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Anthropogenic pedogenesis of Chernozems in Germany? – A critical review

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ABSTRACT

Recently, the idea of an anthropogenic formation of Chernozems in Germany during the Early Neolithic (second half of the sixth millennium BC) has been proposed. This study reviews this idea in an interdisciplinary discourse, involving aspects of geosciences, palaeobotany, and archaeology. The paper discusses three major topics: (i) evidence of fire use in land clearing, from Black Carbon in soil organic matter (SOM); (ii) evidence of Chernozem formation during the Early Neolithic, indicated by radiocarbon dating, and (iii) evidence of anthropogenic pedogenesis based on the spatial coincidence of farmland of the Early Neolithic Bandkeramik (LBK) with Chernozems. However, the idea of anthropogenic formation of Chernozems during the Early Neolithic in Northern Germany is rejected. The suggested relationship between Chernozem formation and LBK does not exist. Although humans may have influenced the evolution of Chernozems by degradation or preservation, fire clearance by LBK settlers is very likely not the main factor in their formation. However, there is a strong need to include Black Carbon formation in the concept of SOM formation in Chernozems.

In memoriam: Arno Semmel (1929–2010).

1. Introduction

A number of papers has been published recently questioning the prevailing theory of Chernozem formation (Schmidt et al., 1999, 2002; Gehrt et al., 2002; Gerlach et al., 2006; Eckmeier et al., 2007). The broad spectrum of arguments brought forward requires an interdisciplinary approach focusing on interactions between human activities and environmental change.

Since the studies of V. V. Dokučaev in the 1880s (Dokučaev, 1883), Chernozems have been an important subject in soil science (for recent reviews on Chernozems, see Altermann et al., 2005; Eckmeier et al., 2007). Soil science textbooks (e.g. Ehwald, 1989; Duchaufour, 1998; Gerrard, 2000; Scheffer and Schachtschabel, 2002) provide a unanimous description of Chernozem formation. In brief, Chernozems form under steppe climate and vegetation. Typical parent materials are loess or other unconsolidated material with high silt content. The core regions for Chernozems in Europe are Southern Russia and Ukraine. In Central Europe, Chernozems are relic soils, thought to be formed during the Preboreal and Boreal period (ca. 10,000–7500 BP). Preservation of Chernozems might be caused by (i) high $CaCO_3$ content of parent material, (ii) hydromorphic conditions in small valleys and at foot slopes, (iii) $CaCO_3$ input through lateral soil water flow (regradation), or (iv) the so-called 'base-pump-effect' in mixed oak forests (Sabel, 1983; Ehwald, 1989; Fischer-Zujkov, 2000; Semmel, 2001). However, preservation of Chernozems in Central Europe might be mostly explained by human cultivation maintaining a 'steppe-like' soil climate. Thus, human activities could counteract natural decalcification, as well as decomposition and depletion of SOM, since the Middle Holocene.

Degradation of Chernozems in Central Europe resulted in the formation of Stagnic Luvisols or Luvic Phaeozems (Fig. 1; Rohdenburg and Meyer, 1968; Schalich, 1983, 1988; Fischer-Zujkov, 2000). In landscapes with a long history of agricultural use, i.e. most loess regions in Central Europe, pedogenesis of Chernozems is also affected by soil erosion and sedimentation. Thus, truncated or buried Chernozem profiles are a frequent phenomenon (Fig. 2). The complex interaction between Chernozem formation and human activity is explained in a model by Fischer-Zujkov (2000).

The idea of (semi) natural Chernozem formation has been challenged, based on the observation that (major) parts of SOM have properties of Black Carbon (Schmidt et al., 2002). It has been concluded that besides climate, vegetation and bioturbation, fire plays a crucial role in the formation of chernozemic soils. At first, post-Mesolithic use of fire by humans for forest clearing was assumed to be likely (Schmidt et al., 1999). Subsequently, the traditional model of Chernozem formation has been questioned in

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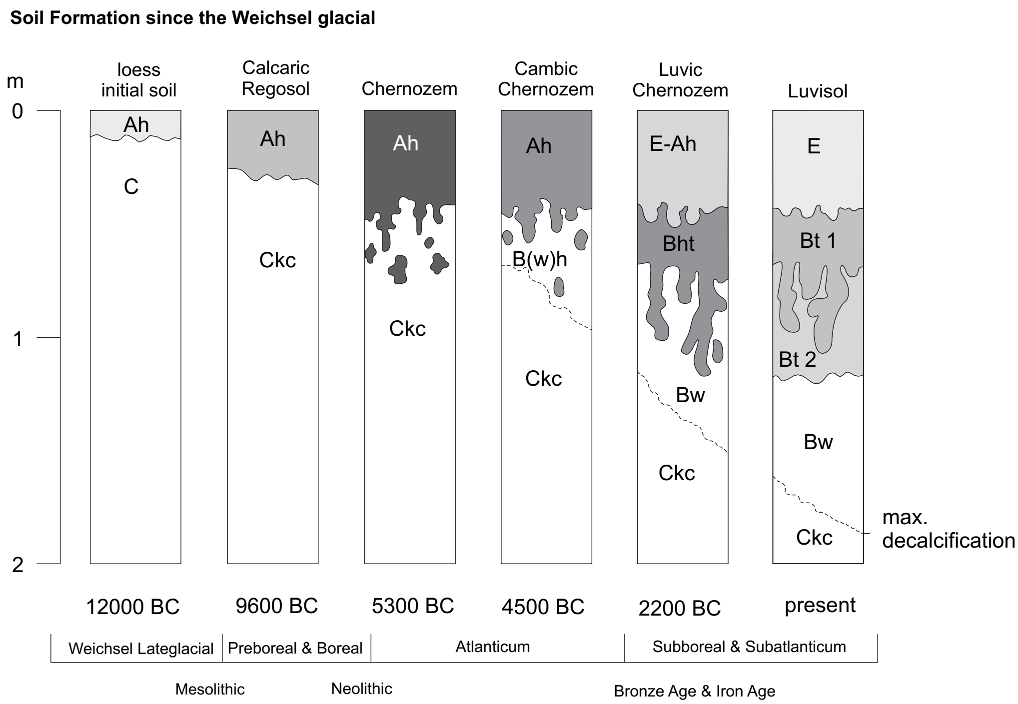

Fig. 1. Chernozem formation in NW Germany (after Schalich, 1988), designation of horizons and soil classification after FAO (2006).

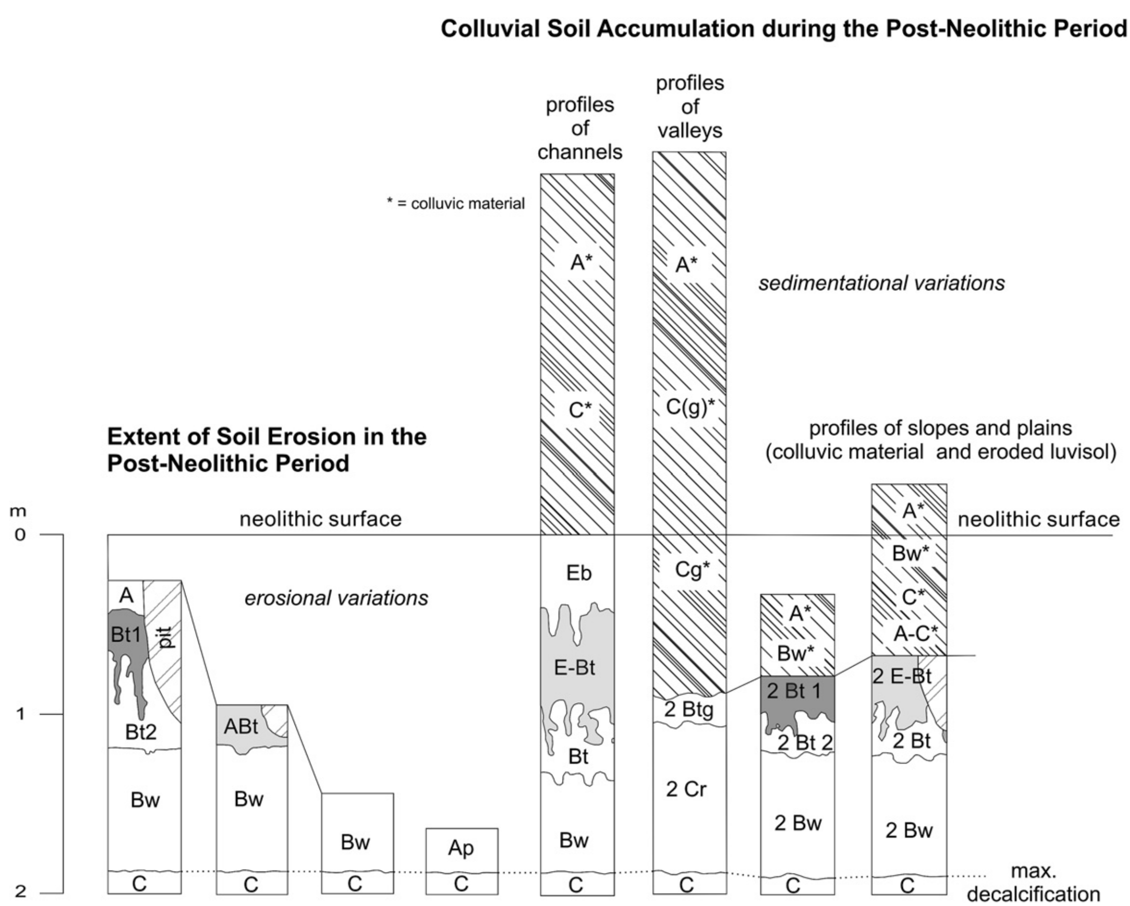

Fig. 2. Pathways of Chernozem evolution under erosional and accumulative conditions in NW Germany (after Schalich, 1988), designation of horizons and soil classification after FAO (2006).

general, and anthropogenic causes have been suggested as crucial for the evolution of Chernozems. Fire clearing by settlers of the Early Neolithic Bandkeramik (LBK), or from other archaeological periods (Gerlach et al., 2006), would have set vast fires, consuming vegetation. At the same time, charred black material could somehow have been rapidly mixed into parent materials.

Discussing these assumptions involves consideration of research from various disciplines, including soil science, palaeobotany, and archaeology. Three topics are the most crucial for the discussion:

- Occurrence of black carbon in the SOM of Chernozems and relationship to fire clearance;
- Radiocarbon dating of Black Carbon in Chernozems; and
- Spatial coincidence of LBK-farmland and Chernozems.

2. Discussion

2.1. Occurrence of black carbon in the SOM of Chernozems and fire clearance

The occurrence of Black Carbon or pyrogenic carbon in SOM of Chernozems, as reported by several authors (Kleber et al., 2003; Brodowski et al., 2005; Dai et al., 2005; Rodionov et al., 2006), is assumed to be a product of extended vegetation fires caused by LBK settlers in deciduous forests of Northern Germany. Black Carbon may contribute significantly to the formation of SOM of Chernozems and has to be included in the existing model of formation. However, there are several problems in the analysis of Black Carbon in soils:

(i) The chemical analysis focuses only on a certain condition within the black carbon combustion continuum of slightly charred, degradable biomass to highly condensed, refractory soot (Masiello, 2004);
(ii) There are considerable problems in accurately determining Black Carbon concentration in soils (Masiello, 2004; Simpson and Hatcher, 2004; Novotny et al., 2006);
(iii) Decay of Black Carbon is a problem (Schmidt et al., 2002, Rodionov et al., 2006); and
(iv) Large proportions of Black Carbon might come from lignite and coal combustion (Brodowski et al., 2005).

It has been suggested that the existence of steppe is neither a precondition for the evolution of Chernozems nor for Neolithic settlements (Gehrt et al., 2002). Eckmeier et al. (2007) concluded

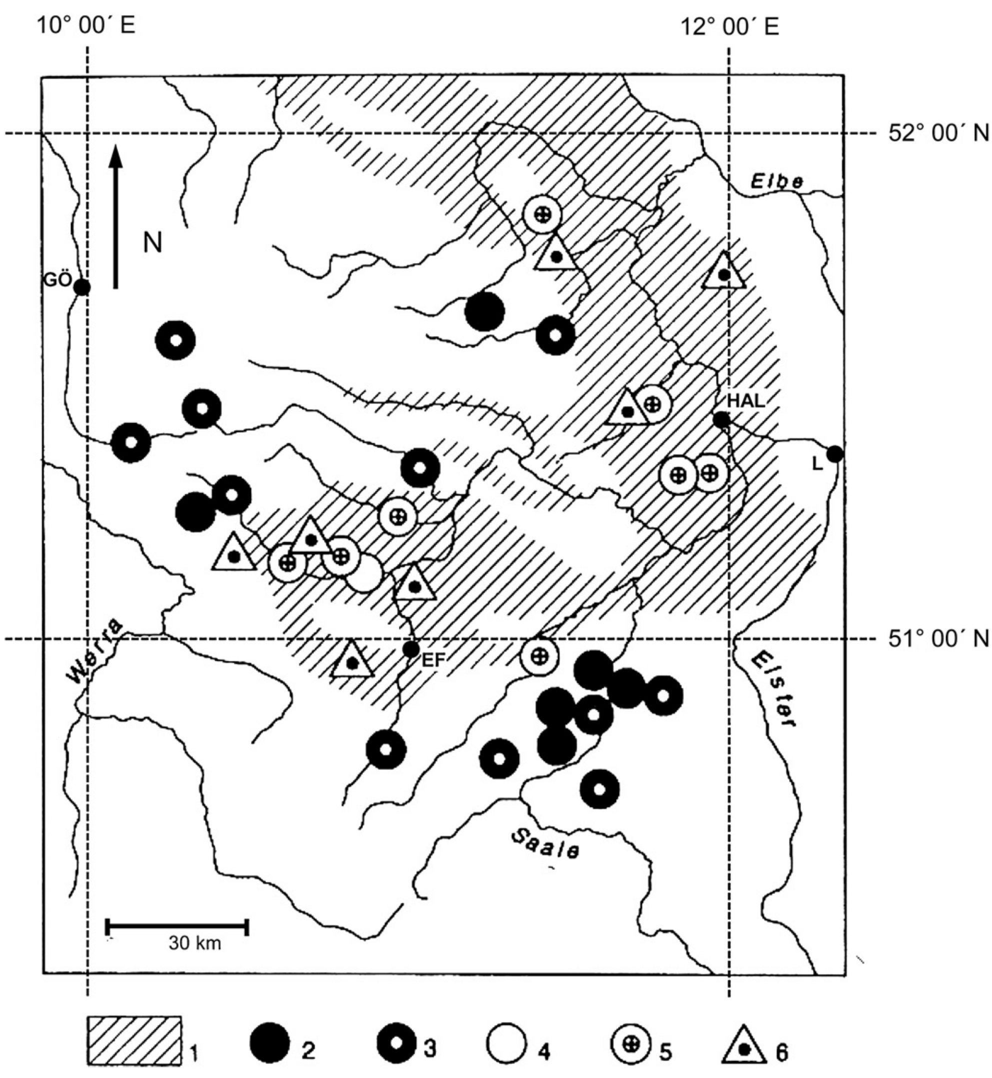

Fig. 3. Distribution of Chernozems in the Circumhercynian dry zones and reconstruction of palaeovegetation using molluscs (Ehwald et al., 1999) 1 = Chernozem areas, 2 = forest fauna, 3 = forest fauna with species of steppe, 4 = non forest fauna with steppe species, 5 = non forest fauna with species of flood plains, 6 = pollen, supporting thesis of sparse forest cover (for location of the study area see Fig. 4).

from stratigraphic records and radiocarbon data that Chernozem formation during the Late Glacial is unlikely.

The question of vegetation cover (forest vs. steppe) and Chernozem formation has been discussed intensively in the past among archaeologists, soil scientists, and palaeobotanists (e.g. Mania, 1995; Ehwald et al., 1999; Altermann et al., 2005). It is indisputable that during the Atlantic Period (ca. 6800–3800 BC) Central Europe was covered by a nearly closed forest. Density and tree composition depended on site conditions (elevation, soils, topography etc.) (Lüning and Kalis, 1988; Litt, 1992; Lüning, 2000; Kreuz, 2008). Pollen diagrams from the northern Upper Rhine Valley show that large parts were probably densely forested with mixed oak forests during the Boreal period (Dambeck and Bos, 2002). In contrast, in the Lower Eichsfeld (south-western foreland of the Harz Mountains, Germany) LBK settlers found a sparse deciduous forest with lime, ash, elm, and oak (Beug, 1992).

For the Circumhercynian dry areas, steppe-like vegetation without trees has been assumed based on micropalaeontological findings of molluscan fauna (Fig. 3). However, for the same region, palynological findings support the idea of closed forest cover (for detailed discussion, see Ehwald et al., 1999). The results of pollen analysis indicate regional vegetation patterns (Moore et al., 1991), whereas molluscan fauna reflect rather local conditions.

The idea of steppe-like vegetation during the Atlantic has been dismissed by most soil scientists (Ehwald, 1980; Sabel, 1983; Litt, 1992), but was accepted by Central German archaeology. It was assumed that the open, tree free landscapes of the Mid-Elbe-Saale-region were avoided by LBK farmers because they depended on wood supply. This is supported by the fact that most LBK settlements are found at the margins of the Circumhercynian dry areas (Kaufmann, 1975).

According to pedological and palynological findings, steppe-like vegetation existed during the Late Glacial and Early Holocene period in Central Europe (Mania, 1995). The formation of Chernozems in Central Europe ended with the beginning of a more humid, oceanic climate during the Atlantic Period and the subsequent closing of the forest cover (Scheffer and Schachtschabel, 2002). Nevertheless, Ehwald (1980) assumes that Chernozems developed in the Circumhercynian dry areas under park savanna or under vegetation that resembles today's forest steppe in Eastern Europe and Western Siberia (Ehwald et al., 1999). A major characteristic is a dense grass and herbal layer, while trees and shrubs might be only scattered in the landscape (Ehwald et al., 1999). Texture of parent materials might be a major controlling factor. Fine-grained materials, e.g. loess, provide site conditions favorable for steppe vegetation (Makohonienko, 2009). Rohdenburg and Meyer (1968) suggested Chernozem formation under initially open, then rapidly closing forests at least in the first phase of the Holocene, if decalcification of the initial substratum has not yet taken place. Even later genesis of Chernozems under human-made open vegetation has been described for the younger Holocene (Rohdenburg and Meyer, 1968).

Therefore, the question of vegetation cover during Chernozem genesis is still open (Altermann et al., 2005). However, if during the Preboreal and Boreal (forest) steppe covered large parts of Central Europe, as it is very likely, then vegetation fires resulting from spontaneous ignition would be a regular phenomenon (Strasburger, 1993; Ellenberg, 1996). Thus, the assumption of human-made fires might not be the only explanation for high BC concentrations in Chernozems.

In addition, there are archaeological arguments against widespread human fire clearance. The idea of the LBK culture settling Northern Germany by establishing extensive shifting cultivation systems (slash-and-burn as a possible source of BC) dates back to the ideas of Childe (1929), which has long been very influential (e.g. Tinner et al. (2005) for the forelands of the Alps). However, Childe's hypothesis has been rejected in most parts and is considered as completely outmoded today (Lüning, 2000). Lüning and Kalis (1992) described relatively small, isolated clearance areas, which comprised only about 5–6% of the wood-covered loess landscapes. Bandkeramik farmers might have also used natural clearings (Kreuz, 2008). LBK settlement activities have not resulted in widespread deforestation by creating large open spaces, but instead caused changes in tree composition (Bakels, 1992).

The idea of Early Neolithic landscapes with a very small share of forested areas is also supported by pedological findings. In this context, "colluvium" is considered as anthropogenic sediment, formed by soil erosion due to soil cultivation (cf. Kleber, 2006). Such anthropogenic colluviums from the LBK period are rare and, as preserved, thin (Lang and Hönscheidt, 1999; Saile, 2001; Kadereit et al., 2002; Mäckel et al., 2002; Schulte and Heckmann, 2002). Only in the immediate environment of settlements can stronger soil erosion and colluvial sedimentation be found (Saile, 1993).

2.2. Radiocarbon dating of black carbon in Chernozems

Radiocarbon dating of SOM obtained from Chernozems has been used to support the idea of formation during the Early Neolithic. However, published dating varies over a wide range and falls predominantly in the period from the middle of the 3rd to the middle of the 1st millennium BC (Gehrt et al., 2002). Based on a mixed record of radiocarbon dating ($n = 33$) of soil organic carbon ($n = 16$), charcoal ($n = 9$) and Black Carbon ($n = 8$), Gerlach et al. (2006) assumed a time span for Chernozem formation from the Mesolithic to the Middle Ages. Eckmeier et al. (2007, p. 293) concluded from these radiocarbon dates that, "*the different ages could indicate that Chernozems formed over a longer time period than thought before*". However, only two of the samples are charcoal from undisturbed soils (Luvic Phaeozems).

Even if it is accepted that organic compounds with lower molecular weight, i.e. younger materials, are destroyed by photo-oxidation before radiocarbon dating and higher aromatic BC is kept intact, the samples are from chronologically mixed horizons, e.g. mollic horizons of Chernozems. In soils without protection from rejuvenation, i.e. surface soils, only the apparent mean residence time of SOC can be detected (Scharpenseel et al., 2002). Topsoil horizons are always more exposed to contamination by younger carbon than are subsoil horizons. A reciprocal relation between ^{14}C ages and depth is common, and is reported for 281 Mollisol profiles by Scharpenseel et al. (1986). Similar depth gradients of radiometric age for Podzols, Andosols, and Chernozems are reported by Breemen and van Buurman (2002). In this context, the frequent burning of harvest remains on agricultural land as well as the possible input of lignite-derived particles – e.g. from combustion of fossil fuels (Brodowski et al., 2005) – has to be mentioned. Samples of Black Carbon or SOC, "contaminated" in this way, would yield unreliable ^{14}C dates, i.e. mixed radiocarbon signals.

Therefore, the results of radiocarbon dating based on SOC or Black Carbon from soils not protected against rejuvenation, i.e. surface soils, are not suitable to determine the time of Chernozem formation with sufficient accuracy. They only give a general *terminus ante quem* (Semmel, 1993; Ehwald et al., 1999; Scharpenseel et al., 2002; Eckmeier et al., 2007). In contrast, Hilgers et al. (2003) reported a ^{14}C date (for humic acids) of 5500 BC for a buried, thus protected against rejuvenation, Chernozem profile near Wiesbaden, Germany. The authors assume formation of the Chernozem during the Boreal period.

A clear indication of the pre-LBK age of Chernozems is given by pits and post holes dated in the Early LBK, which frequently contain calcareous redeposited material of the A horizon of Chernozems (Niquet, 1963; Thiemeyer, 1997). Relicts of Chernozems have been found in the base of pits, since they have not been affected by later processes of soil degradation (decalcification, brunification, lessivation) (Semmel, 2001). Even if the interpretation of pit fillings as Chernozem material is doubted (Gerlach et al., 2006), there are several studies that found LBK settlement structures on Chernozems, that later have been covered by anthropogenic colluvium (Biel, 1995; Reim, 1995; Engelhardt et al., 1998; Meixner, 1998). One of the few examples of a sound pedological description of a Chernozem profile preserved beneath a Late Neolithic – unfortunately not LBK – burial mound south of Leipzig, Germany is given by Baumann et al. (1983). The authors conclude that by 4000 years ago, Chernozems, partly with degradation phenomenon, existed in the Saxonian Chernozem region. For Hungary, Barczi et al. (2009, 2006) described Chernozems found under and on top of burial mounds. They concluded for both modern and palaeo environments (around 6000 BP) Chernozems have been formed under climate and vegetation typical of steppe environments. These examples indicate that it is very likely that the first farmers who settled in Northern Germany around 7500 years ago, found Chernozems at that time.

2.3. Spatial coincidence of LBK-farmland and Chernozems

The assumption that the location of LBK settlements coincides with Loess and Chernozem areas is thought to be supported by a soil map for the southern part of Lower Saxony (Gehrt et al., 2002). The map is based on the *Bodenschätzung*, a nationwide soil survey for the taxation of farmland in Germany. The spatial pattern of Early Neolithic settlements and the dissemination of five soil units were claimed to show that, wherever LBK settlements are known, Chernozems also were initially in existence (Gehrt et al., 2002).

However, the general coincidence of LBK settlements and Chernozems is questionable. It has been known for a long time that neither Chernozems nor soils with a verifiable Chernozem history prevail in agricultural areas of all LBK settlements (Buttler, 1931). In addition to the general preference for soils on loess by Early Neolithic farmers, LBK settlements have been found on non-loess material. As well, there are several loess landscapes, such as the Calenberger and the Peiner Börde (Southern Lower Saxony), and the central dry areas of the Circumherzynian Chernozem region (Central Germany), without any findings of LBK settlements.

It is difficult to make firm conclusions from the *Bodenschätzung* data concerning the history of Chernozems in loess areas. Although it should be possible to recognize Chernozems, Luvic Phaeozems and Luvisols, the distinction of Luvisols with and without Chernozemic origin on the basis of the condition grades (*Zustandstufe*) of the *Bodenschätzung* is not possible, since the necessary criteria – e.g. humic clay skins – have not been recorded.

An example is provided by the relationship between LBK settlements, their economic areas, and soils in a region of 60 × 60 km (Fig. 4) located between the River Weser and the Harz Mountains. The region might be considered as comparatively well explored after intense archaeological research during the last century (Saile and Lorz, 2003). For the region Leine-Ilme-Graben and Seeburger Becken, 129 Early Neolithic settlements are known. A map was constructed from the 1:50000 digital soil map of Lower Saxony (BÜK 50) by classifying type and depth of parent material into six classes (Fig. 4). Pedogenetic processes were excluded,

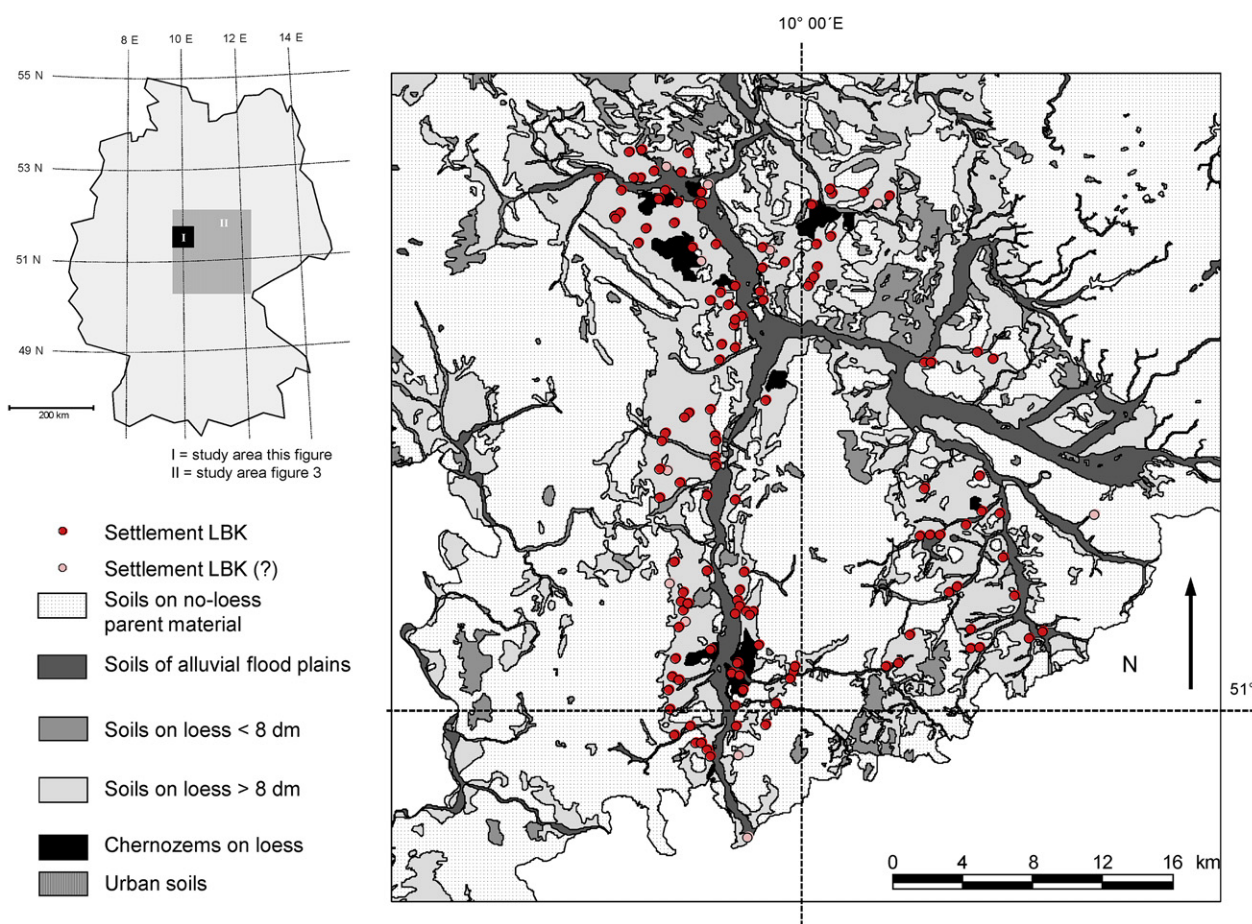

Fig. 4. Soil map and LBK settlements in the South of Lower Saxony. Map based on digital Soil Overview Map (BÜK 50 digital).

because soil conditions during the LBK period can be hardly estimated without detailed studies. However, since it plays an important role in the discussion, the present distribution of Chernozems is also shown in Fig. 4.

The map leads to the conclusion that LBK settlers preferred highly productive and light soils with easy access to water courses (Sabel, 1983). These conditions are provided in the dry loess landscape of the investigated region with a distinctly incised, dense drainage network. Of 129 LBK settlements, 118 are located on loess, i.e. 34% (979 km^2) of the region carries 92% of the LBK settlements. Around 1% (25 km^2) of the region and 3% of the area with loess are covered today by Chernozems. Only 5% ($n = 7$) of the Neolithic settlements are found in those areas.

LBK settlers favored fringes of ecotones, e.g. loess areas bordering alluvial flood plains or loess-free areas respectively. The frequent occurrence of LBK settlements close to loess boundaries is a phenomenon that has been often observed (Bakels, 1978). Altitudes higher than 200 m asl, areas with high precipitation, and areas with shallow, fragmentary loess covers as well as isolated loess areas were avoided, as they did not meet the demands of Neolithic settlers regarding the economic sense for the landscape (Crome, 1924).

However, plotting of known LBK settlements on a small-scale map of today's soils provides only limited information on the palaeo-soilscape, because for Luvisols, presently dominating in loess regions, a Chernozem history cannot be generally verified. Semmel (2001) reports for the Taunus foreland (SW-Central Germany), that even the often used criterion of humus clay skins cannot be accepted as the sole argument for the necessary presence of Chernozems in the antecedent stages of the recent Luvisols. For a reconstruction of palaeo-(soil) environments of archaeological sites, detailed soil surveys would be necessary.

3. Conclusion

The hypothesis of a predominantly anthropogenic pedogenesis of Chernozems in Northern Germany during the Early Neolithic, and also during other younger periods, has to be rejected. The current theory of natural formation is still valid. The presented observations, especially the occurrence of Black Carbon, can be explained by existing models.

Extended human fire clearance during the LBK period as the main reason for the widespread destruction of forests is rather unlikely. Whether Black Carbon was formed through natural or anthropogenic burning can only be speculated upon (Schmidt et al., 2002). Recently, even non-pyrogenic formation of Black Carbon is thought to be likely (Glaser and Knorr, 2008).

It remains unsolved whether all of the soils considered as Chernozems ("Off-site-Schwarzerden", Gerlach et al., 2006) can be described as Chernozems in the pedogenetic meaning. The authors do not see the need of introducing the term "off-site", referring to sites which despite the lack of any findings assumed to be of archaeological origin. For analyses in soil geography, isolated soil profiles are generally less useful. The genetic relation along a catena, i.e. toposequence of soils, has to be analyzed. The complex relationships between formation and preservation of Chernozems can only be reconstructed using landscape based approaches (Gerlach et al., 2006). However, the patchy distribution of Chernozems and Luvisols remains an unsolved problem. The assumed link to the LBK-land use patterns is rather vague, since the respective areas have a land use history of up to 7000 years.

Some soils in Northern Germany have been influenced by human activities, for example the Plaggenesch (Cumulic Anthrosol) in NW Germany (Blume and Leinweber, 2004). In addition, soils at settlement sites might be strongly modified by human activity (Schmid et al., 2002). However, the general reference to anthropogenic soils in other climatic zones and areas with entirely different physical–geographical conditions (e.g. "Terra Preta de Índio" [Indian black earth], Lima et al., (2002)) contributes little to the understanding of Chernozem formation in Northern Germany.

In conclusion, human activities have a crucial effect on soil formation in Germany, and also on the genesis of Chernozems. However, the idea of anthropogenic formation of Chernozems in Germany due to fire clearance during the LBK period has to be rejected.

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