SAND WAVES IN THE NORTH SEA

by

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INTRODUCTION.

In the summer of 1934 the Waterstaat Surveying Ship *Oceaan* (Fig. 1) visited Dover and Calais in order to investigate the sand movements which were supposed to exist in the Channel.

According to geologists and other writers on this subject, this sand-stream should be heading towards the Flemish and Dutch coasts, taking a north-easterly direction due to the flood tides being more powerful than the ebb in this part of the North Sea. The authorities of the Waterstaat wished also to ascertain whether the Channel between Cape Gris Nez and Dover is being scoured out or not.

The full results of these investigations cannot be published yet since they are not completed, but the first results may now be advanced because they seem of particular and general interest.

Firstly the southern portion of the North Sea (roughly south of the line from Lowestoft to Helder) was found to possess a remarkable bottom of a wavelike structure. For miles the regular shaped sand waves or sand dunes appeared on the graphs of the echo-sounding gear, an instrument which is essential for this kind of research work. The instruments used are the British Admiralty machines for shallow or super shallow water made by Messrs. Henry HUGHES & Son, London. Fig. 4 gives a registration of the newest type, the so-called "Dutch model", which was made specially for our needs. The vertical scale of it is 1 cm. = 1 metre. This scale may be altered to 1 cm. = 4 metres.

The heights of these submarine sand dunes were often 10 *metres* (33 ft.) *or more*, the highest being found at the "Tail of the Falls" where their size was 13 *metres* (42.6 ft.) (see Fig. 2). Generally these waves attain heights of 8 *metres* (26.2 ft.) and lengths of about 200 *metres* (220 yds.). Their tops were notably sharp so that it is almost impossible to discover the highest parts with an ordinary lead-line.

Now when a flat bottom starts to wave like this, the tops may become dangerous for passing ships. The same may occur when the sand waves develop in places between the buoy lines, and a special study of them is required since they are likely to change their forms and positions fairly quickly, especially during a storm.

I know of a case, where a shallow point on the hydrographic chart — probably the top of one of these submarine dunes, as was proved later when an echo-sounding machine became available — could not be found again: after much seeking, the hydrographer removed the shoal from his chart, with the bad result that a ship ran aground. Now the top of the dune may have been too small to find with the lead or else the top may have disappeared temporarily, but in either case it illustrates the fact that one has to be careful with waving soils.

The modern echo machines are a welcome help for detecting these treacherous kinds of shallows and for keeping an eye on them.

Another point which is of practical importance is that these kinds of "top" shallows seem easy to dredge away, but in reality they may prove to be very stubborn.

The total amount of material which has to be dredged may be small, because only part of the tops may obstruct (see the shoal off the entrance to Calais harbour, Fig. 3), yet these tops might reform quickly because the causes which are responsible for them may not have been removed. No experience is yet available on this subject, because until recently the structures were hardly known.

The first waves of this size were described by LÜDERS (*Senckenbergiana* 1929) as being found at a spot in the Outer Jade (the entrance of Wilhelmshafen) and having heights of about 8 metres. LÜDERS detected them with his "Schlepplot", a manometer device which was towed over the bottom.

Fishermen working in the North Sea are more or less acquainted with these waving soils. They call them *ridges* (English), *ridens* (French), *ongelijkens* ("irregularities"), *hompels* or *ribben* (Dutch). These ridges produce the "strong ripples" on the water surface, some of which are indicated on the hydrographic charts.

INFLUENCING FACTORS.

Generally speaking the characters of bottom profiles depend on the material of which these bottoms are made. Mud or rock for instance show different forms, the first having soft and flat, the latter angular lines. A sand bottom does not always attain the gigantic wave pattern. The size of the sand grains, the velocity of the streams, the width and depth of the water, and perhaps still other factors seem to be of influence in this respect. Wherever the bottom is of fine hard sand (where a stick would rebound instead of sinking) no waves could be found. Where the velocities of the tidal streams were low as is the case north of the line from Lowestoft to Helder a flat bottom was encountered, although the sand grains seemed to be of the right size. This point, however, has not yet been fully investigated.

Experiments on these subjects are being made in the new Hydraulic Laboratory at Delft (available floor surface, 2500 m^2) (26,900 sq. ft.). In glass sided gutters of sufficient cross section and length, different kinds of sand are being tried under different velocities of ebb and flow, and the causes which make these sands wave are being studied. It is hoped that in this way some of the questions mentioned above may be solved.

Already in the year 1883 REYNOLDS came to the conclusion in his laboratory that remarkable large sand waves with lengths of about 20 to 30 metres (22 to 33 yds.) could be formed by the alternating streams of ebb and flow. Although the real waves attain features of approximately ten times this size, it proves that laboratory practice may be able to come nearer to the solution of the problems.

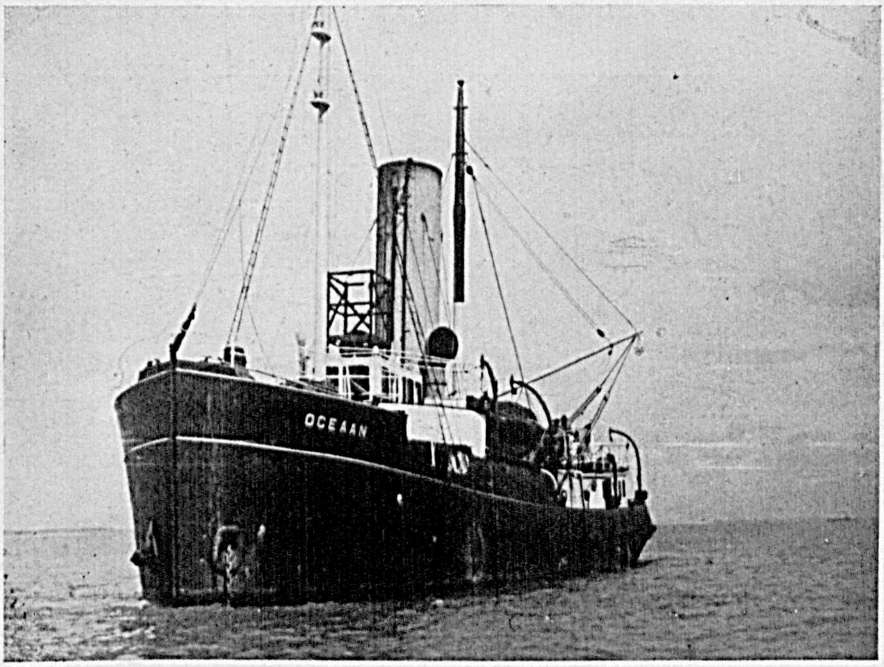

FIG. 1.

Waterstaat Surveying Ship Oceaan.
Navire explorateur Oceaan *appartenant au Waterstaat.*

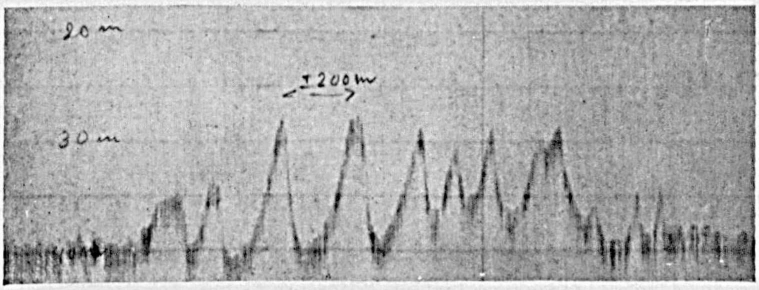

FIG. 2.

High sand-dunes at the "Tail of the Falls". Maximum height 13 *metres.*
Dune de sable élevée à la "Tail of the Falls", hauteur maxima 13 *mètres.*

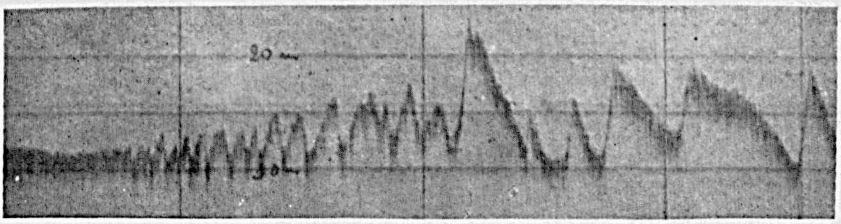

FIG. 3.

Sand-waves off Calais harbour entrance.
Ondulations de sable devant l'entrée du Port de Calais.

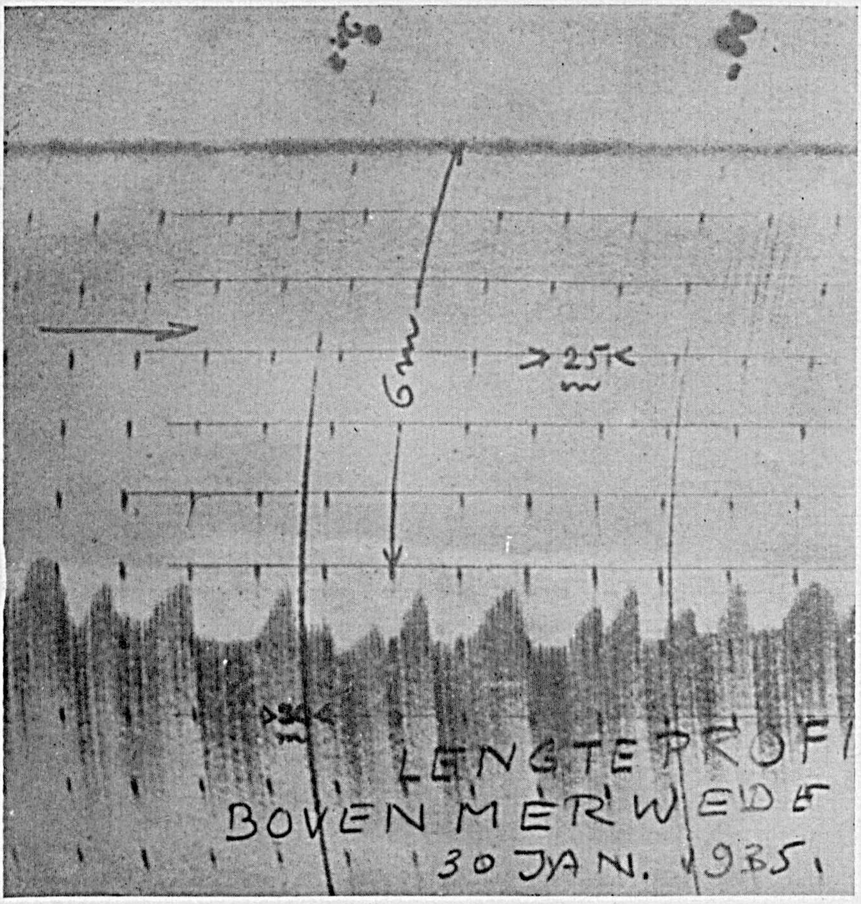

Fig. 4.

Bottom waves in the River Merwede, recorded by super-shallow water echo machine (so called "Dutch Model"). Vertical Scale 1 cm. = 1 metre.

Ondulations de fond dans la rivière Merwede, enregistrées avec la "Super Shallow Water Echo Machine" ("modèle hollandais") : échelle verticale 1 cm. par mètre.

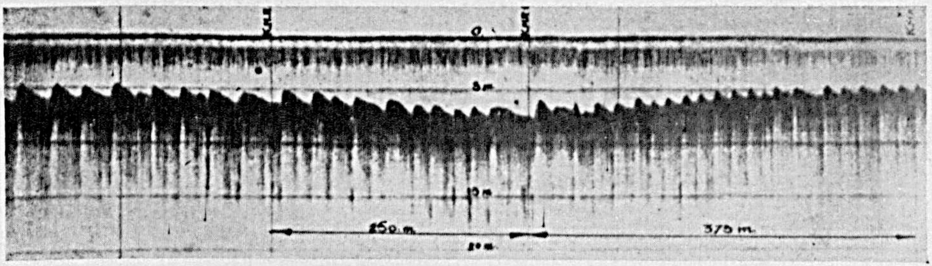

Fig. 5.

Bottom waves in the river Lek.

Ondulations de fond dans le Lek.

RIVER SAND WAVES.

Not only alternating currents produce these gigantic waves but currents of one direction only may produce sand waves of considerable size, as may be seen from Figs. 4 and 5. These figures are photographs of bottom registrations on the rivers Lek and Merwede, both branches of the Rhine. The depths are about 4 to 6 metres (13 to 20ft.) and the height of the waves about 1 to 1 ½ metres (3 to 5 ft.) or approximately 20 % of the free depth.

This same percentage of 20 % to 30 % was often found in the North Sea, where the regular alternating currents made their impression in the bottom. It should be noted, however, that the shape of the waves is different. The Lek waves are of asymmetrical form, the North Sea waves generally being symmetrical. The sizes of the sand grains in the Lek are about 400 micron (0.016 in.) and roughly the same size was found in the sand dunes of the North Sea.

The resistance which these waves offer to the flow of the water is very considerable. The constant of the ordinary flow formula (CHÉZY) has to be corrected accordingly.

THEORY OF WAVE FORMATION.

When two layers of different material pass over each other ryhthmic surface forms may occur. Wind pássing over water produces ordinary water waves, over dry sand, ripples and dunes; and in the same way ripples and dunes may be created when water is streaming at an appropriate velocity over a suitable bottom of sand.

"Though waves are ordinary phenomena of nature, our copious theories are not well balanced with observation and research" declares the well-known German mathematician THORADE (1920 *Ann. Hydr.*). Yet an enormous amount of thought and observation is expended on the subject of waves and ripples. Vaughan CORNISH is devoting his life to these phenomena and found on the Goodwins, ripples of 3 to 5 feet high. D.W. JOHNSON called these "mammoth" ripples.

Rhythms are fascinating, in music as well as in visible nature, but they are not easily caught in the cage of a scientific formula. Yet usually they are as much subject to law as they are complicated.

Henning KAUFMANN strikes a truthful note as follows: "everyone who starts research in wave phenomena will soon find that he has arrived in a peculiar world. The solid ground of his everyday experience is moving from under his feet; cause and effect make a wild dance; the phenomena slip out of his hand whenever he tries to catch them. Even the lights of science, which in other circumstances are reliable beacons, glitter here in a queer and mad way. If, somehow, we dare to hope to emerge from this enchanted castle with a clear head, the only way will be to proceed carefully keeping close contact with observations".

Here again the need of more observations is stressed. Indeed when anything begins to dance, strange things may occur and it is wise to observe the effects carefully.

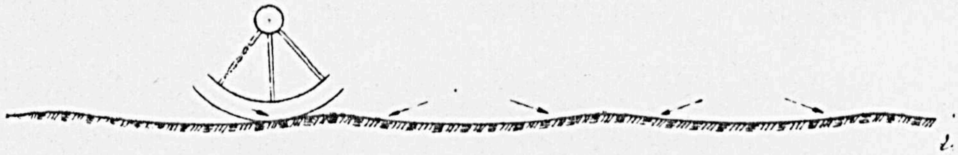

Fig. 6.

Undulating road surface.
Route ondulée.

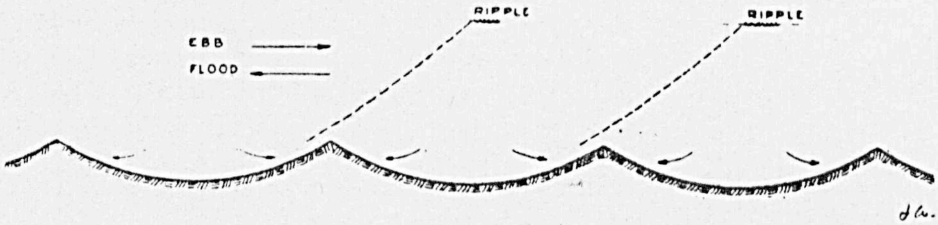

Fig. 7.

Trochoidal sand-waves.
Ondulations de sable trochoïdales.

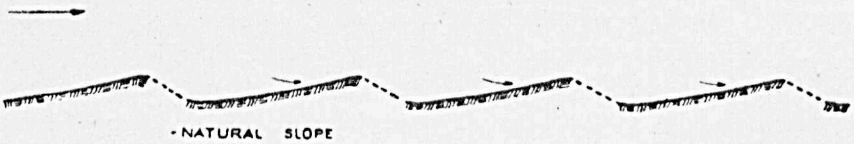

Fig. 8.

Progressive sand-waves.
Ondulations de sable progressives.

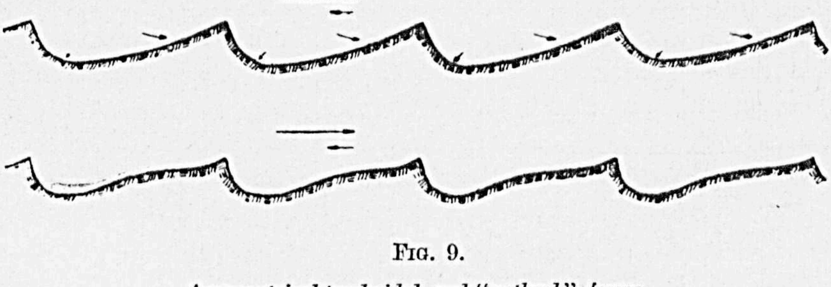

Fig. 9.

Asymmetrical-trochoidal and "catback" forms.
Formes asymétriques trochoïdales et en "dos de chat".

It is a well-kown fact that soldiers are not allowed to march in step over a bridge. The bridge might collapse, not because of the weight of the soldiers, but because of the rhythm. A running machine may be ruined because of the same rhythmic movement; in short, a small force acting with the right period at the right spot, may result in unexpected and almost incalculable phenomena.

A good example of this is a road whose surface has started waving because of the traffic. Once I passed along such a road. The lengths of the waves might have been about 1 yard, the height perhaps no more than 1 inch or less; yet it was impossible to drive over it at more than a few miles per hour. The stress this road put on the car and its engine was tremendous. The wheels jumped from the tops into midway up the following upward slope and this must have added to the effective height of the road waves. Once started, the waves grow higher and higher until some other force or the same force on another place, stops their growth or entirely eliminates them (Fig. 6). Generally the forces grow as the waves grow and vice versa.

This *process of self enforcement* is one of the characteristic features in our "enchanted castle" where cause and effect "make a wild dance".

DIFFERENT WAVE FORMS.

The profiles of the submarine sand dunes may be divided into two different main classes; the symmetrical or trochoidal, and the asymmetrical or progressive waves. Between these two, other characteristic wave forms may be distinguished.

The forces belonging to the symmetrical or trochoidal form (see Fig. 7) are akin to those of the waving road. The ebb falls in from one side, the flood from the other and the result is a high wave with a sharp crest. The upward movement of the water produces a "strong ripple" on the surface.

The progressive sand wave (see Fig. 8) has, in its purest form (current from one direction only), a steep downcurrent slope. The sand grains are pushed up the upcurrent slope and drop by their own weight after having passed the crest. Sometimes they simply tumble over it. The downcurrent slope settles steadily, assuming the natural slope of sand. Often there is an eddy behind the crest which helps to make the sand grains fall.

The "asymmetrical trochoidal" form and the "catback" form may be understood by assuming ebb and flow forces of unequal strength (see Fig. 9).

The latter form is especially interesting because of its resemblance to G. H. DARWIN's progressive tidal waves. The tops remain very sharp but the valleys are well rounded. Examples of these bottom waves may be seen in Figures 10 to 15.

Figure 10 shows a bottom profile of the North Sea off Ymuiden. The direction of progress is toward the Dutch coast but this is only local. Whether such a direction of wave progress is an indication of a general sand-drift in this same direction is not yet known.

Figure 11 shows symmetrical waves on the Fairy Bank. Towards the right of the figure asymmetrical (catback) forms are shown. These occur also on the right of Figure 10.

Figure 12 is a registration of the top of the sand-bank off Boulogne, called the "Baas". Though the progressive wave type was very pronounced, quite another type of wave was found on the same spot later.

Figures 13, 14 and 15 show profiles of three of the Flemish banks. Often the tops are highest on the steep "cut-off" side. The remarkable profile of Figure 15 (West Hinder) is an exception.

The regularity of these wave forms is well shown in the above figures. In the third dimension, however, the regularity is often not so marked as one might expect. The forms are mostly intricate, though subject to some law. Only in one case were the regular long crested sand waves met on the back of a sandbank, as indicated in Figure 16.

THE SUBMARINE DESERT IN THE NORTH SEA: RESEMBLANCE TO LIBYAN DUNES.

In studying these remarkable forms more closely, much may be learned from the study of desert dunes. While passing through the southern part of the North Sea with the echo machine running, one is strongly reminded of passing over a submarine desert.

The difference is, that in most deserts the winds may blow from different directions, whereas in the sea the currents are more regular. So the sand-forms in the sea may be found to conform to laws more than those in the desert, but finely shaped barchans (*) (results of currents of one direction only) are not likely to be found in the sea.

The southern portion of the North Sea possesses a couple of long sand-banks which have a fan shaped position. These are also to be found in the Channel (Varne, Ridge, Baas etc.).

Many people have been wondering how these banks came there and why they remain more or less stationary (see Fig. 17). When making a study of them it is found that their profiles are more or less triangular in shape (sometimes a catback shape) whereas their longitudinal section is bow-like (see Fig. 18). They appear to be heaps of sand lying on a fairly flat pebble bottom which is more or less swept clear of sand. The lengths of these are sometimes 30 kilometres (16 n.miles) or more (The Falls 60 km., 32.5 n.miles). The tops are mostly covered with sand waves of moderate height, whereas the banks themselves may reach heights of about 20 or 40 metres (65 or 130 ft.) above the surface of the deeps. One gets the impression that nearly all the available sand is stored in the sand-banks. This is not so remarkable because the only lee places are to be found behind the banks.

When going further north the sand masses grow larger so that the hard layer of pebbles is no longer swept clean but there is no sharp separation of these two regions. Near Dover practically no sand at all is to be found except in the banks; but farther north sand becomes profuse.

(*) Dr. Ladislas KADAR states, in *The Geographical Journal*, Vol. LXXXIII, No. 6, June 1934, that "the barchan is a crescent or horseshoe-shaped dune, the windward side of which is sloping and convex, the lee side concave with the sand standing at the maximum slope". - I.H.B.

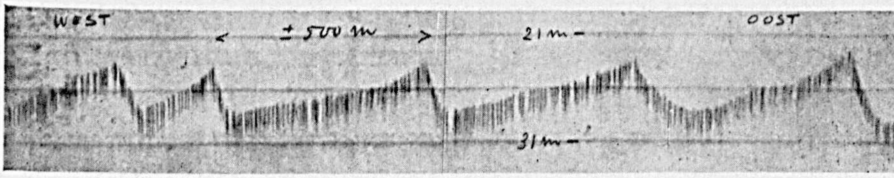

Fig. 10.

Bottom of the North Sea near Ymuiden (progressive type).
Fond de la Mer du Nord au large d'Ymuiden (type progressif).

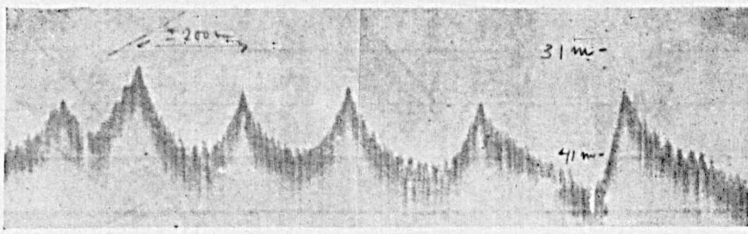

Fig. 11.

Symmetrical waves on the Fairy Bank.
Ondulations symétriques sur le Fairy Bank.

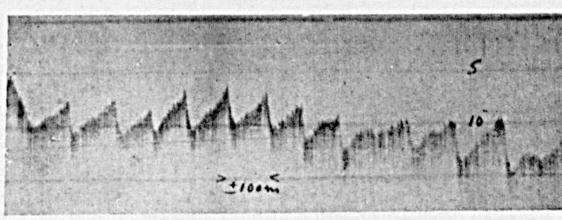

Fig. 12.

Progressive waves at the " Baas" near Boulogne.
Ondulations progressives sur le "Baas" près de Boulogne.

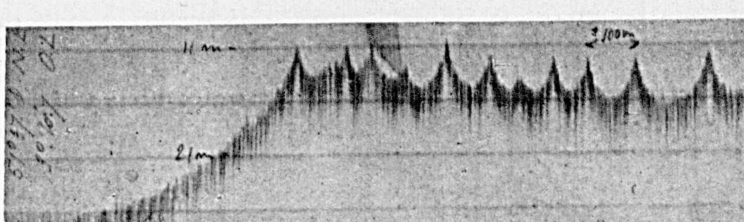

Fig. 13.

Western side of the Rabsbank.
Côté Ouest du Rabsbank.

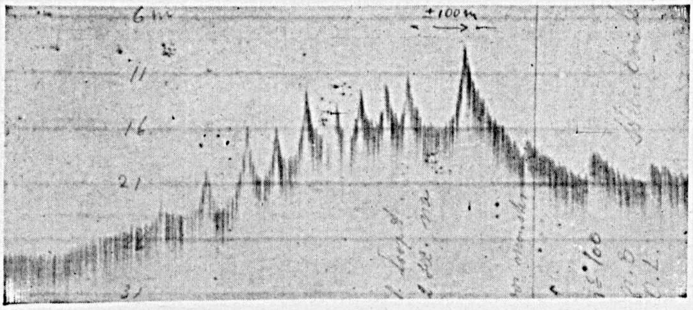

Fig. 14.
Profile of the Steenbank.
Profil du Steenbank.

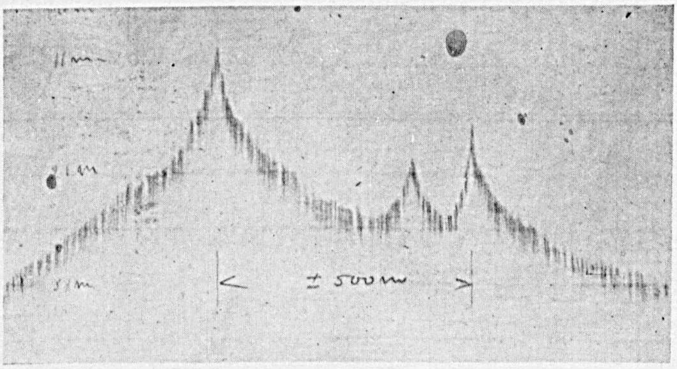

Fig. 15.
Profile of the West Hinder.
Profil du West-Hinder.

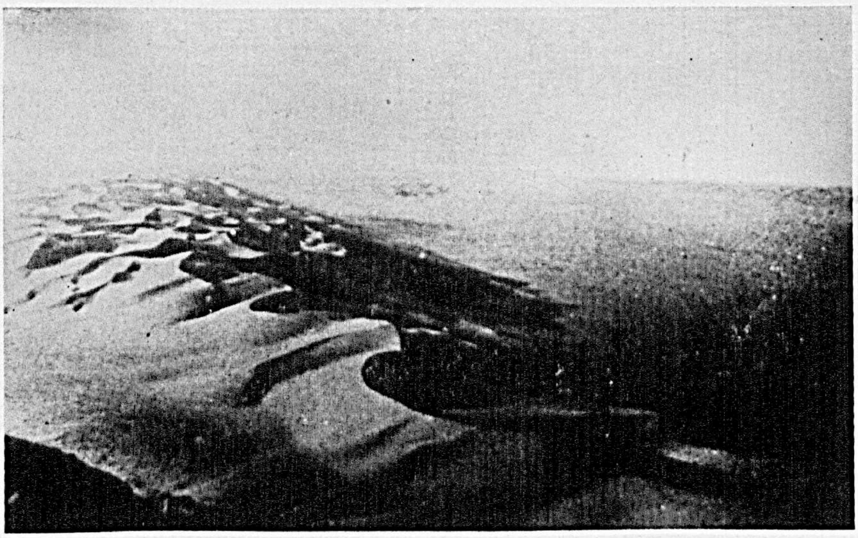

Fig. 19.
Libyan dune ; photograph by Kàdàr.
Dunes de Libye d'après une photographie de Kàdòr.

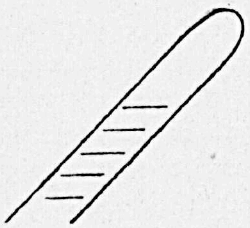

Fig. 16.

Long crested sand-waves on the Ridge.

Longues ondulations sablonneuses à crêtes, sur le Ridge.

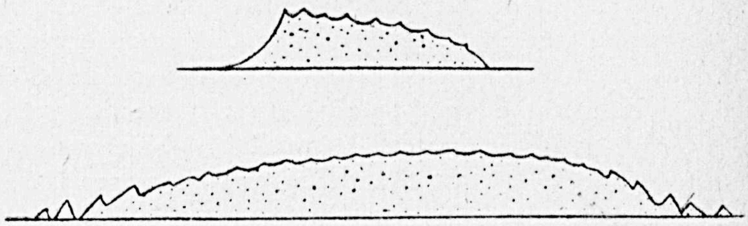

Fig. 18.

General form of the sandbanks.

Forme générale des bancs de sable.

Fig. 17.

Sandbanks in the southern part of the North Sea.

Bancs de sable dans la partie Sud de la Mer du Nord.

Either in the desert or in the sea it may be taken to be true that, in places where a sufficient amount of sand is available, regular sand waves may be produced (complicated when the currents change their direction, simple when they do not) ; and that in places where the hard layer is swept clean and where little sand is available, barchans or other remarkable shapes are found. When an alternating current moves the sand from north to south and back again later, no barchan can be formed but instead a cigar shaped "Libyan dune" may appear.

This name was introduced by Dr. Ladislas KADAR in his article of June 1934, *A study of the sand sea in the Libyan desert* (*Geographical Journal*). Others call them "seif" dunes. Their characteristic feature is that they are parallel to the direction of the prevailing winds. Dr. KADAR describes these dunes as follows: "The plan is of an oval shape (Fig. 18) which is more slender the longer the dunes. The transverse section is usually an isosceles triangle and the longitudinal section has the form of an elongated bow mildly sloping on the windward side and rather steep to leeward. Such uninterrupted forms, however, are rare. Small barchans (dunes) are not infrequently found on the top of these dunes and they make the silhouette resemble waves. The length of these dunes may extend from a couple of hundred metres to several kilometres. The longest I could trace to its end measured 140 kilometres (75 n.miles), their height varies with the length, but is generally about 30 or 40 metres (100 or 130 ft.). The regular Libyan dunes sit close on the soil and their edges are sharply distinguished through their yellow sand from the black-brown pebbles of the soil. Between the dunes the soil is less bare for several kilometres".

Except for a few items this description might be suitable for the southern banks of the North Sea also. One of these exceptions is that the cross sections of the latter are not isosceles triangles, but KADAR writes that with a change of wind direction these profiles change accordingly.

Figure 19 shows one of KADAR's photographs of a Libyan dune. It may be seen that one side of the dune is steep but the top is covered with irregular forms. The cross section is, therefore, not an isosceles triangle but resembles perfectly that of a North Sea sandbank. The figure might serve also for one of the submarine sand-banks as well as for a Libyan dune.

It is interesting to note that KADAR lays stress on the fact that these Libyan dunes are parallel to the winds and that 63 % of the winds in the Libyan desert have a northerly direction and 14 % are southerly. These almost resemble the alternating currents of the North Sea (though not quite) and it may be that this alternation is the reason for the origin and maintenance of both Libyan dunes and the sand-banks.

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