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Kasse, C.

published in
In: Palaeohydrology and Environmental Change
1998

document version
Peer reviewed version

citation for published version (APA)
Kasse, C. (1998). Depositional model for cold-climate tundra rivers. In G. Benito, V. R. Baker, & K. J. Gregory (Eds.), *In: Palaeohydrology and Environmental Change* (pp. 83-97). John Wiley and Sons.

CHAPTER 7

Depositional Model for Cold-climate Tundra Rivers

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INTRODUCTION

During the last decade Weichselian Middle Pleniglacial (isotope stage 3; *c.* 60–26 ka) fluvial sequences have been investigated intensively in The Netherlands and Germany. The sedimentary environments, provenance of the sediment, climate and vegetation have been studied in both exposures and bore holes (Van Huissteden and Vandenberghe, 1988; Van Huissteden, 1990; Ran, 1990; Kasse et al., 1995). Relations between channel pattern and climate have been established and changes in river pattern have been attributed to climate change (Ran et al., 1990; Vandenberghe, 1992; Mol, 1997). In these studies the fluvial sedimentary environment has been interpreted as sandy anastomosing because of the supposed multichannel nature with generally sandy interchannel deposits. According to Nanson and Knighton (1996), however, the term 'anastomosing' should be applied for low-energy river systems with mostly fine-grained or organic deposition (cf. Smith and Smith, 1980; Smith, 1983, 1986). Therefore, in accordance with Nanson and Knighton, the more general term 'anabranching', defined as a system of multiple channels characterized by vegetated or otherwise stable alluvial islands, is used in this study. As opposed to the braided system, the islands of the anabranching system usually persist for decades or centuries, support well-established vegetation and have relatively stable banks.

The aim of this chapter is: (a) to describe the sedimentary facies and depositional environment of the Middle Pleniglacial fluvial system; (b) to compare this fluvial system with existing floodplain classifications; and (c) to establish the factors that favoured floodplain formation during the Middle Pleniglacial.

The investigated sections have been formed during the Weichselian Middle Pleniglacial which is correlated with oxygen isotope stage 3 (*c.* 60 to 26 ka; Vandenberghe, 1992). The study areas Grouw and Dinkel in The Netherlands (Figure 7.1) are part of the southern North Sea Basin, a generally subsiding area of low relief and unconsolidated sediments. In Grouw the Holocene and Weichselian sequence was temporarily exposed in two building pits for a tunnel below the Prinses Margriet Canal (Kasse et al., 1995). The Dinkel valley was investigated mainly by drillings (Van Huissteden, 1990). The Weichselian Middle Pleniglacial fluvial sequences in these sites have been deposited in depressions of Saalian glacial origin by relatively small local rivers (Boorne, Dinkel).

Palaeohydrology and Environmental Change. Edited by G. Benito, V. R. Baker and K. J. Gregory

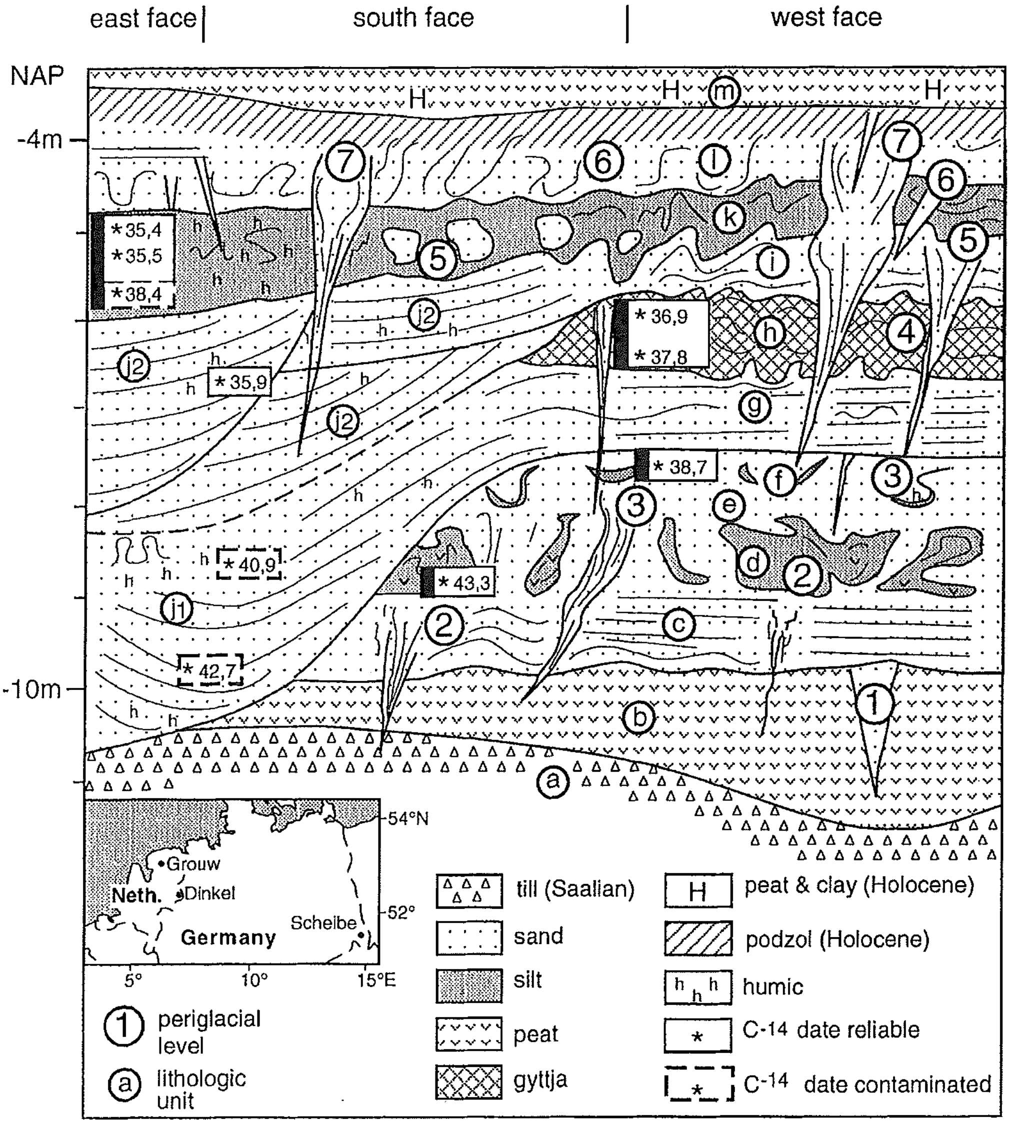

Figure 7.1 Location map of the study areas in The Netherlands and Germany and composite section of exposure at Grouw (strong vertical exaggeration). The eastern and part of the southern pit face are dominated by stacked channel sequences separated by large-scale unconformities. The western and part of the southern pit face contain an 8000 year record of overbank sedimentation. The south face is *c.* 50 m long

In eastern Germany, the Weichselian fluvial sequence has been investigated in the large brown coal pit at Scheibe in the Niederlausitz (Mol, 1997). The sediments are part of a Tertiary and Quaternary sequence deposited at the transition from the Bohemian Central German landmass in the south to the North German Basin in the north. The Weichselian sequence has been deposited in a former proglacial outwash valley (Lausitzer Urstromtal) of Saalian age. During the Weichselian local rivers such as the Spree and Neisse flowed through this valley towards the west.

CLIMATE

The climate during the Middle Pleniglacial was cold and the vegetation was tundra (Ran, 1990; Kasse et al., 1995). Frost cracks are abundant in the fluvial sequences and ice-wedge casts occur occasionally. By comparison with recent periglacial environments a mean annual temperature lower than − 1 to − 5 °C has been inferred (compared with the recent mean annual temperature of *c.* 10 °C) (Vandenberghe, 1992). The Middle Pleniglacial was a period with intense seasonal frost and periodic phases of permafrost (Ran et al., 1990; Kasse et al., 1995). Erosion of the generally sandy ice-pushed ridges (up to 100 m above present-day sea level) and proglacial sands of the previous Saalian glacial led to rapid fluvial aggradation in the former glacial basins and valleys.

SEDIMENTARY FACIES

The Middle Pleniglacial sequences in Grouw, Dinkel and Scheibe, respectively, are *c.* 6 m, 10 m and 9 m thick and span at least 8 ka (43 to 35 ka), 22 ka (*c.* 50 to 28 ka) (Van Huissteden, 1990) and *c.* 18 ka (46 to 28 ka) (Mol, 1997). The standard errors of the ^{14}C dates increase from *c.* 200 years for the younger dates to *c.* 2000 years for the oldest ones.

Two large-scale sedimentary facies have been distinguished in these Middle Pleniglacial fluvial sequences: a channel and an overbank facies (Van Huissteden, 1990; Kasse et al., 1995; Mol, 1997). The two facies types are illustrated in Figure 7.1. In the east and south face of the pit, the channel sediments are fine- to medium-grained (100–500 μm) and they reveal several generations of infilling (stacked channels) generally with low-angle dipping beds. In the west face the overbank facies is characterized by predominantly fine sand (100–250 μm) alternating with more silty or organic units. The overbank facies is often strongly cryoturbated and contains numerous frost cracks and ice-wedge casts formed by thermal contraction during subaerial exposure.

The channel facies is characterized by large-scale cross-bedding at the base of the channel formed by the migration of megaripples or dunes (Figure 7.2 left). Locally, the tabular cross-bedded sets (up to 50 cm high) consist of high-angle foreset bundles, separated by low-angle erosional surfaces (Kasse et al., 1995). These structures have been interpreted as falling stage features or reactivation surfaces separating different flood events (Collinson, 1970). It suggests that the Pleniglacial river system experienced large discharge fluctuations (Jones, 1977). This idea is supported firstly by the presence of silt drapes within the foreset cross-bedding which may be associated with deposition from suspension during the falling water stage in the channel. Secondly, frost cracks have been observed in the channel sequence. Since these can only be formed during extreme cooling of the surface, their presence indicates subaerial exposure and periodic very low or no discharge, probably during the winter. It is proposed that in spring the accumulated winter snow melted and in a short phase meltwater was transported through the system. Flow velocity first increased and the dunes became larger and migrated faster over the channel floor. At the end of the flood event flow velocity decreased, dune migration came to an end and silt was deposited from suspension. The presence of small-scale current ripples in the silts indicates fluvial deposition, although it has been argued that the silt originally is of aeolian origin (loess) (Van Huissteden, 1990).

The major part of the channel infill consists of alternating bedding of sand and humic, sandy silts (Figure 7.2 right and Figure 7.3). The sands were probably deposited during

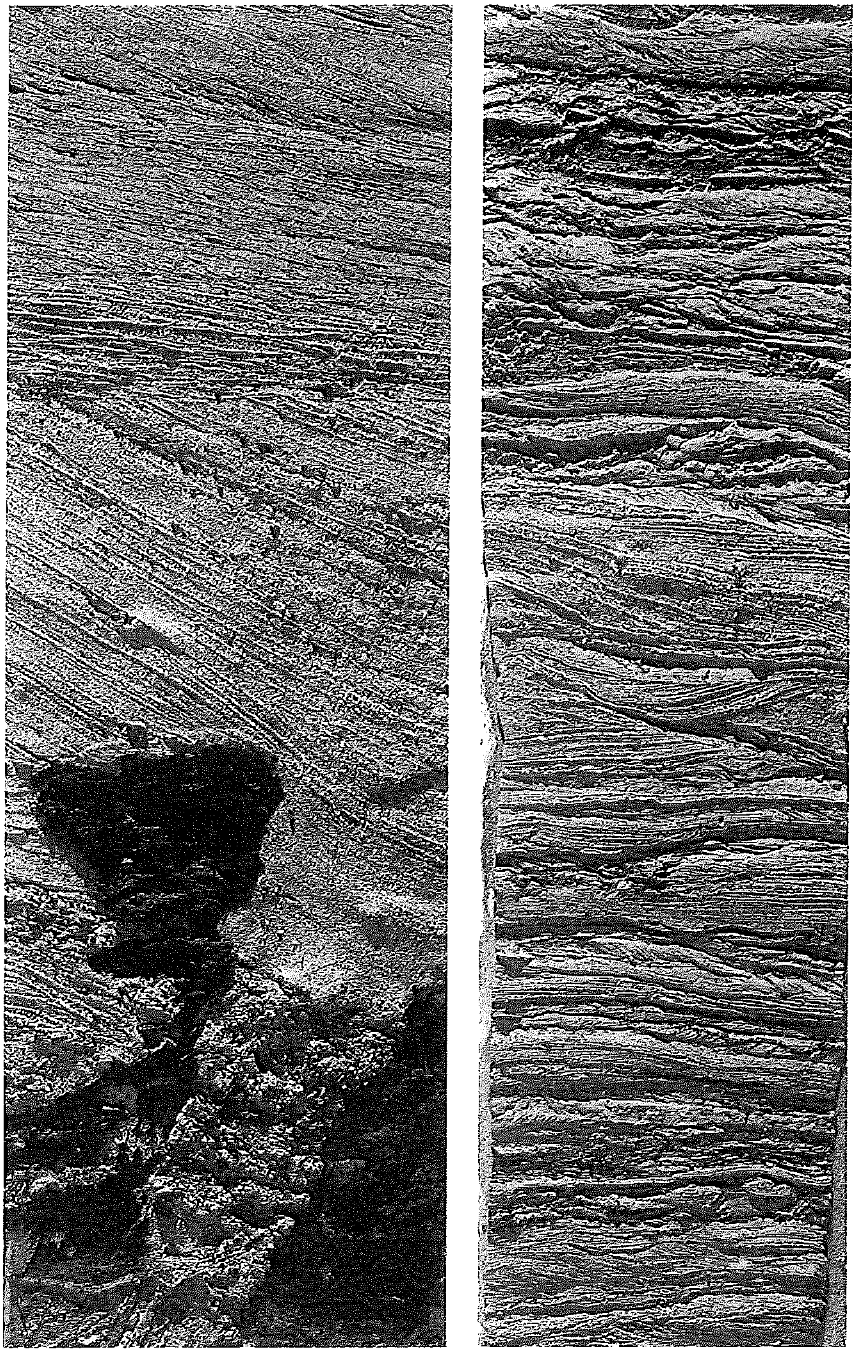

Figure 7.2 Lacquer peels (110 cm high) from the channel facies at Grouw. Left: large-scale cross-bedding formed by dune migration at the base of the channel that erosively overlies Eemian (*c.* 130–120 ka) peat. Right: channel infilling with alternating sand–silt bedding reflecting the episodic and flashy character of the discharge. The high-water stage sands are horizontally bedded or trough cross-bedded; the low-water stage sandy silts are small-scale cross-laminated or massive

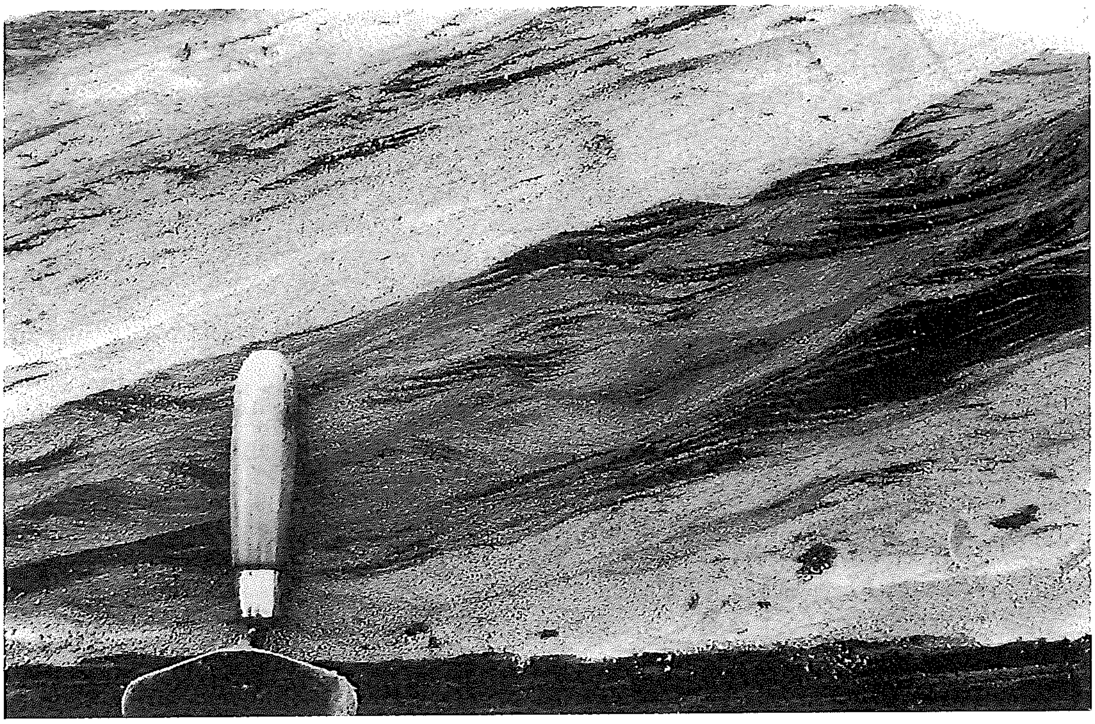

Figure 7.3 Detail of the alternating bedding with climbing ripple cross-lamination in silty fine sand associated with rapid sedimentation in the channel during the falling water stage (exposure Grouw). Trowel is 25 cm long

the snowmelt peak discharge and the silt beds during the waning flow stage. The well-developed climbing ripple cross-lamination points to rapid deposition of fine-grained previously suspended sediment in a decreasing flow (Figure 7.3). The lower boundary of the silty bed is normal graded while the upper boundary is erosive due to the next flood event. These sand–silt couplets reflect, like the reactivation surfaces in the dune foresets, the strong variation in flow velocities and flashy hydrographs of the discharges in the Middle Pleniglacial tundra rivers. The sand–silt couplets, locally with moss mats in the silty beds, may reflect annual cycles and therefore high sedimentation rates. However, the long time span of the total sequence, as shown by the ^{14}C dates, indicates that major hiatuses must be present. Indeed, several generations of channel infilling, separated by large-scale unconformities or erosional boundaries, have been found (Figure 7.1, units j1 and j2).

The overbank facies consist of an alternation of fine sand units (*c.* 0.5–1.0 m thick) and more silty or organic units (*c.* 0.1–0.5 m thick) (Figure 7.4). The sandy units are dominant (*c.* 75% of the section in Grouw). In comparison with the channel facies the overbank facies is often strongly cryoturbated and contains frost cracks and ice-wedge casts. These periglacial features were formed by seasonal frost (cracks) or permafrost (ice wedges) penetrating the soil, later followed by permafrost degradation and periglacial loading. They therefore point to repeated subaerial exposure, which is an argument in favour of deposition in an overbank or alluvial island environment.

The sandy overbank units are predominantly horizontally laminated and small-scale current rippled in those sections that are not disturbed by cryoturbation (Figure 7.5). The horizontal lamination occurs at the base of short (10 cm) fining-upward sequences while small-scale current ripple cross-lamination is found in the upper part of the sequences

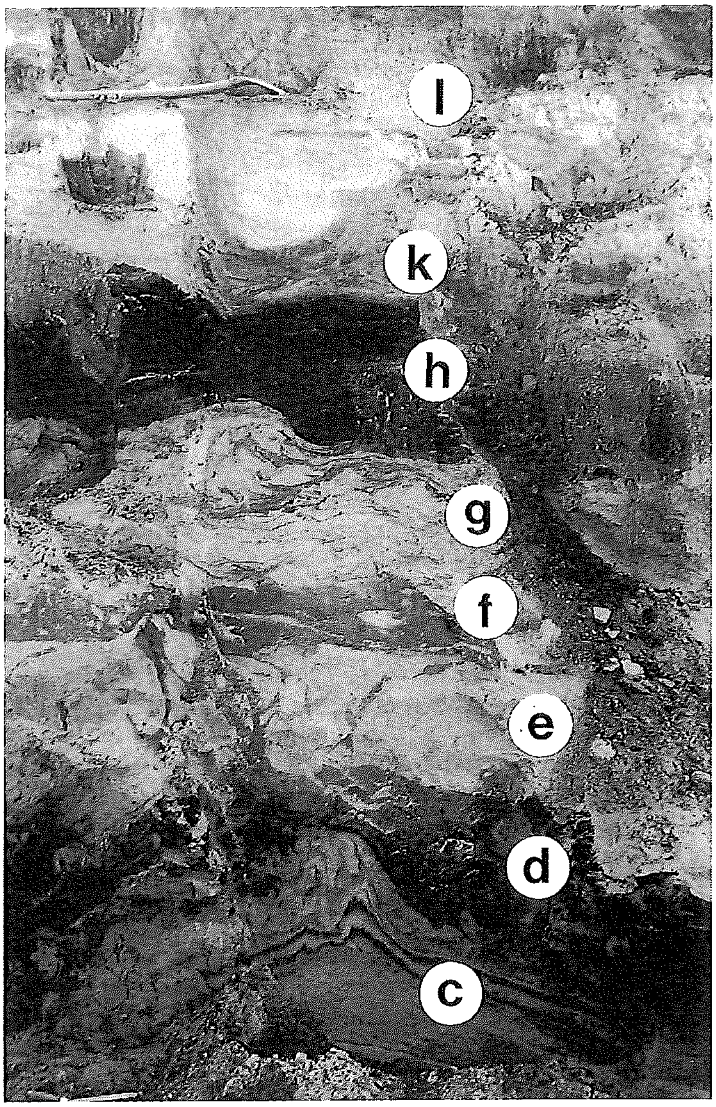

Figure 7.4 Overbank facies with sedimentary cycles of fine sand units (c,e,g,l) and silty or organic units (d,f,h,k) (exposure Grouw). The overbank units are affected by several phases of cryoturbation. Spade for scale is 120 cm long. The letters refer to units in Figure 7.1

(Figure 7.5). Since both bedding types occur within one fining-up sequence, it is concluded that the horizontal lamination is of fluvial origin as well. The fining-up sequences probably represent a change in flow velocity from upper flow regime horizontal lamination into lower flow regime current ripple lamination. The current ripples are locally visible by the draping of organic detritus in the ripple troughs. These sedimentary structures point to strong fluctuations in flow velocity and rather shallow water. The dominance of horizontal bedding and the absence of major channels in the overbank environment may be attributed to sheet flood or crevasse splay deposition during the inundation of the overbank. The upper part of Figure 7.5 shows the upper part of sandy overbank unit c (see Figure 7.1). The increasing disturbance by cryogenic processes (frost cracks and disturbed lamination) may be related to a decreasing sedimentation rate and increasing subaerial exposure at the end of the overbank depositional cycle.

Figure 7.5 Photograph of lacquer peel (110 cm high) from overbank unit c (exposure Grouw). In the lower part of the peel, thin (*c.* 10 cm) fining-upward sequences with horizontal bedding grading upward into small-scale cross-lamination point to sheet flood deposition on the crevasse splay surface. The upper part of unit c is more disturbed by cryogenic processes

A characteristic feature, often encountered in the overbank sequence, is the gradual upward change from peat into lacustrine organic sediment (gyttja) or silt and fluvial sand. This coarsening-upward trend can be explained by channel avulsion when crevasse splays extend into low-lying marshy or lacustrine interchannel areas. This agrees with observations on avulsion deposits in present-day environments (Smith et al., 1989; Smith and Pérez-Arlucea, 1994) where coarsening-upward sequences were formed by crevasse splays extending into interchannel areas. Van Huissteden (1990) noted that locally the horizontally bedded sediments merged laterally into delta cross-bedding. He interpreted this feature as the distal facies of crevasse splays, terminating in shallow lakes (*c.* 0.5–1.0 m deep) on the floodplain.

ALLUVIAL ARCHITECTURE

The geometry of the sedimentary facies has often been used and misused to reconstruct the river channel pattern (Bridge, 1985, and references cited there). The channel/overbank ratio demonstrates the dynamics of the fluvial system (Allen, 1965). Highly dynamic braided systems are characterized by rapid channel migration and therefore have a high channel/overbank ratio. Meandering and anastomosing systems are relatively stable with lateral migration within well-defined channel belts and channel displacement is by the process of avulsion. Consequently, the channel/overbank ratio is low. Bridge and Leeder (1979) and Mackay and Bridge (1995), however, stressed that, in addition to the nature and frequency of lateral channel migration, the coarse to fine ratio in alluvial sequences is also determined by the vertical floodplain aggradation rate, the ratio of floodplain width to channel-belt sand body width, compaction and vertical tectonic movements.

The alluvial architecture of the Middle Pleniglacial tundra rivers is characterized by the following features.

(i) *The low ratio of channel and overbank sediments.* The alluvial architecture has been studied in extensive exposures (Grouw, Scheibe) or by extrapolation between series of bore holes (Dinkel; Figure 7.6). In the Grouw exposure (Figure 7.1) *c.* 50% of the sequence consists of channel sediments. Furthermore, the exposed channel seems to have been rather stable without much lateral migration or erosion, which is illustrated by the stacking of overbank units beside the channel from at least 38.7 to 35.5 ka (Figure 7.1). This stability may be explained by the presence of tundra vegetation and rather consistent loamy, peaty or ground-ice layers in the overbank sequence. Both the low channel to overbank ratio and the bank stability have been associated with an anastomosing or anabranching river pattern (Kasse et al., 1995). Figure 7.6 is one of the many cross-sections over the Dinkel valley (Van Huissteden, 1990). It illustrates the low ratio of channel to overbank sediments. The channel deposits consist of medium to coarse sand; the overbank deposits contain fine sand, silt, clay and organic materials. In general 40 to 55% of the total thickness of the Middle Pleniglacial sequence consists of channel sands (Van Huissteden, 1990). Because of the scarcity of lateral accretion deposits and the dominance of crevasse splay sand sheets and abundance of marshy to lacustrine deposits (low channel to overbank ratio) it was concluded that these Middle Pleniglacial sequences in the Dinkel valley were deposited by an anastomosing river. The Middle Pleniglacial sequence in eastern Germany (exposure Scheibe) is very similar to the Dinkel valley

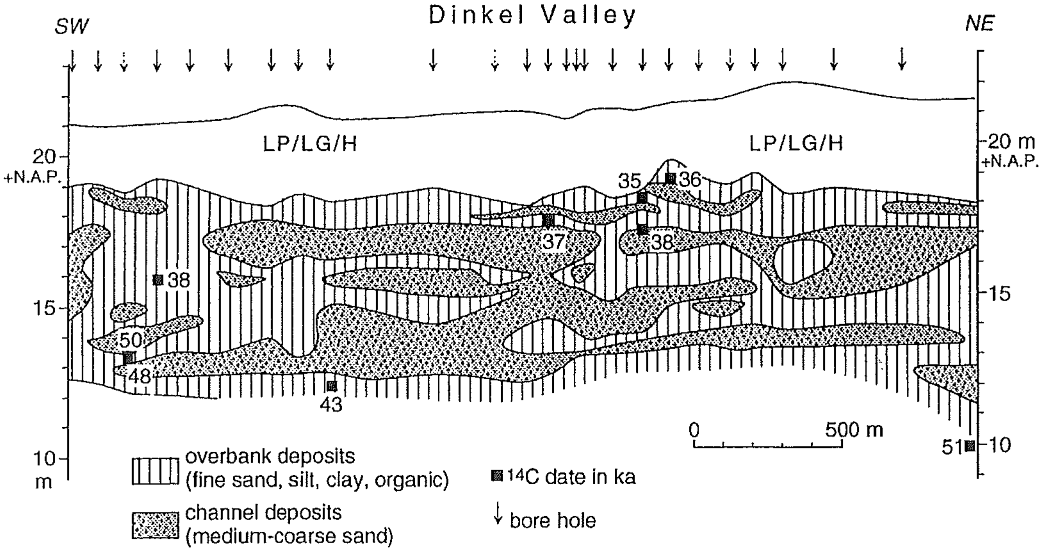

Figure 7.6 Cross-section over the Dinkel valley, eastern Netherlands, illustrating the low channel to overbank ratio (after Van Huissteden, 1990). LP/LG/H, Late Pleniglacial/Late Glacial/Holocene deposits; N.A.P., Dutch Ordnance Datum

(Mol, 1997). The channel to overbank ratio is low and the sequences are interpreted also as being deposited by an anastomosing fluvial system of the Spree or Neisse.

(ii) *The relatively high ratio of overbank sand to overbank fines (silt, clay, organic material).* In the investigated sites of Scheibe, Grouw and the Dinkel valley, 80%, 75% and 70%, respectively, of the overbank sediments consist of fine sand. Low-energy anastomosing river systems, described by Smith and Smith (1980) and Smith (1983, 1986), are characterized by standing water pools in which clay settles from suspension and plants accumulate as peat. Consequently, the overbank sand/fines ratio in such environments is low. The Middle Pleniglacial tundra rivers, however, have a high overbank sand to fines ratio, which means a more dynamic overbank environment. The large volume of sand in the overbank deposits suggests that the floodbasins played an important role in transporting water and sediment during major floods.

DISCUSSION

The Middle Pleniglacial fluvial systems in The Netherlands and Germany have been interpreted previously as sandy anastomosing (Van Huissteden, 1990; Kasse et al., 1995; Mol, 1997). However, in accordance with Bridge (1993), it is difficult to prove the coevality and connection of anabranching river segments in the Middle Pleniglacial alluvial sequences. It therefore cannot be excluded that the alluvial architecture described above was formed by a single channel system characterized by frequent channel avulsions. In the following, the causes for the formation of the Middle Pleniglacial alluvial architecture are discussed and the river pattern will be compared with existing river pattern classifications (e.g. Nanson and Croke, 1992; Nanson and Knighton, 1996).

A reconstruction of the depositional processes in the Middle Pleniglacial river valleys is presented in Figure 7.7. The reconstruction is based on the study of lithology, sedimen-

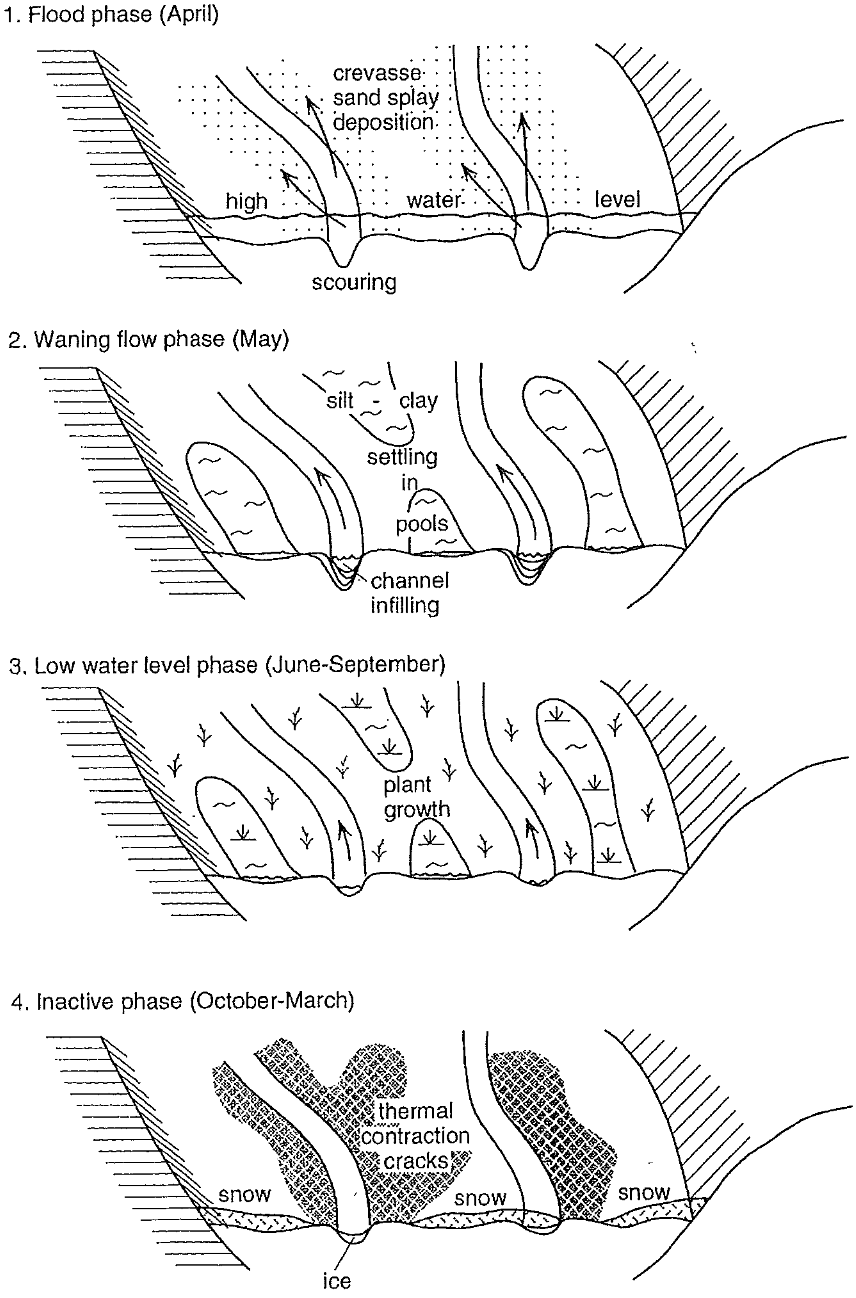

Figure 7.7 Reconstruction of the seasonal depositional processes in the Middle Pleniglacial tundra river valleys

tary sequences and vegetation. The vegetation during the Middle Pleniglacial in The Netherlands and Germany was arctic tundra to shrub tundra (Ran, 1990; Kasse et al., 1995). The months are hypothetical and based on present-day analogues.

During the flood phase (1) the floodplain was inundated by snow meltwater. The channels were scoured and sand was deposited on the overbanks as crevasse splays (Grouw, Scheibe) or crevasse deltas if lakes existed on the floodplain (Dinkel; Van Huissteden, 1990). The flow velocities were high enough to transport medium to coarse sand in the channels and fine sand on the overbank, probably because of the moderate floodplain gradient of 0.0002–0.0004 (20–40 cm km^{-1}).

During the waning flow phase (2) water level dropped, the flow velocity decreased and the water retreated into the channels. The channels were filled first with sand, later with silt forming a couplet of alternating bedding, and locally with climbing ripple bedding. Lateral migration reflected by lateral accretion bedding, a characteristic of meandering rivers, is of minor importance in the exposures, probably because the flow phase was of short duration. In pools on the floodplain some silt and clay settled from suspension.

In the summer period (3) plant growth was abundant on the floodplain as indicated by rooting of the overbank sediment. Locally, moss mats that floated on stagnant water were found in the channel infillings (Grouw; Kasse et al., 1995). This indicates that the fluvial system was rather inactive in this phase and river flow was limited.

In the long winter period (phase 4) the river was most likely inactive, because the floodplain was deeply frozen. Thermal contraction cracks (frost cracks) were formed in snow-free patches on the floodplain, predominantly in the overbank sediment, but locally also in the inactive channels.

The studies in The Netherlands and Germany show that the following factors determine the specific alluvial architecture of the Middle Pleniglacial cold-climate tundra rivers.

(1) *The large width and more or less unconfined character of the valleys.* The Weichselian rivers flowed through large Saalian age subglacial basins (5–10 km wide or more) or proglacial outwash valleys (up to 20 km wide). In comparison with the Saalian meltwater systems the Weichselian rivers are underfit. The unconfined character promoted the overbank deposition. The importance of valley width on the distribution of channel belt bodies within overbank fines has been demonstrated also in fluvial model experiments (Bridge and Leeder, 1979). Indeed, more confined rivers like the Thames reveal a braided channel pattern during the Middle Pleniglacial (Gibbard, 1994).

(2) *The rapid vertical aggradation of the floodplain.* Vertical aggradation in the investigated sites is *c.* 0.5 m ka^{-1}. Van Huissteden (1990) reported somewhat lower mean sedimentation rates for the whole Middle Pleniglacial unit (0.16–0.35 m ka^{-1}). These sedimentation rates are lower than those reported for Holocene anastomosing systems (e.g. $>$ 1.5 mm yr^{-1} (Törnqvist, 1993) and 6 mm yr^{-1} (Smith, 1983)), probably because the Weichselian values are based on a longer period and hiatuses may be present in the sequence. The high sedimentation rates in the basins are probably closely related to periglacial erosion (solifluction, sheet flow erosion, wind erosion) of surrounding higher topography such as till plateaus, sandur plains and ice-pushed ridges of Saalian age. The vertical aggradation enabled the channel to maintain its course. Channel abandonment by means of avulsion occurred at the end of a depositional cycle, when the channel belt had aggraded above the level of the surrounding floodplain. This promoted breaching of the levees and crevasse splay development as indicated by the drowning of overbank peats and the general coarsening-upward trend in the individual overbank units. Ultimately, the crevasse channels evolved into a new course in the lower-lying former interchannel area (Ran and Van Huissteden, 1990).

(3) *The limited lateral migration of the channels.* Limited lateral migration is probably caused by two elements. First, these periglacial tundra rivers were probably charac-

terized by strong seasonal discharge variations related to the spring snowmelt (Woo and Winter, 1993). Because of the shortness of the active flow stage only limited lateral migration could occur and the channels did not develop into meandering channels. Secondly, lateral migration will have been limited by river bank cohesion. The well-developed tundra vegetation on the overbank environment may have stabilized the sediment. In addition the loamy and organic beds in the overbank sequence, despite their limited thickness, may have restricted bank erosion. Finally, especially important in cold-climate rivers, the seasonal or permanently frozen state of the overbank sequence and the presence of ground ice will have limited lateral erosion. Even sandy overbank sediments, normally easily eroded, will be cohesive under such frozen conditions.

(4) *The sandy nature of the source material.* According to Van Huissteden (1990) the generally sandy nature of the overbank sequence may be explained by: (i) later compaction especially reducing the thickness of the loamy and organic units; (ii) restricted organic matter production in the cold Middle Pleniglacial climate. The low organic production will have reduced the overbank sedimentation rate. Channel belt aggradation may have been faster than overbank aggradation and consequently sandy crevasse splays developed and avulsion occurred; (iii) the nival hydrologic regime and blockage of channels by ice dams. The Middle Pleniglacial hydrologic regime was probably characterized by a relatively short snow meltwater phase. In combination with snow or ice dams meltwater floods may have been diverted out of the channels promoting extensive overbank sedimentation of sand. In addition to the foregoing, the sandy character of the Middle Pleniglacial fluvial systems may be determined by the sandy nature of the source material. The sediment sources in the river catchments consist of unconsolidated, mostly sandy (fluvio)glacial and ice-pushed preglacial sediments. Nanson et al. (1986) described a similar relationship for the anastomosing Cooper Creek river in Australia, where the transported sediment consists mostly of sand-sized clay aggregates and the floodplain therefore consists of clay.

The comparison of the Middle Pleniglacial river with existing floodplain classifications (Nanson and Croke, 1992; Nanson and Knighton, 1996) is shown in Table 7.1. Important elements are the channel/overbank ratio and the coarse/fine ratio of the floodplain sediments.

The Middle Pleniglacial systems have a low channel/overbank ratio which is comparable with the more organic anastomosing systems (Smith and Smith, 1980; Smith, 1983, 1986), and with the inorganic anastomosing system (Nanson et al., 1986). However, the coarse/fine ratio of the anastomosing types C2a and C2b is low, which means that the floodplains are dominantly muddy or organic, while the Middle Pleniglacial systems have a high coarse/fine overbank ratio. In this respect they have more in common with the braided system. The peaked discharge character of the Middle Pleniglacial systems resembles the semi-arid inorganic anastomosing type (C2b) as described from Australia (Nanson et al., 1986); however, instead of sand, type C2b is dominated by clay.

Recently, the anastomosing or anabranching floodplain types have been summarized by Nanson and Knighton (1996). In addition to the well-established cohesive (clay/organic) anastomosing floodplains (Nanson and Croke, 1992), sand-dominated anabranching floodplain types are described (types 2 and 4). They occur in tropical

Table 7.1 Comparison of the Middle Pleniglacial tundra rivers with floodplain classifications

Floodplain type (Nanson and Croke, 1992; Nanson and Knighton, 1996)	**Ratio channel/ overbank**	**Ratio gravel–sand/silt–clay**	**Specific stream power**	**Dominant sediment**
Braided (B1)	high	high	(high) medium	gravel/sand
Meandering (B3)	medium	medium	medium	sand
Anastomosing organic-rich (C2a/1b)	low	low	low	clay/organic
Anastomosing inorganic (C2b/1c)	low	low	low	clay
Anabranching, sand-dominated, island-forming (2)	low	high	low	sand
Middle Pleniglacial (this study)	low	medium/high	medium	sand

monsoonal or semi-arid climates and are characterized by a monsoonal or episodic flow regime. Because of the generally non-cohesive nature of sand, these types require the combination of stabilizing bank vegetation and a low stream power to prevent the channels from braiding or meandering (Nanson and Knighton, 1996). Despite the difference in climatic setting, the cold-climate Middle Pleniglacial rivers of northwestern Europe reveal comparable environmental conditions. The discharge was strongly episodic as it was related to the snowmelt period and floodplain sedimentation was predominantly sandy. The stabilizing role of the tundra vegetation and the presence of deep seasonal frost or permafrost enhanced bank stability and the tendency towards lateral migration and meandering was suppressed. It is concluded, therefore, that the Middle Pleniglacial tundra rivers of northwestern Europe are comparable with modern sand-dominated, island-forming anabranching rivers.

CONCLUSIONS

(1) The cold-climate (mean annual temperature − 1 to − 4 °C), low-relief tundra rivers of the Middle Pleniglacial in northwestern Europe are characterized by channel and overbank environments. Alternating bedding of sand and silt and reactivation phenomena (erosional surfaces in the dune foresets, silt drapes) in the channel sediments reflect the peaked discharge of these rivers probably related to the short snowmelt period.

(2) The alluvial architecture of the floodplain is characterized by the low ratio of channel (*c.* 50% of the total sequence) to overbank sediments and by the absence of lateral accretion deposits in the channel belts which suggests an anastomosing or anabranching river style. The overbank sequence is dominated by sand (70–80%) which was deposited in crevasse splays or crevasse deltas during avulsion phases. Despite the sandy character of the system, lateral channel migration associated with river meandering was very limited, because the flood phase was short and the river banks were stabilized by tundra vegetation and seasonal or permanent ground ice.

(3) The development of the specific floodplain architecture is favoured by: the unconfined character of the rivers flowing in former proglacial and subglacial basins; the relative-

ly high floodplain aggradation rate of 0.5 m ka^{-1}; the sandy source material derived from preglacial and Saalian glacial sandy deposits in the catchments; the flashy discharge related to the snow-melt period; the high bank stability because of the tundra vegetation and presence of ground ice in the overbank sequence.

(4) The Middle Pleniglacial systems differ from the cohesive (organic to mud-dominated) anastomosing river types by their predominantly sandy character. These tundra rivers possibly resemble monsoonal or semi-arid, sand-dominated, island-forming anabranching rivers with an episodic flow regime.

ACKNOWLEDGMENTS

The manuscript benefited from the critical review by Dr P.J. Ashworth, University of Leeds. Figures 7.1, 7.2, 7.3, 7.4 and 7.5 have been reproduced from the *Mededelingen Rijks Geologische Dienst* with permission of the Nederlands Instituut voor Toegepaste Geowetenschappen TNO.

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