I thought it important to ascertain in what manner the pebbles escaped past those places, and was happy in finding, upon investigation, that a valuable deduction could be made.

In the description of the accumulative action, it was remarked that the waves having struck the pebbles upwards, became dispersed, and were incapable of returning them to the level from which they were forced. But I now observed that the surface of the rock, being very irregular, constituted numerous channels; so that the waves, instead of returning in a dispersed and weakened form, moved back in columns, which were of sufficient power to return every pebble that had been thrown up; and as these channels offered no impediment to the angular progressive motion of the pebbles, it was more rapid than on the ordinary plane surface. Here, then, was pointed out by nature a principle on which the shingles might be hastened forward,

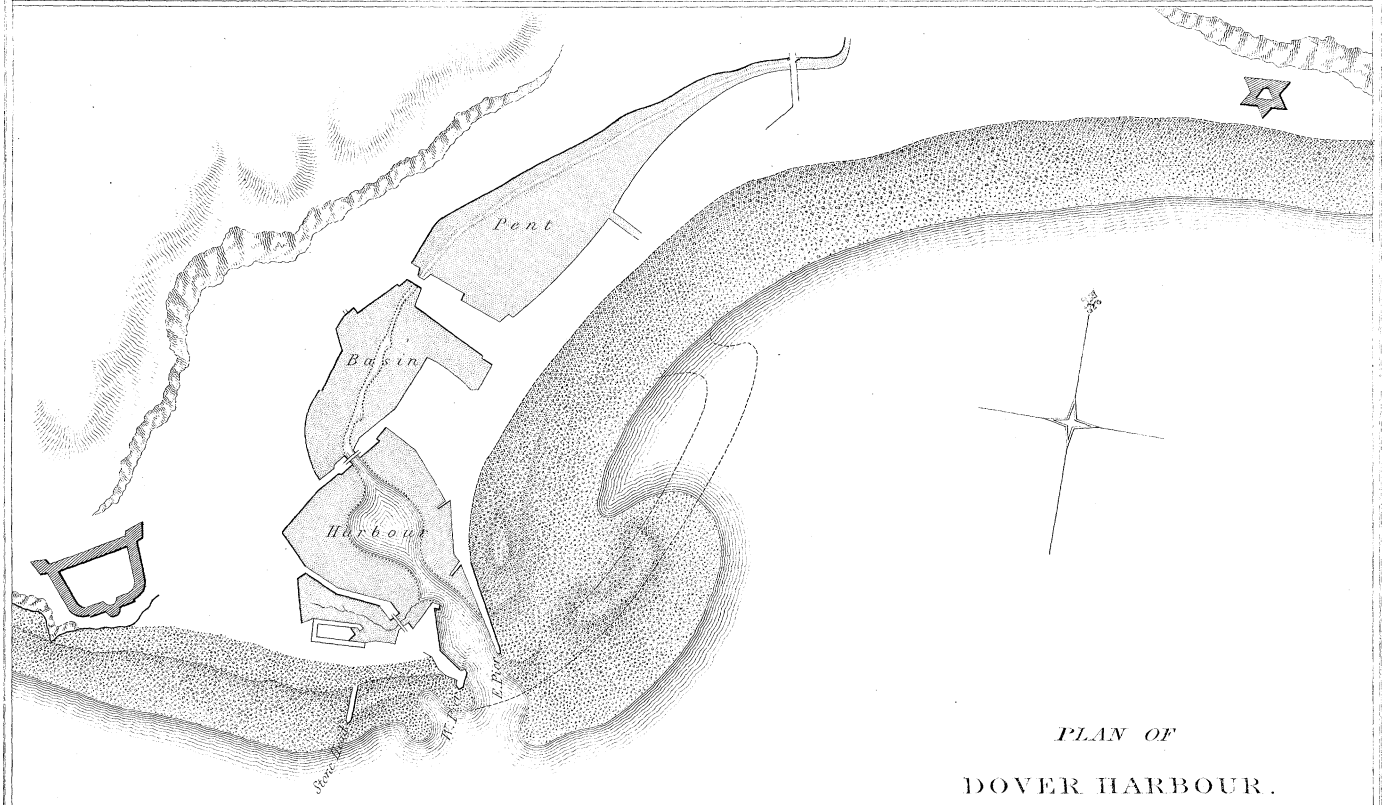
PLAN OF
FOLKSTONE HARBOUR.



Section of the Beach opposite Folkstone Pier.

0 10 20 30 40 50 100
Scale of Section.

0 100 200 300 400 500 1000 2000
Scale of Plan.



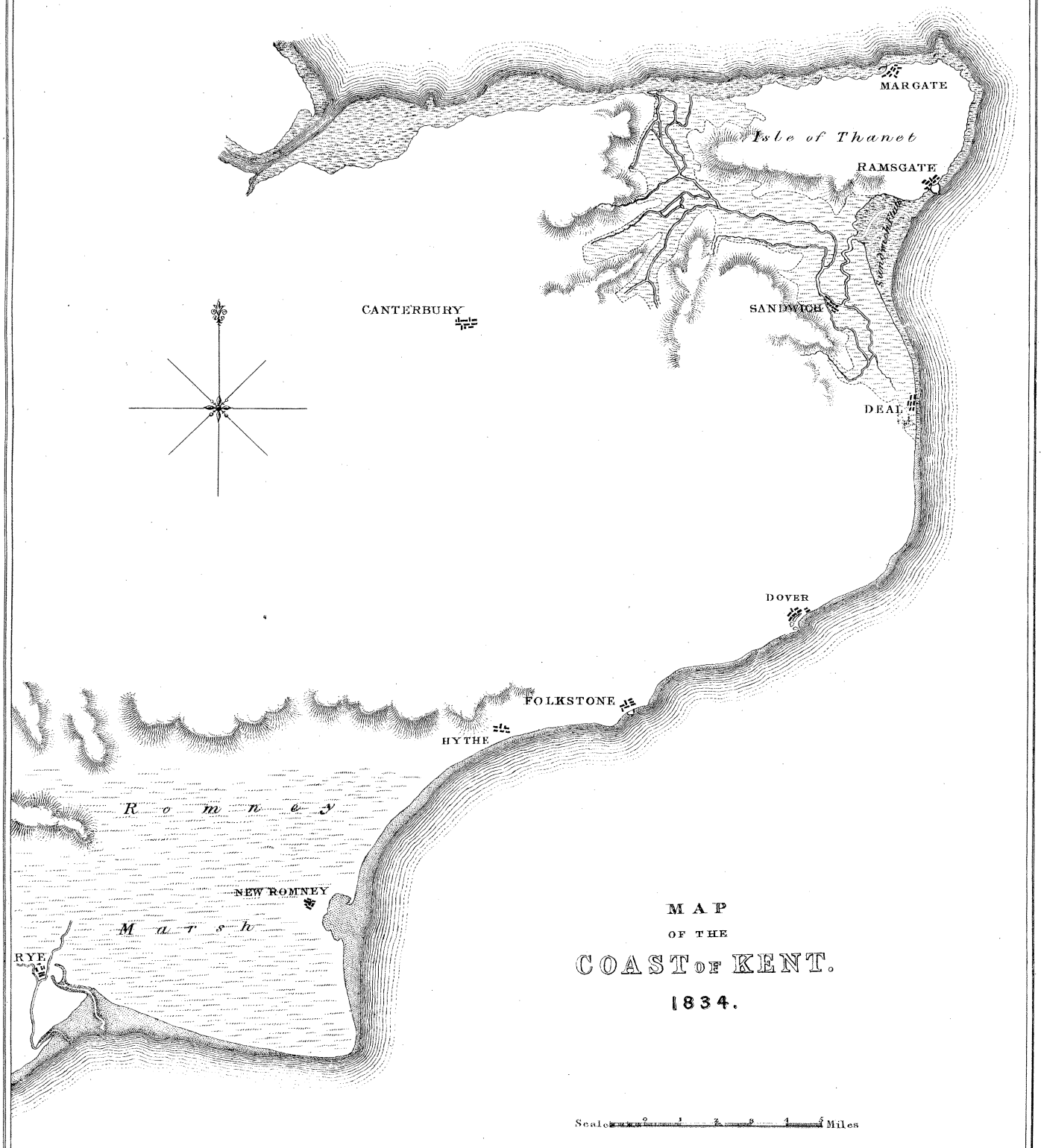
PLAN OF
DOVER HARBOUR.

0 100 200 300 400 500 1000 2000
Scale of Feet.

R.A. Gilpin del.

P. Basire Sc.

PALMER ON SHINGLE BEACHES.



W. Basire Lith.

and their accumulation about any particular place prevented ; and by simply reversing that principle, a method of accumulating or retaining the shingles, where they are wanted, is also suggested, viz. by the reduction of the descending force of the breakers.

The effect of confining the retiring breakers to a column is also exemplified in another manner, when the waves are driven directly upon the beach by a moderate wind, or such as would produce the accumulative action. A succession of waves, acting over the same lines of the beach, soon forms a slight depression, which continues increasing until it becomes a definite channel. The whole line of beach being thus acted upon, it assumes the form of a series of banks parallel with each other. The waves do not then recoil in a dispersed form, but, having broken, are again collected and returned through the channels, and remove all loose matter from them. While in this state, the beach has no progressive motion, but continues (to use a military term) "marking time," until, from the change of wind, an oblique direction is given to the motion of the waves.

Section 5.

The progressive motion of the beach may be easily traced along the coast as far as the bay called Sandwich Flats. See Plate XXVIII. The general character of the motion during its progress is that which is most favourable, under every circumstance, to the chances of becoming securely deposited. Every part of the coast is attempted by every variety of motion in its turn, until a place of final security is discovered.

The locality of Romney Marsh appears to have afforded the sought-for shelter, and now exhibits an extraordinary example of the accumulation, which, having been combined with sand, silt, and vegetable soil derived from other sources, has long been considered an acquisition to our surface of considerable value.

Although this tract has continued increasing to the present day, yet a great quantity of the beach travels past it, and we do not find any other accumulation of much extent between that and Sandwich Flats, beyond which there is no further trace of the shingle which we have so far followed, the pebbles to the northward of these flats being evidently those derived from the cliffs near about them.

On the approach of the shingle to the Sandwich Flats, it becomes gradually dispersed, owing to the increasing inclination of the plane, until it seems to disappear. A considerable extent of these flats has attained a height very little inferior to that of the high-water mark of spring tides ; and it is so nearly horizontal, that the water does not partake of that undulating motion upon it which has before been adverted to.

On the Sandwich Flats there is a continual deposit of soil and silt, brought there from the interior of the country by the river Stour, and which, after its exposure to salt water, is particularly suitable for permanently uniting all the coarser or larger fragments with which it may become intermixed. So much of the materials which have composed the beach as may be conveyed to the higher parts of these flats are not

likely to be again disturbed, because many days may intervene before another tide may reach them; and they thus become united to the surface on which they rest, and gradually contribute to its height.

The greatest motion of the pebbles being where they are exposed to the action of the greatest number of waves, we must look to the lower levels of these flats to trace the further course of the greater portion of the shingle. But even the slope of the surface of the lower levels is so very gradual, that the undulating motion of the water is proportionally diminished; *the action of the water then becomes greatest in the direction of the land.* While, then, we bear in mind the nature of the soil over which it acts, we find an almost insurmountable impediment to the further progress of the shingle, and are enabled to account for the rapid extension of the Sandwich Flats towards the sea, which, in fact, is only the continuation of that process which has been for ages in operation, and which has formed a large portion of those extensive marshes between the Isle of Thanet and the main land of Kent.

Section 6.

Having described those chief principles which regulate the motion of the shingles on this coast, and having traced their progress to a final destiny, I shall now proceed with some further general remarks referring to the application of the foregoing observations.

So much effect has been attributed to the motion of the tidal currents, that vast sums have been expended in attempts to divert the motion of the shingles to a distance from the general line of the shore, from whence, by the increased depth and velocity of the current, it has been expected they would be carried past a particular spot, through which a permanently open channel has been required. Such attempts have been made at various periods during upwards of two centuries at Dover, and more recently at Folkstone in the same neighbourhood. It is hardly necessary to observe, that such attempts have not been successful, and from the principles which I have laid down, their failure may be easily accounted for.

If a wall or pier be extended from the shore into the sea, it is evident that such erection will in the first instance impede and prevent the progressive motion. It is also evident, that the progressive is not necessarily combined with the accumulative action, but, on the contrary, where the former is impeded the latter is assisted. The accumulative action, therefore, continues until the angle formed by the pier and the line of the shore is occupied, and the pier being no longer an impediment to the progressive motion, that motion is again restored, and the general mass proceeds as if no impediment had existed.

The most perspicuous evidence of these results is exemplified at the harbour of Folkestone. (See Plate XXVII.)

Previously to the commencement of this exclusively artificial work, the beach travelled along the line of cliff in the ordinary way.

By extending the walls a sufficient distance into the sea, it was expected that a commodious harbour would be formed, and the shingles diverted so far into deep water, that they could not again appear above the surface until they were removed beyond the harbour's mouth.

The accumulation, however, immediately commenced, and continued as the work advanced until it became apparent that no other effect was produced upon it than a comparatively slight change of direction. The entrance of the harbour being much encumbered with shingle, an additional pier or jetty was erected, and extended about two hundred feet further into the sea without having approached the effect intended. It is true that some advantage was derived from the extended pier, by increasing the distance between the most violent action of the breakers and the still water of the harbour. The shingles, therefore, pass the mouth in a more dispersed form than they originally did, and hence they do not so readily form a barrier, neither does its perpendicular height become so great.

Much valuable information on this part of the subject is recorded in LYON's History of Dover, which, as it may at any time be consulted, is not repeated here. I shall only remark, that from the succession of experiments made at that place, the general result has been in a considerable acquisition of new land, which, although valuable in itself, is not the object intended to be obtained.

If, then, it be admitted that projecting piers will not prevent the encumbrance about the mouth of a harbour, situated as those referred to in the tract of the restless beach, it remains to be seen how far such works may be otherwise injurious.

While the accumulative action is going on, every abrupt projection from the coast is an impediment to the progressive motion of the beach until its angle is filled up. Such abrupt projections offer no protection against the destructive action; when, therefore, by the increase of wind, the action of the sea becomes violent, an accumulation previously caused by a projecting pier is rapidly removed, and again is rapidly deposited where it is not resisted. And there is perhaps no combination of circumstances less capable of resisting, or more favourable to the deposition of, the shingle, than is found in artificial harbours, shielded by an *abrupt* weather pier in a line of beach.

With a long continuance of violent winds from the same quarter, every accumulation of loose shingle is broken down, and is hurried forward, while it unremittingly appears to seek protection. During the recent gales every inlet within the tract of the beach was seriously encumbered with it; commenced with the heap accumulated by the very pier that was intended to prevent such an effect (where such existed), and increased by the successive arrivals of those more remote, together with that quantity commonly passing along the sloping plane, but now brought down by the destructive action and forced along with accelerated motion.

The ordinary state of the beach at Folkestone harbour is represented in Plate XXVII.

the additional extent of the beach on the east side occasioned by the heavy gales is represented by the dotted lines.

The plan of Dover harbour, in the same plate, represents the state of the beach in June 1833, after the wind had blown rather strong for a few days. (This is drawn from a survey made by Mr. J. S. TUCKER, of the Hydrographer's Office in the Admiralty.) The dotted lines to the eastward of the piers represent the general outline of the addition to the former by the recent gales, which having formed a barrier across the harbour's mouth, extended about seven hundred feet beyond it.

Many very interesting facts might be mentioned concerning the effects produced by the continued gales at various places on the coast, but I find that the description of them in sufficient detail to make them useful would extend this paper much beyond the limits assigned: I, however, trust that a reference to two of the most remarkable cases will be found sufficient to illustrate the principles attempted to be explained.

SECTION 7.

The only natural power by which the channels through the beach are retained, is the returning force of the water, which on this coast is generally scanty. And it is obvious, that however judiciously that force may be employed, it is but *remedial in principle*, and necessarily implies a previous evil. So long, therefore, as the cause continues to act, the remedy is prevented, and the harbour becomes inaccessible when protection is most required.

If on inspection of the great bank recently thrown up at Dover (as represented upon the plan), we imagine it to be dispersed over several miles of the sloping plane, and assume the whole to be in continued and equable motion, it will immediately be inferred, that the quantity that would be passing a given spot at one time would be comparatively insignificant; and hence, since we have no reason to suppose that there will be a limit to the quantity, and since it has been shown that its motion cannot be prevented, it follows that the great objects in view must be attained, first, by securing permanently such accumulations as are necessary for the protection of land from the action of the sea, or useful by their addition to its surface; and secondly, by facilitating and inciting the progressive motion of that superfluous quantity from whence the evils complained of are derived: and therefore the uninterrupted and permanent welfare of the numerous harbours which communicate with the sea, through the extensive tract of the shingle beach, is dependent more on a *system of management along the coast*, than upon particular devices adapted exclusively to each separate case.

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