The Sediments and the Transport of Debris in the Graadyb Tidal Area.

By Kaj Hansen.

I.
The sediments.

The Graadyb between the island Fanø and the peninsula Skallingen is the fairway to Esbjerg and the northernmost tidal channel in the Danish Waddensea. The greater part of its tidal area is the bay Ho Bugt with the two channels Hobo Dyb to the west and Hjerting Dyb to the cast of the island Langli. Between Fanø and the Jutish coast the channel Havnedyb runs southward to the Knudedyb Tidal Area.

The Graadyb is about 1 km wide between Skallingen and Søren Jessens Sand. The depth is generally about 11 m with a few deeper depressions going down to 17 m below sea level. In the North Sea immidiate to the west of Graadyb is a submerse sand bar where the depths are only 4—5 m, and an artificial channel has therefore steady to be kept open by dredging, out of regard to the traffic to the port of Esbjerg. The depths in this channel are 7—8 m.

Table I and fig. 2 show the results of the granulometric analyses of bottom samples taken with the "van Veen Grap" in two cross-sections of Graadyb. One between Skallingen and Søren Jessens Sand, the other between Langli Sand and Fanø.

The three samples from the middle of the channel make a special groupe considerably coarser than the others. The middle-grain size is larger than 300 μ and the contents of components coarser than 1 mm varies from 4—19 per cent. The cumulative curve (339) represents an analyse of the same sample as the curve (338) after treatment with diluted hydroclorid acid and it shows that the contents of shells do not play any role for the frequence of the grain-size. The rolled pebbles of clay in the sample (338) are obvious

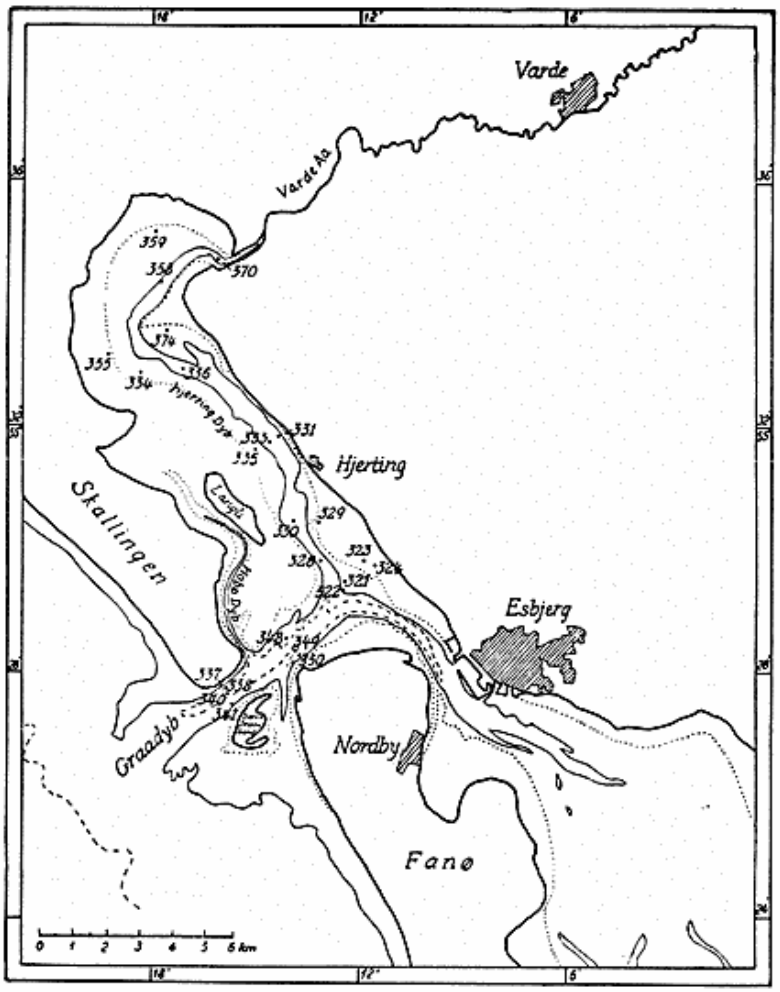

Fig. 1. Sample stations in the Graadyb tidal area.

analogous to the pebbles of integlacial Yoldia-clay mentioned by A. JESSEN[1]) from the beach by Blaavandshuk. JESSEN supposes the pebbles are broken up from Yoldia-clay in situ on Hornsrev in the North Sea.

The four samples from the slope of the channel suggest that there is a clear difference between the northern and the southern side, and that Graadyb is eroding in the slope towards Fanø whereas Langli Sand is built up of the fine wadden sand with a middle grain size about 100 μ mixed with small quantities of silt and clay.

The diagram shows that the frequency curves have two maximas, and that means that the sediment is mixed up by two components. The finest of them has a middle grain size of about 94 μ and is the

[1]) JESSEN, A.: Beskrivelse til geologisk Kort over Danmark. Kortbladet Blaavandshuk. Danmarks geologiske Undersøgelse. 1. Række. Nr. 16. 1925.

Table I.

Sample No.	Md μ	Q_3 μ	Q_1 μ	QDφ	Gravel $>$ 1 mm p. c.	Sand 1 - 1/16 mm p. c.	Silt + Clay $<$ 1/16 mm p. c.
337	90	110	75	0,3	0	100	0
338	420	720	290	0,6	19	81	0
340	320	420	290	0,3	4	96	0
341	118	290	85	0,9	0	100	0
348	90	110	72	0,3	1	92	7
349	360	610	265	0,6	10	90	0
350	210	290	90	0,9	1	99	0

337 1 m Grey sand.
338 15 m Coarse sand with many shells a few stones and rolled pebbles of grey-green clay.
340 12 m Coarse sand.
341 3 m Fine light-grey sand.
348 8 m Fine grey sand with plenty of actinias.
349 12 m Coarse sand with shells.
350 6 m Fine yellowish sand.

present wadden sand going to and fro with the tidal currents. The coarser one originates probably from older layer in which Graadyb has been eroded.[2])

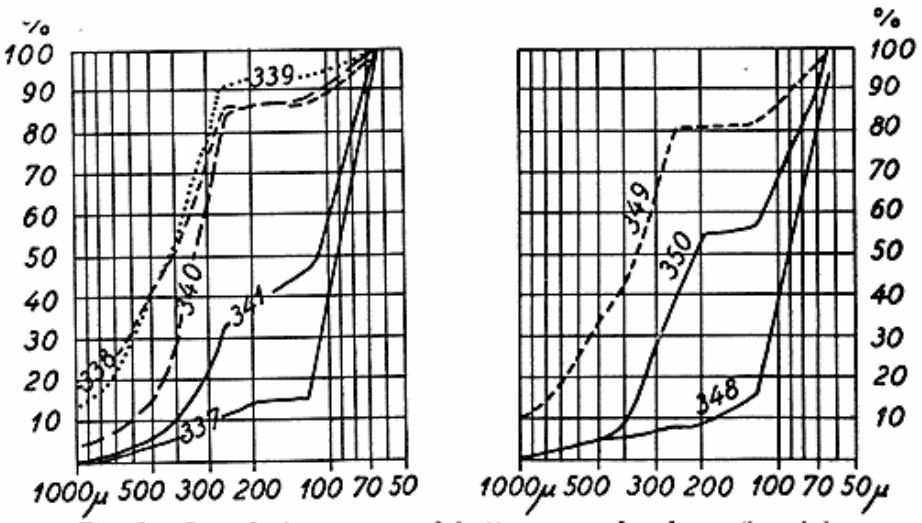

Fig. 2. Cumulative curves of bottom samples from Graadyb.

Hjerting Dyb.

Hjerting Dyb is 400—500 m wide by the entrance and 14 m deep, but further to the north the depth decreases and by the village

[2]) HANSEN, KAJ: Preliminary report on the sediments in the Danish Wadden Sea. Medd. fra Dansk geologisk Forening. Bd. 12. Hefte 1. København 1951.

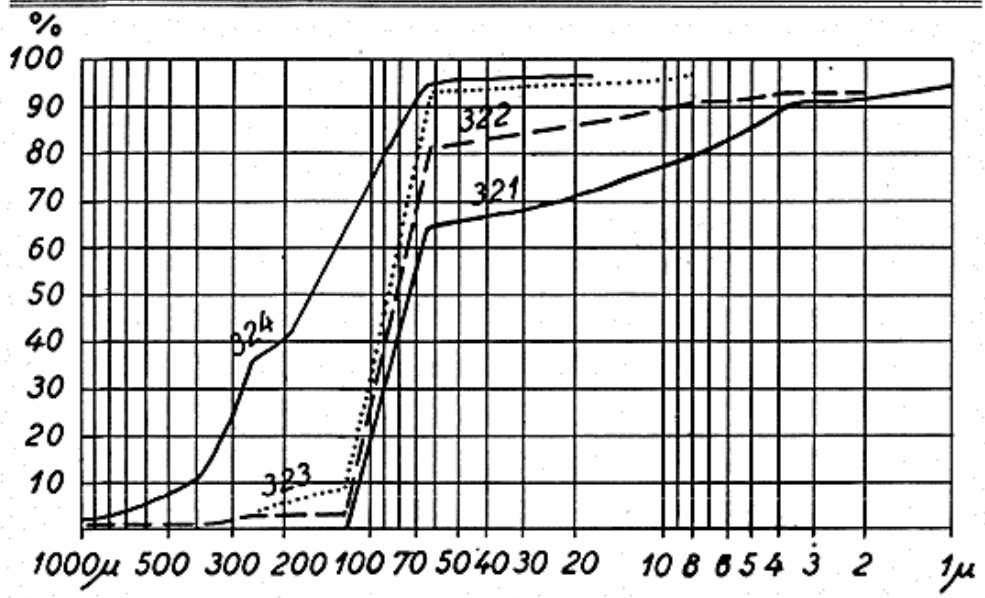

Fig. 3. Cumulative curves of samples from the tidal flats by Lilho.

Hjerting it is only 3 m. The slopes of the channel are mostly very steep. Table II and fig. 3, 4 and 5 illustrates the granulometric analyses.

The three samples from the middle of the channel (328, 330, 333) all consist of wadden sand; (328) with a little contents of gravels, (333) with a rather large amount of silt + clay. This indicates at any rate that some sedimentation takes place or that the bottom of the channel probably is covered with a thin layer of fine sand

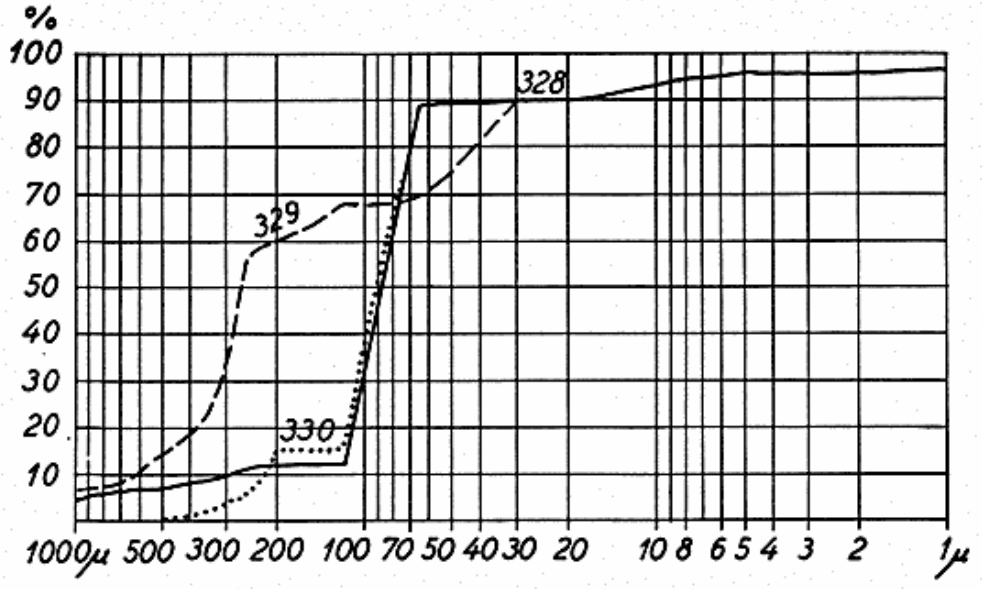

Fig. 4. Cumulative curves of samples from the outher part of Hjerting Dyb.

Table II.

Sample No.	Md μ	Q_3 μ	Q_1 μ	$QD\varphi$	Gravel $>$ 1 mm p. c.	Sand 1 - 1/16 mm p. c.	Silt + Clay $<$ 1/16 mm p. c.
321	75	95	14	1,4	0	64	36
322	90	101	65	0,3	2	80	18
323	90	110	72	0,2	0	93	7
324	160	290	100	0,8	3	92	5
328	85	101	70	0,3	5	84	11
329	375	340	50	1,4	6	64	30
330	90	115	75	0,3	0	100	0
331	370	480	300	0,3	3	97	0
333	70	100	17	1,3	0	64	36
335	80	100	70	0,3	4	83	13

which is continuously wandering to and fro with the changing tidal currents.

In close connection to this groupe are the samples (321, 322, 323) from the wadden by Lilho. The samples (321, 322) are taken on the othermost edge of the wadden in some mytilus bancs, which gives them their rather large contents of silt + clay.

Another groupe includes the samples (324, 329, 331). All of them are taken on the wadden around the village Hjerting or from the slope of the tidal channel. The frequence curves have in all cases two maximas and the sediment is here too a mixture of wadden sand and older deposits. It is remarcable that the sand on the beach especially to the north of Hjerting is noticeable coarse.

Along the whole coast from Esbjerg to the Varde Aa estuary there is a high cliff of miocene mica sand covered by 1—1½ m glacial till. The miocene sand has a middle grain size of 90 μ, the same as the wadden sand, but the sand on the beach in front of the cliff has a middle grain size of 620—646 μ. The thin layer of glacial till covering the miocene sand can scarecely be able to give the beach sand such a coarse character. The coarseness of the beach sand seems better to be explained by supposing that the miocene sand has not retained its original position but is a big floe torned loose and carried away by the ice, and the coarse sand on the beach is diluvium underlying the tertiary mica sand. This assumption has been further confirmed by studying the niveau conditions between the tertiary and the quaternary deposits in the neighbourhood of

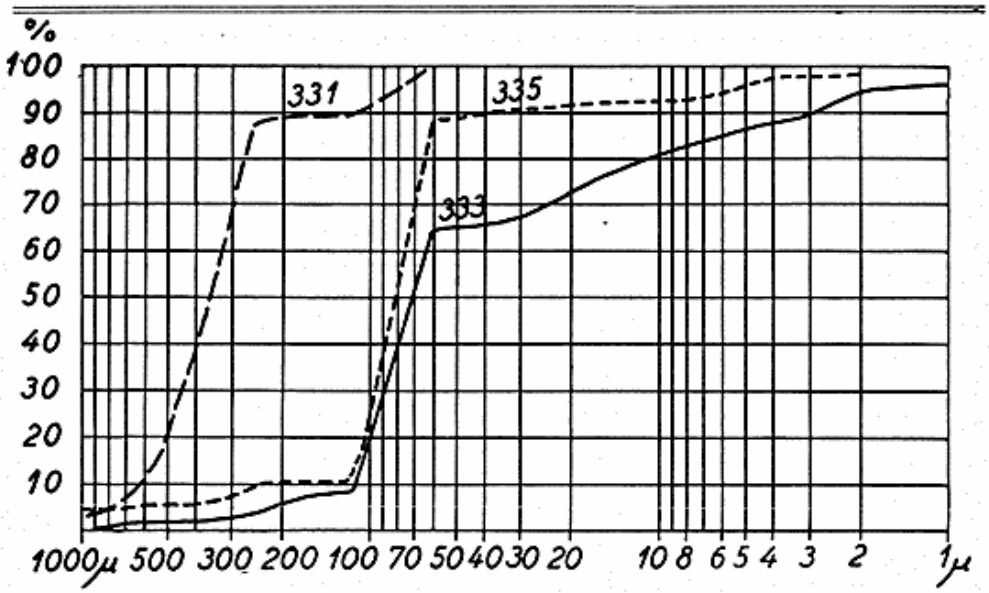

Fig. 5. Cumulative curves of samples from the inner part of Hjerting Dyb.

Esbjerg and by granulometric analyses from the drillings in the wadden sea, in the marshes and in other parts of the soutwestern Jutland.

The inner part of Ho Bugt.

This area is very shallow with depths of only a few meters. To the south-west it is separated from the Hobo Dyb by a wadden area from the northern end of Langli to Halen on the base af Skallingen.

Table III and fig. 6 illustrates the granulometric analyses of the bottom samples from this area.

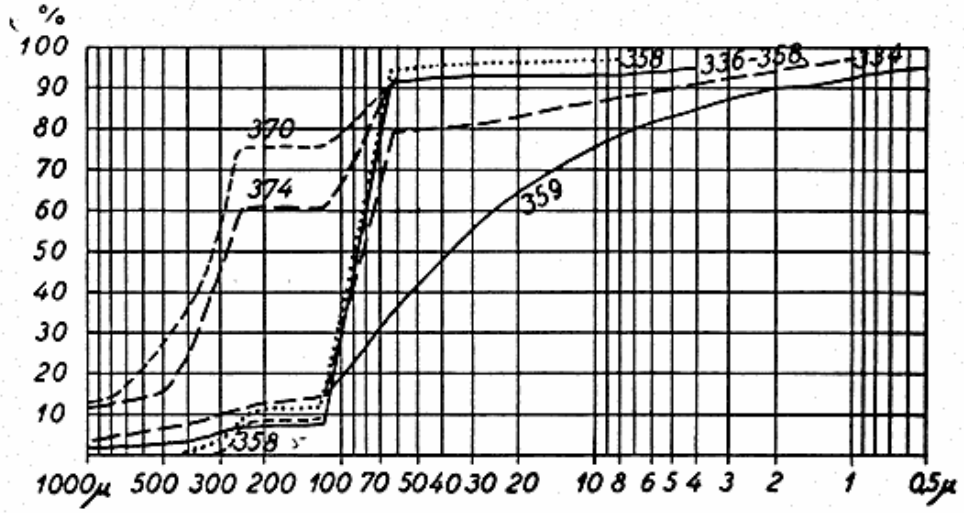

Fig. 6. Cumulative curves of samples from the innermost part af Ho Bugt.

Table III.

Sample No.	Md μ	Q_3 μ	Q_1 μ	QD_φ	Gravel $<$ 1 mm p. c.	Sand 1 - 1/16 mm p. c.	Silt + Clay $<$ 1/16 mm p. c.
334	85	100	65	0,3	4	75	21
336	85	110	70	1,3	2	89	9
355	85	110	67	0,4	0	91	9
358	85	110	70	0,3	0	95	5
359	38	85	10	1,5	0	36	64
370	333	556	250	0,6	13	81	6
374	270	420	90	1,1	6	88	6

The two samples from the Varde Aa estuary (370, 374) have the same coarse sand as the beach by Hjerting and is probably diluvium underlying the tertiary. The samples (334, 336, 355, 358) are the same type of sand found on the bottom of Hjerting Dyb more to the south and on the wadden. The sample (359) has a larger contents of silt + clay which derives from erosion of the old marshes along the western coast of the bay.

In short these investigations has shown that in the northern part of Ho Bugt as far south as Hjerting (sample 333) the bottom of the channels is a fine sand with 21—36 per cent silt + clay and that the content of silt increases to the north so that the bottom deposits in the most northerly part of the bay are silt with 15 per cent clay and 36 per cent sand. In the southern part of Hjerting Dyb the deposits on the bottom of the channel are fine sand with 11 per cent silt + clay and in Graadyb the bottom deposits consists of coarse sand and gravel.

It seems also evident, that Graadyb is eroding in the slope against Fanø and is building up the Langli Sand with fine sand transported by wawes and tidal currents.

II.

The transportation of debris.

In 1938 the director of the Skalling Laboratory Prof. Dr. NIELS NIELSEN started some investigations on a large scale to measure the physical conditions in the Graadyb Tidal Area. Measurements were made of the currents, the temperature, the salinity, the suspended matter and the plankton. The suspended matter has been analysed

by HELGE GRY[3]) who especially writes about the correlation between suspended matter in mg/l. and the current velocity. It is however of greater interest to find the amount of suspended matter

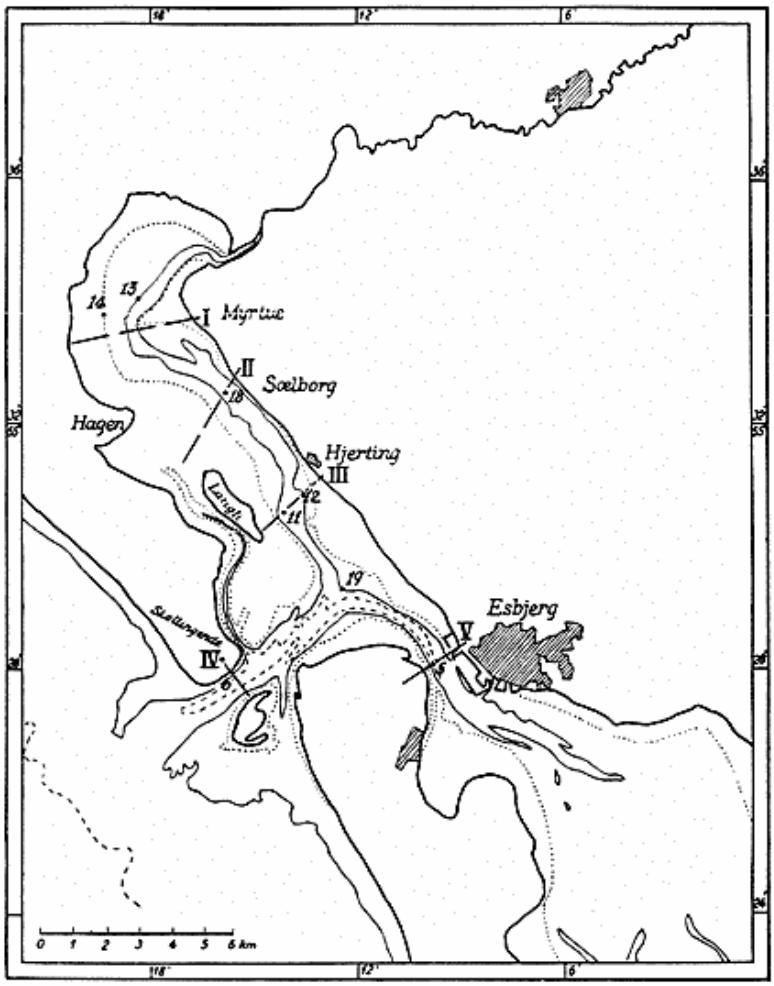

Fig. 7. The eross sections where the amount of suspended matter is calculated.

passing different cross-sections through a tidal period and the author therefore has tried to make some calculations about that from the material given by GRY.

Surely the measurements are rather incomplete to allow such calculations and the diagrams fig. 8—15 are therefore to be interpreted with some prudens, and they indicate only the tendency in the transport of the debris. The map fig. 7 shows the cross-sections in which the calculations have been made.

[3]) GRY HELGE: Quantitative Untersuchungen über den Sinkstofftransport durch Gezeitenströmungen. Folia Geographica Danica Tom. II, Nr. 1. København 1942. (Medd. fra Skallinglaboratoriet Bd. X).

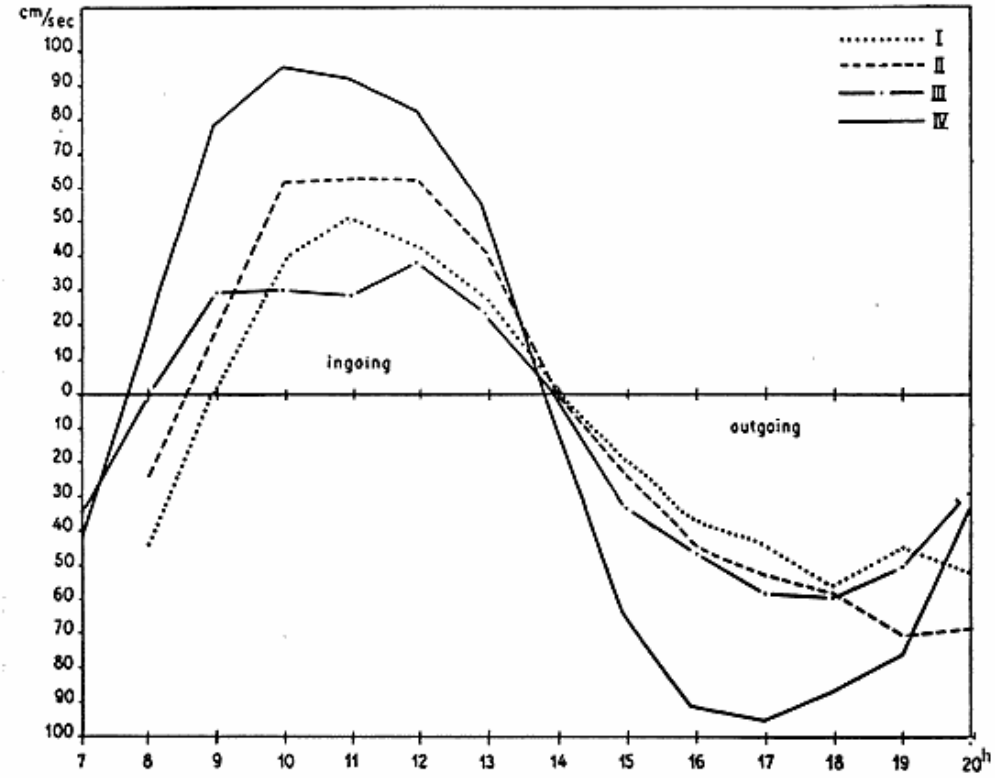

Fig. 8. Tidal current velocity in cross-sections I—IV. 24-8-38.

The two currents-diagrams show, that while the turning of the tidal currents by high-tide from ingoing to outgoing takes place simultaneous in the whole area, the turning by low-tide occurs by Hjerting half an hour later than by Skallingen and about one hour later by Sælborg and one and a half hour later by Myrtue. The times varies a little with the direction and the force of the wind.

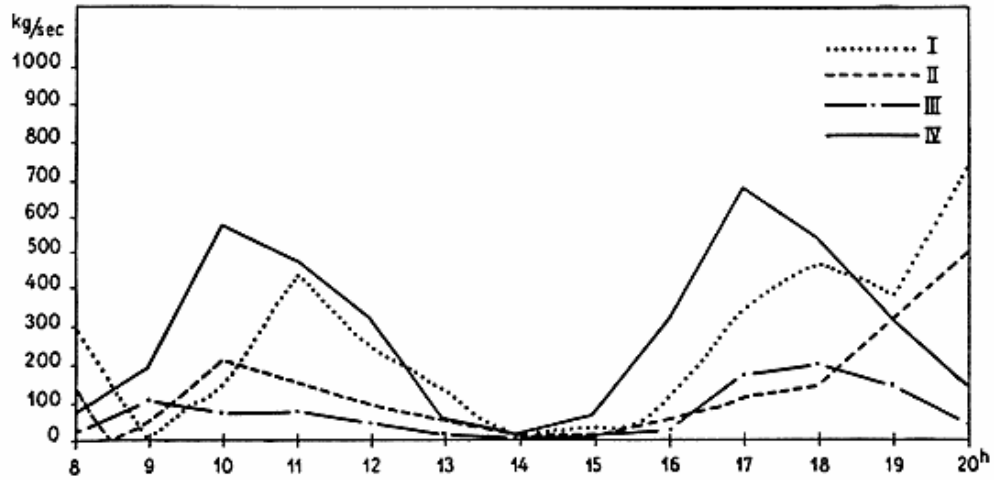

Fig. 9. Transport of suspended matter in cross-section I—IV. 24-8-38.

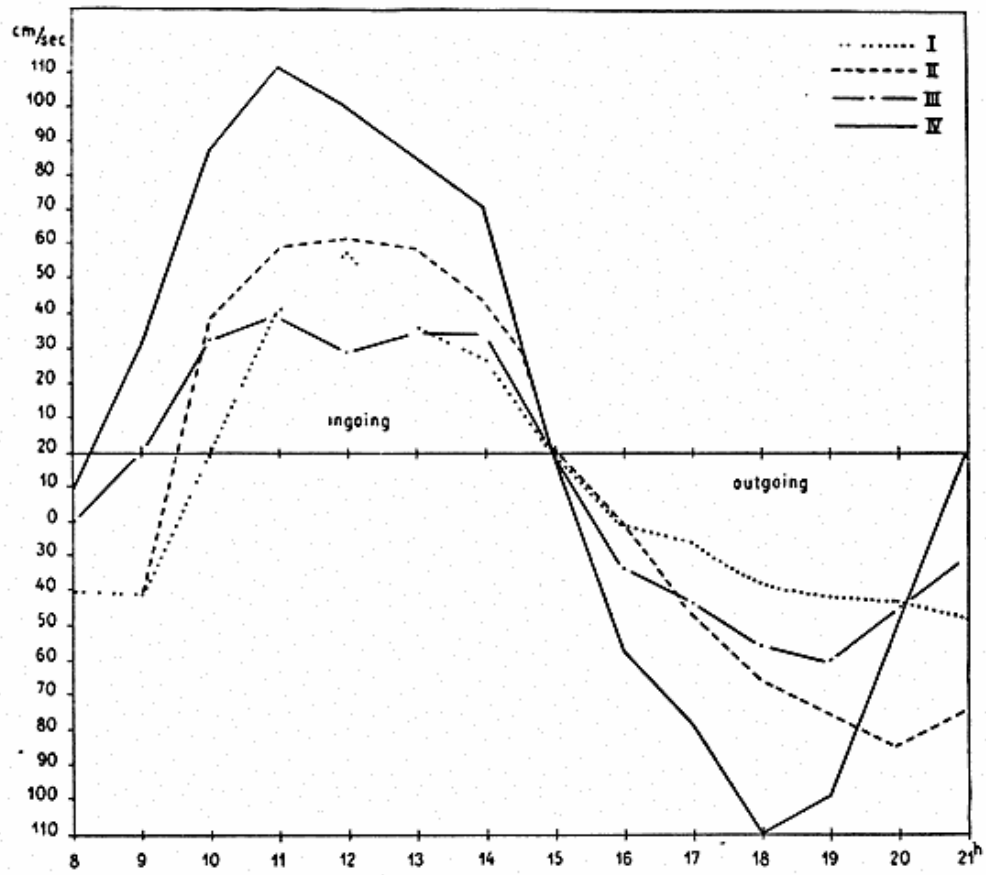

Fig. 10. Tidal current velocity in cross-sections I—IV. 25-8-38.

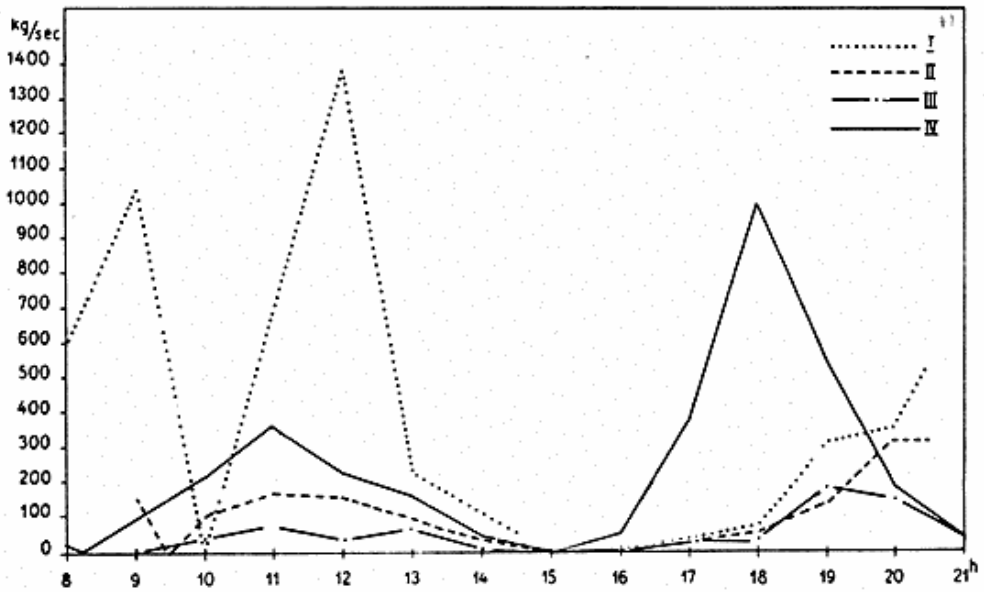

Fig. 11. Transport of suspended matter in cross-sections I—IV. 25-8-38.

The current diagram also shows that the acceleration of the currents in the cross-section III decreases about one hour after the turning of the currents while it is unaltered in the two cross sections farther to the north. This probably means that a stewing of water in front of the strait channel between Langli and Hjerting takes places in the last period of the ingoing current.

By the outgoing current the maximal velocity occurs later and later the more one goes into Hjerting Dyb. Here apparently a stewing of water takes place on the northern side af the strait channel.

According to GRY the wadden area between Ho Bugt and Hobo Dyb is inundated about three hours by high-tide, and some of the suspended matter is transported this way by outgoing current and is later deposited in the marshes on Skallingen.

The diagrams fig. 9 and 11 show that the amount of suspended matter passing the four cross sections varies strongly from one to the other.

By ingoing current it is clearly to be seen that the amount of suspended matter passing the cross-section III is less than that passing any of the others. That means that a considerable part of the water coming in through Graadyb owing to the stewing in Hjerting Dyb must run to the south through Havneløb and the suspensed matter in this water must be deposited here by high tide.

On the other hand a considerably amount of the suspended matter which by ingoing current comes to the northern part of Ho Bugt is taken from the bottom to the north of the cross section III. This is especially clear to see in fig. 11, where the material which at 10 o'clock was on the way out through Hjerting Dyb returns to from where it came.

By the outgoing current nearly the same is to see. In a period of two hours the first day and one hour the next day the amount of suspended matter passing the cross section I, II and III is nearly the same. Afterwards a deposition takes place to the north of the cross section III. That means that only very little of the debris coming in through Graadyb is transported to the inner part of Ho Bugt and on the other hand a rather large body of sand and mud is going to and fro between Myrtue and Hjerting. This is in full harmony with the analyses of the bottom deposits.

To see what happens to the amount of suspended matter going from Graadyb to the south a similar calculation has been made in a cross section in Havnedyb from the fishery harbour in Esbjerg to the north-eastern corner of Fanø.

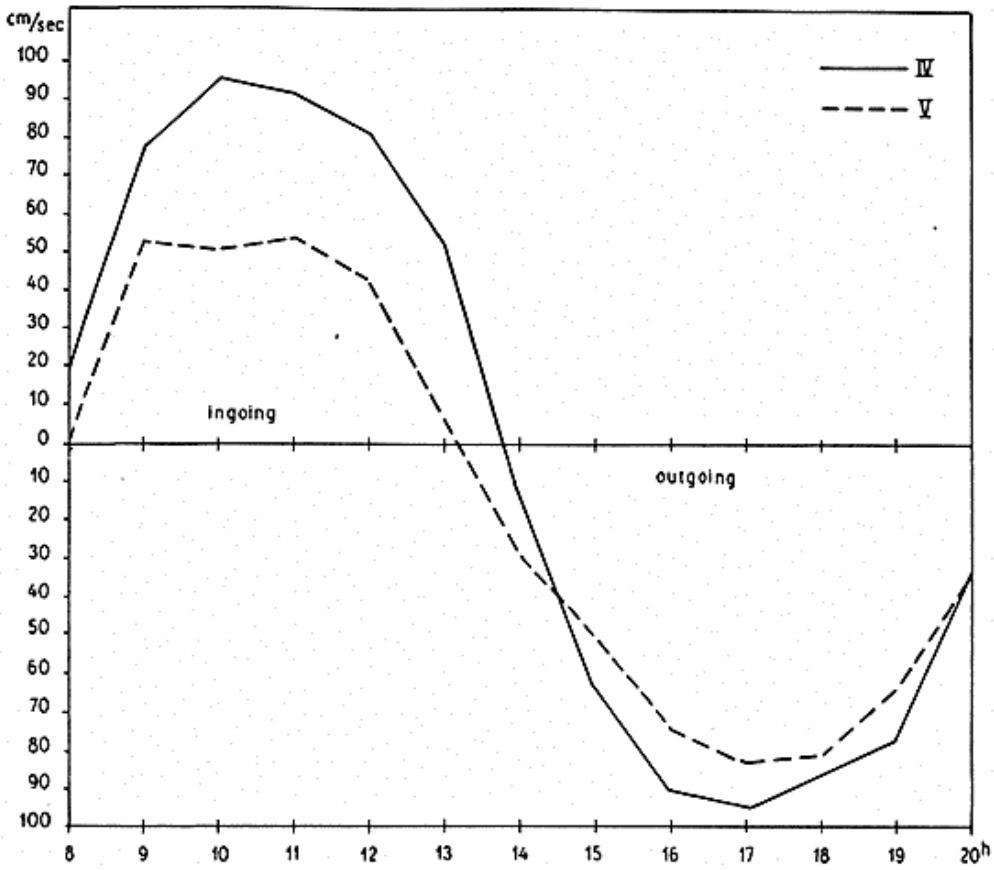

Fig. 12. Tidal current velocity in cross-sections IV and V. 24-8-38.

Fig. 12 and 13 show that the current turning from outgoing to ingoing takes place half an hour earlier in Esbjerg as by Skallingende. This is to explain by the fact that some of the ingoing

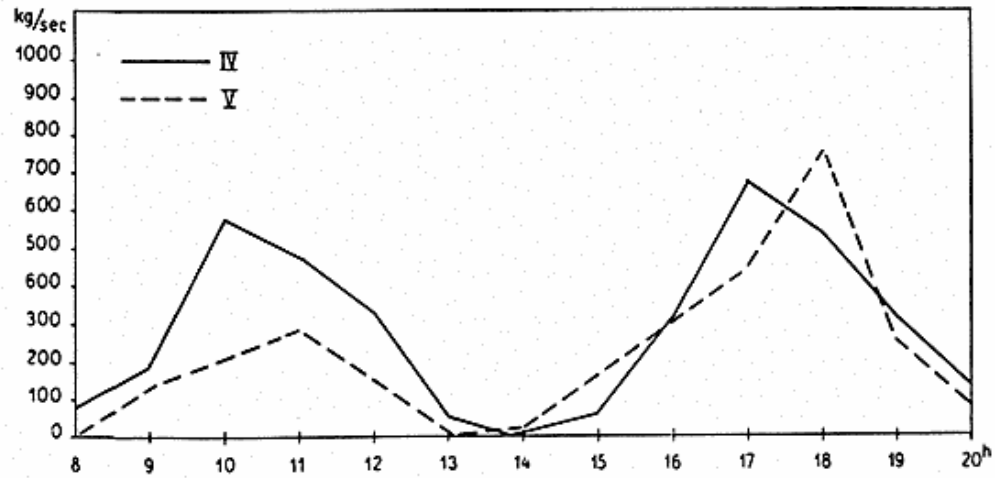

Fig. 13. Transport of suspended matter in cross-section IV and V. 24-8-38.

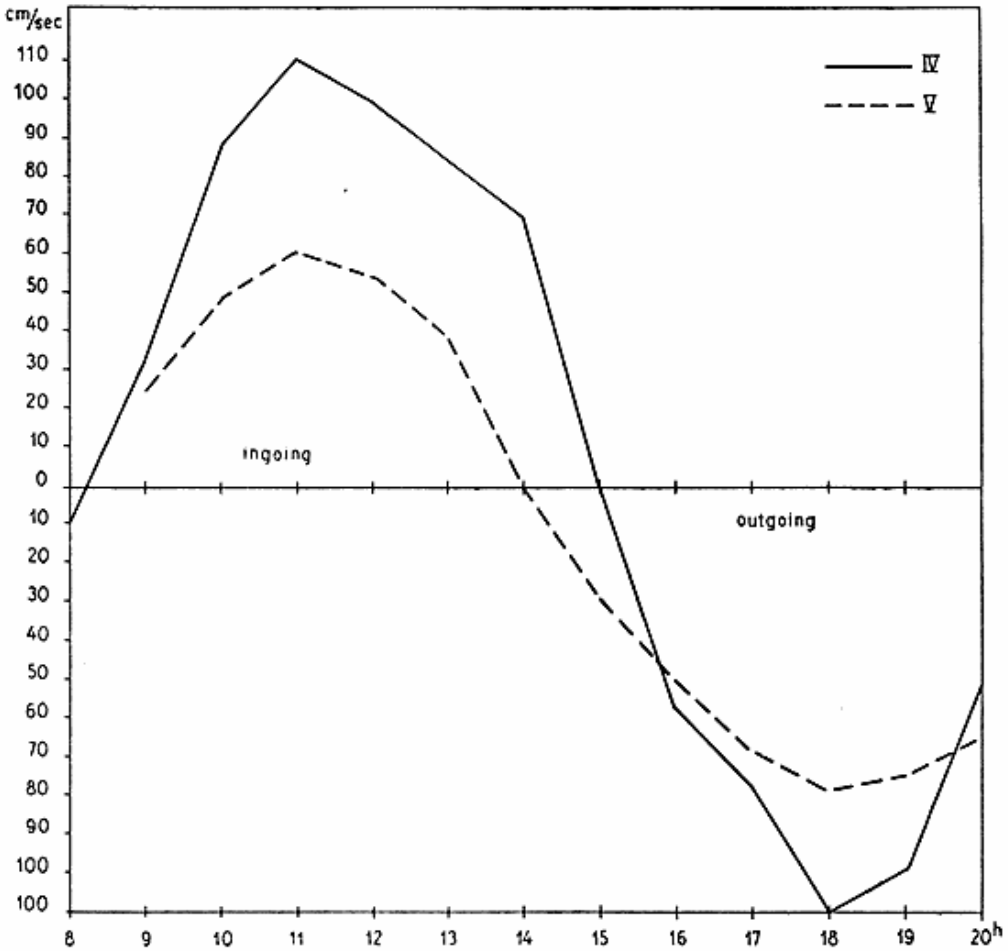

Fig. 14. The variation of the tidal current velocity cross-section IV—V. 25-8-38.

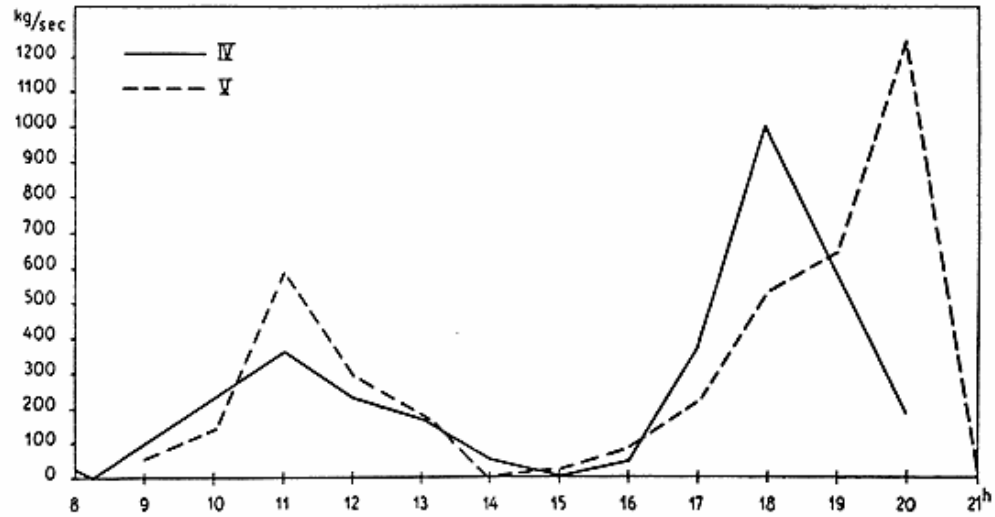

Fig. 15. Transport of suspended matter in cross-section. IV—V. 25-8-38.

water from the Knudeby to the south of Fanø runs to the north through Havnedyb and leaves the Wadden Sea through Graadyb. Fig. 13 and 15 show that especially the last part of this ebb-current has a large amount of suspended matter larger than what goes out through Graadyb. That means that also in the area between Havnedyb and Skallingen a mud and sand body is wandering to and fro with the tidal currents and that this body is steady augmentet from the south. Some of it is transported through Graadyb with the first part of the ebb-current, but after every tidal period there will be a surplus which not reach the North Sea and is driven back into Graadyb with the ingoing current. This is probably the reason that the fairway to Esbjerg steady has to be kept open by dredging.

According to GRY the main part of the suspended matter in the ebb-current through Havnedyb originates from a slickwade in the Nordby-Bay on the eastcoast of Fanø. As mentioned before (KAJ HANSEN 1951) the wadden in the Nordby-Bay is a sand wade and only in the innermost part of the channel Fanø Lo a silting up with clay takes place.

The reason that a relative large amount of suspended matter is passing through Fanø Lo is, that with the ebb-current the water is coming from the south and spreads out over the wadden in the whole bay, when it runs off, this takes its way mostly through the strait channel Fanø Lo in which the suspensed matter is concentrated.