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# TERMINOLOGY AND LITHOSTRATIGRAPHIC DIVISION OF (SURFICIAL) SANDY EOLIAN DEPOSITS IN THE NETHERLANDS: AN EVALUATION[1]



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## ABSTRACT

Koster, E. A. 1982 Terminology and lithostratigraphic division of (surficial) sandy eolian deposits in The Netherlands: an evaluation – Geol. Mijnbouw 61: 121-129.

The terminology of the eolian sand deposits and related form and relief types in The Netherlands is reviewed and evaluated. Because there is as yet no consensus on the criteria for a division of eolian sediments into lithostratigraphic units, the various lithological properties of the following 'sand types' are discussed: Younger and Older Coastal Dune Deposits of the Westland Formation, (Younger and) Older River Dune Deposits of the Kreftenheye Formation, Younger and Older Cover Sand Deposits of the Twente Formation, Older Inland Dune Deposits of the Twente Formation and Younger Inland Dune Deposits of the Kootwijk Formation. Geomorphological criteria, that can facilitate in distinguishing between these seemingly homogeneous 'sand types', have been summarized. A simplified lithostratigraphic division of surficial eolian sediments into three formations is tentatively proposed.

## INTRODUCTION

Eolian sands of Weichselian to Recent age form a substantial part of the surficial deposits in The Netherlands. The main part of these sands lie over non-eolian deposits in a 'blanket'-like form with average thicknesses ranging from less than one to only several metres. Thicknesses of up to ten metres or even more are reached but only in exceptional cases when sands fill major depressions or valleys. The majority of these eolian sands lack a dune relief and belong to the classical 'cover sand region' of The Netherlands. A minor but more conspicuous part of the surficial eolian deposits displays a dune relief. They are found concentrated along the coast or major river courses or scattered in many isolated patches throughout the country. These eolian sands often attain thicknesses of more than ten metres.

The terminology used in describing the eolian sand deposits and related relief forms in The Netherlands (as well as in neighbouring countries) is confusing due to the fact that geomorphological, stratigraphical, and pedological concepts are used indiscriminately. To a large extent this is the result of research being carried out from various institutes of different backgrounds. Whenever eolian sand deposits or forms are being described, it should be made clear which meaning is attached to the descriptive terms used and preferably definitions should be included as a consensus on this subject is still lacking. Even the latest edition of the 'Geological Nomenclature' (VISSER, 1980) is not entirely correct and far from complete in this respect.

In this article the current use of 'eolian terminology' is reviewed and evaluated. Special emphasis is laid on the obvious difficulties in distinguishing various lithostratigraphical units within these relatively uniform sands. Tentative suggestions for a simple lithostratigraphic division of eolian deposits in The Nederlands are given.

## TERMINOLOGY

In a strictly geomorphological sense, three basic relief types are distinguished in eolian areas: dunes (characterized by height differences of at least 5 m and/or maximum slope angles of more than 5 to 6°), undulations (5 - 0.5 m, 5 to 6 -

[1] Manuscript received: 1981-02-25.
Revised manuscript received and accepted: 1981-10-23.
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0.5°) and plains (< 0.5 m, < 0.5°). Individual dune types are identified and classified according to various morphometric and morphogenetic criteria.

The extensive eolian formations in the 'sand-belt' of the West- and Central European Lowlands, of which The Netherlands form the westernmost part, are divided with respect to the geomorphology and depositional environment as follows (KOSTER, 1978): a. *coastal dune forms,* situated along present or former coastlines; b. *river dune forms,* which follow present or previous river courses; c. *inland dune forms,* which comprise all dune occurrences which are not directly related to coastlines or river courses; d. *cover sand forms,* which include all eolian sand formations essentially characterized by a relatively flat to gently undulating relief. Gradual transitions from coastal dunes to river dunes or to inland dunes are relatively uncommon, at least in The Netherlands. Gradual transitions from river dunes to inland dunes on the other hand are common; in those cases where distinction between the two is difficult to make, they are combined and indicated as inland dunes.

Coastal, river and inland dune areas, indicated on geomorphological maps of The Netherlands (scale 1:50 000 and smaller) also include the relief types eolian undulations and plains, which are either too small or too chaotically distributed to be indicated separately. The word *dune* is thus considered useful for its general, genetic implication as a sand body of eolian origin. In a strictly geomorphological sense, however, the term dune is also quantitatively defined. Therefore, (impractical) descriptions like 'coastal/river/inland dune forms including related eolian undulations and plains' are used on geomorphological maps. Cover sand forms are defined as forms consisting of eolian sand covering relatively large areas with a more or less uniform thickness, and with a relief basically characterized by height differences of less than 5 m and slope angles predominantly less than 5 to 6°. They occasionally occur as rather low (isolated) ridges without any steep slopes. Therefore a name like 'cover sand dunes' is considered a contradiction in terms, at least in geomorphological studies.

With respect to the sedimentology and depositional environment eolian sediments are divided as follows: a. coastal dune deposits; b. river dune deposits; c. inland dune deposits; d. cover sand deposits. In The Netherlands a major part of the inland dune deposits consists of so-called *drift sand* ('Flugsand', German; 'sable mouvant', French; 'stuifzand', Dutch). This term is reserved for those eolian sands which originate through relatively 'young', local resedimentation of terrestrial Pleistocene deposits. They usually display a chaotic dune relief and are sometimes still actively forming. Drift sands which are not (yet) stabilized by vegetation should preferably be called 'active drift sands' instead of 'drift dunes' ('Flugdünen', German; 'stuifduinen', Dutch). Eolian sands that are related to present or former river courses and resemble the original fluviatile source sediments should be described as river dune deposits and not as drift sands, even when they are formed recently. Transitions to drift sands can occur, but only in the case of redeposition of original river dune deposits. The use of the term 'river drift sand' ('rivierstuifzand', Dutch) should be avoided however (STICHTING VOOR BODEMKARTERING, 1976), as it only leads to confusion. The same applies for the term 'coastal drift sand'. Eolian sands along small watercourses can be indicated as 'brook dune deposits', although they rarely reach a real dune form. When the material of river dunes is surrounded and partly or even completely covered by younger Holocene fluviatile deposits it is locally called 'donkzand'.

The term *cover sand* ('Decksand', German; 'sable de couverture', French; 'dekzand', Dutch) has a stratigraphical meaning, apart from the already mentioned geomorphological implication. Cover sands are essentially Weichselian eolian sand deposits, which accumulated under periglacial conditions and which are not directly related to present or former coastlines or river courses. In The Netherlands these Weichselian eolian sands usually display a certain relief type – as indicated earlier – that has become known as a 'cover sand relief'. However, going from West to East in the 'European sand-belt' a continually increasing proportion of these Weichselian eolian sands have a dune relief and not a cover sand relief (NOWACZYK, 1976; KOSTER, 1978; KOSTER & SLOTBOOM, in prep.). Therefore it is proposed to make a distinction, on geomorphological grounds, between Weichselian cover sands and likewise Weichselian *dune sands* (Table 1), in spite of the fact that these sand deposits can be more or less identical in lithology and age. These Weichselian dune sands are ascribed to the Older inland dunes ('Altdünen', German), in contrast to the Holocene drift sands, which are ascribed to the Younger inland dunes ('Jungdünen', German; Table 1). In German the term 'Flugdecksand' is often used. Sometimes it is presented as a synonym for 'Flugsand', sometimes for 'Decksand'. In spite of the fact that the term 'Flugdecksand' is now quite current, its use has only added to confusion and is therefore best avoided or at least restricted. In any case, it should not be used as a synonym for drift sand nor for cover sand; it could possibly be used to indicate the material of the Older (Weichselian) inland dunes or 'Altdünen'.

Three other terms which need proper definition when used are 'Wehsand', 'Staubsand' and 'Flottsand'. They should not appear as synonyms for cover or drift sand. Eolian deposits with different textural properties, which probably reflect different modes of transportation and sedimentation, may be indicated by adding simple descriptive adjectives derived from a generally accepted textural classification. The term 'Wehsand' ('soil blowing sand' or 'akkerstuifzand' in Dutch), however, can be used for sediments formed by (sub)recent deflation and subsequent accumulation on arable fields, whereas the term 'Staubsand' ('dust sand' or 'stofzand' in Dutch) should be reserved only for sediments that are accumulations of long-distance atmospheric dust. The name 'Flottsand' can just as well be replaced, in the case where it is of eolian origin, by descriptive terms like loamy cover sand or

Table 1
Proposed terminology and stratigraphic position of eolian sand deposits.

| | Present — app. 1000 | app. 1000 — app.5000 | app.8500 — app.13000 B.P. | app.13000 B.P. — |
|---|---|---|---|---|
| | Middle Ages to Recent | Subboreal to Middle Ages | Late Glacial to Early Holocene | Pleniglacial (Middle Weichselian) and older |
| eolian inland sands | Younger Inland Dune Deposits/"Jungdünen" | | Older Inland Dune Deposits/"Altdünen" | |
| | Younger drift sands/ "Jüngere Flugsande"/ "Jonge stuifzanden" | Older drift sands/ "Ältere Flugsande"/ "Oude stuifzanden" | Younger dune sands/ "Jüngere Dünensande"/ "Jongere duinzanden" | Older dune sands/ "Ältere Dünensande"/ "Oudere duinzanden" |
| | | | Cover Sand Deposits/"Decksande" | |
| | | | Younger cover sands/ "Jüngere Decksande"/ "Jongere dekzanden" II in Late Dryas Stadial I in Early Dryas Stadial | Older cover sands/ "Ältere Decksande"/ "Oudere dekzanden" II in Upper Pleniglacial I in Upper Pleniglacial and older |
| | Kootwijk Formation | | Twente Formation | |
| eolian river sands | Younger River Dune Deposits | | Older River Dune Deposits Kreftenheye Formation | |
| eolian coastal sands | Younger Coastal Dune Deposits Westland Formation | Older Coastal Dune Deposits | | |

sandy loess, depending on the grain size distribution of the sediment.

## LITHOSTRATIGRAPHIC UNITS

DOPPERT ET AL. (1975) summarized the data concerning the lithostratigraphic units of the Quaternary of The Netherlands as an explanation to the General Geological Map of The Netherlands, scale 1:600 000. With respect to surficial eolian sediments four formations are relevant.

In general, the sediments are classified into units based on their characteristic lithological properties, which are preferably readily identifiable in the field. However, as the classification is also based on a genetic distinction, several units comprise sediments of different lithology (texture, structure and composition), but have the same 'genetic origin' or belong to the same 'genetic region'. This approach may therefore result in the joining together of sediments of completely different lithology within one and the same (genetic) formation on the one hand, and the separation of sediments with apparently identical lithology into different formations on the other hand.

The fluviatile deposits are systematically classified according to relative age and provenance of the sediments. The provenance determines to a large degree the appearance, the grain size distribution and the heavy mineral and gravel composition of these sediments, all important criteria for the classification of fluviatile formations. For the sandy eolian sediments, which are usually of local origin, the system has not been followed. They have mostly been included in formations, of which the names are based on their genetic environment and on their relative age. Within certain limits, the seemingly homogeneous eolian sediments can greatly vary in geomorphology, grain size distribution and composition. This variation depends on environmental sedimentation conditions, source materials (substratum) and distance of transport.

In the following section information on the lithology of eolian deposits is compiled almost exclusively from Dutch literature sources. A correlation with the stratigraphic divisions pertinent to this subject in the neighbouring areas (Belgium and Niedersachsen, Germany) can not be made. This is partly due to a lack of relevant data in these countries, but it is also caused by differences of opinion concerning the genetic interpretation of these deposits. The proposed terminology of eolian sands in relation to the chronostratigraphic position and the current lithostratigraphic division is summarized in Table 1. Type-localities and other sites, mentioned in the text, are indicated in figure 1.

### *Younger and Older Coastal Dune Deposits*

Coastal dune deposits are considered part of the *Westland Formation,* which includes all Holocene coastal deposits related to the rising sea level (DOPPERT ET AL., 1975). The Older (Coastal) Dune Deposits have been laid down mainly between app. 5000 B.P. and 100 A.D. and to a minor extent in the 8th and 9th century, whereas the Younger (Coastal) Dune Deposits accumulated after app. 1150 A.D. (JELGERSMA ET AL., 1970). The Older and Younger (Coastal) Dune Deposits

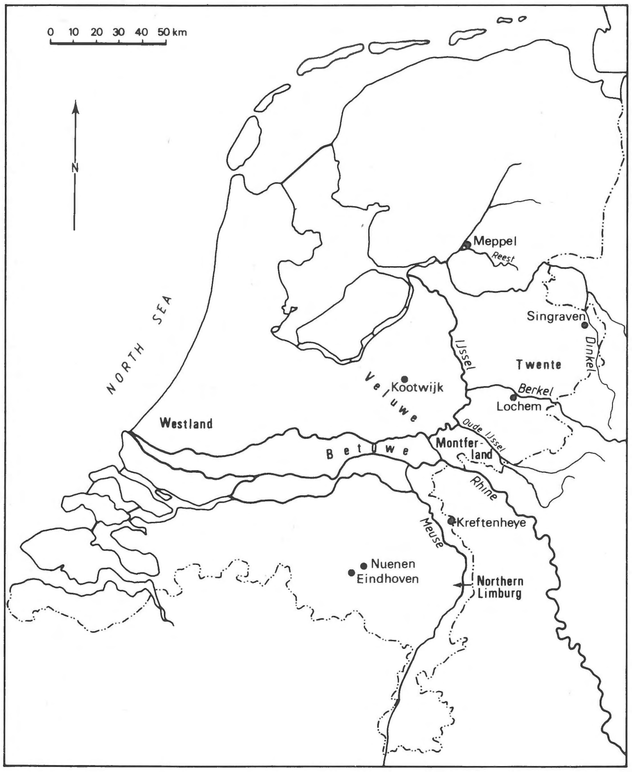


Fig. 1
General map, showing Dutch type-localities and other sites.

display only minor differences in grain size distribution and usually consist of moderately fine to moderately coarse, well-sorted, unimodal, calcareous to non-calcareous, quartz sands with a loose to dense grain-packing (DEPUYDT, 1972; BAKKER ET AL., 1979). These sands vary in mineralogical composition – mainly depending on differences in origin – as shown by the extensive studies of EISMA (1968). The dune sands often show, apart from (sub)horizontally stratified beds, low- to high-angle cross-bedding with trough-shaped set boundaries. In many places intercalated peat layers, vegetation horizons and soil profiles are also present. The distinction between Older and Younger (Coastal) Dune Deposits is accentuated by major differences in geomorphology and soil formation.

*Younger and Older River Dune Deposits*

Weichselian (to very early Holocene) river dune deposits, including partly or completely buried sand dune bodies ('donken'), are considered part of the mainly fluviatile *Kreftenheye Formation* (DOPPERT ET AL., 1975). This formation is connected with the deposits of large rivers (Rhine and Meuse). However, there is still some disagreement in this matter. This can be illustrated by the fact that although the dune sands on the eastern and northeastern side of the Meuse and the river Oude IJssel are shown as belonging to the Kreftenheye Formation in the text of DOPPERT ET AL. (1975), they are indicated on the geological map accompanying that publication as belonging to the Kootwijk Formation; this is probably due to the fact that local resedimentation resulted in the presence of sheets of drift sand. In fact, on this map only the 'donken' along the river courses are indicated as Kreftenheye Formation.

VERBRAECK (1970) states that these so-called 'donk sands', which were deposited predominantly during the Late Dryas Stadial, consist of moderately coarse to very coarse, non-rounded moderately-sorted sands. These sands have a relatively uniform, unimodal grain size distribution and are at present noncalcareous. The heavy mineral composition of the 'donk sands' is more or less identical to that of the corresponding river sands. VAN DE MEENE (1977, 1980) describes an eolian sand deposit at the top of the fluviatile part of the Kreftenheye Formation in the Eastern Netherlands, which has been dated between the beginning of the Late Dryas Stadial and the Atlantic. This sand layer clearly originated when river bed deposits of the Rhine were transported by southwesterly winds. On the basis of similarity with the river dune deposits of VERBRAECK (1970, 1974), these sands are ascribed to the Kreftenheye Formation by VAN DE MEENE (1980). This is in spite of the fact that the geomorphology and age of these deposits might equally point to an interpretation as Younger Cover Sand II of the Twente Formation.

It is not clear which part of the eolian sands northeast of the river Oude IJssel and east of the Meuse in Northern Limburg belongs to the Kreftenheye Formation and which part to the Kootwijk Formation (STICHTING VOOR BODEMKARTERING, 1975; VAN DE MEENE, 1977; TEUNISSEN, 1973). River dune sands and drift sands within a certain area can be almost identical in grain size distribution and as detailed mineralogical analyses are lacking a lithological distinction between the two is sometimes difficult to make. In pedological studies, distinction between the drift sands (Kootwijk Formation) and the river dune sands (Kreftenheye Formation) is mainly based on the absence or presence of a more or less completely developed soil profile at the top of the deposits. Only in those sporadic cases where Late Holocene river dune deposits occur, is it impossible to use this pedological criterion, because the time available for soil formation has been too short. However, the majority of the river dune deposits in The Netherlands seems to have accumulated during the Late Dryas Stadial and possibly the earliest part of the Holocene. These deposits have a relatively dense grain-packing and layers rich in organic material are absent. This is in contrast to what is found in the drift sands.

Along various rivers in The Netherlands eolian sediments have been described as river dune deposits, which more or less resemble cover sands: along the river IJssel from Late Dryas to Early Holocene age (VAN DEN AKKER ET AL., 1964; MAARLEVELD, 1968; STICHTING VOOR BODEMKARTERING, 1979) and from Late Holocene age (HAMMING ET AL., 1965); along the river Dinkel from supposedly Middle Holocene age (VAN DER HAMMEN & WIJMSTRA, 1971); along a former river course of the Berkel near Lochem (SCHOONDERBEEK, 1965); along a former river course of the Reest near Meppel (DE ROEVER ET AL., 1975).

However, according to the authors these river dune deposits can be distinguished in most cases from the cover sands that occur within the same areas on the basis of a higher content of the coloured grains, and/or a higher content of heavy minerals, and/or a higher percentage of little resistant minerals within the river dune deposits. This is in agreement with the observations that the heavy mineral composition of the river dune deposits usually shows more resemblance to that of the supposedly original fluvial sediments than to that of the cover sands. In certain cases it already appears possible to distinguish these deposits on field characteristics like grain size and colour of the sediment. Strictly speaking the Holocene (Younger) river dune deposits could be classified as belonging to the Betuwe or Singraven Formations, analogous to the usage of the eolian part of the Kreftenheye Formation. These deposits, however, occupy a small area within the country and it has not been deemed necessary to show them separately on the geological maps.

*Younger and Older Cover Sand Deposits*

In a lithostratigraphical sense cover sands can be described as essentially Weichselian (to Early Holocene) eolian sand deposits, which are characterized by a strongly developed soil profile (only in the uppermost part of the deposits), a relatively dense grain-packing and a general absence of thin layers rich in organic (sometimes clastic) material. They frequently display periglacial structures (frost cracks) and belong to the *Twente Formation* (DOPPERT ET AL., 1975). Evidence for the periglacial nature of the depositional environment of the cover sands is frequently found (VAN DER HAMMEN ET AL., 1967; MAARLEVELD, 1976; KOLSTRUP, 1980), but proof of the 'niveo-eolian' character of these deposits is still lacking.

The eolian origin of the cover sands has been well-known for a long time (OOSTING, 1936; EDELMAN & CROMMELIN, 1939), and the litho- and chronostratigraphy of the cover sands in The Netherlands and the adjoining northern part of Belgium have been investigated in detail (see the summaries by VAN DER HAMMEN ET AL., 1967 and ZAGWIJN & PAEPE, 1968). The Weichselian stratigraphy of the cover sands has been most closely investigated in the valley of the Dinkel, resulting in a comprehensive documentation by VAN DER HAMMEN & WIJMSTRA (1971). In certain areas, cover sand deposition still continued in Preboreal and Boreal time (TER WEE, 1966; BISSCHOPS, 1973). Pre-Weichselian cover sand-like deposits are either incorporated in the Eindhoven Formation or in the so-called Nuenen (Sub) Group.

The thickness of the extensive cover sand layer in the country is usually less than 3 to 4 metres, but in certain areas (e.g. depressions and valleys) thicknesses of more than 10 metres have been reported (TER WEE, 1966, 1979; VAN DEN TOORN, 1967; VAN DE MEENE, 1977).

Cover sands are usually more or less horizontally bedded, sometimes finely laminated and relatively well-sorted. They vary from very fine to moderately coarse, loamy to non-loamy, predominantly non-calcareous, quartz sands with low contents of coloured grains and heavy minerals. The large variations in grain size distribution determine to some extent, apart from other criteria, the lithostratigraphic division into various members and/or beds. Based on mineralogical investigations, CROMMELIN (1964) concluded that the Younger as well as the Older cover sands are of more or less local origin. The heavy mineral composition of Younger and Older cover sands within a certain region shows a large conformity, which in turn is clearly related to the mineralogical composition of the sediments in the local subsoil. The same applies to percentages of coloured grains, which were studied by MAARLEVELD (1968). The beds of rivers and brooks as well as alluvial fans have been the major local source areas for cover sands according to MAARLEVELD (1968) and KOSTER (1978). VEENSTRA & WINKELMOLEN (1971) analyzed grain size and shape-sorting of a limited number of samples of Younger cover sands and tentatively suggested that the bulk of these sands has been derived from the present North Sea area north and northwest of The Netherlands. They thus more or less follow the original ideas (summarized by VINK, 1949) on the regional character of a part of the cover sands. The conclusion of VEENSTRA & WINKELMOLEN (1971), however, is contradicted by geomorphological (see Table 2 – dominant orientation directions) and mineralogical (CROMMELIN, 1964) evidence.

*Older Inland Dune Deposits*

Weichselian inland dune sands which have more or less the same lithological properties as cover sands, but which are characterized by a dune relief are currently ascribed to the *Twente Formation*. The most obvious examples of these are the so-called 'pseudo-osar' of Late Glacial age in the Central Netherlands (MAARLEVELD, 1951). These large, elongated or parabolic ridges consist of moderately coarse to very coarse sands. Detailed studies on sedimentary textures and structures of these deposits have not been published yet. Apart from these more or less isolated ridges there are dune areas with sands, which appear to have the sediment characteristics of cover sands but a relief that is usually found in the drift sand areas (BISSCHOPS, 1973; KOSTER, 1978). In these cases it is impossible – without detailed field research and sediment analyses – to determine whether the sediments should be ascribed to the (Weichselian) Older Inland Dune Deposits of the Twente Formation or to the (Holocene) Older drift sands of the Kootwijk Formation.

The distinction made in Table 1 between Younger and Older dune sands (both belonging to the Older Inland Dune Deposits) does have a rather academic value, for The Netherlands anyway. However, in eastern European countries like Poland, this distinction is at least as relevant – because of the widespread occurrence – as the well-known distinction in Younger and Older cover sands (KOZARSKI ET AL., 1969; NOWACZYK, 1976; KOZARSKI, 1978; KOSTER & SLOTBOOM, in prep.).

*Younger Inland Dune Deposits*

Inland dune sands that originate by resedimentation of terrestrial deposits, (usually cover sands), and which rest on a clearly developed soil profile in the underlying deposits and/or are characterized by a mainly light yellow-grayish colour, a loose to moderately loose grain-packing, an absence of periglacial structures, and generally the presence of layers rich in organic (sometimes clastic) material are called drift sands in The Netherlands. They are known as the *Kootwijk Formation.* The first small scale drift sand accumulation started in the Early Subboreal (KOSTER, 1978). From various areas Early Subatlantic drift sand occurrences have been reported (WATERBOLK, 1961, 1965-1966; TEUNISSEN, 1973; TER WEE, 1979; KOSTER & SLOTBOOM, in prep.). However, drift sand deposition took predominantly place in and after the Late Middle Ages (KOSTER, 1978). Analogous to the division between Older and Younger (Coastal) Dune Deposits, a more or less synchronous division in Older and Younger drift sands (Table 1) was introduced (KOSTER, 1978).

The drift sands usually consist of (sub)horizontally bedded or low-angle cross-bedded, finely laminated, very fine to moderately fine, non-loamy, well-sorted, non-calcereous, quartz sands. They have a low content of coloured grains and heavy minerals. The grain size distribution and heavy mineral composition of drift sands varies and is in accordance with the locally occurring subsoil. The subsoil usually consists of cover sands or relatively well-sorted fluvio-glacial or fluvio-periglacial deposits.

TER WEE (1966) and VAN DEN TOORN (1967) observed that the drift sands are mostly somewhat coarser than the cover sands within the same area. Apart from a slightly better sorting of the drift sands, KOSTER (1978), however, found no significant differences in grain size between drift sands and non-loamy (Younger) cover sands in the Central Netherlands. On the other hand, drift sands and loamy (usually Older) cover sands are obviously quite different in grain size distribution.

The major part of all drift sand areas is stabilized by afforestation that dates from the end of the last century, but small active areas still remain. In pedological studies, drift sands are normally distinguished from cover sands on the basis of the presence of a vaguely (initial) developed soil profile in contrast to a strongly developed podzolic profile in cover sands. However, this pedological criterion can only be applied to Younger drift sand occurrences. For the time being it appears to be difficult to distinguish between Older drift sands, lacking a dune relief, and (Weichselian) cover sands of the Twente Formation.

So far I have specified the lithological properties of the various eolian sand deposits and indicated just how local differences in these properties can aid in determining the lithostratigraphic units involved. Apart from generally available granulometric data, systematic research on sediment properties of the eolian sands of large regions is lacking. They are needed for a better understanding of the nature of the depositional conditions, the provenance, and the sedimentary textures and structures of these extensive sediments. Figure 2 illustrates the conformity in grain size distributions of these eolian sands. By collecting hundreds of grain size distribution data of these eolian sands from different locations all over the country and by leaving out all the finer- or coarser-grained extremes, a sort of typical ('overall mean') grain size distribu-

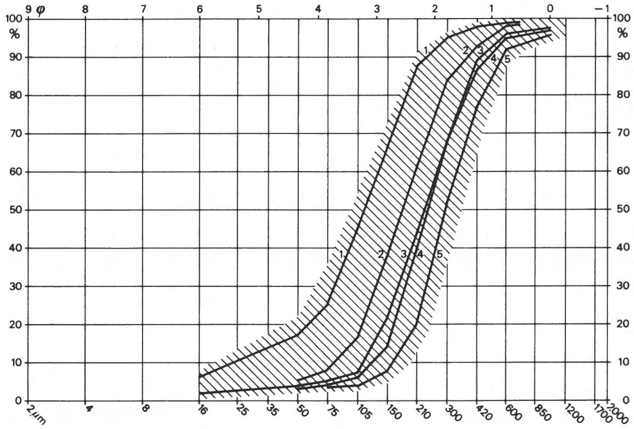


Fig. 3
Average grain size distributions of eolian sands in different formations in a specific region (Map sheet 40 Oost, Arnhem, Eastern Netherlands): 1 - Middle Weichselian cover sands of the Twente Formation; 2 - Younger Cover Sands I and II of the Twente Formation; 3 - River Dune Deposits of the Kreftenheye Formation; 4 - Younger Inland Dune Deposits of the Kootwijk Formation (1-4 compiled after data of Van de Meene, 1977); 5 - Older Inland Dune Deposits of the Twente Formation (data of Drs. J. J. M. van der Meer).

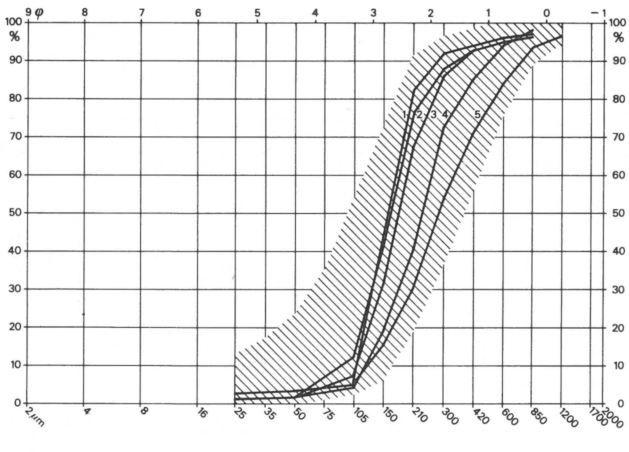


Fig. 2
Typical grain size distributions of eolian sands in different formations in The Netherlands (compiled after various sources): 1 - Coastal Dune Deposits of the Westland Formation; 2 - Cover Sand Deposits of the Twente Formation; 3 - Younger Inland Dune Deposits of the Kootwijk Formation; 4 - River Dune Deposits of the Kreftenheye Formation; 5 - Older Inland Dune Deposits of the Twente Formation.

Table 2
Morphographical and morphometrical properties of eolian forms.

| | Younger coastal dunes | River dunes | Cover sand forms | Older inland dunes | Younger inland dunes |
|---|---|---|---|---|---|
| (local) height differences, predominantly | 2,5-30 m | 2,5-12,5 m | < 2,5 m | ● 2,5-10 m | 1,5-10 m |
| (local) height differences, maximum values | < 52,5 m | < 25 m | < 5 m | ● < 15 m | < 20 m |
| maximum slope angles, predominantly | * 10°-25°/15°-30° (stoss/lee side) | ⊙ 5°-12°/10°-22° (stoss/lee side) | 0,5°-6° | ● 5°-15° | 15°-33° |
| maximum slope angles, absolute maximum | * 34° | ⊙ 25° | < 15° | ● 25° | 47° |
| occurrence of transverse forms | (+) | (+) | (+) | - | (+) |
| occurrence of longitudinal forms | (+) | - | (+) | + | - |
| occurrence of parabolic forms | + | + | + | (+) | - |
| occurrence of irregular forms | (+) | (+) | (+) | - | + |
| dominant orientation directions | N75°-80°/ 255°-260°E | N60°-70°/ 240°-250°E | N65°-110°/ 245°-290°E | app. N70°/250°E | N65°-70°/245°-250°E |
| | Westland Form. | Kreftenheye Form. | Twente Form. | Twente Form. | Kootwijk Form. |

● in the northwestern Veluwe, acc. to data collected by Drs. J.J.M.van der Meer;
⊙ in Northern Limburg, acc. to data collected by J.Stakenborg;
* acc. to data collected by Drs. J.Klijn.
frequency of occurrence: + dominant, (+) common, - rare.

tion has been selected. Although the curves show a tendency of increasing coarseness from the units 1 to 5, it is clear that grain size in general is not a useful criterion for distinction, as the standard deviations in the central part of the distribution of each sample group are more than 0.5 $\phi$. In figure 3, where identical data have been put together for a specific region, c.q. the Montferland area in the eastern Netherlands, the curves show a lesser degree of overlap. In this case standard deviations in the central part of the distributions are less than 0.5 $\phi$. The loamy Older cover sands (1) are obviously finer than the non-loamy Younger cover sands (2) that occur within the same areas. The river dune sands (3) and the drift sands (4) are almost identical in grain size, but clearly coarser than the cover sands. The Older inland dune sands (5) are clearly by far the coarsest eolian sands within this area.

## GEOMORPHOLOGICAL CHARACTERISTICS

In soil mapping, as well as in geological mapping, the geomorphology of the accumulational and erosional forms of the eolian relief does to a certain degree assist in the determination and limitation of the units. As selective lithogenetic criteria are often difficult to assess in the field – as has been shown before – it makes sense to try to use geomorphological criteria also for the lithostratigraphic division of surficial eolian sands.

On the Geomorphological Map of The Netherlands (1974), scale 1:600 000, a distinction is made between coastal dunes, longitudinal dunes (the so-called 'pseudo-osar' in the Central Netherlands), inland dunes (including river dunes), and cover sand forms. On this scale it is obviously impossible to make a distinction between inland dune forms and river dune forms. On the Gomorphological Map of the Veluwe (TEN HOUTEN DE LANGE, 1977), scale 1:100 000, it even became necessary to unite inland dune and cover sand forms in certain cases.

On the Geomorphological Map of The Netherlands, scale 1:50 000, 29 eolian form units are distinguished (TEN CATE & MAARLEVELD, 1977). They fall into the categories: coastal dune forms, inland dune forms (including river dune forms), active 'drift dune' forms, cover sand forms, and (artificial) 'drift dykes' along the coast. Of the river dunes only the so-called 'donken' are indicated as such and eolian sand accumulations along smaller rivers and brooks are usually indicated as cover sand forms.

The individual forms and relief types of the five 'sand types' discussed in this article are usually distinct from each other. As a certain degree of overlap, however, occurs, it is only possible to characterize the relief types by means of maximum values of height differences and slope angles. The geomorphological characteristics have been summarized in Table 2, partly according to KOSTER (1978). Although the geomorphology of eolian forms has been the subject of many investigations, detailed morphometric data are very scarce. One of the few exceptions is the study by KADAR (1938) on German and Polish inland dunes. The data in Table 2 on the slope angles of coastal and river dunes are the values measured in the frontal part of parabolic forms. In the southern and northern tails of these parabolae values will be found that differ from those in the frontal part. KADAR (1938) also found large differences in slope angles especially between the stoss sides of the southern and northern tails of the parabolic dunes. For the frontal parts he presented the following values: stoss sides 6°-16° (mean 10°), lee side 12°-36° (mean 20°). Exceptionally steep slopes, as found in the cliff faces of coastal dunes, have been disregarded in Table 2. The chosen limits of cover sand forms are more or less in agreement with the corresponding values used in the Geomorphological Map of The Netherlands (1974). Slope angles of > 6° do only sporadically occur in cover sand forms. The data on the Older and Younger inland dunes refer to the Central Netherlands (Veluwe). Minimum values are obviously of no use, since examples of both cover sand plains and (more seldom) drift sand plains with local height differences of less than one metre may be found.

The majority of the eolian forms in The Netherlands show more or less identical, dominant orientation directions, irrespective of genesis, age and source areas (KOSTER, 1978). Finally, the frequency of occurrence of various dune forms is indicated in Table 2, demonstrating clear but not exclusive differences. The same applies to the morphometric data in Table 2.

## CONCLUDING REMARKS

The existing division of eolian sand deposits, as discussed in this paper, is obviously a rather unwieldy one. The lithostratigraphic units involved comprise eolian 'sand types', which are distinguished from each other on the basis of various criteria like genetic origin, lithology, relative age, and geomorphology. However, it can be concluded that various surficial eolian sand occurrences within the country are difficult to classify, on the basis of field characteristics alone, as either belonging to the Kootwijk, Twente, or Kreftenheye Formations. Both in lithology and in geomorphology the eolian 'sand types' discussed appear to have a certain degree of overlap. As long as more detailed field research and sediment analyses are lacking it might be better to simplify the stratigraphic nomenclature with respect to the eolian deposits. This might take the form of a division into three units: a. Younger and Older Coastal Dune Deposits, excluding all other (non-eolian) Holocene coastal deposits related to the rising sea level. Elaborating on the research done by JELGERSMA ET AL. (1970) it should be possible to determine a type locality and define a stratotype on a formation level for these deposits; b. Younger and Older Inland Dune Deposits together with Older and Younger River Dune Deposits. All these deposits might well be incorporated in the Kootwijk Formation; c. Cover Sand Deposits, as belonging to the partly non-eolian Twente Formation.

## ACKNOWLEDGEMENTS

I thank Dr. J. Klijn, Drs. J. J. M. van der Meer and Mr. J. Stakenborg for discussions and willingness to supply additional data, Mrs. M. C. G. Keijzer-v.d. Lubbe for typing the manuscript, Mr. A. J. van Geel for drawing the illustrations, and Dr. N. Pears (Leicester) for improving the final English text.

I also thank Drs. M. M. Fischer, Prof. Dr. G. C. Maarleveld, Drs. H. J. Mücher en Drs. G. H. J. Ruegg for critically reading an early draft of the manuscript and for their suggestions to improve the presentation of this paper.

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