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Spatial analysis of loess and loess-like sediments in the Weser-Aller catchment (Lower Saxony and Northern Hesse, NW Germany)

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Abstract: A spatial compilation and visualization of loess parameters was carried out for the Pleistocene loess and loess-like sediments in the Weser-Aller catchment (southern Lower Saxony and northern Hesse, NW Germany), one of the loess regions of Central Europe. As far as available, data about main loess characteristics like thickness, granulometry and stratigraphy were combined for the first time with spatial information extracted from maps. Data storage and analysis in a geographical information system (GIS) permitted creation of large-scale thematic loess maps.
The loess thickness map displays an increase of the thickness in valleys and basins and from north to south. The granulometry map presents main granulometrical facies types of the loess cover. Furthermore, several loess locations with unusual thickness were identified and their special geological and geomorphological conditions are discussed.
In summary, the loessic sediments in the northern part of the study area are of Upper Weichselian age, whereas in the southern upland regions incomplete or detailed Weichselian loess sequences were identified. In conclusion, highly detailed maps of regional loess-property patterns can be created even if only heterogeneous historically published data are taken into account.

[Räumliche Analyse von Lössen und löss-ähnlichen Sedimenten im Weser-Aller-Einzugsgebiet (Süd-Niedersachsen und Nord-Hessen, NW-Deutschland)]

Kurzfassung: Eine räumliche Kompilation und Darstellung von Löss-Parametern wurde für die pleistozänen Lösse und löss-ähnlichen Sedimente im Weser-Aller-Einzugsgebiet (Süd-Niedersachsen und Nordhessen, NW-Deutschland), einer der Lössregionen in Mitteleuropa, durchgeführt. Erstmals wurden Daten, soweit verfügbar, über die wichtigsten Lösseigenschaften, wie Mächtigkeit, Granulometrie und Stratigraphie mit räumlichen Informationen von Karten kombiniert und ausgewertet. Die Datenerfassung und – analyse in einem Geographischen Informationssystem (GIS) ermöglichte die Ableitung großformatiger thematischer Lösskarten.
Daten über Lössmächtigkeiten wurden analysiert und zu einer regionalen Mächtigkeitskarte kompiliert. Zusätzlich dazu wurden zahlreiche Lössvorkommen mit anormaler Mächtigkeit aufgrund spezieller geologischer und geomorphologischer Bedingungen abgegrenzt. Mehrere Lössregionen mit unterschiedlicher granulometrischer Fazies wurden ausgeschieden. Zudem konnten regionale Lössdecken unterschiedlichen Alters kartiert werden. Die Lössdecken im nördlichen Teil des Untersuchungsgebietes haben jungweichselzeitliches Alter, dagegen wurden im Bergland Regionen mit unvollständigen und gut gegliederten weichselzeitlichen Lössabfolgen nachgewiesen. Die Ergebnisse der Untersuchung zeigen, dass auf der Grundlage veröffentlichter, heterogener Daten neue Aspekte und regionale Muster abgeleitet werden können.

Keywords: *loess, loess-like deposits, Pleistocene, Weichselian, spatial analysis, NW Germany*

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1 Introduction

Loess and loess related sediments cover wide parts of Europe. In North-Western and Central Europe they form a continuous loess belt, trending roughly in ESE-WNW direction. The belt is limited by a northern and southern boundary (Haase et al. 2007). In Germany, the northern boundary of the loess belt runs north of the Rhenish Massif, the Harz Mountains and the Ore Mountains and separates the loess and loess-like sediments from cover sands and drift sands (Eissmann 2002, Haase et al. 2007). Five main loess regions adjoin to the northern boundary. These are from west to east the lower Rhine area, southern parts of the Weser-Aller catchment (southern Lower Saxony and northern Hesse), the loess region northeast of the Harz Mountains (Saxony-Anhalt) and the loess region north of the Ore Mountains (Saxony).

The loess and loess related sediments in the Weser-Aller catchment were the subject of many mapping campaigns and studies. Grupe (1916a) and Seltzer (1936a, 1936b) recognized different layers, paleosols and ice-wedge pseudomorphs in the loess outcrops and tried to distinguish loessic sediments of different ages. Schönhals, Rohdenburg & Semmel (1964) published a detailed stratigraphy of the loesses in Hesse that is based on paleosols and tephra. Rohdenburg & Meyer (1966) extended the Eemian and Weichselian part of the pedostratigraphy to southern Lower Saxony and northern Hesse. Rohdenburg (1966) added ice-wedge pseudomorphs. Subsequently, new facies types (Breinum soil, Hattorf soil, Alversdorf soil) of the Middle Weichselian Lohne soil were described by Bartels & Rohdenburg (1968), Ricken & Meyer (1982), Ricken (1983) and Brosche & Walther (1978, 1991).

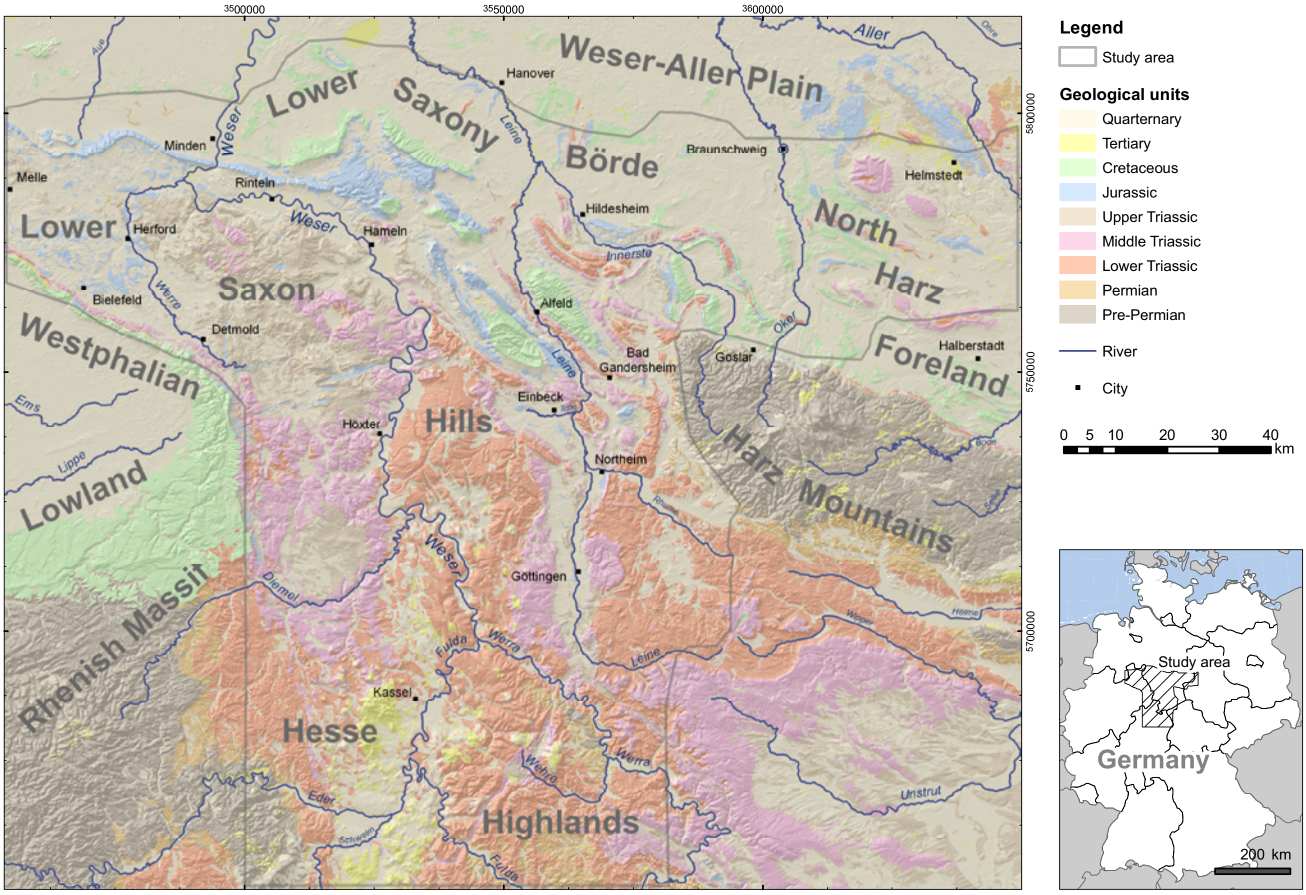

Fig. 1: Outline, main geological units and shaded relief of the study area. (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0)

Abb. 1: Umriss, geologische Haupteinheiten und beleuchtetes Geländemodell des Untersuchungsgebietes. (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA, Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0)

Ricken & Grüger (1988) verified the age of the oldest palaeosols based on a transition between dated lake sediments and paleosols of Eemian and Early Weichselian age. Roeschmann et al. (1982) published a compiled overview of the paleosols in Lower Saxony and Bremen. This loess stratigraphy was proven and correlated with other regions (e.g. Ricken 1983).

In the following years scientists mapped and published a lot of detailed individual loess sections or outcrops in smaller areas based on the above mentioned pedostratigraphy. Brosche & Walther (1978) examined and correlated sections in the brown-coal opencast pits near the northern loess boundary. Jauhiainen & Brunotte (1978), Schwartau (1978, 1979) and Brunotte & Jauhiainen (1979) described a complete Upper Weichselian section in the Leine valley. Ricken & Meyer (1982) and Ricken (1983) studied the loess cover and paleosols in the Southwest Harz Foreland and the Eichsfeld.

In northern Hesse Jacobshagen, Huckriede & Jacobshagen (1963), Bosinski (1969), Kulick & Semmel (1968) and Bosinski & Kulick (1973) analyzed archeological and paleontological findings in loess sections. Semmel (1967) reported new findings of Eltville tephra in Hesse and he published a summary of the loess sections in Hesse in 1968. Brosche & Walther (1980) studied loess outcrops in the Weser valley.

Furthermore, some isolated deposits of Lower or Middle Pleistocene age, not included by the pedostratigraphy of Rohdenburg & Meyer (1966), were examined. Most of the loess remnants survived due to special conditions, e.g. in grabens or subrosive sediment traps. Moreover, they contain paleosols or are intercalated with interglacial sediments. Lüttig (1960a), Jordan & Schwartau (1993) and Grüger et al. (1994) investigated such deposits in the Leine valley. Lüttig & Rein (1955), Lüttig (1965) and Bittmann & Müller (1996) analyzed the interglacial sediments and loesses in the Bilshausen clay pit in the Southwest Harz Foreland. Sabelberg et al. (1976) and Mahaney, Andres & Barendregt (1993) studied the stratigraphically important Dreihausen paleosol sequence in northern Hesse.

The loess and loess related sediments along the northern boundary contain no Eltville tephra and no paleosols of Weichselian age. Therefore, the pedostratigraphical scheme of Rohdenburg & Meyer (1966) can not be applied on these sediments. Gehrt (1989, 1992, 1994) mapped the loess near the boundary between the Leine and Oker valley. He found vertical and horizontal zones of different lithology and age. As a result, he defined a lithostratigraphy of this marginal facies. Hilgers et al. (2001) carried out luminescence dating in order to establish a chronostratigraphy for these loess and sandy-loess sediments.

Beside these stratigraphic investigations the authors tried to analyze the spatial properties of loess and to subdivide the loess region into subregions. Wortmann (1942) published the first loess map of Lower Saxony based on small-scale soil maps displaying sediment lithology and thick-

E&G / Vol. 60 / No. 1 / 2011 / 27–46 / DOI 10.3285/eg.60.1.02 /

ness. Merkt (1968) published a new version of a loess distribution map of southern Lower Saxony and adjacent regions. In contrast to Wortmann (1942), he exploited small-scale geological maps and unpublished material.

Müller (1961), Niederbudde (1976) and Siebertz (1988) analyzed loess properties (e.g. grain size distribution, mineral composition) to outline regional zones within the loess cover. Beside this, scientist tried to distinguish regions that show differences in paleosols, lithology or sequences. They aimed to determine climatic differences and trends. For example, Rohdenburg & Meyer (1966) published outcrop maps, maps of the Lohne soil distribution and described wet and dry loess provinces based on paleosols facies. Furthermore, Walther & Brosche (1983) gave an extended compilation of stratigraphical columns including climatic interpretation near the northern loess boundary. Brosche & Walther (1991) mapped a large number of loess sections in Lower Saxony and north-eastern North Rhine-Westphalia. They provided many details for the regional loess stratigraphy and to the geomorphological periods during the Weichselian. Correlation of loessic, solifluction deposits, fluvial and glaciofluvial sediments in the North Harz Foreland combined with luminescence dating was published by Reinecke (2006).

In spite of the huge dataset only few regional graphical presentations, e.g. location maps, distribution maps, facies maps (Rohdenburg & Meyer 1966, Walther & Brosche 1983, Brosche & Walther 1991), or maps, displaying the distribution of marker horizons like the Lohne soil or the Eltville tephra, were compiled. The available geological or loess maps give only limited information about the third dimension (e.g. thickness, loess sequences or the age of the loess deposits). In contrast to the regional overview of the loess properties in Eastern Germany by Eissmann (2002), there is no recent compilation of such data for Northwestern Germany.

The aim of this study is a regional overview of the main loess characteristics (granulometry, thickness and stratigraphy) in the Weser-Aller catchment which is based on all available descriptive or graphical data. The second objective of the investigation is a spatial analysis of the existing data in order to recognize spatial patterns of regional scale. The following questions are addressed:

- May spatial information be extracted from published data?
- To which level of spatial and qualitative accuracy can the data be extracted over the extended area?
- Can regional ages of the loess cover be estimated, if there are only few numerical ages available?

2 Background

Study area

The study area is located in Northwest Germany covering an area of about 17,800 km² (Fig. 1). It comprises the southern part of the Northwest German Plain and the northern part of the Northwest Central Uplands. The study area is bordered by the Harz Mountains, the Thuringian Basin, the Vogelsberg Mountains, the Rhenish Massif and the Westphalian Lowlands. The rivers Weser and Aller and their tributaries drain wide parts of the study area. The elevation ranges from 30 m a.s.l. in the North to 730 m a.s.l in the South.

The area is subdivided into the northern lowland and the southern mountainous region. The northern part comprises the Weser-Aller Plain, the Lower Saxony Börde and parts of the northern Harz Foreland. The region is covered by extended Pleistocene and Holocene sediments. The underlying Tertiary to Mesozoic sedimentary rocks are exposed in a few ridges or hills only (Fig. 1).

The southern mountainous area is subdivided into the Lower Saxon Hills including Weser and Leine Hills (or Weser-Leine Uplands) and the northern Hesse Highlands. In the higher parts, ridges or hills with marine to terrestrial sedimentary rocks of Upper Palaeozoic to Tertiary age are exposed. In the South mainly Triassic rocks crop out, whereas to the North mainly Jurassic to Cretaceous rocks are exposed. Weak to strong tectonic overprint of the pre-Quaternary rocks is evidenced by normal faults and grabens, inverse faults, thrusts and folds. The tectonic pattern is also influenced and complicated by strong halokinetic processes like salt movements, salt dissolution, and salt intrusion in relation to the various salt-bearing Permian to Mesozoic strata. These processes are still ongoing. The main tectonic directions, visible in the orientation of the large folds, faults, ridges and valleys are NW-SE, N-S and NE-SW. This complex geology of the pre-Quaternary bedrock results in a heterogeneous, small-scale regional pattern of valleys, hills, basins and grabens. Quaternary sediments were mainly accumulated in the valleys, on slopes and in upland basins or marginal basins.

The distribution of the Pleistocene sediments is characterized by three important boundaries (Fig. 2). The northern boundary of the loess belt runs along the line Melle – Minden – Hanover – Braunschweig – Helmstedt. It separates the almost continuous cover of loess and loess-like sediments in the South from regions in the North, where predominantly cover sands and drift sands were deposited. The southern boundaries of the Elsterian and Saalian glaciation cross the study area along a line Rinteln – Alfeld – Seesen – Goslar (Kaltwang 1992). They separate the periglacial Pleistocene sediments in the South from the glacial, glaciofluvial, periglacial and fluvial deposits in the North. The ice-shield of the Weichselian glaciation did not extend to the study area.

Aeolian sediments

The aeolian sediments of the study area can be subdivided by their grain-size distribution into aeolian loess, sand-banded loess, sandy loess, and cover sand (Vierhuff 1967, Weise 1983). In general, the light-coloured, calcareous, unstratified, loess contains more than 15 % of silt (medium to coarse silt), less than 15 % sand (0,063–2 mm), and clay. The sandy loess consists of more than 15 % sand and more than 15 % silt (maxima in medium to coarse silt). The sand-banded loess is a stratified mixture of loess and sandy-loess. During the last century local German names, like "Flottsand" and "Flottlehm" were used for sandy loess. These terms are not exactly defined and used by different authors for different aeolian sediments (Wortmann 1942, Siebertz 1982, Siebertz 1992). Generally "Flottlehm" is a silt-rich sandy loess and "Flottsand" a sand-rich sandy loess (Gehrt 1994). Cover sand has an even higher sand content.

Apart from these, some more loess-like deposits are relevant, which were originated from loess by different processes. Loamy loess or loess loam is loess which was decalcified during weathering and soil genesis. Soliflucted reworked loess was generated by downslope movement during gelifluction or solifluction, which results in a mixed, banded or chaotic structure with possible higher amounts of clay, sand, or blocky gravel from over- or underlying material. The colour is strongly influenced by the amount of these contaminants. When aeolian loess is eroded and transported by water, fluvially reworked loess with a striated structure and gravel or sand intercalations will be deposited.

A special type of aeolian deposition is represented by mixed layers of glacial loam, sand, and silt on top of unweathered glacial till. Many authors interpret their fine sand and silt content as aeolian relics, reworked and incorporated in these layers. This "Geschiebedecksand" may have a basal stone layer, fluvial structures and cryoturbation features.

Loess regions

The northernmost part of the loess belt investigated comprises the "Börde" – a loess-rich region between the northern loess boundary and the slopes of the Lower Saxon Hills and the Harz Mountains (Fig. 2). The almost flat plain ascends slightly to the South. It is underlain by thick glacial, glacio-fluvial and periglacial sediments. The region is structured only by few ridges or swells of Mesozoic bedrock (Fig. 1).

The Börde is 6 to 30 km wide in North-South direction and separated by the Weser, Leine, Innerste, and Oker valleys into different segments: the narrow Lübbecke Löss Börde, the A-shaped Calenberg Löss Börde and the Braunschweig-Hildesheim-Börde. The Börde zone merges east of Helmstedt into the Magdeburg Börde. The loess accumulated all over the lowland and on most slopes, only dissected by drainage networks.

The Elm-Asse-Helmstedt region east of the Hildesheim-Braunschweig-Börde also borders to the northern boundary of the loess belt. This region is characterized by a quite different morphology more similar to the upland dominated by several NW-SE-trending anticlines and synclines of folded Mesozoic to Tertiary sedimentary rocks, where the Elm and the Asse are the largest domes. Due to the undulating morphology the loess cover is not continuously, loess is enriched in valleys and slopes, basins and lower ridges (Merkt 1968). According to Wortmann (1942) there is also loess on the higher parts of the slopes, even on the hills and ridges, e.g. parts of the Elm.

Some areas, which are separated from the loess boundary by ridges and small uplands or those located in the Lower Saxon Hills, have a Börde-like appearance. This includes a huge, extended loess cover and wide, flat areas with smooth or undulating morphology. The loess cover is only dissected by the recent drainage network or influenced by some steeper ridges or slopes. There is the wide region between the Harz Mountains and the anticlines in its foreland and the Ravensburg Hills, a long stripe between the Wiehen Hills, the Tecklenburg-Osning and the Wehre valley in the easternmost part of the study area.

In contrast, the uplands south of the Calenberg Börde and the Hildesheim-Braunschweig Börde, the so called Leine Uplands, show a more pronounced morphology which is caused by synclines, anticlines, and thrusts of folded Mesozoic rocks. The Leine Uplands are subdivided by the narrow Leine and Innerste valley into the Calenberg Uplands, Alfeld Uplands and Innerste Uplands. According to Merkt (1968) loess covers the flat regions, the north-eastern and northern slopes and few south-western slopes of the elongated valleys and hills up to 200 to 250 m altitude and is accumulated in some grabens and subrosion-related structures.

The morphology of the above mentioned long and narrow valleys and basins is quite different from the more irregular and diverse loess accumulation sites in the central parts of the upland. The deposition structures of various sizes and shapes occur mainly within plateaus of Triassic sedimentary rocks, which are dissected by several faults and influenced by subrosion activities. The loess was accumulated in the shallow basins, in sinks, tectonic grabens, and mainly on eastern, north-eastern, and northern slopes up to 230 to 270 m altitude, and in drainage features. The higher ridges, hills, and steep slopes are free of loess. The situation is typical for the Lower Eichsfeld Basin, the Uslar Basin, and the Warburg Börde but is also found within the Lippe Upland, the Pyrmont Uplands and Oberwälder Land, and the Waldeck Uplands and Plains.

Apart from these small-scale irregular and shallow loess accumulation structures wide and extended depressions occur within the Uplands. They were filled with Tertiary and Quaternary sediments during long-lasting periods of subsidence caused by tectonic or halokinetic processes. Loess accumulated within the depressions mainly on the eastern slopes. Large depressions are located in the Leine-Ilme Basin and the West Hessian Depression.

Southwest of the Harz Mountains there are marginal basins with Tertiary fillings and strong subsidence. The basins are smaller and show a small-scale pattern of valleys and ridges. Typical for this type is the triangular Southwest Harz Foreland between the Alfeld Uplands and the Harz Mountains. Common subrosion and karst features are related to highly soluble Permian sulphate and carbonate rocks. Loessic sediments cover the plains, the basins, the valleys and the slopes up to 200 to 300 m in elevation.

The main river valleys within the Lower Saxon Hills and the Hesse Highlands are also distinct, morphological traps for loess deposition. They are treated as separate loess regions in this study. The valleys of the rivers Weser, Fulda, Werra and Leine are rich in loess compared to the adjacent regions.

The upper Leine valley between Göttingen and Einbeck, South of the Leine-Ilme Basin, is mainly influenced by the complex structure of the N-S-striking Leine valley Graben. The wide valley with the distinct, fault-related slopes has a closed loess cover, quite different from the adjacent hills. The valleys of the rivers Fulda, Werra and Werre in the Southeast of the study area follow tectonic structures in a small-scale pattern of NW-SE-trending faults and fractures. The loess accumulated in the narrow and steep valleys, especially on the western or north-western side up to 250 m in elevation. The bedrock consists of Lower Triassic sandstones and subordinate Paleozoic rocks.

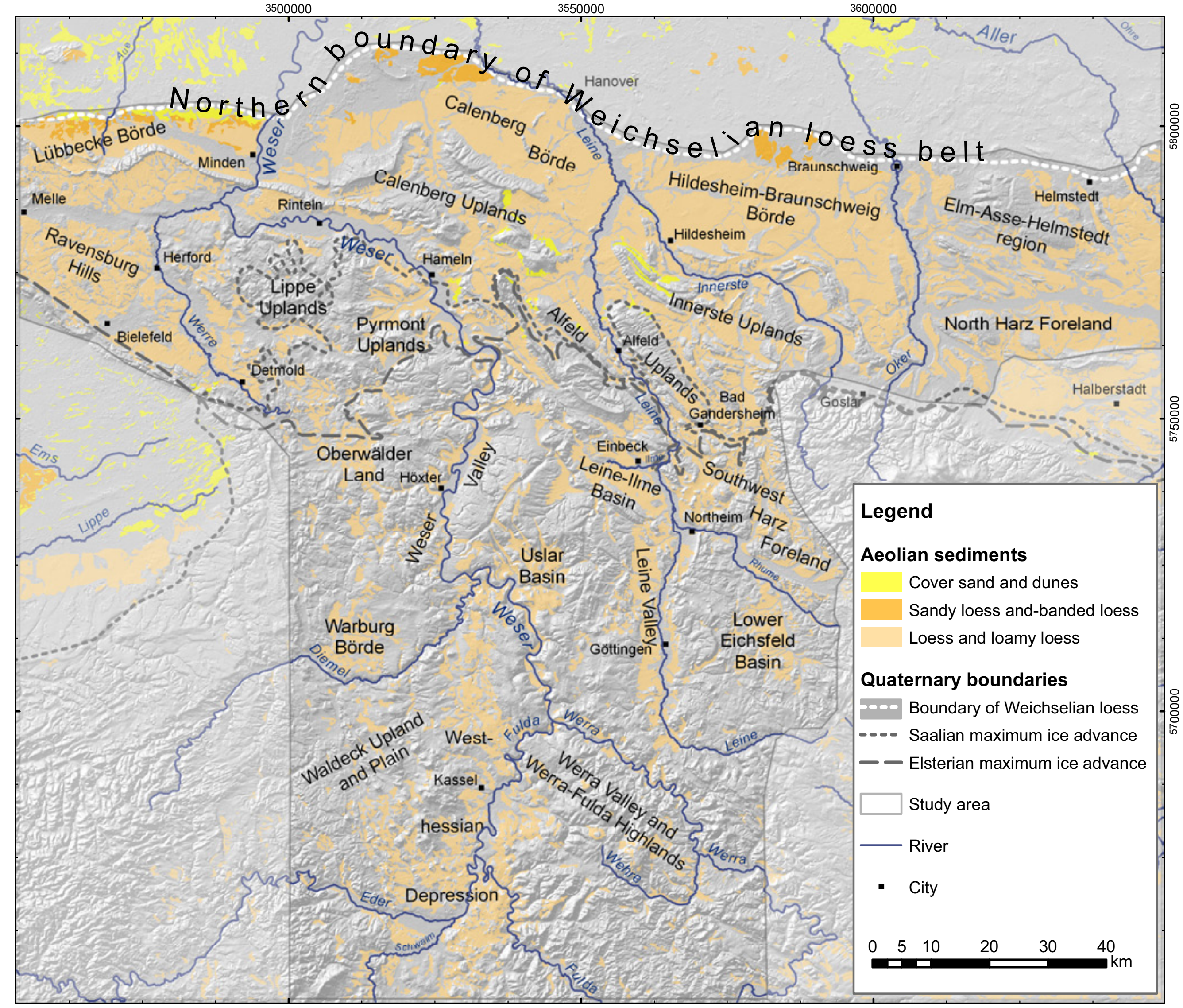

Fig. 2: Aeolian sediments, loess regions and main boundaries of Quarternary age. (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0; maximum ice advance: Kaltwang 1992)

Abb. 2: Äolische Sedimente, Löss-Regionen und wichtige quartäre Verbreitungsgrenzen. (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA; Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0; Maximale Eisausdehung: Kaltwang 1992)

The upper Weser flows in a narrow, meandering valley deeply incised in Lower Triassic sandstone through the so-called Upper Weser Uplands. North of Hameln the river flows in a NW-SE-trending valley through Middle to Upper Triassic and Jurassic to Cretaceous rocks of the Lower Weser Uplands. The river leaves the Lower Saxony Hills through Porta Westphalica and enters the loess Börde of the Northwest German Plain. Along the river loess was mapped on the valley slopes on one or both sides, favourably on northeast-, north- and east-facing sides up to 200 to 300 m altitude. Graupner (1970) and Brosche & Walther (1991) already noted that the region south of Hameln is richer in loess. Single loess deposits were mapped in abandoned lobes, incoming valleys, or subrosive sinks. With increasing distance from the main valley the loess cover thins out and is only found in some patches. Wortmann (1942) mapped some parts of the Weser valley. His loess patches are a bit larger and more connected than on the other maps.

Loess stratigraphy

The loess stratigraphy of the study area comprises Upper Pleistocene loessic sediments and paleosols (Tab. 1). The stratigraphically lowest part of the Upper Pleistocene is the Eemian interglacial soil, a typical brown haplic luvisol (WRB). The Lower Weichselian is composed of loess, which is in most cases decalcified, and has a strong pedogenetic overprint. Besides loess a lot of other sediments are typical for this unit, like pedosediments of Lower Weichselian or Eemian soil horizons, glaciofluvial and glacial sediments, or weathered bedrock. In the stratigraphically upper part of the Lower Weichselian sequence the loess amount increases. The most prominent pedogenetic features are Ah, Al and Bt horizons and features related to stagnic conditions. These soil horizons are relics of haplic chernozem, rendzic leptosol, haplic luvisol and stagnic gleysol. Ricken (1983) mentioned cycles from dry to wet conditions inferred from these palaeosols. The main important marker horizons are up to four Ah horizons includ-

Table 1: Pedostratigraphy of the loess- and loess-like sediments in southern Lower Saxony and northern Hesse (after: Rohdenburg & Meyer 1966, Ricken & Meyer 1982, Brosche & Walther 1991, Pouclet & Juvigne 2009).

Tabelle 1: Pedostratigraphie der Löss und löss-ähnlichen Sedimente in Süd-Niedersachsen und Nordhessen (nach: Rohdenburg & Meyer 1966, Ricken & Meyer 1982, Brosche & Walther 1991, Pouclet & Juvigne 2009).

Period	Loess and loess-related sediments	Marker horizons: southern Lower Saxony		Marker horizons: northern Hesse	Age (ka)
Late Weichselian			Laacher See Tephra		12.900
Upper Weichselian	wj5 alpha loess	wj4 beta soil			
	wj4 alpha loess	wj3 delta soil	Eltville Tephra	E4	20.000
	wj3 gamma loess	wj3 beta soil		E3	
	wj3 alpha loess	wj2 beta soil		E2	
	wj2 alpha loess	wj1 gamma soil		E1	
	wj1 beta loess				
	wj1 alpha loess				
Middle Weichselian	wm	Lohne soil & equivalents		Hahnstatt soil	30.000
		Kirchberg soil		Gräselberg soil	
		Herzberg soil	Niedervellmar soil complex		
Lower Weichselian	wa2	Ah horizon	Niedervellmar soil complex		
		Ah horizon	Niedervellmar soil complex		
	wa1	Ah horizon			
		Ah horizon	Bilshausen soil complex		
Eemian		Eemian soil	Bilshausen soil complex	Erbach soil	117.000

ing one typical Al horizon (bleached zone), disconformities (stone layer), a basal solifluction layer, enrichments in Mn-Fe concretions and charcoal. Due to the wide range of sediments, the influence of local material and the possible soil horizons the Lower Weichselian sections show a high heterogeneity. Without the prominent Ah horizons a clear correlation of different sections is quite difficult.

The Lower Weichselian in the study area was subdivided by Rohdenburg & Meyer (1966) and Ricken & Meyer (1982) into a lower unit (wa1) and an upper unit (wa2). Generally, the base of wa1 is a solifluction deposit of reworked Eemian soil material, the stratigraphically youngest Ah horizon is the boundary to the Middle Weichselian. In some locations a loamy soil complex (Niedervellmar soil complex) was formed instead of typical soil horizons. If it is overlain by Middle Weichselian arctic brown soils or loamy loess, no clear boundary can be drawn. The authors dated the Niedervellmar soil complex as a part of the wa2 and wm (Tab. 1).

The Middle Weichselian is characterized by calcified or partly decalcified loess, a high amount of fluvially reworked loess, and intercalations of gravel and sand. In the loess sequence, artic brown soils and arctic soils are found, e.g. the Herzberg soil and the Kirchberg soil. Reinecke (2006) described very detailed Middle Weichselian loess sequences with several intercalated soils east of the study area. The most prominent marker horizon is the Lohne soil, which is correlated with the Denekamp interstadial. Bartels & Rohdenburg (1968) described a greyish brown soil equivalent called Breinum soil, Ricken (1983) found a stagnic palaeosol of the same age termed Hattorf soil, and Brosche & Walther (1991) located an arctic paleosol equivalent termed Alversdorf soil. The Lohne soil and its equivalents correlate to the top of the Middle Weichselian record.

The Upper Weichselian is the most homogeneous unit of the study area (Rohdenburg & Meyer 1966). It is composed mainly of loess. Up to five arctic palaeosols are found in the loess sequence (wj1gamma, wj2beta, wj3beta, wj3delta, wj4beta), generally the wj3delta soil is the most prominent one. Besides the soils the Eltville tephra, ice-wedge pseudomorphs of various sizes, and frost fissures are important marker horizons. The uppermost arctic paleosol (w4beta) was found very seldom, sometimes in sinks of ice-wedge pseudomorphs, normally but masked by the Holocene soil formation.

3 Data

The available published data about loess in the study area can be subdivided into three different types (Fig. 3).

- The first, most important data type includes descriptions of loess sections, outcrops, or drill-holes. The information is provided mainly as text, sketches or pictures, and few tables.
- In contrast, the second type of data comprises descriptions about loess properties in a limited area, such as local thickness, granulometry, age, or facies of loessic sediments.
- The third type compiles data about loess properties that are already published in a two dimensional way. These can be hard-copies of maps or digital maps. They cover more or less the whole study area, because of the large-scale.

The main data sources used are publications, maps and digital data. Most of the articles, mentioned in the previous chapter, contain extensive descriptions and sketches of loess sections, outcrops and drill-holes. Furthermore, they comprise comments about the local and regional loess properties. These papers are the essential data source of the study.

Additionally, publications about Holocene and Pleistocene sediments were examined, as well as palaeobotanical, geomorphological, archaeological or paleontological topics including supplementary details about loess and loess-like sediments. Furthermore, releases like excursion guides or general publications about the occurrences of unconsolidated construction material or brown coal deposits were included.

Other important input sources are explanatory notes on the geological map sheets. The German geological map sheets on a scale of 1: 25,000 (GK25) have been mapped since the late 19th century by the regional Geological Surveys (Fig. 4). Together with every completed map sheet, the Geological Surveys published an explanatory report of varying extent. In these explanatory notes the authors described every geological unit in detail and added further

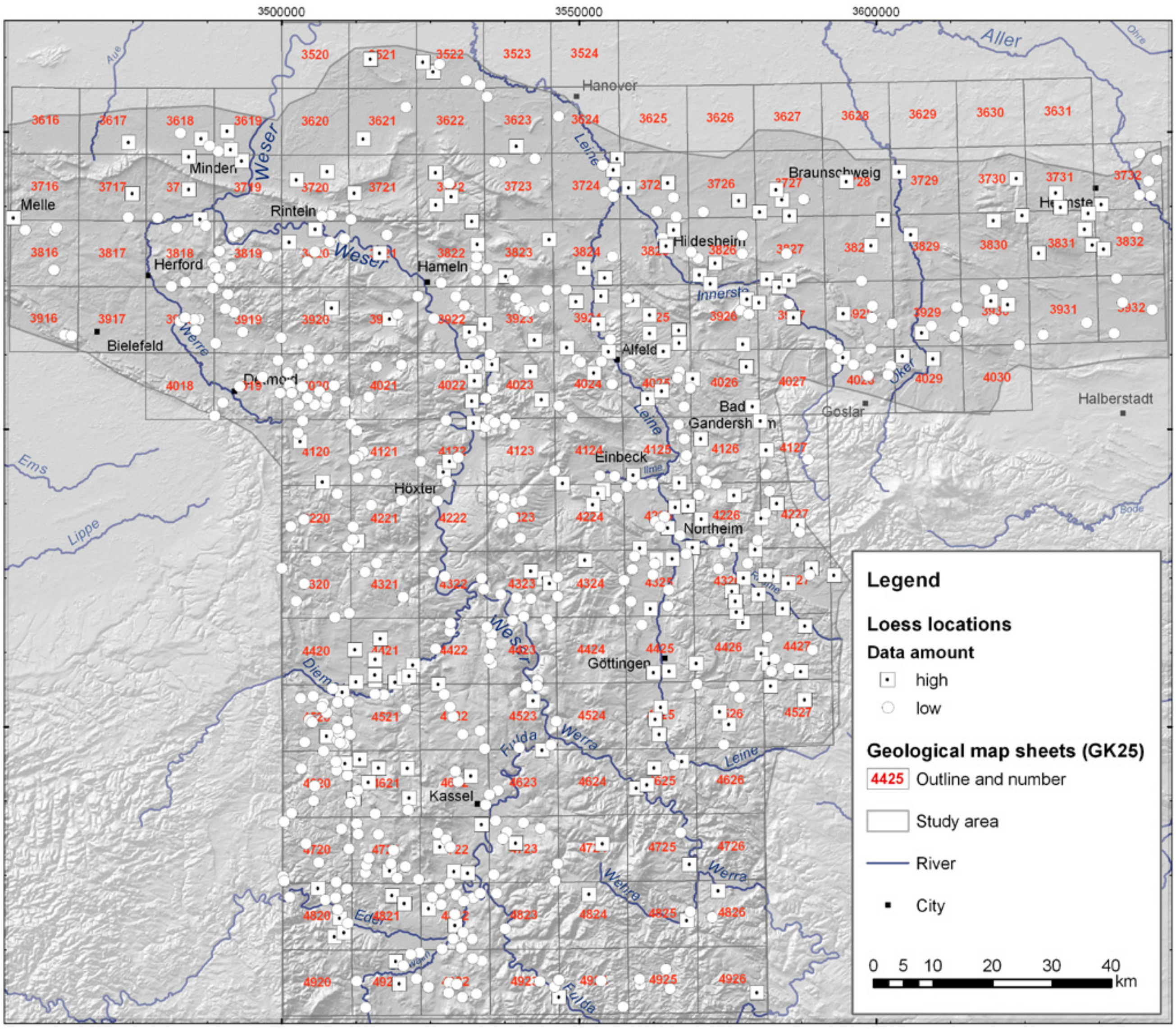

Fig. 3: Loess locations and outline of geological map sheets (1: 25,000 – GK25). (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0)

Abb. 3: Lösslokationen und Umrisse der geologischen Kartenblätter (1: 25.000 – GK25). (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA; Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0) descriptions that are not presented on the associated geological map. For that reason, in most explanations some loess sections or drill-holes have been described in detail and some outcrops with remarkable thickness were cited. Furthermore, the authors released short or extended descriptions of the properties of the loess and loess-like deposits in the particular area covered by the map sheet.

Moreover, different thematic maps, either as hard copies or as digital data, were used for the study. The following three thematic loess maps, available as hard copies, were analyzed.

- The loess map of Wortmann (1942) on a scale of 1: 700,000 is based on small-scale soil maps. On the map the units of the aeolian sediments are classified according to granulometry (loess, "Flottlehm", "Flottsand" and sandy loess) and thickness (0.2 to 0.5 m; 0.5 to 2 m and more than 2 m). Cover sands and drift sands were not considered, because the author could not infer them from the soil maps. The map covers southern Lower Saxony and small areas of Saxony-Anhalt and Thuringia.
- The loess map of Merkt (1968) is based on published geological maps and unpublished drafts from the Geological Survey of Lower Saxony on a scale of 1: 25,000 and a 1: 200,000 general map. The scale of the loess map is 1: 300,000, covering southern Lower Saxony and small parts of North Rhine-Westphalia, Hesse and Saxony-Anhalt. Merkt (1968) distinguished loess, sand-banded loess as well as sandy loess and separated two thickness classes. Additionally, he illustrated the heterogeneous data level of each input map as a small figure.
- Müller (1961) outlined loess, sandy loess, cover sands and drift sands, weathered soils and recent deflation areas on the loess map of North Rhine-Westphalia on a scale of 1: 1,000,000. The latter author distinguished four loess regions according to their grain size values and mineral composition, but without thickness data. Only region IV (Lower Weser Upland) of Müller (1961) belongs to the recent study area.

Furthermore, a geological map of the whole study area was incorporated. The geological map of Germany on a scale of 1: 200,000 (GÜK200) is a digital and generalized compilation of all German geological maps sheets on a scale of 1: 25,000 (GK25). The part of the GÜK200 that covers the study area was used in this study. In contrast to the above maps, this digital map has an attached database containing properties of all mapped units. Aeolian sediments are subdivided in loess and loamy loess, sandy loess and cover sands. But there are no thickness values. A digital elevation model based on ASTER satellite data with horizontal resolution of 25 m x 25 m was inserted. These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (lpdaac.usgs.gov). ASTER GDEM is a product of METI and NASA.

4 Methods

GIS

The database of this study consists of a huge, heterogeneous data set of point data, local descriptions and regional information. All types of data contain spatial references (information about location or coordinates). For spatial analysis the GIS software ArcGIS was used which permits storage, display and analysis of spatial data in so called layers. The graphical part of the data (the map content) is represented in vector format as points, polylines or polygons, or in raster format as images or grids. The individual layers can be superimposed exactly above each other according to accurate coordinates, comparable to a traditional stack of maps or transparent papers. In contrast to a traditional

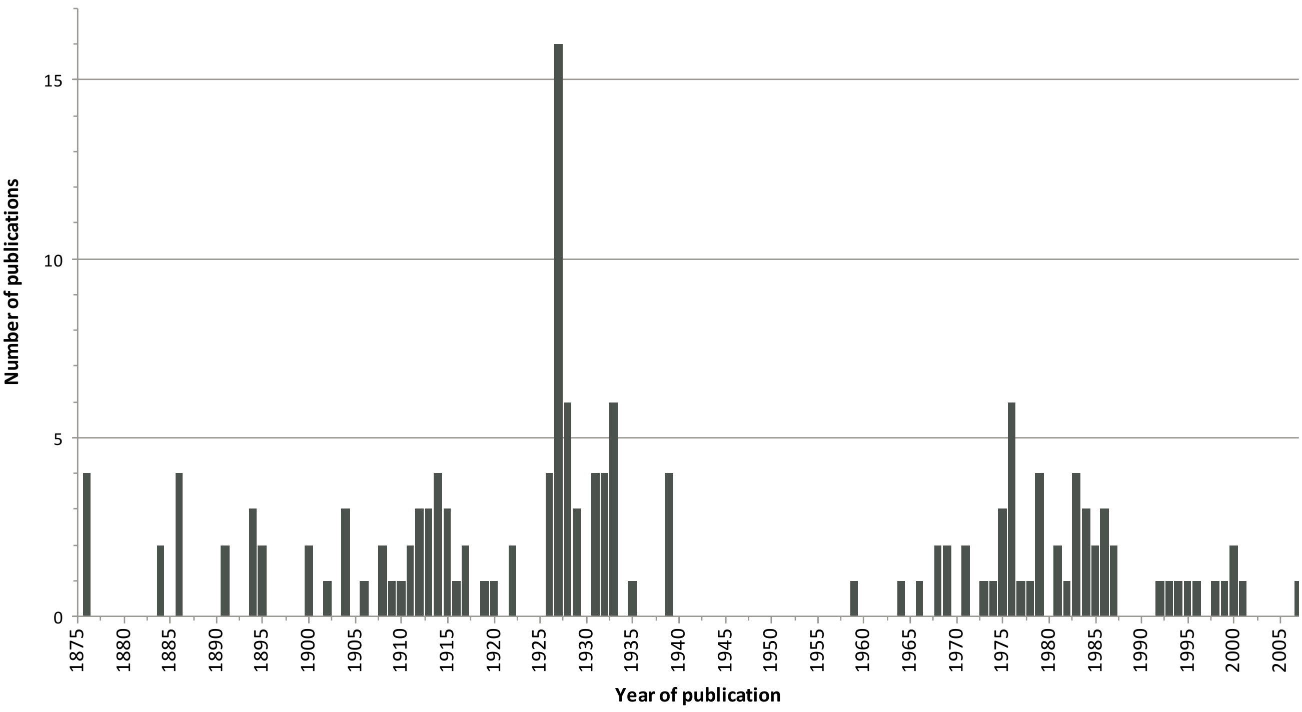

Fig. 4: Year of publishing and number of published explanations on the geological map sheets on a scale of 1: 25,000 (GK25) of the study area.

Abb. 4: Jahr der Veröffentlichung und Anzahl der veröffentlichten Erläuterungen zur Geologischen Karte 1: 25.000 (GK25) des Untersuchungsgebietes.

stack of maps or image processing in graphical software packages the GIS software stores attribute data of each object in a connected table or database. For further analysis objects with relevant attribute data can be extracted based on logical queries, displayed, labelled, and overlain.

A new GIS-project in ArcGIS with the coordinate system Gauß Krüger Zone 3 was created. Firstly, the digital data (GÜK200 files, ASTER DEM files) were imported and prepared for further analysis. The single tiles were merged to create mosaics, the part of the mosaic, covering the study area was clipped. The clipped files were transformed from geographic coordinates to the projected coordinate system Gauß Krüger Zone 3. Afterwards the hard copies of the analogue loess maps were scanned, added to the GIS project, and geo-referenced. Finally, different shaded relief images on the basis of the DEM were calculated.

In contrast to processing of the digital input data most of the spatial information about loess properties is expressed in texts, tables, or sketches in loess-related publications. For use in the GIS program they have to be transformed into GIS layers. Hence, two types of layers for the different data types were created.

The first one is a point layer representing loess outcrops, drill-holes, or sections. All points, independent from outcrop type, were named as "loess locations". These loess locations were digitized as points according to their coordinates or position details or copied from geo-referenced location maps.

Sometimes several single descriptions of loess sections had to be generalized and combined to one loess location. The reasons for that may be that

- different sections were mapped in one outcrop or clay pit,
- several descriptions on one outcrop were made by different authors, or
- several loess outcrops are located close to each other in one region.

These "summary" locations were named after the nearest village, town or natural region. In the connected attribute table the following data, if available, of each loess location were stored:

- name of the loess location
- description of geographical location
- coordinates
- data source
- structural type
- granulometry of sediments
- thickness
- marker horizons
- stratigraphical ages
- fossil content

Hereby, as much information as possible, preferring the latest published data, were extracted and stored. Additional data from older publications were added to create complete description. Unsure and inaccurate descriptions and sections that could not be located were excluded.

In summary, 639 loess locations were created (Fig. 3). Their available attribute data are very heterogeneous, because of large differences in quantity and quality of the outcrop descriptions. They range from few hints about loess outcrops to detailed descriptions with a lot of parameters. The reasons are the different publishing dates of the papers and the context, in which the outcrops were examined (loess, fluvial sediments, deposits, paleontological or archeological investigations). In many loess locations some parameters or details are missing. Most information was available about thickness, less information about the other parameters. Sometimes the description is based on incomplete stratigraphy. The loess locations were classified in a group of very detailed data (421 locations) and in a group of general data (218 locations).

Secondarily, a polygon layer in the GIS project was created to store the data extracted from the explanations on the geological map sheets in scale 1: 25,000. The outline of each map sheet was digitized as rectangle (Fig. 3). All loess-related information was stored in the related attribute table, including:

- number of explanatory note
- publishing year
- author(s)
- loess distribution
- accumulation zones
- horizontal zones and granulometric boundaries
- granulometry and vertical sequences
- morphology of loess cover
- thickness
- stratigraphic age
- fossils
- cryoturbation features

From the notes as much information as possible was extracted, more recently published explanatory notes were preferred. Older notes were checked, additional facts and descriptions were added, if available.

In summary, all available notes were examined and data of 152 of them were stored. The notes were published between 1876 and 2007 (Fig. 4), therefore amount and quality of loess-related data are very heterogeneous. Most publications were released in the 1920s and 1930s or between 1960 and 1985. The older notes released before 1940 give only few details on loessic sediments. Aeolian loess and loess derivates are not differentiated. Moreover, in the oldest prints there is no differentiation between loess and floodplain deposits. Sometimes one note describes two or three map sheets. Few map sheets were published without explanatory note.

In addition to the layers "loess locations" and "explanatory notes", other layers in the GIS project including digitized main topographic features (e.g. rivers, cities, geological boundaries) were created.

Selection of base map

The accurate distribution of loess and loess-like sediments in the study area is a fundamental base for further analysis of the parameters thickness, granulometry and age. The study is not a mapping campaign, so a base map showing a realistic loess distribution to work with had to be selected. The already mentioned loess maps of Wortmann (1942), Müller (1959) and Merkt (1968) and the digital geological map (GÜK200) were evaluated based on the parameters: scale, units, coverage, accuracy and publishing age. The result shows that none of them displays a realistic distribution of loess and loess-like sediments. Reasons are the difference in the map coverage and the inaccuracy due to the combination of aeolian loess, loamy loess, soliflucted or fluvial reworked loess to one „loess unit“. Sometimes even younger colluvial or slope sediments were included.

It is also obvious that the maps based on geological surveys display a smaller, fragmented loess cover, which was caused by the mapping policy before 1960s. Field geologists drilled only few 1-m drill-holes per map sheet. They focused on the mapping of the bedrock to visualize the complex geological and tectonic situation, especially in the Lower Saxon Hills and the Hesse Highlands. Even when the bedrock was only visible in boulders or referred from morphological bends, they mapped the bedrock unit instead of the overlying loose material.

Lüttig (1968) compared the results of different geological surveys in 1890–1891, 1948 and 1956/1961 on the the geological map sheet 4325 (GK25). He proved that a more accurate distribution of loess is displayed in the latest map only, covering much larger areas than in the older maps. From the 1960s on field geologists drilled much more drill-holes (2 m) and tried to map the uppermost geological unit. Most GK 25 sheets, which are the database of the map of Merkt (1968) and GÜK200, were mapped before 1960; some are younger reprints or revision maps with only little changes. Field geologist had no general rule how to map the minimal thickness of loess. Therefore, the loess distribution based on the geological maps show a minimum loess distribution representing a loess cover thicker than 0.5 m, 1 m or 2 m.

The loess unit of the GÜK200 and the loess map of Merkt (1968) show a lot of similarities. In few regions, the GÜK200 shows smaller loess patches. The map of Merkt (1968) displays locally a more realistic distribution. The author examined not only the published GK25 map sheets, but also drafts of modern, unpublished mapping campaigns from the archive of the Geological Survey of Lower Saxony, resulting in some differences and sharp edges between adjacent regions.

The loess map of Wortmann (1942) displays a larger, but also inaccurate loess distribution. The map is based on soil survey campaigns. The uppermost geological unit has a high influence on the resulting soil. Hence, the soil map reflects much more information about the loess and loess-related sediments than the underlying hard rocks. Comparing this map with the map of Merkt (1968) and the GÜK200, a much larger area of loess cover becomes obvious especially in the uplands. However, the map contains loess patches close to the main rivers, where no real loess can be found. Possibly Wortmann (1942) combined loess and loess derivates with younger flood plain deposits (colluvial loess).

Although none of the maps shows a realistic loess distribution, each of them inhibits important details. Therefore, the comparison between the geology based maps and the soil based map can give additional information. This applies especially to thin loess covers in the uplands as recorded by Wortmann (1942).

However, the GÜK200 was selected as main base map for the following analysing steps of the study. The map shows smaller loess patches than the other maps and is based on an unclear minimal loess thickness to be mapped. Nevertheless, the map covers the whole investigation area and is the most detailed because of its small scale. The map is in a digital format, representing the loess and loess-related sediments as polygons, to which new information can be added.

Thickness

In the GIS project all objects of the layers "loess locations" and "explanations" that contain thickness values or thickness ranges were displayed. Each object was labelled with these values or ranges. The loess map of Merkt (1968) was used as background. Then all available thickness values were explored for their minima, their maxima and their typical ranges.

To define thickness classes for a compiled thickness map, some limitations of the data set had to take into account. In general, a loess cover has a very wide range of thickness values in one area depending on the local morphology. There is no or only few loess on steep slopes, but very much loess on E-facing slopes or in other accumulation positions. And there are a lot of transitions between these extremes.

For that reason, wide thickness classes covering the typical ranges of loess thickness were defined. The main focus laid on the maximum values.

> 0.5 to > 2 m (few data)
≤ 3 m
≤ 5 m
≤ 6 m
2 – 8 m
3 – 10 m
3 – 20 m

The thickness values of all input sources were compared and new patches of the same thickness class were outlined. The new thickness classes were added to the polygons of GÜK200.

The following rules were set for this procedure:

- If the area was not covered by the map of Merkt (1968) and no further information (loess locations, descriptions) were available, the class "> 0.5 to > 2 m (few data)" was selected.
- The thickness data of the loess map of Merkt (1968) were copied, if no further information (loess locations, descriptions) were available.
- The same was done, if the loess locations and the thickness in the loess map were similar.
- New thickness patches were outlined, when the loess locations showed higher values, than the loess map of Merkt (1968).

The advantage of the method is the combination of different input data. Basal map information from the loess map of Merkt (1968) was used and regions with higher loess thickness were added. Nevertheless, the loess locations with thickness values are not distributed equally. In some regions no or few loess locations were reported in the literature. Additionally, authors mentioned minimal thickness values or combined thickness values of loessic sediments and other material in their publications.

Granulometry

In the GIS project a query was applied to display all objects ("loess locations" and "explanations") with data about petrography, grain sizes, and typical sediment sequences. The granulometric descriptions of the loess maps of

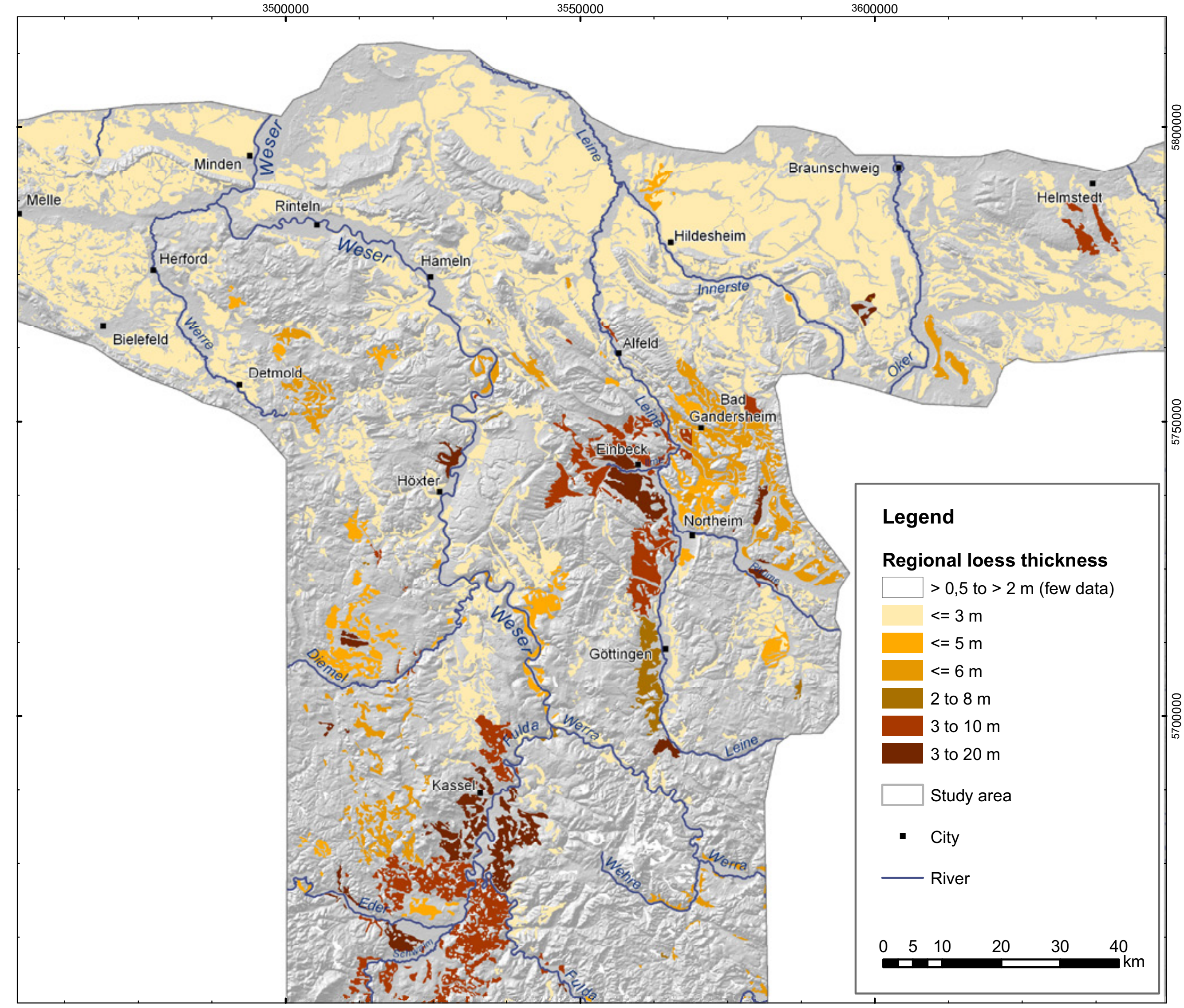

Fig. 5: Thickness map displaying regional thickness ranges of loess and loess-like sediments (including loamy loess, reworked loess, sandy loess, sand-banded loess and cover sand). (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0)

Abb. 5: Mächtigkeitskarte der regionalen Mächtigkeitsbereiche von Lössen und löss-ähnlichen Sedimenten (Lösslhem, Schwemmlöss, Sandlöss, Sandstreifenlöss, Decksand). (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA; Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0)

Merkt (1968), Wortmann (1942), and the geological map (GÜK200) were visualized. These input data vary in quality and quantity. Some loess locations have detailed grain size measurements and grain size curves. In contrast, many others have only rough descriptions, the loess maps displaying only the uppermost loessic sediment in one region. As a result, small-scale details were not separated, but a general subdivision in a loess cover layer and a basal layer was carried out. The cover layer represents the homogeneous upper part of the loess deposits. The underlying basal layer can vary widely in thickness, granulometry, pedogenetic overprint, intercalations, and distribution. The cover layer was separated into:

- sandy facies (sandy loess, sand-stripped loess and derivates)
- loessic facies
- thin or no sandy facies (very thin cover with gaps)
- thin or no loessic facies (very thin cover with gaps)

The lower part (base layer) of the loess cover was subdivided into:

- unknown base layer
- mixed layer or stone layer
- reworked loess

All regions with the same cover layer and the same base layer were outlined. Then, the following combinations of these two layers were generated:

- sandy facies on unknown base layer
- sandy facies on mixed/ stone layer
- sandy facies on reworked loess
- thin or no sandy facies on reworked loess
- loessic facies on unknown base layer
- loessic facies on mixed/ stone layer
- loessic facies on reworked loess
- thin or no loessic facies over reworked loess

These granulometric types were attached to the GÜK200 polygons. During the analysis the outline of the new regions followed the boundaries of the map sheets. In case that a map sheet had no information about the base layer, the class "unknown base layer" was selected.

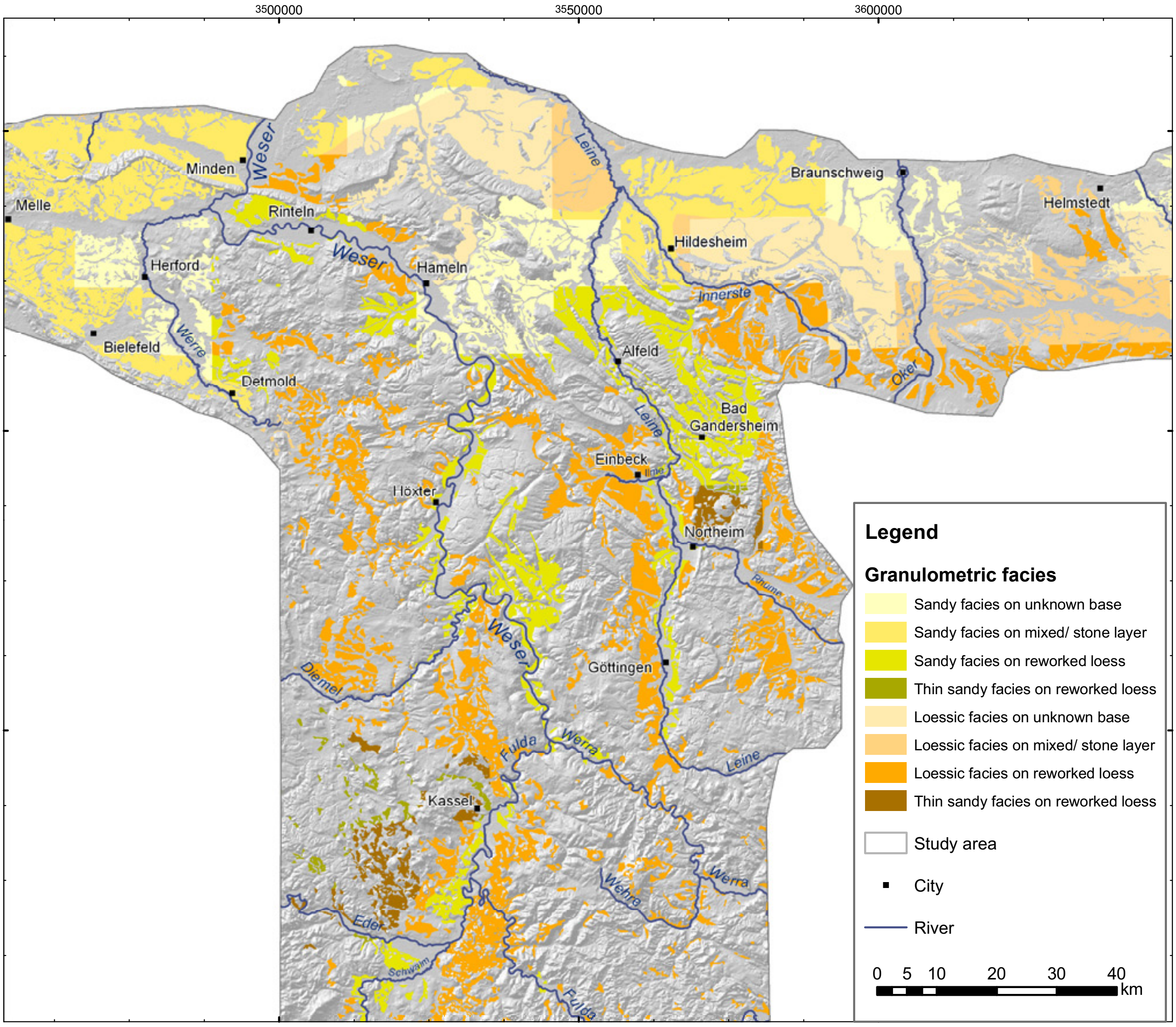

Fig. 6: Granulometric map of the regional types of cover and base layers. (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0)

Abb. 6: Granulometrische Karte der regionalen Typen von Deck- und Basislagen. (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA; Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0)

Stratigraphy

In the GIS project all loess locations with loess age data were extracted. The loess age can be estmated on marker horizons like paleosols or tephra, archaeological or paleontological findings, numerical dating or ages assumed by the author. The loess ages were displayed as combinations of the following symbols representing all horizons that were found in the locations:

- Eltville tephra
- wj: Upper Weichselian loess
- wm: Middle Weichselian loess
- wa: Lower Weichselian loess
- pW: pre-Weichselian loess

155 of 639 loess locations contain age information based on paleosols or tephra, but they are distributed very irregularly over the study area. The data reflect ages of the regional loess cover and of single loess deposits in special sediment traps. Thus, all latter locations were marked to differentiate between two accumulation types. The resulting map distribution of dated outcrops was compared with the thickness map (Fig. 5) and the granulometry map (Fig. 6) to outline regional loess cover areas of the same age (Fig. 7).

5 Results and discussion

Thickness

The resulting thickness map (Fig. 5) permits a more detailed view on loess thickness than the maps of Merkt (1968) or Wortmann (1942). Regions with thicknesses below 2.5 m are very similar, but a lot of new information about thicker loess covers appears.

The thickness of the loess and loess-related sediments ranges between few centimeters and twenty meters. Along the northern boundary of the loess belt and in the Börde region the loess cover is quite homogeneous with slight thickness variations due to exposition. Thickness values range from 0.5 to 2.5 m, sometimes up to 3 m. Thicker layers of sandy loess, sand-banded loess, or loess were found only in some locations with a specific accumulation situation as boundary dunes or in cryoturbation structures.

In the Elm-Asse-Helmstedt region and in the northern

E&G / Vol. 60 / No. 1 / 2011 / 27–46 / DOI 10.3285/eg.60.1.02 /

parts of the Leine Uplands comparable thickness ranges were found. However, morphological ridges clearly influence the thickness resulting in an apparent heterogeneity between loess-free regions and loess accumulation sites.

In the central and southern parts of the study area thickness values show much larger variations. On plateaus or plains the loess cover varies between few centimeter and 3 meters. In shallow depressions and in valleys the regional loess thickness can reach up to 4, 5 or 6 m. Loess thickness up to 10 or even 20 m occurs only in the large depressions (Leine-Ilme Basins and the Westhessian Depression) and in some smaller areas along the Werra Valley, the southernmost tip of the Leine Valley, and in the Southwest Harz Foreland. All these regions are influenced by subrosive activities.

In the uplands loess thickness is strongly influenced by the elevation, the steepness, and the aspect of the slopes. The thickest loess covers were found on slopes facing to E, NE or NW. Slopes in the opposite directions are normally bare or have a thinner loess cover.

Several loess sections with thickness values clearly above those of the surrounding regions were found. Most of them are trapped in karstification as sinks or dolines. Other extreme or untypical thick sections are caused by cryoturbation or glacial structures. Some other locations like abandoned meanders also have higher thickness values. Most likely they contain fluvial reworked loess.

The highest density of small-scale subrosion features were found in the Waldeck Upland, Warburg Börde und western part of the Lower Weser Upland. The thickest loess deposit (up to 20 m) was found at Albaxen in the Weser valley.

In general, loessic sediments thicker than 3 m occur only in valleys, basins, and special sediment-traps related to karstification, subrosion or cryoturbation. In all other regions, the loess thickness varies mainly between few centimetres and 2.5 or 3 m.

Granulometry

The resulting granulometry map (Fig. 6) is quite heterogeneous, due to some missing data, but general trends can be deduced. Several regions have a sandy cover layer with varying amounts of sandy loess, sand-striped loess and aeolian loess.

The main loess region is located along the northern boundary of the sandy belt, as visible on the GÜK200 and described in detail by Gehrt (1989, 1992, 1994, 1998) from the Hildesheim-Braunschweig Börde. Authors of the explanatory notes on the geological map sheets described either a sharp boundary between this zone and the aeolian sediments north of the loess belt or a wide mixing- or transition-zone from loess to sandy loess into cover sands and drift sands.

Additionally, a sequence of the sandy facies was mapped in the long and narrow upland stripe between the Wiehen Hills and the Ravensburg Hills in the north-eastern study area. Here the northern boundary of the loess belts bends between the upland and the Westphalian Lowland to the Southeast. In regions, where this facies was mapped, mostly loess and sand-banded loess were overlain by sandy loess.

Furthermore, the granulometry map (Fig. 6) shows large areas covered with sandy loess, sand-banded loess and loess within the upland. Most of these deposits with a dominant sand content and a more reddish colour were found on wide plateaus of Lower Triassic red sandstones (Bunter Sandstone) in the South of the study area.

In contrast to the northern regions, where coarser sediments increase to the top, the loess sequences in the uplands have higher sand contents at the base and a fining upward trend.

In some regions with large sandstone outcrops, as Fulda Highlands and the Lower Eichsfeld, sandy loess is assumed, but only rare data were available from the literature. Most significant sources of sandy loess are the river valleys that are cut into sandstones. There are many locations where sandy loess or even cover sand makes up the main unit. The sandy loess facies was also found in the central part of the Leine Uplands, the so-called Alfeld Upland. All other regions are covered by the typical loess, as evidenced by the recent available outcrop descriptions.

Beside this, the map shows a zoning of the basal layer types, although less data about this lower part of the sections was found. Along the northern boundary of the loess belt, in large parts of the adjacent Börde regions, and in the Northwest of the study area a mixed layer or a prominent stone layer forms the base of the aeolian sediments.

In the southern part of the study area the loess facies or sandy loess facies is underlain mainly by fluvial or solifluncted, reworked loess. In the Southwest Harz Foreland (around Seesen) and in the Waldeck Uplands and Plains the reworked loess of the basal layer forms the main part of the loess cover. The cover layer is very thin or not existing due to the climatic conditions. Already Brosche & Walther (1991) mentioned the "wet facies" of the Seesen region.

Stratigraphy

The stratigraphic map (Fig. 7) shows a variety of different loess ages. Lower and Middle Pleistocene loess-related sediments occur in some locations all over the study area. However, most loess deposits are of Weichselian age.

The distribution of the loess ages seems to be quite irregular, because of the mixture of different accumulation sites. One group of loess locations belongs to the typical loess cover, e.g. on slopes, on plateaus, in wide basins. The other group are the special locations found in different sedimentary traps. In most of these traps pre-Weichselian sediments were preserved.

On the contrary, if the dated loess locations are examined without these special cases, a zoning of the loess ages becomes obvious. Complete Weichselian sequences, containing Lower, Middle and Upper Weichselian loess occur in the southernmost parts of the study area. Incomplete Weichselian sequences, whether Lower and Upper Weichselian loess or Middle and Upper Weichselian loess, were reported in some valleys or basins in the central and southern parts of the study area. Upper Weichselian sequences were described all over the study area, but mainly in the northern parts. The most complete Upper Weichselian sequences were exposed in the outcrops Elvershausen and Einbeck.

Between the northern boundary of the loess belt and the

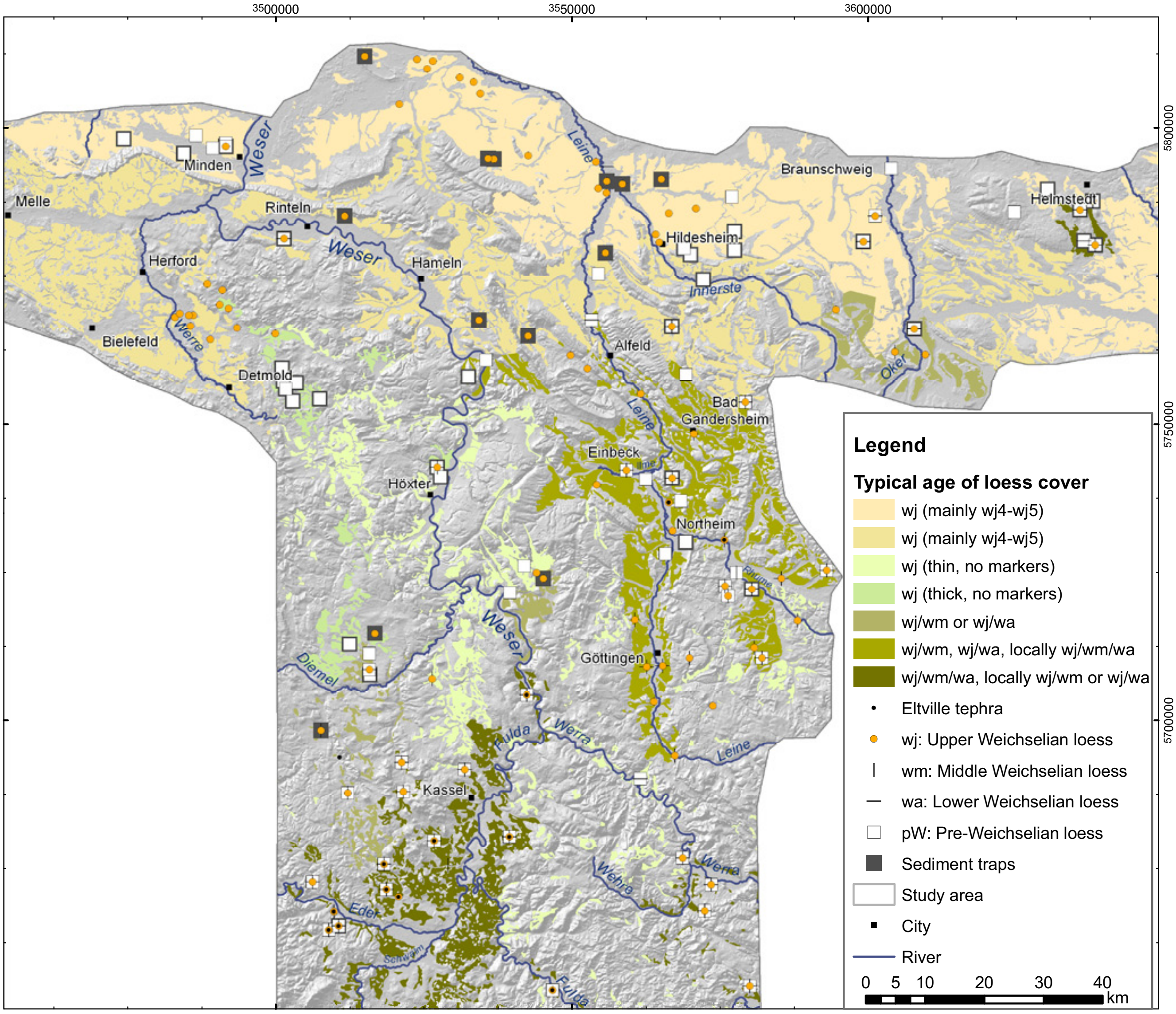

Fig. 7: Stratigraphic map displaying dated loess locations and typical ages of the regional loess cover (including loess-like sediments). (DEM: ASTER GDEM is a product of METI and NASA; river network: OpenStreetMap, published under CC-BY-SA 2.0)

Abb: 7: Stratigraphische Karte der datierten Lössvorkommen und der typischen Alter der regionalen Lössdecke (mit löss-ähnlichen Sedimenten). (DGM: Globales ASTER-DGM ist ein Produkt von METI und NASA; Flussnetzwerk: OpenStreetMap, veröffentlicht unter CC-BY-SA 2.0)

northern slopes of the Lower Saxon Hills, predominantly Upper Weichselian loess and loess-related sediments were preserved. The cover layer consists mainly of sandy or loessic sediments without prominent intercalations of other sediments, gaps or zones of strong pedogenetic or erosional overprint. Moreover, in this area the loess thickness ranges between few centimetres and 2.5 or 3 m. In wide parts, the cover layer is underlain by a distinctive stone or mixed layer over periglacial, glacial or fluvioglacial sediments. This layer was found in several places and can be called a marker horizon. In its fine-grained matrix it may contain remnants of older aeolian sediments. However, a clear or thick basal layer of reworked aeolian sediment, representing older loessic sediments, was not found. In conclusion, the regional loess cover in this area was accumulated after strong periods of fluvial or solifluidal reworking in the Upper Weichselian, because most of the older loessic sediments were eroded.

Similar observations were made by other scientists. Vierhuff (1967) postulated that the age of the sandy-loess north of the loess belt is of Upper Weichselian age. Rohdenburg & Meyer (1966) visualized on their location map a lot of outcrops without marker horizons in the northern part of southern Lower Saxony. They interpreted the regional loess cover as an Upper Weichselian deposit. Gehrt (1989, 1992, 1994) examined a lot of loess sequences in the Braunschweig-Hildesheim Börde, along the northern boundary of the loess belt. He postulated that the sandy and loessic sediments on top of a mixed or stone layer are of Upper Weichselian age. Gehrt (1998) specified the age of these sediments as upper Upper Weichselian (wj4 to wj5). Lower Upper Weichselian sediments (wj1 to wj3) were conserved in the base layer. He mentioned that units of the same age were mapped west of Hanover in the Calenberg Börde.

Reinecke (2006) determined the age of the loess and loess-like sediments of the North Harz Foreland based on palaepedological analysis and OSL dating. Moreover, he separated the regional loess cover into a lower facies (wj1 to wj3), which is only accumulated on Northeast-, East- or

E&G / Vol. 60 / No. 1 / 2011 / 27–46 / DOI 10.3285/eg.60.1.02 /

Northwest-facing slopes, and an overlying regional loess unit of wj4 to wj5 age.

Not only the Börde loess, but also the thin loess cover (less than 3 m, containing no marker horizons) in the upland region of the study area may be of similar age. When the loess thickness exceeds 2.5 or 3 m in valleys or basins, incomplete Weichselian loess sequences become more frequent. In summary, if the loess is thicker than 2.5 or 3 m, it becomes more likely to find loess and loess-like sediments of Upper Weichselian and of Middle or Lower Weichelian age.

Complete loess sequences containing Lower, Middle and Upper Weichselian loess are more common in the southernmost part of the study area in the Westhessian Depression, due to the geomorphological situation in the wide-ranging basin und the weaker erosional overprint.

Moreover, to the Southwest of the study area an increasing number of findings of mammal fossils like *Equus, Cervus elaphus, Rangifer tarandus, Mammuthus primigenius* (Beyrich & Moesta 1876, Grupe 1916b, Horn 1982, Becker & Kulick 1999) and loess snails *Succinea oblonga, Helix bispida, Helix obvoluta, Helix hortensis, Helix pulchella, Pupa muscorum* (Moesta 1876a, Moesta 1891, Moesta & Beyschlag 1886D, Grupe 1916B, Lang & Blanckenhorn 1920, Blanckenhorn 1926, Becker & Kulick 1999) were recorded. It can be concluded that the West Hessian Depression has the best conditions for loess preservation in the study area.

Various authors gave some remarks about the regional ages of the loess cover in the upland (Lower Saxon Hills and Hesse Highlands). Ricken & Meyer (1982) wrote that in the South Harz Foreland the Eemian soil is quite seldom, loess cover starts with Lower Weichselian deposits (soils) on Middle Terrace gravel. Feldmann (2002) mentioned that the Eemian soil is mainly eroded in the Aller catchment area. The age of the loess cover in the Alfeld region was estimated by Lüttig (1960b) mainly postdating the main glacial period. Thus, a Upper Weichselian loess deposition is most likely due to the larger deflation area.

Jordan (1984) found only few relicts of the Eemian soil in the Leine valley in sheltered positions. Brosche & Walther (1991) postulated that the loess in the Northern Harz Foreland is 3 to 5 m thick and of Upper Weichselian or Lower Weichselian age. In the Borgentreich region, west of the Hessian Depression no Lower or Middle Weichselian loess was found, only at the Daseburg and Hofgeismar sections.

Beside this local concepts about loess stratigraphy, Gehrt (1998) established a model of regional loess ages in the lowlands and uplands. He postulated a regional age of the aeolian sediments in the Börde region and along the northern loess boundary of wj4 to wj5. On the slopes of the southerly adjacent upland also patches of older Weichselian loess (Lower Weichselian to wj3) can be conserved above remants of the Eemian soil. These local relicts are overlain by the regional Upper Weichselian loess (wj4 to wj5). The most complete sections of Weichselian loess can be preserved according to his model in upland basins or in subrosion basins.

Based on the local observations and the regional model, typical ages of the regional loess ages in the study area were outlined (Fig. 7). The resulting map represents large-scale zones of loess ages, which are maximum ages and do not show local variations. Therefore, the stratigraphic map gives an orientation where which type of loess sequences might occur.

Conclusions

Based on spatial data, which are quite different in publishing age, amount of information, spatial resolution and data type, loess parameters were analyzed.

A detailed thickness map (Fig. 5), a granulometry map (Fig. 6) and a stratigraphy map, displaying dated loess locations and regional loess ages (Fig. 7), were compiled. By means of this new spatial representation of loess characteristics, large-scale differences and trends become obvious.

The local variations of the loess parameters that are not displayed on the large-scale maps may be the object of future investigations. In such studies limited areas should be selected, which represent different geomorphological regions (Börde, plateau, plain, valley, basin) and loess cover types. There, the local variablility of the loess parameters (thickness, granulometry and stratigraphy) can be examined in detail. Furthermore, the results might be integrated in the regional maps to improve their accuracy.

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