ORIGIN AND TRANSPORT OF MUD (FRACTION < 16 MICRONS) IN COASTAL WATERS FROM THE WESTERN SCHELDT TO THE DANISH FRONTIER

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INTRODUCTION

The conclusions dealt with in this paper are partly based on analyses of bottom samples of newly deposited muddy or clayey material (fractions $< 16\ \mu$). The samples were taken from fresh, brackish and salt parts of estuaries, at different levels with regard to the water level and hence in different environments as to vegetation, groundwater conditions etc., and from similarly varied places on tidal flats and young salt marshes in and along the Dutch and German Wadden Sea. The analyses are compared with others from older marsh deposits, outside the dikes and in polders, that have been embanked within the last 100 years. In total, several thousands of analyses were carried out. No samples of sufficient size could be obtained from material suspended in the coastal waters.

A detailed account of the investigations mentioned in the present paper can be found in the author's thesis (DE GROOT, 1962).

THE MANGANESE SITUATION IN THE EXAMINED DEPOSITS

A main division of the Mn compounds in the investigated sediments can be made into exchangeable Mn and higher oxides. The exchangeable Mn is bound as manganous ions to the soil colloids and is the most mobile form. The higher oxides form a sequence of compounds with varying reactivity. They can be distinguished by their oxidizing power with respect to reducing agents.

The conversions between these Mn forms may be schematized as follows:

$$\underset{\text{exchangeable}}{Mn^{2+}} \rightleftarrows \underset{\text{easily reducible}}{MnO_2} \longrightarrow \underset{\text{rather inert}}{MnO_2}$$

The redox equilibrium between the exchangeable and easily reducible Mn is determined by the pH and the oxygen concentration in the sediment.

The oxidation of bivalent Mn, as indicated above, can take place by purely chemical processes, at pH values above 4.9, whereas microbiological oxidation may occur at pH's ranging from 4.8 to 8.9.

During transport in aerated river or sea water the mud cannot lose Mn, because the latter is almost exclusively present as insoluble higher oxides. Most of it is present in

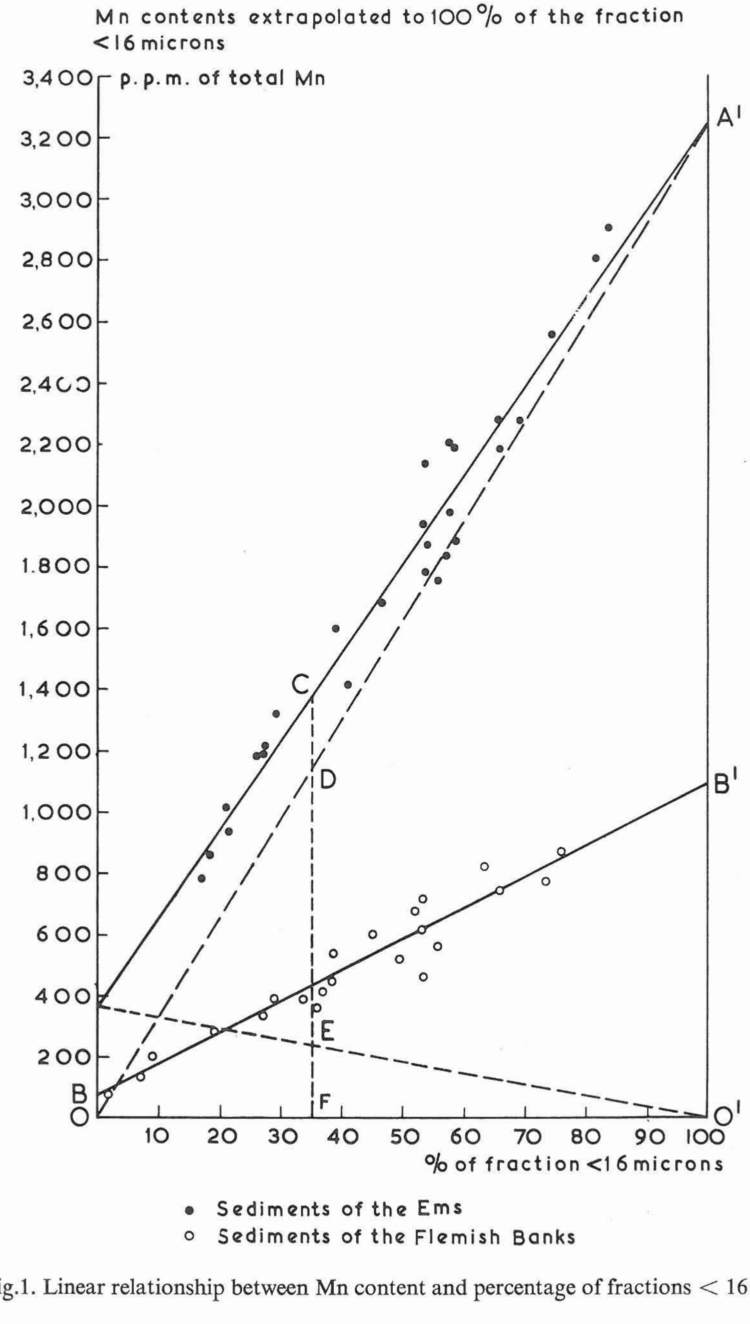

Fig.1. Linear relationship between Mn content and percentage of fractions < 16 μ.

the grain size fractions of 0–35 μ, as coatings around clastic particles or attached to clay flakes or as individual particles. In connection with this preferred occurrence in the fine fractions, a linear relationship is found to exist between the contents of Mn (both total and reducible Mn) and the fraction < 16 μ (in % of the $CaCO_3$-free mineral constituents), at least as long as the origin of the sediments and the environment of deposition are the same.

This relationship makes it possible to characterize a whole group of co-genetic sediments with different granulometric compositions by a single value. The value, chosen in the present study, is the Mn content (in p.p.m.) obtained by extrapolation of the relationship to 100% of the fraction < 16 μ (see Fig.1).

After deposition, reduction can take place to a smaller or larger extent, depending on the redox potential of the environment, followed by loss of Mn by way of the exchangeable form. In deposits of marshes and polders lying above the ground water table, this removal probably takes mainly place by drainage of percolating water. It is less obvious in what manner the Mn is carried off from sediments with very low redox potentials on mud flats. Possibly slow movements of the pore water, and diffusion of Mn ions are at least partly responsible. The degree and the velocity of this removal, in conditions of low redox potential, depends on the salt content, the salt ions dissolved in the pore water tending to replace the Mn attached to the sediment particles. In fresh water environments the Mn content decreases only very slowly.

Notwithstanding this loss of Mn, the relationship between Mn contents and percentages of the fraction < 16 μ remains approximately linear, so that the characteristic values (for 100% of the fraction < 16 μ) can still be determined in the same way as for freshly deposited material. In areas with sediments coming from the same source, these values are therefore more or less indicative of the degree of ageing. In general, salt marshes yield lower values than the forelying tidal flats, while the values for embanked polders are distinctly lower again than those for the marshes (see Fig.3–5).

CHOICE OF REPRESENTATIVE SAMPLES

For drawing conclusions about the origin and the direction of transport of mud on account of the Mn contents, only a part of the investigated samples could be used. For the tidal flats, the choice of these samples had to be limited to the most recently deposited material (not older than a few days), which was scraped from the surface with a knife. Even so it was found that some values were abnormally low, e.g., those obtained from muds that were deposited after heavy storms, during which much older material in the areas had been resuspended. In other cases the variation of the Mn contents was too large to allow calculation of a representative linear relationship from which a characteristic value could be extrapolated. This variation may probably be attributed to the mixing of freshly supplied mud from the rivers or the sea, with various locally reworked older materials. In general, only the highest values in each area could be considered as significant in this respect.

ORIGIN AND TRANSPORT OF MUD

The origin of the mud deposits in Zeeland, investigated along the Western and Eastern Scheldt estuaries appears to be twofold. A minor part is supplied by the river Scheldt, the major part coming from the North Sea (Fig.3). The Scheldt river mud has the higher Mn content of the two. Its sedimentation is mainly confined to the eastern part of the Western Scheldt. The river influence decreases towards the west. Its relatively small importance is especially evident when the Mn contents in the muds of the Western and Eastern Scheldt are compared (Zuid Sloe > Noord Sloe; Kreekrak-polder > Hogerwaardpolder).

The precise origin of the mud carried from the North Sea into these estuaries is not yet certain. One possible source is the waters of the British Channel, entering the North Sea through the Straits of Dover. Another source, which has been suggested in the literature on this subject, could be the mud layers in, and in front of the mouth of the Western Scheldt (Flemish Banks and Wielingen), which have Mn contents lying not very far below those of the Zwarte Polder area, the Zuid Sloe and the Noord Sloe. However, the circumstance that their Mn contents (1092) are still rather high, notwithstanding the relatively high salinities of the water, may indicate that these mud

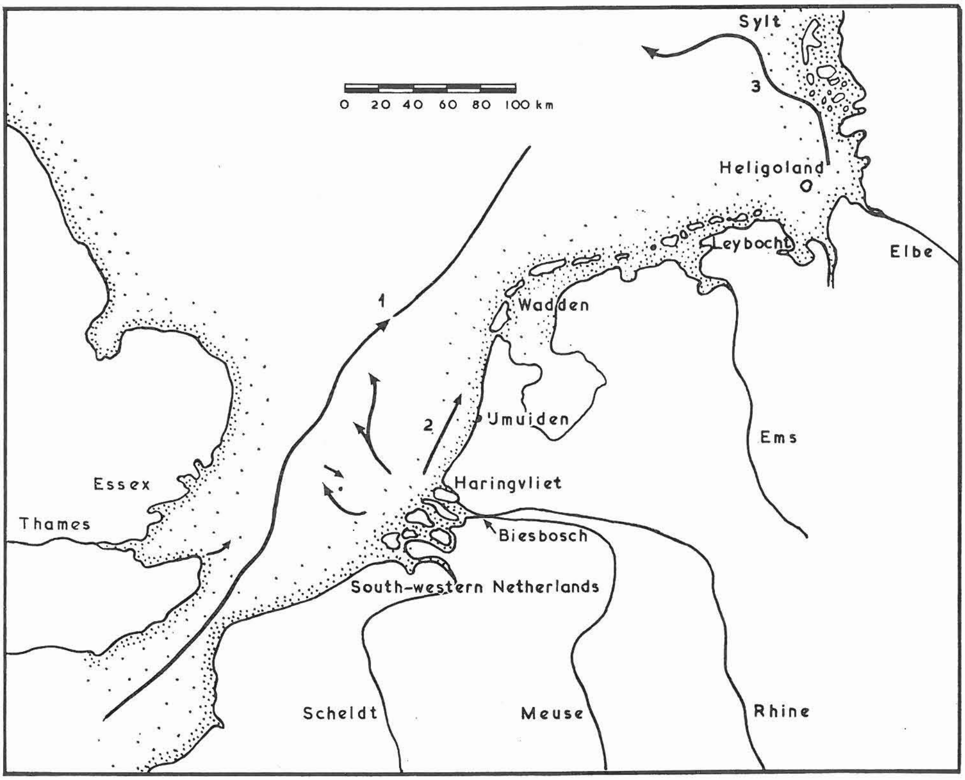

Fig.2. Water movements in the North Sea, according to KALLE (1937).

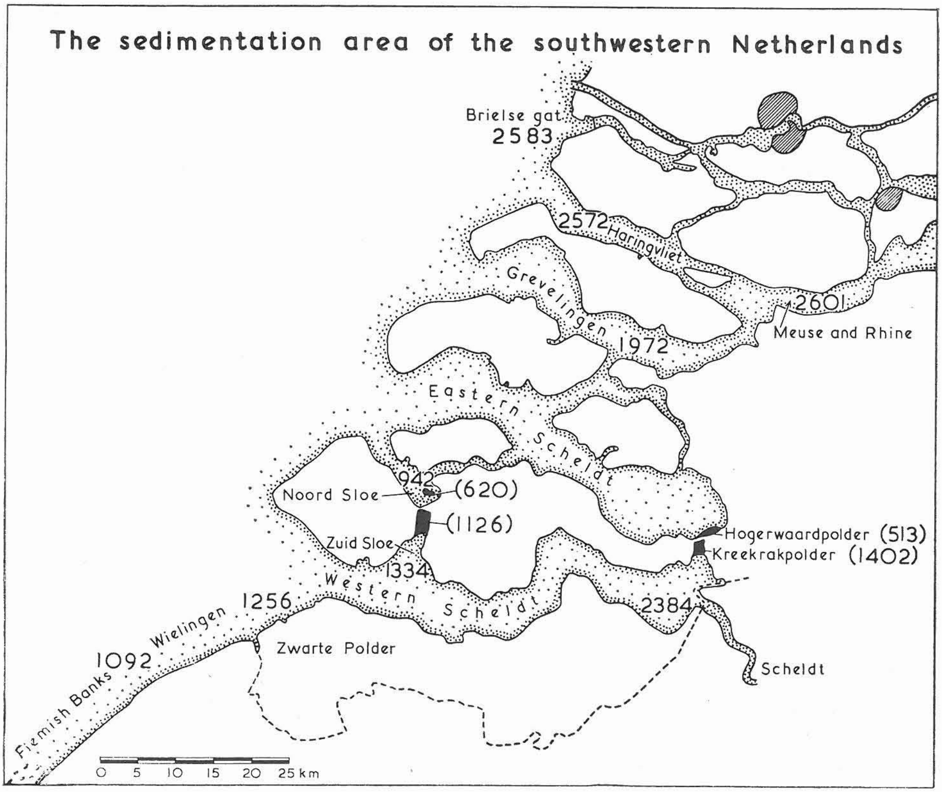

Fig.3. Manganese values (extrapolated to 100% of fraction $< 16\ \mu$). Values between brackets refer to embanked areas. Other values refer to recent deposits outside the dikes (shoals, tidal flats etc.). Values for salt marshes etc. have been omitted.

layers are not old at all, but that they were deposited recently. Consequently, the material of the Flemish Banks and the Wielingen looks rather like another deposit of the same mud supplied via the Straits of Dover.

By investigating the sediments of the fresh water tidal delta of the Biesbosch (Fig.2) it was found that little difference exists between the Mn contents of the mud supplied by the Rhine and those of the Meuse. Approximately the same values were obtained for the Haringvliet and the Brielse Gat, whereas in the Grevelingen the value is lower. The latter is probably the result of mixture with mud supplied from the south.

The mud transported into the western Wadden Sea, and deposited along the shore of Friesland (Fig.4) has the same value. This may point to a direct transport of material from the Rhine and the Meuse, along the coast of South and North Holland in northeasterly direction (2 on Fig.2), an interpretation which seems to be corroborated by analyses of mud in the harbour of IJmuiden.

The lower Mn contents off the shore of Groningen may be partly due to temporary deposition in the Wadden Sea, followed by further transport in eastward direction over the Wadden Sea flats. A similar decrease is found when the analyses of the young

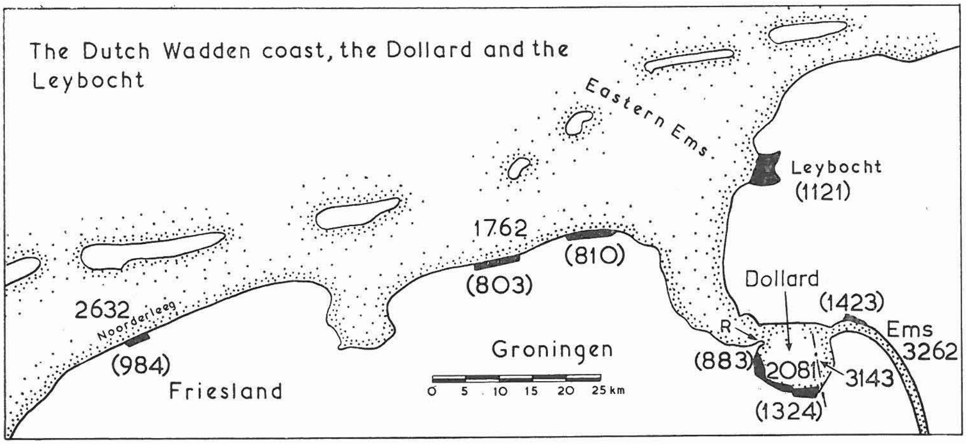

Fig.4. For explanation, see Fig.3.

polder deposits of Friesland and Groningen are compared with each other.

The Mn contents of the mud carried seaward by the river Ems are considerably higher than those of the Meuse and Rhine sediments (Fig.4). Passing along the shores of the Dollard from the Ems mouth via the southern part to the Punt van Reide (R), this influence is seen to diminish gradually. Except for the Punt van Reide itself, the Mn contents in the Ems–Dollard area are everywhere higher than those of comparable deposits in Friesland and northern Groningen, thus clearly showing the significance of the Ems for the sedimentation in the Dollard.

The deposits of the reclaimed area of the Leybocht correspond, in Mn content, to the sediments (of comparable degrees of ageing) along the shore of Friesland, which may point to a common origin, viz. out of the North Sea.

The mud deposited along the western shores of Schleswig Holstein (Fig.5) has a complex origin. Part of it comes from the Elbe and another part from the older Holocene marine clay beds, eroded on the shallow sea floor in front of Dithmarschen and North Friesland. Other sources may contribute to a smaller degree.

The Elbe mud contains more Mn than any other mud investigated. The old clay layers on the sea floor in front of the coast, on the other hand, have very low Mn contents (e.g., Nordstranddamm). The Mn values of the mud deposited at present along this coast therefore depend on the ratio of mixture of the two.

The contribution of the Elbe component carried northwards with the sea currents (3 in Fig.2) decreases from the mouth of the Elbe via the Meldorfer Bay to the mouth of the Eider. However, further northward, along the Hindenburgdamm the Mn contents are again very high. The same variations are found in the young polders along this coast.

In this connection it is interesting to observe that the variations in Mn content in the sampled areas outside the dikes are accompanied by similar changes in the contents of organic matter. The highest values for organic material in this region were obtained in the deposits along the Elbe. Along the shores of the Meldorfer Bay and the mouth of the Eider the contents are much lower (admixture of old marine material, poor in organic matter). The sediments at the Hindenburgdamm again show relatively high values.

In conclusion it may be remarked that at most only a very subordinate part of the mud deposited along the continental coast can be supplied by the river Thames. This

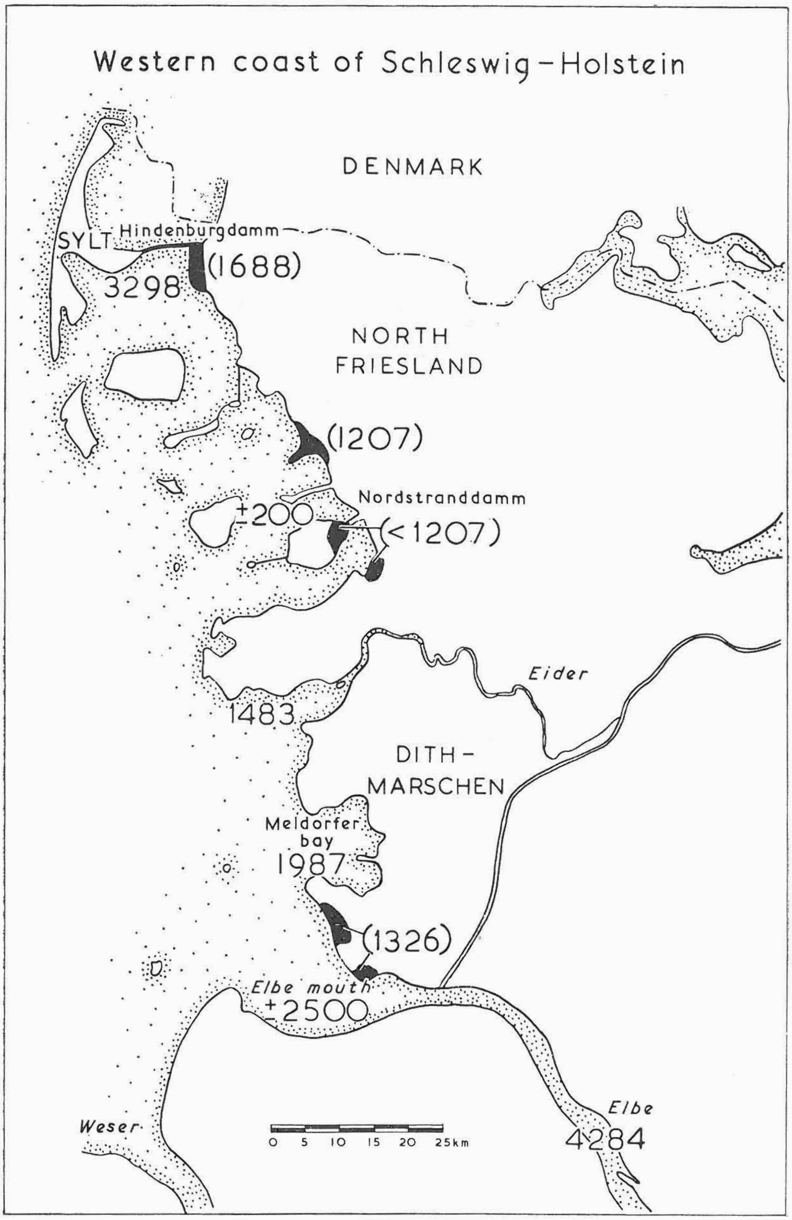

Fig.5. For explanation, see Fig.3.

appears from the low Mn contents of the Thames muds sampled along the shore of Essex. A significant transport of Thames mud across the sea is also unlikely on account of the water circulation in the North Sea (Fig.2). Owing to the flow of water through the Straits of Dover, the waters along the English coast in the vicinity of the mouth of the Thames are carried northeastward, towards the centre of the southern North Sea, rather than across this sea to the shores of Belgium and Holland.

SUMMARY

To determine the contents and character of manganese compounds in Holocene deposits (fractions $< 16\ \mu$) along the North Sea coast of Holland and Germany, several thousands of analyses have been made. It was found, among other things, that the manganese content is very variable, owing to postdepositional migrations. When this influence is allowed for, regional differences appear to exist, which can be interpreted as the result of primary differences in Mn content of the source material. Using Mn as a tracer, the following conclusions can be drawn about the origin of the mud and the directions of transport along the coast:

(*1*) The mud in the Eastern and Western Scheldt is supplied only for a small part by the river Scheldt. The river influence is strongest in the eastern part of the Western Scheldt. Most of the mud deposited in these two estuaries is brought in from the North Sea. Originally it probably comes from the British Channel.

(*2*) The mud of the rivers Rhine and Meuse, which is not deposited in the estuaries, is carried in northeasterly direction, along the coast of South and North Holland and is partly deposited in the Wadden Sea.

(*3*) Supply of mud by the river Ems is an important factor for the sedimentation in the Dollard. The contribution of river material is seen to diminish when going along the Dollard shores from the mouth of the Ems via the southern part to the Punt van Reide.

(*4*) Deposition along the western shores of Schleswig Holstein takes place under influence of the supply of mud by the river Elbe and by erosion of older Holocene deposits on the flats in front of the shores of Dithmarschen and North Friesland.

(*5*) The supply of mud by the river Thames has no visible significance on the composition of the fine grained sediments along the coasts of the continent.

REFERENCES

De Groot, A. J., 1962. *Mangaantoestand van Nederlandse en Duitse Holocene Sedimenten in Verband met Slibtransport en Bodemgenese.* Thesis, Univ. of Utrecht, 205 pp. Also *Verslag. Landbouwk. Onderzoek.*, 69 (7) : 164pp.

Kalle, K., 1937. Nährstoffenuntersuchungen als hydrographisches Hilfsmittel zur Untersuchung von Wasserkörpern. *Ann. Hydrograph. Maritim. Meteorol.*, 65 : 1–18.