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Environmental development and local human impact in the Jeetzel valley (N Germany) since 10 ka BP as detected by geoarchaeological analyses in a coupled aeolian and lacustrine sediment archive at Soven

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Abstract: While archaeological records indicate an intensive Mesolithic occupation of dune areas situated along river valleys, relatively little knowledge exists about environmental interactions in the form of land-use strategies and their possible local impacts. The combination of geoarchaeological, chronological, geochemical and palaeoecological research methods and their application both on a Mesoltihic site situated on top of a dune and the adjacent palaeochannel sediments allows for a detailed reconstruction of the local environmental development around the Soven site in the Jeetzel valley (Northern Germany) since ~10.5 ka cal BP. Based on the results, we identified four phases that may be related to local human impact twice during the Mesolithic, the Neolithic and the Iron Ages and are discussed on the backdrop of the regional settlement history. Although nearby Mesolithic occupation is evident on archaeological grounds, the identification of synchronous impacts on the vegetation in the local environmental records remains tentative even in respect of the broad methodical spectrum applied. Vice versa, human impact is strongly indicated by palaeoecological and geochemical proxies during the Neolithic period, but cannot be connected to archaeological records in the area so far. A younger phase of human impact – probably consisting of seasonal livestock farming in the wetlands – is ascribed to the Iron Age economy and comprises local soil erosion, raised concentrations of phosphates and urease, and the facilitation of grazing related taxa.

Umweltveränderungen und lokaler anthropogener Einfluss in der Jeetzel-Niederung (Norddeutschland) seit 10 ka BP im Spiegel eines gekoppelten äolisch-limnischen Sedimentarchivs bei Soven

Kurzfassung: Während die archäologischen Quellen eine intensive mesolithische Besiedlung der in den Flussniederungen gelegenen Dünen anzeigen, gibt es bislang erst wenige Erkenntnisse zur Mensch-Umwelt-Interaktion in Form von Landnutzungsstrategien und ihres potentiellen Einflusses auf die Landschaft. Die Kombination geoarchäologischer, chronologischer, geochemischer und paläoökologischer Methoden und ihre Anwendung sowohl auf den Bereich der mesolithischen Fundstelle auf einer Dünenkuppe als auch die Verlandungssedimente eines benachbarten Altarmes erlaubte eine detaillierte Rekonstruktion der Landschaftsgeschichte bei Soven in der Jeetzel-Niederung (Norddeutschland) seit etwas 10,5 ka cal BP. Ausgehend von diesen Ergebnissen wurden vier Zeitphasen identifiziert, die mit lokalem menschlichen Umwelteinfluss während des Mesolithikums, des Neolithikums und der Eisenzeit in Verbindung stehen könnten und vor dem Hintergrund der Landnutzungsgeschichte diskutiert werden. Obwohl eine mesolithische Besiedlung wegen der archäologischen Befunde unzweifelhaft ist, bleibt die Identifizierung zeitgleicher Umweltbeeinflussungen in den Landschaftsarchiven trotz des breiten Methodenspektrums hypothetisch. Im Gegensatz dazu legen die paläoökologischen und geochemischen Indikatoren einen menschlichen Umwelteinfluss für die neolithische Epoche nahe, doch fehlen nun die archäologischen Funde für diesen Zeitraum im näheren Umfeld. Eine jüngere Phase menschlicher Umweltveränderung – wahrscheinlich in Form saisonaler Weidewirtschaft in der Niederung – wird der Eisenzeit zugeschrieben und umfasst Bodenerosion, erhöhte Phosphat- und Ureasekonzentrationen und die Ausbreitung von Weidezeigern.

Keywords: *Iron Age, Neolithisation, Mesolithic, OSL, human impact, aeolian sands, pollen, charcoal*

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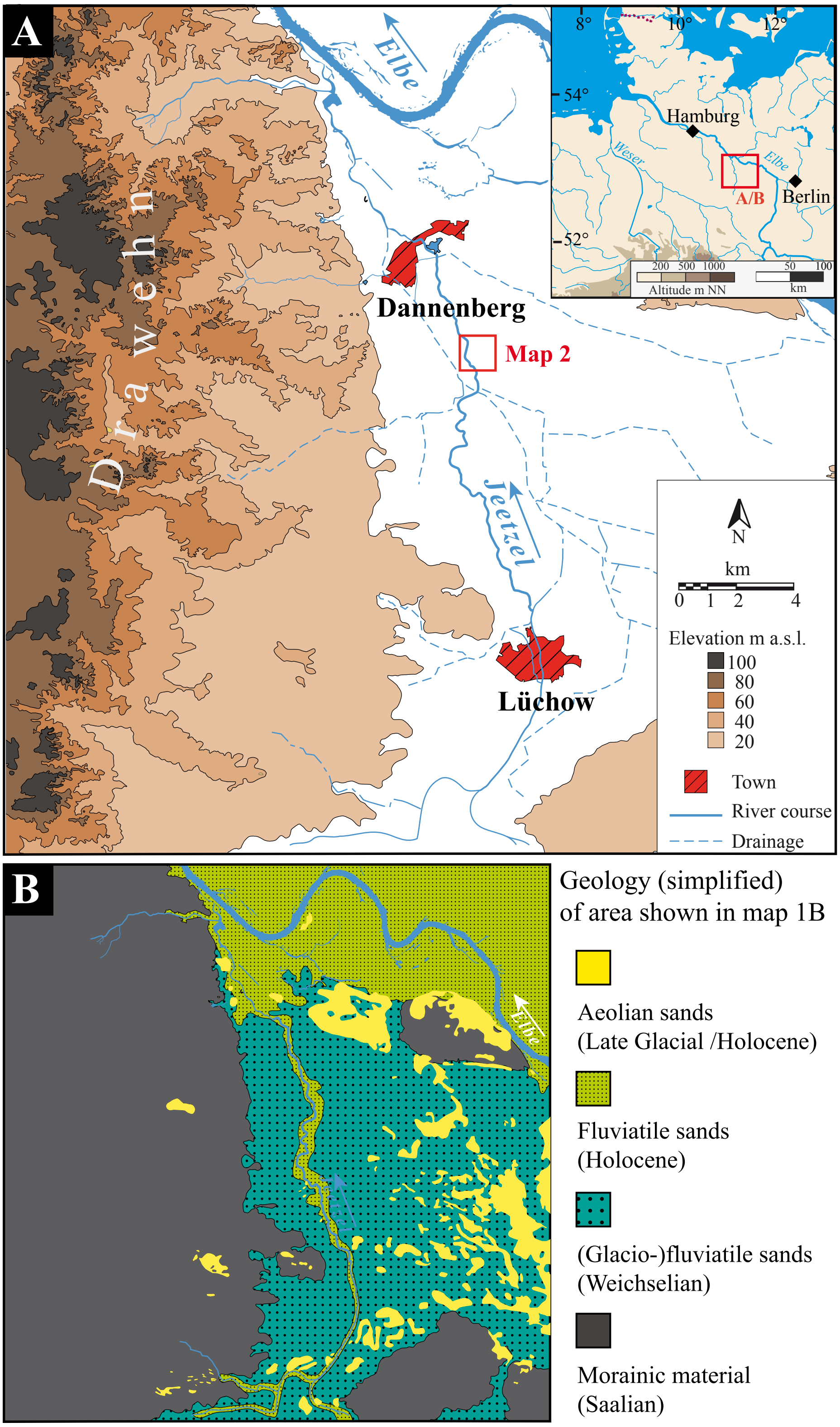

Fig. 1: A – Location of the Soven site within the North European Plain and the Jeetzel valley; B – Simplified geological map of the area of the Jeetzel valley.

Abb. 1: A – Lage der Fundstelle Soven innerhalb der Norddeutschen Tiefebene und der Jeetzel-Niederung; B – Vereinfachte geologische Übersichtskarte der Jeetzel-Niederung.

1 Introduction

One crucial aspect of understanding prehistoric economical systems is their ability to spread into marginal areas and to adapt to different resources and inhabitated areas on a locale scale. Situated in central Northern Germany, the area of the Jeetzel valley is such a marginal area characterised by extensive low-lying wetlands and isolated dune ridges providing potential areas for past human occupation. Intensive archaeological investigations during the last decades have provided evidence for phases of human presence in these wetlands and especially on dunes since the Late Palaeolithic, but a reconstruction of local human impact has been assumed to be difficult due to the rarity of large peat bog areas providing a continuous sedimentation sequence for environmental reconstruction. With respect to the small-scaled and potentially ephemeral nature of land-use in this area, traditional attempts to use larger lakes in the adjacent areas for palynological studies (e.g. Christiansen 2008, Beug 2011, Jahns et al. 2013) are only of partial use for the detection of small-scale human activity. They are too remote and local minor environmental disturbances are difficult to detect in such records that comprise regional signals from a wider area (e.g. Sugita 1994). Therefore, extensive pollen counts and high resolution analysis in these distant records cannot replace the desideratum for more local archives.

Given the good results from palaeochannel sediments as local geo-bio-archives (Turner et al. 2013) and the relocation of aeolian sediments as sensitive indicator for soil erosion induced by land-use (Tolksdorf et al. 2013a), a combination of both archives is a promising strategy to investigate the land-use history in the Jeetzel valley. The reconstruction of land-use history will subsequently be compared to the local archaeological evidence to test if it is mirrored by the environmental proxies.

2 Geology and topography

The study site is located near Soven in the Jeetzel valley (northern Germany). The wider area is characterised by (glacio-)fluviatile sands deposited during the Weichselian period in the Elbe glacial valley. Moraines ascribed to different phases of the Saalian complex are forming a steep slope delimiting the Jeetzel valley to the west (Drawehn) as well as isolated ridges (Höhbeck, Langendorfer Geest, Öring, Lemgow) in the Elbe valley (Meyer 2000). Late Glacial climate dynamics were related to high fluviatile acitivity with change from a braided to meandering river regime in the Jeetzel valley. During changes from a relatively dry to humid climate, new river courses formed during the mid-Younger Dryas and the Preboreal-Boreal transition. Large parts of the abandoned, old channel systems remained as palaeochannel lakes and were filled by lacustrine and telmatic sediments consecutively (Turner et al. 2013). Dunes and aeolian cover sands have been deposited along the Jeetzel river and in the eastern part of the area (Gartower Tannen) during the Pleniglacial and Late Glacial; they were partly remobilised by human activity during the Holocene period (Tolksdorf et al. 2013a). That these dunes, especially the dune near Soven studied here (Fig. 1), provided a favourable area for prehistoric human activities within the surrounding wetlands is corroborated by a considerable number of Mesolithic artefacts and charred organics (wood, shells of hazelnut) that were exposed and collected from several outcrops resulting from sand mining activities and road construction in the last two decades. Regarding the prevalence of simple microlithic points and scalene triangles within the artefact assemblage, the occupation of the dune near Soven was preliminarily dated to the Early to Mid-Mesolithic period from approx. 10500 to 9000 cal BP (Breest 1997a, Brodowski 1998). Younger artefacts have not been detected in the direct vicinity so far. Based on historical maps from the late 18th century the surrounding areas must have been under agricultural use at least since that time (Fig. 2A).

A reassessment of the site in 2009–2011 with a topographic survey using DGPS measurements, aerial photographs and sediment cores revealed a series of palaeochannels in the immediate vicinity of the dune. To estimate the stratigraphical order of the channel generations, samples were taken from the basal lacustrine sediments of the channel fills for palynological investigations. The species composition was compared to records from the Jeetzel valley (Lesemann 1969, Christiansen 2008, Turner 2012, Turner et al. 2013, Tolksdorf et al. 2013b) to estimate their biostratigraphical position. Based on these results, a palaeochannel with the onset of lacustrine sedimentation in the early Holocene was identified at the outskirts of the dune as potential archive for the reconstruction of the local vegetation development during the Holocene (Fig. 2B). Three profiles were sampled in a straight line from the top of the dune

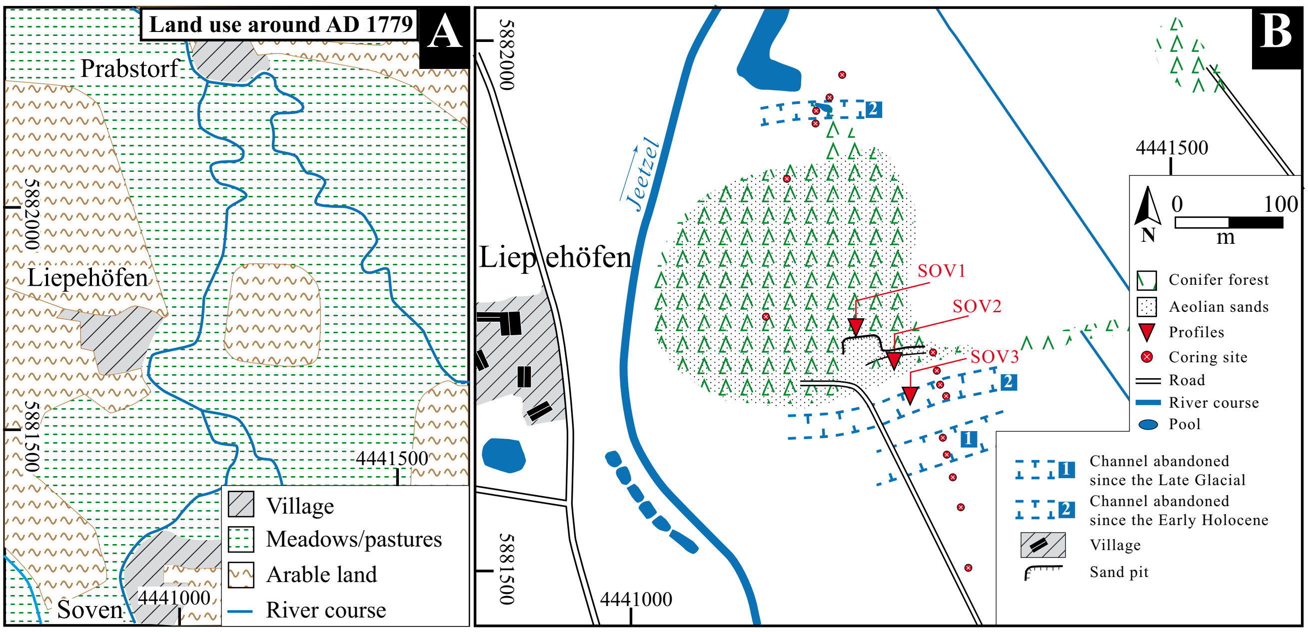

Fig. 2: A – Historical land-use based on a map from 1779 (Kurhannoversche Landesaufnahme); B – Site topography with analysed profiles SOV1–SOV3 and generations of river palaeochannels as derived from aerial photos and palynostratigraphically analysed sediment cores.

Abb. 2: A – Historische Landnutzung des Gebietes auf Grundlage einer Karte von 1779 (Kurhannoversche Landesaufnahme); B – Topographie der Fundstelle mit den analysierten Profilen SOV1–3 und den anhand von Luftbildern und palynostratigraphisch korrelierten Bohrungen rekonstruierten Altarmgenerationen.

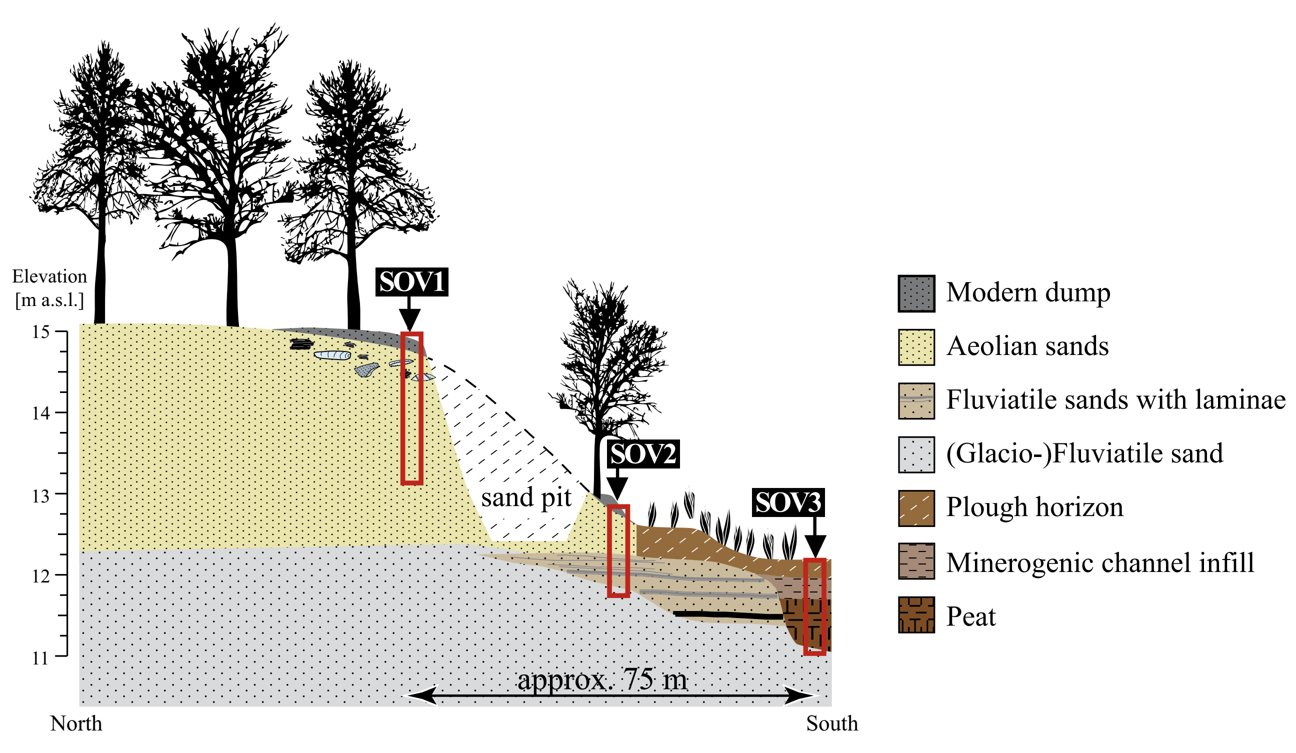

Fig. 3: Schematic transect presenting the sedimentary sequence from the dune ridge to the channel with the location of the profiles SOV1, SOV2 and the coring SOV3.

Abb. 3: Schematischer Transekt mit Sedimentabfolge von der Dünenkuppe bis zum Altarm mit Lage der Profile SOV1, SOV2 und Kern SOV3.

to the centre of the palaeochannel for archaeological, sedimentological and palaeobotanical analyses (Figs. 2 and 3).

3 Methods

3.1 Sampling strategy

The dune ridge with a maximum elevation of 15 m a.s.l. rises for about three metres above the valley floor and represents the most prominent topographic feature in the area (Figs. 1 and 2). Profile SOV1 is located where Mesolithic artefacts and charcoals were exposed in a small sand pit. Three luminescence samples (SOV1-1 to SOV1-3) were collected to study the sedimentation age of the aeolian sands. For radiocarbon dating (^{14}C) and anthracological studies, two charcoal samples were extracted by dry sieving at two different places from the rim of the sand pit in 2009 and 2011; one sample was taken for palynological analysis from the same depth as the archaeological artefacts. The profile SOV2 was recovered at the southern base of the dune at the transition from the valley floor to the palaeochannel; it aimed at detecting potential sediment relocations in this area by sedimentological and palaeobotanical criteria, as well as OSL age estimates (luminescence samples SOV2-1 and SOV2-2). The core SOV3 was taken from the deepest part of this structure at the closest distance to the dune profiles for palynological and sedimentological studies of the palaeochannel sediments (Figs. 2B and 3).

3.2 Radiocarbon ^{14}C-dating

While one AMS-^{14}C age estimate was obtained from charcoals of the Mesolithic layer in SOV1, three AMS-^{14}C samples were dated from SOV3 in order to develop an age-depth model of sedimentation for the early to mid-Holocene. The lowest sample is charcoal from *Pinus*,- but since the charcoal content was too low in the upper part, uncharred macro-remains were selected for the uppermost ^{14}C sample (cf. Table 1). The ages were calibrated with Calib 6.0 (Stuiver & Reimers 1993) and the IntCal09 database (Reimer et al. 2009). To derive age information for the lower part of the SOV3-sequence, a Bayesian time-depth model was calculated using OxCal 4.2 (Bronk Ramsey 2009) and a p-sequence model (Bronk Ramsey 2008). Due to the low number of dates, the results are considered as rough age estimates only.

3.3 Optically stimulated luminescence (OSL) dating

The last exposition of the sediments to sunlight (~ time of deposition) was determined on samples from the profiles SOV1 and SOV2 using OSL to reconstruct the history of local sediment relocation. After the extraction of samples with opaque tubes in the field, the further processing was performed in the laboratory under subdued red light. Subsequently to the extraction of the grain size fraction 175 ± 25 µm, organic matter, clay and carbonates were eliminated by treatment with H_2O_2, $Na_2C_2O_4$ and HCl, respectively. Then the quartz grains were separated using density fractioning, and the remaining material was etched with HF (45%) for 45 min and mounted on stainless steal discs. The measurements were carried out with a Risø TL-DA 15 reader (blue light diode stimulation 470 ± 30 nm; Hoya U340 filter). After the selection of a suitable pre-heat temperature by a pre-heat test, the palaeodose of the samples

(D_E) was determined applying the SAR-protocol (Murray & Wintle 2000) on a minimum of 30 subsamples. For age calculation both the central age model (CAM) and the minimum age model (MAM) were applied (Tab. 2; Galbraith et al. 1999). To assure that all doses were below the saturation level and experimentally reproducible, a dose recovery test was performed. To calculate the dose rate (D_0) within the sediment, the contents of U, Th and K were determined by Becquerel Laboratories (Canada) using neutron-activation-analysis. Based on these data the individual ages were calculated with ADELE (Kulig 2005) assuming a constant water content of 7% within the sediments as for other sites in the area (Tolksdorf et al. 2013a).

3.4 Archaeological age estimation and charcoal spectra from the occupation layer

A chronological assessment of the Mesolithic occupation period was based on a statistical fitting of the microlithic assemblage into the seriation of the microlithic assemblages from the micro-stratified Friesack site (northern Germany; Gehlen 2009) by B. Gehlen (University of Cologne). The statistical tool of seriation is used in archaeology to obtain chronological information about the relative age of assemblages based on the presence, absence and proportion of artefact types. A main drawback is the still small number of well dated Mesolithic sites with short-timed settlement or separated layers of occupation. Moreover the tasks performed at a distinct site or local cultural trends may additionally have influenced the occurrence of tool types within an assemblage. Thus, the results of this analysis should be seen as statistical age estimates only and need cross-check by ^{14}C dates (see above).

Charcoal specimens from the two separate samples collected in 2009 and 2011 from the artefact layers were used for anthracological analyses (Tab. 3). Assuming that they derive from anthropogenic burning, they can provide information about the use of the local vegetation. Taxonomical identification was performed by a stereo microscope (Nikon SMZ1500, magnifications of 7.5x–112.5x) and an incident reflected light microscope (Nikon ME600) at magnifications of 100x, 200x and 500x. Anatomy was observed on freshly broken surfaces in cross sections as well as radial and tangential orientation, according to Schweingruber (1990a, b). Determinations were additionally checked with the reference collection of the Palaeoecology Working Group, Institute for Ecosystem Research, University of Kiel.

3.5 Loss-on-ignition (LOI) and grain size

With respect to the environmental setting, the proportion and size of minerogenic material, both in the profiles with aeolian material (SOV1 and 2) and palaeochannel sediments (SOV3), were analysed to detect sediment relocation by aeolian transport or soil erosion into the channel system. In a first step the proportion of organic to minerogenic material was determined by combustion of the former at 550 °C for 2h. The LOI value is given as weight percentage in dry mass. Subsequently, the residues presenting the minerogenic share were used to measure the grain size distribution by laser diffraction (Fritsch Analysette 22).

3.6 Carbonate and phosphate

Changes of carbonate content in the sediments often correlate with the biogenic production of carbonates within the water body; they may thereby be sensitive to major climate fluctuations (Kaiser 2004). The carbonate content was measured throughout the core SOV3 using the Scheibler method. This is based on the volumetric measurement of CO_2 from the conversion of $CaCO_3$ by HCl. Phosphate was determined by photometric analysis of the reaction with ammonium molybdate (Philips PU8620 Spectralphotometer) as described by Rump (2000). It is generally assumed that the vertical mobility of phosphates within sediments in very limited. Therefore they can be used as an indicator for the input rate of decayed organic matter and faeces, and thereby as proxy of changing human economy and settlement phases (Selig et al. 2007).

3.7 Urease analysis

In order to detect the presence of humans, animals or livestock grazing in the area, the content of urease was determined on the samples from SOV3. Urease is an enzyme which is secreted by microorganisms to degrade urea deriving from excrements. It catalyses urea into carbon dioxide (CO_2) and ammonia (NH_3), and is thereby an even more specific proxy for the influx of faeces than phosphates that trace a wider range of decomposition processes. The amount of urease within the soil is proportional to the initial amount of degradable urea and concentration remains on this level, when urea has been depleted within the soil and the reaction has come to an end. The analysis was conducted using the method developed by Borisov (Borisov et al. 2013), which is especially useful to process a larger quantity of samples and to gain relative values (Chernysheva et al. 2014; 2015). All samples were incubated with urea as substrate at 37 °C together with a phenol red solution ($C_{19}H_{14}O_5S$). The intensity of colour change in the range from yellow to dark red is dependant on the NH_3 concentration that itself is an indirect measure of the urease concentration at the start of the reaction; the content of NH_3 in µg per g dry soil can be calculated based on the parallel calibration samples with defined amounts of NH_3.

3.8 Palynology

For palynological analysis a bulk sample was taken from the layer with artefact scatter in SOV1, six samples were taken from organic layers in SOV2, and the core SOV3 was sampled at 2cm intervals. All samples were prepared applying the standard acetolyse method (Berglund & Ralska-Jasiewiczowa 1986) and counted to a total sum of at least 500 arboreal pollen grains. Pollen and spore identification and taxonomy follow Moore et al. (1991) and Beug (2004). Pollen percentages and charcoal particles were calculated in relation to the total pollen sum, excluding pollen of aquatic plants and spores. For numerical analysis of the pollen record from SOV3, percentages were square root transformed. Zonation was based on a constrained cluster analysis (CONISS, Grimm 1987) using the R-packages rioja (Juggins 2012) and vegan (Oksanen et al. 2012). The Bray-

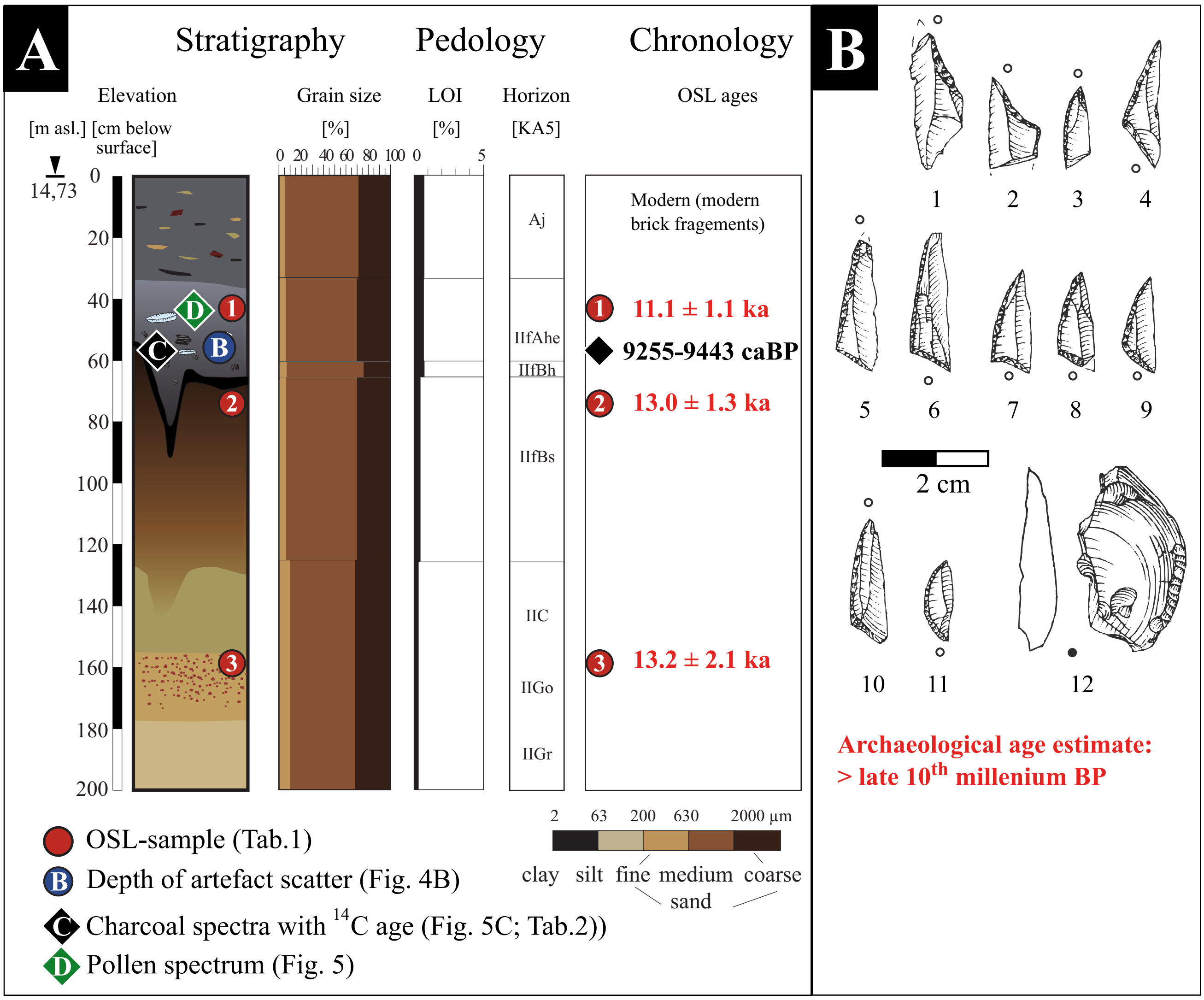

Fig. 4: A – Profile SOV1 with OSL and ¹⁴C ages; B – Artefacts from the Soven site (selection, drawing by K. Breest 1997a), and archaeological age estimate: 1–3: microlithic points, 4–10: triangles, 11: segment, 12: scraper

Abb. 4: A – Profil SOV1 mit OSL und ¹⁴C Alterseinschätzungen; B – Archäologische Funde (Auswahl, Zeichnung K. Breest 1997) mit archäologischer Alterseinschätzung: 1–3: einfache Spitzen, 4–10: Dreiecke, 11: Segment, 12: Kratzer.

Curtis dissimilarity index was used to quantify the compositional differences between sites (Bray & Curtis 1957). The number of significant zones was determined using the broken-stick model (Bennett 1996). After a detrended correspondence analysis (detrending by segments, non-linear rescaling, downweighting of rare taxa), which revealed rather short gradients (Ter Braak & Prentice 1988), principal component analysis (PCA) was conducted on the correlation matrix to identify the main gradients in the pollen assemblage data (Ter Braak 1983). The approximate statistical significance of the ordination axes was determined by comparison with the broken-stick model (Legendre & Legendre 2012). Numerical analysis was performed on the full pollen record SOV3 and a reduced dataset, which contained only the samples from the early to mid-Holocene period (55–103 cm depth, mainly comprising the Atlantic period) to identify the minor changes in local vegetation during this period.

4 Results

4.1 Archaeology

Charcoal from the artefact bearing sediment layer in SOV1 (Fig. 4A; 45–60 cm depth) revealed a ^{14}C age of 9443–9255 cal BP. Further archaeological age assumption can be made by comparing the artefact assemblage to other sites by means of present artefact types. As especially microlithic points have been established to be chronologically sensitive types of tools, the presence of simple points together with a considerable number of non-isoscalene triangular points at Soven generally indicates the Boreal time period (Fig. 4B). Including the Soven assemblage into seriated Mesolithic sequences from northern Germany indicated an age span of 9200–9000 cal BP or slightly older (B. Gehlen, pers. comm.). Although we are aware that these results remain highly tentative due to a single ^{14}C-age estimate, the presumed connection between charcoal deposition and human

Tab. 1: OSL-dating results. All measurements were performed in the Marburg Luminescence Lab (MLL).

Tab. 1: Ergebnisse der OSL-Datierungen. Alle Messungen wurden am Marburger Lumineszenzlabor (MLL) durchgeführt.

Profile	Lab.No.	Depth	H_2O^1	U	Th	K	Over-dispersion	E_D^2	D_0^3	Age Model[4]	Age
		[cm]	[%]	[ppm]	[ppm]	[ppm]	σ %	[Gy]	[Gy/1000a]		[ka]
SOV1-1	MR-795	40	4.7	0.20 ± 0.03	0.70 ± 0.04	0.44 ± 0.02	12	7.60 ± 0.41	0.68 ± 0.07	CAM	11.13 ± 1.13
SOV1-2	MR-796	65	5.3	0.25 ± 0.05	0.90 ± 0.05	0.56 ± 0.02	15	9.96 ± 0.55	0.77 ± 0.08	CAM	12.98 ± 1.28
SOV1-3	MR-797	180	8.4	0.36 ± 0.06	1.50 ± 0.07	0.68 ± 0.03	18	11.18 ± 1.49	0.84 ± 0.13	CAM	13.16 ± 2.06
SOV2-1	MR-836	25	5.9	0.33 ± 0.04	0.90 ± 0.04	0.43 ± 0.02				CAM	2.05 ± 0.288
SOV2-2	MR-837	65	6.3	0.20 ± 0.03	1.00 ± 0.05	0.67 ± 0.03	13	9.86 [-0.52 +0.53]	0.84 ± 0.08	MAM	11.78 [-1.13 + 1.14]

[1] for age calculation a continuous water content of 7±3% was used; [2] equivalent dose; [3] dose rate; [4] CAM = Central Age Model, MAM = Minimum Age Model

occupation plus the lack of systematically excavated areas, these results indicate human presence during the second half of the 10th millennium BP. Younger artefacts were not present in the immediate surroundings of the study area.

4.2 Profile SOV1

The sediments recorded in profile SOV1 consist of aeolian sands which were deposited since Late Glacial times as indicated by OSL ages of 13.16 ± 2.1 ka (MR-797) and 12.98 ± 1.3 ka (MR-796) (Fig. 4A; Tab. 1). Regarding the standard deviation, the uppermost OSL age of 11.13 ± 1.1 ka (MR-795) from the Ae-horizon either indicates aeolian sedimentation during the Younger Dryas or ongoing aeolian activity during the Early Holocene. The artefacts and charcoals became embedded in these sediments; they were probably partly relocated downwards by bioturbation. The two charcoal samples from the fAhe-horizon present two very different spectra. While the small spectrum sampled in 2009 is dominated by *Pinus*, the larger spectrum analysed in 2011 predominantly consists of *Quercus* (Fig. 5A). Minor components in both sample sets are *Corylus* and Maloide-

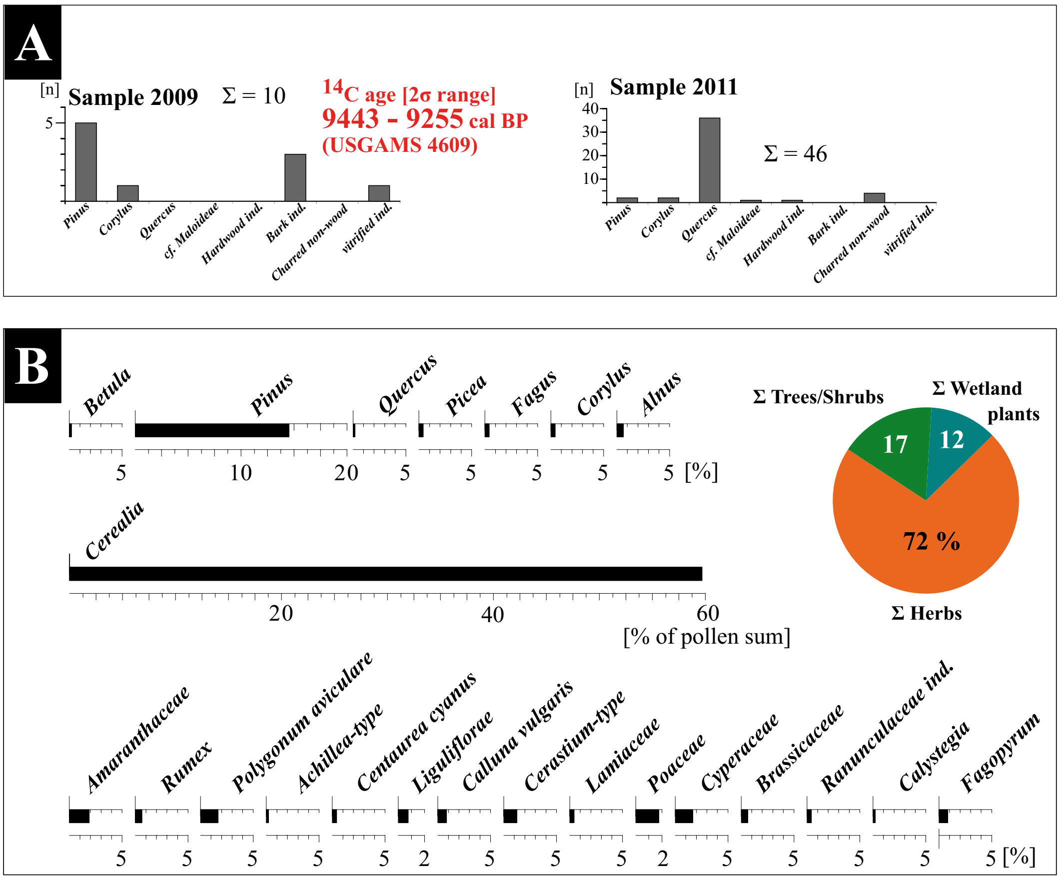

Fig. 5: A – Anthracological spectra analysed 2009 and 2011 with ¹⁴C-dating result obtained from spectrum 2009; B – Palynological spectrum from Ae-horizon in SOV1

Abb. 5: A – Anthrakologische Spektren, die 2009 und 2011 separat geborgen und analysiert wurden, zusammen mit einem ¹⁴C-Alter des Spektrums aus 2009. B – Palynologisches Spektrum des Ae-Horizontes in Profil SOV1.

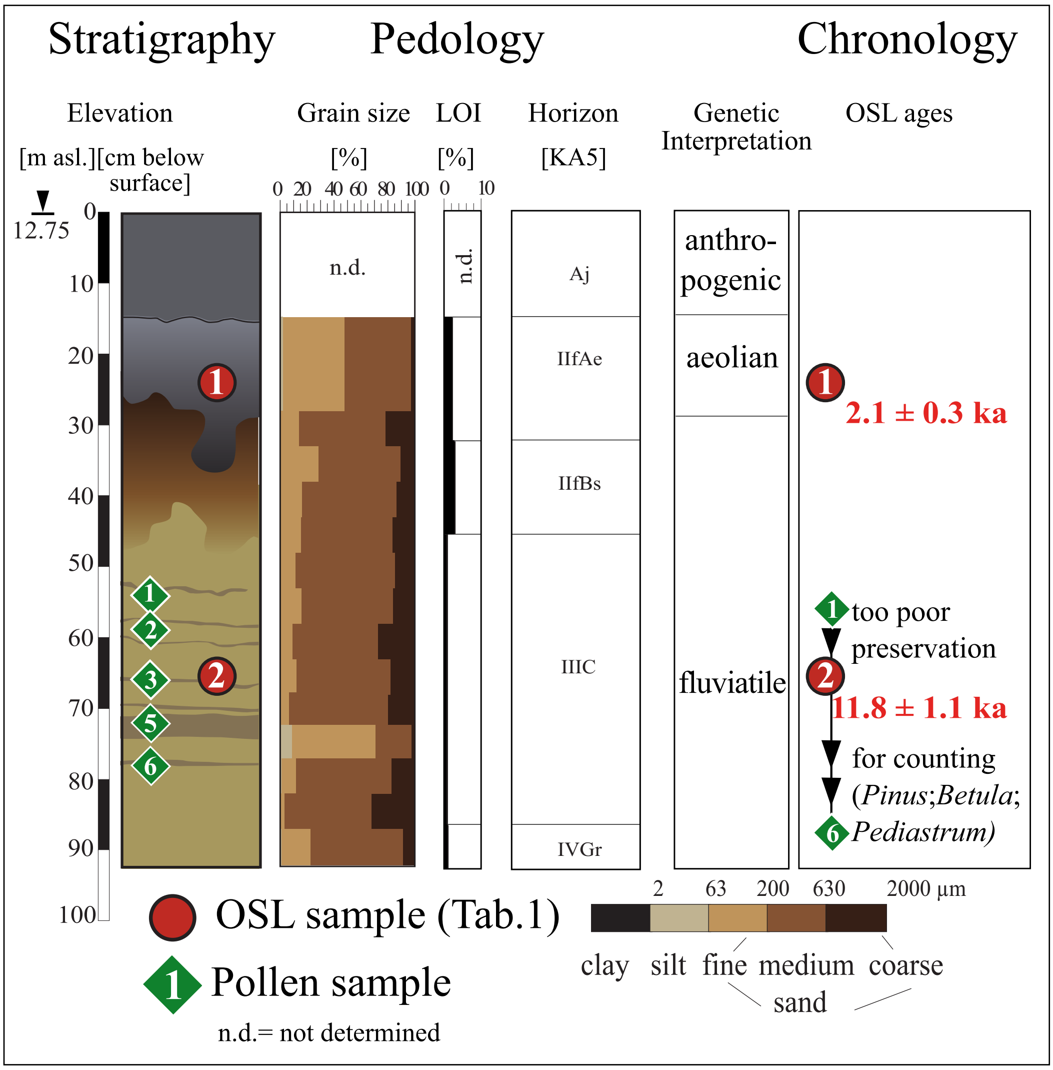

Fig. 6: Profile SOV2 with OSL ages and location of palynological samples

Abb. 6: Profil SOV2 mit Ergebnissen der OSL-Analyse und Position der palynologischen Proben.

ae. Possible explanations of the differences are (i) different ages of the sample sets; (ii) resulting from two different features, e.g. two hearths with different fuel or food preparation; (iii) the result of local *in situ* disintegration of bigger fragments. The absence of taxa like *Fagus sylvatica* or *Carpinus* occurring in this area from the Subboreal period onwards (Christiansen 2008; Turner 2012) and the ^{14}C-age of 9443–9255 cal BP (UGAMS-4609) provide further evidence that the occupation and/or fire activity is not younger than the Atlantic period, ending around 5800 cal BP in this area (Dörfler et al. 2012).

The pollen sampled from the upper fAhe-horizon (Fig. 5B) was sufficiently preserved for analysis. It presents a local spectrum dominated by *Cerealia*-type pollen and weeds typical for agricultural landscapes (Amaranthaceae, *Rumex*, *Polygonum aviculare*). Pollen grains of *Fagoyprum* and *Centaurea cyanus* suggest a late Medieval age at the earliest (Behre 2008, Beug 2011). It cannot be decided, if this indicates a younger age in the upper fAhe-horizon or if it is an effect caused by in-sediment dislocation of pollen grains and small-scale bioturbation.

4.3 Results from profile SOV2

The lower part of profile SOV2 is made up of fluviatile sands with thin intercalated layers of more organic sands (Fig. 6). While the pollen preservation in the latter was too poor for counting, the presence of *Pediastrum* algae in the sediments confirms their fluvio-lacustrine origin (Turner et al. 2014). An OSL age of 11.78 ± 1.1 ka (MR-837) indicates an accumulation during the Younger Dryas or Early Holocene period. The uppermost part of SOV2 consists of aeolian sand clearly visible in the more fine-grained composition with podzolisation. Based on an OSL-age of 2.05 ± 0.3 ka (MR-836) the deposition of the aeolian sediments occurred during the Iron Age.

4.4 Results from profile SOV3

Above the fluviatile sand, the palaeochannel sequence SOV3 consists of sediments with varying organic content that is of lacustrine origin, as shown by the occurrence of *Pediastrum* algae plus pollen grains and macrofossils of aquatic plants like *Nymphaea alba*, *Nuphar pumila*, *Myriophyllum verticillatum*, *Potamogeton* spec., *Oenanthe aquatica* and *Hottonia palustris*. Three radiocarbon dates from the lower part of the sequence yielded ages of 10220–10405 cal BP (KIA-48658; 92–94 cm depth), 9604–10116 cal BP (KIA-48657; 78–80 cm depth), and 9011–7158 cal BP (KIA-48656; 60–64 cm depth) (Tab. 2). Due to the absence of other terrestrial organic material, the radiocarbon analyses were conducted on charcoal (KIA-48657 and KIA-48658),

Tab. 2: ^{14}C-dating results.

Tab. 2: Ergebnisse der ^{14}C-Datierungen.

Profile	Lab.No.[1]	Material and archaeological context	^{14}C	^{14}C (calibrated[2]; 1σ)	^{14}C (calibrated[2]; 2σ)	δ ^{13}C
			[BP]	[cal BP]	[cal BP]	[‰ PDB]
SOV1	UGAMS-4609	Charcoal from artefact scatter	8320 ± 30	9298–9333 9338–9405	9255- 9443	-23.6
SOV3	KIA-48656	Botanical macroremains in channel sediment (60–64 cm depth) [*Scirpus lacustris* fruit (2x), *Betula* fr. (2x), *Poaceae* fr., cf. *Phalaris arundinacea* (5x), *Potamogeton* fr. (1x), *Nymphaea* fr. (1x), *Carex* fr. (1x), *Lycopus europaeus* fr. (1x), indet. fr. (3x), *Juncus* seed (1x), bud scale (1x), charcoal, (1x)]	6125 ± 35	6944–7025 7059-7065 7116–7154	6911-6921 6928-7158	-26.9
SOV3	KIA-48657	Charcoal (*Pinus*) in channel sediment (78–80 cm depth)	8780 ± 40	9703–9725 9726–9830 9833–9833 9840–9888	9604–9924 10070–10116	-25.2
SOV3	KIA-48658	Charcoal (*Pinus*) in channel sediment (92–94 cm depth)	9125 ± 40	10228–10296 10358–10369	10220–10405	-25.9

[1] UGAMS = Center for Applied Isotope Studies, University of Georgia (USA), KIA = Leibniz-Laboratory for Radiometric Dating and Isotope Research Kiel

[2] IntCal09; Calib6.0

and on a collection of terrestrial and a few aquatic plant macrofossils (KIA-48656) to avoid potential contamination by modern roots (Tab. 1). Thus, the dates represent maximum ages due to a possible relocation of charcoal from the dune, while effects like different isotope fractionation seem unlikely based on the δ^{13}C values. The age-depth model indicates that lacustrine sedimentation in the channel started shortly before 10.5 ka cal BP (Fig. 7), which is in good accordance with the biostratigraphical attribution to the late Preboreal / early Boreal period (Fig. 8). In addition, the Atlantic / Subboreal boundary marked by the Elm decline (~52 cm) is dated to 5.6–6.0 ka cal BP and matches accurately dated sequences from Northwestern Germany (Dörfler et al. 2012) and compilations form Northwestern Europe (Parker et al. 2002).

Using CONISS and the broken stick model, the pollen record was split into four significant zones (Fig. 8). The description of grain size composition and geochemistry (phosphate, urease, LOI, carbonate) follows this zonation, since major changes in these records correspond with the palynological zone boundaries.

Zone A (109–101 cm depth) is characterised by the change from fluviatile to lacustrine sedimentation, marked by fining up deposits and increasing LOI. While the percentages of *Betula* and Cyperaceae pollen decrease from maximum values, *Pinus* pollen shows a corresponding increase.

The boundary to zone B (101–50 cm depth) is marked by an increase in pollen of *Quercus* and - on a slightly higher level - *Alnus* and *Ulmus*. This zone presents the maximum values of *Ulmus* and *Corylus* pollen, while *Pinus* remains the dominating taxon. Clay and silt dominate the grain size spectrum, while LOI and carbonate values vary on a comparably high level with distinct maxima in the upper part of the zone (Fig. 8).

The transition to zone C (50–29 cm depth) is palynologically marked by a strong decrease in pollen of *Ulmus* and *Corylus*. Zone C is characterised by an increase in light-demanding wetland and grassland taxa, especially *Polygonum periscaria*-type and to a lesser extent *Aster*-type, *Plantago lanceolata* and Liguliflorae plus some peaks in charcoal particles, phosphate concentration and sand input (Fig. 8).

The uppermost zone D shows decreasing percentages of the sum of tree pollen, mainly driven by a decrease of *Pinus*, the continuous presence of *Fagus* and *Juniperus*, and maximal values of Poaceae, Liguliflorae, *Calluna* and Cerealia (mainly *Secale*) plus other anthropogenic indicators. High phosphate concentrations correspond to strong sand input into the channel (Fig. 8).

Principal component analysis (PCA) was used to explore the samples with a broad range of variables (pollen counts) for environmental trends. As this statistical tool is based on the stepwise reduction of dimensions within the dataset, the optimal number of axes to explain most of the total variances was determined by the broken stick model. It resulted in three significant axes, with 36.3 %, 26.8 % and 13.2 % of the total variance explained. The PCA biplot confirms the zonation results, as samples of different zones are clearly separated (Fig. 9A). Beyond the ordination, results of the palynological dataset mainly represent changes in tree pollen composition that are relatively difficult to explain in terms of local environmental gradients and disturbances.

In addition to the main palynological zones A-D presented above, four relatively short-time "disturbance phases" are recognisable in the palynological and geochemical records (Figs. 8 and 9B). They (1= lowest to 4= uppermost; see Fig. 8) are characterised by the occurrence or an increase of pollen types representing light demanding taxa (*Polygonum persicaria*-type, Liguliflorae, *Aster*-type, Caryophyllaceae) and charcoal particles, together with local

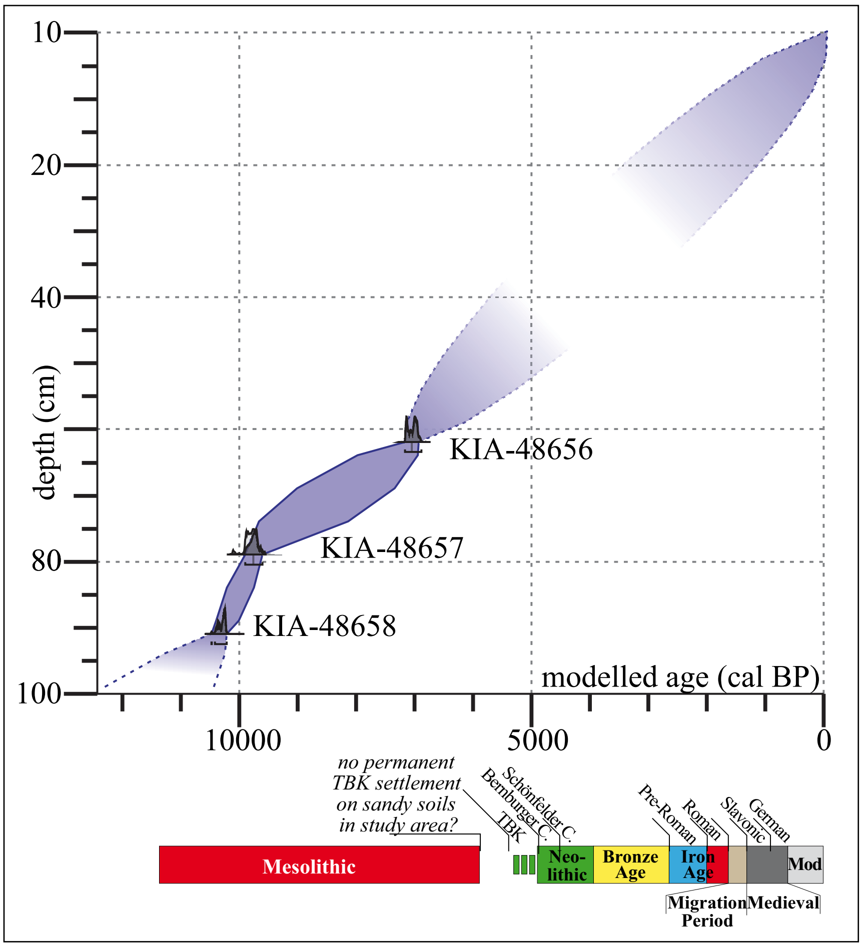

Fig. 7: Age-depth model of sequence SOV3 based on the ^{14}C-ages and comparison with archaeological zonation.

Abb. 7: Alter-Tiefen-Modell der Bohrung SOV3 auf Grundlage der ^{14}C-Alter sowie Zuordnung zu den archäologischen Zeitaltern.

minima of *Corylus* and *Typha latifolia*-type pollen. The geochemical analyses show that these disturbance phases are also marked by lower LOI (= higher input of minerogenic content), an increase in fine sand which might indicate soil erosion from the dune, and in the case of phases 1 and 2 by higher phosphate input as evidence of decaying organic material or faeces. Moreover, phases 2 to 4 show rises in the urease concentration indicating local increase in faeces input. Only phase 3 is connected with the occurrence of Cerealia pollen and moreover presents a rise in herbal pollen on the expense of *Pinus* pollen. These disturbance phases are followed by local minima of LOI, CaCO$_3$ and pollen of early successional shrubs and tree species such as *Salix*, *Betula* and *Alnus* (Fig. 8).

As the three lowermost phases may represent Mesolithic to Neolithic local human impact, they were studied using a reduced dataset (55–103 cm depth) where samples from the disturbance phases show the highest scores on axis 2 in the PCA ordination result (biplot) (Fig. 9B). According to the broken stick model the first five axes are statistically significant and explain 22,6 %, 15,1 %, 12,8 %, 9,7 % and 7,7 % of the total variance. While the first axis is mainly influenced by the changes in percentage among the different tree species, the above named taxa *Polygonum persicaria*-type, *Aster*-type and Liguliflorae show highest scores on the second axis, while the successional species *Salix*, *Betula* and *Alnus* show lowest. Furthermore, phosphate is positively correlated to PCA-axis 2 and samples with higher phosphate concentration show significantly higher scores on the palynological axis 2; thus, the pollen composition and phosphate input were probably triggered by the same environmental factors.

5 Discussion

5.1 General site development

Based on the OSL ages from SOV1 and SOV2 (sample 2) and the lowermost pollen samples from SOV3, the formation of the dune took place during the Late Glacial and probably the Preboreal in the sinuosity of a still active river channel that deposited fluviatile sands on its banks. This is in good accordance to other environmental reconstructions in the Jeetzel valley (Turner et al. 2013, Tolksdorf et al. 2013a).

Zone A of the palynological sequence SOV3 covers the time period from the late Preboreal to the Boreal when the dune was mostly stabilized, the river channel became abandoned and lacustrine sedimentation started. It shows a typical change in forest vegetation with *Pinus* replacing *Betula* in the region (Christiansen 2008, Turner et al. 2013) and becoming the locally dominant taxon on the dune area during the entire Holocene. No signs of short-time changes indicating human impact can be detected in the vegetation development within this zone, however the sedimentation in the oxbow lake was probably not continuous because of strong changes in humidity, water level and the hydrological regime (Turner et al. 2013).

After the establishment of a stable hydrological regime with a high water level a continuous sediment accumulation started in zone B that covers the late Boreal and Atlantic periods. This zone shows the typical establishment

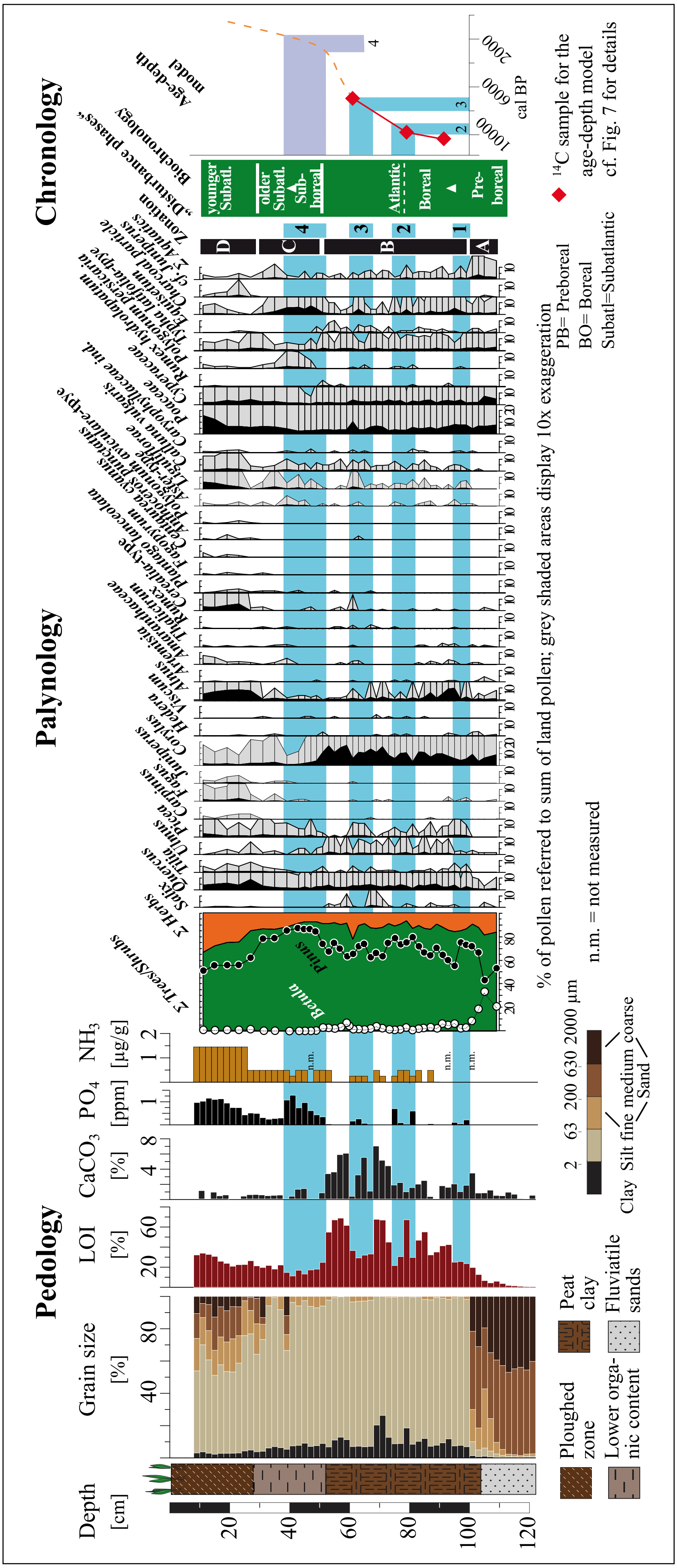

Fig. 8: Stratigraphy and zonation of core SOV3, results of sedimentological and geochemical analyses, as well as frequencies of selected more important pollen types.

Abb. 8: Stratigraphie und Gliederung des Bohrkerns SOV3, Ergebnisse der sedimentologischen und geochemischen Analysen und relative Häufigkeiten ausgewählter, wichtiger Pollentypen.

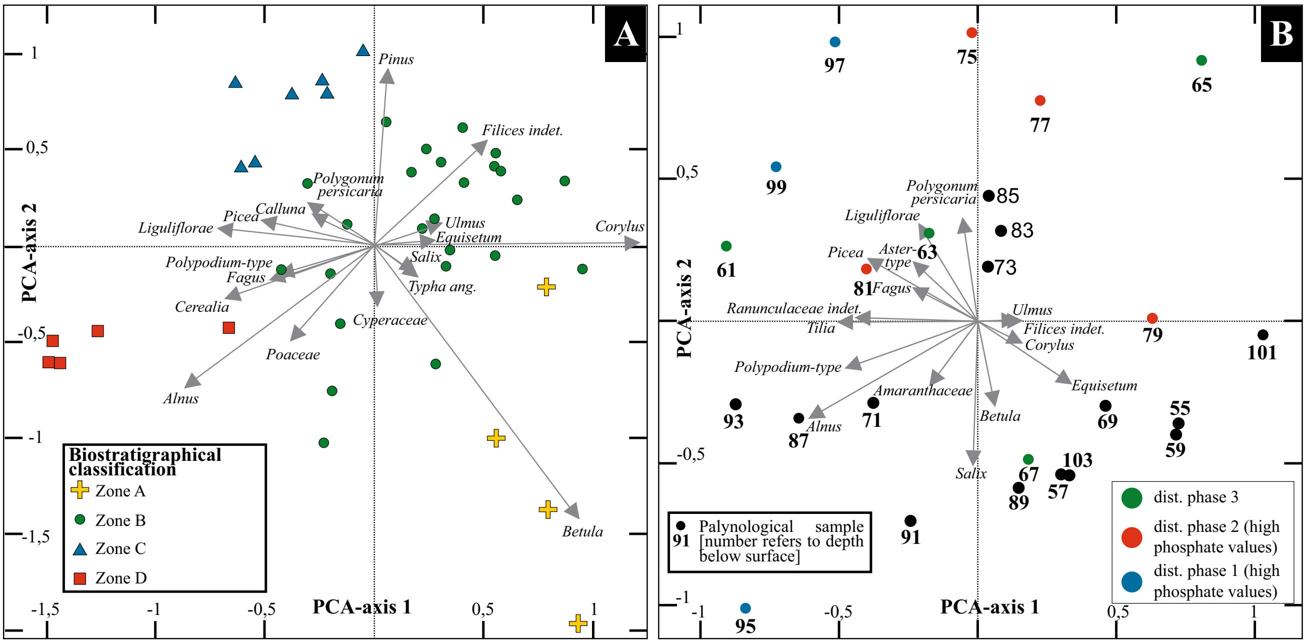

Fig. 9: A – Biplot of principal component analysis (PCA) of all samples from SOV3 used to corroborate the estimated palynological zones. B – Biplot of PCA of the reduced dataset. Samples from the discussed disturbance phases 1–3 are highlighted.

Abb. 9: A – Biplot der Hauptkomponentenanalyse aller Proben zur Bestätigung der palynostratigraphischen Gruppierung. B– Biplot der Hauptkomponentenanalyse mit reduziertem Datensatz. Die Proben aus den diskutierten Störungsphasen 1–3 sind hervorgehoben.

of *Quercus*, *Alnus* and *Ulmus* within the forested environment. The relatively high proportions of *Quercus* and especially *Alnus* pollen in sediments from the late Boreal period (~10–9.5 ka cal BP) seem to be a characteristic feature of palynological records from the region (Fig. 10), perhaps reflecting the early spread or migration of these species in large river valleys (Johansson et al. 1996). This is corroborated by the discovery of tree trunks in sediments of the Elbe river dating to 9.8 ka cal BP (Hiller et al. 1991). Many lake sediments in NW Europe show a (further) spread of *Alnus* – often together with the other deciduous tree taxa like *Quercus*, *Ulmus* and *Tilia* – around 9.5 ka cal BP (Giesecke et al. 2011). In the classical concept of European Holocene vegetation development this marks the Boreal / Atlantic boundary (e.g. Firbas 1949). This increase in percentages of *Alnus*-pollen is well-defined in all records form the Elbe glacial valley and nearby landscapes (Lesemann 1969, Merkt et al. 1993, Christiansen 2008, Beug 2011, Turner 2012).

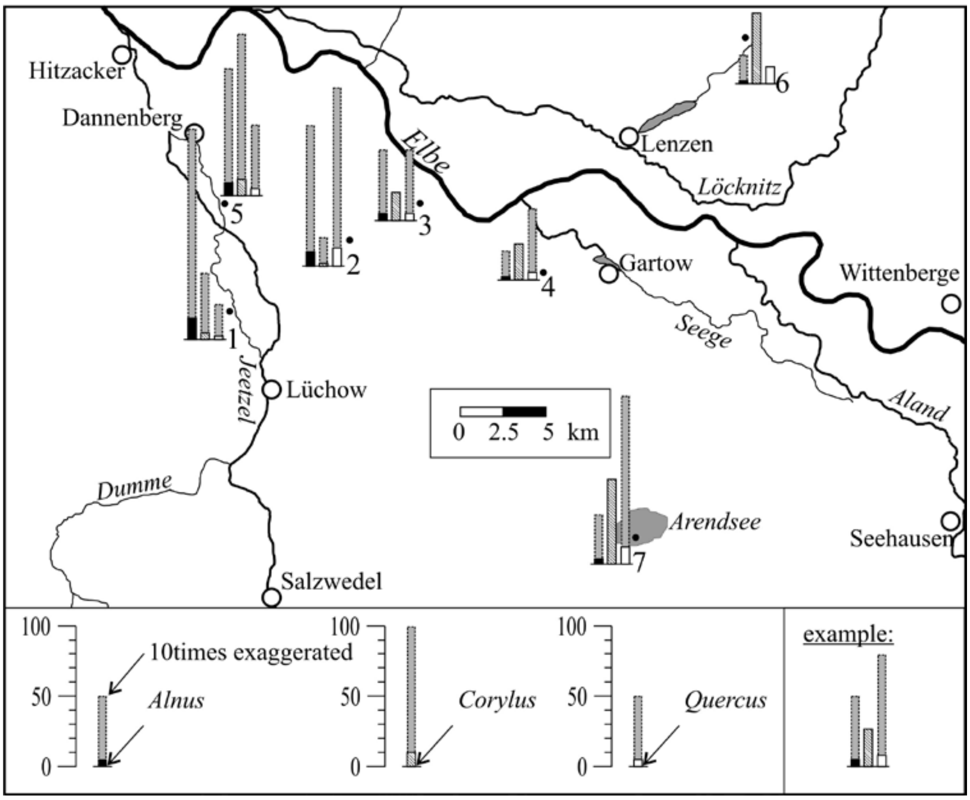

Fig. 10: Maximal proportion of Alnus, Quercus and Corylus pollen in samples attributed to the late Boreal within SOV3 and other late Boreal records of the region: In addition to available chronological information, the Boreal/Atlantic boundary was defined by a strong increase in the values of Alnus pollen, which is well-defined in all records beside Soven: 1: Jeetzel, Turner (2012); 2: Siemen, 3: Laase, Lesemann (1969); 4: Heuweg, Lesemann (1969), Christiansen (2008); 5: Soven (this study); 6: Rambow, Merkt et al. (1993), Christiansen (2008); 7: Arendsee, Christiansen (2008).

Abb. 10: Maximale Anteile an Alnus-, Quercus- und Corylus-Pollenkörnern in dem in das späte Boreal datierten Abschnitt von SOV3 im Vergleich zu anderen spätborealen Pollenspektren der Region. Neben vorhandener chronologischer Information wurde der Übergang vom Boreal zum Atlantikum anhand des starken Anstiegs von Alnus-Pollen festgelegt.

Tab. 3: Results of charcoal analysis.

Tab. 3: Ergebnisse der Holzkohlebestimmungen.

Sample	***Pinus***	***Corylus***	***Quercus***	**cf. Maloideae**	**Hardwood indet.**	**Bark indet.**	**Charred Non-wood**	**Indet. vitrified**	**Comment**	**Σ det. pieces**	**Weight det. pieces** [mg]
SOV-2009	5	1				3		1		6	5
SOV-2011	2	2	36	1	1		4		charred hazelnut shell	41	128

In the SOV3-sequence, percentages in pollen grains of *Alnus* remain remarkably low and fluctuate compared to other sites in the low-lying area with a high natural groundwater table and many eutrophic riverine peatlands (Lesemann 1969, Christiansen 2008). One possible explanation is that the palaeochannel – as a record of rather local vegetation (Sugita 1994) – was too small to allow for the growth of a continuous cover of alder trees along the riverbank, and pine plus elm-oak forests dominated in the nearby floodplain. This is corroborated by values of *Ulmus* pollen of more than 25% in one sample from an undated preliminary core in relatively close distance to the sequence SOV3 (Tolksdorf 2011). In addition, the pollen record of SOV3 may be strongly influenced by the local dominance of pine forest on the adjacent dune. Local pine stands as strong pollen producer can mask the spread of the deciduous trees in the area (Dambach 2000, Broström et al. 2008, Sugita et al. 2010). The very good floatable pine pollen may additionally have been transported by surface runoff directly into the channel in considerable amounts (Amman 1994).

The transition to zone C is well marked by a drop in percentages of *Ulmus* pollen (Elm decline) at a depth of 52 cm and clearly marks the Atlantic / Subboreal boundary. It is dated to approx. 5.8 ka cal BP by the age model and is thereby in very good accordance to the ages given by Parker et al. (2002) and Dörfler et al. (2012). Zone D should mainly be attributed to the younger Subatlantic period based on increasing amounts of anthropogenic indicators recorded in the pollen spectrum, especially the occurrence of *Fagopyrum* pollen and higher proportions of Cerealia pollen. Additionally, the increased sand influx into the oxbow lake (Fig. 8) and a reactivation of the adjacent dune, interpreted from OSL ages in SOV2 (Fig. 6), point to increased anthropogenic land-use and vegetation opening. A map from the late 18th century shows the area almost completely deforested (Fig. 2A). The youngest period may not be covered by the pollen record as the uppermost strata could not be analysed due the decomposition following modern drainage and agricultural use; it is, however, probably reflected by the pollen spectrum of the SOV1-sample (Fig. 5).

5.2 Phases of local anthropogenic impact

The first three identified phases of "vegetation disturbances" fall into the timespan of ~10.3 to 5.8 ka cal BP. While the oldest phases 1 and 2 have to be discussed below on the cultural backdrop of the Mesolithic, the disturbance phase 3 should be placed into the cultural context of the Neolithic.

While it is known that hunter-gatherer societies can cause changes on the vegetation in the immediate vicinity of their camp sites (Hicks 1993), the intensity and nature of human impact on the environment is generally under controversial dispute for the Mesolithic period (Mason 2000, Bos & Urz 2003, Ryan & Blackford 2010, Tolksdorf et al. 2013a). Due to its presumed ephemeral nature, the detection of potential traces of human impact and their differentiation from natural disturbances (e.g. wildfires, wind-throws, flooding) remains difficult (Kuneš et al. 2008). Nonetheless intentional burning of reed vegetation is proven for the site of Star Carr (Hather 1998) and vegetation burning has been postulated as integral part of Mesolithic land-use in Britain (Simmons & Innes 1996, Innes & Blackford 2003). Although the presence of Mesolithic occupation on the dune ridge near Soven during the 10th millennium BP cannot be doubted, a correlation with the weak "disturbance phases" 1 and 2 remains tentative, although the latter is dated to ~9.5–9.1 ka cal BP by the age-depth model and thereby to the same time period as the human occupation. The evident correlation of the palynological "disturbance phases", which – considering the relatively low resolution of the diagram – may reflect repeated small-scale openings/disturbances in the local wetland supporting the growth of light demanding herbaceous plants, plus higher phosphate and urease-activity in corresponding samples could be considered as hint for their anthropogenic origin. Compared to sites like Friesack, where local soil erosion caused by Mesolithic occupation was detected on the flank of a dune (Gramsch 2000), direct evidence for soil erosion cannot be given for the study area as the time span for the uppermost OSL-age from SOV1 covers both the late Pleistocene and the early Holocene and no significant rise in the input of sandy material can be detected in the palaeochannel record.

More evident are the vegetation changes designated by phase 3, which are also accompanied by rises in the input of aeolian sands as well as phosphates and urease. They indicate local vegetation disturbance by human impact. This is supported by *Cerealia*-type pollen indicating crop cultivation in the area, although archaeological evidence is still missing in the vicinity and especially on the dune ridge. By pollen analysis of sediments from the large lake Arendsee at 30 km distance to the Soven site, however, Christiansen (2008) describes a first increase of anthropogenic indicators in a comparable biostratigraphical position. The decline of direct indicators of human impact after this disturbance phase 3, similarly recorded in the Arendsee sediments, is remarkable and evokes the question about the nature and duration of the land-use that caused these environmental changes. It emphasizes that our knowledge about the dynamics of Neolithic land-use in marginal areas is still very sparse and especially lacks from well-dated archaeological sites. It may, therefore, be that disturbance phase 3 represents a first attempt of Neolithic crop farming in the area that failed and did not persist as supposed for other areas (Stevens & Fuller 2012).

Studies from the Netherlands and Belgium have shown that the spread of Neolithic economical elements into low-lying wetlands was complex and often made use of the isolated dryer high grounds provided by inland dunes (Cappers & Raemaekers 2008, Deforce et al. 2012). The Boberger dune sites near Hamburg bear assemblages with a mixture of local Mesolithic material and imported ceramics from the Neolithic groups further to the south (Ramminger 2012). In a comparable environmental setting, this provides an example that the transition to Neolithic economy might have been a complex and non-linear process with varying influence from southern Neolithic groups. Isolated Neolithic imports have also been found in the Jeetzel area (Breest 1997b; Breest & Veil 2001). The decline of Neolithic farming activity seen in the Soven record may in addition have been connected to rising water levels in the low lying areas of northern Germany during the Boreal and Atlantic periods (Kaiser et al. 2012).

Based on the palynological spectrum, zone C falls into the Subboreal and early Subatlantic period. Especially in the lower part of zone C distinct environmental disturbances can be seen, as phase 4 is based on the increase in open wetland and grazing-facilitated taxa and the high input of charcoal particles plus phosphate, urease and fine sand from the immediate vicinity. This input of aeolian sand may correlate with the last phase of aeolian deposition dated in profile SOV2 to 2.1 ± 0.3 ka, i.e. the Iron Age in archaeological terms. Other sites in the Northern European plain indicate that both aeolian remobilisation (Tolksdorf & Kaiser 2012) and soil erosion (Dreibrodt et al. 2010) occurred during this period probably as a result of intensified or changed land-use. The rising values of *Polygonum persicaria*-type, *Aster*-type and *Liguliflorae* and the comparatively low values of Cerealia-type pollen during this phase point to a probably seasonal use of the low-lying wetland area for stock grazing, which is a typical feature of Bronze and Iron Age economy (Lüning et al. 1997; Benecke et al. 2003), but has also been part of land-use in river valleys from NW Germany until the early 20th century (e.g. Pott & Hüppe 1991, 2001). In the Jeetzel valley it may be related to the phase of settlement expansion reconstructed from the archaeological (Nüsse 2002) and palynological records (Christiansen 2008) for the first centuries AD. Additionally, cereal cultivation may have been hampered by high water levels in the area as reconstructed by Turner et al. (2013).

The youngest zone D contains a significant share of *Fagopyrum* that has become common as cereal-substitute in northern Germany during the 12th–15th century (Behre 2008, Beug 2011). This uppermost zone D probably connects the channel record to the spectrum obtained from the uppermost part of the SOV1 profile, which probably represents the use of the area as arable land after extensive deforestation shown on the map from the 18th century (Fig. 2A). Both the position of the arable land signature on the historical map and the dominance of Cerealia (mainly *Secale*) together with very low percentages of arboreal taxa strongly indicate the local cultivation of crops directly on the dry dune.

6 Conclusion

The application of geoarchaeological, chronological, geochemical and palaeoecological research methods on an onsite record (Mesolithic site situated on a dune ridge) and the near off-site record (palaeochannel at the foot of the dune) allowed for a detailed reconstruction of the local environment since ~10.5 ka cal BP. The combination and cross-check of various methods both in terrestrial (onsite) and lacustrine (off-site) archives has great potential to overcome the problems that still exist in the identification of weaker human impact or land-use of non-agrarian societies in the pollen record alone. However, the main challenges are to establish a dense chronological framework for the correlation of the different archives, and to deal with discontinuous records.

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