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Settlement and land use on crevasse splay deposits; geoarchaeological research in the Rhine-Meuse Delta, the Netherlands

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Abstract

Until recently, most archaeologists assumed that human occupation of the Dutch river area in the Neolithic period and Bronze Age was rare and predominantly seasonal. Settlement and land use were thought to be limited to abandoned alluvial ridges and aeolian dunes. However, recent archaeological research revealed that Neolithic and Bronze Age human activity occurred at many locations in the Rhine-Meuse Delta. Human settlement and agricultural land use in the Rhine-Meuse delta from at least 3200 BC to 1100 AD was much more common than previously thought. Crevasse splay complexes of active and abandoned river systems proved to have provided favourable sites for settlements. These elevated areas were suitable for agriculture, as they were fertile, easy to plough and possessed suitable hydrological conditions. In addition, people could exploit the surrounding floodplain for hunting, fishing or herding their cattle. Furthermore, the river or residual river channel was near for transport. From the start of the Middle Bronze Age B (1400 BC) occupation of crevasse splay deposits in the delta was widespread. Farmsteads were built on splays that varied in size and morphology. Some locations were abandoned after a few decades, while others remained occupied during a much longer period. During the period of occupation, the crevasse splays gradually lost their relatively high position in the landscape due to subsidence and ongoing sedimentation on the floodplain.

LIDAR data combined with digital coring databases and/or detailed soil maps have proven to be an excellent method to identify and map crevasse splays and archaeological sites on these. The resulting new maps form a major basis for archaeological prospection and preservation policy.

Keywords: archaeology, Neolithic, Bronze Age, crevasse splay deposits, geoarchaeology, prediction modelling, the Netherlands

Introduction

Since the 1950s, Dutch archaeologists widely agreed on the idea that prehistoric occupation in the Dutch river area only occurred on channel belts and aeolian dunes (Modderman, 1949a, 1949b, 1955; Pons & Modderman, 1951). Soil scientists, however, showed that prehistoric sites in this area were also situated further away from the channel belt, in particular on crevasse splay deposits (Pons, 1953; Havinga, 1969, 1993; Havinga & Op 't Hof, 1975, 1983). They attributed the occurrence of these crevasse sites to the relatively high position of these deposits in the alluvial landscape during and shortly after the time of formation. However, this idea was not generally recognised among the majority of the Dutch archaeologists. Only a few excavations were carried out where a-priori knowledge existed that a Bronze Age settlement was situated on crevasse splay deposits; an example is the excavation 'de Hien' near Dodewaard (Hulst, 1967, 1970, 1991). Also Louwe Kooijmans (1974, 1985) confirmed the presence of prehistoric human occupation on crevasse splay deposits. Still, large scale archaeological excavations in the Rhine-Meuse Delta near Wijk bij Duurstede ('de Horden') in the 1970s and 80s showed that this idea was not commonly adopted (Hessing, 1989): during this excavation three occupation layers were found, separated by layers of sediment of varying thickness. Only during the final stages of the excavation, it was realized

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these were crevasse splay deposits (Hessing & Steenbeek, 1990). From this, it becomes also clear that it was not generally known that crevasse splays may occur as superimposed deposits, and that these buried sites may have excellent preservation conditions for archaeological material.

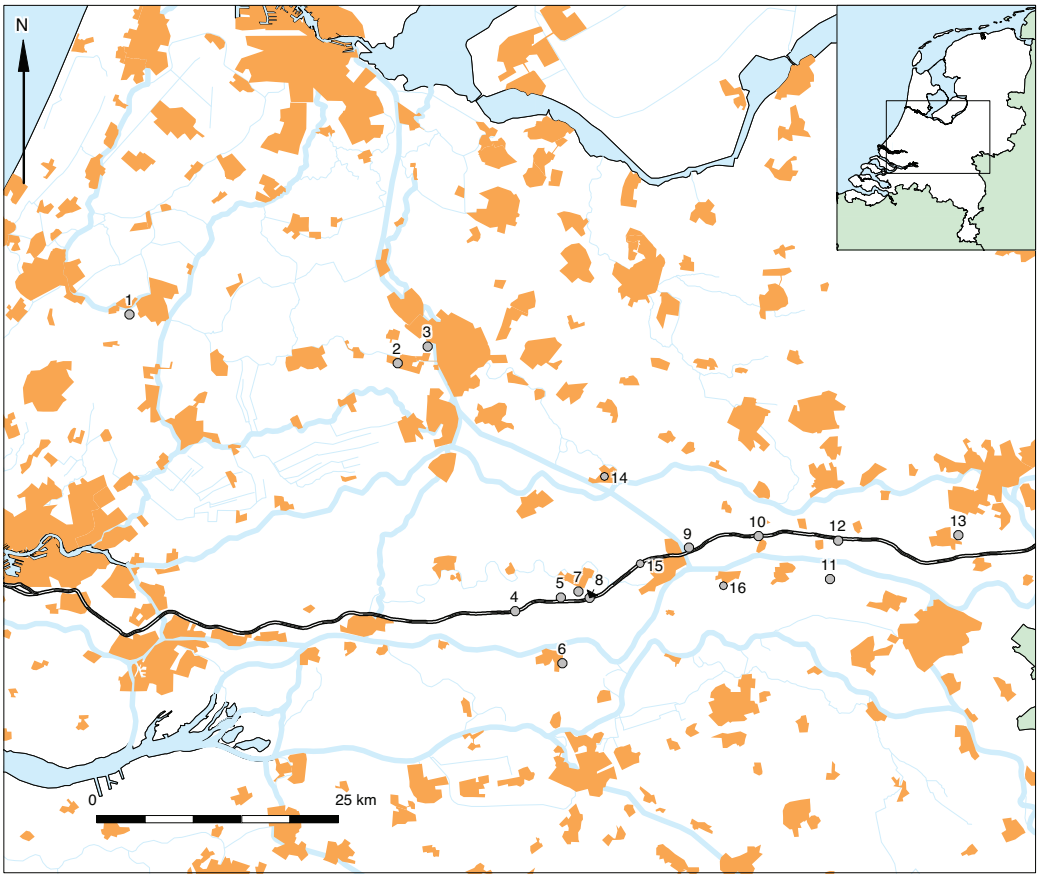
During the last two decades archaeological research in the Dutch river area has boosted because the European Union drew up a treaty in Malta in 1992, called the 'Valletta treaty' or 'Malta Convention' (European Convention, 1992). This treaty aims to protect the European archaeological heritage '*as a source of European collective memory and as an instrument for historical and scientific study*'. It implies that before any disturbance of the subsoil, mainly for building activities, is going to take place archaeological investigations have to be carried out. The costs of these investigations have to be paid by the 'disturber'.

During the 1990s plans arose for the construction of a railway track between Rotterdam and Germany (called the '*Betuwe-route*'), transversing the Rhine-Meuse Delta longitudinally (Fig. 1). The subsequent archaeological research provided an excellent opportunity to test the hypothesis that human exploitation in the delta was only sparse and seasonal, and confined to alluvial ridges and aeolian dunes, as was thought until then by the majority of archaeologists. In this paper we synthesise the large number of excavation results that have been obtained so far, but which are largely published in 'grey' literature: written in Dutch language, hard to obtain, and/or only partly published. The objective of our study was to assess whether and, if so, where human occupation occurred outside channel belts in the Rhine-Meuse delta during Neolithic and Bronze Age time. Furthermore, we aimed at determining which landscape factors determined the suitability of overbank deposits in floodplains for human occupation.

Crevasse splays

Crevasse splay deposits in the Rhine-Meuse delta

The Holocene Rhine-Meuse Delta in the Netherlands has been studied extensively over the past decades. The fluvial architecture and avulsion history is exceptionally well known, as is shown in the palaeogeographical reconstruction of the delta during the Holocene by Berendsen & Stouthamer (2001). Crevasse splay deposits form essential components of the fluvial architecture of this delta (a.o. Berendsen, 1982: Törnqvist, 1993; Weerts, 1996; Makaske, 1998; Stouthamer, 2001). Crevasse



1 Hazerswoude-Windmolenpark; 2 Utrecht-De Balije; 3 Utrecht-Hogeweide; 4 Rumpt-Eigenblok; 5 Geldermalsen-De Bogen; 6 Zaltbommel-De Wildeman; 7 Geldermalsen-De Plantage; 8 Geldermalsen-Hondsgemet; 9 Tiel-Medel; 10 Lienden-Woonwagenkamp; 11 Druten-Deesd aan het water; 12 Dodewaard-De Hien; 13 Elst-Westeraam; 14 Wijk bij Duurstede-De Horden; 15 Tiel-Malburg; 16 Beneden Leeuwen-De Ret

Betuwe railway track

Fig. 1. Location of the Betuweroute railway track and archaeological sites mentioned in this article.

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splays develop when a small channel is eroded through a natural levee during excess discharges. Subsequently, sediment is transported through this channel and deposited in the flood basin (Smith, 1983). Crevasse channels and associated splays in the lower Rhine floodplains were first mentioned by Vink (1926; he called them 'levee bulges') and later by various soil scientists (Edelman, 1950; Pons, 1957; Havinga, 1969), who described their large variety in lithology and morphology. Berendsen (1982) started mapping and describing crevasse splay deposits in the Rhine-Meuse Delta in detail. He made a distinction between splays that were formed due to peak discharges and those that were formed due to blockage of river discharge caused by tidal influences. Since then, crevasse splays have been accepted as a fundamental architectural element in the Rhine-Meuse delta.

Crevasse splay deposits are well known for their complexity in structure, texture and geometry (Fisk, 1947; Coleman, 1969; Smith, 1983; Cross & Smith, 1985; O'Brien & Wells, 1986; Farrell, 1987; Mjøs et al., 1993; Makaske, 1998). Many crevasse splays lack a well distinguishable sand body and consist largely or completely of calcareous sandy and silty clay. Often only sandy deposits are considered as splay deposits (Mjøs et al., 1993). As a consequence, underestimation of 70% of the volume of the splay landform can occur (Farell, 2001). Based on the large spatial variation in the subsoil, Weerts & Bierkens (1993) suggested that accurate mapping of crevasse splay deposits in the Netherlands requires a mean coring distance of 25-30 meters. Most geological and geomorphological maps from the Rhine-Meuse delta are based on corings spaced much further apart. This implies that many crevasse splay deposits in the Netherlands are poorly mapped or, more commonly, not mapped at all.

Crevasse splay development

Smith et al. (1989) introduced a conceptual model of splay development consisting of three intergradational forms. Each form is associated with a characteristic sand body geometry (Fig. 2). Whether the breakthrough point becomes plugged, enlarges or reaches a steady state depends upon the ratio of crevasse to main-channel bed slope, height of the crevasse bottom above the bed of the main channel, and bed grain size (Slingerland & Smith, 1998). Figure 2 also displays active crevasse splay systems belonging to the Columbia River in NW-Canada, as an example of what a recent crevasse splay complex looks like. Farrell (2001) explored the genesis, architecture, geometry and connectivity of facies in 3D. Furthermore, she slightly revised the model of crevasse splay formation introduced by Smith et al. (1989) by differentiating sand facies, i.e channel and mouth bar, from heterolithic marginal and distal bar facies. Additionally, crevasse splay deposits may incise through the splay deposits into the subsurface or may non-erosively overly floodplain deposits (Makaske, 1998).

Definition of crevasse splay deposits

From Fig. 2b, it becomes clear that it is difficult to discriminate between crevasse splay and levee deposits when crevasse splay sediments are deposited directly behind and against the natural levee. Furthermore, crevasse splay deposits are formed by the same processes as natural levees and, therefore, their deposits do often not differ in structure and texture from levee deposits. Consequently, many splays are mapped as natural levee. In this study, crevasse splay deposits are defined as deposits in flood basins that have a coarser texture and/or an increased $CaCO_3$ content when compared to surrounding flood basin deposits. Furthermore, the distinction with levee deposits is based on the spatial distribution of the sediment. Two types of crevasse splays are distinguished: a) clear channels with bar facies that protrude into the flood basin; and b) large irregular bulges of the 'levee' indicating the presence of a sheet of crevasse splay sediments deposited directly aside levee deposits. In fig. 2b both types are depicted in a present-day situation.

Methods

At first a reconnaissance study of the area concerning the planned '*Betuweroute*' railway track was carried out (Asmussen, 1991, 1994 and 1996). This research involved literature review and a coring campaign and revealed 160 archaeological sites. According to the standard criteria of the former National Service for Archaeological Heritage (ROB, nowadays the Cultural Heritage Agency) 50 of these sites should be preserved. A selection of 11 sites were excavated and the remaining were preserved *in situ*. The excavations were accompanied by extensive geological investigations that involved description of sections and detailed coring around the site. In this way, detailed information was obtained on the diversity in architecture, geometry and sedimentlogical structures in the subsoil surrounding the site.

Within approximately 500 m of each of the 11 excavation sites, corings where carried out with hand auger equipment, with spacing varying from 10 to 40 m, resulting in over 200 corings per km^2. The cores were described in the field using the methodology of Berendsen & Stouthamer (2001) at 10 cm intervals with regard to texture, median grain size, organic matter content, colour, Fe-oxide content, $CaCO_3$ content, groundwater levels and (palaeo)soils. In addition, the amount, size and diversity of archaeological artefacts was described (Isarin & van der Kroft, 2001). Archaeological artefacts are for example fragments of pottery, bone, stone, charcoal, loam, burned clay and other inclusions that naturally are not present in the subsoil. Furthermore, discoloration of the sediment, for instance caused by iron-phosphate aggregates, can indicate former occupation. Cores were numbered sequentially and the geographical location (±5 m XY, Dutch coordinate system) and

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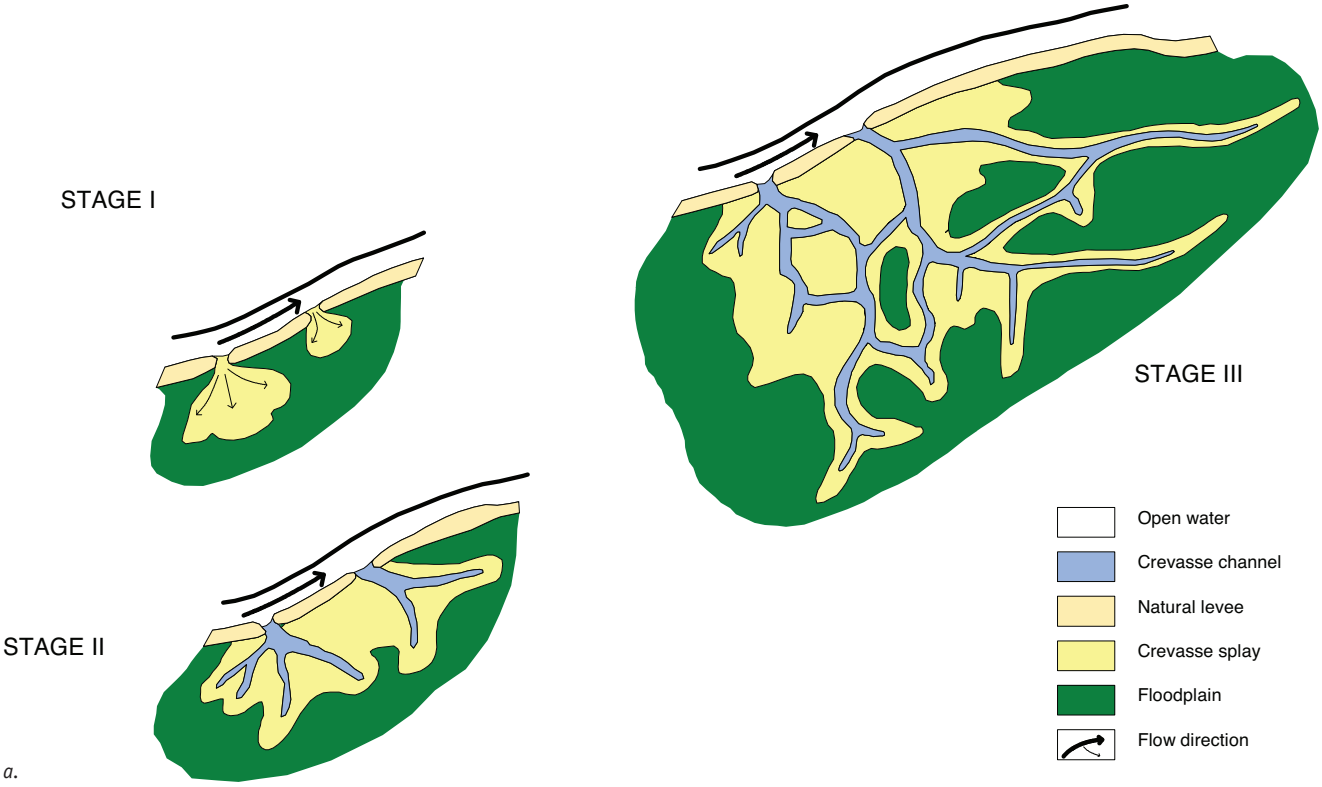

a.

b.

Fig. 2. a. Formation of a crevasse splay complex (Smith et al., 1989); b. Active crevasse splay systems, upper Colombia River, Canada (photos: B. Makaske).

surface elevation (± 0,05 m relative to Dutch O.D. = NAP ≈ mean sea level) were registered. Sections at the excavation were described in the same way but at 5 cm intervals.

Figures 4 and 5 are based on corings that were carried out in 1998 and 1999. Locations of the cross section in Fig. 4 and the depicted area in Fig. 5 are shown in Fig. 3. Sediment bodies belonging to different crevasse splays were distinguished on the basis of depth, stratigraphy, lithology and spatial extent. The thickness of the two upper splay deposits was derived from the descriptions and interpolated with a standard interpolation using the inverse distance weighting in the thematic mapper option of MapInfo Professional 5.2 and a search radius of 30 m. Archaeological layers in corings were distinguished on the basis of the presence of archaeological artefacts in a sediment layer. Subsequently, these layers have been interpreted as farmstead, farm yard or fields/used area according to the thickness of the layer as well as the amount, size and diversity of archaeological artefacts (Groenewoudt, 1994). The finds in the excavation pits were used to control the interpretation of the coring data.

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Results

Betuweroute railway track

Of the 50 archaeological sites meeting the criteria of the National Service for Archaeological Heritage, three turned out to be situated on aeolian dunes and 27 were situated on alluvial ridges. The remaining 20 sites were situated on crevasse splay deposits. The investigation of sites on crevasse splay deposits provided insight in the evolution of the landscape and human settlement associated with splays. This shows that the extent of prehistoric settlement in the delta has been seriously underestimated by many archaeologists until now.

Archaeological sites in the Rhine-Meuse Delta

The excavated site near Kesteren

The 'Lienden-Woonwagenpark' archaeological site southeast of Kesteren was excavated in 1998 (Schoneveld & Kranendonk, 2002). The site was situated just north of the Westerveld channel belt (Fig. 3). No residual channel was found during the coring campaign. Therefore, an accurate date for the end phase of this meander belt could not be obtained. Berendsen & Stouthamer (2001) assumed that this alluvial ridge is connected to the Homoet meander belt upstream. The base of the residual channel deposits of this latter channel belt was dated 3290±70 BP (Berendsen & Stouthamer, 2001). This means this channel belt was abandoned between approximately 1700 and 1400 cal BC: the Middle Bronze Age in the Netherlands. Because of the supposed correlation, this date is also presumed to be valid for the end phase of the Westerveld channel belt. The Echteld channel belt, situated south of the site (Fig. 3), is younger and has cut through the Westerveld channel belt.

A cross section through the excavation area (Fig. 4) clearly reveals several packages of crevasse splay deposits, some of which are deposited directly on top of each other. The distinction between crevasse splay and levee deposits is based on the spatial distribution of the deposits. The width of the levee deposits is fairly constant along the channel belt, whereas the crevasse splay deposits form large irregular bulges extending into the floodplain. Locally, several phases can be distinguished, deposited on top of each other. Crevasse splay deposits of phases 2 and 3 were deposited by the Westerveld channel belt. These packages consist of homogeneous sandy clay that fines upwards into silty clay and lacks any sedimentary structures. At the top of both sediment bodies a vegetation horizon occurs, that represents a phase of reduced (or absent) sedimentation, during which soil formation has started, and decalcification occurred. It thus represents an old surface and is recognisable as a black to dark-grey layer in clayey sediments (Schoute, 1984; Steenbeek, 1990). This demonstrates that the crevasse splay deposits of phase 3 generally overlie deposits of phase 2 non-erosively. Both vegetation horizons contain an admixture of sand and small pieces of archaeological relicts like pottery, burned clay, stone and charcoal. This indicates that human activity took place on the palaeo-surfaces and, therefore, the layers are interpreted as occupation layers (Fig. 4). The pottery found in the occupation layer at the top of phase 2 dates to the Early Bronze Age (2000-1800 BC, Corded Ware culture, Sier & Koot, 2001). The occupation layer at the top of deposits from phase 3 was dated by ^{14}C and these dates revealed a Middle Bronze age at the transition from phase A to phase B (~1650-1400 cal BC; Schoneveld & Kranendonk, 2002)[1].

Figure 5 shows the spatial distribution of both crevasse splay bodies. In the Early Bronze Age two lobate crevasse splay bodies are present (Fig. 5a). Both splay bodies cover approximately 3 ha and are between 30 and 150 cm thick. Based on their planform they can be interpreted as stage I types of Smith et al. (1989, see Fig. 1). This type is formed by shallow, unstable channels and generally has steep edges.

Evidence of human occupation is also depicted in figure 5. The thickness and occurrence of archaeological artefacts in the occupation layer in several corings suggest that a farmstead was constructed on each splay. The admixture of sand and small pieces of charcoal in the adjacent vegetation horizon suggests trampling and indicates that the entire surface of the splay was used by humans, probably for crop cultivation. These sites were not excavated, as they were not threatened by the construction of the Betuweroute railway.

The crevasse splay deposits of phase 3 are more extended (Fig. 5b). On the western side of the excavation area, a 400-m long and 10-m wide channel is visible. The residual channel fill is about 3 m thick and has relatively thick crevasse splay deposits on either side, resembling miniature levees (app. 50 m wide; cf. fig. 4). Beyond the far end of the channel, sediment was deposited as a thin sheet over a wide area of the floodplain. Excavation in this area demonstrated that a farmstead was built on the western levee of the channel (Schoneveld & Kranendonk, 2002). Archaeological artefacts are only present in the upper part of the channel fill, showing that occupation started when the channel already ceased functioning and had started to fill. After some time, the farmstead was rebuilt on nearly the same spot. The average lifespan of a farmstead is currently assumed to be about 30 years, but recent research has shown that a lifespan of 70 to 100 years is possible (Jongste, 2008). By that time, the channel had completely filled up and could be crossed as was shown by hoof imprints present in the vegetation horizon that formed in the top of the channel fill (Fig. 6). This occupation phase is dated to the Middle Bronze age. On the eastern side of

1 Based on ten radiocarbon dates on wood, charcoal, bone and (food) residual left on potsherd (GrN 15980, 16183, 16189, 24480, 25477, 25479, 25483-25485, 25700; results ranging between 3130 and 3270 BP), resp. eight dates from eastern settlement area and two from western settlement area.

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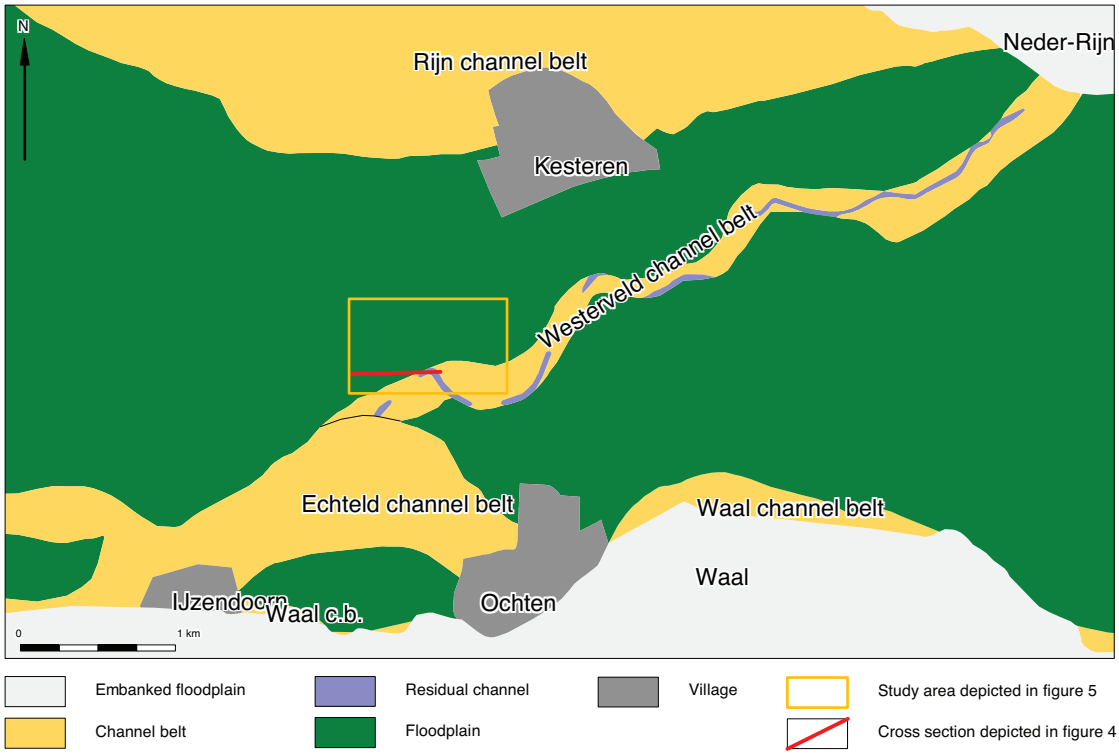

Fig. 3. Geologic map of the area surrounding archaeological site 'Lienden-Woonwagenpark' (after Berendsen, Faessen and Kempen, 1994).

the excavation area, an extensive settlement area has been found. Here, several farmsteads probably existed simultaneously. Some of these farmsteads were rebuilt during the occupation phase. The occupation phases on both crevasse splay bodies were radiocarbon dated at around 3300-3100 BP and were almost certainly occupied simultaneously.

These observations reveal that crevasse splay complexes can be stacked, almost non-erosively, on top of each other. The excavation near Lienden demonstrates that occupation during the Early Bronze Age, the deposition of a crevasse splay (phase 2) and habitation during the Middle Bronze Age all took place within approximately 300-500 years. This implies that the occupation during the Early Bronze Age lasted only for a maximum of several human generations. It is not known whether a hiatus longer than the period of crevasse splay formation existed between the two habitation periods. So, it remains a question whether the Middle Bronze Age people knew that their ancestors lived on the same locality.

Other Betuweroute excavations

Other excavations that were carried out within the framework of the Betuweroute have revealed additional information about crevasse splays complexes and human occupation. For example,

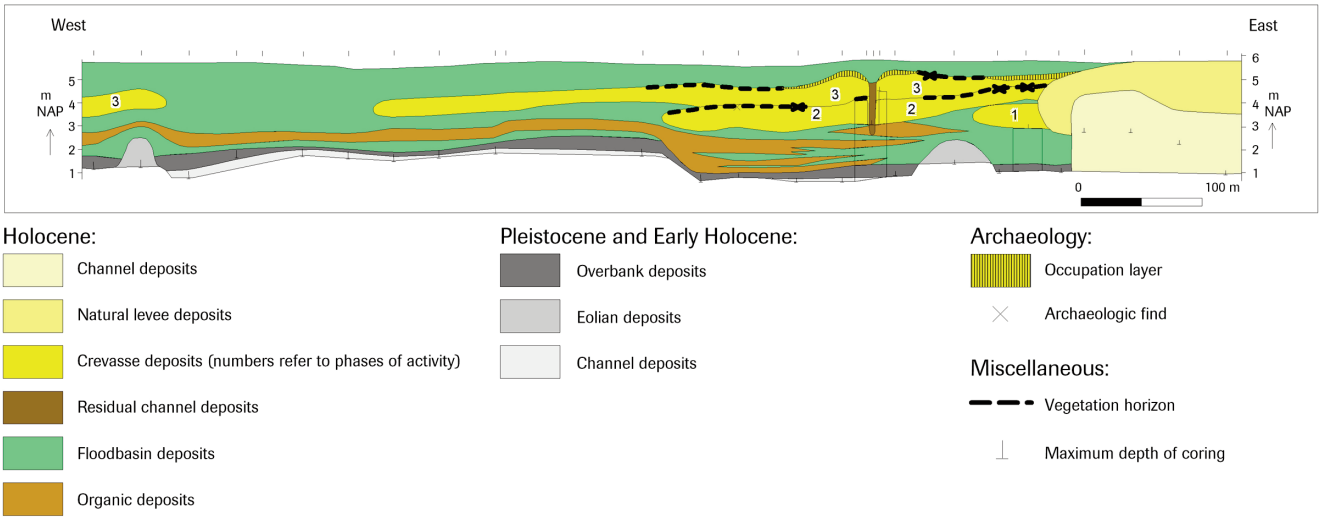

Fig. 4. Cross section of archaeological site 'Lienden-Woonwagenpark'.

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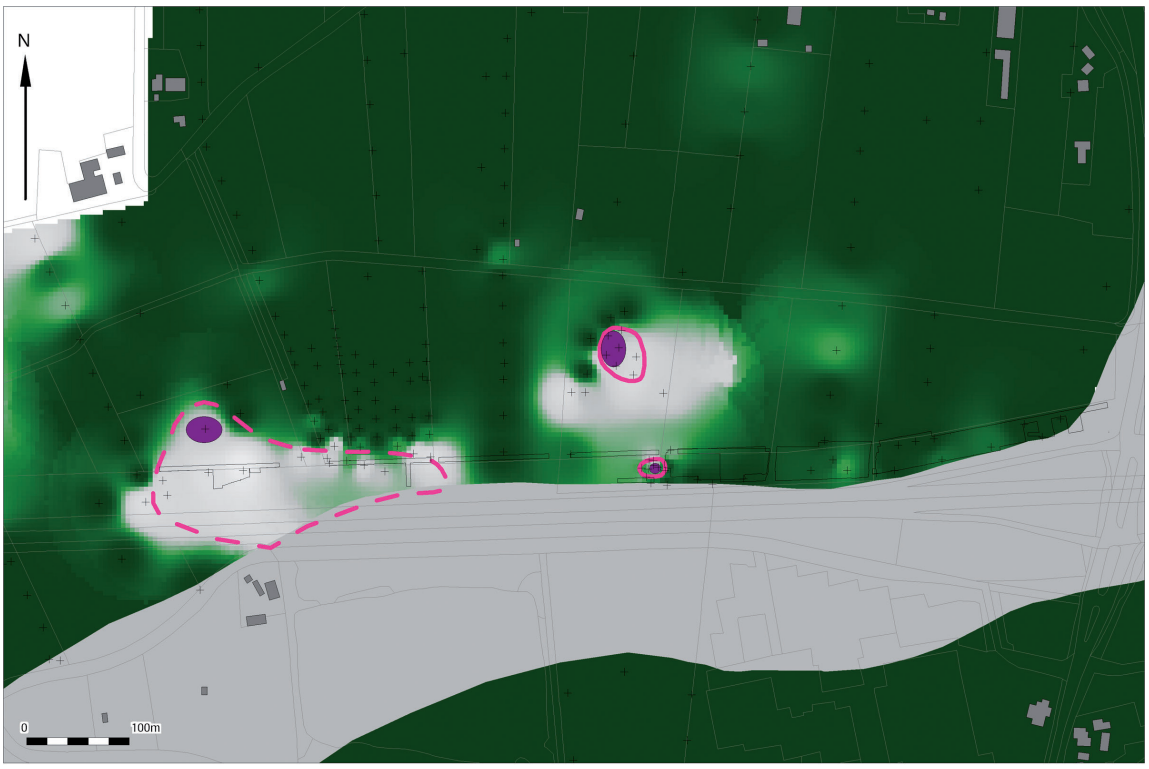
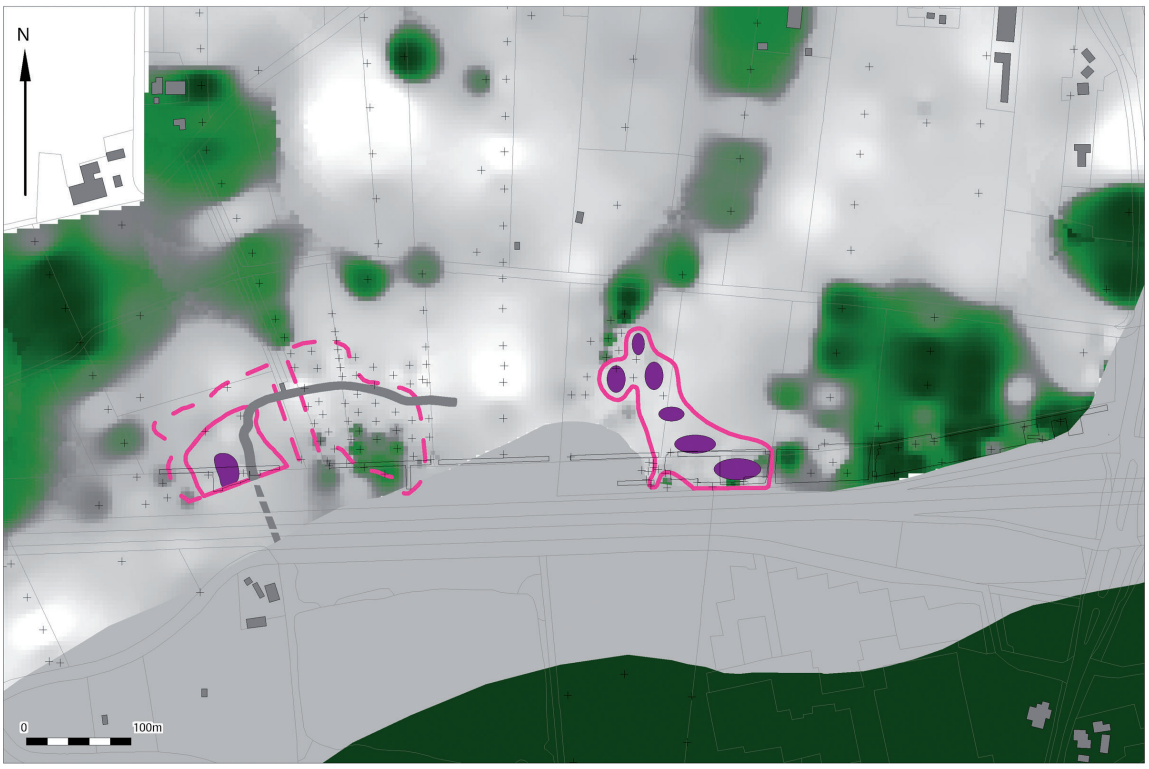


a.



b.

Thicknes of crevasse splay deposits (in cm)
- > 180
- 120 - 179
- 70 - 119
- 60 - 69
- 30 - 59
- 0 - 29

Morphology:
- Alluvial ridge
- Crevasse channel

Archaeology:
- Farm stead
- Farm yard
- Fields / used area

Miscellanious
- Coring
- Trench

Fig. 5. Spatial distribution of crevasse splay deposits near the archaeological site 'Lienden-Woonwagenpark': a. Early Bronze Age; b. Middle Bronze Age.

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a. b.

Fig. 6. a. Hoof imprints in the top of the channel fill at the archaeological site 'Lienden-Woonwagenpark'; b. Human footprint in floodplain at the archaeological site 'Rumpt-Eigenblok'.

the excavation 'Eigenblok' near Rumpt has shown that people were willing to build a farm on a very small piece of dry ground – a crevasse splay measuring only 30 by 30 m – during the Middle Bronze Age. Here, the adjacent alluvial ridge was used for agriculture (Jongste & Van Wijngaarden, 2002). Striking was the presence of several human footprints at the edge of the crevasse splay (Fig. 6b). Excavation site 'De Bogen' near Meteren revealed that crevasse splay deposits of only 20 to 30 cm in thickness were apparently considered suitable for settlement (Meijlink & Kranendonk, 2002). Furthermore, a large crevasse splay complex was mapped there, that measured roughly 1 km^2. This splay was already exploited during the latest phase of the Late Neolithic period (2450-2000 BC), however this activity might (initially) have been seasonal. In the Middle Bronze Age farmsteads were built on the splay and most likely used for permanent settlement (Meijlink & Kranendonk, 2002; Arnoldussen, 2008). This human settlement lasted uninterruptedly until the end of the Middle Bronze Age (1250 BC), indicating a period of more then 1000 years of continuous exploitation. During this period, sedimentation took place on the adjacent floodplain and on lower parts of the splay, as shown by the deposition of sediment on the lower edges of the splay, followed by the formation of a new vegetation horizon and younger archaeological features (Fig. 7). Thus, due to subsidence, the available arable area reduced increasingly over time. The rate of subsidence depended on the composition of the underlying alluvium and architecture of the crevasse splay itself. At 'De Bogen' new crevasse splay formation, due to a nearby avulsion, ended the exploitation phase. This event took place by the end of the Middle Bronze Age or in the first half of the Late Bronze Age. The newly formed crevasse splay complexes were used for human exploitation in the Middle Iron Age, as demonstrated by the presence of a burial, an enclosure and several other features associated with human activity (Meijelink & Kranendonk, 2002).

In addition, settlement areas on crevasse splay complexes dating from the Late Iron age (250-12 BC), Roman Period (12 BC - 450 AD) and the Middle Ages (800-1200 AD) were discovered during other excavations carried out in advance of the construction of the Betuweroute (resp. Milojkovic & Smits, 2002; Sier & Koot, 2001; Oudhof et al., 2000). This implies that human occupation on crevasse splay deposits was a common aspect in the Rhine-Meuse delta in both prehistory and history before river embankment.

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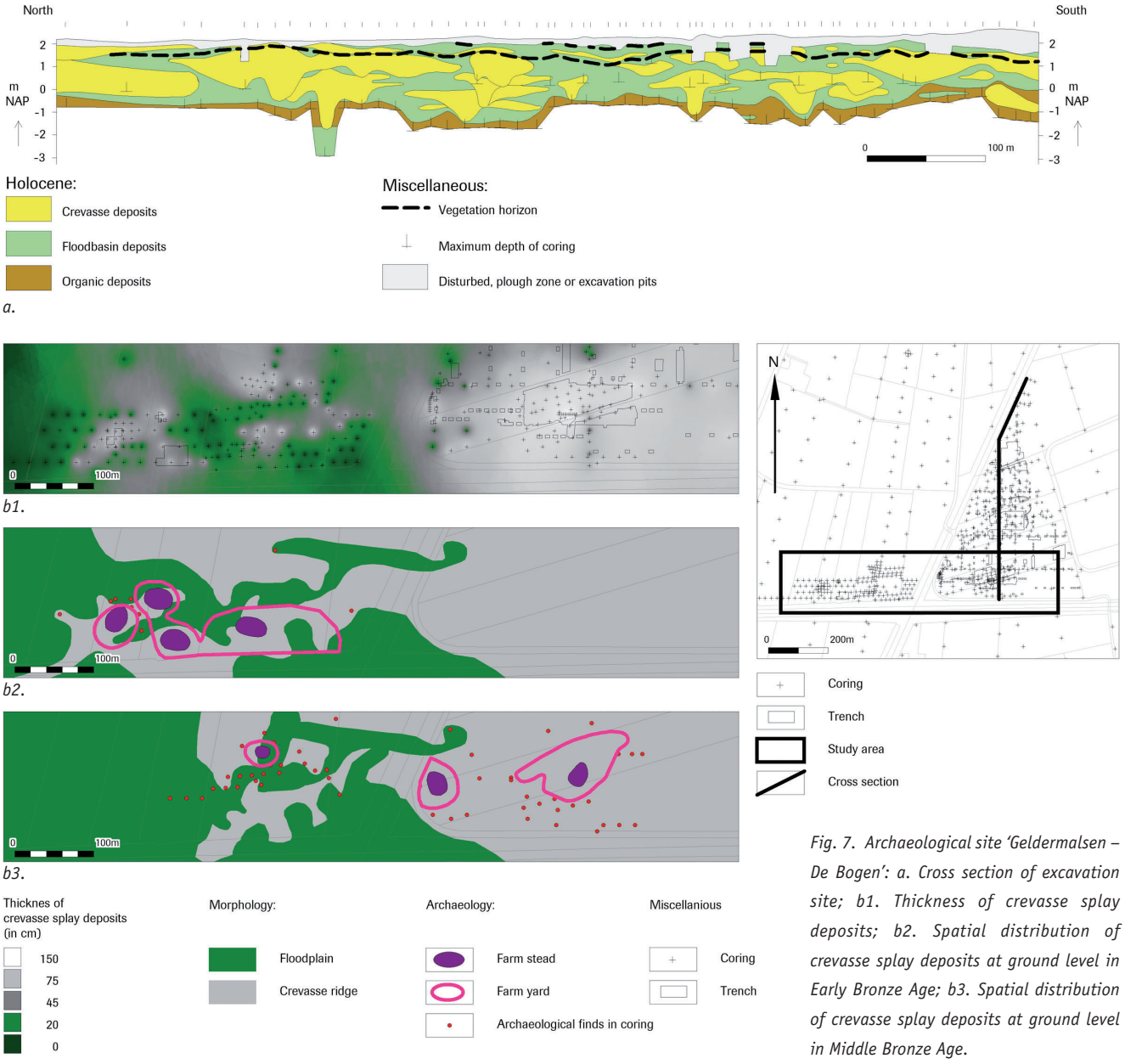

Fig. 7. Archaeological site 'Geldermalsen – De Bogen': a. Cross section of excavation site; b1. Thickness of crevasse splay deposits; b2. Spatial distribution of crevasse splay deposits at ground level in Early Bronze Age; b3. Spatial distribution of crevasse splay deposits at ground level in Middle Bronze Age.

Other archaeological excavations

Since the Betuweroute-project was undertaken, the possibility of (pre)historic habitation on crevasse splays has become widely accepted among Dutch archaeologists (e.g., Jongste 2001; Arnoldussen, 2008; Arnoldussen & Fokkens, 2008). This has resulted in an increasing number of archaeological sites that were found on crevasse splay deposits (Fig.1; a.o. Maas en Waal – De Ret (Vos, 2003), Geldermalsen – Hondsgemet (Van Renswoude & Van Kerkhoven, 2009e), Leidsche Rijn – De Balije (Vos & Blom, 2003), Tiel - Medel (Hielkema, 2003; Ufkens, 2004; Heeren, 2005), Elst – Westeraam (Prangsma, 2005), Zaltbommel – De Wildeman (Veldman & Blom, 2010), Druten – Deest aan het water (De Boer et al., 2003), Utrecht – Hoogeweide (Den Hartog, 2009), Hazerswoude – Windmolenpark (Diependaele, in prep.), Geldermalsen – De Plantage (Tops et al., 2006).

Discussion

Based on the many detailed studies of crevasse splay deposits encountered during archaeological research projects that have been carried out during the last decades, several observations can be made with regard to:

1. The development of crevasses splays during the life-time of an alluvial ridge;
2. The start and kind of exploitation by man;
3. A model for exploitation of crevasse splays during their life-time;
4. The potential of new survey techniques for improving archaeological prospection and preservation policy.

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The development of crevasses splays during the life-time of an alluvial ridge

Crevasse splay deposits can form at any stage in the history of an active alluvial ridge. However, we assume, based on observations from several areas in the Rhine-Meuse Delta, that crevasse splay complexes are mainly formed during the mature and final phase of an alluvial ridge. During the initial phase of alluvial ridge development, levees are still relatively low. Therefore, water can flow easily over the levees onto the floodplain during flood stages without creating catastrophic levee breaches. These sediments can be easily recognized as flood basin sediment with a higher $CaCO_3$ content and slightly higher silt content. These sediments are usually not consolidated and lack a vegetation horizon at the top. During the mature phase of the river, channel width and levee height are usually in equilibrium with main river discharge. Crevasse splays will only develop during exceptional, catastrophic peak discharges, and can be recognised as coarser grained sediment bodies within a clayey substratum. During the final phase, as upstream avulsion has occurred, within-channel sedimentation becomes dominant (Makaske et al., 2002). Makaske et al. (2009) conclude that in certain parts of anastomosing rivers bed aggradation may also outpace levee accretion. In both cases, even a modest increase in discharge may cause levees to collapse frequently and crevasse formation will take place extensively.

The start and kind of exploitation by man

If the presumed chronological correlation between the Homoet and Westerveld alluvial ridge is correct, the crevasse splays near Kesteren were inhabited during the final phase of activity of the alluvial ridge. As this occupation probably occurred on newly developed crevasse splays, it also implies that the crevasse splay deposits of phase 3 at this location were formed during the final phase of the alluvial ridge. During this phase, the river discharge already started to decrease and the river became under-fit.

Based on abundant ^{14}C evidence and pottery finds from the sites of Eigenblok, Tiel – Medel, Geldermalsen – Hondsgemet, Wijk bij Duurstede – De Horden and other, we think that most splays became inhabited during the latest phase of alluvial activity or after full avulsion of the alluvial ridge had taken place. However, a few exceptions are known, as for example the Hazerswoude – Windmolenpark and Malburg sites are situated at a fair distance from the formerly active river. It should be mentioned that the first site is probably characterized by repetitive seasonal use and lacks traces of permanent settlement.

The crevasse splay complexes probably gradually lost their relatively high position in the landscape due to ongoing sedimentation in the floodplain. We think that human occupation itself caused increased subsidence. For example, when inhabitants dug ditches, this caused additional drainage and thereby additional subsidence of the splay complex itself into the subsoil. This subsidence occurred probably within a human lifetime: as subsidence exponentially decreases with time, 80-90% takes place within a decade (Locher & De Bakker, 1990), so likely within human awareness.

A model for exploitation of crevasse splays during their life-time

Based on the observations mentioned above, we present a conceptual model for landscape evolution around a crevasse splay (Fig. 8). The model also shows when humans were most likely to use this evolving landscape. During the first phase, the crevasse splay complex was formed (Fig. 8a).

When the crevasse channel silted up, sedimentation on the splay ended and soil formation started in the top of the splay complex (Fig. 8b). The splay then became suitable for human occupation. During the Neolithic these locations were probably used for temporary settling, e.g. as spots for fishing or hunting. Man probably took the benefit of the rich wildlife along the natural land-water gradient and the different environments within close range. From the end of the Neolithic onwards, the crevasse splay complexes were in use for agricultural purposes as these areas were fertile, easy to plough, and offered suitable hydrological conditions. Moreover, the adjacent floodplain could be exploited easily. From there, construction wood, especially alder (*Alnus*), and reed could be retrieved and utilized. During the summer, this area was used for herding as well as for hunting and fishing. The nearby river and residual crevasse channel made the locality readily accessible.

In time, the crevasse splay complex gradually lost its relatively high position in the landscape, due to subsidence and ongoing sedimentation in the surrounding floodplain (Fig. 8c). As a result, the available arable and inhabitable area became smaller, eventually ending occupation, although the area was still suitable for pasturing or agriculture.

Finally, the crevasse deposits became completely covered with floodplain deposits (Fig. 8d). Between approximately 1200 and 1350 AD, the rivers in the Rhine-Meuse delta became embanked (Lambert, 1985; Van de Ven, 1993), which terminated the formation of new crevasse splay deposits. After embankment, differential compaction has caused many older (buried) crevasse splay deposits within the embanked areas to become visible again (Fig. 8e).

The potential of new survey techniques for improving archaeological prospection and preservation policy

Although there is increasing awareness that crevasse splay deposits may contain a wealth of well-preserved archaeological sites, consensus towards a standard for the investigation of floodplains in archaeological policy documents is still lacking.

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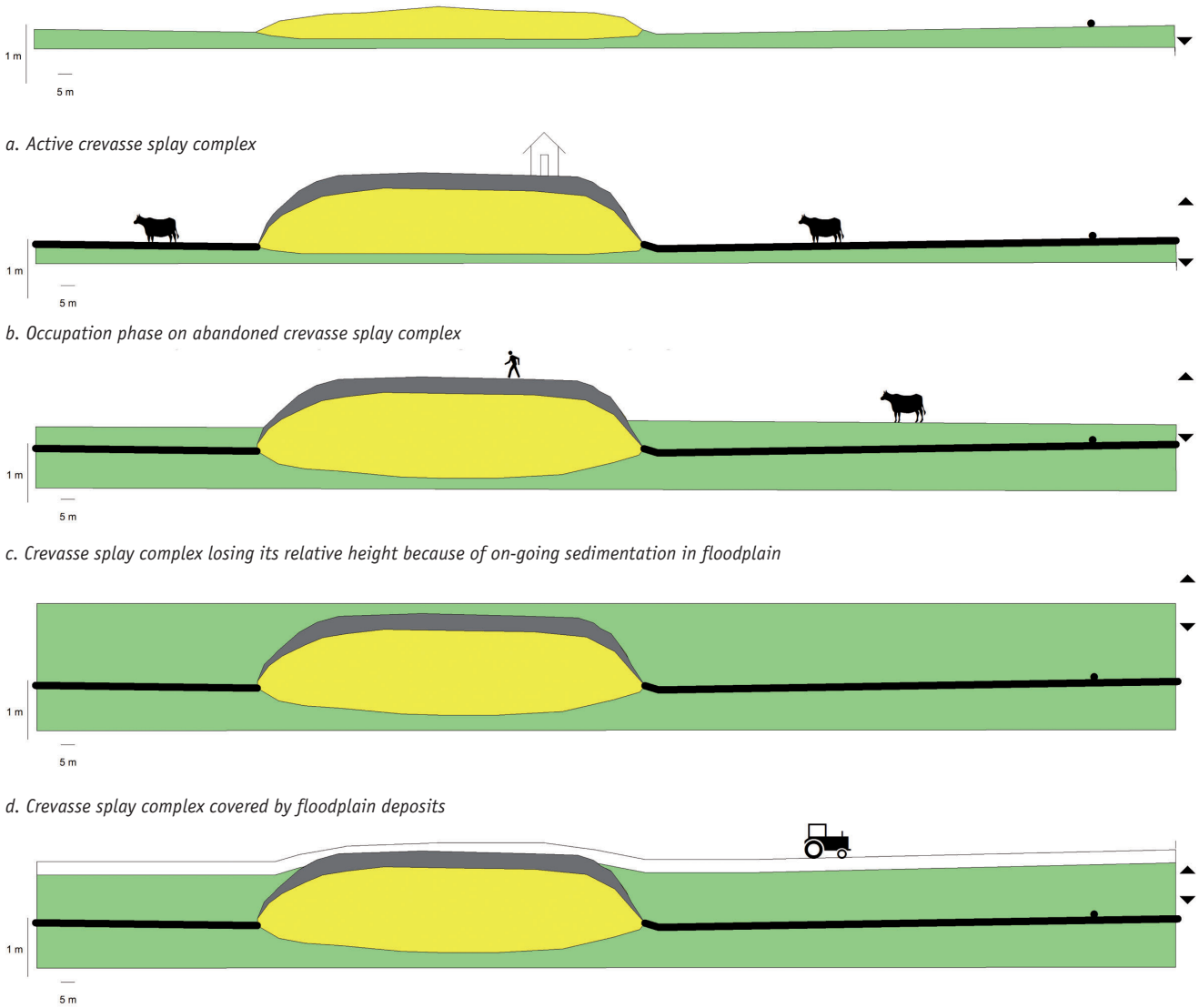

Fig. 8. Schematic evolution of the landscape around crevasse splay deposits.

In the recently published policy maps, for example the third edition of the Dutch Indicative Map of Archaeological Values and the Map for Cultural and Historical Values in the Province of Zuid-Holland (IKAW, http://archis2.archis.nl/archisii/html/), flood basins are still mentioned as areas with a low expectation value. Due to differential compaction after river embankment, many crevasse splays partly regained their relatively high positions in the alluvial landscape. Since 2004, detailed height measurements from LIDAR-based images (Laser Imaging Detection and Ranging) have become available. Combined with coring databases (www.dinoloket.nl; Berendsen, 2005) and/or available detailed soil maps (scale 1 : 25,000 or less), these turn out to be excellent tools for tracing and mapping the outlines of many crevasse splay complexes (Fig. 9; a.o. Van Zijverden & Laan, 2005; Waldus & Van der Velde, 2005; Berendsen & Volleberg, 2007). Still, these novel techniques remain totally unappreciated in archaeological prediction modelling. In archaeological policy documents, flood basins are still structurally ignored on the basis of the so-called 'wet-feet criterion', which is the idea that man avoided flood basins for exploitation because of the relatively high water level in these areas. This false idea leads to a structural under-appreciation

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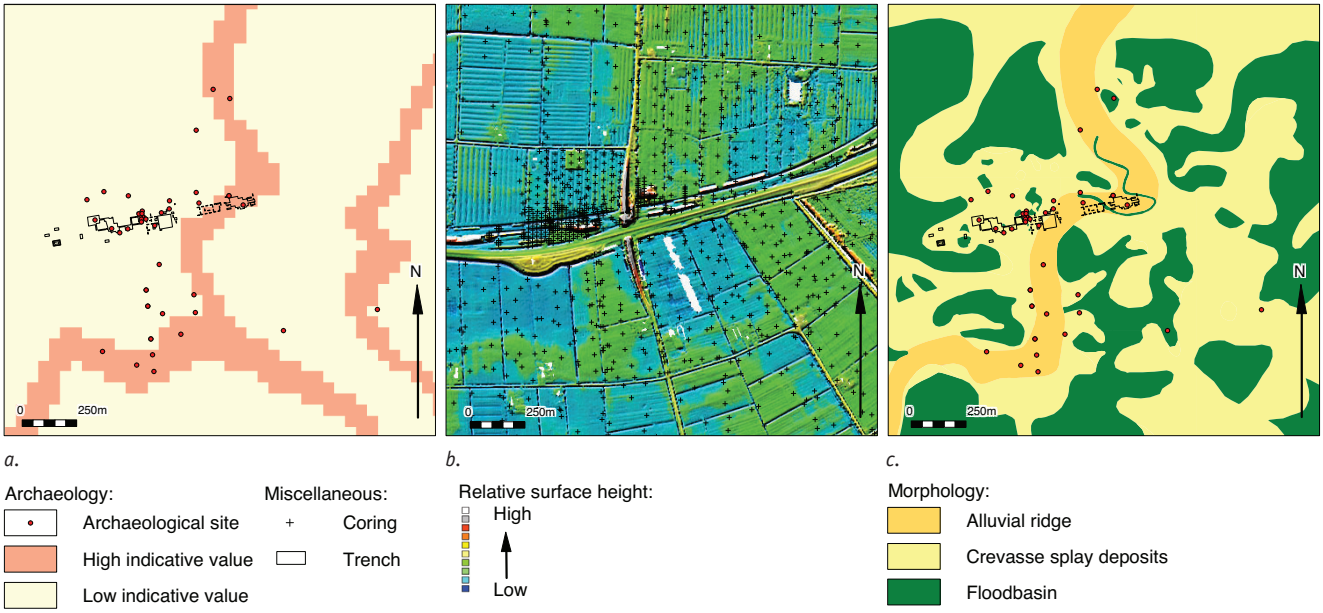

Fig. 9. Site 'Rumpt – Eigenblok'; a. Archaeological Indicative Map; b. Digital elevation model; c. Morphological map.

of flood basins for archaeological investigation, running the risk that crevasse splays deposits farther away from the alluvial ridge and their archaeological sites are missed. This attitude leads to the self-fulfilling prophecy that flood basins do not contain deposits that were suitable for human settlement and therefore lack any traces of exploitation by man.

Conclusion

Recent research in the Rhine-Meuse delta has revealed that young crevasse splay complexes were preferred locations for human settlement within flood basin areas. This implies that human occupation in the Rhine-Meuse delta was more extensive than previously thought. The splays formed relatively high and dry areas of varying sizes for settlement, some so small as to be barely large enough for one farmstead. A thickness of only 20-30 centimetres was enough to raise the complex above the surrounding floodplain and to allow for (temporary) settlement. The nearby alluvial ridge and surrounding splay complex could be used for arable farming. Furthermore, crevasse splay complexes represented important environmental gradients and were ideal for exploiting the adjacent floodplain. The nearby river and water containing residual crevasse channel, made the splay localities easy to reach. Usually habitation continued after avulsion had taken place.

Because of subsidence and ongoing sedimentation in the surrounding floodplain, crevasse splay complexes gradually lost their relatively high positions in the landscape. This process may have continued at an accelerated velocity during the period of human occupation, sometimes limiting the duration of occupation. Occupation has been shown to vary from one generation (~30 years) for small splays to over thousand years for very large splays.

The first exploitation of crevasse splay deposits can be dated to the Middle-Neolithic, 3200-2800 BC. Permanent human occupation of young crevasse splay complexes took place from at least 1400 BC (Middle Bronze Age B) and possibly since the last phase of the Late Neolithic (2450-2000 BP).

Although crevasse splay deposits are nowadays well known for their well-preserved archaeological sites, they are still unappreciated in documents for archaeological policy. Many crevasse splay deposits, and accordingly, archaeological sites on top of them, are not mapped very well or at all. During archaeological investigations in floodplains the 'wet-feet criterion' is still often used, leading to a lower research intensity or no research at all. The use of a LIDAR data combined with coring databases and/or detailed soil maps should be included in policy documents as a potential research method.

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