Composition, origin and distribution of Dutch coastal sands between Hoek van Holland and the island of Vlieland

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INTRODUCTION

Dutch coastal sands – dune, beach and sea sands – vary greatly in size and composition, but apart from local variations two main types of sand can be distinguished. One type has a rather high quartz content ($> 95\%$) and contains comparatively many coloured quartz grains, while garnet is predominant in its heavy fraction (s.g. > 2.88) (BAAK, 1936). On the beaches and in the dunes, as well as on the nearshore North Sea floor, this type is found chiefly north of Bergen on the North-Holland coast (Fig. 1; EDELMAN, 1933; BAAK, 1936). MEYBOOM (1959) found that on the beaches and in the dunes this northern type of sand is characterized by the presence of coarse garnet ($> 210\ \mu$).

The other type occurs farther south. It has a lower quartz content ($< 90\%$) and contains few coloured quartz grains; saussurite and hornblende dominate its heavy fraction. According to EDELMAN's data (1933) the boundary between the two types of sand on the beach near Bergen is sharp: mixing occurs over a distance of less than 1 km. The results of MEYBOOM (1959), however, suggest mixing over at least 10 km.

The difference in mineralogical composition suggests a difference in origin. EDELMAN (1933) found in the coastal sands all types of minerals typical for the following sources:

a, river sands from the Rhine, Meuse and perhaps Scheldt;
b, river sands of "eastern origin" which were deposited in large amounts in the central and northern Netherlands during the early Pleistocene, and
c, sands present in the Saalian glacial deposits.

Reworked Tertiary sands from the mouth of the Scheldt, present at least as far north as Scheveningen, are indicated by the presence of Tertiary Bryozoa (NOORDHOORN VAN DE KRUYFF & LAGAAY, 1960). Virtually no sand along the Dutch coast comes from the French and English Channel coasts (EDELMAN, 1933; BAAK, 1936).

Recent supply of river sand from the Rhine, and probably also from the Meuse and the Scheldt, is very small (VAN VEEN, 1936; TERWINDT, DE JONG & VAN DER WILK, 1963) but conditions may have been different during the older Holocene periods (VAN STRAATEN, 1963). The presence of gravel in Subboreal deposits of Rhine sands near the coast at Schiedam (DE JONG, 1964) indicates that comparatively large amounts of sand may have reached the sea during that period. VAN STRAATEN (1961, 1963, 1965) therefore suggested that the beach and dune sands south of Bergen are mainly reworked late Pleistocene and Holocene Rhine sands, the difference in mineralogical composition

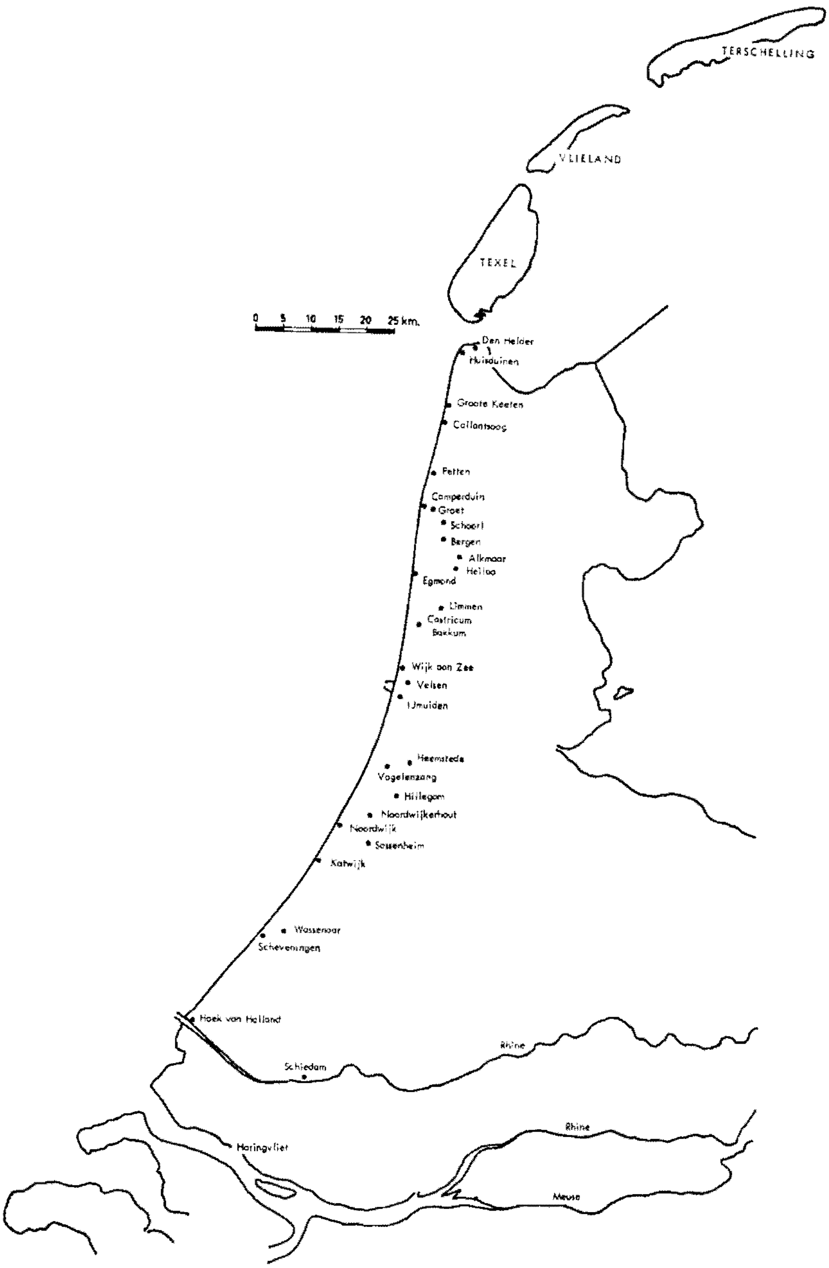

Fig. 1. Sketch map of the Dutch coastal area.

between the beach sands and the late Pleistocene-Holocene Rhine sands being due to the difference in grain size. North of Bergen the coastal sands would contain a large amount of reworked older Pleistocene sands.

EDELMAN (1933, 1938) and BAAK (1936) concluded, however, that the older Pleistocene sands had become mixed and transported southward into the Channel area during the Saalian glaciation when most of the North Sea was covered by ice and the flow of river water and melt water of the ice sheet must have been generally southward. Subsequently, after the disappearance of the ice, the marine transport became generally northward, as it is at present, and the mixed sands were transported towards the Dutch coastal area. Partly at least, this must have occurred already during the Eemian interglacial: the marine Eemian sands, except in the nearshore areas near the river mouths of that time, have the same mineralogical composition as the present coastal sands (BAAK, 1936; ZONNEVELD, 1958). It would follow that the present coastal sands are mainly early and middle Pleistocene sands which probably have been reworked several times during the Eemian, the Weichselian and the Holocene.

The difference in mineralogical composition of the sands north and south of Bergen was attributed by EDELMAN (1938) to mixing of the same components (Rhine-Meuse sands, sands of "Eastern origin" and Saalian glacial sands) in different proportions. Fine gravel of eastern origin of 3–5 mm is present in very small quantities in nearshore deposits off Den Helder and off Petten (J.S. ZANDSTRA, personal communication). STEENHUIS (1915) found an admixture of small Saalian gravel in the dune sands near Schoorl which is absent in the dune sands farther south. This points to the presence of a relatively large amount of sand derived from the Saalian glacial depositis, which lie at the surface somewhat farther north and east. The higher percentages of garnet also support this argument.

High garnet percentages, however, can also be the result of local selection on beaches where severe erosion occurs. This has often been observed along the Dutch coast at Goeree, Vlieland and near Bergen-Schoorl (VAN DER SLEEN, 1912; CROMMELIN & SLOTBOOM, 1945; DE VRIES, 1949). Still another process which can result in high garnet contents in the heavy fraction is selective weathering; late Pleistocene podzol profiles, occurring in the subsoil along the coast, have high garnet contents in the B-layer (DE JONG, 1957; CROMMELIN, in DU BURCK, 1959).

Besides being different in mineralogical composition, the two main types of sand also contain different amounts of calcium carbonate, magnesium carbonate and iron. Data given by DELESSE (1871), VAN

DER SLEEN (1912), DOEGLAS (1950) and DOING (1966) indicate that the beach sands north of Bergen to Terschelling have a low $CaCO_3$ content, usually below 0.5%. South of Bergen to Hoek van Holland the $CaCO_3$ content is higher, usually more than 2%. In the latter area the highest lime contents, up to 12% (DELESSE, 1871), occur between Wijk aan Zee and Noordwijk. South of Hoek van Holland on the beaches of the islands of South-Holland and Zeeland, the $CaCO_3$ content again is lower and may decrease to less than 1%.

In the dunes the $CaCO_3$ content was determined by BYHOUWER (1926). North of Bergen the dune sands generally contain as little $CaCO_3$ as the beach sands, with local accumulations of shell fragments near the nesting places of seagulls. Usually the foredune has a slightly higher lime content than the dunes farther inland, probably due to admixture of fresh shell fragments from the beach. South of Egmond the lime content of the dune sands is generally high and may increase locally to more than 25% through sorting, as shell fragments, being heavier and usually larger than sand grains, tend to accumulate in lag deposits. Similar lag deposits on the beach are usually reworked after a short time so that such high concentrations are less common there. In the high dunes which form the landward boundary of the coastal dunes, a top soil layer, often poor in lime and 10–15 cm deep, has been formed by leaching. Most authors mention mollusk shell fragments, dead shells and other organic remains (*e.g.*, spines of *Echinocardium*, a sea urchin) as the main source of the calcium carbonate in the sands. RETGERS (1891, 1895) also found detrital calcite grains, while VAN BAREN (1927) noticed fresh calcite rhombohedra in beach sands near Vogelenzang.

Magnesium carbonate in beach sands was determined by VAN DER SLEEN (1912): between Bergen and Terschelling he found 0.02–0.15‰ $MgCO_3$, between IJmuiden and Katwijk 0.10–0.60‰. These data give Ca:Mg ratios of 0.6–7.5 (Bergen to Terschelling) and 8–29 (IJmuiden to Katwijk).

Iron content varies between 0.14–0.32% Fe_2O_3 (Bergen to Terschelling) and 0.69–1.04% (IJmuiden to Katwijk; VAN DER SLEEN, 1912). DOING (1966), using a different method, gives somewhat lower values: 0.09–0.16% between Camperduin and Egmond and 0.25–0.62% from Velsen to Hoek van Holland. The iron occurs mainly as ferric hydroxyde coatings on the grains, which results in marked differences in colour: the northern sands are light-creamy, the southern sands brownish.

The brown coating on the grains of the southern sands is at least partly caused by comparatively recent deposition of iron. VAN STRAATEN (1965) found brown stained sands in the nearshore area off Scheveningen and IJmuiden and suggested that iron had been deposited by upwelling fresh groundwater. Brown coloured mollusk shells, mainly *Spisula* sp., *Cardium edule* and *Macoma balthica*, have their maximum abundance at 10–18 m water depth, which corresponds with the occurrence of coarse brown sands at the same depth in the subsoil near the coast. EISMA *et al.* (1966) found that iron-rich sands occur as far as 12 miles offshore and that their distribution is related to the outflow of fresh water from the Rhine and Meuse.

In the dunes the variable composition of the sands has resulted in the development of very different types of vegetation, which are mainly related to the amount of calcium carbonate present (JESWIET, 1913; DOING, 1966). Due to this difference in vegetation, and to the different colour of the sands, the boundary between the two main types of sand near Bergen is a marked feature in the dunes and on the beach.

There appears to be no clear difference in grain size between the northern and southern sands. DOEGLAS (1946, 1950) found four types of size frequency distribution in the beach sands between Den Helder and Hoek van Holland, separated by sharp boundaries at Bakkum, IJmuiden, Vogelenzang and Scheveningen. DOEGLAS' analyses were made with a sedimentation balance. FABER (1955, 1960), who determined average grain size and sorting of some beach and dune sands by measuring and counting the grains under a microscope, found boundaries at Grote Keeten, Petten, Bergen, Wijk aan Zee and Vogelenzang.

A few analyses of sea sands collected off Scheveningen and IJmuiden were given by DOEGLAS (1950). Subsequently PRATJE & SCHÜLER (1952) and JARKE (1956) published maps showing the general distribution of grain size in the southern North Sea. These studies indicate that in the Dutch coastal area there is a gradual decrease in grain size from southwest to northeast. West of Texel and Vlieland, however, coarse sands occur again, mixed with gravel and occasionally boulders.

The fairly sharp boundaries between sands of different composition suggest that longshore transport of sand is slight (DOEGLAS, 1950). The general resultant movement of the bottom water off the Dutch coast is towards the north-northeast (RAMSTER, 1965), but nearshore wave movement, more at right angles to the coast, becomes important. Tank experiments by TIMMERMANS (1935) indicate that a beach can be formed entirely by waves with an angle of incidence of about 90°. VAN STRAATEN (1961) concluded from a discussion of waves and from the lack of asymmetry of the beaches and the submarine slope at the IJmuiden harbour entrance, that between Noordwijk and Texel little residual longshore transport can be expected. Tidal currents and short, high waves tend to move sand towards the north, long-period waves towards the south. South of Noordwijk there must be some longshore movement towards the northeast, while along the Wadden Islands there is strong longshore movement towards the east.

The object of the present study was fourfold:

a, to determine quantitatively whether the coastal sands contain a large admixture of Holocene and Late Pleistocene Rhine sands, or whether they are mainly reworked older Pleistocene sands. To do this the mineralogical composition of beach and dune sands between Scheveningen and Den Helder was studied in detail and compared with the mineralogical composition of sands of known origin;

b, to study the influence of local sorting, and weathering, on the mineralogy of the beach and dune sands;

c, to study the factors that govern the distribution of calcium carbonate, magnesium carbonate and iron hydroxyde;

d, to reach some conclusions on the transport of sand along the Dutch coast.

The analytical data are presented in part A, preceded by a short description of the area and the location of the samples. A discussion of these data follows in part B. The conclusions are given in part C.

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Admixture of fine sand from the old-Holocene tidal flat deposits and from the recent Rhine may also explain why in the sea sands iron content decreases instead of increases, towards the finer sizes. As the finer sizes are much more mobile than the coarser sizes, fine grains with and without a secondary deposit of iron will tend to become mixed much stronger than the coarser grains. Moreover, iron will be concentrated on the coarser grains which predominantly are moved along the bottom. All this will lead to a comparatively low iron content in the finer size fractions as is found in the sea sands.

C. CONCLUSIONS

1. The coastal sands are predominantly reworked early- and middle-Pleistocene sands. North of Bergen reworked Saalian glacial sands, Meuse sands and Rhine sands of the S-association are present with probably a small admixture of sand of eastern origin and some Rhine sands of the AS-association. Leaching has resulted in loss of some hornblende and probably of some augite. The sands south of Bergen are mainly reworked Rhine sands of the S-association with an admixture of late-Pleistocene-Holocene Rhine sands. The proportion of Rhine sands of the AS-association is larger south of IJmuiden than between IJmuiden and Bergen.

2. The existence of two types of sand of very different mineralogical composition near to each other without large scale mixing is due partly to the relatively recent (Holocene) conditions along the coast, partly to the general history of the sands. In pre-Saalian time, Rhine sands of the S-association and to a lesser extent, of the AS-association, were deposited in the northwestern Netherlands, together with some Meuse sands and, presumably, some sands of eastern origin. During the Saalian, ice covered the northern half of the Netherlands and sands of the A-association were deposited in that area. Since in post-Saalian time the Rhine had a mainly southern course, supplying some AS-type of sand to the southern coastal sands, virtually no sand of AS-type was supplied to the northern area.

The mixing of the Saalian A-sands, Rhine sands of S-type and Meuse sands occurred mainly during the Eemian (by the sea), the Weichselian (by the wind) and the Holocene (during coastal erosion and the formation of inlets). Erosion during the Weichselian and the Holocene, and probably also during the Eemian, did not reach great depths, except locally in the tidal inlets, which explains the virtual absence of an admixture of sands of eastern origin, usually present at some 25–60

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m or less below the Saalian deposits. During the Holocene the area north of Bergen remained land or shallow tidal flat until very recently, separated from the coastal sands farther south by tidal inlets. An inlet in the area of Bergen-Schoorl was filled up, around 3500 B.P., with sands from the north, whereas much later, during the early Middle Ages, an inlet at Bakkum-Bergen was filled up mainly from the south. After this inlet was closed more sand again came from the north, probably in connection with erosion of the coast north of Bergen and the formation of the tidal inlet between Huisduinen and Texel. Thus the zone of mixed sands between Bakkum and Bergen was formed, with lower feldspar contents near to the beach and higher feldspar contents in the most landward dunes. After a period of erosion, during which the sharp boundaries north of IJmuiden originated, the beach became stable between IJmuiden and Egmond, but continued to retreat farther north.

3. Offshore the recent sediment pattern is mainly determined by the residual transport northwards by tidal currents of sand grains smaller than about 300 μ, whereas along the beach the sediment pattern is mainly determined by sand movement at right angles to the coast, the residual transport (mainly of grains $< 200\ \mu$) parallel to the coast being small. Thus along the beach sharp boundaries are found between the various types of sand, whereas offshore the boundaries are diffuse.

The beach sands north of IJmuiden are mainly locally reworked older Holocene sands, the boundaries between the various types coinciding with marked, older Holocene features. The sharp boundary at IJmuiden reflects a general change in grain size. The beach sands south of IJmuiden are mainly recently deposited sands moved shorewards from the sea floor.

Offshore coarser sands occur off Hoek van Holland-IJmuiden and off Texel-Vlieland, whereas fine sands, containing an admixture of sand grains $< 300\ \mu$ transported northwards occur between IJmuiden and Den Helder. The areas off Hoek van Holland-IJmuiden and Texel-Vlieland are areas of (slow) erosion, characterized by comparatively high amounts of dead mollusk shells, shell fragments and Eemian fossils. The area off IJmuiden-Den Helder is an area of (slow) deposition.

4. Generally, offshore as well as along the beach and in the dunes, Al and Fe contents are comparatively low north of Bergen, high farther south. Along the beach and in the dunes there is also a difference in Ca and Mg content: it is low at km-piles 2–34, high at km-piles 44–92, with a gradual increases between km-piles 34–44.

The distribution of Al and generally also of Fe is related to the origin of the sands. Al is contained in the feldspars; Fe, as considered here, is present in the coatings on the grains. Secondary (recent) deposition of iron occurs off Hoek van Holland-IJmuiden and in low quantities over the entire area of investigation. Secondary loss occurs under reducing conditions nearshore and, by leaching, under subaereal conditions. Leaching is especially evident in the sands north of Bergen.

Only in the fine size fractions is the distribution of Ca and Mg (partly) related to the origin of the sands. In these size fractions Ca and Mg occur in detrital calcite grains and in a recent secondary admixture of organic carbonate grains (Foraminifera, Echinoid spines, Bryozoa). In the coarse size fractions ($> 200\ \mu$) Ca and Mg are mainly present as a recent secondary admixture of mollusk shell fragments.

5. The secondary deposition of iron on the sea floor is related to the release of iron from sediment particles in the Rhine-Meuse estuary. This results in relatively high concentrations of dissolved iron in the estuary and in the nearshore water of the North Sea. Flocculation then leads to deposition of iron on the sea floor. On the beach, deposition of the iron floccules is prevented by strong turbulence.

6. Shell fragments are formed mainly by fragmentation of the more fragile mollusk shells (of the species *Abra alba*, *Abra prismatica*, *Angulus fabula*, *Angulus tenuis*, *Ensis* sp.). This fragmentation is chiefly done by one species of bottom fish, *Pleuronectes platessa*, the plaice, which feeds on these mollusk species and cracks the shells. Mechanical action by currents and waves seems to be of minor importance.

The distribution of the species with fragile shells indicates that the nearshore area with fine grained sediments is the main source of shell fragments. The distribution of fine shell fragments (315–400 μ), however, does not show a nearshore maximum due to the subsequent landward transport of the fragments by the waves. Where the beach advances, as at km-piles 57–91, and also to a lesser extent where the beach is more or less stable (as at km-piles 37–53), shell fragments are accumulated on the beach. North of km-pile 37, shell fragments do not show a nearshore maximum partly because the coast is retreating, partly because this area only became marine in the Middle Ages.

Offshore the relative amounts of shell fragments are high off Hoek van Holland-IJmuiden and Texel-Vlieland, and low off IJmuiden-Den Helder where also sand moved northwards from the south, is deposited. The distribution of whole dead shells and coarse fragments $> 1000\ \mu$ is similar to the distribution of the living mollusks except off Hoek van Holland and off Texel-Vlieland where secondary accumulations have been formed by the removal of finer material.

7. The distribution of magnesium generally follows the distribution of calcium but the Ca : Mg ratio is variable. This is due to: *a*, an irregular admixture of Echinoid fragments which have a higher Mg-content than mollusk shell fragments; *b*, secondary sorption of Mg from sea water on the shell fragments, and *c*, a relative increase of Mg during acid leaching under subaereal conditions.

8. Summarizing, the difference in Al, Fe, Ca and Mg content between the southern and northern beach and dune sands is due to the combined effect of: *a*, the difference in origin; *b*, the pronounced effect of leaching in the northern sands; *c*, the fact that the northern sands became beach sands only during the Middle Ages whereas the southern sands have been beach or sea sands already since the Atlanticum; *d*, separation of the northern and southern sands by tidal inlets since the Atlanticum, which prevented the direct movement of southern sand towards the north; *e*, a generally slow residual movement of sand from south to north, and *f*, continuing erosion of the coast north of Bergen so that there is virtually no recent deposition of shell fragments on the beach.