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Distribution of Chernozems and Phaeozems in Central Germany during the Neolithic period

Hans von Suchodoletz\textsuperscript{a*}, Christian Tinapp\textsuperscript{b}, Tobias Lauer\textsuperscript{c}, Bruno Glaser\textsuperscript{d}, Harald Stäuble\textsuperscript{b}, Peter Kühn\textsuperscript{f}, Christoph Zielhofer\textsuperscript{a},

\textsuperscript{a} University of Leipzig, Institute of Geography, Johannisallee 19a, D-04103, Leipzig, Germany

\textsuperscript{b} Saxonian Archaeological Heritage Office, Zur Wetterwarte 7, D-01109, Dresden, Germany

\textsuperscript{c} Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, D-04103, Leipzig, Germany

\textsuperscript{d} Martin-Luther University Halle-Wittenberg, Institute of Agronomy and Nutritional Sciences, Soil Biogeochemistry, von-Senckendorff-Platz 3, D-06120, Halle/Saale, Germany

\textsuperscript{e} Department of Geosciences, Research Area Geography, Laboratory of Soil Science and Geocology, Eberhard Karls University of Tübingen, Rümelinstraße 19-23, D-72070, Tübingen, Germany

\textsuperscript{*} hans.von.suchodoletz@uni-leipzig.de

Abstract

A well-based knowledge about the former distribution of Chernozems and Phaeozems is necessary to (i) better understand the factors influencing formation and degradation of these highly fertile soils, and (ii) better explain prehistoric settlement patterns that were also determined by natural factors such as soil fertility. During this archaeopedological study carried out in Central Germany we applied sedimentological and micromorphological methods to compare soils and pedosediments from the recent Chernozem/Phaeozem region with black-coloured pedosediments buried in early Neolithic structures of the recent Luvisol area directly to the east. Relocated clay coatings and significantly lower magnetic enhancement compared to Chernozem/Phaeozem-derived material were found in most black-coloured pedosediments in the Luvisol area. This demonstrates that despite their location next to an extensive Chernozem/Phaeozem area these sediments do not originate from Chernozems or Phaeozems. Instead, their dark colour must either originate from anthropogenic input similar to black-coloured Anthrosols (“Dark Earth”), or must stem from Ah-material of former Luvisols. Consequently, may be apart from a small relatively dry and carbonate-rich Luvisol region northwest of Leipzig there was obviously no significantly larger distribution of Neolithic Chernozems and Phaeozems in this region during the past. Consequently, the regional early Neolithic settlers of the Linear Pottery Culture settled intensively also in areas outside the distribution of Chernozems and Phaeozems, and the activities of these settlers did not lead to the formation of such soils. Thus, fertile soils were obviously only one factor among probably others to explain the regional Neolithic settlement pattern. Significantly lower carbonate contents were found for the parent material of the black-coloured pedosediments in the Luvisol region compared with the parent material of Chernozems and Phaeozems. This demonstrates that the decisive factor to explain the recent and former spatial distribution of Chernozems and Phaeozems in this relatively dry area is the carbonate dynamics. Anthropogenic activity since the early Neolithic period obviously helped to preserve the naturally formed Chernozems and Phaeozems by re-carbonatization processes, but humans were not the main soil forming factor in early settled regions.
Introduction

Highly fertile black-coloured Chernozems and Phaeozems after WRB (IUSS Working Group WRB, 2014; “Tschernosem” after German classification, Ad-hoc AG Boden, 2005) are intensively used for agriculture, and often have a long-lasting history of agricultural use (Zech et al., 2014; IUSS Working Group WRB, 2014). Accordingly, they have been a focus of intensive archaeopedological research aimed at understanding timing and causes of their formation and degradation (Gehrt et al., 2002; Eckmeier et al., 2007; Huang et al., 2009; Chendev et al., 2010; Andreeva et al., 2011; Lorz and Saile, 2011; Gerlach et al., 2012; Lisietskii et al., 2013; Vyslouzilova et al., 2015; Kühn et al., 2017). In this context, questions arise about the former distribution of Chernozems and Phaeozems in regions that are covered by other soil types today. This is based on observed traces of black-coloured soil material in these regions that are proposed to result from systematic Chernozem/Phaeozem-degradation due to changing climate conditions (Schalich, 1988; Alexandrovskiy, 2000; Gerlach et al., 2012; Ershova et al., 2014). However, the evaluation of the former distribution of Chernozems and Phaeozems is often complicated by the existence of similar black-coloured surficial Anthrosols and human-derived black-coloured fillings of archaeological structures. The latter also show high contents of organic carbon that was accumulated by the input of metabolized human waste and anthropogenically produced charred organic matter (Macphail et al., 2008; Borderie et al., 2015; Wiedner et al., 2015). Such anthropogenic black-coloured soils and sediments as recently described for different regions such as Amazonia (Terra Preta de Indio: Neves et al., 2003; Glaser and Birk, 2012), eastern Russia (Andreeva et al., 2011) or southern, eastern and central Europe (e.g. Urban or Nordic Dark Earth: Macphail et al., 2008; Devos et al., 2009; Leopold et al., 2011; Nicosia et al., 2011; Wiedner et al., 2015; Borderie et al., 2015) can potentially be confused with (the remains of) Chernozems and Phaeozems. However, a well-based knowledge about the former distribution of Chernozems and Phaeozems is necessary to better understand the factors influencing their formation and degradation. Furthermore, it is also of interest in a geoarchaeological context since prehistoric settlement patterns were also determined by natural factors such as soil fertility (Bonsall et al., 2002; Brigand and Weller, 2013; Filipovic et al., 2014).

Central Germany is an ideal region to address this issue: (i) The westernmost continuous Chernozem/Phaeozem region of Eurasia is located in the relatively dry area in the eastern rain shadow of the Harz Mountains (Fig. 1). Thus, this region forms a border area of the distribution of these soils where also slight changes of natural conditions (e.g. climate, lithology) should show quite large effects on pedogenesis. A natural formation of the regional Chernozems and Phaeozems is suggested by partly degraded well-developed Chernozems below late Neolithic burial mounds that must have formed prior to Neolithic land use (Baumann et al., 1983; Saile and Lorz, 2003). (ii) Chernozem-like pedosediments buried in archaeological structures are reported for areas close to the current Chernozem/Phaeozem-region that are covered by other soil types today (Baumann et al., 1964; Bode et al., 2003; Bartels et al., 2003). This potentially indicates a larger distribution of natural Chernozems and Phaeozems during the early and middle Holocene which were either eroded or formed further towards the currently occurring soil types that are related to a more humid climate since the Atlantic period (Schalich, 1988; Lüning, 2000). For other German regions such as the Lower Rhine Basin (Gerlach et al., 2012), Central Bavaria (Leopold et al., 2011) or the Island Poel in the Baltic Sea (Albrecht and Kühn, 2011; Acksel et al., 2016, 2017) an anthropogenic origin of similar buried black-coloured material is suggested. However, in contrast to those regions such sediments in Central Germany are found adjacent to a large region in which naturally formed Chernozems and Phaeozems occur today, but a possible larger extension of these soils during the past was not systematically investigated so far. (iii) Central Germany is archaeologically well investigated, and was characterized by long-lasting human land use with several periods of intensive settlement activity since the early Neolithic period ca. 7.5 ka ago (Tinapp and Stäuble, 2000; Stäuble, 2014a). This facilitates the comparison between the former soil pattern and the prehistoric settlement distribution. During this archaeopedological study we investigated a possible larger distribution of Chernozems and Phaeozems east of the current Chernozem/Phaeozem area in Central Germany prior to the Neolithic colonisation. To do so, we compared sedimentological and micromorphological properties of black-coloured pedosediments from early Neolithic structures in the current Luvisol region east of the current Chernozems/Phaeozem region with those of soils and pedosediments from the latter. The ages of the pedosediments were determined using archaeological and/or luminescence-dating. Furthermore, we discussed these data in the context of potential factors influencing the formation of Chernozems.

2. Study area and studied sites

2.1. Study area

Central Germany comprises the federal states Saxony, Saxony-Anhalt and Thuringia (Fig. 1). During the Quaternary, the northern and eastern lowlands were repeatedly covered by ice shields of the Elsterian and Saalian glaciation, followed by loess deposition and periglacial reworking processes during the latest Saalian and Weichselian period (Eissmann, 2002). The region belongs to the European loess belt (Haase et al., 2007). The loess shows a distinctive distribution pattern (Fig. 2): In the north and east close to the floodplains of the rivers Mulde, Saale and Elster, i.e. the main sources of aeolian material, sandy grain sizes dominate. Towards the south and west the material becomes finer, forming loess-deposits of several meters thickness but thinning towards the foothills of low mountain-ranges in the south (Ore Mountains, Thuringian Forest) (Neumeister, 1971; Eissmann, 2002). Chernozems and Phaeozems occur in southern and central Saxony-Anhalt, the northwesternmost part of Saxony and the Thuringian Basin (Fig. 1, inset) between 50 and 300 m a.s.l. mostly on loess and loess derivatives. These are the driest parts of the region with mean annual precipitation between 440 and < 580 mm (Fig. 2, inset) and mean annual temperatures between 8°C and 9.5°C (Deutscher Wetterdienst 1981-2010, www.dwd.de). Around this dry area, precipitation systematically increases to values > 1000 mm/a in the low mountain ranges in the south (Fig. 2, inset). According to the Köppen-Geiger climate classification the region belongs to the fully humid warm temperate Cfb-climate zone with maximal summer precipitation (Kottek et al., 2006). Areas covered by Chernozems and Phaeozems are surrounded by areas with Luvisols, Cambisols, Stagnosols and partly also calcareous Regosols (Landesamt für Geologie und Bergwesen Sachsen-Anhalt, 1995; Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 1993). The climate during the early Holocene was warm with a subcontinental character, followed by more humid conditions since the middle Holocene from ca. 6.7 cal. ka BP (Wennrich et al., 2005). Agricultural activity and thus influence on the natural vegetation of the study area started ca. 7.5 ka ago with the early Neolithic Linear Pottery Culture. Since that period, the region was nearly continuously populated with varying intensities (Tinapp and Stäuble, 2000; Stäuble, 2014a).

2.2. Studied sites

Three early Neolithic on-site structures of the Linear Pottery Culture (ca. 7.3 ka) containing black-coloured sediments were studied in the actual Luvisol area of northwestern Saxony (locations see Fig. 2):

2.2.1. Droßdorf

This archaeological site was excavated in the forefront of the opencast lignite-mine Vereinigtes Schleenhain (mining field Peres) in a flat plain west of Borna in northwestern Saxony (Kretschmer et al., 2014). This area is covered by 50 cm thick Weichselian loess (Eissmann, 2002). Here, the sedimentary filling of a 70 cm deep early Neolithic pit including black-coloured pedosediments and the actual stagnic Luvisol were studied, the latter for comparison with the properties of local natural soils. It seems as if the stagnic luvisol had also developed inside the pit. To prepare the archaeological excavations, the plough horizon with a depth of about 40 cm was already removed.

2.2.2. Lützschena

During construction works in the NW of Leipzig in northwestern Saxony, archaeological excavations investigated an early Neolithic settlement on a slightly inclined slope (ca. 1° towards the south) about 500 m north of the Weiße Elster valley. Here, a thin layer of sand loess covers till of the first Saalian glaciation (Eissmann, 2002). Several early Neolithic pits containing black-coloured pedosediments...
were discovered. In a horizontal distance of 1 m, one pit filling and an undisturbed stigmatic Luvisol were studied, the latter for comparison with the properties of local natural soils.

2.2.3. Mügeln
In advance of a road construction, archaeological excavations were carried out south of the valley of the Döllnitz River (Conrad et al., 2014) in the Central Saxonian loess area with a loess thickness >10 m. According to Meszner et al. (2011) the loess is decalcified to a depth of 1.5 m at most sites. An early Neolithic settlement was found on both sides of the small tributary river Grauschwitz. Among others, an 80 cm deep post-hole of an early Neolithic house was excavated and investigated. The post hole was located on a slope with a slight inclination of 2° towards the east. Adjacent to the post-hole a Luvisol is developed at the surface of the loess.

For comparison, three sites in the actual Chernozem/Phaeozem region of southern Saxony-Anhalt and northwestern Saxony were studied (locations see Fig. 2). To trace the properties of regional Chernozems and Phaeozems through time and thereby make this comparison more robust, Chernozem/Phaeozem-borne soil material derived from two different periods was investigated: buried Neolithic pedosediments to allow the direct comparison between Neolithic materials of similar age (period A), and buried Medieval to sub-recent surficial soil material to trace the properties of regional Chernozems and Phaeozems through time (period B).

2.2.4. Uichteritz
The area of the sand pit of Uichteritz above the western bank of the Saale River in southeastern Saxony-Anhalt is covered by solifluorally re-deposited Weichselian sandy loess (Eissmann, 2002). The loess is overlain by ca. 50 cm thick Ah horizons of Chernozems and Phaeozems. Two sites were investigated: The actual soil at an east-facing slope of 3-4° (Uichteritz I; period B), and black-coloured pedosediments buried in an archaeological on-site structure, a loam-pit with an average diameter of 7.5 m and a depth of 180 cm at a slightly NW-facing slope (ca. 1°) 250 m west of site I (Uichteritz II; periods A and B).

2.2.5. Zauschwitz
Zauschwitz is located at the eastern border of the Chernozem/Phaeozem area south of Leipzig in northwestern Saxony. The area is covered with ca. 7 m thick loess (Lauer et al., 2014), in which Chernozems and Phaeozems are formed with an average thickness of the Ah-horizon of ca. 70 cm. Two sites were investigated: The actual soil in a loam-pit on the east-facing (1-2°) upper left bank above the Weiße Elster River (period B), and a buried soil in a core hole at the flat western margin of the Weiße Elster floodplain ca. 900 m NE of the loam pit (site Zauschwitz-Großstorkwitz after Tinapp et al., 2008; period A).

2.2.6. Neumark-Nord
Site Neumark-Nord is located on a flat plain at the northeastern wall of the flooded former opencast lignite mine “Geiseltal” in southeastern Saxony-Anhalt where the sediment layers were not disturbed by mining activity. The landscape is covered with 4-5 m thick Weichselian loess (Eissmann, 2002), in which Chernozems and Phaeozems were formed with varying thickness. This results from surface levelling of a gently rolling landscape by erosional processes and colluvial filling of former small depressions, leading to a largely flat landscape. Two sites were investigated: Site Neumark-Nord I is located at a former small “ridge” and crops out the actual soil (period B), and site Neumark-Nord II ca. 20 m west of Neumark-Nord I represents the filling of a small depression with around 160 cm of black-coloured pedosediments (periods A and B).
3. Methods

Profile description followed the FAO classification (IUSS Working Group WRB, 2014), and moist soil colour was determined using the Munsell soil colour chart. According to the geoscientific language usage in Germany the term “colluvium” is considered as a sediment resulting from human-triggered soil erosion (Leopold and Völkel, 2007).

Calcium carbonate content was determined following Scheibler: Depending on the pre-tested approximate carbonate content, 1-10 g of material was filled into an Eijkelkamp Calcimeter apparatus, and 10% HCl was added continuously until the reaction ceased. Calculation of carbonate-bound C was based on the CO₂-volume produced during the reaction.

Total organic carbon (TOC) was determined by subtracting inorganic carbon (calculated from carbonate-bound C) from total carbon that was measured using a Vario EL cube elemental analyser.

Proportion and composition of black carbon (BC) were determined by measuring benzene polycarboxylic acids (BPCA) contents and patterns according to Glaser et al. (1998), modified by Brodowski et al. (2005). This method comprises metal removal with 4 M trifluoroacetic acid (Brodowski et al., 2005) followed by nitric acid digestion (170°C, 8 h under pressure), cation exchange chromatography, trimethylsilylation (derivatization) and gas chromatography with flame ionization detection (Glaser et al., 1998). The sum of individual BPCAs was converted to the BC content by multiplication with 2.27 (conversion factor for charcoal; Glaser et al., 1998).

Measurements of mass-specific (γ) and frequency dependent magnetic susceptibility (χ(fd)) were performed using a Bartington MS3 magnetic susceptibility meter equipped with a MS2B dual frequency sensor. After softly grounding and densely packing the material into plastic boxes, volumetric magnetic susceptibility was measured with low (0.465 kHz, k_LF) and high (4.65 kHz, k_HF) frequency. Normalizing k_LF with the mass of a sample yielded mass-specific magnetic susceptibility χ. To make this proxy comparable between the sites, pedogenic enhancement of χ was calculated for every site by subtracting the value of unweathered parent material from that of the measured site-specific value (for the calculations see Supporting Online Material SOM-2). Most values for unweathered parent material are very similar and vary between 0.17 and 0.21 * 10⁻⁶ m³/kg. The only exception is Mügeln where a value of 0.27 * 10⁻⁶ m³/kg was obtained for unweathered loess from a nearby site, a value that is similar to values obtained for unweathered loess from nearby sites by Baumgart et al. (2013). Owing to similar parent materials (mostly loess and loess derivatives) all enhancement values should be comparable (Hanesch and Scholger, 2005). Frequency dependent magnetic susceptibility χ(fd) was calculated with the formula:

\[ \chi_{fd} = \frac{(k_{LF} - k_{HF})}{k_{LF}} \times 100 \]

To determine contents of total phosphorous (P_total), air-dried samples were sieved < 2 mm and subsequently ground in a vibratory mill for 10 min to get the required grain size < 30 mm. Afterwards, a 32 mm-pellet was produced by mixing and pressing 8 g of the ground material with 2 g CEREOX Licowax prior to measurement with a Spectro Xepos-X-ray fluorescence spectrometer.

Luminescence samples were taken in light-proof steel cylinders. Sample processing was carried out under subdued red light (wavelength 640 ± 20 nm). The samples were sieved 90-200 µm before destroying carbonate using 10% and 32% HCl, and organic matter using 10% and 37% H₂O₂. Density separation to remove heavy minerals (ρ > 2.75 g/cm³) and feldspars (ρ < 2.62 g/cm³) was performed using sodium metatungstate-monohydrate. Subsequently, the obtained quartz fraction was etched with 40% HF for 45 min to remove any remaining feldspar and the α-irradiated outer rim of the grains. After removing the fraction <63 µm by sieving, the quartz grains were mounted on 12 mm-aluminium cups using a 2 mm-mask. Measurements were performed on a Risø-Reader TL/OSL-DA-15 (Thorn-EMI 9235QA photomultiplier, ^{90}Sr/^{90}Y β-source). Stimulation was with blue LED’s, and detection in the range 340 ± 20 nm. After preheat-tests to determine most appropriate preheat-temperatures, the single aliquot regeneration protocol (SAR) of Murray and Wintle (2000) was used for measurements. Due to a large scatter of equivalent doses (De’s) indicating incomplete bleaching during last sediment transport, we calculated the De’s used for age calculation from the lower part of the De-distribution
based on the minimum age model of Galbraith et al. (1999). In parallel with the luminescence samples material was taken to gravimetrically determine the water content, and to measure the dose rate using low-level gamma spectrometry in the Felsenkeller laboratory of the VKTA Rossendorf/Germany. OSL-parameters and ages are listed in Table 1.

For micromorphological investigation, oriented undisturbed soil samples were taken. After air-drying and impregnating with Oldopal P 80-21, hardened blocks were cut and sliced into 70 × 50 mm thin sections which were described at 50–400 magnification under a polarizing light microscope mainly using the terminology of Bullock et al. (1985) and Stoops (2003).

*Grain size analyses* were performed using 10 g of bulk sample material. After destroying organic matter with 35% H₂O₂, samples were dispersed in 10 ml 0.4 N sodium pyrophosphate solution (Na₄P₂O₇) followed by ultrasonic treatment for 45 min. Sand content (63-2000 µm) was determined by dry sieving. Clay content (<2 µm) was determined by measuring the material <63 µm with X-ray granulometry (XRG) using the SediGraph III 5120 (Micromeritics).

### 4. Results and interpretation

Location, altitude, (archaeological excavation number and year of the excavation), mean annual precipitation, individual soil horizons with depth, type of material, sediment age, colour, structure and occurrence of pebbles and archaeological artifacts for each site are given in Table 2. Stratigraphical sketches with proxies and dating results and the results of micromorphological analyses are presented in Figs. 3-6.

#### 4.1. Early Neolithic structures containing black-coloured sediments in the actual Luvisol region

##### 4.1.1. Droßdorf (Fig. 3a)

Due to erosion of Saalian glacial deposits, non-calcareous Elsterian glacial deposits are directly covered by decalcified Weichselian loess.

The colluvial filling of the *early Neolithic pit* contained black-coloured sediments between 35 and 60 cm (colluvium 2). Bleached areas indicate seasonal stagnic conditions after filling of the pit. Both pit filling and underlying glacial till contain pebbles, but the till shows considerably more sand. Macroscopic and microscopic charcoal pieces, early Neolithic artifacts and broken fragments of relocated clay coatings are found in the pit filling, the former indicating human impact and the latter originating from Bt horizons of former Luvisols that were filled into the pit (Fig. 4a). Furthermore, increasing clay contents with depth and undisturbed dusty brown clay coatings and clay infillings in the pit demonstrate clay enrichment due to actual clay illuviation processes (Fig. 4b). Especially in the upper part of the pit filling channels and enchytrae excrements detected by micromorphology indicate bioturbation processes.

The *actual stagnic Luvisol* is formed by two Btg horizons that are developed in the upper loess layer. The loess contains less sand compared with the underlying glacial till. Elevated clay contents in the upper part indicate clay translocation into the Btg horizons.

##### 4.1.2. Lützschena (Fig. 3b)

Both sections are overlain by a colluvial layer (colluvium 1).

The pit filling (colluvium 2) contains black-coloured pedosediments with microscopic (Fig. 4c) and macroscopic charcoal pieces and early Neolithic artifacts, indicating human impact. Furthermore, undisturbed brown clay coatings and infillings of postsedimentary Luvisol formation but no fragments of relocated clay coatings as indicators of pre-Neolithic Luvisols were detected by micromorphology (Fig. 4d). Furthermore, the channel microstructure and excrements of lumbricids and enchytrae indicate some degree of post-sedimentary bioturbation. The pit filling is non-calcareous, whereas underlying Saalian till (C) is calcareous below 140 cm. Furthermore, current clay illuviation is also
indicated by clay enrichment in the central filling, and the pit filling contains less sand compared with the underlying Saalian till and the overlying colluvial layer 1.

The undisturbed stagnic Luvisol has higher clay contents resulting from clay illuviation and mottling originating from seasonal stagnic conditions in its lower part (Btg). Its upper part is non-calcareous, whereas Saalian till contains calcium carbonate from 120 cm.

4.1.3. Mügeln (Fig. 3c)

The construction pit around the post mold was filled with loess and black-coloured soil material during house construction, and the latter material is relevant for this study. Channel to spongy microstructure is characteristic for the black-coloured soil material, and channel microstructure for the adjacent undisturbed loess. Many passage features like crescent complete infillings and loose crumbly continuous infillings are present in the filling of the posthole and in the adjacent loess. Undisturbed brown clay fillings and brown to dark brown clay coatings of post-sedimentary Luvisol formation were found in the black-coloured soil material (Fig. 4e). Furthermore, brown to blackish coloured fragments of relocated clay coatings were found only in parts, where filling material of the posthole is present, independently if this material is reworked by bioturbation or not. This leads us to the interpretation that the fragments of clay coatings were derived from pre-Neolithic Luvisols (Fig. 4f). After its destruction the former position of the post mold was also filled with black-coloured soil material that will not be discussed in this context.

4.2. Sites in the actual Chernozem/Phaeozem region

4.2.1. Uichteritz (Fig. 5a)

A solifluidal mixture of Weichselian loess and Saalian till forms the parent material for Holocene pedogenesis at site Uichteritz I. The uppermost 40 cm contain homogenous and almost carbonate-free black soil material, divided into an Ap horizon down to 30 cm and an underlying Ah horizon down to 40 cm depth. Decreasing values of TOC, χ and χfd demonstrate that below a diffuse stone layer at 40 cm the soil fades into the underlying calcareous parent material (AhCk). Here, a layer of carbonate nodules is developed at 70-80 cm (Ck). Despite a moist chroma >2 of the mollic horizon, the presence of secondary carbonates <50 cm below this horizon might suggest a Chernozem (IUSS Working Group WRB, 2014).

Below the upper 25 cm thick Ap horizon the black-coloured filling of the prehistoric loam pit of site Uichteritz II was divided into an upper part (25e80 cm; colluvium 1) with a homogenous colour, and a lower part (80-180 cm; colluvium 2) with lenses of lighter material and a generally lighter colour than colluvium 1. The lighter colour of colluvium 2 is caused by a lower TOC-content attributed to the admixture with unweathered loess. The micromorphological sample from colluvium 1 showed a well-developed channel microstructure with lumbricide excrements indicating intensive bioturbation, but no microscopic charcoal was detected (Fig. 6a). Besides traces of bioturbation, the micromorphological sample from colluvium 2 shows signs of post-sedimentary brunification and loamification, as well as small undisturbed clay infillings and coatings indicating small-scale clay illuviation after filling of the pit (Fig. 6b). Also in this sample no microscopic charcoal was detected. Unlike the underlying loess the pit filling is almost free of carbonate. Macroscopic charcoal and sporadic bone fragments occur between 180 and 150 cm. Several potsherds between 90 and 100 cm were classified as middle Neolithic (most likely 6-5 ka; oral communication T. Schunke, Archaeological Service Saxony-Anhalt). The OSL age of 1.4 ± 0.2 - 1.3 ± 0.2 ka classifies colluvium 1 as early Medieval, and in accordance with the overlying middle Neolithic potsherds the OSL age of 7.0 ± 1.1 ka demonstrates an underlying early Neolithic colluvium 2 (Table 1). Although a moist chroma >2 was observed for both colluvia, secondary carbonates <50 cm below the mollic horizons at the surrounding slopes might suggest their origin from a Chernozem (IUSS Working Group WRB, 2014).

4.2.2. Zauschwitz (Fig. 5b)
The black-coloured Ap horizon in the upper 20 cm of the loam pit is strongly admixed with unweathered loess. An almost carbonate-free and darker colluvial layer follows down to 65 cm. This layer contains dispersed lighter spots of unweathered loess, early Neolithic to Medieval potsherds, charcoal pieces and in ist lower part yellowish krotovinas. Between 65 and 100 cm and delimited by a sharp discordant boundary, the colluvium extends tongue-shapely into underlying calcareous loess. The loess contains dark-coloured krotovinas and carbonate nodules (Ck), and its upper 15 cm are interfused by black material. Here, systematically decreasing values of TOC, $\chi$ and $\chi_{\text{d}}$ and increasing carbonate values with depth evidence a transitional AhCk horizon. The micromorphological sample from this horizon exhibits a channel to spongy microstructure with lumbricide and enchytrae excrements indicating intensive bioturbation, whereas no microscopic charcoal was detected (Fig. 6 c). Despite a moist chroma >2 of the colluvium, secondary carbonates <50 cm below the mollic horizon might suggest its origin from a Chernozem (IUSS Working Group WRB, 2014).

The drilling core in the Weiße Elster floodplain showed a 35 cm thick Chernozem/Phaeozem buried by a flood loam of around 150 cm. This thickness of the covering sediment should have conserved the Ahb horizon at the status quo of the Middle Holocene at around 6 ka (Tinapp, 2002). The black-coloured Ahb horizon is non-calcareous whereas the underlying loess contains ca. 5% of carbonate (cf. Tinapp, 2002). However, carbonate contents of 14% in the upper loess of the nearby loam pit demonstrate an originally higher carbonate content of the loess that may have been decreased already by dissolution of calcium carbonate in the C horizon (i.e. Cw horizon) or by lateral water transport in the floodplain. The micromorphological sample from the Ahb horizon shows a channelly to spongy microstructure with lumbricide and enchytrae excrements indicating intensive bioturbation, but no microscopic charcoal was detected (Fig. 6 d). A moist chroma >2 might suggest a former Phaeozem (IUSS Working Group WRB, 2014).

4.2.3. Neumark Nord (Fig. 5c)

At site Neumark-Nord I a former small “ridge” is covered by 80 cm of calcareous black-coloured soil material. The upper 20 cm form an Ap1 horizon, but only sparse carbonate mycelia indicate disturbance by ploughing up to 40 cm (Ap2). Unlike underlying pebble-free loess, brick fragments and small pebbles found up to 65/80 cm indicate a colluvial layer tonguing into underlying calcareous loess with singular carbonate concretions (Ck). Despite a moist chroma of the colluvium >2, secondary carbonates <50 cm below the mollic horizon suggest its origin from a Chernozem (IUSS Working Group WRB, 2014).

Calcareous material of the upper 25 cm of the filled small depression of site Neumark-Nord II contains pebbles, brick fragments and modern potsherds (Ap1). Down to 45 cm also carbonate pseudomycelia sporadically occur (Ap2). The material up to 90 cm (colluvium 1) contains numerous pseudomycelia, carbonate nodules, few pebbles and Medieval potsherds (oral communication T. Schunke, Archaeological Service Saxony-Anhalt). The OSL age of 0.8 ± 0.1 ka (Table 1) confirms the high medieval age of this layer. The material between 90/100 and 157 cm is generally carbonate-free (colluvium 2). However, calcareous root-channels extend into its upper, and large carbonate nodules and partly calcareous krotovinas occur in its lower part. Besides a complex microstructure with channelly, massive and fissured parts as well as lumbricide and enchytrae extrements indicating bioturbation (Fig. 6 e), the micromorphological sample from colluvium 2 exhibited a microscopic charcoal piece and signs of loamification and brunitification (Fig. 6 f). Despite the absence of potsherds or pebbles the OSL age of 6.2 ± 0.8 - 5.9 ± 0.8 ka (Table 1) indicates a middle Neolithic colluvium. Between 157 and 170 cm, a brownish decalcified Bw horizon is developed in the underlying loess. Sporadic carbonate nodules are found in this horizon, and black material is illuviated along root channels and voids. Below 170 cm calcareous loess with few black-coloured krotovinas and singular carbonate concretions occurs (Ck). Despite a moist chroma >2, the presence of secondary carbonates <50 cm below the mollic horizon in the surroundings of the section might suggest an origin of both colluvia from a Chernozem (IUSS Working Group WRB, 2014).

5. Discussion
5.1. Did Chernozems and Phaeozems exist in the actual Luvisol area during the Neolithic period?

To obtain information about the Neolithic distribution of Chernozems and Phaeozems in Central Germany, we selected sedimentological proxies that are indicative for these soils and/or for human activities: (i) The content of total organic carbon (TOC) is higher in Chernozems and Phaeozems compared with other soil types due to intensive accumulation of organic material (IUSS Working Group WRB, 2014). (ii) Mass-specific magnetic susceptibility ($\chi$) is noticeably enhanced in Chernozems/Phaeozems compared with underlying material due to intensive bacterial or fire activity (Hanesch and Scholger, 2005; Eckmeier et al., 2007). (iii) The signal of frequency-dependent magnetic susceptibility ($\chi_{fd}$) shows very high values in Chernozems and Phaeozems and is mostly produced by bacterial activity (Torrent et al., 2007; Jordanova and Jordanova, 1999). (iv) Phosphorous is often brought into soils and sediments by human activities such as fertilizing, cattle breeding or waste disposal. Due to its low mobility $P_{total}$ potentially traces on-site anthropogenic influence in soils and sediments (Holliday and Gartner, 2007), and was investigated to better identify human impact on the sites. (v) Black carbon (BC) is a typical component of the soil organic matter of Chernozems and Phaeozems (Glaser and Amelung, 2003; Eckmeier et al., 2007; Rodionov et al., 2010). BC can be produced by anthropogenic and natural fires (Knicker, 2011) and biological activity (Glaser and Knorr, 2008), and is discussed as a relevant factor for the formation of Chernozems/Phaeozems (Eckmeier et al., 2007). The values of these proxies for early Neolithic black-coloured pedosediments in the actual Luvisol area were compared with those of Chernozem/Phaeozem-borne soil material derived from periods A (buried early to middle Neolithic soil material) and B (early Medieval to subrecent soil material) (Fig. 7). However, the following material was excluded from the comparison: (i) Ap horizons that are not regarded as representative for natural Chernozems and Phaeozems due to strong modification by agricultural activity during the last decades or even centuries (Thiele-Bruhn et al., 2014). (ii) The uppermost part of colluvium 1 in Neumark-Nord II that was intensively modified by industrial and mining dust. This is indicated by TOC-contents $>3\%$ and elevated $\chi$-together with low $\chi_{fd}$-values, demonstrating a non-pedogenic origin of the magnetic enhancement (Rumpel et al., 1998, Fig. 5c). (iii) For $\chi$ and $\chi_{fd}$ the data of site Zauschwitz-floodplain, since similar to other waterlogged soils the initial magnetic signal was obviously destroyed by anoxic conditions (Neumeister and Peschel, 1968; Hanesch and Scholger, 2005). This is indicated by notably lower $\chi$-values for underlying loess in the floodplain (ca. $0.1 \times 10^6$ m$^3$/kg) compared with the uppermost loess in the neighbouring loam pit ($0.21 \times 10^6$ m$^3$/kg). In contrast, similar $\chi$-values (between 0.17 and $0.21 \times 10^6$ m$^3$/kg) for unweathered loess-borne parent material in Drossdorf, Lützschena, Neumark-Nord, Zauschwitz-loam pit and Uichteritz indicate that despite evidence for seasonal stagnic conditions at the two former sites their magnetic signal was obviously not notably influenced by this effect.

All Chernozem/Phaeozem-derived material (periods A and B) shows similar values of TOC, $\chi_{fd}$ and pedogenic enhancement of $\chi$. In contrast, the contribution of BC to TOC is notably higher for period A (Neolithic) compared with period B (early Medieval to sub-recent). Furthermore, unlike in period A the content of $P_{total}$ strongly fluctuates in period B (Fig. 7). These differences can be explained by post-Neolithic modifications of Chernozems and Phaeozems, i.e. by dilution of the organic matter with non-charred organic material (Thiele-Bruhn et al., 2014) and input of phosphorus by human activity (Holliday and Gartner, 2007). Comparing these values with those of black-coloured pedosediments from the actual Luvisol region, the following observations are remarkable (Fig. 7): (i) Compared with Chernozem/Phaeozem-derived material, the values of $\chi_{fd}$ are similar to the black-coloured material in Mügeln but lower in the pit fillings of Droßdorf and Lützschena. This also holds true for TOC, given that mean value/error bar of TOC for period A of Chernozem/Phaeozem-derived material are lowered/enlarged due to the dilution of colluvium 2 by unweathered loess in Uichteritz II. (ii) The contributions of black carbon of TOC are similar for all kinds of Neolithic material, i.e. for period A of Chernozem/Phaeozem-derived material and black-coloured Neolithic pedosediments in the actual Luvisol area. (iii) Contents of $P_{total}$ are very heterogeneous between the sites in the actual Luvisol area: Whereas the pit filling of Lützschena and the black pedosediments in Mügeln have low values that are similar to period A of Chernozem/Phaeozem-derived material, the pit filling in Droßdorf shows the highest value of all investigated sites. (iv) All black-coloured pedosediments in the actual Luvisol area have notably lower pedogenic enhancement of $\chi$ compared with Chernozem/Phaeozem-derived material.
The black-coloured pit fillings in Droßdorf and Lützschena show notably lower TOC contents and weaker pedogenic enhancement of χ compared with all Chernozem/Phaeozem-derived material (Fig. 7). This either indicates that (i) pedosediments derived from other soil types than Chernozems and Phaeozems were filled into these pits, or (ii) Chernozem/Phaeozem-derived material was diluted by non-pedogenic sediments such as loess, or (iii) these black pedosediments have an exclusively anthropogenic origin. In the latter case, elevated χ plethora-values of 5-6% could potentially be caused by the formation of ultra-fine magnetite due to heating or incorporation of potsherd-derived material (Chlupáčová et al., 2012; Jrad et al., 2014). However, finer grain size distributions in both pit fillings compared with underlying glacial sediments indicate that a large part of the fillings originates from the thin surficial loess layers in which the Holocene soils are developed (Fig. 3a and b). Furthermore, their relatively low χ-values are not typical for intensively burnt sediments (Jrad et al., 2014) so that elevated χ plethora-values should indicate a significant pedogenic signal (Fig. 7). Given that χ plethora does not depend on the concentration of magnetic particles and is thus not influenced by dilution with non-pedogenic material, lower values for the Neolithic pit fillings in the Luvisol area compared to values of Chernozems and Phaeozems indicate a weaker pedogenic activity than in the latter. Thus, on the one hand both pit fillings must contain a large proportion of pedosediments that do not stem from Chernozems and Phaeozems. On the other hand, significant anthropogenic input is demonstrated by macroscopic charcoal pieces and several archaeological artifacts (Table 2), and in Droßdorf also by notably elevated contents of P total compared with the P total contents of the adjacent undisturbed Luvisol. Furthermore, elevated BC values and microscopic fragments of charcoal are found in both pit fillings (Fig. 4a-c; 7). However, whereas microscopic charcoal particles were hardly detected in the investigated sites in the recent Chernozem/Phaeozem area (Fig. 6), also buried Neolithic soil material derived from naturally formed Chernozems and Phaeozems (period A) shows BC-values comparable to those of the early Neolithic pit fillings (Fig. 7). This can be explained by the fact that charred organic matter (BC) is not only of anthropogenic origin but could also originate from natural fires: For instance, studies detected small charcoal pieces and up to 800 g BC*kg⁻¹ TOC also in surficial Chernozems and Phaeozems (Gehrt et al., 2002; Eckmeier et al., 2007). Thus, BC does not necessarily indicate anthropogenic input of burnt organic material. All in all, both pedosediments derived from non-Chernozem/Phaeozem-soils as well as human-derived material are found in these pits. Accordingly, fragmented clay coatings in the pit filling of Droßdorf (Fig. 4a) demonstrate that well-developed Luvisols instead of Chernozems and Phaeozems built up the early Neolithic surface at this site and were subsequently filled into the pit. This is supported by the fact that no fragmented clay coatings were found at the investigated sites in the Chernozem/Phaeozem region (Fig. 6): Instead, only signs of intensive bioturbation, partly indications for brunification/loamification and in Uchteritz also small undisturbed clay infillings and coatings were detected. Thus, similar to black-coloured “Dark Earth” settlement soils that also show high TOC-values the black colour of the filling in Droßdorf must be of anthropogenic origin and originate from metabolized human waste and anthropogenically produced charred organic matter (Macphail et al., 2008; Borderie et al., 2015; Wiedner et al., 2015). In contrast to Droßdorf, only undisturbed but no fragmented clay coatings were detected in the pit filling of Lützschena (Fig. 4d). On the one hand, this could indicate the absence of early Neolithic Luvisols not ruling out the former existence of Chernozems or Phaeozems at this site. On the other hand, however, it cannot be excluded that only soil material of Ah or E horizons of former Luvisols is filling the pit. Thus, our data do not allow a definite decision whether the black colour of the pit filling of Lützschena originates from Chernozems and Phaeozems already present in the early Neolithic, or if it is also of anthropogenic origin.

Black-coloured pedosediments in Mügeln were brought into the post-hole during construction of the early Neolithic house. On the one hand, the values of TOC and χ plethora, the contribution of BC to TOC and the content of P total are similar to Neolithic pedosediments derived from naturally formed Chernozems and Phaeozems (period A). On the other hand, absolute enhancement of χ is distinctly lower than typical values for Chernozem/Phaeozem-derived material (Fig. 7). Thus, the black-coloured material is clearly soil-borne although obviously not derived from a typical Chernozem or Phaeozem. This is supported by fragmented brown clay coatings (Fig. 4f) that demonstrate pre-Neolithic clay illuviation processes in humus-rich Ah-horizons. Looking into small valleys close to Mügeln, black-coloured organic-rich layers of Middle Holocene age overlie well-developed Luvisols (Wolf and Faust, 2013). This suggests that these black-coloured layers cannot be derived from former Chernozems or Phaeozems, but must originate from former thick Ah horizons of other soil types.
Summing up, neither in Droßdorf located ca. 7 km east of the actual Chernozem/Phaeozem-region nor in Mügeln in the Central Saxonian loess area Chernozems or Phaeozems existed when first Neolithic settlers arrived. For Lützschena located ca. 5 km east of the actual Chernozem/Phaeozem-area, however, it remains open whether such soils already existed during the early Neolithic.

5.2. Factors explaining the observed spatial distribution pattern of Chernozems and Phaeozems

Originally, Central German Chernozems and Phaeozems were regarded as soils indicating steppe vegetation during the early Holocene (Laatsch, 1938, Altermann and Mania, 1968; Mania, 1980). However, pollen studies demonstrated that even the driest areas of Central Germany were covered by (open) forests instead of steppes during the early Holocene (Müller, 1953; Lange, 1980; Litt, 1992). Thus, climate, natural or anthropogenic input of BC and carbonate dynamics are still discussed as factors influencing formation and preservation of Chernozems and Phaeozems in Germany (Neumeister, 1971; Sabel, 1982; Gehrt et al., 2002; Altermann et al., 2005; Eckmeier et al., 2007).

Considering these potential soil forming factors for the studied sites, it appears that annual precipitation at Chernozem/Phaeozem-sites is between 521 mm/a (Uichteritz) and 602 mm/a (Zauschwitz), i.e. partly overlapping with Luvisol sites where precipitation varies between 562 mm/a (Lützschena) and 618 mm/a (Mügeln) (Fig. 2 inset; Table 2). Likewise, also the potential amount of soil seepage water (under grassland) for Chernozem/Phaeozem-sites varying between 98 mm/a (Uichteritz) and 155 mm/a (Zauschwitz) partly overlaps with Luvisol sites where these values range between 127 mm/a (Lützschena) and 177 mm/a (Mügeln) (Climate Data Center of DWD, see Supporting Online Material SOM-1). Thus, although a relatively dry climate like in the study area is a precondition for formation and preservation of Chernozems and Phaeozems (Altermann et al., 2005) this seems not to be the decisive factor to explain the differences between the investigated sites. Likewise, similar contributions of BC to TOC in black-coloured pedosediments of Neolithic age from the Luvisol area and the Chernozem/Phaeozem region demonstrate that different BC contents cannot be a crucial indicator for the formation of Chernozems and Phaeozems (Altermann et al., 2005). Finally, carbonate contents in parent materials of investigated Chernozems and Phaeozems are between 11.5% and 20%, and carbonate was not dissolved deeper than 80 cm below the actual land surface (Fig. 8). The calcareous loessic to solifluidal parent material is at least 2 m thick. In difference, the originally calcareous 50 cm-thick loess layer that overlies the much earlier decalcified Elsterian moraine in Droßdorf is completely decalcified today so that carbonate is only found deeper than 2 m. Similarly, the Central Saxonian loess close to Mügeln originally contained ca. 8% of calcium carbonate but is completely decalcified today up to a mean depth of 150 cm (Meszner et al., 2011). Also the ca. 50 cm thick loess cover in Lützschena is totally decalcified today, and with an actual carbonate content of 8% in the Saalian moraine below a depth of 120 cm carbonate leaching at this site has an intermediate position (Fig. 8).

These results agree with the generally accepted role of the carbonate dynamics as the main factor to allow formation and preservation of organic-rich Chernozems and Phaeozems, given a relatively dry climate with precipitation and soil seepage water values generally <600 or <160 mm/a, respectively (Altermann et al., 2005, Fig. 8): The carbonate content of the parent material that shows thicknesses of at least 2 m was sufficiently high of not being decalcified under climate conditions supporting the formation of Chernozems and Phaeozems. In difference, the only 50 cm thick layer of Weichselian loess covering decalcified Elsterian material in Droßdorf must have been decalcified quite quickly during the early Holocene so that the formation of Chernozems and Phaeozems was hindered. A similar situation is also likely for Mügeln, where slightly higher precipitation and potential amount of soil seepage water than in the Chernozem/Phaeozem region (618 and 177 mm/a, respectively) leached the primarily lower carbonate content of the loess (8%) more rapidly and thus impeded the formation of Chernozems and Phaeozems. In Lützschena, a similar carbonate content as in Mügeln of 8% is found in the Saalian moraine at 120 cm, but mean annual precipitation and potential amount of soil seepage water of 510 and 127 mm/a are slightly lower than in Mügeln. Furthermore, (i) carbonate in the Saalian moraine of Lützschena is often found as individual larger pieces that are more resistant to weathering than finely dispersed carbonate generally found in loess, and (ii) the slightly inclined slope in Lützschena (1°) is oriented southwards whereas the slope in Mügeln (2°) is oriented towards the east, adding slightly more soil seepage water due to less evaporation in Mügeln. Thus, decalcification
was obviously somewhat slower in Lützschena compared with Mügeln so that formation of Chernozems and Phaeozems prior to Neolithic settlement cannot be excluded for this site (Fig. 8).

The (mostly) anthropogenic black-coloured pedosediments from the Luvisol area and those from the Chernozem/Phaeozem region show notably different values of pedogenic magnetic enhancement as well as different carbonate contents and partly also thicknesses of their carbonatic parent materials. In addition to the fact that Chernozems and Phaeozems were already buried by Late Neolithic burial mounds (Baumann et al., 1983), these systematic differences strongly argue for a natural genesis of these soils in Central Germany (Altermann et al., 2005; Lorz and Saile, 2011). However, magnetic properties alone cannot generally be used to discriminate between material originating from naturally formed Chernozems and Phaeozems and black-coloured pedosediments of anthropogenic origin. This is due to the fact that ultrafine magnetite can also be formed by heating or the incorporation of potsherd-derived material (Chlupáčová et al., 2012; Jrad et al., 2014). Thus, strong magnetic enhancement with high \(\chi_{MF}\)-values can also be found in anthropogenic material. For example, the “Nordic Dark Earth” soil in Lower Saxony investigated by Wiedner et al. (2015) shows an enhancement of mass-specific magnetic susceptibility of \(0.67 \times 10^{-6} \text{ m}^3/\text{kg}\) and \(\chi\)-values up to 8.5% (unpublished data). Thus, a multi-proxy approach such as that of this study should be used.

5.3. The Neolithic settlement pattern of Central Germany with respect to natural conditions

Our study demonstrates that the Chernozem/Phaeozem area was not notably larger during the Neolithic period. Thus, in agreement with findings of Lorz and Saile (2011) for Lower Saxony and unlike Lüning (2000) our study corroborates settlements of the early Neolithic settlers of the Linear Pottery Culture outside the Chernozem and Phaeozem areas, i.e. in mostly Luvisol-covered regions in northwestern Saxony (Fig. 9; Stäuble, 2014a). Similar findings are known from Romania where archaeological sites are found on both Chernozems and Cambisols (Brigand and Weller, 2013). Moreover, the drought-prone Chernozems of the Hungarian Plain were even less suitable for Neolithic agriculture compared with the soils of the river valleys (Bonsall et al., 2002).

Thus, fertile soils were obviously only one factor between others such as water supply and the availability of sufficient wood for house construction to explain the Neolithic settlement pattern. For example, the sandy regions north of the Elbe River were not settled by the first Neolithic farmers because of the less fertile soils, whereas the loess-covered area around Bautzen in eastern Saxony was not settled most probably because of less favourable climate conditions (Meller, 2000). Therefore, if soils had some minimal conditions for agricultural use (at least moderate fertility and water retention capacity) we have to consider not only natural conditions but also cultural influences for the selection of settlement sites by the early Neolithic settlers (Stäuble, 2014b).

Interestingly, the dense network of early settlements in Central Germany did not lead to the large-scale formation of black-coloured soils. Herewith it is questionable if humans are generally the main forming factor for these soils in early settled regions, as was proposed by Gerlach et al. (2012) based on investigations of widely spread black-coloured anthroposols that were formed by Neolithic settlement activity in the Lower Rhine Basin in NW-Germany. In contrast to other regions, the pre-Neolithic Chernozems and Phaeozems in Central Germany were preserved up to now. This could possibly be explained by the drier climate and agricultural land use since more than 7000 years. Accordingly, several earlier studies proved an anthropogenic influence on preservation: (Pre)historic soil erosion and subterranean lateral water flow in hilly landscapes may increase the carbonate content of soils under arable land in distinct positions (Fischer-Zujkov, 1999), and fertilizing or regular ploughing since Neolithic times had reduced the process of degradation (Altermann and Mania, 1968; Semmel, 1995). A combination of these processes could have led to minor degradations of the black-coloured natural Chernozems and Phaeozems in Central Germany. Accordingly, similar to site Neumark-Nord the calcareous character of some post-Neolithic Chernozems and Phaeozems in Central Germany is confirmed by good bone preservation in early Neolithic near-surface burials close to Großstorkwitz in northwestern Saxony (Friederich et al., 1997).

6. Conclusions
The study area in Central Germany is characterized by regions with Chernozems/Phaeozems and by regions dominated by Luvisols. Based on the existence of black-coloured pedosediments in early Neolithic structures within the neighbouring Luvisol region it was assumed that Chernozems and Phaeozems have had a larger distribution in the past. We systematically compared soils and pedosediments from the current Chernozem/Phaeozem region with black-coloured pedosediments buried in early Neolithic structures of the current Luvisol area in northwestern Saxony. Relocated clay coatings and notably lower magnetic enhancement compared to Chernozem/Phaeozem-derived material were found in most black-coloured pedosediments in the Luvisol area. This demonstrates that despite their location next to an extensive Chernozem/Phaeozem area these sediments do not originate from Chernozems or Phaeozems. Instead, their dark colour must either originate from anthropogenic input similar to black-coloured Anthrosols (“Dark Earth”) as demonstrated by archaeological artifacts and partly microscopic charcoal pieces or high phosphorous contents, or must stem from Ah-material of former Luvisols. The calcareous substrate of the black-coloured pedosediments in the Luvisol region showed notably lower carbonate content and partly also thicknesses compared with the calcareous substrate of Chernozems and Phaeozems. Thus, according to earlier studies the decisive factor to explain the actual and former spatial distribution of Chernozems and Phaeozems under the relatively dry climate of Central Germany is the carbonate dynamics.

There was no notably larger distribution of Neolithic Chernozems and Phaeozems than already known in northwestern Saxony, although a slightly larger extension of these soils during the Neolithic period cannot be ruled out only for the relatively dry and carbonate-rich Luvisol region close to Lützschena northwest of Leipzig. Consequently, we infer that early Neolithic settlers of the Linear Pottery Culture settled intensively also in areas outside the distribution of Chernozems and Phaeozems at least in northwestern Saxony, and that the activities of these settlers did not lead to the formation of such soils. Thus, fertile soils were obviously one factor among probably others to explain the Neolithic settlement pattern of this region.

Finally, similar climate conditions but different magnetic enhancement and carbonate contents of the parent materials of black-coloured pedosediments from the Luvisol area and of soil sediments from the Chernozem/Phaeozem region corroborate the natural genesis of Chernozems and Phaeozems for Central Germany.

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Appendix A. Supplementary data
Supplementary data related to this article can be found at https://doi.org/10.1016/j.quaint.2017.10.041.

References


Table 1

OSL-parameters and calculated ages. The finally calculated OSL-ages are given in bold.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Uichteritz-II, OSL-1</th>
<th>Uichteritz-II, OSL-2</th>
<th>Neumark Nord-II, OSL-1</th>
<th>Neumark-Nord-II, OSL-2</th>
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<tr>
<td>Sampling depth (cm)</td>
<td>40</td>
<td>150</td>
<td>80</td>
<td>145</td>
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<td>U-content (ppm)</td>
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<td>3.24 ± 0.41</td>
<td>3.05 ± 0.17</td>
<td>2.90 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>2.98 ± 0.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>3.55 ± 0.13&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Th-content (ppm)</td>
<td>10.8 ± 0.5</td>
<td>10.8 ± 0.5</td>
<td>10.7 ± 0.4</td>
<td>11.4 ± 0.5</td>
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<td>K-content (%)</td>
<td>2.03 ± 0.06</td>
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<td>1.83 ± 0.09</td>
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<td>11.7 ± 1.2</td>
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<td>240</td>
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<td>Number of measured (usable) aliquots</td>
<td>19 (19)</td>
<td>17 (15)</td>
<td>17 (16)</td>
<td>17 (17)</td>
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<td>Equivalent dose De (Gy)</td>
<td>4.25 ± 0.45</td>
<td>21.82 ± 2.42</td>
<td>2.28 ± 0.29</td>
<td>19.57 ± 1.47</td>
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<td>Numerical age (ka)</td>
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<td>0.8 ± 0.1</td>
<td>6.2 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>1.3 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>5.9 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
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Table 2
Location, altitude, (archaeological excavation number and year of the excavation), mean annual precipitation, individual soil horizons with depth, parent material, sediment age, colour, structure and occurrence of pebbles and archaeological artifacts for each investigated site.

<p>| Profile (for archaeological sites with reference number and year of excavation) | Location (latitude, longitude) | Altitude (m a.s.l.); exposition, slope | Precipitation (mm/a)* | Horizon | Depth (cm) | Material (for underlying material with carbonate content in %) | Sediment age | Colour | Structure | Pebbles | Artifacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sites in recent Luvisol area |
| Droßdorf pit-filling (DSD-01/154, since 2011) | 51°08'57&quot;N 12°22'35&quot;E | 150; 0° | 611 | (E)/Bt | 0 - 20 | Colluvium 1 | Early Neolithic | SYR5/4 (reddish brown) 10YR6/3, 10YR7/3 (bleached) | Angular blocky | X | Daub-fragments, potsherds, charcoal |
| | | | | | | | | | | | | |
| | Bt | 20 - 35 | Colluvium 1 | Early Neolithic | SYR4/2 (dark reddish grey) | Angular blocky | X | Daub-fragments, potsherds, charcoal |
| | | | | | | | | | | | |
| | Bt | 35 - 60 | Colluvium 2 | Early Neolithic | 7.5YR3/2 (dark brown) SYR4/2 (dark reddish grey) | Angular blocky | X | Daub-fragments, potsherds, charcoal |
| | | | | | | | | | | | |
| | Bt | 60 - 70 | Colluvium 3 | Early Neolithic | 7.5 YR4/3 (brown) | | X | - |</p>
<table>
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<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Depth</th>
<th>Layer</th>
<th>Color</th>
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<th>Comment</th>
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<tr>
<td>Droßdorf recent Luvisol</td>
<td>51°08'57&quot;N 12°22'35&quot;E</td>
<td>150; 0&quot;</td>
<td>611</td>
<td>Loess</td>
<td>Weichselian glacial</td>
<td>10YR4/4 (dark yellowish brown)</td>
<td>Angular blocky</td>
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<td>BtC</td>
<td>30+ 1</td>
<td>Moraine (0%)</td>
<td>Elsterian glacial</td>
<td>10YR4/6 (yellowish brown)</td>
<td>Subangular blocky</td>
<td>X</td>
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<td>Lützschena pit-filling (LS-37/42, 2013)</td>
<td>51°23'10&quot;N 12°16'44&quot;E</td>
<td>112; 1&quot;, south</td>
<td>562</td>
<td>Colluvium</td>
<td>10YR3/3 (dark brown)</td>
<td>Subangular blocky</td>
<td>X</td>
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<td>Lützschena recent Luvisol</td>
<td>51°23'10&quot;N 12°16'44&quot;E</td>
<td>112; 1&quot;, south</td>
<td>562</td>
<td>Colluvium</td>
<td>10YR3/1 (very dark grey)</td>
<td>Subangular blocky</td>
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<td>Location (GWC-01/1332, 2012)</td>
<td>Coordinates</td>
<td>Depth (cm)</td>
<td>Horizon</td>
<td>Landscape</td>
<td>Colour</td>
<td>Texture</td>
<td>Age</td>
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<td>Mügeln</td>
<td>51°14'09.6'' N 13°03'59.6'' E</td>
<td>618</td>
<td>Ah</td>
<td>Weichselian glacial</td>
<td>7.5YR4/2 (brown)</td>
<td>Subangular blocky</td>
<td>-</td>
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<tr>
<td></td>
<td>140; 2°, east</td>
<td></td>
<td>E</td>
<td>Weichselian glacial</td>
<td>10YR5/3 (brown)</td>
<td>Subangular blocky</td>
<td>-</td>
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<td></td>
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<td></td>
<td>Bt</td>
<td>Weichselian glacial</td>
<td>10YR4/4 (dark yellowish brown)</td>
<td>Subangular blocky</td>
<td>-</td>
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<td></td>
<td></td>
<td></td>
<td>C</td>
<td>Weichselian glacial</td>
<td>10YR5/4 (yellowish brown)</td>
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<tr>
<td>Black-coloured soil materia</td>
<td>Around post-mold</td>
<td>150 cm 8%</td>
<td>Black-coloured soil</td>
<td>former topsoil</td>
<td>Early Neolithic</td>
<td>7.5YR3/1 (very dark grey)</td>
<td>Angular blocky</td>
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<td>Black-coloured soil</td>
<td>In post-mold</td>
<td>Anthropogenic material</td>
<td>Early Neolithic</td>
<td>7.5YR3/2 (dark brown)</td>
<td>Subangular blocky?</td>
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<td>Daub-fragments</td>
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### Sites in recent Chernozem/Phaeozem area

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>Color</th>
<th>Texture</th>
<th>Age</th>
<th>Other Materials</th>
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<tbody>
<tr>
<td>Uichteritz I</td>
<td>51°12'29''N 11°54'38''E</td>
<td>120; 3-4°, east</td>
<td>521</td>
<td>Ap</td>
<td>0-30</td>
<td>Colluvium</td>
<td>7.5YR3/2 (dark brown)</td>
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<tr>
<td>Ah</td>
<td></td>
<td>30 - 40</td>
<td>Solifluidal material/colluvium</td>
<td>Weichselian glacial/Holocene?</td>
<td>7.5YR3/2 (dark brown)</td>
<td>Angular blocky</td>
<td>X</td>
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<tr>
<td>AhCk</td>
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<td>40 - 55</td>
<td>Solifluidal material</td>
<td>Weichselian glacial</td>
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<td>X</td>
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<tr>
<td>Ck</td>
<td></td>
<td>55+</td>
<td>Solifluidal material (11.5%)</td>
<td>Weichselian glacial</td>
<td>7.5YR6/6 (reddish yellow)</td>
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<td>X</td>
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<td>Uichteritz II</td>
<td>51°12'29''N 11°54'38''E</td>
<td>120; 1°, northwest</td>
<td>521</td>
<td>Ap</td>
<td>0-25</td>
<td>Colluvium</td>
<td>7.5YR3/2 (dark brown)</td>
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<td>25 - 80</td>
<td>Colluvium</td>
<td>Early Medieval</td>
<td>7.5YR3/2 (dark brown)</td>
<td>Brittle angular blocky</td>
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<td>80 – 180</td>
<td>Colluvium</td>
<td>Early Neolithic</td>
<td>5YR4/2 (dark reddish grey)</td>
<td>Stable angular blocky</td>
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<tr>
<td>Ck</td>
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<td>180+</td>
<td>Loess (12%)</td>
<td>Weichselian glacial</td>
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<td>Zauschwitz loam pit</td>
<td>51°10'51''N 12°15'38''E</td>
<td>130; 1-2°, east</td>
<td>602</td>
<td>Ap</td>
<td>0-20</td>
<td>Colluvium</td>
<td>10YR4/2 (dark greyish brown)</td>
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<td>20 - 65 (100)</td>
<td>Colluvium</td>
<td>Medieval-sub-recent</td>
<td>7.5YR3/1 (very dark)</td>
<td>Angular blocky</td>
<td>X</td>
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<td>Location</td>
<td>Latitude/Longitude</td>
<td>Age (ka)</td>
<td>Depth (cm)</td>
<td>Material</td>
<td>Color</td>
<td>Texture</td>
<td>Additional Notes</td>
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<td>Zauschwitz floodplain</td>
<td>51°11′10″N 12°16′59″E</td>
<td>125; 0°</td>
<td>602</td>
<td>Flood loam</td>
<td>&lt; 6 ka</td>
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<td>Ahb</td>
<td>150 – 185</td>
<td>Loess</td>
<td>Weichselian glacial</td>
<td>7.5YR3/1 (very dark grey) 7.5YR2.5/1 (black)</td>
<td>Subangular blocky?</td>
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<td>Ahck</td>
<td>185-200</td>
<td>Loess</td>
<td>Weichselian glacial</td>
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<tr>
<td>C</td>
<td>200+</td>
<td>Loess</td>
<td>Weichselian glacial</td>
<td>7.5YR5/4 (brown)</td>
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<tr>
<td>Neumark-Nord I</td>
<td>51°19′33″N 11°53′29″E</td>
<td>105; 0°</td>
<td>532</td>
<td>Ap1 0-20</td>
<td>Colluvium</td>
<td>7.5YR3/1 (very dark grey) Crumbly x Potsherds</td>
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<tr>
<td>Ap2</td>
<td>20 - 40</td>
<td>Colluvium</td>
<td>7.5YR3/1 (very dark grey) Crumbly x Potsherds, brick-fragments</td>
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<td>40 – 65 (80)</td>
<td>Colluvium</td>
<td>Medieval? 7.5YR3/1 (very dark grey) Angular blocky x Brick-fragments</td>
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<tr>
<td>Ck</td>
<td>65 (80)+</td>
<td>Loess</td>
<td>Weichselian glacial</td>
<td>7.5YR6/4 (light brown)</td>
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<tr>
<td>Neumark-Nord II</td>
<td>51°19′33″N 11°53′29″E</td>
<td>105; 0°</td>
<td>532</td>
<td>Ap1 0-25</td>
<td>Colluvium</td>
<td>7.5YR3/1 (very dark grey) Crumbly x Potsherds</td>
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<tr>
<td>Ap2</td>
<td>25 - 45</td>
<td>Colluvium</td>
<td>7.5YR3/1 (very dark grey) Crumbly X Potsherds</td>
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<td>Type</td>
<td>Age</td>
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<td>Texture</td>
<td>X</td>
<td>Potsherds, brick-fragments</td>
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<td>45 – 90/100</td>
<td>Colluvium</td>
<td>Medieval top: 7.5YR3/1 (very dark grey) bottom: 7.5YR3/2 (dark brown)</td>
<td>Angular blocky</td>
<td>X</td>
<td>Potsherds, brick-fragments</td>
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<td>90/100 - 157</td>
<td>Colluvium</td>
<td>Late Neolithic 7.5YR3/1 (very dark grey) 7.5YR3/2 (dark brown)</td>
<td>Angular blocky</td>
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<td>Bw 157 - 170</td>
<td>Loess</td>
<td>Weichselian glacial 7.5YR4/4 (brown) 10YR5/4 (yellowish brown)</td>
<td>Angular blocky</td>
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<tr>
<td>Ck 170+</td>
<td>Loess (18%)</td>
<td>Weichselian glacial 7.5YR6/4 (light brown)</td>
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Figures

Figure 1

Distribution of Chernozems and Phaeozems in Europe (black colouring; taken from FAO/IIASA/ISRIC/ISSCAS/JRC 2012: Harmonized World Soil Database (v. 1.2). FAO Rome, Italy & and IIASA, Laxenburg, Austria). Inset: The study area in Germany (red rectangle). The distribution of black-coloured soils is shown with black colour after Eckmeier et al. (2007, modified). HM = Harz Mountains.
Figure 2

Distribution of loess and loess-derivatives (after Eissmann, 2002) and location of investigated sites in Central Germany. Actual Chernozem and Phaeozem areas are derived from Landesamt für Geologie und Bergwesen Sachsen-Anhalt (1995) and Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie (1993). Inset: Average annual precipitation in the region between 1981 and 2010 (Climate Data Center of DWD, see Supporting Online Material SOM-1).
Figure 3

Investigated early Neolithic structures with black-coloured pedosediments in the actual Luvisol area with analytical results.
Figure 4

Selected micromorphological features of pit fillings and black-coloured materials in the Luvisol area. 
a) Fragments of clay coatings and charcoal piece in the pit filling of Droßdorf, b) Undisturbed clay infilling and charcoal piece in the pit filling of Droßdorf; c) Charcoal piece in the pit filling of Lützschena, d) Undisturbed clay infilling in the pit filling of Lützschena; e) Undisturbed clay coating in the black-coloured material of Mügeln, f) Fragmented and relocated clay coatings in the black-coloured material of Mügeln.
Figure 5
Investigated soils and pedosediments in the actual Chernozem/Phaeozem area with analytical results.
Figure 6
Selected micromorphological features of soil material from the Chernozem/Phaeozem area. a) Channel microstructure in upper colluvium 1 of site Uichteritz II, b) Small clay infillings and coatings in lower colluvium 2 of site Uichteritz II, c) Loose continuous infilling with enchytrae excrements in the AhCk horizon of site Zauschwitz-loam pit, d) Channel microstructure with lumbricide excrements in the Ahb horizon of site Zauschwitz-floodplain, e) Characteristic loose crumbly infilling caused by bioturbation (note the roundish feature occupying nearly the complete right half of the microphotograph) in lower colluvium 2 of site Neumark-Nord II, f) Charcoal piece and loamified material in lower colluvium 2 of site Neumark-Nord II.
Figure 7
Comparison of sedimentological proxies between Chernozem/Phaeozem-derived material and black-coloured pedosediments from early Neolithic sites in the actual Luvisol area. Data for the respective periods from individual sites were averaged (see Figs. 3 and 5). For the calculations of magnetic enhancement see Supporting Online Material SOM-2.

Chernozem/Phaeozem-derived material
A = Neolithic age (period A)
B = Medieval till sub-recent age (period B)

Black pedosediments in recent Luvisol area
Dro. = Droßdorf
Lütz. = Lützschen
Müg. = Mügeln

* Due to destruction of the magnetic signal without site Zauschwitz-Roedelthin
Figure 8

Distribution of the investigated sites from West to East with Neolithic soil type, potential amount of potential soil seepage water, depth of carbonate below the surface and carbonate content of the parent material. Potential soil seepage water was calculated by subtracting monthly potential evapotranspiration over grassland from the corresponding amount of monthly precipitation (Climate Data Center of DWD, see Supporting Online Material SOM-1). To ensure that the carbonate contents for the Chernozem/Phaeozem sites were not biased by secondary calcification, the values for Neumark-Nord (ca. 20%) and Uichteritz (ca. 11.5%) are those values that were found in the uppermost loess of both sites I and II, and for Zauschwitz we used a value of ca. 14% that was described for the loess down to ca. 2 m by Lauer et al. (2014).

* In Lützschena and Drossdorf, the thin loess covers that were the main parent material of Holocene soil formation are totally decalcified today so that their original carbonate contents at the beginning of the Holocene cannot be given. Whereas in Lützschena we give the value of ca. 8% of the underlying Saalian moraine, the underlying Elsterian moraine in Droßdorf must have been already strongly decalcified during the Late Pleistocene so that carbonate is only found in a depth of ca. 2 m today. Thus, a value of 0 was taken for the (moraine) parent material in Droßdorf.
Figure 9

Actual and possible former distribution of Chernozems and Phaeozems (Landesamt für Geologie und Bergwesen Sachsen-Anhalt, 1995; Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 1993), and early Neolithic settlement sites in the studied region (taken from Preuß, 1998; for Saxony complemented with data from Stäuble and Veit, 2016).