GEOLOGIE EN MIJNBOUW VOLUME 56 (1), p. 5-24 1977

FEATURES OF MIDDLE PLEISTOCENE SANDUR DEPOSITS IN THE NETHERLANDS

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ABSTRACT

Ruegg, G.H.J. (1977). Features of Middle Pleistocene sandur deposits in The Netherlands. Geol. Mijnbouw, 56, p. 5-24.

The sandur deposits discussed below appear to be much similar to alluvial fan deposits. Only minor differences may occur which are related to the nature of the source area (slopes, availability of non-consolidated material) and to climatic conditions.

In the introduction a synopsis is given concerning river types and their deposits in general, represented in the deposits of this part of the North Sea Basin; subsequently, Neogene and Quaternary fluvial deposits (including sandur deposits) in The Netherlands are classified based on the type of deposition.

INTRODUCTION

Whether a river meanders or braids (for the sake of conciseness transitional forms will not be discussed here) depends in the first place on climate and relief. Variables which can be deduced from these are: gradient, sediment load, discharge, and bank erodability. As "third order" factors are mentioned in the literature: whether or not a vegetation cover is present, the nature of this cover, whether or not the soil is frozen, roughness of stream floor, and the occurrence of a hardly transportable coarsest fraction in the sediment load (cf. L e o p o l d *et al.*, 1964; A l l e n, 1965; C h u r c h, 1972).

The characteristics of meandering contributive rivers and their deposits are fairly well-known. Sequences built up by regularly migrating rivers are described by A l l e n (1965) and V i s h e r (1972). The characteristics of floodbasin deposits are summarized by L e o p o l d *et al.* and A l l e n.

From recent investigation it is apparent that the Quaternary fluvial deposits of The Netherlands are for the greater part laid down by meandering rivers.

Braided contributive rivers are primarily characterized by sediment overloading and irregular discharges. In comparison with meandering rivers similar and higher gradients may occur (cf. fig. 7-39 in L e o p o l d *et al.*). The succession of the predominant natures of deposition in decreasing gradient values mag in general be as follows, as deduced from the literature: (a) sedimentation resulting from passing longitudinal bars (D o e g l a s, 1962; S m i t h, 1970); (b) sedimentation resulting from passing transverse bars; these transverse bars may subsequently be cut up into longitudinal shapes during a more erosional phase (S m i t h, 1970, 1971, 1972); (c) sedimentation *inter alia* resulting from passing dunes and ripples (lower flow regime), a deposit often subsequently cut up into longitudinal bar forms (C o l e m a n, 1969).

D o e g l a s (1962; *in* P a n n e k o e k *et al.*, 1973) made a correlation in the nature of deposition between the often gravelly so-called Middle Terrace deposits (Caberg Terrace, Saalian) in the southeastern part of The Netherlands and the deposits of the Durance river (deposition under the influence of a steep gradient – 2.5 m/km – and achieved by passing gravelly longitudinal bars).

Parts of the Late Pleistocene Kreftenheye Formation have much in common with the Brahmaputra deposits as described by C o l e m a n (1969). In shallow exposures Coleman has observed a sequential setting resembling that produced by meandering rivers. Based also on recent investigation of the previously mentioned comparable deposits in The Netherlands the following differences with the sequential setting as a result of deposition by meandering rivers may be mentioned: (a) continuity of relatively thin and irregular sequences for a considerable distance; (b) dominance of large trough-shaped cross-bedded and locally complex sets; (c) comparatively many climbing-ripple cosets and load-slump structures indicating sedimentation from an overloaded medium; (d) sequences which are often less truncated. These deposits will be treated in a future article.

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B u l l (1972) published a compilation of the characteristics of the deposits of (distributive) alluvial fan rivers (piedmont rivers). Sediments of alluvial fans appear to consist entirely, of for a considerable part, of water-laid deposits; debris-flow deposits may also occur. The water-laid deposits consist for the greater part of parallel-laminated sheetflood deposits, and for a variable part of stream-channel deposits depending on the position on the fan. In this paper the striking similarity between Saalian sandur deposits (Drente Formation) in The Netherlands and "classic" alluvial fan deposits will be pointed out. A future article will discuss deposits of this type from an older glacial time (so-called Cromerian time-complex) viz. the oldest part of the Urk Formation ("Mengzone") as visible in excavations in the northeastern Netherlands.

Besides contributive meandering rivers, contributive braided rivers, and distributive high gradient fan rivers, a fourth principal type of river may be deduced from Dutch Neogene and Quaternary deposits, namely the type described *inter alia* by V e r b r a e c k (1970). The characteristics of this fluvial environment are: distributive channel pattern, channels that are not migrating laterally, low gradient, and rapid sedimentation influenced by tides (perimarine area); probably a strong vegetation cover is indispensable. From cross-sections of Holocene deposits nearly symmetrical lenses of "bar finger sands" (in transversal sections) are found, embedded within fine-grained backswamp sediments with peaty intervals, as revealed by borings. A sudden break-through must have scoured an initial channel; during filling-up of this channel new space for deposits is created above

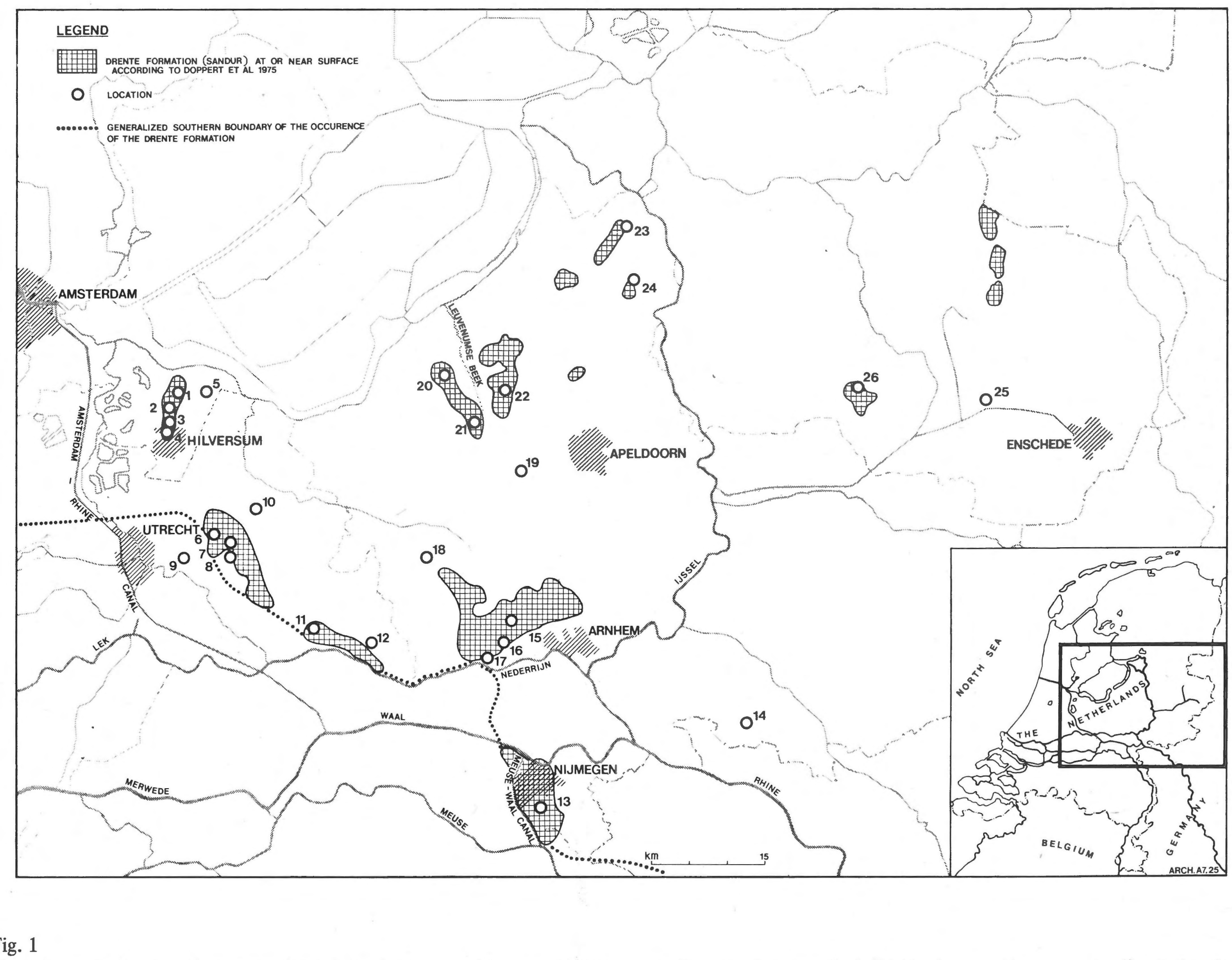

Fig. 1
Situation of the locations mentioned in the text, with co-ordinates according to the so-called "shifted co-ordinate system" of the State Trigonometry Survey.
1 Naarden 141-476; 2 Hilversum, railroad cutting 140-474; 3 Hilversum, world broadcasting building pit 139-472; 4 Hilversum, N.O.S. (television studios) pit 140-472; 5 Huizen, Rijsbergen pit 145-477; 6 Soesterberg, pit Tammer 146-459; 7 Soesterberg, pit Cirkel 148-458; 8 Soesterberg, T.N.O. pit 148-456; 9 Zeist, motorway crossing 142-456; 10 Amersfoort, Monnikenbosch 151-462; 11 Leersum 158-447; 12 Veenendaal 166-444; 13 Malden 188-420; 14 Zeddam 214-435; 15 Wolfheze, motorway crossing 184-448; 16 Wolfheze, motorway cutting 183-445; 17 Heelsum 181-442; 18 Lunteren 173-456; 19 Assel 185-467; 20 Ermelo, Ullerberg 175-479; 21 Garderen, Waayenberg pit 178-472; 22 Ermelo, de Kril 183-476; 23 Hattemerbroek 198-498; 24 Heerde, Koerberg 199-491; 25 Delden, motorway crossing 244-476; 26 Holten 229-476.

and progressively on both sides of the initial channel due to differential compaction; lateral migration must either have played a minor role or was lacking. After complete filling-up the course must suddenly have been abandoned after a new break-through upstream.

This type of river environment may be recognized also in deposits belonging to the Tegelen Formation (Lower Pleistocene) (cf. Kortenbout van der Sluys and Zagwijn, 1962) and the Kiezeloölite Formation (Brunssum Clay Member, Pliocene) of Southern Limburg.

An analogous depositional configuration has been described by Fisk (1961) for the Mississippi Delta, with bar finger sands embedded in a fine-grained delta front, natural levee and delta-plain deposits.

This publication is the result of observations made in a number of pits and quarries (fig. 1) during the last 15 years. For the general palaeogeographical framework during Saalian time in The Netherlands (till and basin deposits, ice-pushed ridges, ice-marginal valleys) reference is made to the map and explanatory notes of Jelgersma and Breeuwer (1975); for the stratigraphic position of the glacigenic Saalian deposits within the Quaternary lithostratigraphy of The Netherlands the reader is inferred to Doppert *et al.* (1975).

SANDUR DEPOSITS: PREVIOUS WORK

Sandur, an Icelandic word signifying "sand" or "sand plain", has long been employed by the Icelanders to refer to alluvial outwash plains formed by rivers carrying meltwater away from fronts of glaciers, and has become generally accepted to refer to glacial outwash. Sandurs are characteristically areas of rapid aggradation, crossed by braided streams that continually shift their pattern and course as local erosion and deposition occur (Church, 1972).

Sandur deposits are generally, together with esker sediments, the more coarse members of the glacio-aqueous sediment group, *in casu* compared with glacial basin (including kame) sediments.

The Saalian sandur deposits here discussed are situated within a framework of ice-pushed ridges; often these ridges were originally more than 100 m high. Therefore it is not surprising that reworked material from the ridges forms the bulk of the sandur sediments; components derived from Scandinavia often form less than 10% of the gravel assemblage, and even deposits with less than 1% occur (Maarleveld, 1956).

During Saalian glacial time the inland ice could penetrate the Central Netherlands. Here a number of ice-pushed ridges were formed, consisting of the preglacial deposits (occasionally sandur deposits already present were also pushed up), in several phases. From these ridges a basic form around a former lobe can often be recognized. At the outward ice-free side of the ridge sandur plains generated. Presently these sandur deposits occur over extensive areas as a fringe zone alongside the ridge.

Differences between the Saalian glaciated regions of Northern Netherlands and Central Netherlands are striking. The former region is rather flat and shows only faint undulations ("till plateau morphology"); major pushing phenomena are scarce; till occurs as an essentially continuous layer over extensive areas parallel and close to the surface; sandur deposits are absent. The Central Netherlands on the other hand show much more relief and large ice-pushed ridges; till occurrences are scarce and restricted in area; however, they are structurally more varied compared with tills from Northern Netherlands; sandur deposits frequently occur (cf. Maarleveld, 1955; Jelgersma and Breeuwer, 1975; Doppert *et al.*, 1975). Similar regional differences are known elsewhere, e.g. in the Weichselian of Denmark (Marcussen, 1975).

Various hypotheses have been postulated on the true character of sediments presently known as sandur deposits in The Netherlands. The following short review is partly from Teunissen (1961). Staring (1860) has made the first systematical study of all types of deposits outcropping in The Netherlands; he assigned the sandur deposits discussed here without further distinction to the "Mixed Diluvium", based on the presence of northern (Scandinavian) as well as southern (supplied by a former "Rhine"-"Meuse" river system) rock fragments. Lorié (1887) distinguished a "stratified Mixed Diluvium" within the "Mixed Diluvium". Many topographically elevated undisturbed sandur deposits were considered to be remnants of an "Undisturbed Rhine delta" (van Capelle, 1896), or "Main Terrace" (Lorié, 1902). Van Waterschoot van der Gracht (1913) was the first to use the term "fluvioglacial deposits". However, according to his concept they were overlying the undisturbed "Main Terrace". The first qualification as "sandur" came from Keilhack (1915); he included in this type of sediment the deposits south of Nijmegen (*in casu* Malden) and those of Wolfheze-Heelsum already, *inter alia* because of their topographic dips towards the south (if these deposits were remnants of an undisturbed deposit of a former Rhine and/or Meuse a topographic dip towards the west would be more logical). Tesch (1924) advocated the term "fluvioglacial mantle"; this term assumes an all-round bordering of the ice-pushed ridges of the Central Netherlands by fluvioglacial deposits; however, a considerable part of the deposits, which in this concept were considered to be fluvioglacial, subsequently appeared to be of periglacial nature (e.g. coversands). Tesch still attributed the deposits near Wolfheze-Heelsum to a remnant of a true river terrace even on a geological map published in 1935.

More recent investigations have been made by Maarleveld (1955, 1956) and by Augustinus and Riezebos (1971). The former (1955) summarized the following features as characteristic of sandur deposits in the central part of The Netherlands: (a) low and gradual topographical dips, downward from the ice-pushed ridge; (b) the undisturbed (not pushed) nature; (c) scarcity of fine-grained sedi-

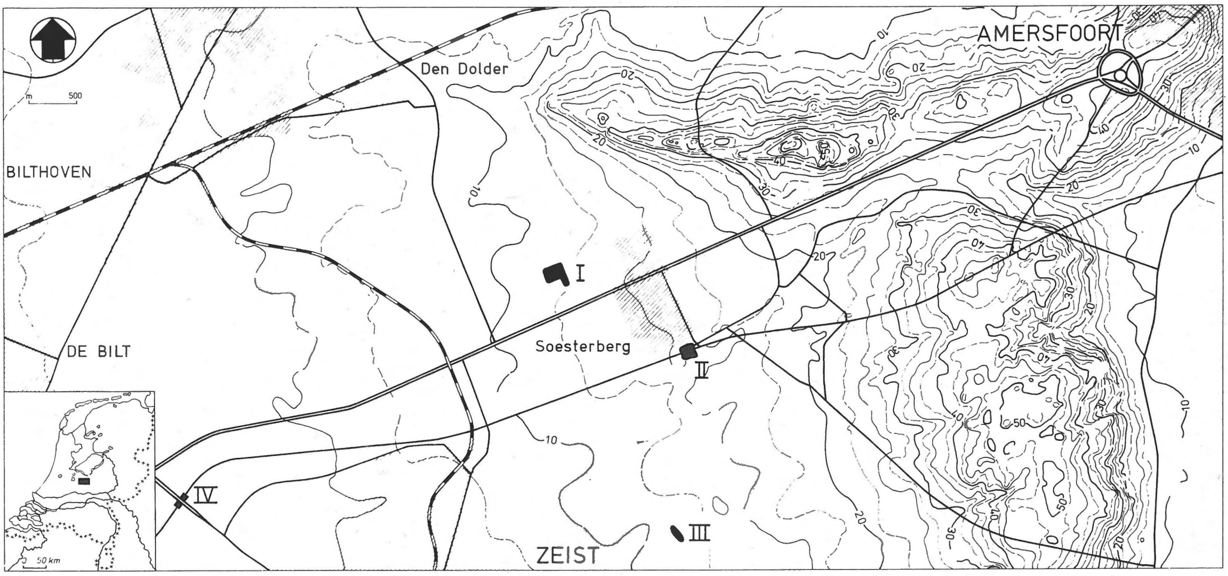

Fig. 2
Topographic map of the Soesterberg-Zeist area, with the ice-pushed ridges to the right and upper-middle part, the sandur fringe in the remaining middle part and to the left; on the left these sandur deposits are overlain by coversands increasing in thickness to the left (west); legend see Fig. 3

ments; (d) the frequent occurrence of Scandinavian-derived rock fragments; (e) diminishing grain-size with increasing distance from the bordering ice-pushed ridge. Maarleveld (1956) recognized a few ice-pushed glacio-aqueous (term according to Francis, 1975) deposits, which were shown on a map presenting the distribution of fluvioglacial (including kame) deposits in the central part of The Netherlands.

Augustinus and Riezebos (1971) describe sandur deposits from pits near Soesterberg (I, II and III on fig. 2). They are the first who discuss the structural sedimentary setting thoroughly. The deposits described are plane-bedded strata, frequently alternating with channel-fills formed by lateral filling up of depressions and showing a "festoon lamination". The authors emphasize the absence of small- or large-scale cross bedding derived from ripples or dunes. Based on dip measurements on sets of strata a fanlike outbuilding of the outwash plain is suggested.

An example of an investigation of a fossil sandur deposit outside The Netherlands is the work of Jewtuchowicz (1953); it deals with the morphology, structure and texture of a Polish Weichselian sandur complex of 120 km parallel to the inferred current direction and a maximum width of 75 km. The following characteristics are mentioned:

(a) the gradient diminishes downcurrent from 3.1 m/km to 0.6 m/km;

(b) in the downcurrent direction a progressive domination of certain structural sedimentary units is noticeable. First channel-fills with coarse gravel are abundant; in imitation of Gilbert (1914) and Andersen (1931) these structures are thought to originate during a phase called "anti-dune phase" or 'phase IV'. Next parallel bedding of coarse sand with gravel predominates (phase III). Finally "dune" deposits (viz. (semi-)tabular cross-bedded sets) parallel-bedded gravelless sands and sediment with "ripple-marks" (among which climbing-ripple cosets) are formed for the greater part (phase II). Parts of this lateral succession are found in vertical relationship, often several times repeated within one section. Upward successions IV-III-IV-III-IV, II-III-II-III-II-III-II and IV-III-IV-III-II-III-II are mentioned. More downstream the gravelly channel-fills of phase IV are absent. Correlation of this sequence with an aquatic regime of decreasing current velocity is based on Sorby (1918). Gilbert (1914) and Andersen (1931);

(c) more downstream, the average dip of the cross-bedded sets decreases. It may be expected that in a downcurrent direction these deposits will lose their alluvial fan characteristics more and more.

Church (1972) studied recent valley sandurs on Baffin Island, with special attention to discharge, sediment transport and the adaptiation of radial and transverse cross-sections to differences in discharge and sediment load. Nival floods, summer icemelt floods and summer storm runoff generate significant sediment transport events; a frozen soil causes an immediate runoff. Sediment is transported mainly as bedload. Gradient is around 8 m/km. Sandur streams are wide and shallow. Erosion in channels is hampered by: (a) lag armouring; (b) increased imbrication and packing; (c) increasing sediment supply. Most sandur bedding is parallel. Coarseness of the material often makes bedding features inconspicuous. It is suggested that the bulk of the sedimentation results in massive, essentially structureless sheets of material, parallel to the channel or sandur surface.

MORPHOLOGY

In the subdivision into valley sandurs and plain sandurs originally proposed by K r i g s t r ö m (1962, cited in C h u r c h, 1972) by far the majority of the Dutch sandur deposits belongs to the latter. However, the environmental setting of close, parallel lying plain sandurs may resemble that of valley sandurs; another consideration may be the environmental similarity between the valley sandur environment and that of high gradient braided (valley, non-sandur) rivers. The recent morphological setting is that of a fringe zone, dipping slightly and gradually away from the bordering ice-pushed ridge (comparable with a piedmont plain or bajada, except that the elevations of the plain and the ridge are not in mutual harmony). This fringe zone developed by the growing together of individual fans. Near Soesterberg-Zeist (cf. fig. 2) the dip of the top of the sandur deposits amounts to 2.2 m/km; near Malden (cf. fig. 3) a comparable slope amounts to about 14 m/km; it is not known whether these surfaces represent time levels. B e r e n d s e n and B i j n e n (1973) mention a top-sandur dip of 10-40 m/km near Leersum. Recent slopes on valley sandurs amount to 18 m/km (M c D o n a l d and B a n n e r j e e, 1971) 2-15.5 m/km (B o o t h r o y d, 1970), 8 m/km (C h u r c h, 1972), 5 m/km (G u s t a v s o n, 1974).

From piedmont alluvial fan deposits overall slopes are recorded from 3.5 m/km to 29 m/km (B u l l, 1964), from 1 to 15 m/km (E m b l e t o n and K i n g, 1968), from 17 m/km (distal zone) up to 98 m/km (apex zone) (B o o t h r o y d and N u m m e d a l, 1975) and generally from 50 m/km to 100 m/km (R e i n e c k and S i n g h, 1973). Generally piedmont alluvial fan slopes appear to be steeper than the slopes of sandur deposits, a feature alreday mentioned by B o o t h r o y d and N u m m e d a l (1975).

Individual fan-forms are not discernable (cf. figs. 2 and 3); valleys now visible and running at right angles to the sandur zone are not invariably between two fans which are more or less grown together; it seems reasonable to suppose that so-called dry valleys are formed where a higher amount of discharge could exist, i.c. in the former fan-apex areas; these dry valleys are often known to be formed during periglacial Weichselian conditions.

The deposits at Lunteren, Veenendaal and Hilversum either overly or cut into an ice-pushed ridge. In these cases there might be a more direct resemblance to a valley sandur.

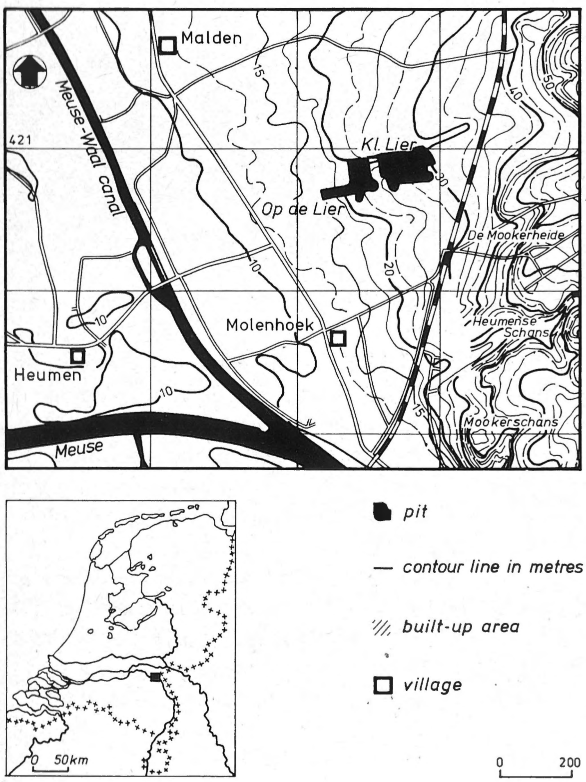

Fig. 3
Topographic map of the Malden area, with the ice-pushed ridge at the right, the sandur fringe in the middle part, and younger fluvial deposits on the left side (west of the Maas-Waal Canal).

TYPES OF SANDUR DEPOSITS

In accordance with the description of alluvial fan deposits by B u l l (1972) water-laid deposits (sheetflood and stream-channel deposits) and debris-flow deposits may be distinguished. In the Dutch Saalian sandur deposits no aeolian intercalations have been encountered to date; C h u r c h (1972) mentions the occurrence of small wind-rippled sand areas and of aeolian lag pavements of gravel or stones at the surface (he does not mention covered positions of aeolian deposits nor the polishing or facetting of particles).

Water-laid deposits

Two (sub) types can be distinguished, namely sheetflood deposits and stream-channel deposits.

Sheetflood deposits – These sediments are nearly always parallel-bedded[2)] or give that impression when observed

[2)] The term "cross bedding" is used in the sense of "large-scale cross-stratification" or "dune-stratification"; the term "cross lamination" is used in the sense of "small-scale cross-stratification" or "ripple-stratification" (cf. W a l k e r, 1969). A more directly genetic implication is expressed by the terms "parallel-laminated" and "parallel-bedded", referring to a structural setting produced in low-energy and high-energy current velocities respectively. The term "set", "coset" and "lamen" are used according to M c K e e and W e i r (1953).

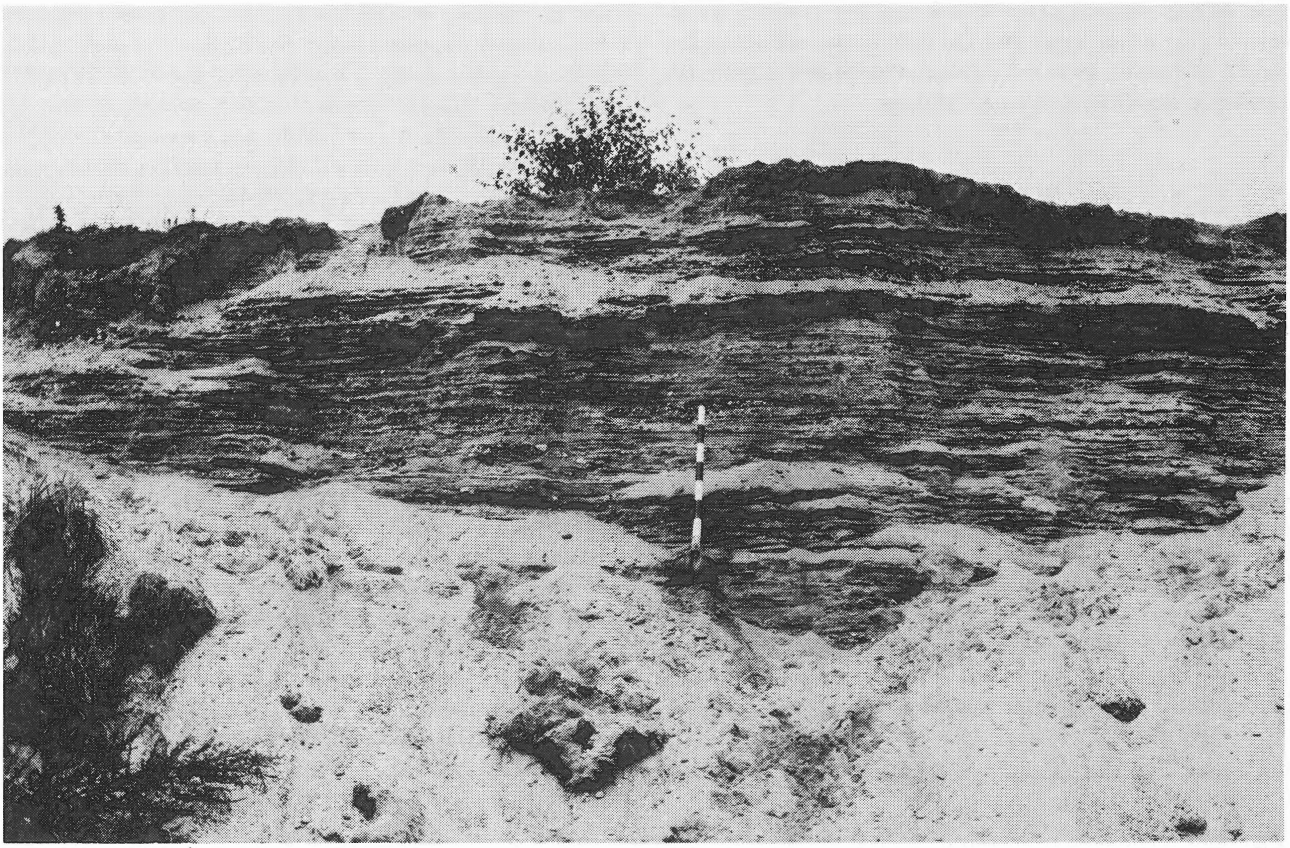

Fig. 4
Parallel-bedded gravelly coarse-sandy sandur deposits near Zeddam. Spade-shaft shows dm-notation.

from a greater distance (cf. fig. 4); closer examination often reveals the existence of a variable number of low-angle units with average lengths from some decimetres to some metres and thicknesses from some centimetres to one or two decimetres (cf. the non channel-fill parts on fig. 9; fig. 10); locally an intricate mosaic pattern of these low-angle units may dominate the picture (Malden) in which in fact only a few true horizontal layers occur (fig. 10). The deposits consist mainly of coarse sand[3)] with a varying amount of gravel; the latter may be concentrated in levels or be present in an isolated position. The sediment is thought to be deposited over a large area by a shallow, supercritical flow (upper flow regime) during periods of considerable discharge. If both fine and more coarse sediment occur in a direction perpendicular to a sandur zone, the finer sediments are further away from the bordering ice-pushed ridge than the coarser deposits (Soesterberg-Zeist, Malden). Even the finer sandy deposits near Zeist seldom contain (thin) beds formed under lower flow conditions (cf. fig. 12); of the sandur occurrences discussed here that of Zeist is the furthest from its adjoining outcropping pushed ridge, namely 6 km.

Imbrication of flat gravel particles may be encountered in all parallel-bedded coarse sandur deposits; this type of orientation is the most reliable palaeocurrent indicator in these deposits (cf. Rust, 1972).

In the cross-sections, features indicating the presence of longitudinal accumulation bars have not been found. This is in agreement with Bull (1972) as regards piedmont alluvial fans; this is also in accordance with the results of the study by Church (1972) of recent sandur deposition. Others, like Boothroyd (1970) and Gustavson (1974) suggest that their longitudinal sandur bars are accumulation bodies; Williams and Rust (1969) do not indicate whether the longitudinal bars are either accumulation or erosion forms.

Very rarely concentrations of thin loamy layers occur, in combination with very coarse sandy laminae; bedding parallel

3) According to the classification system used by the Geological Survey of The Netherlands "sand" has a composition of <8% <2 μm and >50% between 63 and 2000 μm. Compositions with a medium value of the sand portion <210 μm are called "fine" (with the median classes 63-105 μm – extremely fine –, 105-150 μm – very fine –, and 150-210 μm – moderately fine –). Compositions with a median value of the sand portion >210 μm are called "coarse" (with the median classes 210-300 μm – moderately coarse-, 300-420 μm – very coarse –, and 420-2000 μm – extremely coarse –).

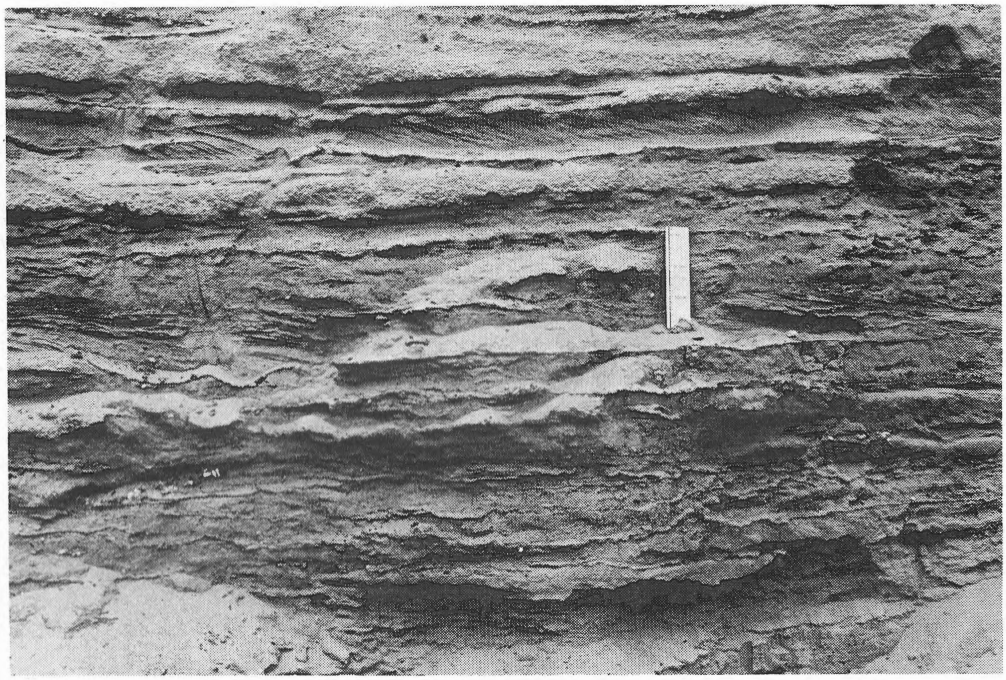

Fig. 5
A 5 cm thick tabular cross-bedded coarse-sandy set, interpreted as a result of deposition by a transverse bar, intercalated into a mostly parallel-bedded more or less gravelly coarse-sandy sandur deposit (overlying a till remnant layer); Leersum. Measuring-rod: 15 cm.

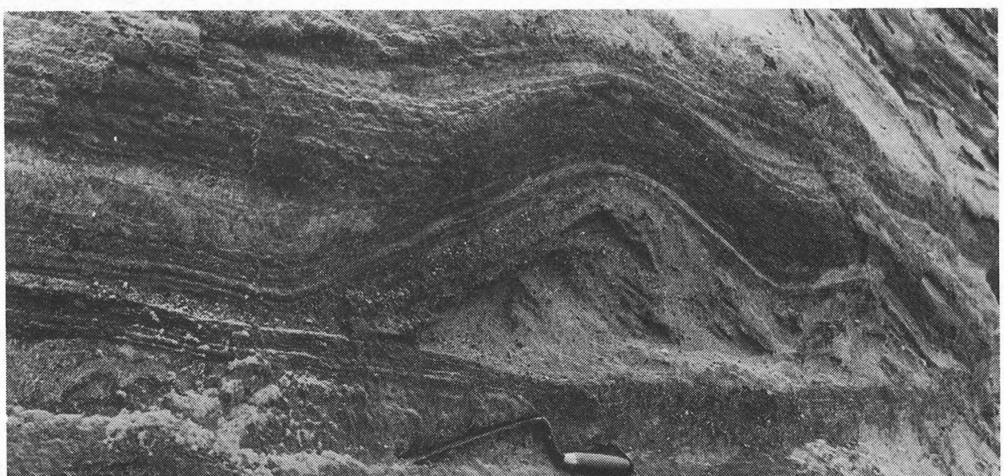

Fig. 6
A complex dune deposit, interpreted as an antidune-deposit, amidst a fluvio-aqueous deposit characterized by many thin loamy layers; Veenendaal, eastern location. Length of jointer: 30 cm.

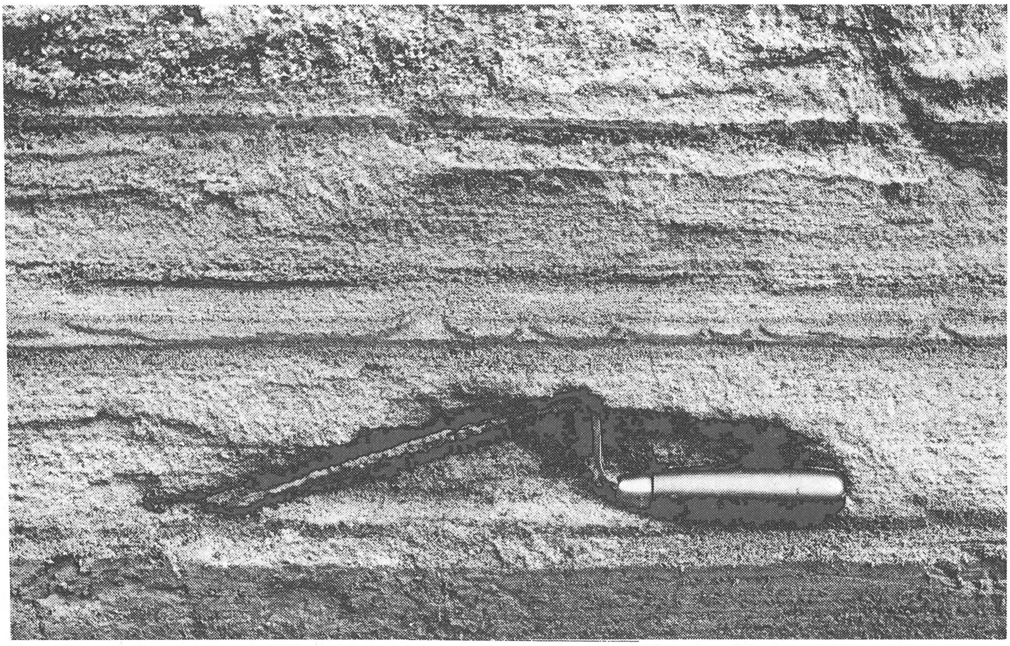

Fig. 7
Mud curls in sandur deposit; Lunteren.

to a horizontal sedimentation surface is maintained in these cases. As an example the location at Lunteren may be mentioned. Here the presence of loamy layers is restricted to one "unit" (cf. paragraph concerning sequential setting); to one side of the cross-section a transition from loamy layers to "normal" sandur deposits could be noticed. Contacts between loamy layers and sandy layers are mostly very sharp. The loamy part contains a horizon with mud curls (cf. Picard and High, 1973), which is a direct indication for metadepositional emersion of the sedimentation surface (fig. 7).

Other syn- and metadepositional structures are also very scarce in these sheetflood deposits characterized by parallel bedding. At Leersum in the upper sandur deposit some tabular cross-bedded sets could be noticed, up to 5 cm in height and laterally noticeable for several metres (fig. 5); they are thought to be made by transverse bars as described by Smith (e.g. 1972) and McDonald & Bannerjee (1971); in Lunteren comparable sets up to 20 cm in height have been found.

Normally the (longest) a-axis of the coarsest particles does not exceed 10 to 12 cm; the particles are mostly rather rounded, a feature especially striking in Scandinavian-derived material.

Ice-rafted stones and gravels do not occur, except in the previously discussed loamy sediments at Lunteren; here randomly dispersed gravel particles occur infrequently within relatively much finer sediment layers. In the gravelly coarse-sandy deposits particles of out-standing size are absent. About twenty years ago, however, at a Hilversum location (World Broadcasting Building pit) a relatively very large stone was found approximately one metre above the top of a till layer; now it cannot be ascertained whether this was lifted from the till by ice-mound forming as described by Church (1972) or a case of ice-rafting. Ice-cemented sand lumps have not been observed in the Dutch parallel-laminated sheetflood deposits.

Armoured mud balls, however, are fairly frequent in these deposits, especially in comparison with other Dutch fluvial deposits, for example at the Hilversum and Naarden locations; these balls are mostly 5 to 15 centimetres thick; the clay content is presumably derived from preglacial deposits.

Bedding configuration, occurrence of armoured mud balls and mud curls, as well as the absence of relatively coarse isolated particles, point to deposition in very shallow water. The presence of small channels, often occurring in horizons (cf. paragraph concerning stream-channel deposits), is in agreement with this concept.

At Veenendaal at the western location a primary dip up to about 25° in the parallel-bedded gravelly coarse sands formed under upper flow conditions could be observed; apparently at this location a flank of a sandur valley formed in the ice-pushed ridge is exposed (fig. 8). This location and the one mentioned later in this paper are spatially separated; the base of the sandur deposit at the western location (as seen on fig. 8) is topographically about ten metres higher on the ice-pushed ridge than the base of the Saalian deposits at the

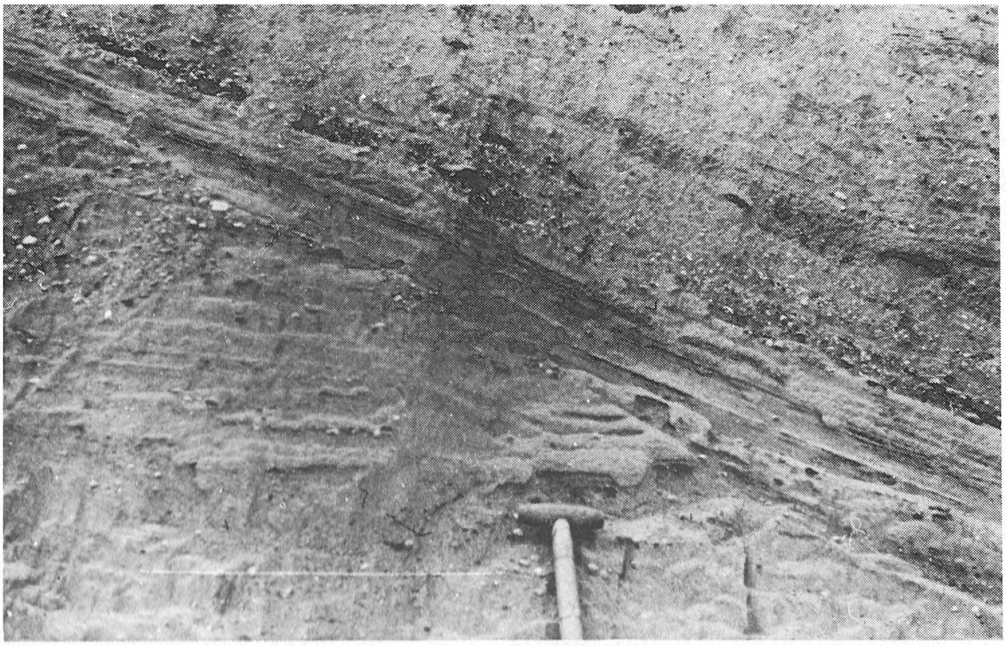

Fig. 8
Erosive contact between parallel-bedded sandur deposits and pushed pre-Saalian deposits; Veenendaal, western location.

eastern location at Veenendaal (thin sandur deposit, overlain by till, overlain by loamy glacio-aqueous deposits, overlain by a proximal sandur deposit).

In a pit complex near Malden a 6 m (west side) to at least 8 m (east side) thick sandur deposit overlies a 6 m thick visible (west side) glacio-aqueous deposit with different characteristics. The sandur deposit is gravelly and coarse-sandy, and is dominated by low-angled units as previously mentioned (fig. 10); gravel imbrication points to a current direction from the east. The glacio-aqueous deposit underneath is poor in gravel and contains fine-sandy and silty layers. This deposit can be subdivided into several fining-upwards sequences. Climbing-ripple cosets form an important part of these sequences. Cross bedding and cross lamination indicate a current direction from the south. Whether these strata are either kame deposits or sediments formed in more stagnant water enclosed by an ice-pushed ridge and sandur fans still remains an open question.

In a pit near Delden a section was exposed showing more than two metres of predominantly fine glacio-aqueous sands of which large parts where of climbing-ripple nature, discordantly overlain by a complex several metres thick of parallel-bedded coarse-sandy sandur deposits with intercalations of thin till layers occasionally wedging out within the exposure.

Relatively fine-grained parallel-bedded sandur deposits may easily be misinterpreted as parallel-bedded coversand deposits (cf. fig. 11).

Stream-channel deposits – In the sandur deposits described here stream-channel deposits occur much less frequently than sheetflood deposits. In alluvial fan deposits Bull (1972) has noticed that channel-fill deposits form a minor part of most fans.

Two types of channel-fills can be distinguished within the Dutch sandur deposits:

(a) Small fills, up to some decimetres deep and often less than one metre in width. Often these fills are concentrated at levels (fig. 9), occurring in deposits which consist for the greater part of parallel-bedded sediments (sheetflood deposits). It may be assumed that this type of channel-fill has been formed either by distal parts of the channels described under (b) or during periods of low discharge which may have occurred more frequently on the distal part of a fan (outflow of subsurface discharge may be a reason). Channel-fills formed by the latter process indicate a temporary emersion of the sedimentation surface (cf. paragraph concerning sheetflood deposits); it is reasonable to believe that the occurrences at levels are characteristic of the latter process of formation.

(b) The channel-fills related to periods of considerable and increasing discharge, to which those of more than one metre in width and up to several metres in thickness belong. This type is comparable with the type of stream-channel deposits described by Bull (1972). They have been recognized in the locations at Soesterberg, Veenendaal (eastern location), and Heelsum.

It is expected that transitional types of channel-fills belonging to channel systems generated under considerable and increasing discharge occur.

Fig. 9
Parallel-bedded sandur deposit with small channel-fills; the latter are more or less concentrated in levels; Hilversum, railroad cutting. Measuring rod: 30 cm.

Augustinus and Riezebos (1971) have reported the frequent occurrence of short large-scale cross-bedded sets, formed by channel infilling. They distinguish two types, based on the form and size of the channel cross-section and on the structure of the infilling. The smaller and more usual type is up to 70 cm thick; the structural setting within the fill is called festoon lamination (term according to Doeglas, 1962). The larger type is more than 1 m thick and contains a normal cross-bedded fill on the upcurrent side, gradually passing into festoon lamination downcurrent. In both types they have noted that a new channel was frequently cut into a "sanded-up" channel. In these channel-fills ice-cemented loam boulders are present. For an explanation of the features encountered, the authors refer to a paper by Hjulström (1952) on recent Icelandic sandur deposits.

At present the Soesterberg deposits may be related to the sandur deposits near Zeist, which are more fine-grained, situated topographically lower and further away from the bordering ice-pushed ridge (cf. fig. 2). At least the second type of channel-fill as described from the Soesterberg locality has apparently been formed during considerable discharge.

In pits within the catchment area of the Leuvenumse Beek (Ullerberg and de Haspel near Ermelo, Waayenberg near Garderen and de Kril near Elspeet) glacio-aqueous deposits are composed of noticeably thick (up to at least ten metres) channel-fills with overflow deposits. The lower parts of these sequences are parallel-bedded to massive, very coarse-sandy, mostly containing large amounts of gravel, and in many places with ice-cemented sand blocks[4], relatively large stones and many armoured mud balls (cf. Maarleveld, 1962). These deposits grade upwards into gravelless and finer sands in which fine-sandy and loamy layers and even rare thin clay layers appear, with ripple configurations and cross-stratification (e.g. climbing-ripple cosets) in many places. These upper parts show many similarities with the kame deposits described by Jopling and Walker (1968). The lower parts of the sequences are some metres wide; the upper parts are of much greater extent; they are either cut off by younger channel-fills or their lateral extension is not entirely exposed in the pit.

In one place in the Ullerberg pit the channel-fill deposits are overlain by a zone consisting of gravelly coarse-sandy parallel-bedded sandur deposits (sheetflood deposits) with a thickness of some metres. It seems that at a later stage the discharge obstruction disappeared and environmental conditions changed from those favouring kame formation to those producing an alluvial fan[5].

Due to particle positions and ripple configurations in the kame deposits a current direction towards the north may be inferred. In the deposits in the pits Ullerberg, Waayenberg and de Kril the current direction in various places also has a component towards the west. In the pit de Haspel ripple configurations point to a current direction towards the northeast; here the deposit is situated twenty to thirty metres from the ice-pushed ridge. Current directions with a strong component towards the south were not encountered.

[4] As far as examined these angular blocks all have an internal parallel-bedded structure and seem to be of a glacio-aqueous nature. According to Hofland their dimensions parallel to the internal bedding may be up to 10 m; however, their dimensions perpendicular to the bedding do not exceed 1 to 1.5 m (Hofland. 1958). The explanation of this feature may tentatively be sought in undercutting and erosion of a frozen upper part of an active layer on top of the deposit being formed. Church (1972) mentions the presence of an active layer with a thickness of 1 m for recent Baffin Island sandur deposits.

[5] Maarleveld (1955) considers all glacio-aqueous deposits occurring in the valley of the leuvenumse Beek to be of kame nature, on account of variations in grain size and percentages of Scandinavian gravel content.

Fig. 10
Intricate mosaic pattern of low-angle units; in the middle part a true small channel-fill; length of jointer is 30 cm; Malden.

Therefore draining of the kame-lake must have been to the north and northwest.

At Veenendaal at the eastern location a deposit with many thin loamy layers is present within a synclinal setting of the strata, with flanks cur off by the erosional surface. The deposit overlies till with a similar configuration, and is overlain by a sandur deposit. The latter, although badly exposed, consists of gravelly coarse sands, for the greater part developed as cross-bedded sets; it is tentatively interpreted as a stream-channel deposit.

In the deposit with many thin loamy beds, sandy fine gravel containing parallel-bedded layers and cross-bedded dune bodies are intercalated. The latter are apparently partly formed by antidunes[6] (fig. 6) as may be inferred from set dip directions which are opposite to the general current direction; the general current direction (to the east and southeast, viz. parallel to the ridge) may be inferred from the occurrence of scarce ripple bedforms and their internal lamination, slump and drag structures. The complex setting of some of these dune bodies is also an indication of deposition by antidunes. In this connection reference is made to the work of McCracken (1972), who found antidune structures in alluvial fan deposits from the Ventura Basin. We also refer to the Skeidará sandur (Iceland); here current velocities as high as 8 m/sec have been measured during frequently occurring catastrophic glacial lake drainages or jökulhlaupe; the current velocity after the peak of such a discharge decreases rapidly; it is assumed that sedimentation by these floods is a very important mechanism (Embleton and King 1968). Church (1972) also notices that such surges are normal phenomena; he reports that impounding is often caused by snowbanks.

Gravel particles occur within the loamy beds; the boundaries between loamy and sandy parallel layers are often strikingly abrupt as in the previously mentioned unit with loamy beds at Lunteren. For this glacio-aqueous deposit at Veenendaal an environment of deposition more or less resembling that of kame deposits may be assumed; important differences with the latter are the absence of climbing-ripple sediment and the scarcity of other cross-laminated structures.

It is remarkable that, although the locations at Hilversum,

6) No reference is made to the "transverse ribs" as described from the surface of recent sandur deposits by Boothroyd (1970), McDonald and Bannerjee (1971) and Gustavson (1974). These "ribs" have not been encountered in Dutch sandur deposits.

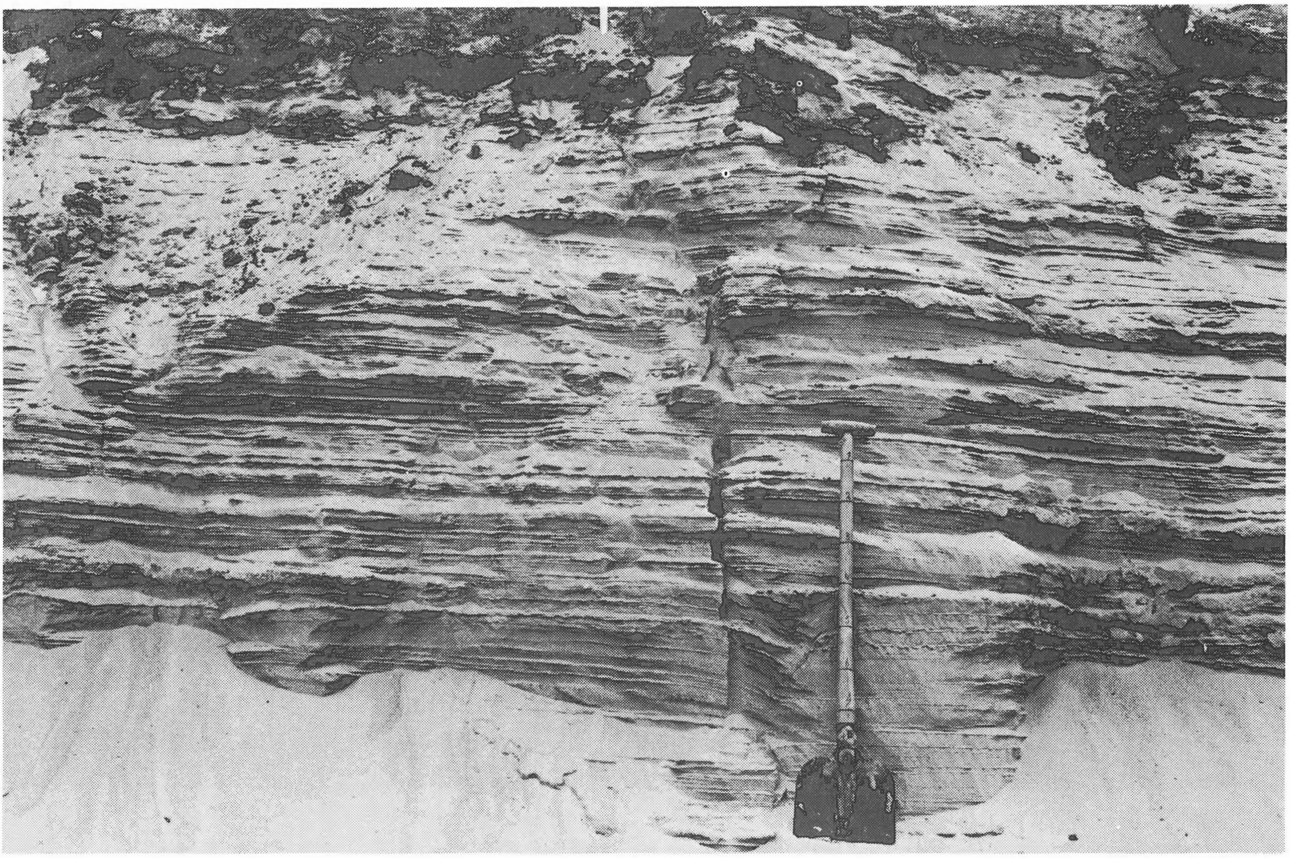

Fig. 11
Parallel-bedded rather fine-grained sandur deposit (moderately coarse sand) strongly resembling parallel-bedded coversands; Hilversum, NOS. pit.

Lunteren and Veenendaal (western location) are situated within the ice-pushed ridge areas, the sandur deposits at these locations are sheetflood deposits. It therefore seems that stream-channel deposits are not invariably present within each sandur fan complex. The absence of stream-channel deposits in certain sandur fans may be due to the overwhelming availability of suitable material to form sandur fans. The occurrence of piedmont fans without stream-channel deposits is not reported explicitly (cf. Bull, 1972).

Debris-flow deposits

Debris-flow deposits are very poorly sorted; they have been deposited by streams containing such high sediment-water ratios that they act as plastic viscous masses which excludes selective deposition (Bull, 1972). Only rare thin till layers, intercalated within the water-laid deposits *in casu* sheetflood deposits, may be considered to be debris-flow deposits. Locally the intercalations wedge out in one direction. Such till intercalations have been encountered at the locations at Amersfoort-Monnikenbosch (pers. comm. Zandstra), at Heerde-Koerberg (pers. comm. Zandstra) and near Delden. Within the glacial model these till layers may be considered to be flow tills. Pushing phenomena do not occur immediately below these till layers.

SEQUENTIAL SETTING

In the sheetflood deposits a differentiation into units with a sequential character is rare. In most places the deposit consists of a monotonous layering varying from parallel bedding to a mosaic pattern of fairly small low-angle sets of sandy sediments, with minor lithological and structural variation. If there is a fine-sandy intercalation then it also forms part of the parallel bedding (cf. fig. 14). This picture can be noticed in pits near Hilversum and Naarden, Assel, Hattemerbroek, Veenendaal (western location), Wolfheze (motorway crossing) and Zeddam (fig. 4), and also in major parts of the exposed sandur sediments near Ermelo, Delden, Malden, Lunteren, Zeist, and Leersum. The presence of levels with shallow channel-fills alternating with parallel-bedded trajects may be interpreted as a superposition of sequences; it is possible that the thin upper parts of these sequences formed in a lower flow regime have nearly always been removed during subsequent phases of increased discharge.

In some places a tendency towards a differentiation of strata under the influence of waning current velocity to lower flow conditions could be observed. Near Zeist thin, more or less loamy cross-laminated layers have been encountered, which were more conspicuous on a lacquer peel (fig. 12). These layers overly strata containing several dm thick trough-shaped cross-bedded sets; the superposition is very similar to that given by Picard and High (1973, p. 191). This is possibly a pool deposit (Mc Donald and Bannerjee, 1971; Church, 1972), fortuitously saved from erosion. Otherwise the bulk of the fluvioglacial deposits of this pit is parallel-laminated, and generally finer-grained in the upper part.

Apart from those in channel-fills or as a transverse bar deposit (Leersum), (high-angle) cross-bedded sets are very scarce. Although thin cross-bedded (-laminated) finer-grained top layers of sequences may have been removed by increasing discharge, the extreme scarcity of sediments deposited under lower flow conditions clearly points to short time-intervals for the undoubtedly frequent periods of decreasing current

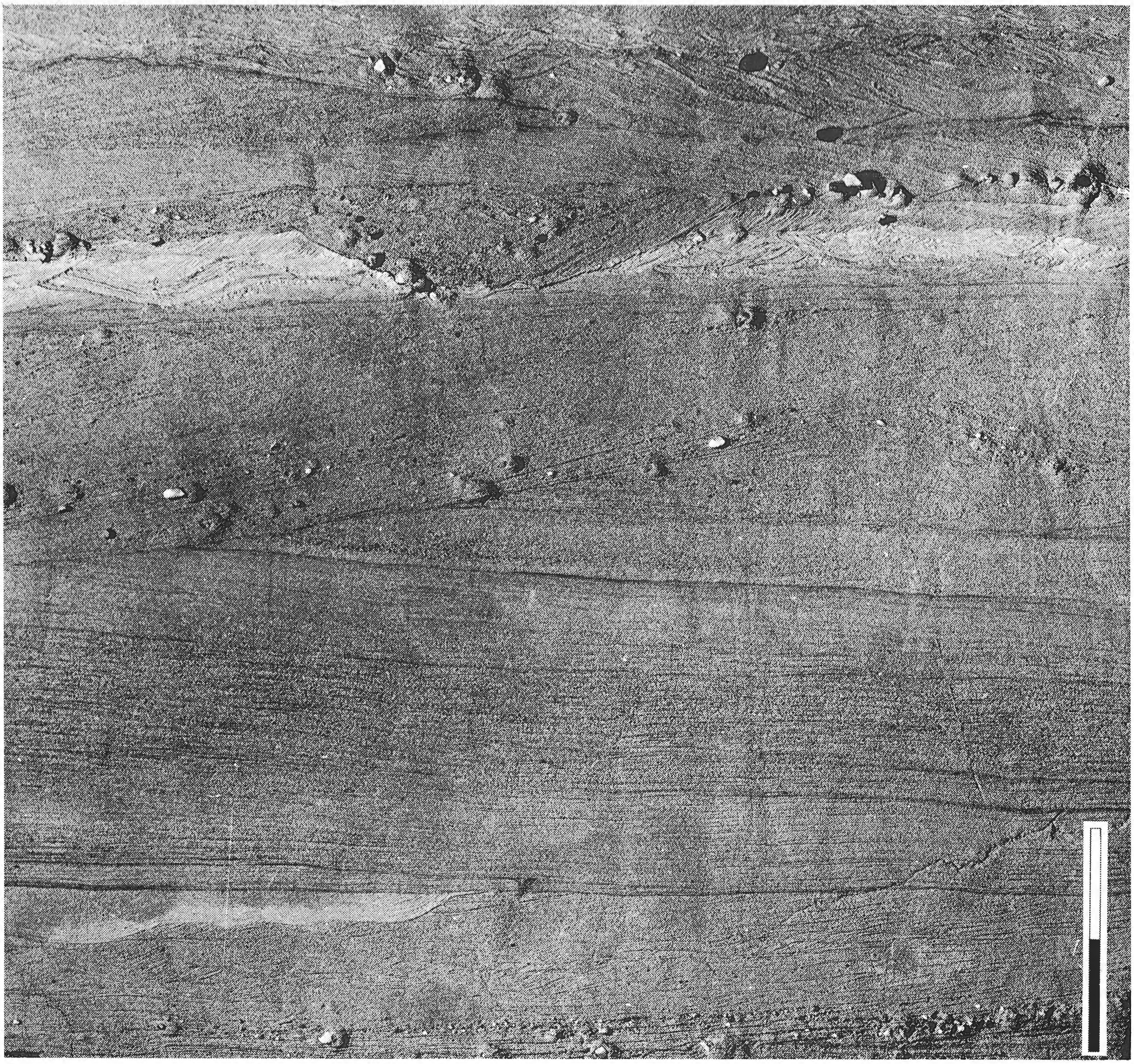

Fig. 12
Sandur deposit partly formed under lower energy conditions; Zeist. Measuring rod: 2 dm.

Fig. 13
Sandur deposit with internal angular unconformity caused syngenetically by inland ice pushing; Lunteren.

velocity.

At Lunteren the sandur deposit may be subdivided in at least four units, separated by angular unconformities caused by syngenetic glacial pushing (fig. 13). The combined result of these minor and late pushing "microphases" is a synclinal configuration of the sandur-till-sandur complex (the presence of a pre-existing valley cannot be proved). Except for the unit containing loamy layers and other lower flow derived sediments (occurring about the axis of the syncline) the sandur deposits are gravelly, coarse-sandy and parallel-bedded to mosaic low-angle bedded. In each of the four units a certain fining-upwards tendency of the mean grain size is apparent. Based on gravel positions the Lunteren deposit has been deposited by a sandur stream from the north; it seems reasonable to regard this deposit as a northern extension of the Wolfheze-Heelsum sandur complex.

In exposures near Zeist and near Hilversum a general fining-upwards tendency is shown. Augustinus and Riezebos (1971) have observed this feature in one of their pits near Soesterberg.

From three exposures in the Wolfheze-Heelsum sandur complex the one near the village of Wolfheze has given the impression that here free discharge of meltwater was more or less obstructed, at least temporarily. At present the area with sandur deposits is for the greater part surrounded by ice-pushed ridges; only a small opening towards the south exists. According to Maarleveld (1953) these ridges are formed in at least two pushing phases. Near the crossing of the Utrecht-Arnhem motorway with that leading to Heelsum an exposure has shown a parallel-bedded "normal" sandur deposit; near Wolfheze layers formed under lower flow conditions were visible, e.g. climbing-ripple cosets; near Heelsum cross bedding was very conspicuous. The latter location is situated exactly in the opening towards the south between the ridges mentioned above, a locally occurring steep gradient here may have caused incision and the forming of stream-channel deposits.

The following two conclusions may now be drawn:

(a) With regard to the presence of pools and riffles in a channel area, and the preservation of their deposits, it may be stated that in the Dutch sandur deposits sediments only rarely occur which may be interpreted as pool sediments. Characteristics of riffle sedimentation as mentioned by McDonald and Bannerjee (1971), have not been observed in the encountered stream-channel deposits.

(b) On the question of whether accumulation by longitudinal bars may occur in braided rivers and particularly in a sandur environment different opinions are presented in the literature. Doeglas (1962) and Smith (1970) are of the opinion that longitudinal accumulation bars may occur, deduced from their investigations of non-sandur braided streams (-deposits); Boothroyd (1970) and Gustavson (1974) express similar ideas on recent valley sandurs. On the other hand, Church (1972) rejects the above mentioned type of sedimentation for his recent valley sandurs. Williams and Rust (1969; recent valley sandur), McDonald and Bannerjee (1971; recent valley sandurs) and Doeglas (in Pannekoek *et al.*, 1973; braided stream deposits in general) have not presented opinions. Bull (1972) has not mentioned this sedimentation mechanism in his review of piedmont fan deposits. Indications in favour of the existence of longitudinal accumulation forms could not be found in the Dutch sandur deposits studied; longitudinal bars appear to be erosional forms, or interchannel areas (term from McDonald and Bannerjee, 1971).

The question of how far in the downcurrent direction sandur deposits can be recognized as such cannot be answered here. In The Netherlands only fluvioglacial deposits relatively close to adjacent ice-pushed ridges can be studied in situ. Further downcurrent counterparts are not exposed. Absence or scarcity of outcrops may be due to the outflow of sandur streams into ice-marginal valley streams, to erosion by subsequently occurring fluvial systems, and/or to covering by younger sediments.

OTHER CHARACTERISTICS

Vertical relationship sandur deposits and kame-like deposits

In the previous part the localities Ermelo-Ullerberg, Malden and Delden have been mentioned as sites where both types of deposits occur together. A fourth locality was found recently near Holten; the glacio-aqueous nature of the deposits in this area has been mentioned in the literature, e.g. by de Veer (1967).

In all these localities kame(-like) circumstances were followed by sandur deposition; the reversed order has not been observed.

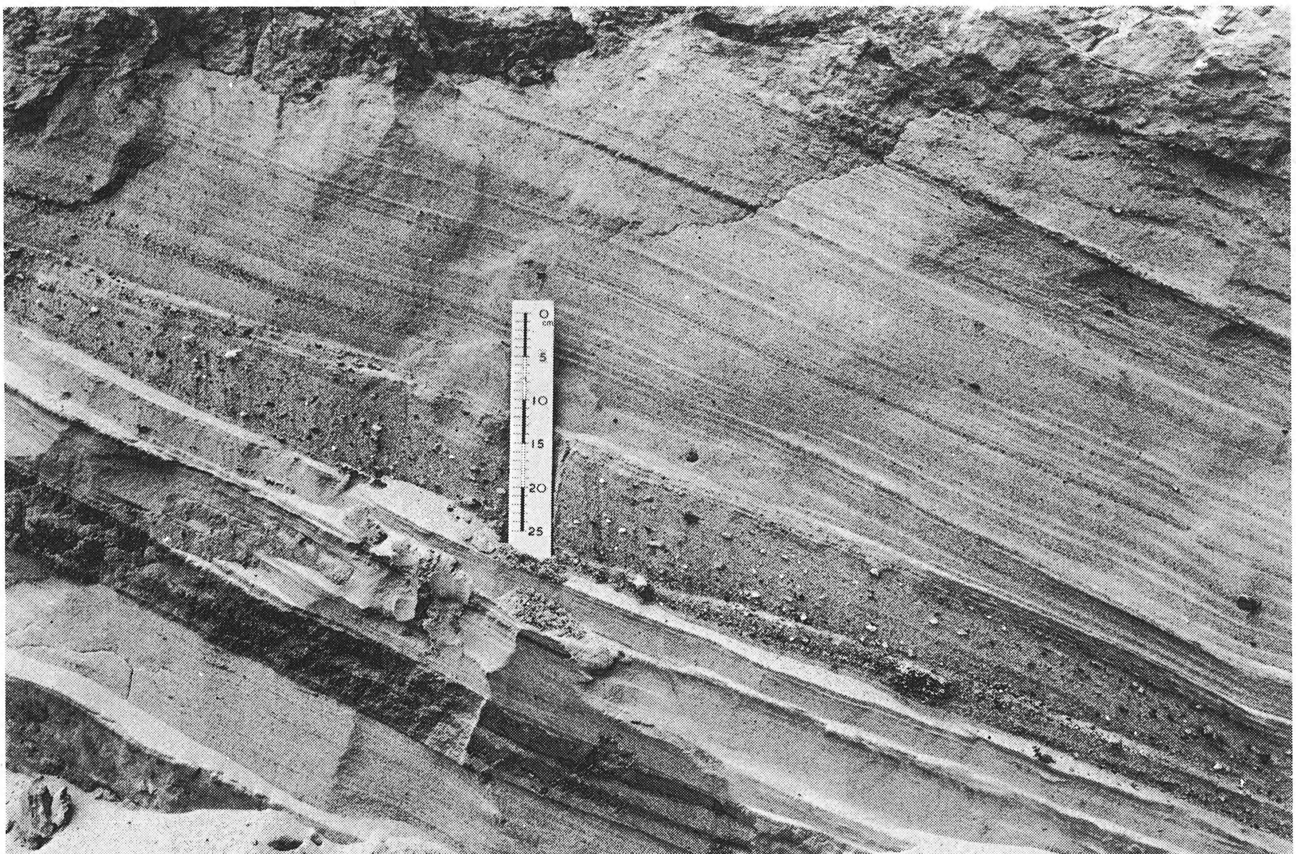

Fig. 14
Lithologically variegated sandur deposit in inclined position; Hilversum, NOS-pit. Measuring rod with cm-scale.

location	number	structure	%<63 µm	modality	$\overline{\overline{X}}\varphi$	$\overline{\overline{X}}\mu m$	$\sigma_{\overline{X}\varphi}$	$\sigma_{\overline{X}\mu m}$	$\overline{\sigma_{\varphi}}$	$\sigma\sigma\varphi$	$\overline{\alpha_3\varphi}$	$\sigma_{\overline{\alpha 3\varphi}}$	$\overline{\alpha_4\varphi}$	$\sigma\overline{\alpha_4\varphi}$
Heelsum	10	1	0.80	3.1	1.67	314	0.50	222-444	0.76	0.15	0.77	0.93	8.08	3.26
Leersum	6	1	2.00	3.3	2.02	247	0.50	174-349	0.92	0.15	0.98	0.86	7.90	3.19
Lunteren	16	1	0.94	3.4	1.73	301	0.29	247-369	0.84	0.15	0.18	0.72	6.12	1.74
Hilversum NOS	10	1	0.67	2.6	1.79	289	0.27	240-349	0.67	0.11	1.22	0.86	9.63	4.02
Total	42	1	0.99	3.1	1.77	293	0.38	225-382	0.79	0.16	0.68	0.90	7.67	3.19
					$\overline{X}\varphi$	$\overline{X}\mu m$			$\sigma\varphi$			$a_3\varphi$		$a_4\varphi$
Heelsum	1	2	0.1	5	0.95	518			0.92			0.09		3.13
Heelsum	1	3	0.3	3	1.51	351			0.88			0.00		4.23
Heelsum	1	4	62.1	2	4.87	34			1.32			0.65		1.66
Heelsum	1	?	9.1	5	2.38	192			1.39			1.10		4.24
Leersum	1	5	0.7	3	1.75	297			0.78			0.64		7.92
Lunteren	1	6	83.6	2	5.44	23			1.02			2.16		6.47
Lunteren	1	7	4.6	5	0.79	578			1.51			1.73		6.49
Hilversum NOS	1	8	0.8	2	2.24	212			0.58			1.86		13.39
Hilversum NOS	1	9	12.6	2	2.31	202			1.50			1.46		4.29

Table 1.
Generalized numerical values extracted from 51 samples from sandur deposits. Legend: structures: 1 = parallel bedding, 2 = cross-bedded channel-fill, 3 = cross bedding, 4 = parallel lamination, 5 = transverse bar cross-bedded set, 6 = parallel lamination to cross lamination, 7 = massive sandy gravel bed, 8 = climbing ripple cross lamination, 9 = solifluction ("currant-bread" structured); % < 63 µm as part of the 0-2000 µm reach = 100%; $\overline{\overline{X}}\varphi$ = mean of means, in phi-units; $\overline{\overline{X}}\mu m$ = mean of means, in µm-units; $\sigma\overline{X}\varphi$ = standard deviation of means, in µm-units; $\sigma\overline{x}\mu m$: standard deviation of means, in µm-units; $\overline{\sigma\varphi}$ = average standard deviation, in phi-units; $\sigma\sigma\varphi$ = standard deviation of standard deviations, in phi-units; $\overline{a_3\varphi}$ = mean of skewness (third moment), in phi-units; $\sigma\ \overline{a_3\varphi}$ = standard deviation of skewness, in phi-units; $\overline{a_4\varphi}$ = mean of kurtosis (fourth moment), in phi-units; $\sigma\ a_4\varphi$ = standard devation of kurtosos, in phi-units; $\overline{x}\varphi$, $\overline{x}\mu m$, $a\ \varphi$, $a_3\varphi$ and $a_4\varphi$ are resp. mean in phi-units, mean in µm-units, standard devation, skewness and kurtosis for individual samples.

Relation of sandur to till deposits

Where till is present as a continuous layer it is invariably intercalated within the sandur deposits. This holds for the occurrences at Hilversum, Lunteren and Leersum; in Veenendaal (eastern location) the till is situated between a thin sandur deposit below and the loamy glacio-aqueous deposit above.

The sandur deposit overlying the till in some places has a different areal distribution than the deposit underlying the till, as could be observed at Hilversum and at Lunteren; at both places high-lying occurrences are concerned, not considered to be fringe deposits. In the latter location the sandur deposit underneath the till contains a different gravel composition (without Scandinavian components) compared to the upper sandur deposit; an analogous feature could be noticed between the two sandur deposits from Leersum (Z a n d s t r a, 1974).

Thin till layers which not seldom wedge out within the exposure (Amersfoort-Monnikenbosch, Heerde-Koerberg, and Delden) have already been mentioned in the paragraph concerning debris-flow deposits.

Glacial-tectonic influence

Although most sandur deposits are undisturbed and horizontal, there are a number of locations where these sediments occur in more or less pushed positions, caused syn- or postgenetically. At these locations the disturbance is of a larger scale than a mere "contortion" of a thin zone beneath a till layer corresponding with a former inland ice cover. Such observations can be made at: Huizen-Rijsbergen, Assel-E. 8 roadcutting, Hilversum-NOS (fig. 14), Lunteren (fig. 12), Veenendaal (eastern location), and Leersum (at least the lower unit). All these occurrences are situated upon or very near to the ridge composed of pre-Saalian deposits; at Huizen-Rijsbergen the pushed sandur deposits form an intricate part of the ridge. In the Assel roadcutting it was clearly shown that the sandur deposits are dipping towards the west; in the western part of the exposure the beds are horizontal; towards the east their dips become steeper and locally the beds are overturned where they border the ridge. The situation near Lunteren has already been discussed.

Grain-size

Within the framework of the investigation 51 samples from sandur deposits have been analysed, with a ¼ phi sieve set and a pipette. The statistical parameters, average grain size, standard deviation, skewness and kurtosis, as defined by F r i e d m a n (1961, 1962, 1967), have been calculated mechanically[7]. The upper half of table 1 gives a number of numerical characteristics for groups of samples from parallel-bedded sandur units; the lower half presents the results for the individual units showing other structures.

7) According to a programme for the Hewlett-Packard desk calculator model 9810 made by Mr S. Prins; grain-size analyses are available on request.

	number	structure	%<63 µm	modality	$\overline{X\varphi}$	$\overline{X\mu m}$	$\sigma_{\bar{X}\varphi}$	$\sigma_{\bar{X}\mu m}$	$\overline{\sigma\varphi}$	$\sigma\sigma_{\varphi}$	$\overline{\alpha 3\varphi}$	$\sigma_{\overline{\alpha 3\varphi}}$	$\overline{\alpha 4\varphi}$	$\sigma_{\overline{\alpha 4\varphi}}$	environment	formation
Tegelen	10	3+2	0.48	2.2	1.42	373	0.48	268-521	0.73	0.13	1.21	1.22	10.80	7.04	fluvial meandering	Sterksel Formation (Middle Pleistocene)
Hilversum -palace	4	3	0.37	2.7	1.10	466	0.06	447-486	0.74	0.13	0.97	0.60	7.12	3.22	fluvial (prob. meandering)	Urk Formation (Middle Pleistocene)
Blaricum	8	1	1.26	1.0	2.29	409	0.08	387-432	0.69	0.13	1.32	0.64	10.46	3.58	eolian	Twente Formation (Weichselian)
IJmuiden	13	1	1.56	1.4	2.60	165	0.13	151-180	0.52	0.11	2.89	1.18	21.03	6.12	beach	Westland Formation (Holocene)
Heerlen	13	1	0.26	1.1	2.26	209	0.14	189-230	0.34	0.08	1.45	2.23	16.98	18.57	beach	Heksenberg Form. (Miocene)
cf. table 1	42	1	0.99	3.1	1.77	293	0.38	225-382	0.79	0.16	0.68	0.90	7.67	3.19	alluvial fan	Drente Formation (Saalian)

Table 2.
Generalized numerical values extracted from grain size data from samples of some other sedimentary environments, and compared to those of parallel-bedded sandur sediments; for explanation of signs see table 1.

Although the sampling may not have been entirely at random, the impression is that the ratio of samples from parallel-bedded units to samples from units showing other structures gives a fair representation of the actual configuration within the Dutch Saalian sandur deposits. Moreover, the proportion (42 out of a total of 51 samples) is probably on the low side for the parallel-bedded (to low-angle cross-bedded) sediments.

Table 2 shows similar data for groups of sandy deposits which bear some resemblance to sandur deposits, either in the environment of deposition or in the sediment configuration, viz. (1) meandering river deposits and (b) parallel-bedded deposits (aeolian and beach)[8]; these are compared with those of the combined 42 samples of parallel-bedded sandur units.

It is apparent that the main difference can be found in the polymodality. The sandur deposits on average show more than three peaks, whereas the samples from the other environments have less than three peaks, and often considerably less (very small peaks (≤0,1%) in "tails" (with fractions <1%) of the grain size distributions are kept out of consideration). Moreover, if the ratios between the two higher mxima in bi- and polymodal compositions are compared, those of sandur depostis appear to be mostly between 1 and 1.5 to 2.0; compositions from the other environments are either unimodal or the ratios concerned may reach somewhat greater values (especially the eolian and most of the beach samples).

The average standard deviation ($\sigma\varphi$) and the standard deviation of the standard deviations ($\sigma\sigma\varphi$) also seem to be characteristic. Moreover, grain size distributions from sandur deposits are positively skewed ($\alpha_{3\varphi}$), to a lesser degree, and their values for kurtosis ($a_{4\varphi}$) are generally smaller and less variable ($\sigma a_{4\varphi}$) than those of the deposits from the other environments encountered. It should be stated that these conclusions are provisional, and probably only applicable to deposits from this part of the eastern side of the North Sea Basin, due to the important – and within one depositional area similar – influence of provenance and reworking on grain size distributions.

Concerning the position of the peaks a certain uniformity may be noticed. Within the saltation subpopulation peaks are in the ranges 125-150 µm (Heelsum and Leersum, only secundary maxima), 177-210 µm (Heelsum, Leersum, Lunteren, and Hilversum-NOS; many principal maxima), and either 250-300 µm (Lunteren and Hilversum in part) or 300-354 µm (Heelsum and Leersum; Lunteren and Hilversum in part; also with many principal maxima). Within the rolling subpopulation maxima are in the ranges 420-500 µm, 600-707 µm (most consistent at Heelsum and Leersum) or 707-850 µm (most conspicuous at Lunteren), and 1.41-1.68 mm (Heelsum, Lunteren in part) or 1.68-2.00 mm (Lunteren in part).
In all four locations the ranges up to 125 µm are normally very scarce represented; the ranges 150-177, 210-250, 354-420, 500-600 and 850-1410 µm are relative minima.

The location of maxima within the saltation subpopulation has its influence upon the path of the graphic representation according to the method of V i s h e r (1969); the correlative part of the graph often consists of some parallel line-parts.

In general the rolling subpopulation appears to be so small that it can hardly develop its own specific expression in the graphic representation.

In fig. 15 some grain size distributions representative of parallel-bedded sandur deposits are given graphically, together with some "average" distributions from the other environments mentioned above. The similarity in curve form be-

8) Tegelen: (south) eastern part of The Netherlands, near Venlo; pit Laumans;
Hilversum-Palace: several hundred metres southwest of location 4 on fig. 1;
Blaricum: several hundred metres east of location 5 on fig. 1;
IJmuiden: western coastal part of The Netherlands, about 2 km east of the actual beachline;
Heerlen: southeastern part of The Netherlands; "silversand" pits.

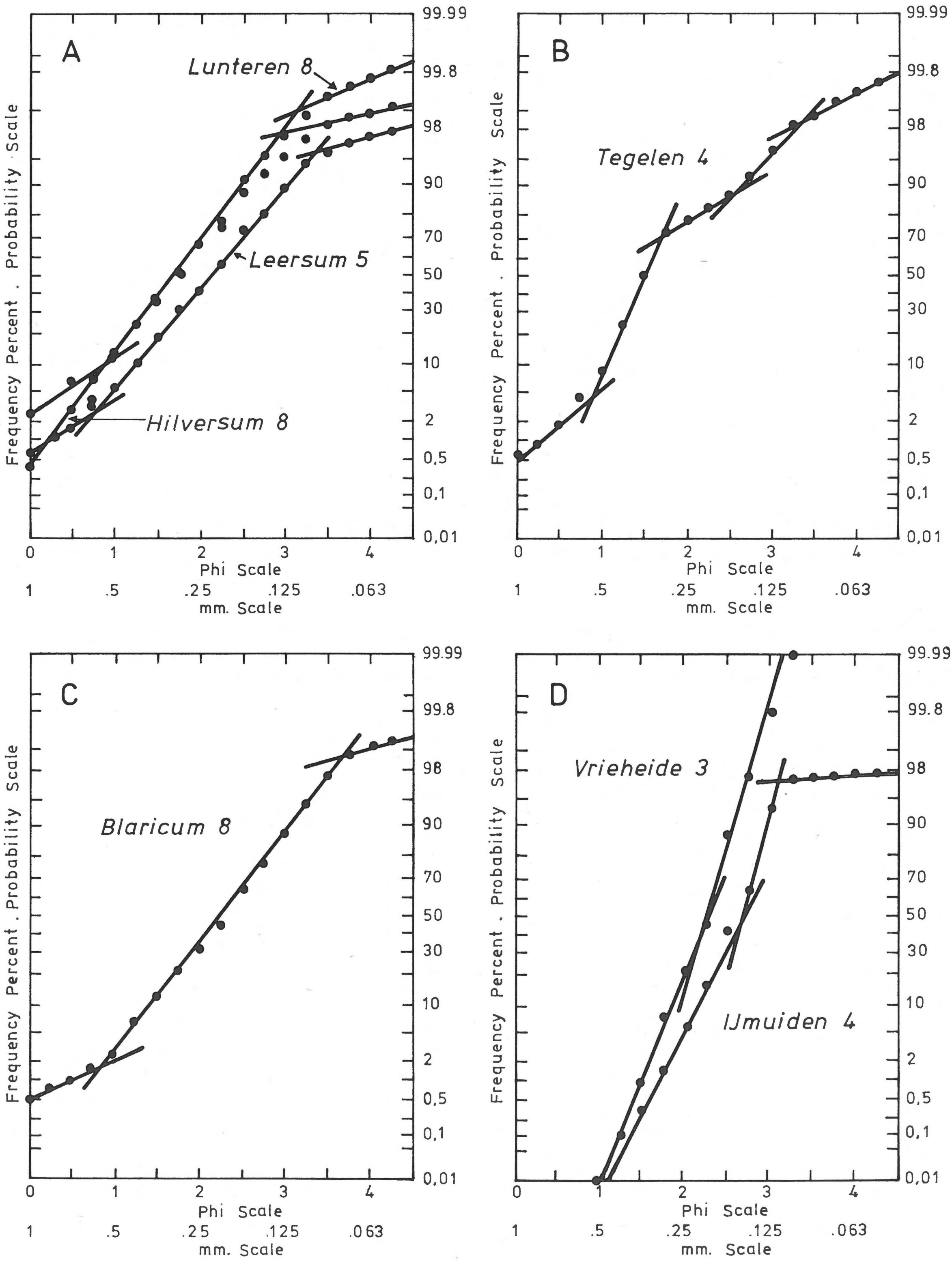

Fig. 15
Grain size distribution curves from samples of sandur deposits (A), a meandering river deposit (B), a parallel-bedded coversand deposit (C) and two parallel-bedded beach sands (D).

tween sandur deposits and coversand is striking.

The reason for the polymodalic and relatively less sorted character of these sandur deposits may tentatively be explained by the minor amount of sediment differentiation, as these sediments have for the greater part been reworked from lithologically varied fluvial ice-pushed deposits in the vicinity.

In the few cases where the gravel content has been determined (Lunteren, Hilversum) as a percentage of the whole grain size composition, it occasionally forms a surprisingly large part; in some cases no intervening grain sizes between gravel and the nearest sand-subfraction are represented.

CONCLUSIONS

The investigated sandur deposits in The Netherlands may be considered to be alluvial fan deposits in the sense of Bull (1972). The following typification can be made of to their structure.

(i) Parallel bedding and mosaic low-angle bedding are by far the most frequently occurring bedding types, developed in coarse sand with varying amounts of gravel (sheetflood deposits); locally this monotonous picture is interrupted by one or more minor channel-fills at some places concentrated in horizons.

(ii) Further towards the bordering ice-pushed ridge a facies may occur characterized by larger scale channel-fills (stream-channel deposits).

(iii) In the alluvial fan deposits sediments formed in a lower flow regime, viz. cross-bedded and cross-laminated dune and ripple deposits and parallel-laminated silty layers, are very scarce. These types of deposits may be tentatively considered to be pool sediments, which were not subjected to erosion. Other indications pointing to sedimentation related to a pool-and-riffle system have not been encountered.

(iv) Glacio-aqueous deposits characterized by a relative abundance of climbing-ripple cosets and load/slump dislocations, and generally composed of finer grain sizes (up to silty layers) compared to sandur deposits, have been formed during accelerated deposition. This accelerated deposition is assumed to have been caused by out flowing into a water-body of a larger size. The (hydrodynamic) environment of deposition is comparable to that of a kame. In places where these sediments occur together with sandur deposits, the latter are overlying.

(v) Whether or not longitudinal bars are accumulation or erosional forms, it may be stated that no indications have been found favouring sedimentation by longitudinal bars, parallel to a rounded bar form in cross-section (as suggested by McDonald and Bannerjee, 1971) or otherwise.

(vi) Grain size analyses reveal a strong polymodalic character, compared to those of samples from meandering-fluvial deposits and from parallel-bedded aeolian and beach deposits collected in the same area viz. the eastern side of the North Sea Basin. The low degree of differentiation may be due to a relatively very short transport distance of a mixture of various types of mainly reworked fluvial sediments.

(vii) Differences from piedmont alluvial fan deposits are generally minor. Piedmont fans are steeper in general. Sandur streams may often contain loose material from moraine ridges in excess, as shown on Baffin Island (Church, 1972) or from ice-pushed ridges like in The Netherlands. Piedmont fan deposits may show a degree of oxidation and/or a certain salt content (gypsum, calcite; cf. Bull, 1972), features not encountered in Dutch sandur deposits. Phenomena related to a cold climate are not necessarily present in piedmont fan deposits.

ACKNOWLEDGEMENTS

I should like to acknowledge the Director of the Geological Survey of The Netherlands for permission to carry out the investigation and to publish the results, Mr J.G. Zandstra who critically reviewed the manuscript, the Geophysical Department of the Survey and especially Mr S. Prins for the discussions on statistical parameters, Mr J.W.Chr. Doppert who reviewed the English text, Mr A. Koers and Mr J.A.M. Bruinenberg who produced the drawings, Mr Willemsen who produced most of the photographs, the analysts of the Granulometric Laboratory especially Miss E. van Wieringen and Mr J. Vermeule, and Mrs M.E.I. Jouini-Spruyt who typed the text.

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