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THE FREQUENCY DISTRIBUTION OF THE CURRENT SPEED AT THE NETHERLANDS LIGHTVESSELS AND ITS POSSIBLE INFLUENCE ON THE COMPOSITION OF SEDIMENTS IN THE SOUTHERN NORTH SEA

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ABSTRACT

Frequency distributions of current velocities were determined from the Netherlands lightvessels in the North Sea. Near the lightvessel "Texel" the frequency distribution shows a considerable degree of symmetry. By means of a simple model for transport of sediment the consequences of such a frequency distribution for the transport of particles of different sizes are investigated. There appears to be a distinct maximum in the transporting velocity near the lightvessel "Texel" for a certain particle size. This particle size is estimated to be about 300 μ, a value that corresponds with a relative poverty of particles between 200 μ and 300 μ "downstream" of the position of the lightvessel.

Questions regarding the maximum velocity of the current which may be expected in the North Sea induced a statistical study of a 10 year series of current data from the Netherlands lightvessels. The results of this study have been published elsewhere (O t t o, 1970). Some particularities of the frequency distributions of the velocities induced a brief investigation of the possible sedimentological implications of these results.

Since the currents at these lightvessels are alternating in first approximation, the current data have been simply split up in two categories: "flood" and "ebb". The frequency distributions of the current velocity for the "flood" and "ebb" current separately, are given in fig. 1. The mean "flood" and "ebb" directions for the four lightvessels are as follows:

	"flood" current	"ebb" current
Noord-Hinder (51° 39′N 2° 34′E)	40°	220°
Goeree (51° 56′N 3° 40′E)	44°	224°
Texel (53° 01′N 4° 22′E)	32°	212°
Terschellingerbank (53° 29′N 5° 08′E)	76°	256°

The current data consist of hourly averages of the velocity, measured with a "vertical log" at 6 m depth (C a r r u t h e r s, 1935). The period 1954 till 1963 (inclusive) has been used.

The frequency distribution f (V) of the velocities shows a considerable degree of asymmetry for the "Texel" data. On the other hand the results of the other lightvessels are not far from symmetrical for the ebb and flood currents.

Now we may ask what the consequences might be of such an asymmetrical velocity distribution for the transport of sediment. In the following this aspect will be discussed. We consider a simple model as follows.

We assume, first, that there exists a fixed ratio between the speed of the current near the bottom, V (b), and the current speed measured at 6 metres depth. Then we assume that sediment particles of a given size are stirred up by a current near the bottom with a speed V_g (b), are transported with a speed proportional to V (b) as long as V (b) exceeds V_g (b) and settle as soon as V (b) decreases below V_g (b). Then the mean transporting velocity of the particles for a speed at the depth of observation $V \geqslant V_g$ (where V_g is the current speed at observation depth

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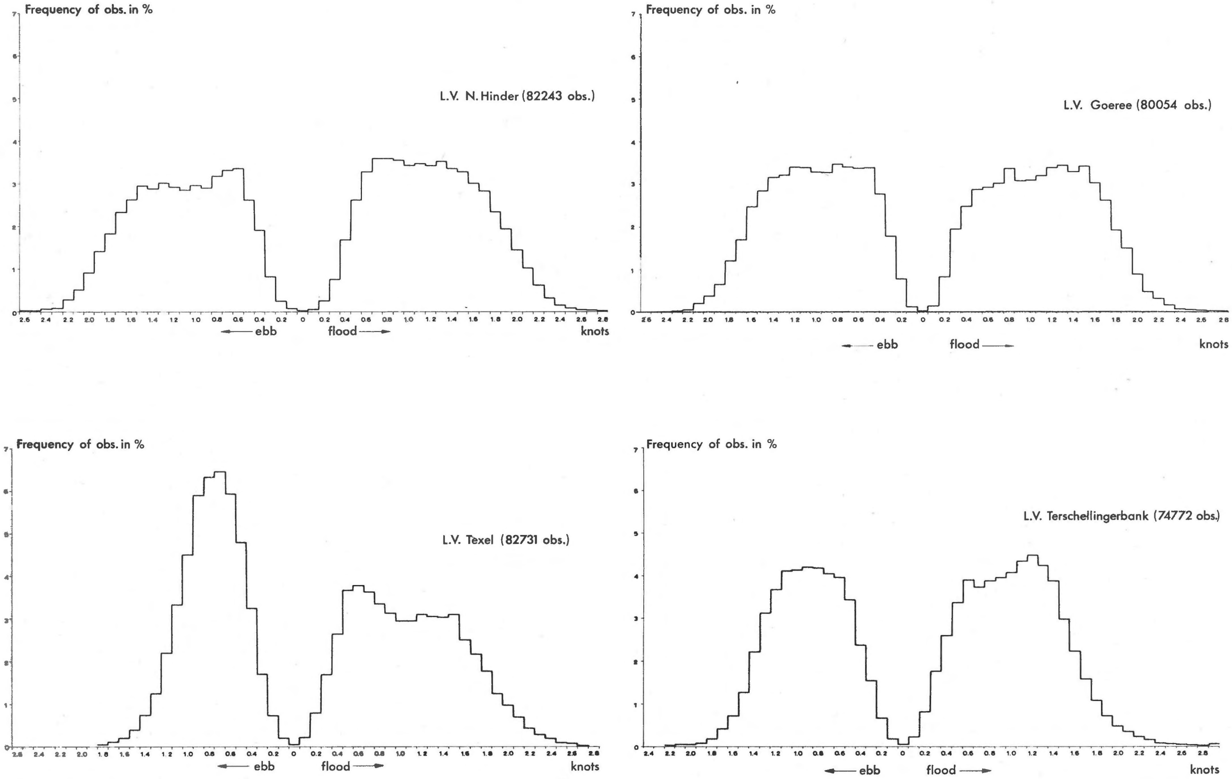

Fig. 1
a. Frequency distribution of current velocity for Noord-Hinder L.V.
b. Frequency distribution of current velocity for Goeree L.V.
c. Frequency distribution of current velocity for Texel L.V.
d. Frequency distribution of current velocity for Terschellingerbank L.V.

corresponding with V_g (b)) is proportional to V. The proportionality-factor a depends on the units chosen, on the thickness of the sediment carrying layer, and on the ratio of the mean velocity of this layer (averaged according to the sediment concentration of the different sub-layers) and the velocity at 6 metres. Here we assume a independent of time and of the velocity V. Obviously the effect of the time-lag for stirring-up and settling of the particles has been neglected in these suppositions. If this time-lag is large, V_g (b') may not coincide with the true initial entrainment velocity of the particles. For the purpose of our argument, which deals with statistics of current velocities instead of the variation of the velocity with time this difference is not relevant.

Considering transport in the "flood" direction as positive, and in the "ebb" direction as negative, the mean transporting velocity of particles with a critical stirring-up velocity V_g can now be written as

$$T = a \int_{V_g}^{\infty} \{ f(V)_{Flood} - f(V)_{Ebb} \} V dV$$

The values of T/a for different values of V_g have been calculated, using the frequency distributions shown in fig. 1. The results are given in fig. 2. The value of T/a for $V_g = 0$ gives an approximation of the average residual current at 6 metres depth. (It has to be mentioned that this is only an approximative residual current as the currents here are considered as alternating, while in reality the current vector shows small directional variations).

The most conspicuous feature of fig. 2 is the peak for T/a at the lightvessel Texel for $V_g = 1.2$ knot. Unless the (unknown) proportionality factor a is rapidly decreasing with the particle size, this means that relatively coarse particles (with V_g, say 1.2 knot) are transported faster than small-grained particles (with corresponding lower V_g-values) and that even

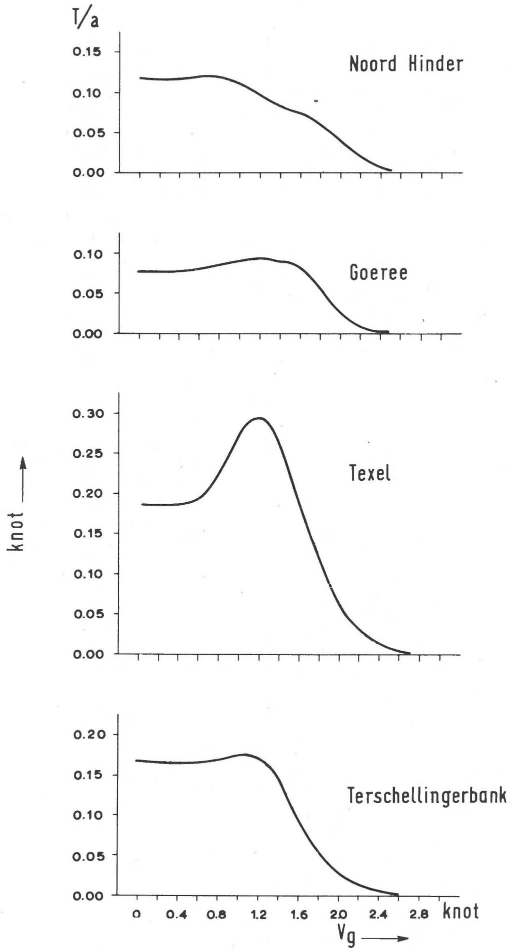

Fig. 2
Transporting velocity of particles, stirred up at different current velocities.

this transporting velocity may surpass the velocity of the residual current. A similar, be it less conspicious, behaviour is found for Goeree L.V.

It is conceivable that this effect will have its consequences for the size distribution of the sediment particles. If the character of the T/*a* curves as found for the lightvessels is representative for larger areas around the lightvessels, irrespective of the absolute values, the following may be said about the transport of sediment.

Between Noord Hinder and Goeree we may expect a impoverishment of coarser particles ($V_g > 0.6$ knot) relative to the smaller particles, because of the lower T/*a* values at Noord Hinder and the higher values at Goeree. This effect will be much more pronounced in the area between Goeree and Texel, while between Texel and Terschellingerbank, on the contrary, there is a relative enrichment of coarser particles.

Of course an equilibrium will be established, in which the lower concentration of coarser particles "upstream" of Goeree and Texel will be such that the product of concentration and transporting velocity, giving the transport, will be constant. This means a relatively low concentration of coarse particles in the area south of Texel, and a higher concentration between Texel and Terschellingerbank.

Now we note that the size distribution of the sediment particles at sea along the Netherlands coast is in agreement with these deductions. According to Eisma (1968) the sediments to the south of Texel are especially poor in particles of the size fraction between 200 μ and 300 μ with respect to the sediments more to the north.

The question now arises whether this size distribution is in accordance with the variation of transporting velocity with V_g.

Bonnefille (1963) has combined the results of a number of studies on the initial entrainment of sediment particles. He gives graphs of the relation between the vertically averaged velocity of a steady flow for different water depths. His results have been applied to the present study using a water depth between 20 m and 30 m (the depths near Texel L.V.). The maximal transporting velocity occurs at a V_g-value of 1.2 knot or 0.6 m/sec, which according to an empirically derived relation of van Veen (1936, 1937) corresponds with a vertical mean velocity of about 0.55 m/sec. In the relation given by Bonnefille this is the entraining velocity of sand grains with a diameter between 100 and 50 μ.

This figure does not agree with the observed difference of the size distributions. However, Bagnold (1963) has pointed out that ripple formation leads to reduced values of the initial entrainment velocity for grain diameters $< 700\,\mu$. This effect will shift the grain diameter corresponding to a V_g value of 1.2 knot from 50 μ to about 300 μ. This makes the agreement with the observed size distributions better than could be expected in view of the simplifications that have been used. It is also realised that other effects, such as the influence of waves, should be considered for a full explanation of the sedimentological properties of the North Sea bottom. The mechanism of transport of sediment therefore should be investigated with more information on ambient conditions than current statistics alone. We may conclude, however, that the special character of the variations of the current (tidal and residual current), reflected in the frequency distribution of the velocities, should be taken into consideration in the study of the size distribution of the sediments in the southern North Sea.

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