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A transition from a braided to a meandering channel facies, showing inclined heterolithic stratification (Late Weichselian, central Netherlands)

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Abstract

An excavation near Deest (Land van Maas en Waal, central Netherlands) offered an opportunity to study sedimentary structures near the top of the Late Weichselian Kreftenheye Formation in two point bar sequences showing different lithofacies. The sandy point bars rest on gravelly braided river deposits (facies 1). The older point bar sequence (facies 2) was formed by a small-scale channel and is characterized by clayey lateral accretion surfaces, indicated by inclined heterolithic stratification (IHS). This point bar sequence has features indicative of variable discharge during deposition during a transitional stage from a braided to a meandering channel pattern. The younger point bar sequence (facies 3) was formed by a larger channel that incised the braidplain and is thought to represent a fully developed meandering channel pattern. IHS was not found in these deposits. Point bar formation at the study location ceased during the Allerød or early Younger Dryas when the meandering channel was abandoned. The fill of this residual channel (facies 4) consists of gyttja, peat and (humic) clay. Finally, the point bars and the residual channel were covered by floodbasin deposits of Holocene meandering river systems (also facies 4) which consist predominantly of clay.

Introduction

The upper part of the Kreftenheye Formation in the Netherlands consists mainly of coarse gravelly sands, deposited by Late Weichselian braided rivers. It is overlain by a bed of sandy clay (Doppert et al. 1975, Verbraeck 1984, 1990). This bed belongs to the Wijchen Member which is part of the Kreftenheye Formation (Törnqvist et al. 1994). It is considered to be an overbank deposit of the first meandering rivers during the Late Weichselian (Doeglas 1951).

A Weichselian Late Glacial transition in river channel pattern from vertically accreting braided to incised meandering was described for the eastern part of the Netherlands' river area (Pons & Schelling 1951, Pons 1957, Verbraeck 1984, 1990, Berendsen et al., in press). This transition is believed to have been caused by the climatic change, whereby warming of the climate restored the vegetation cover. This resulted in a decreasing and over the year more evenly distributed discharge, and in a reduced supply of sand relative to silt and clay.

Previous studies of the Kreftenheye Formation in the Land van Maas en Waal (Fig. 1A) relied on textural borehole data (Pons 1957, Berendsen et al., in press). Interpretations of changes in river channel patterns were based on subsurface mapping of fluvial sequences. Information on sedimentary structures was absent. However, data on sedimentary structures do provide important information to infer the paleo-river channel pattern.

The objective of this paper is to report on the sedimentary structures of point bar deposits which were found in the upper part of the Kreftenheye Formation in juxtaposition with a residual channel of Younger Dryas age (10720 ± 60 BP, Berendsen et al., in press). This channel incised the top of the braided river sediments of the Kreftenheye Formation. In this paper we

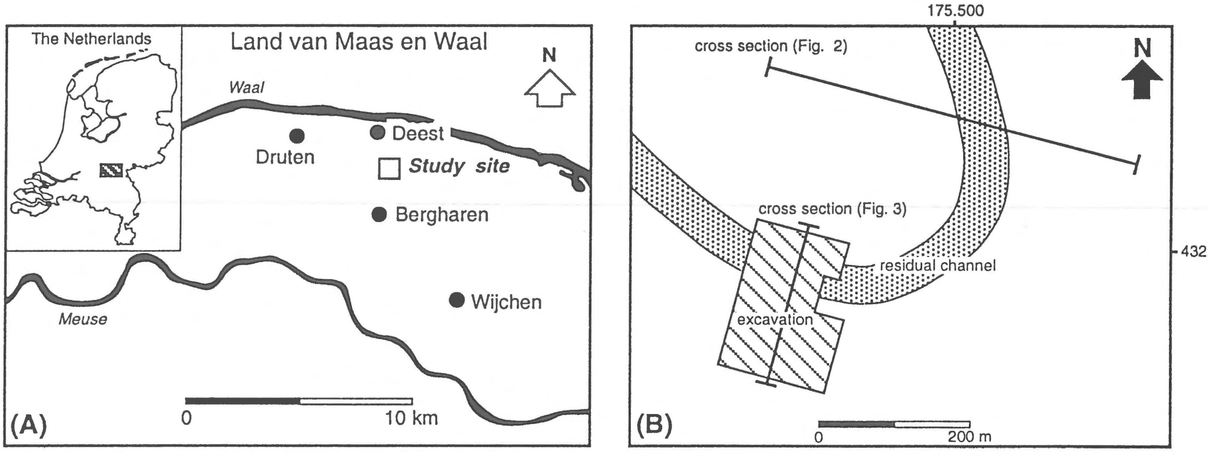

Fig. 1. *(A)* Location of the study site in the Land van Maas en Waal, *(B)* Location of a residual channel and of the cross sections and excavation.

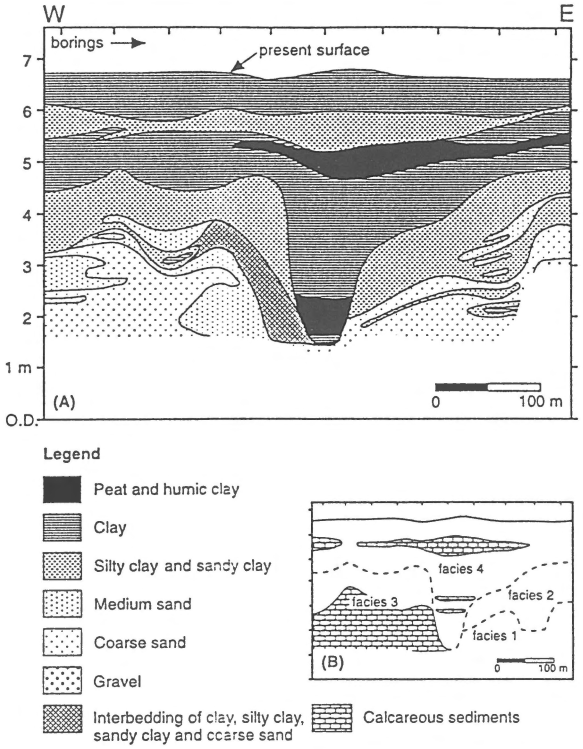

Fig. 2. *(A)* Lithological cross section near the excavation (see Fig. 1B for location), *(B)* carbonate content of the sediments in the same cross section and a correlation with the facies 1 to 4 (Fig. 3).

will use the term 'Lower Terrace' for the surface of the Kreftenheye Formation at the study location, following Pons (1957).

The study was made possible by the presence of a temporary large gravel pit near Deest, Land van Maas en Waal (Fig. 1). In the excavation sand and gravel were present at depths of 3.5 to 6.0 m. Part of the original paleo-relief was exposed during stripping of surficial peat and clay, in order to prepare the pit for exploitation. Pit highwalls were troweled and sedimentary structures were drawn and photographed and also observed in small holes at the bottom of the pit. The geometry of a residual channel as well as the level of erosional contacts were determined, using a level and rod. To enlarge three-dimensional control, 29 auger borings were carried out just outside of the excavation. The carbonate content of the sediments was tested in the field with a 5% HCl solution. If any reaction was noticed, the sediments were called calcareous.

Description of lithofacies

In and near the excavation a large residual channel was identified and its course near the excavation was reconstructed using borehole data (Fig. 1B). The fill of this residual channel is also described by Berendsen et al. (in press). A cross section shows that west of the residual channel, calcareous sand and silty and sandy clay are present, in contrast to the east side of the residual channel where the sediments are non-calcareous (Figs 2A, B). East of the channel the top of the coarse sand bed has a marked stepped appearance. This bed is capped with a one-metre-thick bed of light-grey silty and sandy clay with admixed coarse sand

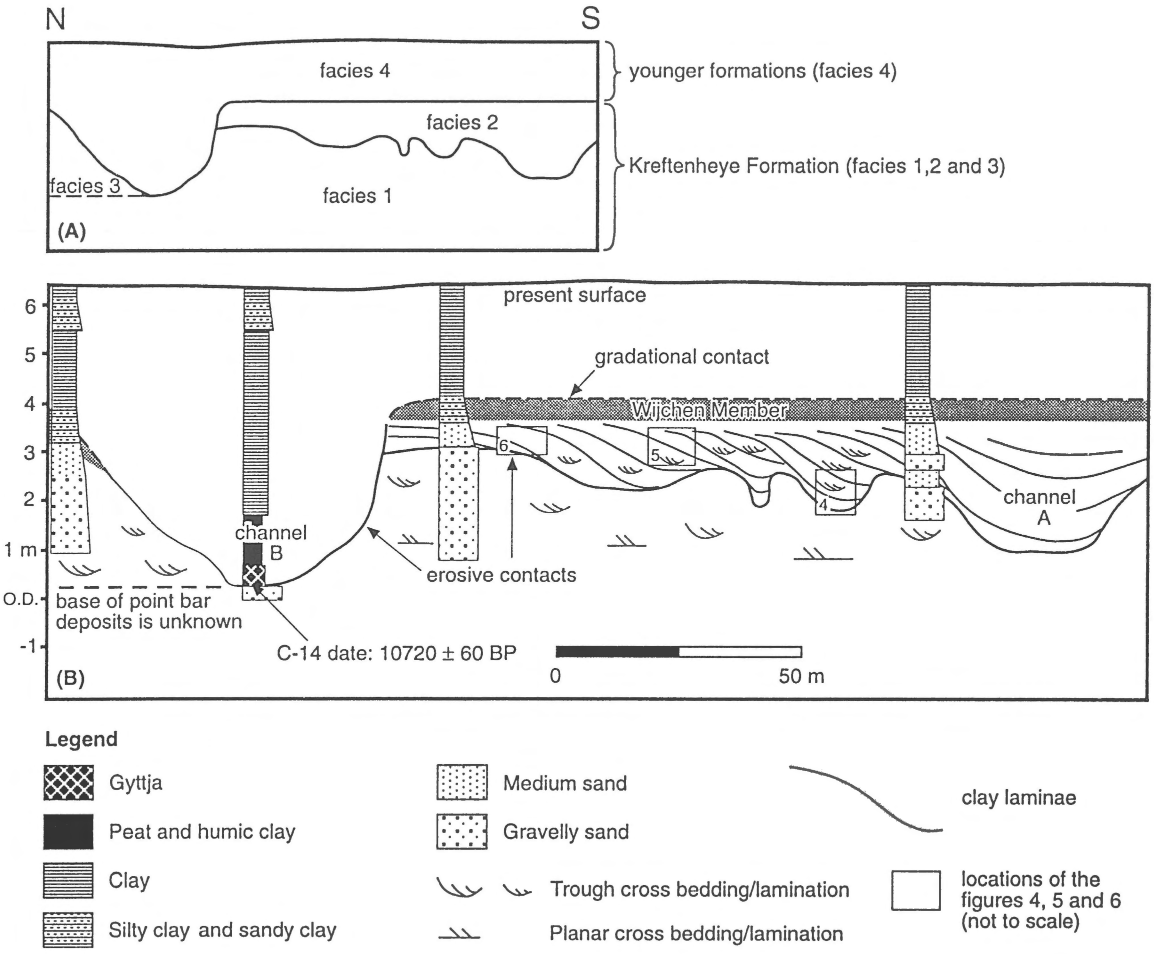

Fig. 3. *(A)* and *(B)* show a N-S cross section in the excavation (see Fig. 1B for location). *(A)* The four facies present in the excavation, *(B)* summary section of lithology and sedimentary structures.

particles (Wijchen Member), which also appears on the west side of the residual channel. Clay, humic clay and peat make up the rest of the sequence, except for a minor bed of silty and sandy clay at approximately one metre below the present surface.

In the excavation, four lithofacies were distinguished (Fig. 3A). *Facies 1* consists of non-calcareous gravelly coarse sand (Fig. 3B). The gravel is pebble-sized. Alternating structures of planar and trough-shaped sets of cross-lamination and cross-bedding are present, suggesting variable current directions and velocities during formation. However, many beds appear rather massive without internal structure. Most beds are horizontal, although some are slightly inclined (< 5°), roughly in a northeasterly direction. The bed thickness ranges from 10 to 20 cm, and the gravel content of the bed varies. Some beds show an upward increase in gravel content and the base of most beds is marked by a thin (one pebble thick) layer of gravel.

Facies 2 has a very irregular scoured base and its finer grain size contrasts with the underlying gravelly sand (Fig. 3). The thickness of this facies ranges from 0.5 to 2.5 m. It grades upwards into a light-grey sandy clay bed (Wijchen Member) which was included in this facies. The overlying dark clay is part of facies 4. Facies 2 is characterized by inclined heterolithic stratification (IHS; Thomas et al. 1987).

The individual inclined heterolithic strata in facies 2 are tens of centimetres thick. They consist mainly of medium grained sand that is non-calcareous. Each sand bed is bounded by very thin (a few mm to a few cm), calcareous, light-grey to white laminae of clay. Most of the clay laminae extend to the base of facies 2 (Figs 3B, 6). The contacts between the clay laminae

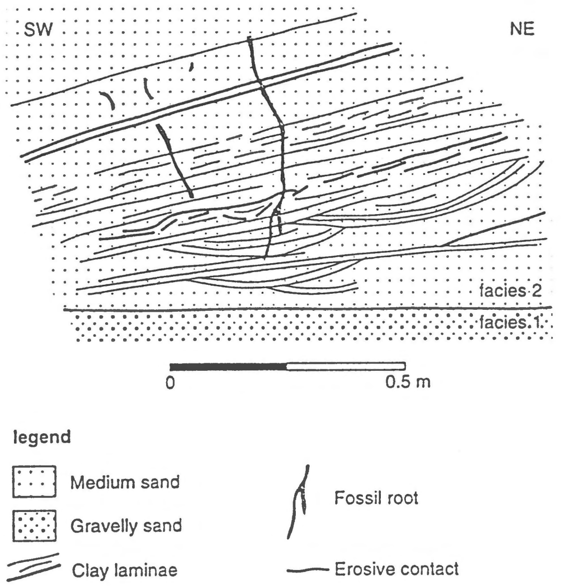

Fig. 4. Through cross bedding in the sand beds of the IHS. The clay laminae are thin (mm to one cm) and often discontinuous (no vertical exaggeration; see Fig. 3 for location).

and the sand beds are sharp. The laminae dip approximately southwest at an angle of 10 to 24°. They have a sigmoidal shape. Some thin clay laminae are discontinuous with a broken-up appearance. Near the scoured base, shallow troughs (Fig. 4) and gravel lenses (Fig. 5) occur between the clay laminae. Along the strike of the clay laminae, planar cross-stratified sets of tangential megaripple foresets (up to 20 cm thick) indicate a local northwesterly directed paleoflow. Locally, many fossil tree roots are present in facies 2. Deeper scour of the underlying gravelly sands is always associated with steeper clay laminae (Fig. 3B). In the southern part of the excavation the medium grained sand beds and clay laminae fill up a channel (channel A). At some places in the excavation facies 2 is absent or consists only of one thin horizontal calcareous clay bed, overlain by a thicker bed of light-grey sandy clay (Wijchen Member).

Frequently, carbonate appears as concretions up to a few centimetres in diameter, embedded in the clay laminae. These concretions resemble caliche nodules as they can be very solid and are more or less rounded. Some clay laminae have a calcrete-like appearance due to carbonate cementation and abundant concretions. At places where gravel lenses appear between the calcareous clay laminae, this gravel rests in a matrix of light-grey to white calcareous clay (Fig. 5).

Facies 3 is rich in carbonate, while facies 1 is non-calcareous (this is comparable to the situation shown in Fig. 2). Carbonate concretions however, do not appear in this facies and clay laminae are rare. Sets of tangential megaripple foresets and troughs, both up to 30 cm thick and consisting of gravelly sand, are present in facies 3 adjacent to the base of the residual channel (Fig. 3B). They indicate a local northwesterly paleoflow direction. Facies 3 fines upward in texture as well as in the scale of sedimentary structures. Locally, the sand contains fossil roots. The top of facies 3 (like the top of facies 2) consists of a bed of light-grey sandy clay (Wijchen Member).

Facies 4 overlies facies 1, 2 and 3 (Fig. 3). It consists mainly of clay, with minor lenses of humic clay, peat and sandy clay. It includes the fill of the residual channel (channel B), consisting of gyttja, clay and peat. This residual channel is asymmetrical in cross section (Fig. 3B). Calcareous clayey gyttja at the base of the channel was radiocarbon-dated at 10720 ± 60 BP. The carbonate fraction was dated at 10690 ± 230 BP (Berendsen et al., in press). This means that the end of river activity probably is Allerød or early Younger Dryas in age (Berendsen et al., in press).

Interpretation of the sedimentary facies

Facies 1 is thought to represent a braidplain that forms the top of the Lower Terrace. The alternation of planar and trough-shaped sets suggests rather variable paleocurrent directions at a local scale, which is an important characteristic common to braided stream deposits (Cant & Walker 1976). Moreover, facies 1 is entirely non-calcareous in contrast to the facies 2 and 3. Pons (1957) described the Lower Terrace as non-calcareous due to *in situ* decalcification, as only the top is non-calcareous.

The IHS in facies 2 is interpreted as deposited by point bar accretion. Sedimentary structures present in the sand beds between the dipping clay laminae, indicate a unidirectional paleoflow perpendicular to the dip direction of the clay laminae (Fig. 4). The IHS indicates very irregular discharge during times of deposition. Gravel and sand lenses (Fig. 5) were formed by high-velocity currents, while clay laminae that extend to the base of the unit, suggest very slow to no currents resulting in deposition of suspended load. Broken-up clay laminae are interpreted as minor desiccation cracks indicating subaerial exposure during reduced water levels. Frequently the bases of the clay laminae

Fig. 5. Gravel lens in facies 2, covered by sand-clay couplets. Note the light colour of the clay drapes due to high carbonate content. (See Fig. 3 for location).

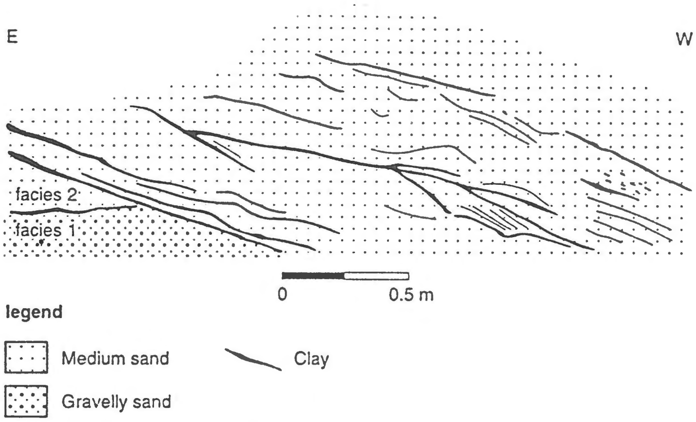

Fig. 6. Variable angle of the IHS, averaging 18° (no vertical exaggeration; see Fig. 3 for location).

are erosional, covering deeper scours in the underlying gravelly sands (Fig. 6). The clayey matrix of the intercalated gravel lenses in facies 2 probably originated as clay pebbles, hydraulically behaving like gravel during high flow stages (Williams 1966). Stewart (1981) also found clay pebbles in the conglomerates of the point bars he described.

No datable organic remains were found in facies 2. At some places in the pit, the cut-bank of channel B cuts off the clay laminae of facies 2 (Fig. 3B). This erosive contact suggests an older age for facies 2 relative to facies 3. The Wijchen Member that forms the top of facies 2 is generally thought to be of Bølling to Allerød age where it covers the Lower Terrace. The gradational contact between the point bar deposits and the Wijchen Member within facies 2 suggests that soon after point bar formation stopped, overbank sedimentation of sandy clay began. The sandy clay probably was deposited by the meandering channel B (Fig. 3B).

Pons (1957: 13) described the sediments of the top of the 'Lower Terrace' as follows: 'river sand; alternating coarse and fine sand beds, sometimes with

Table 1. The lithofacies at Deest in the Land van Maas en Waal, compared with earlier interpretations (see text 'Discussion')

Lithofacies	Ancient river systems		Chronostratigraphy	
	(Pons 1957)	(Berendsen et al., in press)		
facies 4	not defined	generations 6–8	Holocene	
facies 3	stages III & IV	generation 3	Allerød and Younger Dryas	Late Weichselian
facies 2	stage II	generation 2	Bølling and Older Dryas	
facies 1	stage I			

slightly clayey laminae, sometimes with very coarse sand- or gravel beds'. This description for the sediments just below the Wijchen Member corresponds very well to facies 2, and suggests a geographically more widespread occurrence of facies 2.

Pons (1957: 18) described the Late Weichselian braided system at the top of the Lower Terrace as composed of: (1) relatively deep, slightly meandering main channels, (2) small dispersal channels, carrying water away from the main channels and (3) gathering channels, collecting water from the dispersal channels for return flow back to the main channel. Similar braided river systems were described by Fisk (1944) and Nordseth (1973). In this terminology, facies 2 could represent point bar and channel-fill deposits of a small dispersal or gathering channel, as is suggested by its small scale. Subsequent incision of the main channel caused abandonment of the dispersal and gathering channels and meandering of the main channel increased (Pons 1957: 18–19). Although lateral erosion and accretion are not very common in individual braid channels, they may occur, as described for example by Leopold & Wolman (1957: fig. 39) and Allen (1983).

Facies 3 represents a point bar deposit of the incised main channel B. This facies is distinguished lithologically from facies 1 by its high carbonate content. The interpretation of facies 3 as point bar deposits is based on: (a) the gradual fining upward (Fig. 3B), (b) the asymmetrical geometry of the residual channel B (Fig. 3B), (c) the meander bend reconstructed from borehole data (Fig. 1B) and (d) the northwesterly paleoflow direction indicated by the foresets of some climbing megaripples preserved in the point bar deposits. These megaripples climbed slightly obliquely to the trend of the residual channel (WNW at that place) up the point bar, which is considered to be a result of the spiralling flow through the meander loop.

Facies 4 includes all sediments deposited after channel B was abandoned. The fine-grained nature of the fill of this channel suggests sudden abandonment. The fill grades upward into floodbasin deposits of Holocene meandering systems as described by Berendsen et al. (in press).

Discussion

This study provides a more detailed sedimentological description and interpretation of Pons' (1957) Lower Terrace and the various generations of river systems described by Berendsen et al. (in press). Table 1 shows which stages of the ancient river system recognized by Pons (1957: 15–19) and which river generations described by Berendsen et al. (in press) are represented by the lithofacies in the excavation. These 'stages' and 'generations' are groups of paleorivers with similar morphological characteristics. Pons (1957) described the transition from a braided to a meandering river system as a sequence of four stages. In this sequence the braided system with a slightly meandering main channel on the one hand, and dispersal and gathering channels occupying the initial floodbasin on the other hand, can be viewed as a transitional system (stages II and III). Berendsen et al. (in press) described the braidplain as generation 2 and the meandering main channels as generation 3 rivers. Facies 2 records lateral accretion as well as irregular discharge in a small-scale channel and shows sedimentological evidence for a gradual transition in channel pattern from braided to meandering. In this way, analysis of sedimentary structures and facies associations at one location can support regional studies that are mainly based on borehole data.

IHS, termed epsilon cross stratification, was first described by Allen (1963). Collinson (1986) noted that

IHS is not known from modern point bars but that it is well known from tidal creeks. This is due to periodic deposition of clay laminae separating the inclined sandy strata in tidal environments, making the structure recognizable. Calverley (1984) and Smith (1987, 1988) reported IHS from modern low-energy fluvial and tide-influenced fluvial environments. A large number of ancient examples of IHS was interpreted as being of tide-influenced (e.g. Cuevas Gozalo 1989, Cuevas Gozalo & De Boer 1991, Rahmani 1988) or anyway marine-influenced origin (Flach & Mossop 1985).

Considering this, the IHS in facies 2 was found in quite an extraordinary setting, as the Lower Terrace was a braidplain well outside marine influence. The gradient of the Lower Terrace in the Land van Maas en Waal is rather steep, averaging 31 cm/km (Pons 1957: 19). The present altitude of the Lower Terrace at the study site is about 4 m above sea level. Eustatic sea level at 11000 BP (abandonment of channel B), however, was estimated to be 65 m lower than at the present (Fairbanks 1989: fig. 2). Sea level in the North Sea Basin has risen approximately 90 m since then because of tectonic and isostatic subsidence (Jelgersma 1980: fig. 6). Considering these conditions, it can be excluded that the IHS of facies 2 was formed under tidal or marine influence. Probably the deposition of the clay laminae was controlled by a local base level.

Puigdefabregas (1973) described IHS in Miocene deposits interpreted to originate from point bar deposition in small-scale ephemeral meandering streams. Facies 2 compares well to his description of IHS as the fine-grained laminae extend to the base of point bars and the IHS has approximately the same scale.

The depositional explanation of the clay laminae in facies 2 is based on the interpretation of channel A (Fig. 3B) as a dispersal or gathering channel located in the initial floodbasin of the transitional river system. During seasonal flooding, water spilled over the banks of the main channels in the dispersal and gathering channels. During these high-flow-stages the sandy and gravelly beds of the IHS in facies 2 were deposited. However, the rising water-level in the floodbasins during these events acted as a local base level, that finally blocked the discharge in these channels. As flow decelerated, suspension load was deposited as clay laminae draping the accretionary point bar. This happened rather rapidly as inferred from the sharp contacts between sand and clay in the IHS. Subsequent lowering of the water table during the dry season led to subaerial exposure of the channel and desiccation cracking of the clay laminae. Parts of the clay laminae were eroded during subsequent flooding as they are often discontinuous (Fig. 6). The gradual upward transition of the IHS into the sandy clay of the Wijchen Member shows that floodbasins further developed and that finally suspended load deposition dominated.

In contrast, facies 3 represents point bar accretion by a deeper main channel carrying water all year round. Flow conditions in channel B (Fig. 3B) never permitted suspended load deposition (before abandonment). Therefore, the point bars of facies 3 lack IHS and result of bed load accretion only. Facies 3 can be classified as a sandy fluvial point bar lithofacies, like those reported from modern fluvial environments by Nanson (1980) and Smith (1987).

Conclusions

The study site showed evidence for lateral accretion in a small-sized channel (A) at the top of the Lower Terrace. This channel was subject to large discharge fluctuations and probably was part of a river system that can be regarded as transitional from braided to meandering. Subsequently, incision into the Lower Terrace and lateral erosion and accretion took place in a larger meandering channel (B). Point bar formation ceased during Allerød or early Younger Dryas time.

From this study it appears that IHS can be formed in fluvial environments well outside marine and tidal influence in small-scale channels that are subject to irregular discharge.

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