CHAPTER 103

STABILITY OF TIDAL CHANNELS DEPENDENT ON RIVER IMPROVEMENT

by

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1. Abstract

Many authors have dealt with the migration of sand in front of the German coast of the North Sea. Especially the movement of sand-banks and deep channels in the Weser-estuary was subject-matter of several investigations with different results.

Thorough investigations of selected cross-sections point out, that the movement goes on in some regions. The important shipping channel however has obtained a certain stability during the last 3o - 4o years, because the migration of sand occurs otherwise than in former days.

This phenomenon coincides with the extensive and decisive river improvement measures in the inner part of the Weser-estuary.

Current measurements in the investigation area demonstrate, that concentrated tidal currents in the deep channels guarantee a sufficient clearance for shipping purpose.

It seems to be sure, that for the present no essential shifting of the main channel calls for important measures in the field of shipping, dredging and building of sea-marks.

2. Introduction

The estuaries of the navigable rivers in the Federal Republic of Germany flowing to the North Sea are deep cutting bights with fine sand bottoms.

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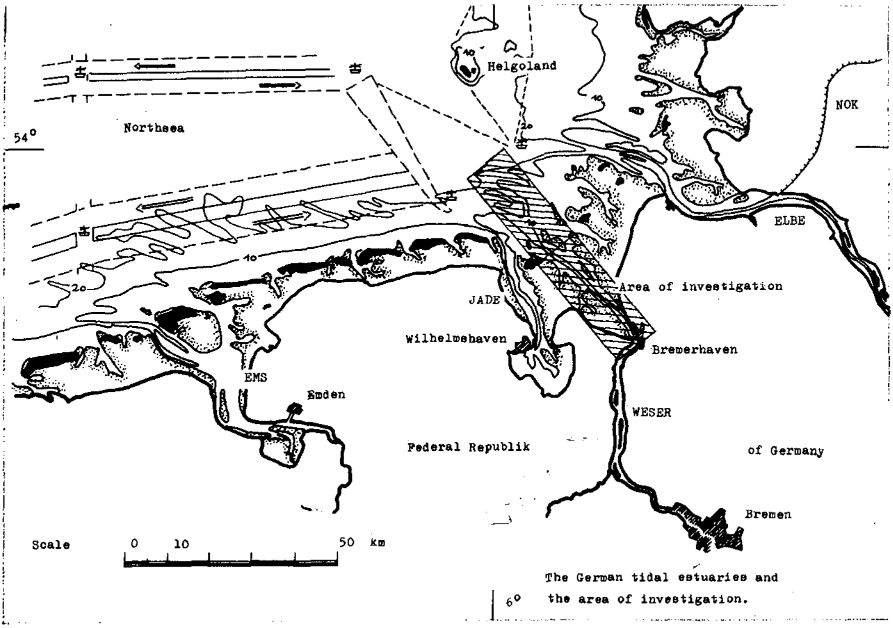


Fig. 1

On Fig. 1 one can see a part of the German bight with the large tidal rivers Ems, Jade, Weser and Elbe. The investigation area, which is to be spoken about, lies inside of the Weser-estuary. A few words of explanation to the situation:

The Outer Weser has a length of about 6o km, extending from the open sea til Bremerhaven, and important port of transshipment of ore, cars, fruit, mixed cargo an with a most important container terminal. About 65 km upstreams lies the city of Bremen with its also important harbour at the lower Weser.

Between Bremerhaven and Bremen the harbours of Nordenham and Brake are situated. Ships with a draught up to 45 feet can go to Bremerhaven, those with a draught up to 35 feet can go til Bremen.

The atlantic tidal wave penetrates in a wide-spread front into the North Sea and it has its largest tidal range on the right side, i.e. at the Scottish coast. The right branch proceeds very fast into southern direction whereas the left branch remains behind. Arriving at the German coast the tidal wave turns aside to the east and now follows the coast-line counter clockwise. The predominant tidal currents go in the same direction in the flood tide, the currents in the ebb-tide have a predominant direction from east to west. Caused by reflection and the deflecting power of the rotation of the earth there are some rotational tides in the North Sea which influence the directions of the tidal currents too. The tidal waves penetrate into the estuaries and are reflected, absorbed and deformed dependent on the morphology of the estuary. But those phenomenons are well known.

3. Morphological changes

The evident north-east directing migration of sand in front of the German coast effected by dominant waves and currents carries material from the North Sea Reservoir and eroded sand from the East Friesian Islands. This material crosses the estuaries and causes permanent shift of the channels and sand banks in the reef region.

On Fig. 2 one can see the migration of channels and sandbanks in two cross-sections in the Outer Weser from 191o til 1975.
The two important tidal and navigable channels with depths down to 2o sometimes 25 m are the "Neue Weser" and the "Alte Weser". The surrounding sand-banks come up to a height of 2.5 m beneath the water surface and the other less important channels are not directly connected with the river - bed of the Weser. The drawing shows the movement of the center or the axis of gravity of the most important banks and channels referring to a fixed line.

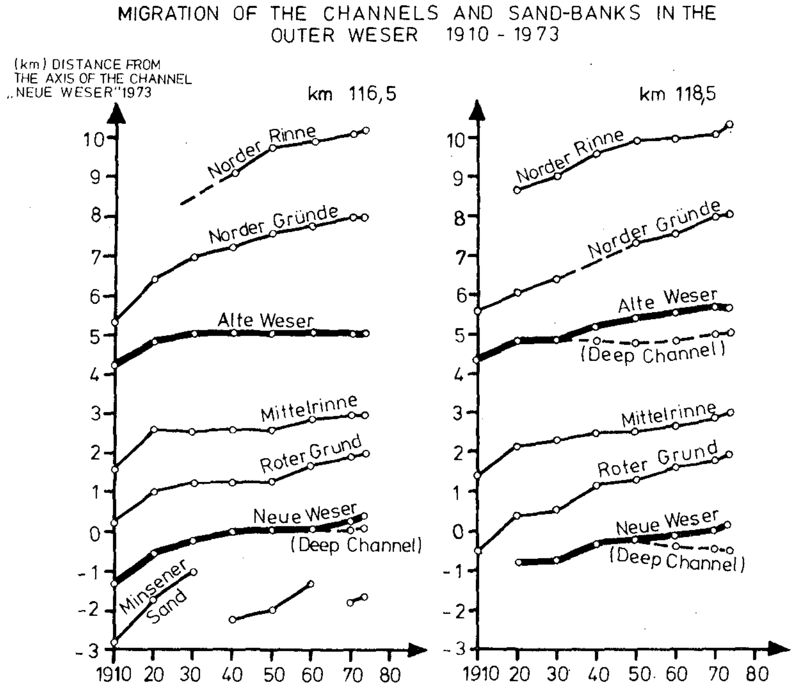


Fig. 2

The movement is also to be seen on a simplified graph in Fig. 3

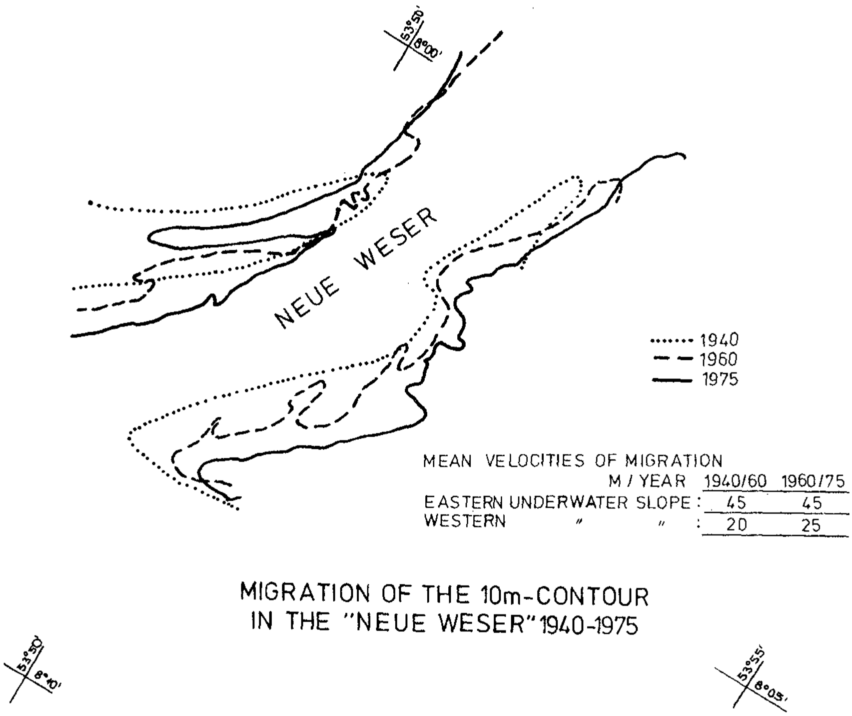


Fig. 3

You see the contours of the 1o - m - line in the "Neue Weser" in the states of 194o, 196o and 1975. The mean velocity of migration is

on the west side: 2o m / year
on the east side: ~ 6o m / year on an average.

Because of this provable migration the navigable channels, the buoys and the pertinent sea-marks (i.e. light houses, directional beacons etc.) had to be transferred or given up several times in the past.

The laws and regularities of this migration in the reef region have been discussed by several authors until now (Ref. 2,6,7). And there were different results of investigations:

Some of them discovered, that it takes a sand-bank 6o - 7o years to cover the distance to the next sand-bank. Plate (Ref. 6) writes about the "return of similar forms" in the reef region. Göhren (Ref. 2) presents an extensive classification of all these statements and points out a "return of similar states" every 11o - 12o years.

There are maps of the Outer Weser since 1859, which are sufficiently exact for an investigation of the migration in the reef region. Since 191o the maps are so exact that you can follow the motion of single cross-sections. In an extensive research of the morphological changes from that time until now it was found out, that the migration of sand in the decisive regions happens otherwise today than in former days. This finding seems to be of an eminent importance for navigation, building of sea-marks and dredging.

In former days the penetration of flood in the reef region was delayed by a labyrinth of shallow channels and sandbanks, spread over the whole estuary. The sand migrating from west to east crossed the estuary in large sandbanks and underwater-dunes, the height of which was often only 2 - 3 m beneath the water surface. This undulatory motion seemed to lead to a recurrence of similar states in morphology in a period of 11o - 12o years. This regularity still required a development, which was undisturbed by all artificial influences.

After a thorough investigation of up to 8 cross-sections in the reef-region one can see, that the migration of large sand-banks nearly stops in parts of the cross-sections between 192o and 193o. In Fig. 2 it is shown, that especially in the "Neue Weser" and in the "Alte Weser" this effect is evident. The increase of the graph of "Neue Weser" and "Alte Weser" comes to zero, while in the time between 1859 and 192o it was nearly steady. The results of the other cross-sections, show the same trend.

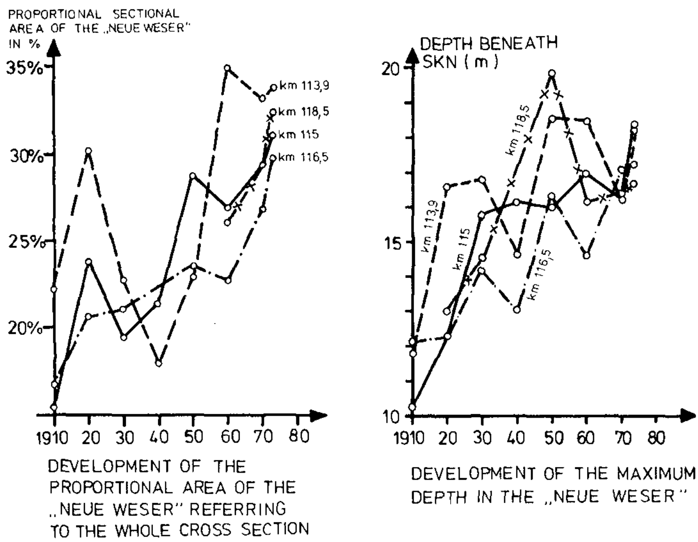
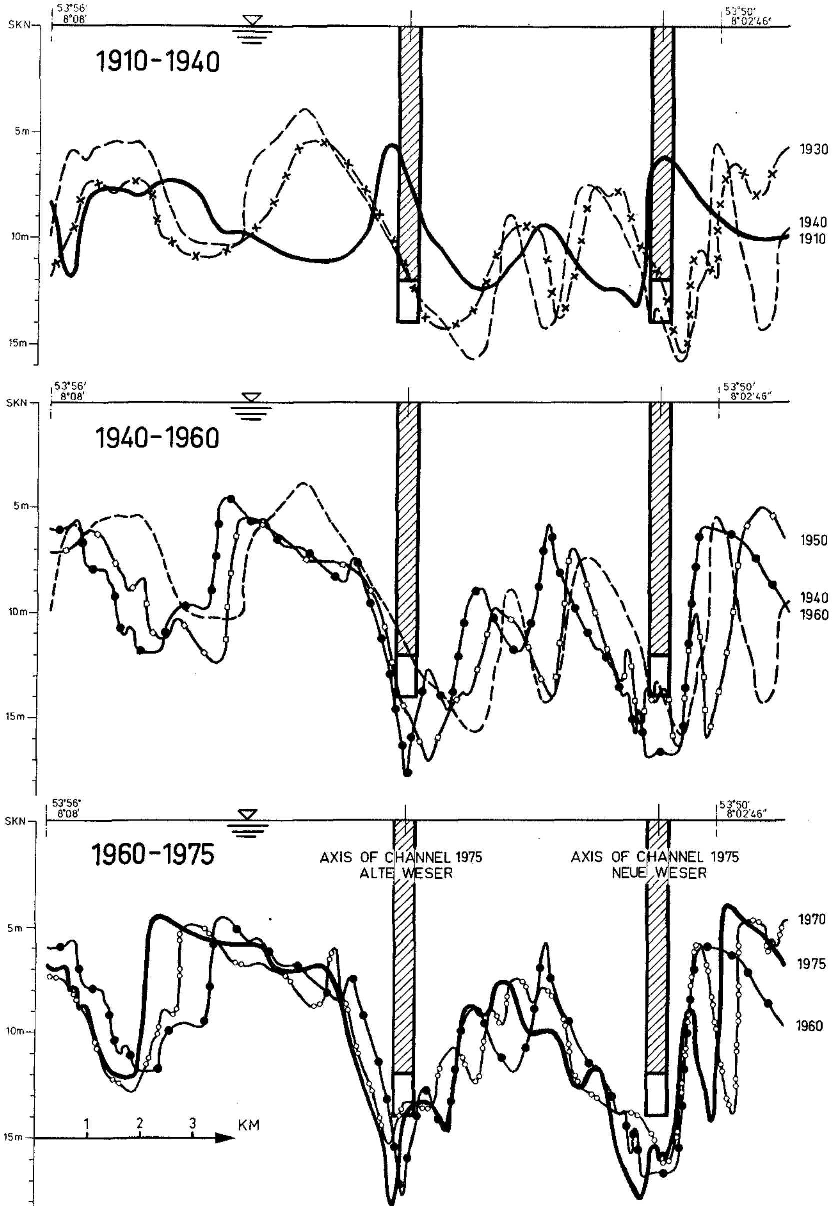


Fig. 4

Fig. 4 presents the development of the channel "Neue Weser" (NW). The left part indicates, that the proportional sectional area of the NW has been growing since 193o from 21 % to 33 % on an average. The development of the maximum depth in the NW shows an increasing tendency with deviations. That ist not so obvious in the AW.

A careful study of the development of the cross sections in their chronological sequence gave the picture, which is to be explained in Fig. 5 in one cross-section, though it is to be found in nearly all of the analysed ones: Before 192o/3o the large sandbanks cross the estuary as a whole, leading to a permanent alteration of the navigable channels and the banks between them. But then there is a change in behaviour. The underwater - slopes moving from the west become steeper, a small underwater dune is



ALTERATION OF THE CROSS-SECTION KM 115 FROM 1910-1975

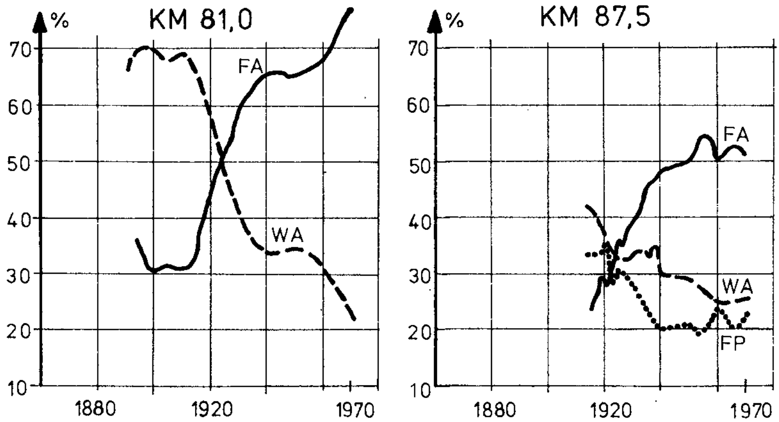
Fig. 5

separated from its origion bank and moves with increasing loss of size down to the bottom of the channel NW where it isn't to be found again.

Where does this behaviour come from?

Already in 1935 it could be proved, that the shift in the reef region had affected the conditions of the shipping channel of the inner part of the Outer Weser. Yet a mutual influence between inner and outer region could not be detected at that time.

Within the period of 192o - 193o the large and important improvement measures and dredgings in the middle section of the Outer Weser were carried out and influenced the hydraulic conditions in a good manner. Misplacing of the unfortunate shipping channel into a better position, building of a lot of groynes and training walls and dredging led to a more undelayed penetration of the tidal wave and affected the concentration of tidal currents in a positive way. The further morphological development in the Outer Weser showed, that the river structures in connexion with dredging operations had fully achieved their effect. An extensive study of these facts was carried out in 197o/1972 and was lectured on the 14th CEC in Kopenhagen 1974. It showed that most of these hydraulic and morphological developments began soon after those important improvement measures. (Ref. 5)



DEVELOPMENT OF THE PROPORTIONAL SECTIONAL AREAS F_0 OF THE CHANNELS "FEDDERWARDER ARM" (FA) "WURSTER ARM" (WA) AND "FEDDERWARDER PRIEL" (FP)

Fig. 6

The maximum current velocities grew in parts of the river with 3o %. The distribution of the quantity of flow in those parts of the river, which are divided into two branches, is of a great importance for the hydraulic behaviour. The development of this distribution was also satisfactory, as Fig. 6 shows in one example. Besides the whole river up to Bremen was deepened from 189o til now (12 m beneath SKN* in the Outer Weser). The mean tidal range in the Lower Weser grew from o.25 m to 3.5 m.

4. Current measurements

Though there was no opportunity to compare nowadays measurements with elder ones there were carried out a lot of measurements of current velocity and direction in the whole area to support the theory of nowadays behaviour of the reef region. The therefore required instruments are developed especially for an application in shallow water in Western Germany. All current meters were installed about 1,5 m over the bottom to record the currents near the bottom. The evaluation method for the measured values which are photographed by a camera is well - known (Ref. 3). During the interpretation great importance was attached to the ratio

$$\frac{Ve\ max}{V_f\ max} \quad \text{and} \quad \frac{SVe}{SV_f}$$

and the maximum and resulting currents (Fig. 7,8)

$SV_{e,f}$ = amount of the vector $Fe,_f$

$$V_{e,f} = \int_{Ke}^{Kf} v_i dt$$

The interpretation of all measured values gives the following characteristics of currents in the investigation area:

The maximum currents are situated in the deep channels, especially at the west side of the "Neue Weser". The intensity of the currents, i. e. the amount of velocity with regard to it's time of influence, has it's maximum values in the same region. The time of less transportation of sand ($v \leq 25$ - 3o cm/s) is very short here (1 hour) and is growing with decreasing distance to the east side of the investigation area. (3.5 hours)

* SKN = the German word "Seekartennull" = mean low water of a spring tide

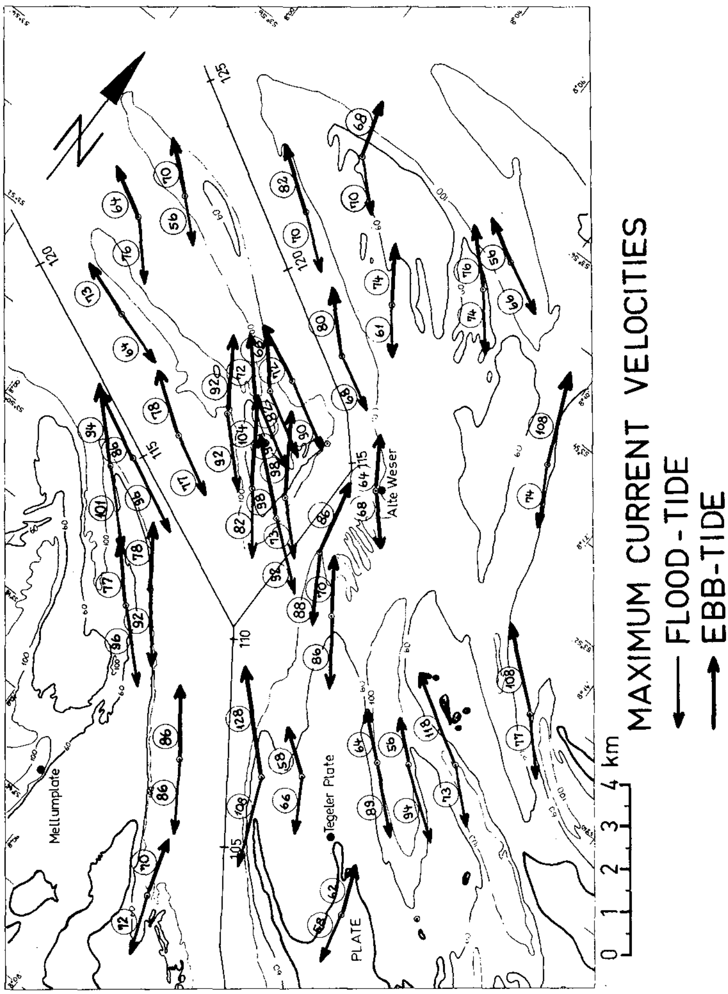

MAXIMUM CURRENT VELOCITIES
FLOOD-TIDE
EBB-TIDE
Mellumplate
Tegeler Plate
Alte Weser
PLATE
0 1 2 3 4 km

Fig. 7

The directions of the currents, which are affected by wind and rotational tides demonstrate the possible transportation of sand.

The resulting current vector

$$V = \int_{Ke}^{Ke} v_i \, dt$$

shows the displacement of a water particle during one tide. One can recognize, that the directions of the resulting vectors only in the "Neue Weser" (Fig. 8) correspond with the direction of the channel axis. In the other regions, especially on the sand-banks, there is an enormous displacement to the North -East. The dependence of the resulting vectors' directions on wind-affected tides is very important.

The ratio $\frac{ve\ max}{v_f\ max}$ and

$\frac{SVe}{SV_f}$ finally shows, that there is a

predominance of flood currents in the "Neue Weser" and of ebb-currents in the "Alte Weser".

There is every reason to believe that the migration of sand on the sea-floor is proportional to the fourth power of the current velocities (Ref. 1,4). Therefore the evaluation method includes the computation of the values.

$$\sum_{D_f} \overline{(v_f - vgr) \cdot v_f^3} \quad \text{and} \quad \sum_{D_e} \overline{(v_e - v_{gr})\, v_e^3}$$

v_{gr} = limiting value of velocity for the start of sand-transportation (~ 25 cm/s)

$D_{f,e}$ = period of flood/ebb - current

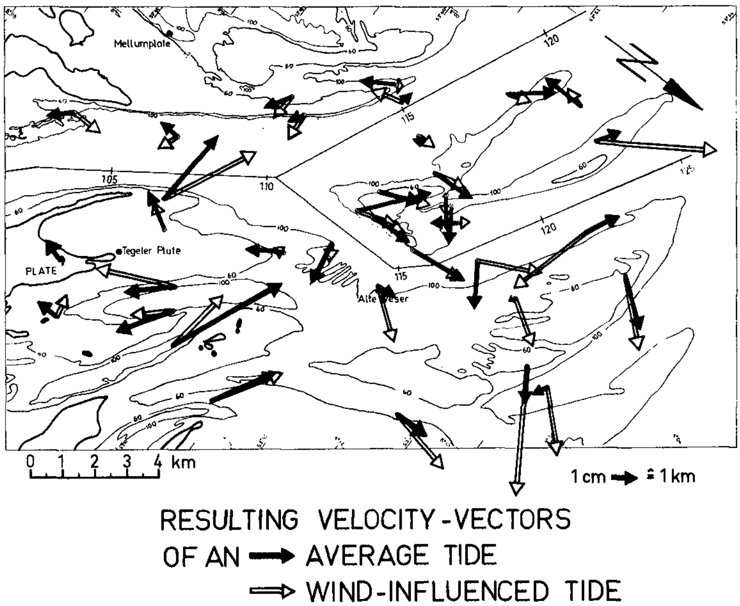

Mellumplate
Tegeler Plate
PLATE
Alte Weser
0 1 2 3 4 km
1 cm ≙ 1 km
RESULTING VELOCITY-VECTORS
OF AN AVERAGE TIDE
WIND-INFLUENCED TIDE

Fig. 8

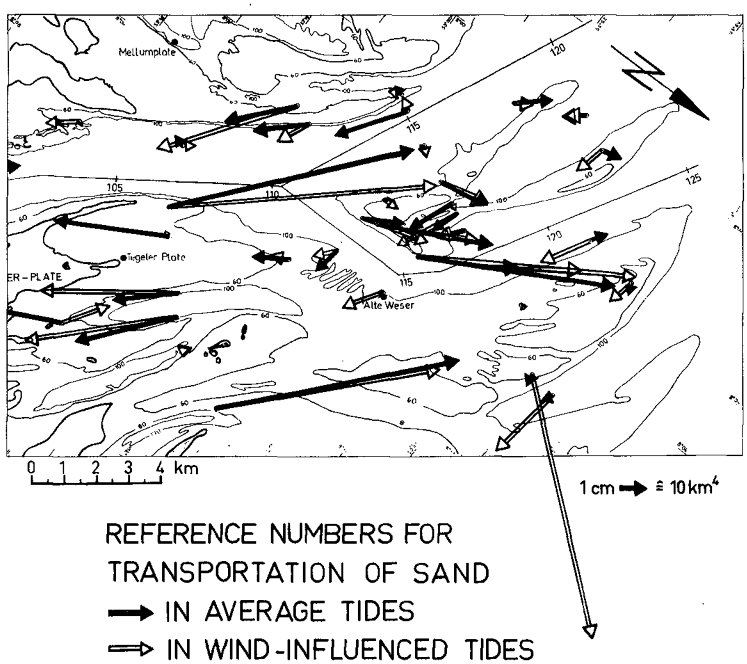

Mellumplate
Tegeler Plate
ER-PLATE
Alte Weser
0 1 2 3 4 km
1 cm ≙ 10 km⁴
REFERENCE NUMBERS FOR
TRANSPORTATION OF SAND
IN AVERAGE TIDES
IN WIND-INFLUENCED TIDES

Fig. 9 shows the resulting reference numbers of sand-transportation which give another indication for the direction and amount of the movement of sand.

5. Conclusions

Comparing the results of the current measurements with the view of morphological changes you see the following proceedings in the reef area:

Effected by wave motion and tidal currents the sand is eroded at the steep underwater slopes of the NW and AW and crosses the deep channels as giant ripples, which seldom narrow down the required depth. On the back of the extended sand-banks the sand moves on zig-zag course with a resulting North-East direction. The migration in little ripples occurs there as well as the motion of larger underwater-dunes. At some places the underwater slopes come up to a speed of 6o m a year. The average speed is 2o to 3o m a year. Both of the deep channels are changing their form; the crucial deep channel for shipping-especially in the NW is nearly steady however. Beside the tidal currents wave motion has especially on the sand banks an essential part in migration of sand. Therefore the direction of migration depends on the respective wind direction too. It will be the task for the next years, to filter the quantitative part of wave motion in the interaction between waves and currents by measuring.

As a by-product of the investigations the cover-line of the same cross-section in different years (Fig. 5) gives a clue to the kind of material (sedimented or undisturbed) which can be found at dredging.

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