

## **Definition of two new members in the upper Kreftenheye and Twente Formations (Quaternary, the Netherlands): a final solution to persistent confusion?**

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### **Abstract**

The upper part of the Late Saalian to Early Holocene Kreftenheye Formation in the Netherlands usually consists of a relatively fine-grained, clastic bed (frequently referred to as 'loam bed'), which is generally regarded as an overbank deposit of incipient meandering fluvial systems. It was formed essentially in two phases, during the Allerød and the Early Holocene. The 'loam bed' is sometimes covered by eolian river dune deposits which have also been considered as part of the Kreftenheye Formation. Both sedimentary units have a large areal extent, a number of characteristic lithologic properties and a distinct stratigraphic position. It is shown that the 'loam bed' in a lithologic sense rarely consists of loam. The currently existing terminological confusion concerning the 'loam bed' and (to a lesser extent) the river dune deposits is caused by the mixing of lithologic, genetic, lithostratigraphic and chronostratigraphic criteria. In order to avoid further confusion, two formal lithostratigraphic units are introduced and lithologic descriptions are given for the holostratotypes of these units. The Wijchen Member of the Kreftenheye Formation essentially contains the 'loam bed'. The definition of the areally variable Wijchen Member is supported by a hypostratotype. The river dune deposits are incorporated in the Delwijnen Member. The Delwijnen Member is included in the Twente Formation because its lithologic characteristics and stratigraphic position are more similar to the Younger cover sands (Wierden Member) of the Twente Formation than to the fluvial coarse-grained deposits of the Kreftenheye Formation.

### **Introduction**

The Kreftenheye Formation was established as a lithostratigraphic unit by Zonneveld (1958) and included deposits of the River Rhine in the Netherlands that are rich in volcanic minerals, especially augite. They were formed in the period from the maximum extent of the Saalian glaciation in the Netherlands to the Weichselian. After contemporaneous sediments of the River Meuse (Van der Heide & Zagwijn 1967), as well as eolian river dune

deposits (Verbraeck 1970: 40) had been added to the Kreftenheye Formation, a formal description including a well-defined stratotype was given by Doppert et al. (1975). According to them, the 10–25 m-thick Kreftenheye Formation predominantly consists of coarse sands and gravels with a heavy mineral association rich in augite, deposited by the Rivers Rhine and Meuse during the time interval from the maximum extent of the Saalian ice sheet until the Early Holocene. Included are also a loam bed overlying these coarse-grained deposits, as well

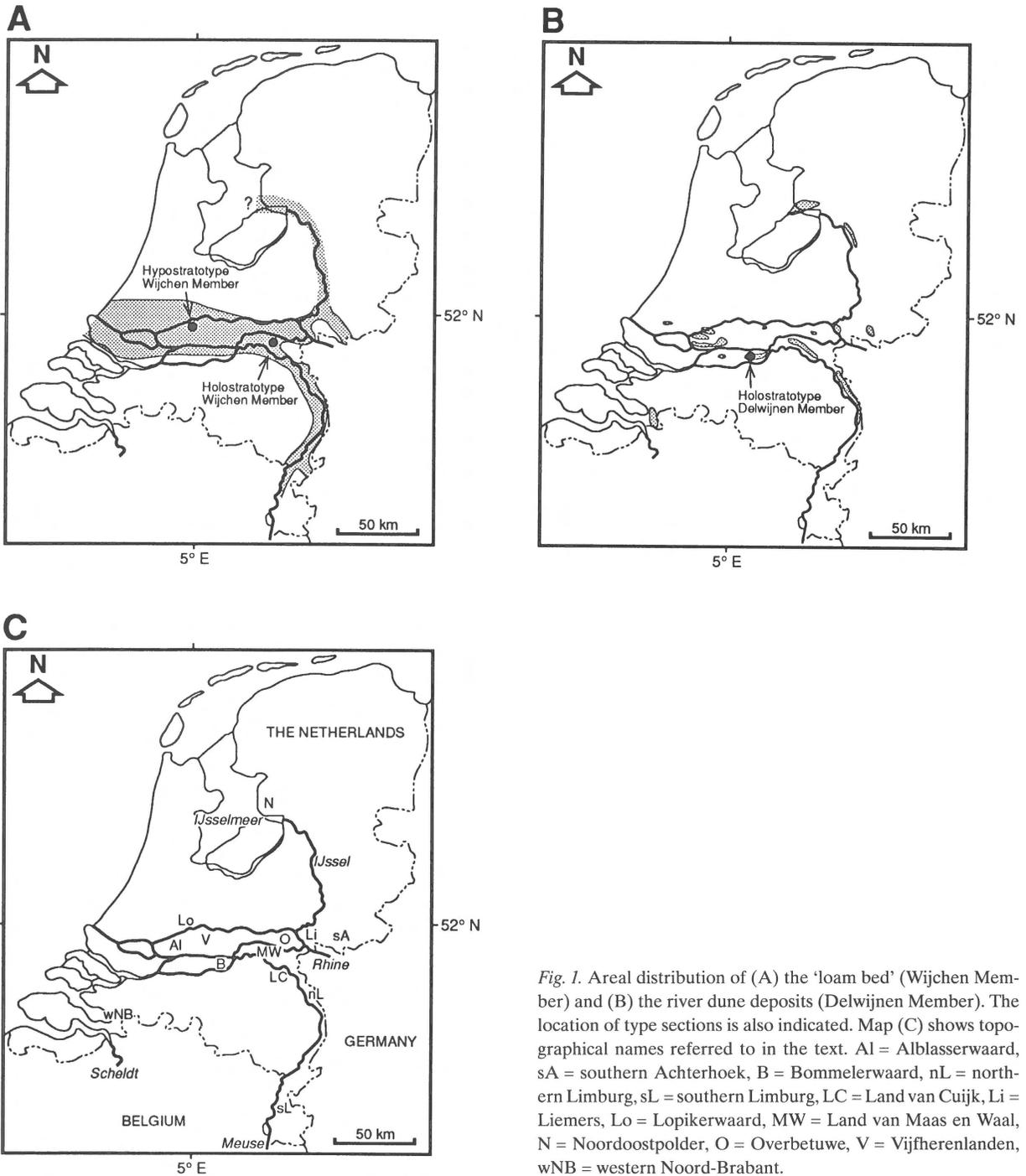


Fig. 1. Areal distribution of (A) the 'loam bed' (Wijchen Member) and (B) the river dune deposits (Delwijnen Member). The location of type sections is also indicated. Map (C) shows topographical names referred to in the text. Al = Alblasserwaard, sA = southern Achterhoek, B = Bommelerwaard, nL = northern Limburg, sL = southern Limburg, LC = Land van Cuijk, Li = Liemers, Lo = Lopikerwaard, MW = Land van Maas en Waal, N = Noordoostpolder, O = Overbetuwe, V = Vijfherenlanden, wNB = western Noord-Brabant.

as river dune deposits, which usually occur on top of the loam bed and are considered to be genetically related to the fluvial deposits of the Kreftenheye Formation (Doppert et al. 1975: 13, 25). An informal subdivision of the Kreftenheye Formation into six

sub-units, mainly on the basis of sediment-petrologic characteristics, was given by Verbraeck (1984: fig. 34).

The sediments that are now considered as belonging to the upper part of the Kreftenheye For-

mation already received attention in the classical thesis by Vink (1926: fig. 5, 402–406). He gave a description of a loamy or clayey bed underneath outcropping, Pleistocene sand bodies (river dunes) in the Alblasserwaard. The sand bodies were interpreted by him as erosional remnants of the Lower Terrace. Steenhuis (1941) noticed that the loam or clay bed occurred also in the surrounding flood basins, at approximately the same level. The loam bed was studied more extensively by Koenigs (1949) in the eastern Netherlands, where it occurs close to the surface. It was correlated with the ‘Hochflutlehm’ (Koenigs 1949: 24; Pons & Schelling 1951), which had been described as the uppermost deposit of the ‘Niederterrasse’ in the adjacent part of Germany. Bennema & Pons (1952) subsequently correlated the loam beds in the eastern and the west-central Netherlands.

Ever since the early reports of Vink (1926) and Steenhuis (1941), a confusing lithologic terminology concerning the loam bed has developed. Although ‘loam bed’, ‘clay bed’ and ‘Hochflutlehm’ were the most widely used terms, descriptions like ‘old river clay’ (Poelman 1965: 125), ‘decantation clay’ (Van den Toorn 1976: 103), ‘flood basin deposits’ (Van de Meene 1980), ‘clay/peat bed’ (Van de Meene 1977: 80; Teunissen 1983) and ‘clay/gyttja/peat bed’ (Verbraeck 1984: 109–112) have also been used. Koenigs (1949: 11) noticed that the grain-size distribution of the fine fraction of this material cannot be discriminated from that of clay.<sup>1</sup> In spite of this, the term ‘loam’ has gained general use, although many authors (Pons & Bennema 1958: 125; Poelman 1965: 125; Van der Woude 1983: 9; Verbraeck 1983) have shown that this is in fact incorrect. Van der Woude (1983) correctly pointed out that the term ‘loam’ has usually been used in a lithostratigraphic sense rather than as a lithologic description. This is obviously a result of the characteristic, firm nature of this material and its presumed genetic origin, as indicated by the term ‘Hochflutlehm’. The confusion became

<sup>1</sup> Classification of sediment textures in the Netherlands is based upon De Bakker & Schelling (1966). The recent standard NEN 5104 (Nederlands Normalisatie-instituut 1989), which is followed in the present paper, uses essentially the same boundaries between texture classes.

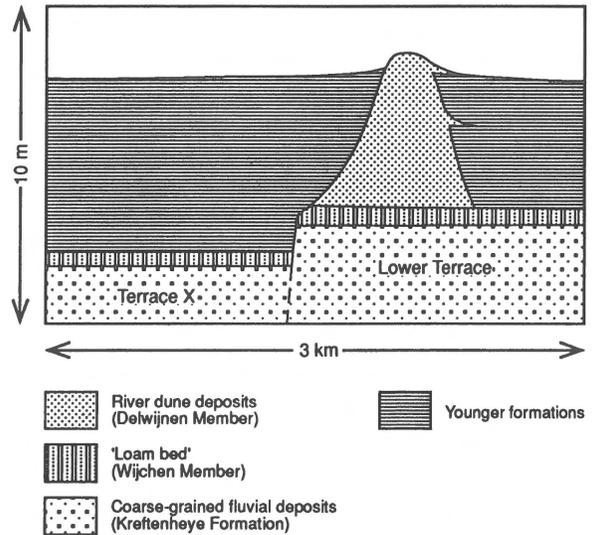


Fig. 2. Schematic cross section depicting the stratigraphic position of the ‘loam bed’ (Wijchen Member) and the river dune deposits (Delwijnen Member).

even greater when it was attempted to use also chronostratigraphic criteria to identify this unit. For instance, Havinga & Op ’t Hof (1983: 42) state that the ‘loam bed’ only comprises Late Weichselian sediments. The mixing of lithologic, genetic, lithostratigraphic and sometimes also chronostratigraphic criteria has resulted in a confusion that we consider unacceptable (cf. Hedberg 1976).

To a lesser extent, some related problems occur in the definition of the eolian river dune deposits. As has been discussed extensively by Koster (1982), the identification of various surficial sandy eolian deposits in the Netherlands and their incorporation into different formations by Doppert et al. (1975) is usually based on genetic criteria rather than lithology. In some cases even age plays a role, for instance in the distinction between the Kreftenheye Formation and the Kootwijk Formation (Verbraeck 1984: 145–146).

Although the uppermost sediments of the Kreftenheye Formation (‘loam bed’ and river dune deposits) have distinct lithologic and stratigraphic features and have been the subject of numerous studies, a formal lithostratigraphic designation has never been proposed. Much confusion can be avoided when this is done in a proper way, especially in cases where many different names are in use for essential-

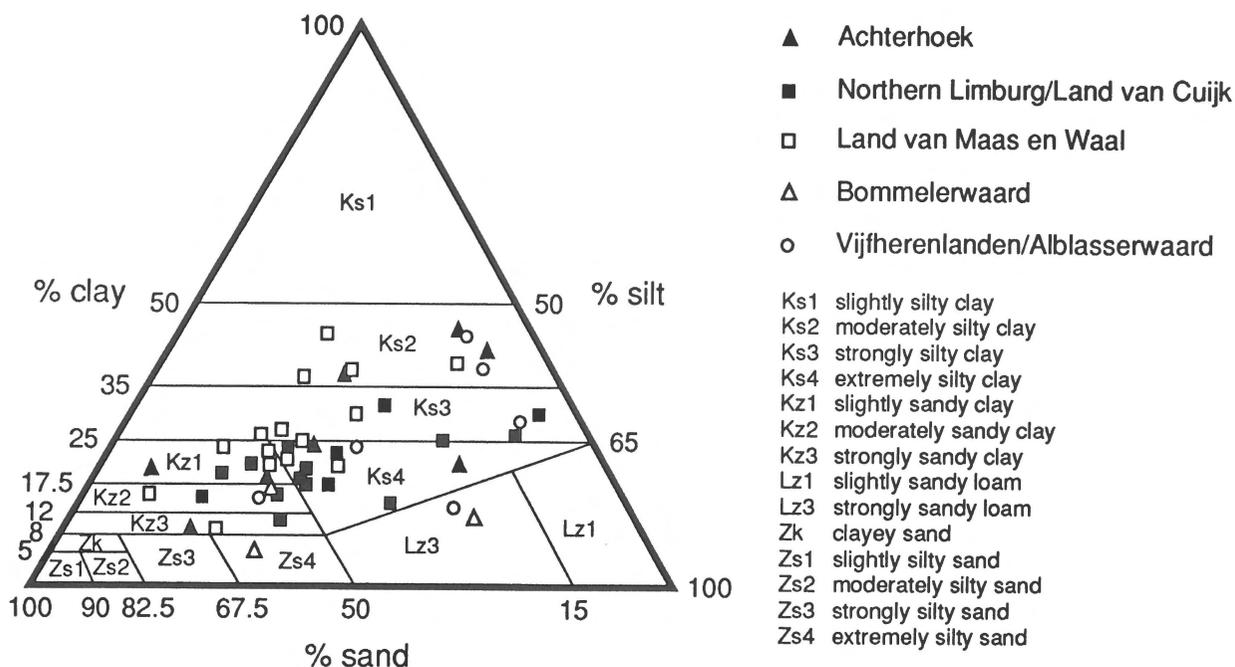


Fig. 3. Grain size of the 'loam bed' (Wijchen Member), indicated in a textural triangle following the classification of the Nederlands Normalisatie-instituut (1989). In those areas where the 'loam bed' crops out, only grain-size data from depths > 50 cm below the surface have been used. Note further that samples from the Vijfherenlanden and Alblasserwaard were nearly all taken from the lower (less clayey) part of the 'loam bed'. Sources: Schelling (1951), Van den Broek & Maarleveld (1963), Pons (1966), Van den Toorn (1976), Van de Meene (1977), Törnqvist et al. (1986), Miedema (1987) and T.E. Törnqvist (unpub. data).

ly the same unit (cf. Van Loon & Wiggers 1975, 1977). It is the purpose of this paper to introduce a practical and simple lithostratigraphic nomenclature for the 'loam bed' and the river dune deposits, and to provide a useful stratigraphic framework for future studies. The paper does not aim to go into detail on the sedimentary history of these deposits.

### Characteristics and origin of the upper Kreftenheye Formation: a review

#### *Areal distribution, lithology and genesis*

##### *'Loam bed'*

The 'loam bed' (in a lithostratigraphic sense) covers a major part of the distribution area of the Kreftenheye Formation (Fig. 1A), and it is especially widespread in the Rhine-Meuse area of the central Netherlands. Its large areal extent also applies to the adjacent part of Germany, where it is found upstream to Köln (Brunnacker 1978: 405). Smaller oc-

currences, both with regard to areal extent and thickness, were reported from the IJssel valley (Hamming et al. 1965) and the IJsselmeer area (Wiggers 1955). Even smaller occurrences were described from southern Limburg (Stichting voor Bodemkartering 1970). The 'loam bed' also occurs along the Meuse in the adjacent part of Belgium (Paulissen 1973: 142–144, 150).

It has long been recognized (Pons 1957: fig. 18) that the 'loam bed' consists of at least two separate layers of different age, generally occurring at different elevations (Fig. 2). Especially in the upstream areas, notably in Limburg, at least three terraces covered with 'loam' have been identified (Van den Broek & Maarleveld 1963; Stichting voor Bodemkartering 1970). In the eastern Netherlands a height difference of 1–2 m between two different layers has been observed (Berendsen et al., in press). 'Loam beds' covered by river dunes are generally of the highest level (Vink 1926: 27; Van der Woude 1983: 63; Berendsen et al., in press). The 'loam bed' may locally be absent. This is explained by the pres-

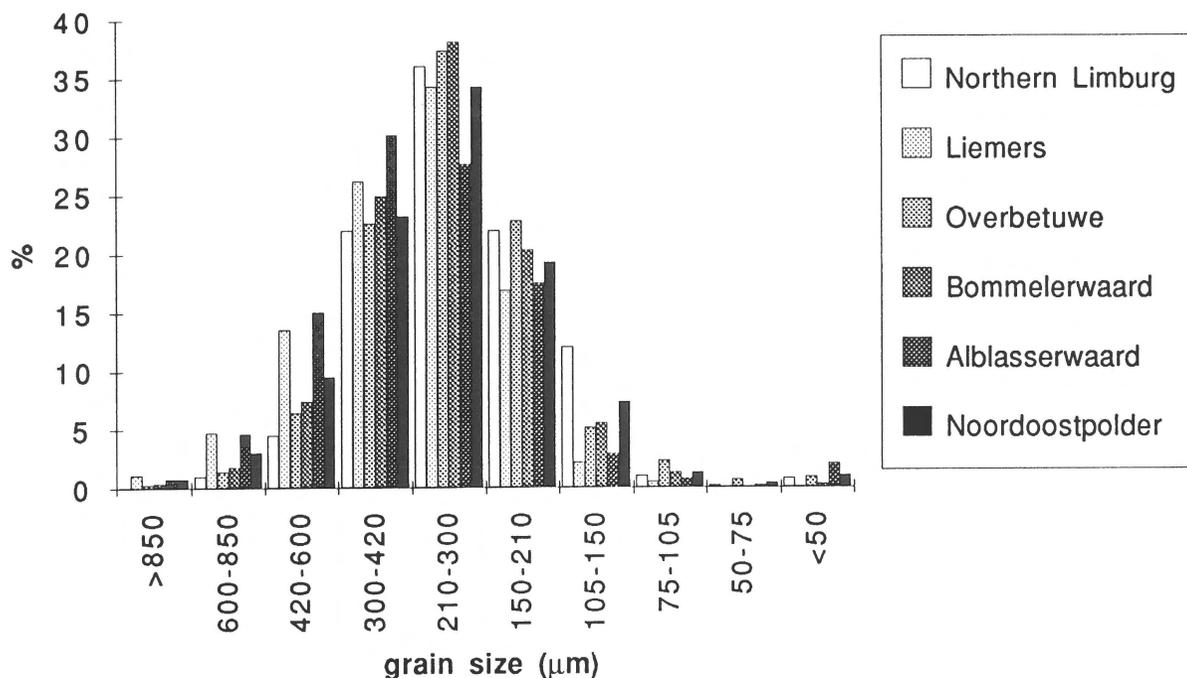


Fig. 4. Grain size of representative samples of river dune deposits (Delwijnen Member), indicated as histograms. Sources: Schelling (1951), Verbraeck (1974, 1983), Van Loon & Wiggers (1977). The Bommelerwaard sample is sample 3 from the type section of the Delwijnen Member (Fig. 7).

ence of relatively small-sized abandoned channels (Verbraeck 1983; Van der Woude 1983: figs 17–19; Törnqvist et al. 1986). Furthermore, incision by Holocene channels has resulted in large-scale erosion of the ‘loam bed’.

The grain size of the ‘loam bed’ is shown in Fig. 3. Only two of the 48 samples actually consist of loam (strongly sandy loam) and one sample is classified as sand (extremely silty sand). Most of the ‘loam’ samples consist of clay: strongly to extremely silty clay (45%), slightly to strongly sandy clay (30%) or moderately silty clay (20%). There is a slight tendency for a higher silt content of the samples from northern Limburg and the Land van Cuijk, which is a result of the admixture of fluvially transported loess from the south.

In the west-central part of the Netherlands various authors have recognized a bipartition of the ‘loam bed’, namely an upper, dark grey, non-calcareous clay grading downwards into a light grey, strongly calcareous (sandy) clay (Hageman 1969; Van Staaldin 1979: 38; Van der Woude 1983: 9;

Verbraeck 1990). In other areas the colour is usually bluish or greenish grey (Törnqvist et al. 1986).

Doeglas (1951) interpreted the ‘loam bed’ as an overbank deposit belonging to an incipient meandering fluvial system that developed ‘around the Pleistocene–Holocene transition’, when conditions had become unfavourable for braided channels. This explanation is still generally accepted, although there is now much more detailed evidence on the age of this deposit.

Based on its typical characteristics (among others its firmness, low organic matter content and, at least in his study area, the absence of carbonate), Koenigs (1949) concluded that the ‘loam bed’ must have undergone prolonged weathering (see also Miedema 1987). The typical firm character is due to the fact that this deposit has been at the surface for a prolonged period of time. This can be explained as a result of fluvial incision in the Early Holocene and a lowering of the groundwater table. The upper, dark-coloured part of the ‘loam bed’ in the west-central Netherlands is interpreted as a vegetation horizon. This can also be related to the reduced flu-

vial sedimentation in the Early Holocene (cf. Berendsen et al., in press).

Another typical feature of the 'loam' is the admixture of sand, mainly of the fraction 210–300  $\mu\text{m}$ . This has also been explained by pedogenic processes (Hoeksema 1953: 26–27): mixing with the underlying fluvial sands due to faunal activity. Van de Meene (1977: 81–82) expressed a similar view based on a comparison of grain-size data of a few samples. On the other hand, Schelling (1951: 94) and Pons (1957: 15) suggested that the sand, especially that which is found in the upper part of the 'loam bed', has an eolian origin, and can be related to the (partly) contemporaneous river dune formation. This opinion is supported by Van der Woude (1983: 61–62), who showed in his study area in the western Netherlands that the grain size of the admixed sand is almost identical to that of eolian sand in nearby river dunes.

#### *River dune deposits*

River dune deposits occur all over the distribution area of the Kreftenheye Formation, as well as in a few other areas (Fig. 1B). In the Rhine-Meuse area, river dunes were described, among others, by Bennema & Pons (1952), Pons (1957), Verbraeck (1970, 1974, 1984), Van de Meene (1977, 1980), Törnqvist et al. (1986) and Berendsen (1988). In the IJsselmeer area, river dunes were described by Wiggers (1955: 38–43), Ente (1971), Van Loon & Wiggers (1976, 1977) and Gotjé (1993), along the River Meuse in northern Limburg by Schelling (1951) and Teunissen (1983) and along the River Scheldt in western Noord-Brabant by Schwan (1991).

The grain-size distribution of some representative river dune sands is shown in Fig. 4. Nearly all samples have a median grain size between 210 and 300  $\mu\text{m}$  (fine-medium sand). The admixture of silt is less than 3%. The portion of coarse sand (> 500  $\mu\text{m}$ ) is generally less than 10%. A regional comparison of the histograms in Fig. 4 gives no indication for a systematic granulometric trend of the river dune sands. Surficial river dune deposits are always non-calcareous (< 1% carbonate). However, the lower parts of the large river dunes in the west-central Netherlands may contain some carbonate (Vink 1926: 402–406; Van der Woude 1983: 62).

Bennema & Pons (1952) were the first to recognize the eolian origin of the river dunes. The formation of the river dunes in the Netherlands is generally related to environments with braided river systems. These provide a suitable source area for extensive eolian sedimentation (e.g. Pons 1957: 27). However, they also may occur in connection with meandering channels (Isarin & Berendsen 1992).

#### *Age*

Geochronologic and chronostratigraphic units used in this paper follow the definitions of Mangerud et al. (1974; see also Janssen & Törnqvist 1991). Dating of the deposits under discussion here is problematic. This holds true especially for the eolian sands, which cannot be  $^{14}\text{C}$ -dated directly. Dating of the 'loam bed' has been considered crucial, not only to understand the sedimentary history of this deposit itself, but also to determine the beginning of the period of formation of the river dunes.

Early publications dealing with areas in the eastern Netherlands (e.g. Koenigs 1949; Pons 1957: 19) present ample palynological evidence which directly or indirectly dates the 'loam bed' as Late Weichselian, predominantly Allerød. According to Schelling (1951), the 'loam bed' may also be of Early Holocene age. These results were confirmed by later studies (e.g., Teunissen & Van Oorschot 1967; Teunissen & De Man 1981). In the west-central Netherlands, predominantly Early Holocene ages were reported for this deposit. All ages in this area were obtained from sites where the 'loam bed' is not covered by river dune sand (e.g. Pons & Bennema 1958; Verbraeck 1974; Van Staalduinen 1979: 40; Berendsen 1982: 55). According to Hageman (1969) and Van der Woude (1983: 62), this age applies to the upper, dark grey part of the 'loam bed'. As was already observed by Pons & Bennema (1958: 133), there is a tendency for the younger ages of the 'loam bed' to be found in the more western areas. As mentioned before, the 'loam bed' in the Rhine-Meuse area occurs at two different levels (Fig. 2), which appear to converge in a western direction (Pons 1957: fig. 16). In the westerly areas the two layers are likely to occur on top of each other. The two distinct

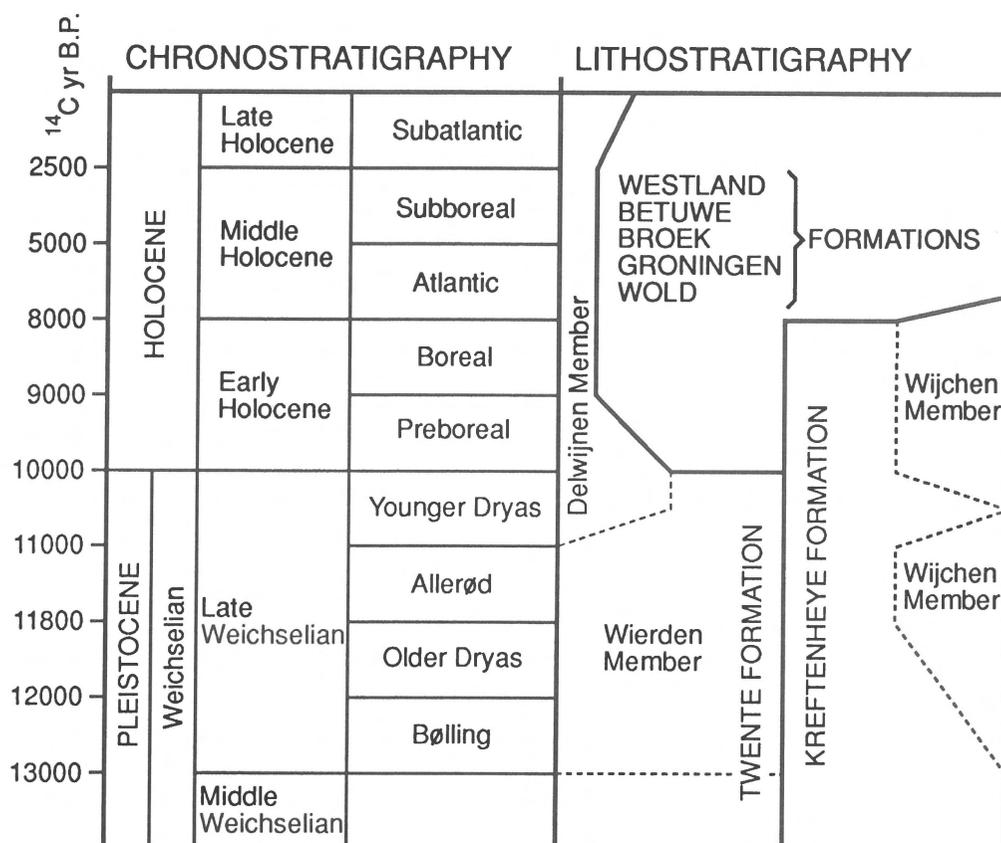


Fig. 5. Stratigraphic table showing the lithostratigraphic units discussed in the text. Chronostratigraphy after Mangerud et al. (1974).

levels in the eastern Netherlands represent two separate generations of river evolution (Berendsen et al., in press). The oldest is found at the highest elevation. It generally covers the Lower Terrace and is predominantly of Allerød age. The Early Holocene 'loam bed' which covers the so-called Terrace X (Pons 1957: fig. 18) is found at a lower level. Apparently this younger deposit is much more widespread in the western areas than upstream.

Due to the general lack of organic matter, only a few  $^{14}\text{C}$  ages of the 'loam bed' are available. Wiggers (1955: 42) dated peat which is part of this unit at a site where it is underlain by cover sand and overlain by river dune sand. The age obtained was  $10500 \pm 280$  yr B.P. (GrN-375). A sequence of  $^{14}\text{C}$  ages in a compact peat bed intercalated between fluvial and eolian sand in northern Limburg yielded ages between  $12210 \pm 190$  yr B.P. (GrN-4787) and  $10870 \pm 100$  yr B.P. (GrN-4786; Teunissen 1983). Another peaty facies of this unit underneath a river dune

near Wijk bij Duurstede was  $^{14}\text{C}$ -dated at  $11700 \pm 100$  yr B.P. (GrN-11469; Törnqvist et al. 1986; Berendsen 1988). A similar sample in the Bommelerwaard had an age of  $10800 \pm 60$  yr B.P. (GrN-18105; H.J.T. Weerts, unpub. data).

Some recently obtained  $^{14}\text{C}$  ages of the vegetation horizon which forms the upper part of the 'loam bed' in the west-central Netherlands, point to an age in the range 7000–8000 yr B.P. (T.E. Törnqvist, unpub. data), indicating that deposition of this unit continued into the Early Atlantic. It can thus be concluded that the formation of the oldest 'loam bed' predates the (primary) river dune formation (see below), whereas the youngest 'loam bed' post-dates it.

The river dunes were generally formed in the second half of the Younger Dryas (Kasse et al., in press). River dune formation probably ended at the beginning of the Holocene, when forests recovered. The terminus post quem for river dune formation

can be deduced from several  $^{14}\text{C}$  ages:  $10500 \pm 280$  yr B.P. (GrN-375, Wiggers 1955);  $10870 \pm 100$  yr B.P. (GrN-4786, Teunissen 1983);  $10320 \pm 60$  yr B.P. (GrN-10924, De Jong 1981/1983);  $11700 \pm 100$  yr B.P. (GrN-11469, Törnqvist et al. 1986; Berendsen 1988);  $11240 \pm 50$  yr B.P. (GrN-12743, Schwan 1991);  $10500 \pm 60$  yr B.P. (GrN-11568, Bohncke et al. 1993) and  $10800 \pm 60$  yr B.P. (GrN-18105, H.J.T. Weerts, unpub. data). A terminus ante quem of  $9050 \pm 45$  yr B.P. (GrN-12744) was obtained by Schwan (1991) for river dune formation in the area east of the Scheldt. Although the source areas (floodplains of braided fluvial systems) had disappeared, redeposition of eolian sand continued locally throughout the Holocene, as is evidenced by intercalations of river dune sand in overlying formations (Fig. 2; Pons 1957: fig. 24; Pons & Bennema 1958: fig. 6; Van der Woude 1983: fig. 18). In some areas (notably along the Meuse in northern Limburg) this reactivation and reworking has been intensified in more recent years, especially since the Late Middle Ages.

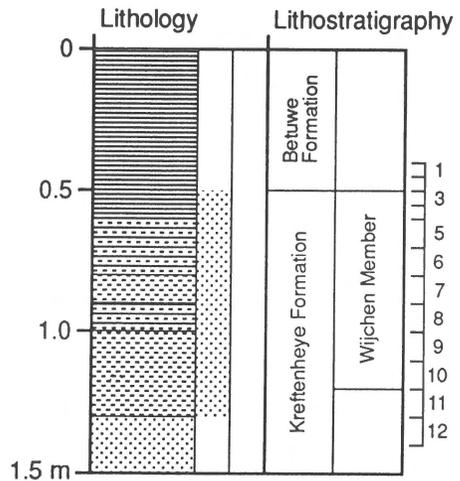
**Discussion**

A formal lithostratigraphic subdivision is needed to eliminate the currently existing confusion concerning the sediments of the upper part of the Kreftenheye Formation. We therefore introduce two new members, viz. the Wijchen Member and the Delwijnen Member, that include the 'loam bed' and the river dune deposits respectively. The stratigraphic context of the Wijchen and Delwijnen Members is shown in Fig. 5. Detailed descriptions of these lithostratigraphic units are given in the next section.

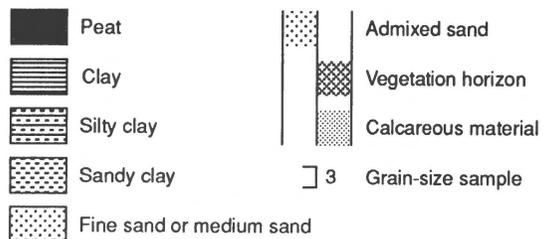
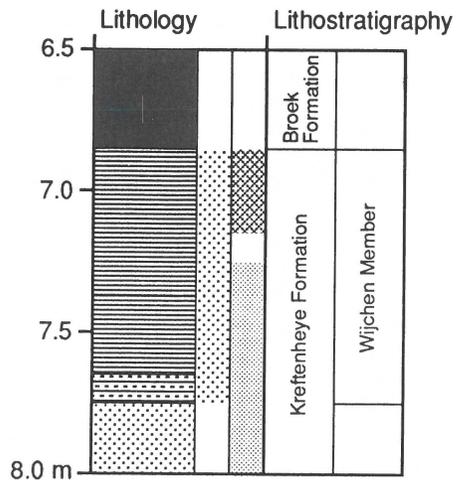
Chronostratigraphic or genetic criteria do not play a role in the lithostratigraphic classification presented here. According to Hedberg (1976: 31), 'Lithostratigraphic units are recognized and defined by observable physical features and not by inferred geologic history or mode of genesis'.

The Kreftenheye Formation has mainly been defined on the basis of its heavy mineral content. It is generally assumed (Verbraeck 1970: fig. 40) that the river dune deposits and the fluvial coarse-grained source material have a comparable (although not identical) mineralogy. Since mineral composition

**A**  
Holostratotype Wijchen Member  
177.180/427.660/+6.2



**B**  
Hypostratotype Wijchen Member  
127.340/439.035/-1.0



partly depends on grain size (Zonneveld 1946; Verbraeck 1970: fig. 10) and augite occurs mainly in the coarser fractions, the coarse-grained fluvial deposits of the Kreftenheye Formation have a higher augite content than the finer river dune deposits. River dune deposits that were formed outside the area where Rhine deposits occur have a different heavy-mineral composition. This is for instance the case with river dunes east of the Meuse in Limburg and east of the Scheldt in western Noord-Brabant. We therefore prefer not to take into account sediment-petrologic characteristics. Such characteristics generally only play a minor role in lithostratigraphic subdivisions of surficial deposits in the Netherlands (cf. Doppert et al. 1975). Many other diagnostic lithologic properties exist to characterize the sediments discussed in this paper, thus enabling lithostratigraphic classification directly in the field, without the necessity of additional laboratory analyses.

We consider the Wijchen Member (the former

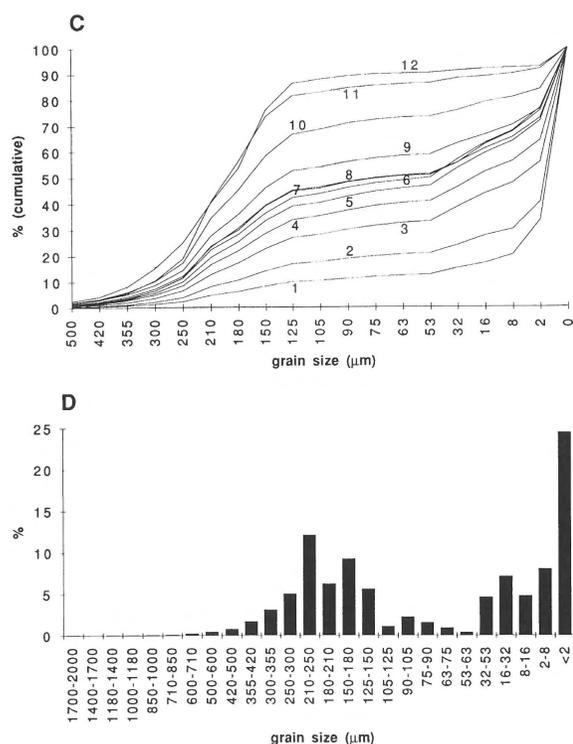


Fig. 6. Type sections of the Wijchen Member. (A) Holostratotype, (B) hypostratotype, (C) cumulative plots of grain size of samples from the holostratotype and overlying and underlying deposits, (D) grain-size histogram of sample 7. Location of type sections in Fig. 1A.

‘loam bed’) as part of the Kreftenheye Formation, which is in accordance with previous subdivisions. The Delwijnen Member traditionally also belongs to the Kreftenheye Formation. However, the question is whether this is justified. Lithologically, the Delwijnen Member is characterized by (1) a vertically and laterally homogeneous grain size, (2) a good sorting and (3) a lack of carbonates. These lithologic features, which can easily be determined in the field, differentiate the Delwijnen Member from the other sediments of the Kreftenheye Formation. On the other hand, these features are comparable to those of the Younger cover sands (Wierden Member) which form the upper part of the Twente Formation (Van der Hammen 1971; Van Huissteden 1990), although the sands of the Delwijnen Member are significantly coarser. The grain-size distributions of cover sands of the Wierden Member have maximum values in the fraction 150–210 μm, whereas underlying cover sands are even finer (Wijmstra et al. 1971). The stratigraphic position of the Delwijnen Member is roughly comparable to that of the Wierden Member of the Twente Formation. On lithologic and stratigraphic grounds, we therefore include the Delwijnen Member in the Twente Formation. In this context, it is interesting to note that river dunes (north)east of the Meuse in the Land van Maas en Waal and northern Limburg were classified as Twente Formation on the 1:600000 geological map of the Netherlands (Van Staalduinen & Van Veen 1975).

### Description of the new lithostratigraphic units

The definitions of the Wijchen Member of the Kreftenheye Formation and the Delwijnen Member of the Twente Formation follow the guidelines of Hedberg (1976). Both members are defined by a holostratotype; for the Wijchen Member also a hypostratotype is given. This is needed to account for lateral facies variation within this unit (cf. Hedberg 1976: 26). For the selection of the type sections we considered it of prime importance to find complete vertical sequences which are lithologically representative and easily accessible (cf. Van Loon 1981).

*Wijchen Member*

*General description*

The Wijchen Member of the Kreftenheye Formation generally consists of silty clay or sandy clay (Figs 3, 6A, C, D). It is especially characterized by its firmness and its admixture with varying amounts of sand (usually in the fraction 210–300 µm). In the west-central Netherlands, where the member is usually more clayey (Fig. 6B), a conspicuous dark grey horizon (vegetation horizon) frequently constitutes its uppermost part. More or less organic facies of the member occur locally. The member is mostly non-calcareous (<1% carbonate). However, in the west-central Netherlands its lower part is usually rich in carbonate. The (maximum) areal distribution of the Wijchen Member in the Netherlands is shown in Fig. 1A.

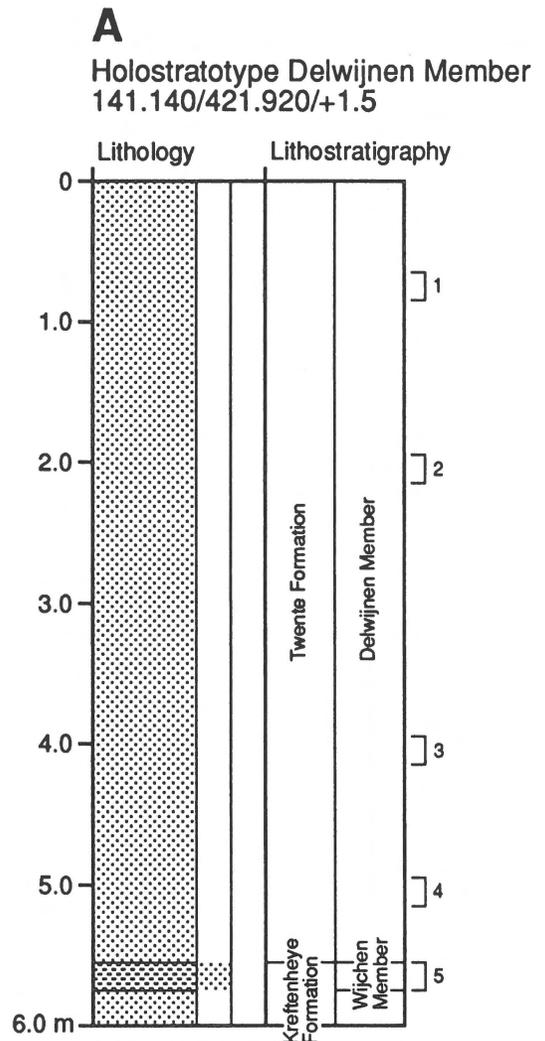
*Thickness*

The thickness of the Wijchen Member is usually 0.5–1.0 m. In many cases, however, it is larger or smaller. For instance, in the Lopikerwaard, significantly thicker occurrences may be present as witnessed by a core discussed by Berendsen (1982: 204–205); here this unit comprised almost 3 m. In this area occasional thicknesses of up to 6 m have been observed (Törnqvist 1993), presumably representing residual channel fills. Van der Woude (1983: 63) reported thick (> 2.5 m) occurrences of this unit underneath river dunes. In the Noordoostpolder and the IJssel valley the Wijchen Member is relatively thin (0.2 m; Wiggers 1955: 42–43; Hamming et al. 1965).

*Stratigraphic position*

The Wijchen Member constitutes the uppermost part of the Kreftenheye Formation. In the central Netherlands it occurs either at the top of the Lower Terrace or at the top of Terrace X. In both cases it overlies sands and gravels of the Kreftenheye Formation. Occasionally it can be found on top of cover sands (Wierden Member) of the Twente Formation (Wiggers 1955: fig. 16; Törnqvist 1993). On the other hand, cover sands may also be found overlying the Wijchen Member (Verbraeck 1970: 47; H.J.T. Weerts, unpub. data). The Wijchen Member con-

sists of at least two separate layers which usually occur at different levels. In the west-central Netherlands these two layers may occur directly on top of each other. Outside the areas where the Wijchen Member crops out, various younger deposits can be found on top of it, one of which is the Delwijnen Member (Twente Formation). Elsewhere, organic deposits or clastic fluvial or marine deposits, belonging to the Betuwe or Westland Formations according to the nomenclature of Doppert et al. (1975), cover the Wijchen Member. Following the nomenclature of Roeleveld (1974) or Berendsen (1982, 1984), the Groningen, Wold or Broek Formations can be found on top of the Wijchen Member.



### Relation to previously described units

The Wijchen Member has been described previously with many different names. Many authors have referred to it as 'loam bed', 'clay bed' or 'Hochflut-lehm'. Also its lateral facies variability has been mentioned (e.g. Van de Meene 1977; Teunissen 1983; Verbraeck 1984). In the west-central Netherlands it contains both the light grey and the dark grey deposits discussed by Hageman (1969), Van Staalduinen (1979), Van der Woude (1983) and Verbraeck (1990). Verbraeck (1990) considered it as part of the Kreftenheye VI deposits, because of its genetic relationship with the Kreftenheye VI channel deposits.

### Genesis

Essentially overbank deposits (natural levee deposits and flood basin deposits) of incipient meandering fluvial systems, usually with an admixture of sand due to syn-sedimentary eolian input or post-

sedimentary bioturbation. Locally residual channel deposits.

### Age

The two widely occurring layers of the Wijchen Member are of Late Weichselian (predominantly Bølling to Allerød) and Early Holocene (extending into the Early Atlantic) age, respectively (Fig. 5).

### Type sections

Holostratotype: boring in the Wezelsche Broek, NW of Wijchen (Land van Maas en Waal); coordinates: 177.180/427.660; surface elevation: +6.2 m; interval: 0.50–1.20 m below the surface (Fig. 6A). Hypostratotype: boring in the Polder Middelbroek, SE of Ameide (Alblasserwaard); coordinates: 127.340/439.035; surface elevation: –1.0 m; interval: 6.85–7.75 m below the surface (Fig. 6B).

### Delwijnen Member

#### General description

The Delwijnen Member of the Twente Formation generally consists of fine sand or medium sand (210–300  $\mu\text{m}$ ), sometimes with an admixture of silt or a minor amount of coarse sand (Figs 4, 7B, C). Due to extensive leaching the upper few meters of the sands are always non-calcareous (< 1% carbonate). The lower parts occasionally contain some carbonate. The heavy-mineral composition of the Delwijnen Member in general reflects the mineralogy of nearby local source material. In the central Netherlands it is comparable to the fluvial sands of the Kreftenheye Formation. The areal distribution is indicated in Fig. 1B.

#### Thickness

The thickness of the Delwijnen Member is variable due to the irregular dune topography. Maximum thicknesses are about 15 m in the central Netherlands and about 20 m along the Meuse in northern Limburg.

#### Stratigraphic position

In the Rhine-Meuse area the Delwijnen Member is usually underlain by the Wijchen Member, al-

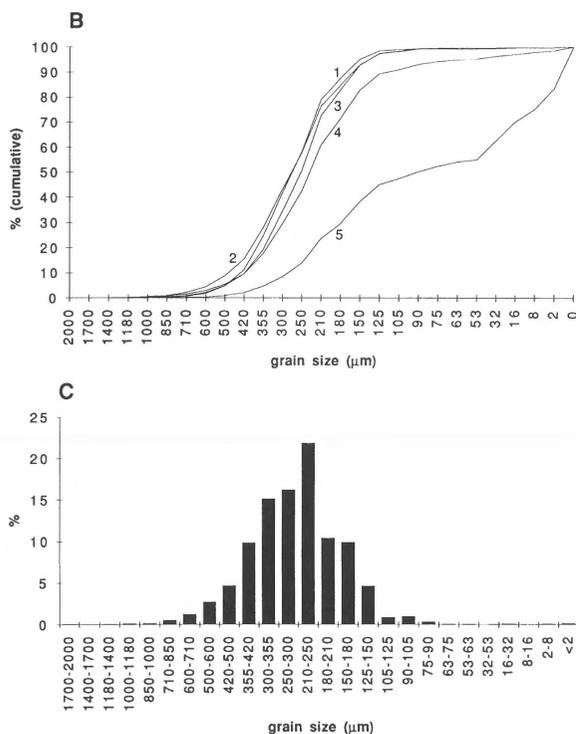


Fig. 7. Type section of the Delwijnen Member. (A) Holostratotype, (B) cumulative plots of grain size of samples from the holostratotype and underlying deposits, (C) grain size histogram of sample 3. Location of type section in Fig. 1B, legend in Fig. 6.

though the latter may occasionally be absent. In these cases the Delwijnen Member rests directly on fluvial sands and gravels of the Kreftenheye Formation. Outside the Rhine-Meuse area (for instance east of the Scheldt) the Delwijnen Member overlies other deposits, presumably in most cases the Wierden Member of the Twente Formation (cf. Schwan 1991). In several areas the Delwijnen Member merges laterally into cover sands (Wierden Member). For instance, in the Liemers (Van de Meene 1980) and the Bommelerwaard (Törnqvist et al. 1986), the boundary between the two units may be arbitrary. Outside the areas where the Delwijnen Member crops out, it is covered by the same formations as the Wijchen Member. In the case of later redeposition of eolian sand, the Delwijnen Member interfingers with these younger formations. Since deposition of the Wijchen Member has in many cases continued longer than river dune formation, the Delwijnen Member and the Wijchen Member may occasionally also interfinger.

#### *Relation to previously described units*

The Delwijnen Member comprises the river dune deposits as distinguished in many publications, notably the geological maps of the Netherlands (e.g. Verbraeck 1970, 1984; Van de Meene 1977). River dune deposits in the central Netherlands so far have been included in the Kreftenheye Formation, and recently redeposited river dune deposits in the Kootwijk Formation (Verbraeck 1984).

#### *Genesis*

Accumulations of blown sands deposited along the courses of predominantly braided fluvial systems.

#### *Age*

Late Weichselian (essentially Younger Dryas). Small-scale eolian redeposition took place during the Holocene and is still going on.

#### *Type section*

Holostratotype: boring on the river dune 'Delwijnsche Loo', N of Delwijnen (Bommelerwaard); coordinates: 141.140/421.920; surface elevation: +1.5 m; interval: 0–5.55 m below the surface (Fig. 7A). The borehole is located in a depression which

was formed by human sand digging in the central part of the river dune. At the edge of this depression the uppermost 1–2 m of the river dune sand can easily be exposed.

#### **Final remarks**

With the introduction of the Wijchen Member of the Kreftenheye Formation and the Delwijnen Member of the Twente Formation as formal lithostratigraphic units, we have attempted to retain maximal flexibility. In view of the large area covered by the two units, lateral facies changes do occur. It may therefore be necessary to define additional hypostatotypes to account for this variability, for instance in the organic facies of the Wijchen Member. Likewise, further subdivision of the two members into beds is also possible. This might be particularly useful for the Wijchen Member, since this unit consists of two separate layers occurring at different levels, especially in the eastern part of the Rhine-Meuse area. Whether there are also systematic lithologic differences between these layers is not yet clear.

Another advantage of lithostratigraphic units at the member rank is that they are allowed to be part of more than one formation (Hedberg 1976). For instance, in northern Limburg the Kreftenheye and Veghel Formations can hardly be distinguished (W. Westerhoff, pers. comm., 1991). In this case it might be necessary to incorporate deposits of the Kreftenheye Formation (which are poor in augite in this area) into the Veghel Formation. The Wijchen Member can then retain its status and become part of both the Kreftenheye Formation and the Veghel Formation.

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