Chapter III

I. Detrital Sedimentology in the Southern Bight of the North Sea

by

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During 1972 and 1973 some 1200 samples were analysed taken at regular intervals, mostly with a Van Veen sampler, in the Southern Bight of the North Sea. The sampling net is indicated on fig. 3.1, together with the essential isobaths as synthetised by Houbolt and put graciously at our disposal.

Analytical procedure and calculation of used parameters has been presented in our report : Analytical Flowsheet for Detrital Sediments (1972).

In this progress report, five maps will be commented upon, representing the distribution of five parameters which have proved to be of significance. Instead of giving long tables with the 5 × 1200 parameters, the results are presented on the maps with a system of symbols which allow a close enough identification of the exact values. For each map are successively discussed in A, the choice of the parameter, in B comments on the distribution, in C interpretation of the facts.

fig. 3.1.

1.- Gravel

A.-

When the history of the North Sea, as far as known, is taken into account it can be stated that gravel occurring on the actual seabottom may have four origins :

1) Fossil gravel sediments deposited subaerially during glacial low sea-level stages as fluvial or fluvio-glacial sediments.

2) These continental sediments reworked by the transgressive sea during sea level rise at the transition to an interglacial stage. Most effective will have been the Flandrian transgression but it must be foreseen that also the earlier Eemian transgression has left relicts.

3) Erosion of the sea by wave abrasion or tidal current erosion of all types of earlier deposits as well as the tertiary and cretaceous subsoil to form a residual lag-gravel, being a concentration of all elements too heavy to be transported by these currents.

4) New gravels brought in by the actual rivers or modern coastal cliff erosion.

This analysis shows that gravel occurrences on the actual seabottom are an indication for high wave activity or current velocity that bring about either actual erosion or prohibit actual sedimentation.

B.-

Fig. 3.2 shows a strong concentration of gravel occurrences.

North of 50°40' N and along the south-eastern shore only a very limited number of samples contain some coarser particles. Only one sample contains more than 10 % , seven samples contain between 2 and 8 % . These samples occur dispersed, apart from one SW-NE trending pattern 45 km east of Outer Gabbard, and it is to be stressed that north of the Rhine mouth not a single gravel was found in a broad area 75 km out of the coast.

In the southwest the gravel samples are strikingly more abundant and their gravel content also very high, up to 100 % . Most of the occurrences are grouped and can be easily outlined. In doing this the topography is important as obviously the gravel occurs in the swales

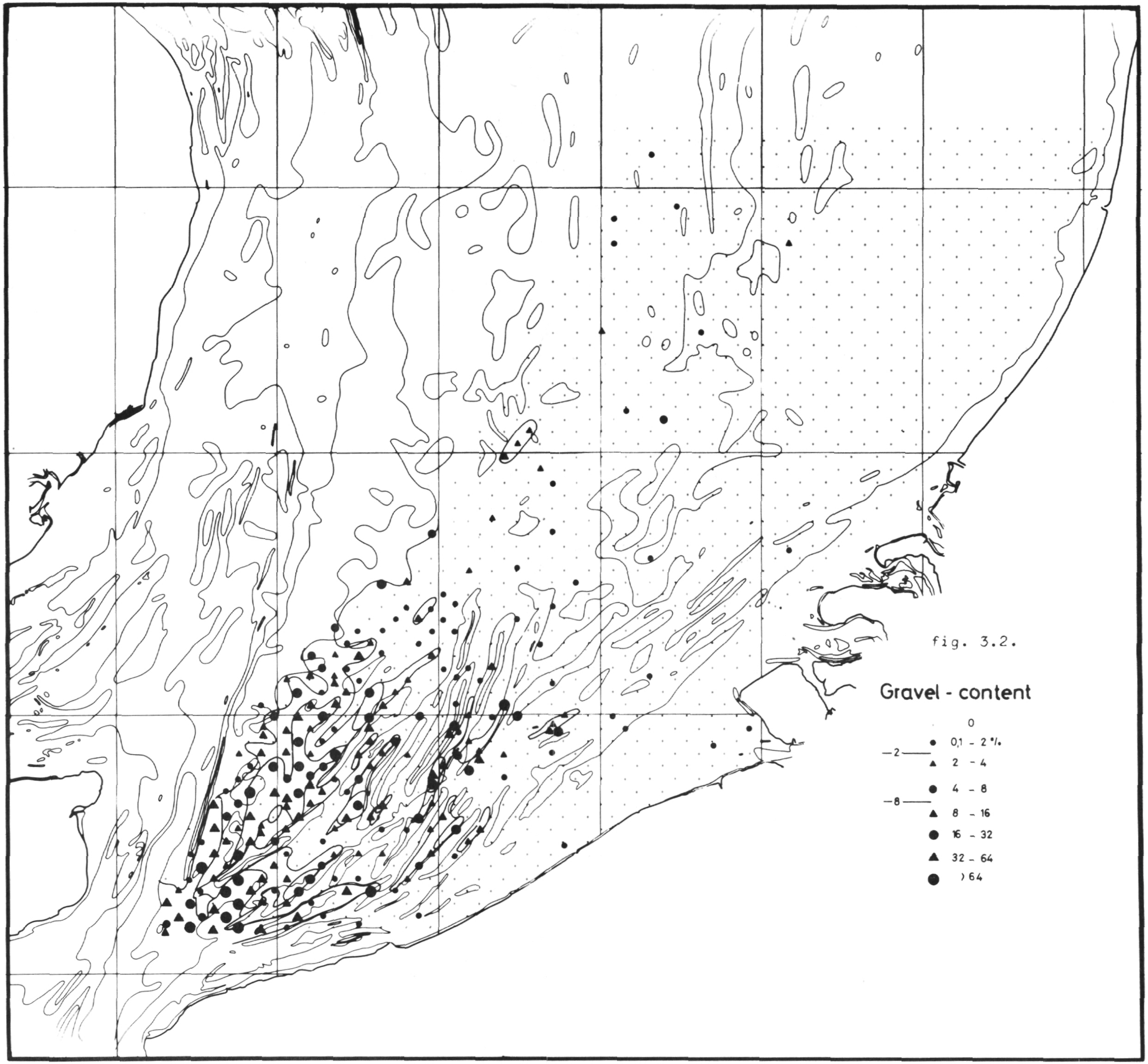

fig. 3.2.

Gravel - content

between the sandbanks. The density of gravel samples allowed to outline two gravel classes 2 - 16 % and more than 16 % . The map shows two cartographic expressions of the gravelly sediments.

1) In the Hinder Banks and the northern Flemish Banks the gravels occur in narrow, elongated, enclosed stretches in the swales between some banks. The gravelly sediment is only present in the deeper swales and occurs in the eastern part at a swale depth of 30 m , deepening between Oost and West Hinder to 40 m and along the Fairey Bank to 45 m . In the same direction exists a definite trend towards higher gravel percentages.

2) In the southern Flemish Banks and in the Sandettie Falls area an inverted situation exists. The majority of the bottom is now gravelly and the much more individualized sandbanks stand out clearly. The gravel patches are not only larger but also higher percentages of gravel occur and several samples were pure gravel. The depth oscillates between 50 and 60 m and the purest gravels correspond to the deepest parts.

It must be stressed that the western boundary lines have only a limited value as they coincide with the extent of the sampling.

C.-

The map refines the distribution map of gravels given by Veenstra (1969). It shows that in the southern part of the Southern Bight exists a generalized gravel surface which lies at a depth of 60 m in the central, deepest channel and rises at first rapidly then slowly to - 30 m . It may be assumed with certainty to continue in the gravel layer which was found generalized by Briquet (1931) between the tertiary subsoil and the pleistocene cover in the coastal plain of northern France and Belgium, at the same depth of - 30 m .

The origin of this gravel layer will be studied in a future step by analyzing its petrographic composition. Veenstra (1969) who had not such abundant material indicates already a distinction between the eastern part with a majority of gravel reworked out of the local tertiary subsoil, and the marked appearance of foreign gravel in the deeper central portion. Its occurrence shows certainly the existence of actual tidal currents strong enough to prohibit sedimentation, eventually to erode the subsoil.

2.- Shells and shell fragments

A.-

The amount of shells or shell fragments has been determined on the fraction coarser than 2 mm . No attempt has been made to distinguish between living organisms, whole shells or commuted shells. This means that high shell percentages do not necessarily point to high biological activity. They can also originate through current accumulation of shell debris.

Low shell percentages are certainly an indication of low biological activity, but might also be influenced by rapid sedimentation.

B.-

The analytical results are shown on figure 3.3. After study of the distribution it was found that the data could significantly be grouped in three classes :

- less than 0.2 % : those containing no shells at all or only 0.1 % in the group 0.1 - 2 % ;
- from 0.2 to 8 % ;
- more than 8 % : grouping all the very shelly samples; only ten contained between 32 and 64 % ; only one, taken in a shell bank, contained 100 % .

In delineating the groups the principle was followed that at least two samples in the same group were necessary. This minimum requirement occurred only 6 times. This means that generally large patches have similar composition and proves that the analytical results are worthfull.

The cartographic expression shows immediately two results. There is no significant relation between bottom topography and shell content as the boundaries do not follow the bathymetric picture.

There is a definite trend in diminishing shell content from south to north and from deep water to the coast.

1) Areas without shells

A first very conspicuous configuration is the regular occurrence of shell-free sediments along the coast with tonguelike projections into

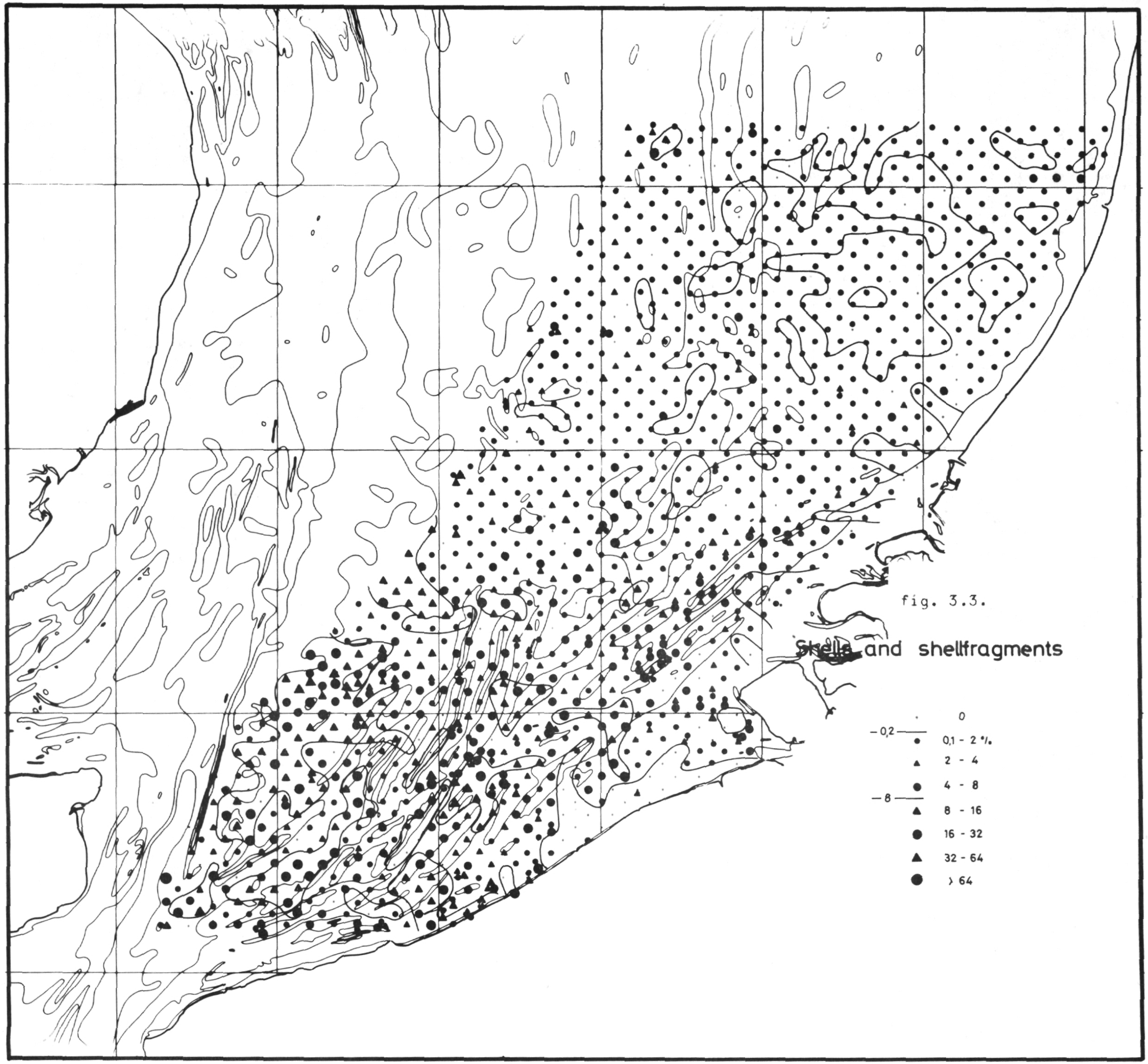

fig. 3.3.

Shells and shellfragments

the sea. The patch before the eastern Belgian coast and along the south bank of the Scheldt mouth is the most important and is at the same time the most shell-free as 85 % of the samples are of the class 0 . Towards the south a small patch extends out of the Yzer mouth and in front of Dunkerque. Towards the north up to Scheveningen the areas are not contiguous along the coast and are limited to individualized tongues. At the same time they are less shell-free as 75 % of the samples have a 0.1 % shell content.

In open water there is also a remarkable change in pattern from south to north. In the south two well defined stretches occur corresponding to two sandbanks, together with isolated low values in the distribution of which no correlation could be traced. Further north the area of shell-free sediments increases with 98 % of the samples in the 0.1 class. Out of the North-Holland coast a very large uniform area exists which dissolves into isolated patches towards the coast as well as towards the deeper sea.

2) Areas with high shell content (> 8 %)

Those are clearly located in the southern part of the map. A large stretch exists in the deepest part between Falls and Sandettie. It breaks up into isolated but large areas towards the coast. One of them touches the coast at the Belgian-French border and is responsible for the very shelly beaches there. The same pattern exists towards the north and more rapidly in front of the Scheldt estuaries. North of 51°45' N only a few isolated values occur just above 8 % excepted the small patch west of Brown Bank.

3) Areas with intermediate shell content (0.2 – 8 %)

As an intermediate class it occupies evidently the remaining space. Nevertheless the detail symbols allow to stress some trends. The surface occupied by this group is much larger in the north. Furthermore the southern half is predominantly characterized by values between 4 and 8 , while north of 52° N they are dominantly below 2 , the exceptions being located west of Brown Bank and in front of the Yser-mouth.

C.-

The literature is very silent on this type of parameter although for the interpretation of actual sedimentation and for the understanding of fossil deposits it can be important. An explanation of the observed data can only be tentative.

1) If a certain shell content in these undeep and well aerated waters can be estimated as normal then it must be explained why a general trend towards less shells from south to north is present. This might be due to changing ecological conditions, becoming less favorable. Diminishing tidal range, and so diminishing tidal currents, towards the north should have a bearing on the oxygen-content and might diminish population density. However shell percentages are an integration in time of population density. For the same population density the shell percentage will decrease with increasing rate of sedimentation. It was indeed seen qualitatively that, except for a few pure shellbanks, high shell percentages had relatively much more shell fragments, indicating their reworked and even transported character. It becomes obvious that the southern part is a more stable sea bottom with slow sedimentation rate and that this changes abruptly north of 51°45' N . The fact that in the south the lowest shell percentages (even two stretches of 0 %) lie on the ridges indicates a more rapid sediment renewal on these ridges, offering a less stable environment. The high shell content is correlated to the bank topography and the intervening gravelcovered swales all due to the same high tidal current system.

2) The extremely low shell percentages (group 1) can then be explained in the first place by rapid sedimentation rate exemplified by two ridges in the Flemish banks. The big area of the coast of North-Holland corresponds with the zone in which Houbolt (1968) found extensive transverse mega-ripples indicative of a regular bottomsand transport corresponding with sediment renewal and high sedimentation rate. This coincidence corroborates the validity of the explanation.

Clearly however the patches along the coast with their tonguelike projections into the sea cannot be explained by high sedimentation rates. The large one in front of the Belgian coast coincides with mud sedimentation.

The rate of this sedimentation is not yet known but can hardly explain the low shell content which is mostly 0 . Furthermore the delimited areas do not coincide with any special relief form.

Obviously they are related to the different river mouth of Rhine and Scheldt. More precisely each tongue can be traced to a mouth with a net tendency towards a south-western deviation. This is in agreement with ebb-current direction and shows that these shell-poor zones are correlated with the outcoming watermass of the estuaries.

In certain conditions this could be due to the inflow of fresh water. However, excepted for the Rhine mouth, all these estuaries have nearly the same salt content as the sea. So other physico-chemical characteristics of these waters, pollution, must be the reason. In this hypothesis it would be worthwhile to verify if the tongue north of Europoort is not due to affluents from the large urban area of The Hague. It merits to be signaled that the Yser mouth is completely devoid of this negative influence and on the contrary high shell percentages occur there. This means that the Amsterdam urban area does not send into the sea pollutant effluents.

Because the same pollution holds true for the Yser estuary in the extreme south-west the same explanation must be valid for the large shell-free area off the Belgian coast.

The tidal ebb-current brings the Scheldt water to the south-west and its effect is reinforced by effluents from the coastal urban areas. These coastal waters are then taken up by the stream pattern in the more open sea and swept to the north by the flood current.

3.- <u>Sand percentage</u>

A.-

It is necessary to recall that the sand percentage is not defined here as the percentage on the total sample. In the flowsheet used [Gullentops (1972)], particles coarser than 2 mm are first sieved off, and the fraction finer than 2 mm is then decalcified. The remainder, considered as the total detrital non-calcareous sediment, is then divided at 62 µ into the sand fraction and the suspension fraction. The map (fig. 3.4) depicts in this way the distribution of the sand percentage and at the same time of the complementary mud percentage.

The numerous analytical classes distinguished by symbols could again be united in three significant groups : from 100 to 98 % sand, between 98 and 68 % and less than 68 % sand.

B.-

The distribution of the three groups is significant :

1) Pure sands : 100 – 98 %

90 % of the samples fall in this category and more than half of them contain more than 99 % sand. This means that only a negligible amount of mud is trapped in the sand pores or might even have adhered to the grains and was loosened by the analytical procedure. Dispersed into this area occur some twenty single sample points in which the mud content reaches up to 5 % and which were not outlined. They are all situated in deeper parts of the irregular bottom topography.

2) Mud bottoms : less than 68 % sand

Most of the samples in this group contain less than 36 % sand and are true muds. They are concentrated south west of the Scheldt estuary and a small path south west of the Rhine mouth. The outlining of the areas suffers from the sample distances and does not sufficiently take into account the detailed bottom topography.

Two patches occur in the Scheldt estuarine funnel along the flood and ebb-channels. A big area occurs in front of the eastern Belgian coast and has strikingly the same form as the shell-free area. The same holds true for the patch in front of the Yser mouth.

3) Muddy sands : between 2 and 32 % mud

This type of sediment occurs essentially in front of the Belgian coast as an extension of the pure mud bottoms and is also present elongated stretches at some distance from the coast in the swales between the

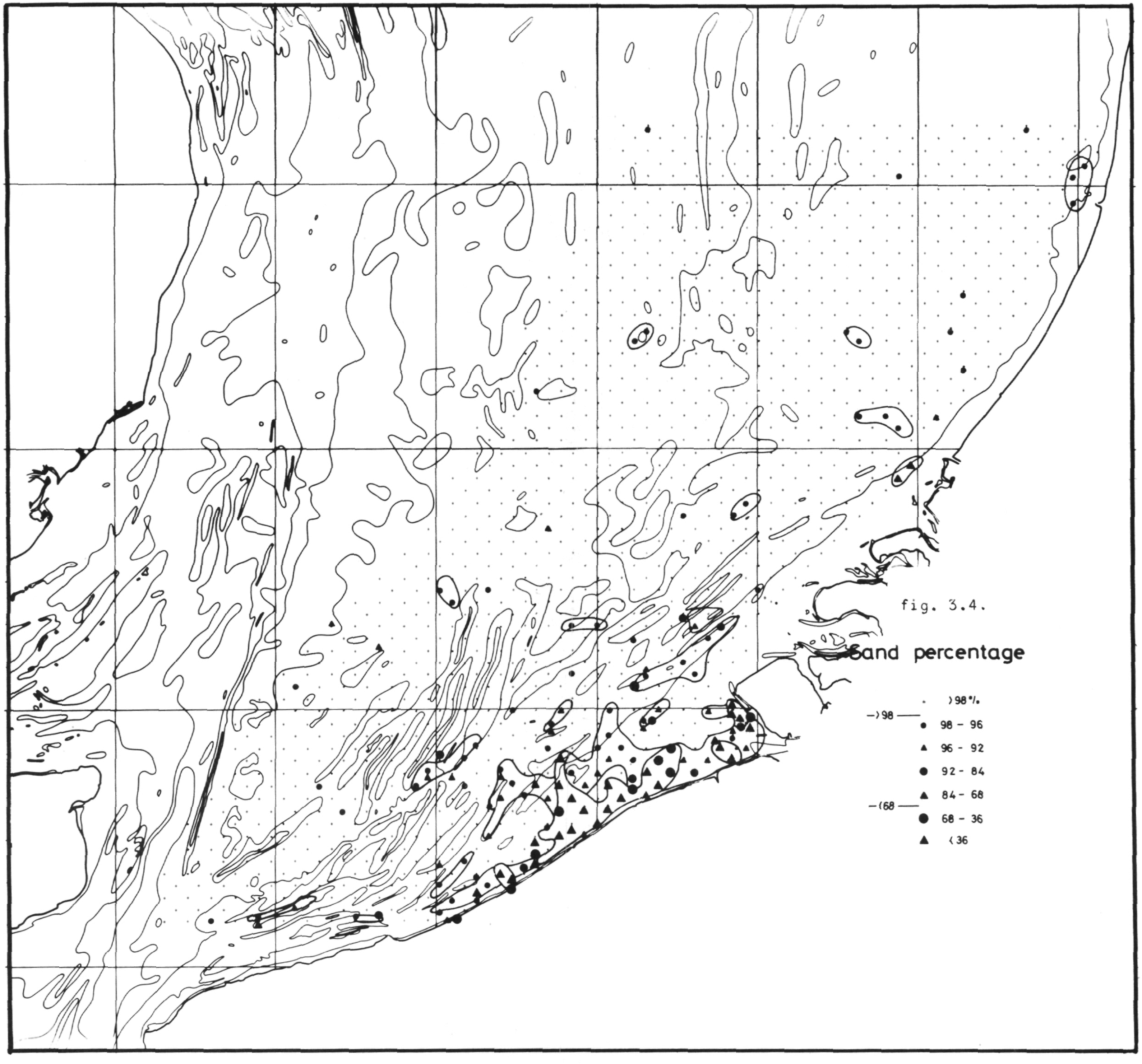

fig. 3.4.

Sand percentage

Zeeland and Flemish Banks. Further north only small patches occur, the most important ones before the mouth of Rhine and Yser. Remarkable is their practically complete absence in the open but also deeper sea.

C.-

1) The extremely low mud content in the greater part of the sampled area shows that in general the energy on the seabottom is sufficiently high to prohibit permanent deposition of mud. It has been shown [Moens (1972)] that in the open North Sea the suspension load of the sea water is rather low, with a mean of 3 mg/ℓ , but that after stormy weather this may increase considerably. The low suspension load in the middle of the Southern Bight was already shown by Maff (1957). The axe of minimum of turbidity corresponds rather well with the axe of maximum of salinity which correlates with the inflow through the Channel of clearer Atlantic water with higher salinity. This minimum correlates at the same time with greatest water depth and so lowest tidal current velocities.

Two forces may be responsible for the lack of permanent deposition. Tidal currents are strong and their force is depicted by the median grain size of the transported sands. Around current reversal the velocity drops however sufficiently to allow some fall out of suspended material. Current erosion will depend on the mechanical characteristics of the freshly deposited mud. Wave induced bottom turbulence is certainly more powerful to bring freshly deposited muds back in suspension. Maximum waterdepth in the sampled area is 60 m , which corresponds approximately to half the mean wave length. As stormy weather is generally produced by north west wind directions corresponding to maximum fetch, high wave bottom turbulence may be expected up to this depth.

It can be concluded that wave turbulence may be considered as the primary factor to inhibit permanent mud deposition and that tidal currents are responsible for the stepwise transportation of the suspended material to deeper parts of the sea where it will be out of reach of wave bottom turbulence.

2) The large mud content in front of the Belgian coast has been studied by Bastin (1973) and by Moens (1973).

In the large context of a sandy Southern Bight this distribution is very conspicuous. Two questions need to be answered : Which is the source of this mud and why is it deposited there?

a) The source of the mud will have to be found by detailed analysis of its grain size, mineralogy, physico-chemical properties and composition of its organic compounds. However this research can be guided by the consideration of three possible hypothetical sources.

- Bastin (1973) has put forward that the mud can derive from the local sea erosion of the underlaying tertiary clays. At a depth of - 30 m occurs under the modern seafloor sediments and ridges the abraded surface of the tertiary subsoil in which clays of eocene and oligocene age are predominant. In the deeper swales and channels this subsoil might be reached and eroded by the strong tidal currents or as Professor Faas[1] suggested by biogene erosion such as crab burrowing. Until now no outcrops have been located and it is doubtful that they could account for the large amount of mud deposited.
- The tidal inflow through the Straits of Dover brings in Atlantic water which has a low turbidity [Lee and Folkard (1969)] and hence a low suspension sediment load. Coastal waters are more turbid and can bring suspension load to the north. However the coast to the south is essentially composed of sand beaches and chalk cliffs and the Somme is the first somewhat important stream. So a southern coastal water mud source is real but can difficultly account for all the mud deposition. It may be stressed that continued development of harbour and industrial activity in the Calais-Dunkerque area might in the future have an increased effect on sediments along the Belgian coast.
- Ebb current outflow from the Scheldt estuary can lastly contribute. The actual upper Scheldt annual suspension load has been estimated by different authors [Gullentops (1973), Bastin (1973), Wollast (1971)] as between 1 and 2 million tons of mud. The percentage of this load finally carried out to the sea must historically have increased because

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[1] Oral communication.

the surface of the natural tidal flat sedimentation areas in the estuary has continuously been reduced by endiguing. In recent times the output has been increased artificially by the channel dredging activities for the Antwerp harbour. As this Scheldt estuary exists only some 1500 years and the important human interference only a few centuries, the mud deposition before the coast should also be historical if essentially related to the Scheldt. Up till now the mud sedimentation has not expressed itself in a typical morphological appearance but seems to drown the coastal sand ridge topography. This would be in favour for a recent development. A program for coring the mud sediments and studying their age and evolution of characteristics with depth will try to answer this question.

b) An explanation of the mud sedimentation must also explain why it is not eroded again. Here also a final answer is not yet available but a few hypotheses can be formulated.

- Sedimentation of mud is enhanced by the amount present. If concentration of suspended matter is very high floculation and aggregation of particles will increase. By biological activity aggregates can be formed and held on the bottom in such a way that there is a net surplus of sedimentation on renewed erosion. Shell life was seen to be very low in this area but other organisms as worms, especially Polydora, can be responsible.
- Bottom depth is rather low in these coastal waters, not exceeding 20 m . Wave turbulence should be very high and indeed coastal water turbidity is high [Moens (1973)]. However wave height is considerably reduced by the numerous north east tranding Flemish and Hinder Banks which cause the long swell to break. This coastal zone is in the wave shadow and experiences a much lower energy. These pre-coastal ridges tend to produce sublagoonal conditions in their shadow.
- Bastin (1973) and Moens (1973) studying the residual tidal currents found that this mud area was characterized by low residual currents which means that the turbid waters do remain in the area with only very low escape possibilities near the Wandelaar Bank.

If placed in the macromorphological situation it could be deduced from the trend of Flemish and Hinder Banks that the major tidal current direction, created by the Channel funnel, deviates from the coast. This combined with the tidal pump action of the Scheldt estuary might create in front of the Belgian coast a clockwise gyre in residual tidal currents with low escape possibilities of mud towards the north.

The mud area could *in globo* be explained by the tendency to form an outerlagoon behind the prelittoral ridges in which increased suspended matter arrival tends to be preserved by the current pattern is floculated and aggregated by biological activity and preserved from net erosion by weakened wave activity.

3) The class of medium mud content is in fact much narrower than the theoretical 98 to 68 % of sand. Indeed, the great majority of samples in this class contain only between 2 and 6 % of mud. Although the grab samples do not allow for stratification observations it can be argued that this mud is not present as a general mixture with the sand but as fine mud layers; they can be interpreted as sedimented during periods of slack currents combined with low wave turbulence. These layers could either be temporarily sedimented and sampled before renewed erosion or covered by the progression of sand waves and so represent a more definite sedimentation. For the more extensive patches the second hypothesis is more likely. Those lying in the neighbourhood of the mud areas can be regarded as extensions of this sedimentation and might indicate the danger of an extended mud cover in the future.

4.- Carbonate content

A.-

To distinguish eventually different types of carbonate origin the carbonate content was determined on a shell-free basis. It was determined by acid digestion on the sediment fraction smaller than 2 mm. The analysis results are expressed by symbols in seven classes with logarithmic boundaries. These could be grouped after study of the distribution in three meaningful groups : less than 4 %, from 4 to 12 % and more than 12 %. It was found indeed that in the class

8 – 16 % the samples with more than 12 % occurred in the same cartographic areas as the group above 16 % and was genetically related.

B.-

Figure 3.5 shows a striking distribution pattern, with a very strong trend to low carbonate content from south to north.

1) High carbonate content above 12 % occurs only south of 51°35' N . It falls clearly in two areas. The first follows the deepest water. It has very high percentages in the south up to 50 % and breaks up into patches towards the north.

The second lies along the coast, a smaller area in front of the Belgian-French border, a larger off the Belgian coast. The last one has several norrow protrusions towards the north, the image of which may not be exact due to the distant sampling.

2) Medium carbonate content (4 – 12 %)

South of 51°45' N the whole remaining area is taken by the medium class and the sharp boundary towards the north illustrates well the diminishing carbonate gradient in that direction. Inside the class values are higher in the south and gradually towards the north more samples occur with low carbonate content. Only two patches of low content can however be delineated in the area.

North of this line only three small patches of medium content can be delineated in the open sea. Along the Dutch shore however the medium class is well represented by small patches in front of the northern delta exits, a bigger one in front of the Rhine mouth and a more important one in the extreme north east near the Yser mouth.

3) Low carbonate content (less than 4 %)

Occurring only in the norther part. The diminishing trend is further accentuated by the predominance of the class 2 – 4 % in the southern part and the predominance of the class 0.2 % in the northern part. Towards the coast there is a definite increase as between Rhine and Yser mouth only values in the higher 2 – 4 % occur.

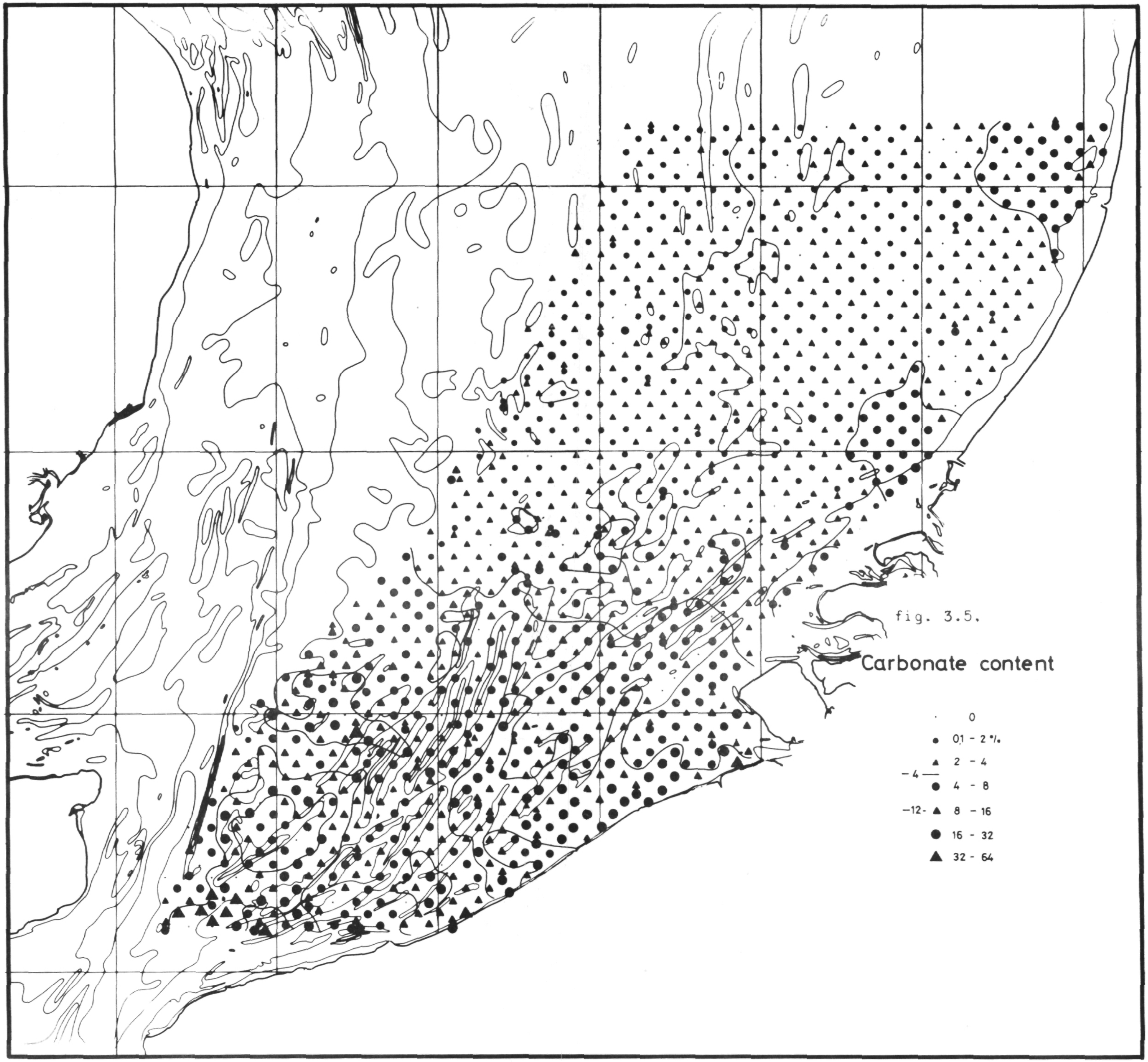
fig. 3.5.

Carbonate content

C.-

The major trend of diminishing carbonate content towards the north corresponds exactly with the trend in shell percentage as does the sharp boundary between north and south. This makes it clear that a positive correlation exists between shell content in the total sample and carbonate content in the fraction smaller than 2 mm . It shows that the carbonate content is due essentially to biological activity and is formed by commuted shells and microfossils. Highest values occur along the central axis with extremes of more than 50 % in the south. Influence of eroded chalk cannot be excluded here. Also the area before the Belgian-French border corresponds with high shell concentration. In this fraction smaller than 2 mm the high percentages can less be explained as lag deposits. Small platy shell fragments have indeed a higher transport capacity than equal quartz grains. This would indicate that the diminishing trend towards the north is essentially caused by less abundant mollusc life.

The three carbonate-rich areas before the Belgian coast, the Rhine and Yser mouths cannot be explained in the same way. Before the Belgian coast the area corresponds largely with a shell low or even shell-free area, and at the same time with predominance of mud, the carbonate is high and values between 20 and 30 % are frequent. This means that the carbonate is essentially present in the mud fraction. Its origin can be shell-flower but it cannot be excluded to be of local biochemical origin. The inflow of Ca-rich Sheldt waters and the presence of muds rich in organic substances may create physico-chemical conditions favourable for the development of calcareous nanno-organisms or even $CaCO_3$ precipitation.

The same relation with Rhine-Meuse waters holds in front of Rotterdam. The area is however much smaller. In this constellation can be seen a different behaviour of Scheldt waters which are trapped by the outer-lagoonal configuration while Rhine-Meuse waters are easily dispersed in open sea.

The area before the Yser mouth is again different and corresponds clearly with good biological conditions and correlates with higher shell percentage and low mud content.

To test these hypotheses the carbonate content will be further analysed by studying the grain size distributions of the carbonate, its mineralogical nature in the different fractions and the biological or chemical origin of the particles.

5.- Mean grainsize of the sands

A.-

The sandfraction is the load transported along the bottom. Its grainsize should be in equilibrium with the currents present when the sand is now being transported. A measure of central tendency of the sand should then depict the current energy on the seabottom.

After eliminating from the total sediment the gravel fraction, the suspension fraction, the carbonate and organic content, the pure sandfraction is obtained. As a measure of central tendency was chosen as a first approach the median, determined graphically on the cumulative curves of the sandfraction.

In figure 3.6 the obtained values are indicated by symbols referring to median grainsize classes based on a logarithmical series. After studying the distribution pattern 4 major groups were distinguished and named :

- Median finer than 175 µ : very fine sand;
- Median between 175 — 250 µ : fine sand;
- Median between 250 — 350 µ : coarse sand;
- Median coarser than 350 µ : very coarse sand.

In delineating the different areas greater difficulties were encountered than for the other maps. This was especially so in the southern ridge region. This could be expected because current velocities differ considerably in the swales, on the flancs and on the top of the ridges and sampling is too distant to give an information on this detail. Nevertheless a significant picture was obtained.

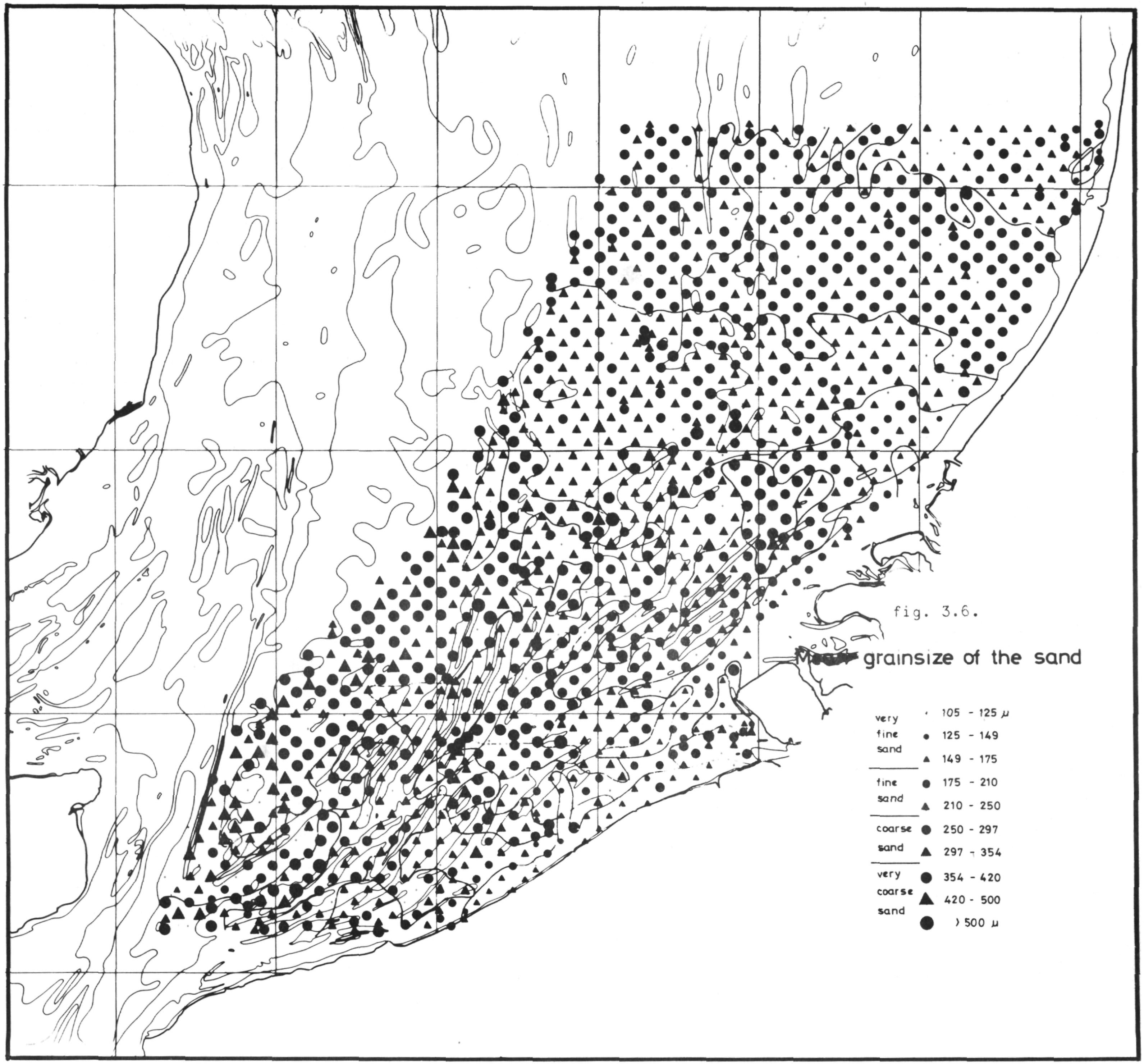

fig. 3.6.

Mean grainsize of the sand

B.-

1) Very fine sands

The very fine sands are strikingly only located along the coast. Two small patches occur in the neighbourhood of Rhine and Yser mouth. By far the biggest area is to be found along the Belgian coast, and on and in front of the triangular funnel plate of the Scheldt estuary.

2) Fine sands

At the northern border of the map appears a concentration of fine sand values approximately limited at 52°30' N . Further down the coast a large bulge is located at the Rhine-Meuse mouth and is continued by a small ledge along the coast up to the Scheldt estuary. In front of the Belgian coast this zone broadens but is at the same time interrupted by coarser sands in the Flemish Banks. In more open sea only one small area occurs south of West-Hinder Bank.

3) Very coarse sands

The very coarse sands follow an opposite pattern. The biggest area lies at the south-western border and coincides with the deepest water.

It is not only the largest area but it has the highest concentration of sand-medians above 420 μ . Other areas occur in the deeper swale between Sandettie and Flemish Banks and between the Hinder and Zeeland Banks.

North of the Zeeland Banks a few patches occur the largest one immediately to the north-east of them and located very close to the coast. North of 52° N only isolated samples of the very coarse sand occur.

4) Coarse sands

This class fills up the rest of the map as an intermediate zone but close inspection allows to separate it in two subclasses : the median between 250 – 297 μ and between 297 – 354 μ which will be named here medium-coarse and rather coarse.

North of a rather sharp line approximately at 52°12' N the great majority of samples is of the medium coarse subclass. Immediately south the rather coarse subclass is dominant with appearance of very coarse samples.

Further south once that the ridge topography starts this subdivision is much less meaningfull and gives only an indication that which subclass is more frequent. In this way the Zeeland Banks, the eastern Flemish Banks and Sandettie belongs to the medium coarse subclass, while the Hinder and western Flemish Banks are rather coarse.

C.-

The description has made it clear that the major trends in grainsize distinguished by Jarke (1956) are present, but more samples have refined and at the same time complicated the picture.

When trying to find explanations for this distribution it must first be stressed that we conceive the sampling of the uppermost sedimentlayer to have touched only material which is in equilibrium with actual conditions, either modern sediments on sedimentation areas or lag sediments on erosion areas.

A first major trend is the diminishing grainsize towards the north clearly shown by the parallel lines which separate the classes, coarser than 350 μ south of 52° N , coarser than 300 μ south of 52°12' N , coarser than 250 μ south of 52°25' N . This regular succession corresponds with a general rather flat bottom topography, characterized by megaripples progressing towards the north [Houbolt (1968)]. As bottom depth is uniform in this direction this change must be correlated with diminishing velocity of tidal currents as the tidal range diminishes from 3 to 1.5 m .

Note that in this area tidal currents are neatly opposite with a net residual current in NNE direction perpendicular to the grainsize limit-lines. In terms of sediment transport the grainsize fall from 350 to 250 μ should correspond with a velocity drop of one third.

In the southern ridge topography the picture is more complicated. The very coarse sands occurring in the deepest parts and in the swales between the ridges correlate often with high gravel and shell percentages and must be interpreted as lag deposits. All finer grainsizes are swept away. Problematical are the coarse patches surrounding the Zeeland Banks and which are in less deep water. Some of these might be depositional areas or represent fossil sediments.

The ridges have a great variation in grainsize which depends on the part of the ridge where the sample was taken as shown by Houbolt (1968). Nevertheless several families can be recognized.

- The coarsest ridge systems are the northern Flemish Banks and the Hinder Banks. Their direction is parallel with the tidal currents which are perfectly opposite with a net transport to the north.
- Less coarse is the Sandettie Bank situated in very deep water and its grainsize has a relation to the Falls. Sandettie is known to be fastly moving and is the major obstacle in the Channel route. Together with the Falls Van Veen (1936) considered it to be a broken up ebb-parabolic.

Another hypothesis would be to derive Sandettie material from the Falls. The rest currents in the Falls seem to be directed to the south with protrusion of the bank into strong channel currents. The sand here is taken up and swept to the north, building up Sandettie on the other side of the current axis with rest currents to the north. Mineralogical research will be conducted to verify this hypothesis.

The eastern Flemish banks are also less coarse corresponding with less energy. The same is true for the Zeeland banks. These have a topographical trend at an angle with the Hinder system which would favour the explanation of Houbolt (1968) as being stabilized fossil forms. We believe the actual tidal currents to be too strong to preserve ridges with which they are in desequilibrium. Their direction should then be an influence of the tidal pump system of the Scheldt estuaries on the general long-shore tidal current system.

The map demonstrates however another significant fact. In the open northern part the seabottom energy diminishes practically not along the coast. Only at the Yser mouth in the lee of a small bank the grainsize is finer and in front of the Rhine-Meuse mouth, due to local output.

However, in the southern part together with the development of the ridge topography the fine coastal sandy sediments become important. Highest energy is not situated along the coast but in the distant tidal ridges, this proves that wave energy is less important here than tidal currents for sedimentation.

6.- General conclusion

Sedimentation in the Southern Bight of the North Sea is essentially organized in response to a current system due to the funnel shape starting in the Straits of Dover.

In the southern part high current velocities are responsible for arranging the mobile very coarse sand in parallel ridges with swales in which lag deposits, gravel and shells, dominate. The lateral tidal pump system of the two Scheldt estuaries is responsible for the deviation of the ridges in front of the eastern Belgian coast. In this triangle finer sands are in equilibrium with lower energy. In the northern part sand size diminishes parallel to the coast proportional to lowering current velocity. Abruptly a new equilibrium is established with a flat bottomed sea without longitudinal ridges but with much smaller transverse megaripples. This system holds true up to the immediate neighbourhood of the coast proving that sedimentation is not organized by a wave model perpendicular to the coast, but by a current model parallel to the coast.

The Southern Bight is strikingly free of muddy sediments indicating that currents and here also wave turbulence are high enough to allow only temporary decantation but no final deposition. Only in front of the Meuse-Rhine mouth increased fluvial input of suspension material influences the bottom sediments. The big exception is the low energy triangle in front of the eastern Belgian coast in which muddy sedimentation is developing to a considerable extent due to local affluents as the Yser but mostly to the suspension material dragged out of the Scheldt estuary by low tide and trapped in this area.

ERTS-A, remote sensing documents, proved this fact strikingly showing a suspension plume in front of the Rhine mouth and a huge turbid area in front of the eastern Belgian coast connected with an extremely turbid Scheldt estuary.

References

BASTIN, A., (1973). Natural Radioactive Tracers and their Use in Belgium, *Tracer Techniques in Sediment Transport*, Techn. Rep. Ser. N° 145, I.A.E.A., Vienna.

BRIQUET, A., (1931). *Le littoral du Nord de la France et son évolution morphologique*, Paris.

GULLENTOPS, F., (1972). *A flowsheet for analysis on recent detrital sediments*, Progr. Noordzee, Groep Sedim., Rapport 1972.

HOUBOLT, J.J.H.C., (1968). Recent sediments in the Southern Bight of the North Sea, *Geol. & Mijnb.*, *47* (4), 245-273.

JARKE, J., (1956). Der Boden der südlichen Nordsee, *Deutsch. Hydr. Zeitschr.*, *Heft 1*.

LEE, A.J. and FOLKARD, A.R., (1969). Factors affecting turbidity in the Southern North Sea, *J. Cons. int. Explor. Mer*, *32*, 291-302.

M.A.F.F., (1957). *Hydrographical Observations 1957*, Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory Lowestoft.

MOENS, M., (1972). *Suspentiemateriaal*, Progr. Noordzee, Groep Sedim., rapport 1972.

MOENS, M., (1973). *Suspended matter – Bottom sediments*, Progr. Noordzee, Groep Sedim., rapport 1973.

STRIDE, A.H., (1963). Current-swept sea floors near the southern half of Great Britain, *Q.J.Geol. Soc. London*, *119*, 179-199.

VAN VEEN, J., (1936). Onderzoekingen in de Hoofden in verband met de gestelheid der Nederlandse kust, *Nieuwe verh. van Bataafs Gen. voor proefonderv. Wijsbegeerte te Rotterdam*, *Reeks 2*, *deel 11*.

VEENSTRA, H.J., (1969). Gravels of the Southern North Sea, *Mar Geol.*, *7*, 449-464.

WOLLAST, R., (1971). *Discharge of particulate pollutants in the North Sea by the Scheldt*, Techn. Rep. 1971 Sed. Scheldt.