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Author(s): R. L. Cloet
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HYDROGRAPHIC ANALYSIS OF THE GOODWIN SANDS AND THE BRAKE BANK

R. L. CLOET

THERE MUST be few mariners who are ignorant of the existence and the dangers of the Goodwin Sands. Together with the Brake Bank, the Sands form a distinct submarine morphological unit, much less complex than the banks in

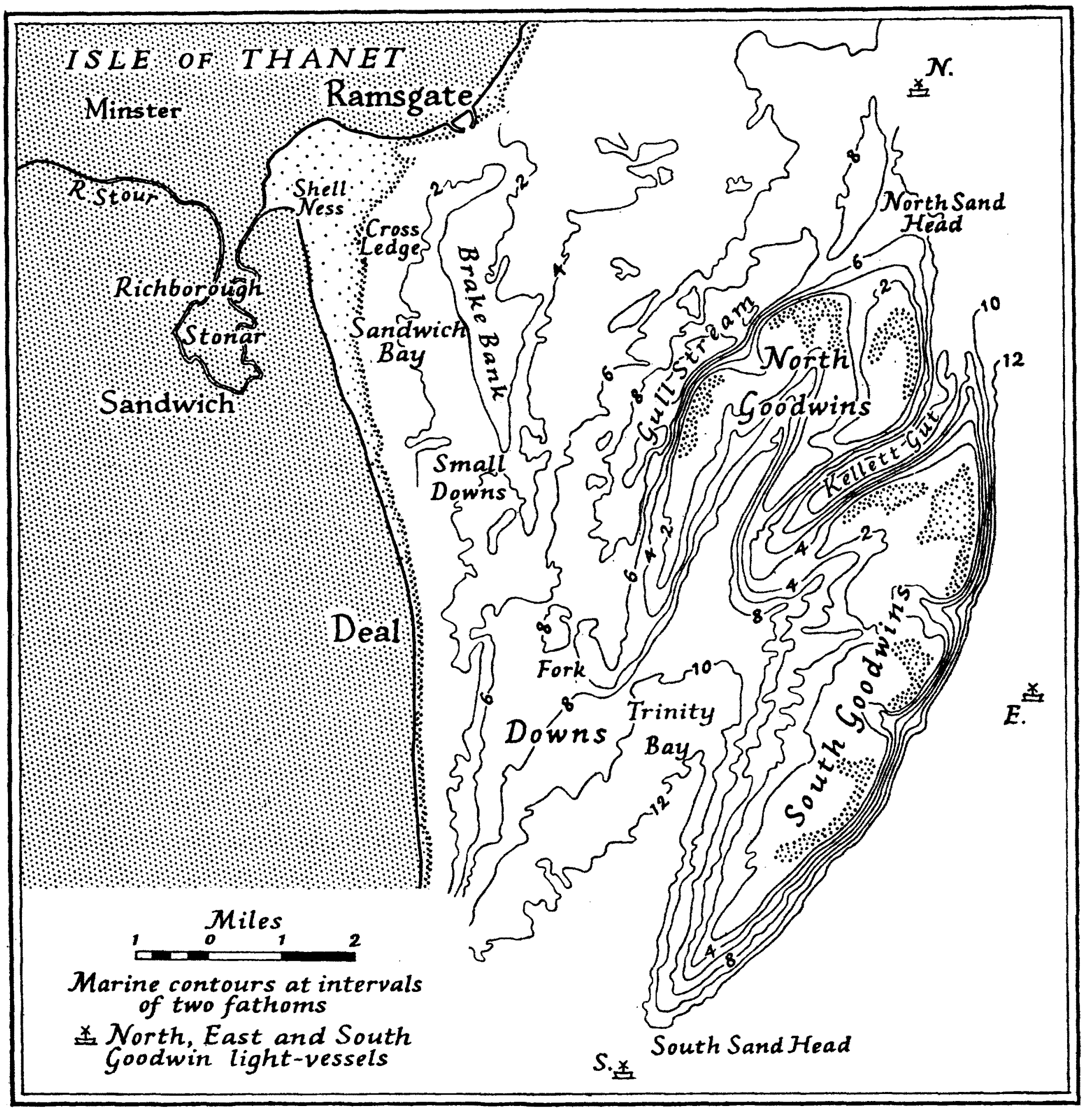

Figure 1

the Thames Estuary, or the series of sandbanks off the Franco-Belgian shoreline.[1] Because of this relative simplicity we are in a position to analyse the movements in which the two banks are subject (see Fig. 1).

[1] Admiralty charts nos. 2182a and 1828 (London).

The Goodwin Sands undergo a slow rotatory movement in an anti-clockwise direction, whereas the Brake Bank has an overall coastward component. From the navigator's point of view the importance of the rotation lies in the westward movement of the western North Goodwins, and the eastward movement of the South Sand Head. The former tends to narrow down the Gull Stream while the latter infringes on the outer shipping lane round the sandbank.

Because of its position on one of the busiest shipping routes of the world, the Goodwin Sands receive much public attention, and a number of confused statements have from time to time been made about the nature and origin of the bank. It is the object of this paper to discuss the stability of the Goodwin Sands in particular, and to account for the pattern of sediment circulation as shown by surveys made over the last hundred and fifty years.

It is perhaps only natural that a large and dangerous sandbank, like the Goodwin Sands, should have become the subject of legends about its former existence as a fertile island (the ancient island of "Lomea") which became drowned by the "convulsions of Nature," as one author puts it.[1] Legends of this kind are found on the Flemish and North French shores in connection with the submerged sand ridges to be found there. In the case of the Goodwin Sands, the disappearance of the island, marking the site of the Sands, is said to have coincided with a great storm in 1099, recorded in the Anglo-Saxon Chronicle.[2] Gattie, quoting some "early writers", suggests that the Goodwins are the "Infera Insula" they mention, but this latter island could also have been Stonar bank, north of Sandwich.

A number of borings in which clay was said to have been reached are sometimes taken as evidence of the existence of a former island, but none of these reports can be traced. Lyell has misled a number of people by ignoring a boring made in 1849, after the publication of the first edition but before the subsequent ones.[3] He stated in his first edition that clay was reached at a depth of 15 feet, without giving a position on the bank, but the 1849 boring later penetrated 78 feet to the chalk substratum without penetrating a clay stratum at all. In his later editions Lyell retained unaltered that the Goodwins probably were "an island like Sheppey composed of clay" only adding to this "and later the chalk was reached." Hence the theory that there may also be a chalk ridge under the bank.[1]

I have attempted to determine that part of the bank which on the evidence of surveys made during the last hundred years has been relatively stable, assuming that the clay-covered "island" could only have existed where there is a measure of stability. In compiling a chart of this core, use was made of all the Hydrographic surveys made between 1844 and 1947. The procedure was the following: The survey fair sheets, which are on scales of 1/25,000 and 1/36,500, were contoured at 1-fathom intervals. One particular contour was then collected from each of the different surveys onto a separate sheet. This was done for each contour over the whole depth range. On each collector sheet there remained now a blank area inside the belts of fathomlines. Now this area, on the evidence of the surveys, has not at any time between 1844 and 1947 been deeper than the particular depth of the contour in question. Since the area has proved stable, or at least fully compensated between the survey dates, the chart which has been compiled from the new limiting contours is a "stability chart." Clearly the chart is only a record of a relatively short period and its reliability depends

[1] G. B. Gattie, 'Memorials of the Goodwin Sands' (London, 1904).

[2] B. Thorpe ed. 'The Anglo-Saxon Chronicle,' ii, 1861, p. 203.

[3] Sir C. Lyell, 'Principles of Geology' (1st edition) (London, 1830), vol. 1 p. 276.

on the frequency with which surveys were made during that period, and the rate at which the bank moves. Earlier surveys were not included because of the difficulty of transferring them to a modern chart. However, we must consider the trends of movement which they show to have existed before 1844.

The stability chart (see Fig. 2) has been drawn at 2-fathom intervals to avoid its becoming illegible, but in the vicinity of the Brake Bank, the 3- and 5-fathom stability contours have been added to give a better delineation of the topography. On the Goodwin Sands, it will be noticed that little remains which is shoaler than 2 fathoms. Of the four 2-fathom patches which remain, the two southernmost would disappear once the earlier surveys were included. There remain the two "islands" on either side of the Kellett Gut. With sea level as it is at present, the case for an inhabitable island is poor, but the Dunkirkian transgression which occurred about A.D. 400 raised sea-level by 4 to 6 metres in Flanders, or by about 3 fathoms.[1] This means that the hypothetical island could have been above chart datum in pre-Dunkirkian times, but not at any later date. However, this lower sea-level would still make it liable to flooding at every high tide to a depth of at least 10 feet. In other words the existence of a bank uncovering at low water, as at present, may have applied also in Roman days, which bears out Holmes' theory that "an obstacle existed here in Cæsar's time."[2] The evidence suggests that the flooding in the eleventh century was probably only of a local nature. Since the Goodwin Sands are well off shore and have deep water all around, such flooding would not in any case have had anything like the same effect as one gets in shoaler water. It is more likely that if it had been possible for an island to exist here it would have been destroyed by A.D. 400.

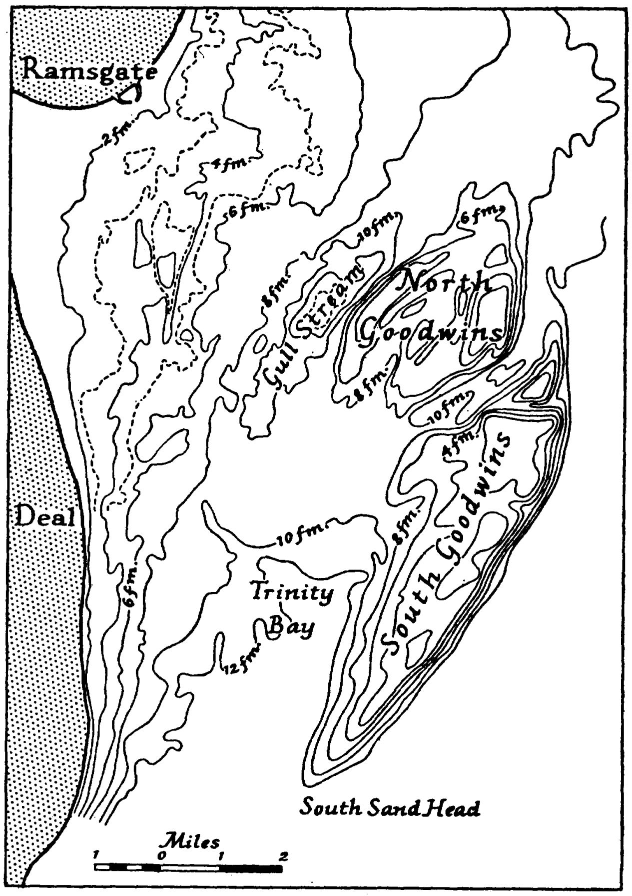

Figure 2

Examining the problem morphologically, we conclude that the feature which possibly existed is likely to have been similar to the present-day Goodwin Sands. Any island which could have been artificially reclaimed by relatively primitive methods would have been in a very precarious position at best.

The composition of the Goodwin Sands.—Our most detailed knowledge of the

[1] R. Blanchard, 'La Flandre' (Paris, 1906), pp. 135–47.

[2] T. R. Holmes, 'Ancient Britain and the invasion of Julius Cæsar' (London, 1907), p. 528.

composition of the bank derives from the 1849 boring made under the supervision of Sir J. H. Pelly of Trinity House [1] (Fig. 3). It reached the chalk substratum at a depth of 78 feet below sea-level or 82 feet below the surface at the time. There is no evidence of clay strata in the column at all. Clay was reported in other borings on the Sands made about 1790 and 1817, but at the depths at which it purported to have been found the bank is so unstable that any idea of an ancient land level is untenable. It is probable that nothing moıe than "clay nodules," or rounded lumps of clay, were encountered, as were found in 1849, or possibly a clayey sand. Reference to Figure 3, which shows the 6-fathom line for 1844 and 1947, gives some idea of the amount of movement to which the Sands are subjected. When investigating the literature, it becomes evident that the reports by various authors of clay having been found nearly all derive from Gattie's book on the Goodwin Sands. Reports of the borings of 1790 and 1817 mentioned by Lyell and already referred to, in which clay was stated to have been found at 7 and 15 feet respectively, are extremely vague and no position is available for them. In any case they have little significance because the bank has been thoroughly disturbed at these depths.

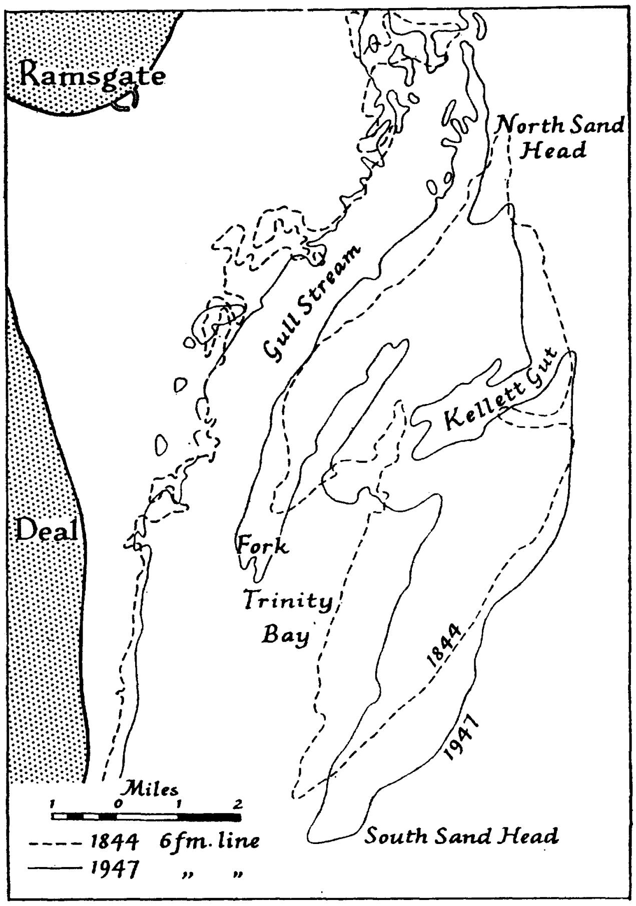

Figure 3

The chalk substratum.—By itself, Pelly's boring gives very little information about the chalk topography under the bank. In order to gain a better impression of this topography, a chart has been compiled on a principle not dissimilar to the one used for the stability chart.

Whenever an Admiralty survey is made, the "quality of bottom" is determined at a number of points. Around the Goodwin Sands, the rock floor is covered by only a thin layer of superficial deposits and the chalk itself is exposed in various places at different times. The soundings where the quality of bottom was determined as chalk have been collected from all the surveys and replotted on a collector sheet; a closer distribution than normally occurring on any one of the surveys then becomes available for examination. Figure 4 shows the chalk soundings so obtained, as well as chalk surface contours based on these soundings. Superimposed on this, to facilitate comparison, is inserted the 10-fathom line from the stability chart.

The traditional method of sampling, to determine the quality of bottom,

[1] G. B. Gattie, 'Memorials of the Goodwin Sands' (London, 1904).

still employed in some cases, is the use of the lead line. The hollow in the base of the lead is filled with tallow; sand, or small pieces of gravel, either stick in it or leave an imprint. Rock often makes no recognizable impression on the tallow, but it is identified by the marks left on the lead. The method, although crude, does yield surprisingly reasonable results in practice.[1] It may be thought that chalk boulders might easily have been mistaken for the solid bottom, but in this case we can refer to the stability chart which provides a useful check. By superimposing the stability chart on the chalk chart, we can ascertain whether a greater depth was recorded at any time and on any one of the surveys where a particular chalk sounding was recorded. Those chalk soundings which lie above the stability surface have been rejected since they cannot have been rock bottom, at least if their position was accurately determined.

We naturally expect a higher density of chalk soundings to occur where the unconsolidated capping is thinnest, or most frequently disturbed. Such an area is found to exist east of the Isle of Thanet (Fig. 4), where a conspicuous feature can be discerned from the trend of the contours. It is a ridge which marks the continuation of the Minster anticline, forming the southern slope of the Isle of Thanet on the mainland. The ridge curves southeastward to be finally lost just north of the Gull Stream, where the sand cover is disturbed less frequently. However the trend of the contours suggests that the ridge may continue under the Goodwins. There are few chalk soundings in the Gull Stream, but the rock bottom is found at 12–13 fathoms near the north end, while east of the southern entrance are two 9-fathom soundings, and south of it a 10-fathom sounding. They indicate that the Richborough synclinal fold persists as far east as this. Furthermore, if we take the evidence of the stability in conjunction with the chalk chart, we discover the possible existence of a channel cut into the chalk, at least at the southern end of the Gull Stream. It is conceivable that this channel was cut at the time of a lower sea level, the period preceding the Flandrian transgression. If so it may have been an over-spill channel established about the time the Creux de Lobourg was breaking through the Straits of Dover.[2] The Creux de Lobourg runs along the eastern slope of the

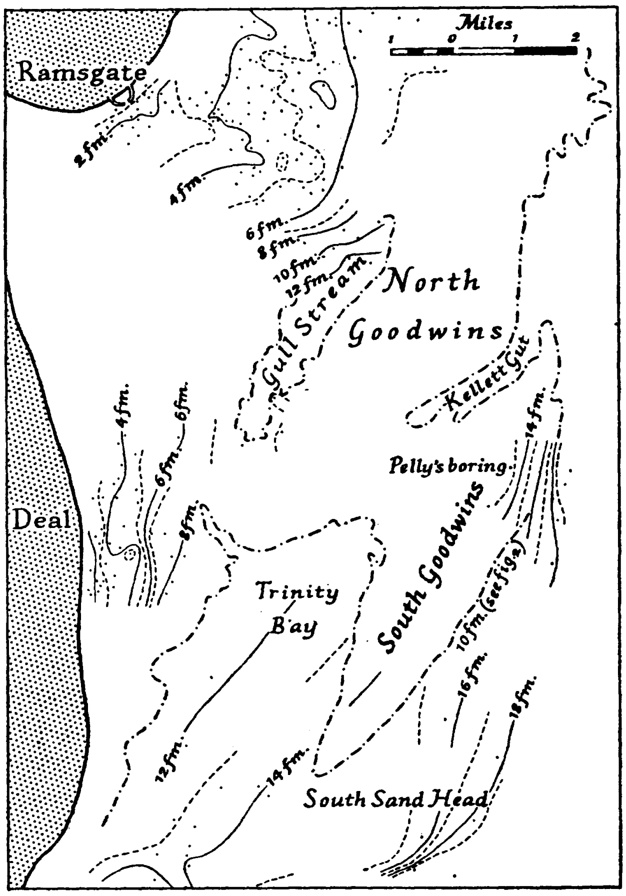

Figure 4

[1] W. B. R. King, "The Geology of the eastern part of the English Channel," *Quart. J. geol. Soc. Lond.* 104 (1948) 327–36.

[2] A. Briquet, 'Le littoral du nord de la France' (Paris, 1930).

Goodwin Sands, as can be seen from the closely spaced chalk contours east of Pelly's boring. It is thought to have been a river channel which cut back through the isthmus joining Britain to the Continent. Alternatively the ponded water, in front of the ice in the North Sea basin, may have over-spilled through a number of channels of which the Gull Stream was one, and eventually have established the Creux de Lobourg as the only permanent drainage channel.[1]

The movement of the Goodwin Sands.—The more obvious trends of the movements of the Sands have been known for some time. Admiral Beaufort, a far-sighted hydrographer, commenting on General Redman's plan for building fortifications on the Sands, in 1848 states in his minutes to the Lords Commissioners of the Admiralty: ". . . within these few years, since they (the Goodwins) have been surveyed with scrupulous accuracy, it appears that they have all had an annual movement to the westward, constantly tending to narrow the Gull Stream, although the Brake Bank is also approaching the shore." [2]

Before attempting to unravel the interrelated evolution of the Goodwins and the Brake Bank, together with its effect on the development of the shoreline, I will now examine the Goodwin Sands separately. It is by far the major bank and an appreciation of its movement will help us greatly in understanding the larger circulation. The most remarkable feature of the Goodwin Sands, which almost completely severs the South Goodwins from the North, is the Kellett Gut. It was much discussed when H.M.S. *Kellett* demonstrated its existence in a survey made in 1926. The Kellett Gut cuts right across the widest part of the Sands, yet there have been periods during which this channel ceased to exist altogether. The survey of 1865 showed no sign of it, nor did it exist between that date and 1896, the date of the last survey before 1926 which covers the area of the Kellett Gut. The Channel does appear on the 1844 survey of Captain Bullock (Fig. 3) as well as on the 1795 survey. Though it still appears on the 1936 and 1947 surveys, there are unmistakable signs that it has been shoaling and presumably continues to do so.

The Gut is remarkable for its size, but such a channel as this, cutting right across a sandbank seemingly where it is firmest, is not an unusual feature. There are some equally well-known channels crossing the Banks of the Thames Estuary. Robinson [3] recently gave an analysis of the Edinburgh Channels, twin channels cutting across the Long Sands. Channels of this nature are called "swatches" or "swatchways," words deriving from the Saxon "swaeth," meaning furrow. Such swatches are not necessarily as deep as the Kellett Gut, which attains 13 fathoms, but they appear to cut through the unconsolidated sediment to the firmer substratum. In the case of the Kellett Gut, this is the chalk, and in the case of the Edinburgh Channels probably the London clay, or at any rate a well compacted clay.

On old pilot charts, the Goodwin Sands are often shown divided into two parts in the approximate latitude of the present Kellett Gut. Sometimes "swatch" is written against the eastern entrance to the channel, indicating it to be the principal and probably the deepest of the several possible swatches. Lucas Waghenaer, the Dutch navigator, who gave his name to the "waggoners," as charts used to be called, shows the Sands entire, without swatchway, in 1584, but another Dutch cartographer, Pieter Goos, represents the bank in two sections in 1666. Labelye, in 1736, and Ross, in 1779, also chart the swatch. The

[1] P. Tesch, "Over de onderzoekingen in de Hoofden en langs de Nederlandsche Kust" *Tijdschr. Kon. Ned. Aardr. Gen.* 1937.

[2] Hydrographic Department of the Admiralty, Archives.

[3] A. H. W. Robinson, "The changing navigation routes of the Thames Estuary," *J. Inst. Navig.* 4 (1951) 357–70.

latter however shows a $3\frac{1}{2}$ fathom sounding in the swatch, indicating that the channel was not then fully formed. In 1795, the swatch was well established, and down to the chalk at 13 fathoms as shown by a chalk sounding on the survey. The swatch continued to exist until about 1850 (it was there when the boring was made in September 1849 close south of it), but there was no trace left when a survey was made in 1865. As stated before, the Kellett Gut was discovered in 1926 in about the same position as where the swatch had been, but it would appear from information provided by Mr. Kirkaldie, former coxswain of the Ramsgate lifeboat, that the Channel actually came into being about 1910, and was used by some vessels during the First World War.

On the landward side of the North Goodwins an interesting evolutionary cycle has been observed along that limb of which the Fork is the southern extremity. On the surveys of the last thirty years, it has been possible to see a slight inflexion in the fathomlines, near the North Sand Head, grow laterally deeper into the bank, while the entire feature was travelling down the Gull Stream. That inflexion, which may be called a lateral wave, gradually took on the appearance of a recurved spit (Fig. 1). The neck of this spit grew more tenuous, until a small shoal, the original recurved end of the Fork, was thrown off, as can be seen on the 1945 survey. Unfortunately, the 1947 survey did not cover the area where the remains of this shoal should still have been. It has doubtless disappeared by now, and was probably quite small even in 1947. A new cycle may already have started near the North Sand Head.

There is sufficient evidence from the surveys of the past century to suggest strongly that we are dealing with a more or less continuous series of lateral waves travelling down the Gull Stream. These waves do not occur either on the Brake Bank, or on the eastern side of the Goodwins, but the more common type of wave, the so-called giant ripple or sandwave, has been found on the Brake Bank and described on the Goodwin Sands.[1]

When considering the outline of the Goodwins, which I have for convenience taken as the outer 6-fathom line, one is struck by its resemblance to a symmetrical aerofoil, except for the gap caused by Trinity Bay, and the smaller indentation of the Kellett Gut (Fig. 5).

By fitting aerofoils to each of the surveys from 1795 to 1947 it becomes possible to analyse the general movements of the sandbank in relation to (1) length of the major and minor axes; (2) angle at the nose or rounded end of the bank; (3) orientation of the shape in the flow, or in this case the angle of the major axis with the meridian. The major and minor axes are the dimensions of length and width, while the angle at the nose gives an indication of how far along the length the greatest width occurs.

When we consider the length of the bank from 1795 onwards, we see that the main bank is now shorter than it was in 1795, although it has increased in length since 1844 at an average rate of 0·6 cables per decade or about 4000 feet per century. However, the minor axis has shown an almost steady but slight increase since 1795. The general trend resulting from this is seen to be an expansion of the bank. It should be noted that this trend was temporarily reversed between 1887 and 1916 (see Fig. 5), the period during which the Kellett Gut ceased temporarily to exist.

The angle at the nose has become sharper since 1795, with a reversal of this trend about the same time as in the case of the expansion of the shape. The sharpness of this angle is also closely related to the size of the minor axis, as if

[1] R. L. Cloet, "Sandwaves in the Southern North Sea and the Persian Gulf," Lecture at the Challenger Society, January 1954 (to be published, *J. Inst. Nav.* 7, 3 (1954)).

the bank expands as a direct result of sediment being redistributed from the North Goodwins southwards. We will return to this point when the overall sediment circulation is discussed.

The orientation of the Sands is here taken to mean the angle of the major axis with respect to the meridian, which is also the angle of the axis of symmetry with the meridian. The trend has been a rotation towards a north–south alignment, which has been slowing down steadily until at present it seems to be almost stationary, though it would be unwise to attempt any predictions. There are again signs of a temporary reversal of this trend between 1887 and

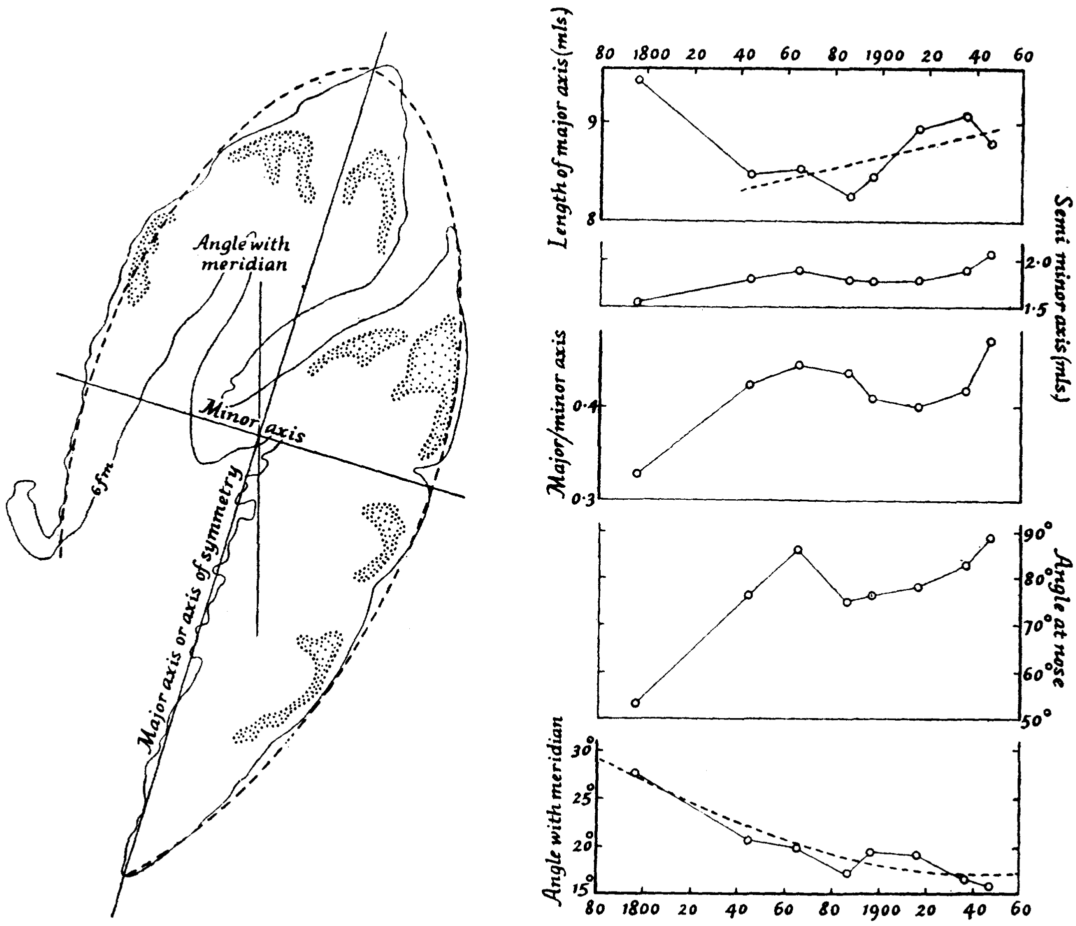

Figure 5

1916. The use of the aerofoil for this trend analysis is possible because the position of the Goodwins in a converging flow towards the Strait of Dover from the North Sea seems to have produced a feature of which the extremities, The Fork and South Sand Head, are also converging, but we must not lose sight of the fact that a considerable portion of this ideal shape is missing in Trinity Bay.

The Brake Bank.—Extending southward from the mainland of Thanet at Ramsgate, lies the Brake Bank. As was pointed out by Admiral Beaufort in 1848, the Brake was (and still is) moving towards the coast. On closer examination however we discover that this movement is not a simple coastwise motion, but that the Bank is bending into Sandwich Bay, tending more and more to take the curvature of the Bay (Fig. 6). The middle portion, which corresponds in latitude to the position of the former Cross Ledge, has moved relatively farther west than the southern extremity. The Cross Ledge is now covered by the main bank, which has passed sufficiently far beyond it for the leading line into Ramsgate Harbour to have moved farther west.

A survey of Cross Ledge, made in 1950 as a result of yet another report of westward movement, revealed the existence of an interesting set of sandwaves.[1] An analysis of the E/S, or echo-sounding, traces showed that these were not moving westward. The crestlines of the waves were west-north-west to east-south-east, approximately transverse to the direction of movement. Thus by implication we have a local sediment transportation across the line of movement of the Brake Bank as a whole, but interestingly enough in the same direction as the coastal drift from Deal towards Shell Ness at the entrance of the Stour.[2]

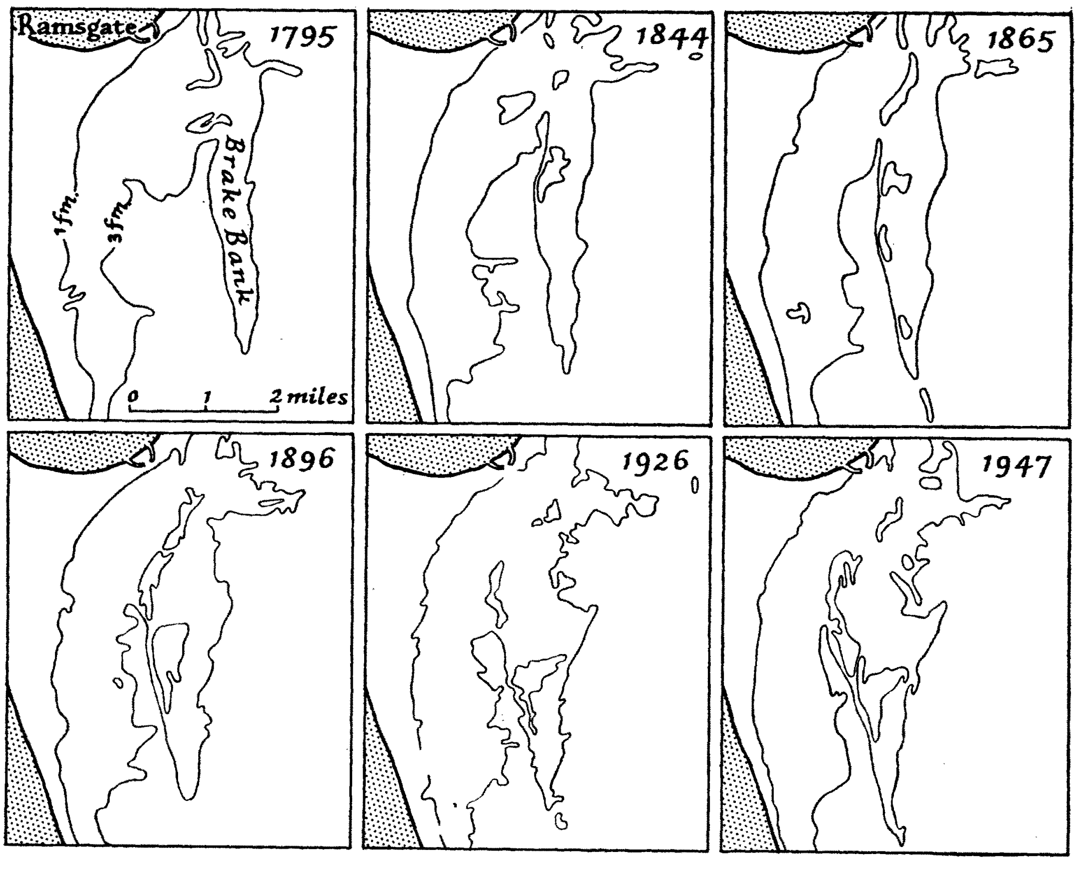

Figure 6

The evolution and shape of the Goodwin-Brake system.—An interesting explanation of the layout of this sandbank system can be derived from a theory advanced by Van Veen, Chief Engineer of the Dutch Waterstaat.[3] He states that ebb and flood establish individual channels and tend to throw up obstacles against each other in the shape of blunted wedges which could be termed parabolic wedges.

[1] R. L. Cloet, "Sandwaves in the southern North Sea and the Persian Gulf," Lecture at the Challenger Society, January 1954 (to be published, *J. Inst. Nav.* 7, 3 (1954).

[2] A. H. W. Robinson and R. L. Cloet, "Coastal evolution of Sandwich Bay," *Proc. Geol. Ass., Lond.*, 64, 2 (1953) 69–82.

[3] J. Van Veen, 'Onderzoekingen in de Hoofden in verband met de gesteldheid der Nederlandsche Kust' ('sGravenhage, 1936).

For example, in a field of transportable material a maximum amount of sediment is removed along the line of maximum velocity, the amount of transported material decreasing rapidly on either side. Consequently there is more sediment available for deposition along this line when the tide turns, resulting in a sediment wedge with maximum height at the apex. The opposing tidal stream is thereby deflected but similar features are produced on one or both sides of the first wedge and in the opposite direction. Once this system is formed, the residual water movement inside the elongated wedges increases in size, there being alternately ebb and flood residuals alongside each other. On the whole, the existence of residual water movement in one or other direction is accompanied by a net sediment transportation. In this way sediment carried with the ebb will tend to collect in the ebb wedge and conversely sediment carried on the flood in the opposing flood wedges. It follows from this that the shape of the wedges and the amount of sediment contained in them depends firstly on the carrying capacity of the stream and secondly on the availability of transportable sediment.

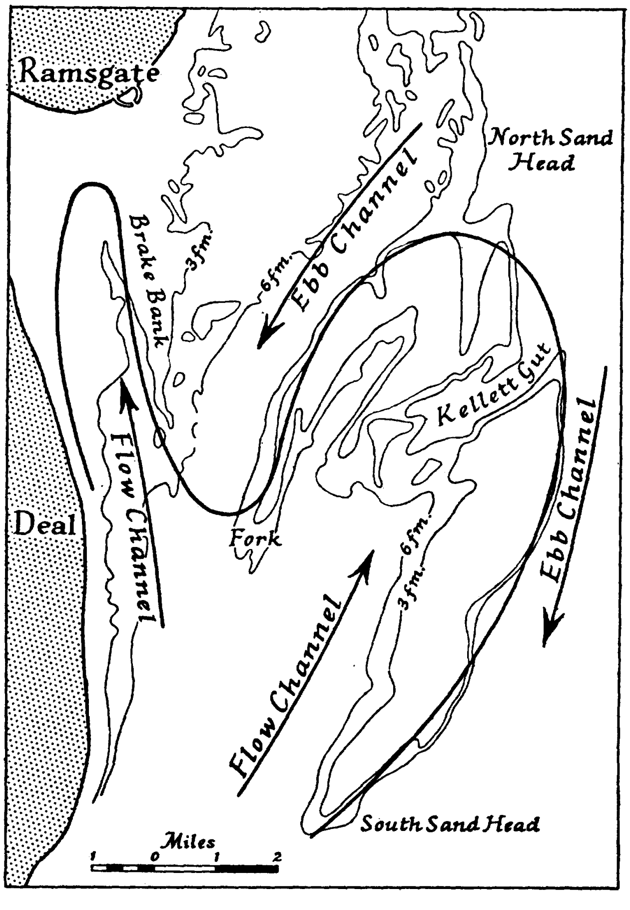

Figure 7

In the case of the Goodwin Brake system we have two flood channels, one into Trinity Bay and the other into the Small Downs, west of the Brake Bank. These are separated by the ebb channel of the Gull Stream, while the residual current along the East Goodwin light-vessel (as recorded in 1889) makes the outside of the Goodwins also behave as an ebb channel (Fig. 7). Can this system of channels, in the light of our interpretation of Van Veen's theory, provide a satisfactory explanation of this sediment movement?

I have shown that the sediment of the Cross Ledge is travelling northward. A recent Notice to Mariners earlier this year reported slight shoaling just north of Cross Ledge and may be taken as supporting evidence of this.[1] It is also in accord with sediment movement in a flood channel. The Goodwin Sands outer contour is expanding. This is in agreement with what can be expected to happen in a flood channel which carries more than the adjacent ebb channels. Where this is the case, the return movement of the ebb channel cannot entirely dispose of all the sediment which has overspilled the flood parabola. The Gull Stream ebb channel is incomplete at the head of that channel because ebb,

[1] Admiralty Notice to Mariners no. 2817/1953 (London).

coming across the almost barren chalk shelf east of the Isle of Thanet, does little more than move sediment by longitudinal drag on the Goodwin and Brake Banks. It is this drag which is responsible for the lateral wave travelling down the side of the North Goodwins to the Fork. The overspilling of the Trinity Bay flood channel is greater at South Sand Head, where the ebb residual flow, along the outside of the bank, has become less marked. The resulting movement of the whole of the sandbank due to the unequal outward movement of the Fork and South Sand Head is, as we have seen, a counter-clockwise rotation. This in its turn is responsible for the Brake being pushed westward by the Gull Stream channel trying to maintain the debit of water through it. Although the Small Downs flood channel west of the Brake is able to move some sediment northwards, it is weaker than the Trinity Bay flood channel.

So far the North Sand Head has not been mentioned. It is a relatively small shoal mostly detached from the Goodwins proper and elongated in the prolongation of that bank, though somewhat to the west of the extended axis of symmetry. The ebb stream coming from the northward divides on reaching the Sands into the Gull Stream and east of the Goodwins. This leaves a wedge of almost no velocity in the upstream prolongation, where sediment deposited by the opposing flood stream is unlikely to be much disturbed. It is in any case also an area where secondary flow in the ebb stream would tend to deposit sediment, since it is a known fact that sediment is moved from the lines of greatest velocity to the area of least velocity.[1] In this way the North Sand Head could be brought into being and maintained, although its size probably depends on the width of the Goodwins, and of course on the amount of sediment brought on. This formation of a shoal heading into a residual flow and possibly extending in that direction as the size of the main sandbank increases, may also well be the reason why the north pointing spit east of the Kellett Gut, on the South Goodwins, has been extending some distance northward between 1936 and 1947.

The Kellett Gut is a major feature of the Goodwins. It is cut down to the chalk substratum and appears to be a further formation in the ebb and flood channel system. Indeed it has penetrated with its sediment wedge some way into Trinity Bay, while the flood channel has penetrated deeper into the North Goodwins between it and the Fork.

It has been seen that the Goodwin Sands expanded fairly steadily from 1795 to 1865 and from 1916 to 1947. Similarly, the rotation of the major axis showed a reversal of the trend over the same period. On the whole the ebb movement of sediment is insufficient to remove the material which the fanwise expansion of the flood channel in Trinity Bay has brought on. The expansion of the North Goodwins is successfully counteracted, as is evidenced by the increasing angle at the nose of the aerofoil. The ebb probably carries little sediment in suspension until it reaches the Sands. It does therefore not contain any worthwhile amount of sediment along its maximum flow streamline but this is brought into suspension by longitudinal drag along the bank. The ebb can then successfully counteract flood only where it is not saturated with sediment, *i.e* on that part of the aerofoil which is in front of the greatest width.

Flood widens the bank, thereby increasing the obstacle in the path of the ebb, and the ebb flow streamlines converge even more as a result. Also it is conceivable that the ebb sediment transportation is able to remove the fine fraction from the grain-size distribution of the sand in such a way that the homogeneity of the sediment is disturbed at a critical point along the outline

[1] L. Prandtl, 'The essentials of fluid dynamics' (London, 1952).

of the bank. The combination of a steep velocity gradient alongside, due to the closing up of streamlines and the removal of the cohesive fraction from the sediment, may produce a breaking point which leads to the formation of a channel like the Kellett Gut. This explanation is of course tentative, but it could probably be cleared up if a set of samples could be obtained from the bank and the grain-size distribution in them analysed.

This theory does not, perhaps, provide a clue to the formation of swatchways in general, as for instance the navigationally important Edinburgh Channels, lying farther north, in the Thames Estuary. I am unable to offer an adequate alternative to Robinson's suggestions that the later arriving English Channel flood stream has cut across the Long Sand, but in this case one would expect that the broad rise joining the Tongue Sand and Kentish Knock which would lie in its path should also have been cut into. I believe that we should think along the lines that these Thames Estuary banks contain the greater part of the transportable sediment and that here also there exists a cell circulation of sediment on each bank. I have given a description of the possible development of this type of circulation in another paper.[1] It seems possible that in the case, both of the Edinburgh Channels and of the Kellett Gut such cells become over-extended by an excess of sediment transportation in one direction. This cell may then become unstable and a swatchway is cut at the critical place. It is worth noting that there are hardly ever two deep swatches close together across one sandbank. The Edinburgh Channels have become separated by the growth of a shoal (Shingles Patch) in the original channel.

To summarize, I have advanced some arguments suggesting that the Goodwin Sands consist of an accumulation of sediment resting on a fairly even chalk surface. The existence of a former island is doubtful, and the only evidence of it is legendary and of questionable value. However, the Sands, though subject to an appreciable amount of movement, have probably existed in their present position for a considerable time. The reason why the Goodwins do not move either into the Straits of Dover or farther into the North Sea is thought to be the interplay of an ebb and flood channel system of transportation. Because either one or the other stream is locally stronger on different parts of the same sandbank the addition of sediment seems to produce a *widening* of the feature where the opposing stream is least able to counteract this tendency. This continues until a new balance is temporarily achieved. Superimposed on it is the differential effect of two flood channels on the enclosed ebb channel of the Gull Stream. The ebb is weaker as a sediment carrier than the flood in Trinity Bay, while it does more than keep in check the expansion of the Small Downs flood channel. It has been suggested that the formation of the Kellett Gut is a response to the widening of the Goodwins. The occurrence of a lateral wave on the Gull Stream side may be parallel development where the inequality of capacity between ebb and flood channels is not so marked, the stress does not here build up to breaking point.

It may be that we can go still further and surmise that eventually the whole arm of the Fork may be severed from the Goodwins while a new North Goodwin develops from that part which is north to the Kellett Gut and the Brake Bank merges with the shore. This brings us to the larger conception of sediment circulation on an open shore, which may be possibly an almost closed cell circulation within each limb between ebb and flood channels, superimposed on

[1] R. L. Cloet, "Sandwaves in the Southern North Sea and the Persian Gulf." Lecture at the Challenger Society, January 1954 (to be published, *J. Inst. Nav.* 7, 3 (1954)).

a slow drift of the sandbanks toward the shore as their sediment content is slowly increased.

This latter drift is not likely to be continuous but probably consists of a growth to unstable proportions followed by a severing from the parent bank. The formation of the Kellett Gut may consequently either be an attempt to redress the balance between ebb and flood, or be the beginning of a more drastic change culminating in the origin of a new Brake Bank.

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