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Loess from Saxony

A reconstruction of the Late Pleistocene landscape evolution and palaeoenvironment based on loess-palaeosol sequences from Saxony (Germany)

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Übereinstimmungserklärung

Die Übereinstimmung dieses Exemplars mit dem Original der Dissertation zum Thema:

„Loess from Saxony“

wird hiermit bestätigt.

Dresden, 2016/09/02

Sascha Meszner

That's one small step for mankind but one giant leap for a man.

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du musst mich nur ertragen.
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Abstract

Background A number of studies have been published in the last few decades on Pleistocene palaeo-temperature reconstruction based on isotopic studies on deep sea cores and ice core records from Greenland. Such temporal high-resolution data represents northern hemispheric circulations and has to be reconfirmed through the study of terrestrial archives in order to recognise the character of such fluctuations in different regions. Loess-palaeosol sequences (LPSs) are suitable to interpret them as palaeoenvironmental archives, because loess is a widely distributed terrestrial deposit and is datable using luminescence techniques.

The Saxon loess region (SLR) is characterised by a loess cover of ca. 8 m thickness, mainly representing deposits of the last glacial cycle. Over the past 35 years, Saxon loess remains under-researched wherefore a reactivation with the objective of contributing to the European loess research is important. There is a clear need to re-examine Saxon LPSs and close this gap of knowledge, because in recent years much work has been done on important and European-wide known loess sections as well as in adjacent loess areas. In this study, LPSs from Saxony were investigated and a regional palaeoenvironmental reconstruction of the last Glacial/Interglacial cycle was developed. The established stratigraphical scheme has to be advanced by results of optically stimulated luminescence (OSL) dating. The stratigraphical results should be compared with previous work from Saxony and with results from adjacent loess areas, to verify if our results have to be interpreted as singularities or if they are in accordance with known European conceptions.

Methods Therefore, 8 sections, mostly never investigated before, were described and correlated with each other to finally generate an independent standard stratigraphy for this area. Carbonate content, pH-value, soil organic

matter, total and pedogenic iron, magnetic susceptibility and classical grain size analyses were obtained from every section. Furthermore, rare earth elements concentrations were measured from selected positions in order to prove if there are variations in the deposit composition during the glaciation. The OSL datings were processed by Kreutzer (2012).

Results As previously noted, the first step towards a regional palaeoenvironmental reconstruction was to establish a standard stratigraphic scheme where all found units are involved. Based on features regarding grain size distribution, the found palaeosols and the magnetic susceptibility (Baumgart et al. 2013), 5 units could be defined. Unit V reflects the pre-Weichselian sediments modified by the Eemian soil formation. Unit IV contains deposits from the beginning of the Weichselian glaciation. Typically, this unit starts with the first Weichselian deposit, a bright-greyish Mn- and Fe-precipitates enriched layer which shows an aggregation of charcoal at its top. This layer is covered by a greyish, humus-enriched and reworked relict of a Chernozem-like soil. After a Gelic Gleysol and a reddish-brownish soil sediment, a loess package with an embedded interstadial Cambisol-like soil is preserved. The top of the unit is represented by another brownish soil sediment which forms the lower part of the Gleina complex. Typically, unit IV is characterised by stronger reworked layers and soil sediments but at the Rottewitz section an older loess package is preserved.

Unit III represents the reactivation of aeolian sedimentation. The base of this unit is made up of a strong Gelic Gleysol (upper part of the Gleina complex). The deposits of this unit are mostly pedogenically overprinted and show features of at least two Gelic Gleysols. Unit II is dominated by unweathered loess. Its lower part (unit IIb) is built of a more stratified loess facies whereas the upper part (unit IIa) is built of a homogeneous loess facies. They are separated by a strong Gelic Gleysol. Unit I represents the upper part of the loess section, which is modified by the Holocene and Late Pleistocene soil development. Within this succession, a huge hiatus is found between unit III and IV of ca. 35 ka. It is labelled as the Gleina complex according to Lieberoth (1963). Furthermore, we demonstrate how combined analyses of high-resolution grain size distributions and microscopic analysis can be used to discriminate depositional and pedogenetic features of loess-palaeosol profiles from the SLR.

Generally, it was observed that an increase of coarse material is linked with an increase of the mineralogical components which refers to slope processes. Rounded shapes of Mn- and Fe-precipitates, mostly found in Early Weichselian humus layers, indicate strong interstadial soil development modified by subsequent redeposition. Further observations suggest that the class of medium sand is dominated by secondary precipitates. The varying amount of very fine sand shows that sequences are cyclically built up of pure loess comparable to the Nussloch section. Studying coarse grain size fractions by microscopic analysis, a differentiation between loessic layers formed by periglacial slope processes and layers overprinted by pedogenetic processes is possible. Furthermore, an increase of fine material and secondary Mn- and Fe-precipitates can be attributed to soil forming processes (clay formation, redoximorphic processes, and illuviation).

Additionally, a palaeoenvironmental reconstruction for the Late Pleistocene is proposed. As palaeo-temperature proxies ice wedges, pure loess sedimentation or the platy soil structure due to former ice lensing for cold periods and soil formations or vegetation remnants for warmer periods were used. A reconstruction of wind speed is directly deduced from the very fine sand content. The stability/instability of the landscape surface could be indicated by soil formation (stable) or through an increase of coarse sand (active). The type of soil development for the reconstruction is of major importance. For example, a humus enriched soil indicates warmer and dryer conditions than a Gelic Gleysol.

Conclusions The results of grain size analyses reveal a similar temporal and lithogenic pattern of Weichselian aeolian dynamics of the study area and other records from Europe. Furthermore, grain size results independently confirm the luminescence chronology of the studied sections. Reworked loess-like sediments show varying OSL age estimates; aeolian loess shows a systematic change of OSL ages.

Generally, the findings of this study agree with observations from other loess areas. In most areas, a similar hiatus between Middle and Upper Weichselians is documented. Additionally, OSL dating suggests that we found an older loess package with an age between ca. 60 and 70 ka and a younger loess package with an age of ca. 15 and 30 ka. These periods of aeolian deposition are in accordance with MIS 4 and MIS 2 as well as with dust concentrations results derived from lake sediments and from ice cores.

A major finding of this study is that we uncover the internal differences of loess-palaeosol sequences regarding their temporal resolution. In periods of loess sedimentation, a temporally high-resolution record is preserved. In contrast, in periods dominated by interstadial soil development or redepostition, a temporal low-resolution record is preserved and a reconstruction of palaeoenvironment is almost impossible.

Zusammenfassung

Einleitung In den vergangenen Jahrzehnten wurden viele Studien über die Rekonstruktion der pleistozänen Temperaturentwicklung veröffentlicht, welche anhand von Isotopenanalysen aus Tiefsee- und Eisbohrkernen des grönländischen Eises abgeleitet werden konnten. In solchen zeitlich hochaufgelösten Daten sind nordhemisphärische Klimaschwankungen repräsentiert und diese sollten durch Untersuchungen terrestrischer Archive validiert und deren regionale Ausprägung in verschiedenen Räumen abgeschätzt werden. Löss-Paläobodensequenzen eignen sich hervorragend als Paläoumweltarchiv, da der Löss ein weit verbreitetes Sediment und mittels Lumineszenzverfahren datierbar ist.

Die Sächsische Lössregion ist durch eine ca. 8 m mächtige Lössdecke charakterisiert, welche vornehmlich aus Ablagerungen des letzten glazialen Zyklus besteht. In den vergangenen 35 Jahren wurde die Lössforschung in diesem Raum vernachlässigt, sodass eine Wiederbelebung wichtig ist, um einen Beitrag zur europäischen Lössforschung zu leisten. Da in den letzten Jahren an wichtigen europäischen Lössprofilen, wie auch in angrenzenden Lössregionen, intensiv geforscht wurde besteht der dringende Bedarf, die Forschungen an sächsischen Löss-Paläobodensequenzen wieder aufzunehmen und die entstandene Wissenslücke zu schließen.

In dieser Studie werden sächsische Löss-Paläobodensequenzen untersucht und eine regionale Umweltrekonstruktion für den letzten glazialen Zyklus vorgestellt. Die Standardstratigraphie wird dabei durch OSL-Alter erweitert. Die Ergebnisse werden mit älteren Arbeiten aus diesem Raum verglichen, um abzuschätzen, ob es sich hierbei um Einzelbefunde handelt oder ob sich die Ergebnisse in schon bekannte europäische Konzepte einordnen lassen.

Methoden Es werden 8, meist noch nie bearbeitete Profile beschrieben und

miteinander korreliert, um schließlich eine unabhängige Standardstratigraphie für diesen Raum zu erarbeiten. Von jedem Profil wurde der Kalkgehalt, der pH-Wert, der Anteil der organischen Substanz, das pedogene und Gesamteisen, die magnetische Suszeptibilität und die Korngrößenverteilung (klassisch) bestimmt. Zudem wurde die Konzentration der Seltene Erden Elemente an ausgewählten Positionen bestimmt, um zu prüfen, ob es Verschiebungen in der mineralogischen Zusammensetzungen über das letzte Glazial hinweg gab. Die OSL-Datierungen wurden dabei von Kreutzer (2012) realisiert.

Ergebnisse Wie schon erläutert wurde, bestand der erste Arbeitsschritt darin, eine Standardstratigraphie zu erarbeiten, worin alle Befunde integriert werden können. Auf Grundlage der Korngrößenverteilung, der gefundenen Paläoböden und der magnetischen Suszeptibilität (Baumgart et al. 2013) konnten 5 Einheiten ausgewiesen werden. Die Einheit V stellt die prä-weichselzeitlichen Sedimente dar, welche von der eemzeitlichen Bodenbildung überprägt wurden. Einheit IV beinhaltet die Sedimente vom Beginn der Weichselkaltzeit. Typischerweise befindet sich an der Basis dieser Einheit eine hellgraue, an Mn- und Fe-Konkretionen angereicherte Schicht, welche eine Häufung von Holzkohlebruchstücken im oberen Bereich zeigt. Diese Schicht ist wiederum von einem Rest einer schwarzerdeähnlichen Bodenbildung überlagert und zeigt eine Anreicherung an organischer Substanz. Über einem Nassboden und einem rotbraunen Bodensediment ist ein Lösspaket, mit einem zwischengelagerten interstadialen braunerdeartigen Boden, erhalten. Der obere Bereich der Einheit IV ist durch ein weiteres rötlichbraunes Bodensediment geprägt, welches dem unteren Teil des Gleinaer Komplexes entspricht. Normalerweise ist die Einheit IV in Sachsen durch stark umgelagerte Schichten charakterisiert, jedoch ist im Profil Rottewitz in dieser Einheit ein älteres Lösspaket erhalten.

Die Einheit III repräsentiert eine Reaktivierung der äolischen Sedimentation. Ihre Basis bildet ein kräftiger Nassboden (oberer Teil des Gleinaer Komplex). Die Sedimente dieser Einheit sind meist pedogen überprägt und es können mindestens zwei separate Nassböden ausgewiesen werden. Die Einheit II besteht vornehmlich aus unverwittertem kalkhaltigen Löss. Ihr unterer Abschnitt (Einheit IIb) wird durch eine streifige Löss-Fazies gebildet, wohingegen der obere Teil von einer homogenen Löss-Fazies dominiert wird. Diese sind durch einen kräftigen Nassboden voneinander getrennt. Die Einheit I bildet den oberen Teil des Lössprofiles und ist durch die pedogene Überprägung der spätpleistozänen und holozänen Bodenentwicklung geprägt. In dieser Abfolge ist ein Alterssprung von ca. 35 ka zwischen der Einheit IV und III nachgewiesen. Dieser Hiatus befindet sich im durch Lieberoth (1963) definierten Gleinaer Komplex.

Weiterhin konnte gezeigt werden, dass mit Hilfe einer kombinierten Untersuchung aus Korngrößenanalyse und Mikroskopieren es möglich ist, eine durch Bodenbildung bedingte und eine durch Umlagerung hervorgerufenen Überformung von Lösssedimenten voneinander zu unterscheiden. Generell wurde festgestellt, dass ein Anstieg der groben Kornfraktionen oft mit einer Erhöhung der mineralischen Komponente einhergeht und dies auf laterale Umlagerungsprozesse hindeutet. Abgerundete Mn- und Fe-Konkretionen aus humosen frühweichselzeitlichen Schichten lassen eine kräftige interstadiale Bodenentwicklung mit anschließender Umlagerung vermuten. Es wurde zudem festgestellt, dass die Mittelsandfraktion durch sekundäre Fe- und Mn-Konkretionen dominiert wird. Der variierende Feinstsandanteil zeigt, dass die Sequenzen in verschiedenen Zyklen aus unverwittertem Löss aufgebaut wurden, wie es auch aus dem Profil Nussloch beschrieben wird. Bodenbildungsprozesse bedingen demgegenüber ein Anstieg der Feinkomponenten und der Mn- und Fe-Konkretionen in den Sandfraktionen.

Weiterhin wird eine Paläoumweltrekonstruktion für das Spätpleistozän vorgeschlagen. Hierbei werden verschiedenste Indikatoren als Paläotemperaturzeiger herangezogen. Für kalte Phasen stehen zum Beispiel Eiskeilpseudomorphosen, Pakete aus unverwittertem Löss oder plattige Strukturen infolge von Schichteisbildung. Für wärmere Phasen sprechen Paläoböden oder Pflanzenreste. Eine Rekonstruktion der Paläowindgeschwindigkeiten wird direkt über die Feinstsandanteile abgeleitet. Die Stabilität einer Landschaftoberfläche wird durch Bodenbildungen (stabil) oder einem Anstieg der groben Sandkomponenten (aktiv) repräsentiert. Den Paläoböden kommt bei einer solchen Rekonstruktion eine Schlüsselstellung zugute. Zum Beispiel signalisiert ein Steppenboden wärmere und trockenere Bedingungen im Vergleich mit einem Nassboden.

Fazit Die Ergebnisse der Korngrößenuntersuchungen zeigen, dass hinsichtlich ihres Aufbaues und ihrer chronologischen Einordnung die äolisch dominierten Phasen der sächsischen Lössprofile bekannten Mustern aus anderen Archiven in Europa folgen. Zudem zeigt sich, dass die Ergebnisse der Korngrößenverteilung die mittels OSL bestimmten Alter untermauern. Umgelagerte Sedimente zeigen größere Altersschwankungen, wohingegen äolische Sedimente eine kontinuierliche Altersentwicklung haben.

Die Ergebnisse dieser Untersuchungen stimmen mit Beobachtungen aus anderen Lössgebieten überein. In den meisten Regionen wird ein ähnlicher Hiatus zwischen der mittleren und oberen Weichselkaltzeit beschrieben. Zudem deuten die OSL-Ergebnisse an, dass in Sachsen ein älteres Lösspaket mit einem Alter von ca. 60 bis 70 ka und ein jüngeres Lösspaket mit einem Alter von ca. 15 bis 30 ka existiert. Die beiden äolischen Phasen korrelieren mit der marinen Isotopenstufe 4 (MIS) beziehungsweise der MIS 2, sowie mit Ergebnissen pleistozäner Staubkonzentration der Atmosphäre, abgeleitet aus Seesedimenten oder Eisbohrkernen.

Eine wichtige Erkenntnis dieser Untersuchungen ist, dass wir innerhalb eines Lössprofiles Pakete unterschiedlicher zeitlicher Auflösung identifizieren konnten. Aus Phasen kräftiger Lösssedimentation sind zeitlich hoch aufgelöste Sequenzen erhalten. Demgegenüber ist aus Phasen, dominiert durch Bodenbildungen oder Umlagerungen, ein zeitlich nur sehr schlecht aufgelöstes Archiv erhalten, weshalb anhand dieser Abschnitte eine Paläoumweltrekonstruktion nur bedingt möglich ist.

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List of Abbreviations

BP	Before Present
DFG	German Research Foundation
GIS	Greenland interstadial
IRSL	infrared stimulated luminescence
ka	thousand years
LGM	Last Glacial Maximum
LPS	loess-palaeosol sequence
Ma	million years
MIS	marine isotope stage
OSL	optically stimulated luminescence
REE	rare earth element
SLR	Saxon loess region
SOM	soil organic matter
TL	thermoluminescence
TOC	total organic content

Chapter 1

Introduction

1.1 Relevance of Quaternary palaeoclimate research

The presented dissertation is based on investigations and results developed during the research project "Environmental reconstruction of the Late Pleistocene in Saxony (Germany) based on loess-palaeosol sequences". The project was founded by the German Research Foundation (DFG) between September 2008 and February 2012. This thesis summarizes information derived from Saxon loess-palaeosol sequences (LPSs). On the basis of these results, a landscape evolution model of Late Pleistocene for this region is proposed. The time frame for this reconstruction is given by the deposit itself, because most studied LPSs from the investigation area dates back to the last glacial cycle (Weichselian glaciation). In well preserved geomorphological positions the sequences start at the base with the last interglacial soil (Eemian soil). The investigation of the palaeoclimate and palaeoenvironment is an important field of geoscientific research because many answers are directly connected to our human history (e.g. Collaborative Research Centre 806 "Our Way to Europe"). Pioneers of climate history research (e.g. Emiliani 1966) did isotopic analysis on foraminiferal species of deep-sea cores and show that global seawater temperatures varied considerably during the Pleistocene. The results underline the ancient idea of an alternating Quaternary climate, which were developed on the basis of investigations of terrestrial archives. Further research was done, for example, by Shackleton (1967). He assumed that changes in oxygen isotope composition are connected with a huge extraction of seawater during the growth of ice sheets at the beginning of and during the glaciations and are of limited suitability to serve as a palaeothermometer only. Imbrie et al. (1984) confirm the idea of the astronomical theory for the Pleistocene ice age from Milankovitch and applied the chronology for the deep-sea isotopic variations. Furthermore, major advances have been made with radio-metrically dated volcanic flows which carry normal or reverse remanent magnetisations. Referring to this, Cox et al. (1963) suggested a table of Pleistocene geomagnetic epochs. Since that time, a valid model for Pleistocene global ice volume changes has been established. This model is still up to date; of course there are many advantages. For example, today the variance in benthic $\delta^{18}O$ could be reconstructed for the last 5.3 Ma with a much higher resolution and quality (Lisiecki & Raymo 2005). Additionally, various events mostly inconsistent with Milankovitch's astronomical theory extend this model (e.g. Heinrich 1988; Bond et al. 1992; Dansgaard et al. 1993). A further result of the Quaternary climate research during the 20th century (summarized by Paillard 2015) is a precise notion of palaeotemperature of the northern hemisphere derived from Greenland ice cores (e.g. Andersen et al. 2004). Therefore, however, palaeooceanography and isotopic research provide critical advances for Quaternary climate history, but the work and interpretation of terrestrial archives are also very important. For example, the initial impulse for palaeoclimatical research comes from the investigation of terrestrial archives. The fact that outcrops, whether of glacial, fluvial or aeolian origin, show an internal subdivision with some strange looking faunal and floral remains embedded in them finally initiated the assumption of an alternating climate during former geological eras. Rather, on the basis of terrestrial archives, it is possible to reconfirm results derived from deep-sea or ice core drilling and draw a picture of regional climatic characteristics. Furthermore, terrestrial archives rarely contain direct information about climatic parameters as temperature, moisture or wind direction. In fact, they carry predominantly proxy data about the behaviour of a landscape, their forcing geomorphological dynamics and the environmental conditions (for example vegetation) of a specific region. The results derived from terrestrial archives as presented in this thesis are needed to downscale the global knowledge about the climate history to a more regional order. First studies which prove the palaeoenvironmental information derived from continental archives with isotopic-based palaeoclimatic data were carried out by Kukla (1975) and Kukla (1977). Ding et al. (2002) introduced a stacked 2.6 million years (Ma) grain size record from the Chinese Loess Plateau correlated with deep-sea $\delta^{18}O$ record. Loess as an aeolian deposit is quite a favourable material for such palaeoenvironmental studies.

1.2 Loess as an object of palaeoenvironmental research

Loess is a widely distributed terrestrial deposit (Fig. 1.1) and covers more than 10 % of the subaerial surface (Pécsi & G. Richter 1996). The deposit

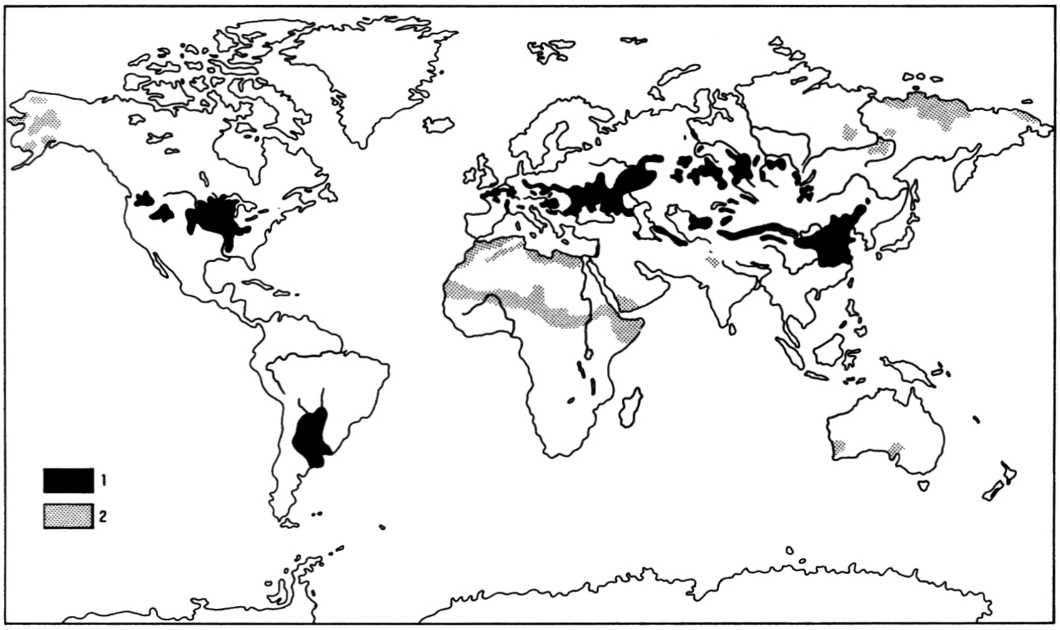

Figure 1.1: Global distribution of loess and loess-like sediments after Pécsi & G. Richter (1996)

1 - loess; 2 - loess-like sediments

itself can be subdivided in many different ways. Grain size distribution of the deposit is mostly used as a criteria for subdivision. Complex summaries according to the properties, the methods of classification and terms of loess and loess-like sediments were made by Pye (1984), Pécsi (1990) or Pécsi & G. Richter (1996). There is also differentiation based on the climatic conditions, respectively the dominating environmental conditions during deposition. Pye (1995) coins the terms peridesert loess (deposited at desert margin), periglacial loess (in Central Europe and North America), and perimontane loess (around huge mountain areas, for example Tibet). In this context Zöller & Faust (2009) mentioned that after a long debate, but since the end of the 20th century, the term desert-margin loess (for warm, peridesert, desert (Tsoar & Pye 1987), lower latitude loess, and many other equivalent terms) has been widely accepted. Because of its widespread distribution, loess is most suitable for palaeoenvironmental studies. Loess could be found in numerous regions with different climatic conditions. Therefore, it is possible to compare and correlate results along climatic or orographic transects over long distances. Partially, as for example in Eurasia, loess builds a continuous nearly closed cover. In Central Europe loess also shows a dense distribution, but deposits with a thickness greater than 3 m have a more patchwork-like distribution (see D. Haase et al. 2007). Another important advance is that loess, due to its aeolian origin and its high amount of quartz and feldspar, is datable using thermoluminescence (TL) and OSL techniques. Especially for deposits from the last glaciation, in most cases a precise chronological model on the basis of luminescence dating results could be developed (Antoine et al. 2009b; Frechen et al. 2001; Fuchs et al. 2012; Fuchs et al. 2008; Terhorst et al. 2011; Zöller et al. 1988). Furthermore, this is due to the combination of palaeosols with embedded packages of unweathered sediment LPSs carrying various information about the palaeoenvironment. A compilation of possible investigations is given in Figure 1.2. In this Figure there is a differentiation between the "deposit" itself without any relocation and the pedologically modified "embedded soil". The soils give information about the environmental conditions during the time of soil formation on the basis of the soil type, intensity of soil formation, and preservation after covering by younger deposits. The deposit below or above carries information about the process of aeolian deposition and its secondary relocation. For example, Rousseau et al. (2014) and J. Sun (2002) demonstrate that analyses of the mineralogical composition in combination with results of grain size analyses can help to indicate the source area of the dust. Interpreting a LPS means connecting all extractable information and creating a general idea about the past environment. However, LPS carry multiple, geomorphological and pedological information, mostly overlaying each other and are of great interest for palaeoenvironmental studies. Additionally, several "remnants" of plants or animals help us to interpret the LPS. Analyses of molluscs extracted from loess sequence are well established in Quaternary research (Bibus et al. 2007, 2002; Ložek 1990; Ložek 2001; Moine 2008; Moine et al. 2002). On the basis of known ecological living conditions of a mollusc's assemblages, environmental information about the time the mollusc lived could be derived. But there are also several "limits" and challenges for loess research which have to be taken into consideration. Most studies on LPS (e.g. Shi et al. 2003) were done at one site or on one borehole so that a comparison with a neighbouring section in a different geomorphological position often causes difficulties. But an evaluation of results from one profile is only possible through a comparison with other sites. Particularly, when investigating mollusc assemblages, the former geomorphological position (habitat) is of essential meaning regarding the species composition and the resulting palaeoenvironmental interpretation. To sum up, LPSs are datable using OSL, have a widespread distribution, and carry numerous palaeoenvironmental proxy data (see Fig. 1.2). Therefore, LPSs are suitable for regional palaeoenvironmental research. For that reason, loess is actually a well studied deposit (since 2006 nine Special Issues of the journal "Quaternary International" with the topic loess (152/153, 196, 198, 234, 240, 296, 319, 334/335, 351); since 2011 two issues of the journal "Quaternary Science Journal" (Vol. 60/1, 62/1) but showing a long history of research too (a summary for Central Europe is given by Zöller & Semmel 2001).

Figure 1.2: Loess as an object of palaeoenvironmental research (own compilation, raise no claim to completeness)

1.2.1 Retrospect, research objectives, and motivation

The SLR, as it will be mentioned in chapter 2.1.1, 3.2, and 4.2, is located at the northern branch of the European loess belt and represents a part of the northern loess boundary. It takes a central position between the more isolated patches of loess in western Europe and the more closed distributed loess cover in eastern Europe (Fig. 1.1). The investigation of LPSs in Saxony began with studies by Pietzsch (1922) and Gallwitz (1937). In the 1960s, intensive stratigraphical and palaeoenvironmental research on LPSs in Saxony reached its first heyday. During this time in particular Lieberoth (1963) established a solid stratigraphy for this area. On the basis of his results, Saxon loess sequences were comparable with neighbouring loess areas in other countries (proposed correlation: Fink 1964; Lieberoth 1962a; Lieberoth & G. Haase 1964; Ricken 1983; Semmel 1968). A summary of Saxon research history on loess and most of the results from the period between 1960 and 1970 are presented in a special issue published by G. Haase et al. (1970). Additionally, in other loess regions in both parts of Germany, Quaternary research has been focused on loess since approximately 1960 and has lasted for decades (Zöller & Semmel 2001 gave an overview). Figure 1.3 shows two important loess standard profiles of this time from Germany. Outlines of the Hessian standard loess profile (Fig. 1.3: left column) had already been introduced by Schönhals et al. (1964) and Semmel (1968). Still today, it represents an important overview showing all major (palaeo-) pedological variations separated by several known and unknown hiatuses recorded or rather missed in LPSs from Germany. The chronostratigraphy is based on TL dating and advanced the scheme in the late 1980s and 1990s. In the decades following 1960, loess became a focus of research also in other European countries. Demek & Kukla (1969) summarized results of loess research of the former Czechoslovakia in a comparable special issue to G. Haase et al. (1970). Important Czechoslovakian loess researchers of that time include Kukla et al. (1962) and Ložek (1964, 1965, 1968). In Poland, Jersak (1969, 1973) and Maruszczak (1980) (after Jary 2007) established schemes of loess stratigraphy for Silesia and eastern Polish loess areas. Jersak (1969, Fig. 16) proposed with the "Stratigraphy of losses" a scheme for Polish LPSs which was still largely consistent with findings by Lieberoth (1963) and Semmel (1968) or with findings from the

Sequani (France) loess area (Antoine et al. 2003a, pp. 315, Fig. 2). But also other European countries went through a period of booming loess research. A list of involved researchers is given by D. Haase et al. (2007) (see "Acknowledgement" section). An ambitious project of this active time of loess research was to build up a high-resolution European Loess Map. At a meeting in former Yugoslavia in 1966, the Commission on Loess of International Union for Quaternary Research (INQUA) decided to implement the mapping project (D. Haase et al. 2007). From the author's point of view, this project embodied the spirit of an active international loess community marvellously, and with a high level of scientific exchange.

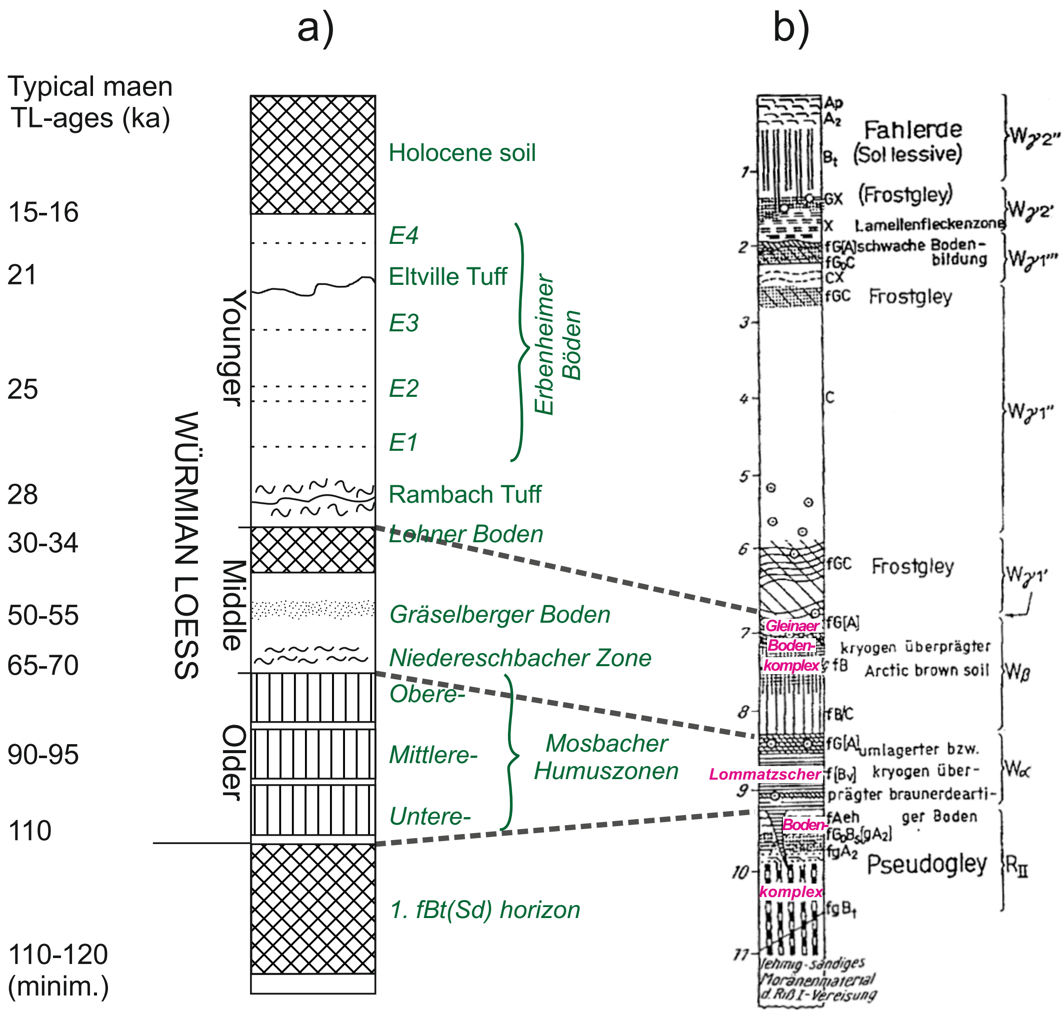

Figure 1.3: Two last glacial loess standard profiles from Germany

a) Würmian loess stratigraphy in southern Hesse and surrounding areas after SEMMEL (1969) with TL ages after ZÖLLER (1995) and ZÖLLER et al. (2004); b) Loess stratigraphy of Saxony according to LIEBEROTH (1963)

Correlation lines are added by the author

The right column of Figure 1.3 shows the standard profile of the SLR according to LIEBEROTH (1963). It shows some differences in detail, but the main units could be correlated with findings from the Hessian loess area (SEMMEL 1969). At the base the Saxon standard profile starts with a strong Luvisol or Albeluvisol soil type which showed a hydromorphic and podsolic overprinting (R_{II}). Together with a brownish soil sediment above, representing the Older Weichselian deposits (W_{α}) according to LIEBEROTH (1963), this sequence is labelled as "Lommatzscher Bodenkomplex". The Middle Weichselian (W_{β}) is composed of slightly reworked loess with a brownish soil at its top. This soil is often characterized by greyish bleached material at the upper boundary and is labelled "Gleinaer Bodenkomplex". The Younger Weichselian loess (W_{γ}1") is subdivided by some Tundra Gley soils (Gelic Gleysol) in the upper part and shows features of stronger re-deposition in the lower parts (W_{γ}1'). The uppermost part of the sequence is composed of a weak soil (W_{γ}1"'), an overlaying lenticular horizon, another Gelic Gleysol (W_{γ}2'), and the Holocene Albeluvisol (W_{γ}2"). Compared with SEMMEL (1969), the main differences are obviously in the Older Weichselian, where SEMMEL differentiated three Chernozem-like soils ("Humuszonen") and in the uppermost part underneath the recent surface, where LIEBEROTH subdivided several soil formations. The Gleina soil complex is potentially comparable to the Lohne soil ("Lohner Boden").
The important differences between both profiles are not obvious and are not within the stratigraphical sequences, however, but there is no chronostratigraphical control for profiles of the SLR. Since 1970, LPSs from Saxony have been poorly researched and the knowledge remains static at the level of 1970. A resulting problem is that most pits and outcrops described by LIEBEROTH (1963) and G. HAASE et al. (1970) were filled and re-cultivated. So there is no open sequence which could serve to compare published profile descriptions with recent field observations. It has to be underlined that, since 1982, attempts have been made to carry out luminescence dating of loess in Germany (WINTLE & BRUNNACKER 1982; ZÖLLER et al. 1988), but until now there has been no attempt to derive numerical dating from Saxon LPS. A second problem is that SEMMELs and LIEBEROTHs stratigraphical sequences reflect meanwhile an aged schemata of Central Germany. Recent studies (ANTOINE et al. 2013, 2009b; FRECHEN et al. 2007; HAESAERTS et al. 1999) have led

to an increase of resolution of loess stratigraphy so that a refined stratigraphy based on weak soil formations is necessary (also recommended by Zöller & Semmel 2001). The central thrust of this thesis is to revive the past due loess research in this area. A fundamental step for this work is to build up a solid standard stratigraphy and advance it by a chronology based on numerical dating. The following tasks and questions will serve as a focus:

1. Establishing an independent and refined standard scheme comparable to Antoine et al. (2001) or Haesaerts et al. (1999)
   - Work in the field: describing profiles in terms of their pedological, sedimentological, and geomorphological characteristics
   - Work in the lab: pedo-chemical investigations and grain size analyses (see 2.2)
   - Classifying palaeosols based on fieldwork results supplemented by data measured in the laboratory. A further important target is to differentiate whether the palaeosol is an in situ soil or a soil sediment.
   - Verify, if a differentiation between younger and older loess units related to their sedimentological or geochemical composition is possible?
2. complete the refined standard profile with a new chronostratigraphy, established by high-resolution OSL dating
3. Summarize all pedological, sedimentological, and geomorphological data for a comprehensive environmental reconstitution of the Late Pleistocene for this area
4. Comparing the refined and independent results with findings from neighbouring loess areas

1.3 Thesis format

This thesis is a cumulative work and includes three first-author studies (Chapter 2, 3 & 4) published (accepted and printed) in three international peer-reviewed journals. The formatting of all studies is adapted to this thesis so

that the reference lists are not formatted as they are in the printed versions. Due to their origin as articles, every chapter has its own independent list of references. At the end of the thesis a global list with all cited references is presented.
The included studies refer to different questions on loess research but also show some overlapping with regard to their content. This is due to the fact that some assumptions changed during the course of the project. The first study (Chapter 2) was published in 2011 and provides an overview of most studied sections, showing their pedo-physical and geochemical characteristics. It introduces a first concept of a standard profile based on the correlation of all studied sections. The next study (Chapter 3) focuses on grain size results and introduces a regional concept to interpret grain size data from Saxon LPSs. In chapter 4 a revised standard profile combined with OSL ages is proposed. Additionally, a revised palaeoenvironmental reconstruction for the SLR is discussed. Chapter 1 and 5 give the conceptional frame for this thesis and serve as an extended summary.

Further related studies

During processing time of the project between 2008 and 2012, several studies were done by students supervised by the author and in cooperation with other specialized research. In this context the cooperation with Dr. Ulrich Hambach (University of Bayreuth) has to be mentioned. Together with former student and now colleague Philipp Baumgart, we published the following study which focuses on the environmental magnetic of Saxon LPSs. These studies are not included in this thesis but were developed in close cooperation with the author:

Baumgart, P., U. Hambach, S. Meszner & D. Faust (2013). "An environmental magnetic fingerprint of periglacial loess: Records of Late Pleistocene loess-palaeosol sequences from Eastern Germany". In: *Quaternary International* 296, pp. 82-93.
DOI: 10.1016/j.quaint.2012.12.021.

This work serves as an important contribution to the project, because it illustrates that the magnetic properties of several Saxon LPSs follow similar patterns with depth. Additionally, magnetic properties retrace the unit-

subdivision which were derived from fieldwork observations. Therefore, magnetic investigations obtained on LPSs served as a stratigraphical control. Furthermore, two types of magnetic susceptibility enrichment are described in Saxon LPSs. The uppermost parts of the profiles show a magnetic enrichment known from the Chinese loess plateau. In contrast, the middle and lower parts show magnetic behaviour described from Alaskan and Siberian loess sequences (wind vigour model).
In a further cooperation with Dr. Michael Zech we focused *n*-alkane biomarkers in loess sequences from Saxony. *n*-alkane biomarkers were measured from two LPSs in order to contribute to the reconstruction of the Late Quaternary vegetation history of the SLR.

Zech, M., T. Krause, S. Meszner & D. Faust (2013). "Incorrect when uncorrected: Reconstructing vegetation history using *n*-alkane biomarkers in loess-paleosol sequences - A case study from the Saxonian loess region, Germany". In: *Quaternary International* 296, pp. 108-116.
DOI: 10.1016/j.quaint.2012.01.023.

Zech, M., S. Kreutzer, T. Goslar, S. Meszner, T. Krause, D. Faust & M. Fuchs (2012). "Technical Note: n-Alkane lipid biomarkers in loess: post-sedimentary or syn-sedimentary?". In: *Biogeosciences Discuss* 9, pp. 9875-9896.
DOI: 10.5194/bgd-9-9875-2012.

Such collaborative studies contribute vastly to our understanding of the driving processes of the SLR and show that a solid stratigraphy with an assigned chronostratigraphy is of great interest to adjacent research fields.

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Chapter 2

Study I: Loess-palaeosol sequences from the loess area of Saxony (Germany)

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Contributions to the manuscript

	SM	MF	DF
Field work	90%	-	10%
Lab work	100%	-	-
Stratigraphy	80%	-	20%
OSL sampling	33%	-	33%
OSL dating	-	100%	-
Manuscript preparation	70%	5%	25%

Abbreviations are the authors' initials.

Abstract

Based on new descriptions of LPS, we present a new composite profile for the SLR, Germany. In addition to former studies of Lieberoth & Haase, new stratigraphic marker horizons and palaeosols were added. Concerning the so far poorly differentiated Weichselian pleniglacial we identified three palaeosols. A palaeoclimatic interpretation for the last glacial (Weichselian) is presented and discussed.

2.1 Introduction

The SLR is situated in the centre of Saxony, East Germany (Fig. 2.1) and represents the transition zone between the North European Plain and the Central Upland (Erzgebirge). In this area of gently rolling hills, a loess cover of up to 20 m was accumulated during the last glacial cycle (Weichselian), intercalated by a number of palaeosols. These LPS represent an excellent sediment archive for reconstructing environmental and climate change of the last glacial cycle. The first study of loess sediments in Saxony was carried out by Pietzsch (1922), dividing the sedimentary record into two main parts; one lower part with reworked sandy loess sediments and an upper one composed of more or less pure loess. In the following years, studies focused on loess distribution and on the general composition of loess and loess-like sediments (Grahmann 1925). In a first approach Gallwitz (1937) described a section close to the Elbe river, where he was able to distinguish several loess layers with intercalated levels of ice wedges and reworked loess. Grahmann (1932) published the first map of loess distribution in Europe. Since 1960 the loess in Saxony was the subject of intense palaeopedologic and stratigraphic investigation. Based on several sections, Lieberoth built up a stratigraphy, which has been accepted until now (Lieberoth 1962b, 1964a; Lieberoth & G. Haase 1964; Lieberoth 1959, 1963). Later on, G. Haase (1963, 1968) and Neumeister (1966) worked on geomorphic features of the northern loess boundary (Lössrandstufe). At this time, the loess research of Eastern Germany was summarized by Gellert (1965) and H. Richter et al. (1970). Since then, only a few articles have been published (Altermann et al. 1978; Biering & Frühauf 1999; Koch

& Neumeister 2005; Meng 2003; Zöller et al. 2004). A systematic approach with further results is still lacking. In the present study the existing results are summarized in respect to the Saxon loess stratigraphy and improved by new findings to broaden our knowledge of LPS in Saxony. As most sections mentioned before are inaccessible today, new sections had to be opened for this study. Due to the fact that LPS of Saxony represent an important link between the Western European loess records formed under moister conditions and the Bohemian loess records formed under more continental conditions, the SLR provides valuable information about the palaeoclimate change in this transitional zone.

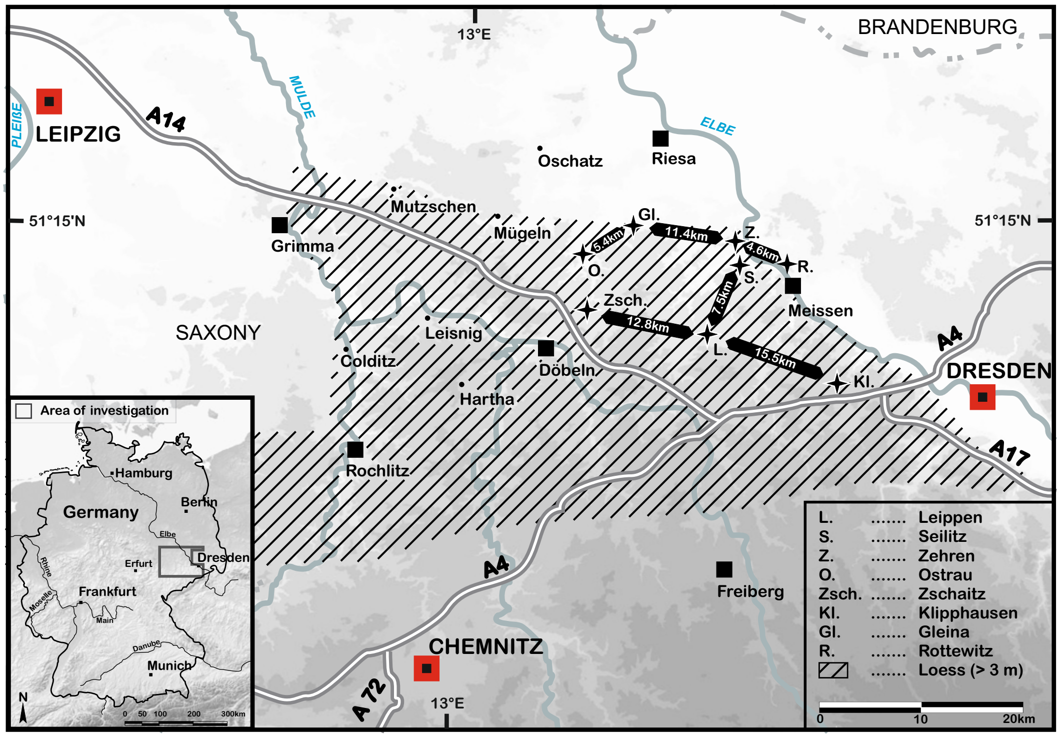

Figure 2.1: Map showing study area and distribution of loess (>3 m thickness).

2.1.1 Geographical setting

The SLR is situated in East Germany, west of the city of Dresden and characterized by gentle rolling hills, covered by up to 20 m thick loess accumulations (Fig. 2.1). The landscape is dissected by small rivers incised into the loess cover down to the bedrock (Granite of Meissen). The loess was deposited in the foreland of the Erzgebirge, forming a plateau-like topography, representing the so-called "Saxon Loess Plateau". Surrounded by deep incised valleys of the Elbe and the Mulde River the landscape is and was endangered by soil erosion processes even in former times. In the Early to Middle Pleistocene the study area was covered by the ice shield of the Elsterian Glaciation. From the First Saalian Glaciation glacial deposits are described by EISSMANN (1994). These deposits were reworked and enriched by loess deposits of the Late Saalian Glaciation (Warthe), which show evidence that the Late Saalian ice advance stopped some kilometres further north. The last period of loess accumulation took place during the Weichselian Glaciation. The fertile soils, formed during Late Pleistocene and Holocene, were cultivated by early farmers around 7500 BP (cf. OEXLE 2000). Today the landscape is characterized by varying soil patterns showing a mosaic of truncated Luvisols of different stages owing to extended agricultural activity. The valley bottoms are filled by colluvial material up to 4 m thick. Some strongly eroded hill slopes show that the underlying calcareous loess is already at the surface and is mixed into the soil by modern ploughing. In positions of little erosion we assume a deepness of decalcified loess due to soil formation of about 1.8 m. We conclude that at some places more than 2 m of soil was eroded.

Today the mean annual temperature is about 8.8°C, as determined in a nearby climate station (Döbeln). The mean annual precipitation is about 600 mm with its maximum in summer.

2.2 Methods

Field Work

In order to select the locations for detailed fieldwork and profile description, the study area was investigated using aerial and satellite images. After deciding to open seven new sections, fieldwork included cleaning, drawings, and sampling of each profile. The samples were taken in respect to the layering of the section. Some sections were sampled equidistant with a 2 cm resolution. Standard sedimentological and pedological analyses like granulometry, pH value, carbonate content, soil organic matter (SOM), and content of several iron compounds were conducted in the laboratory of the Institute of Geography (Dresden University of Technology). During fieldwork we already established a preliminary litho- and pedostratigraphy with a focus on the identification of loess-palaeosol complexes. Magnetic susceptibility was measured in SI units in the field with a portable Bartington MS2 susceptibility meter. For this purpose we chose an interval of less than 5 cm. Commonly, three measurements were averaged (cf. Dearing 1999).

Sedimentology

At the Institute of Geography (Dresden), soil textures were analysed. Bulk sample (10 g) was mixed with 25 ml dispersing solution (sodium hexametaphosphate: ($(NaPO_3)_6$ - 39 g/l H_2O) and 200 ml H_2O. After rotating the suspension for at least 2 h it was stored for 12 h for complete dispersion. The grain-size measurements of the sand fraction were carried out by means of the wet sieve technique(2.0 - 0.63 mm: coarse sand; 0.63 - 0.2 mm: medium sand; 0.2 - 0.125 mm: fine sand; 0.125 - 0.063 mm: very fine sand). Coarse silt (0.063 - 0.02 mm), medium silt (0.02 - 0.0063 mm), fine silt (0.0063 - 0.002 mm) and clay ($<$0.002 mm) were measured by pipette analyses (Schlichting et al. 1995). The carbonate content was determined by CO_2 gas volume. Soil samples were added with hydrochloric acid in a closed system, and the resulting CO_2 gas volume was measured by a Scheibler-apparatus (cf. Schlichting et al. 1995). The SOM was determined by oxidation with $K_2Cr_2O_7$ in a concentrated H_2SO_4 medium and measurement of absorbency at 590 nm (cf. Schlichting et al. 1995). The pH value was determined in a 1:2.5 soil/solution ratio in 25 ml 0.01 M $CaCl_2$ (cf. Schlichting et al. 1995). After stirring the suspension for 30 min., the pH value was measured. To extract the pedogenic iron compound (Fe_d), soil samples were deferrated by the bicarbonate-buffered dithionite-citrate procedure (cf. Schlichting et al. 1995). To determine the total iron content (Fe_t), 100 mg of soil material was digested with 2 ml concentrated nitric acid (HNO_3) and 2 ml concentrated hydrofluoric acid (HF) using steam autoclaves. The amounts of pedogenic (Fe_d) and total (Fe_t) iron were measured using an atomic absorption spectrometer.

Mollusc analyses

The mollusc analyses were carried out by HAMANN (2010). Samples of about 10 to 15 kg were taken, sieved (200 or 400 µm mesh size) and washed to extract the mollusc shells, which were counted and identified. The species were classified according to LOŽEK (1964).

IRSL Dating

Samples for infrared stimulated luminescence (IRSL) dating were taken using steel cylinders, hammered into the cleaned loess section to avoid any contamination of the samples with light-exposed material. Sample preparation was performed under subdued red light (640 ± 20 nm), using the polymineral fine-grain fraction (4-11 µm) for luminescence measurements.

The equivalent dose (D_e) was determined by applying a multiple aliquot additive dose protocol. To construct a saturating exponential growth curve for D_e determination, 10 natural aliquots and six groups of artificially irradiated aliquots (five each) were used. Artificial irradiation was carried out with a $^{90}S/^{90}Y$ b-source (9.9 Gy/min). During IR stimulation (880 ± 80 nm), the shine-down curves were measured for 60 s at room temperature after a preheating at 220°C for 300 s and using a detection filter combination of BG39, 2 x BG3 and GG400 (390-450 nm). Before IRSL measurements, the samples were stored (room temperature) for a minimum of one month after artificial irradiation. Finally, the D_e was calculated from the 0-40 s signal integral after subtracting the 'late light' signal of the 55-60 s integral (AITKEN & SMITH 1988; AITKEN & XIE 1992). In addition, an extra set of aliquots was used to test for anomalous fading and to determine the α-efficiency (a-value) of the measured material. No anomalous fading was detected. Dose rates were obtained using low-level γ-spectrometry and conversion factors given by ADAMIEC & AITKEN (1998).

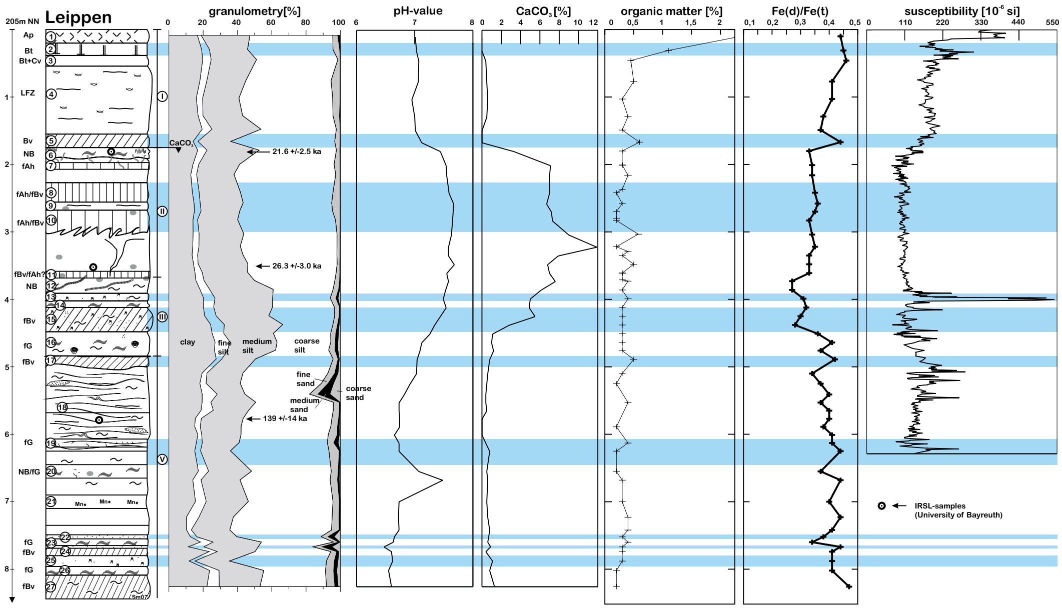

Figure 2.2: Leippen section with geochemical results

2.3 Results

2.3.1 Leippen section (Tab. 2.1; Fig. 2.2)

Due to roadcuts close to the village of Leippen (GK R 459345 H 566726) this section was open in summer 2005. A detailed description is given in Table 2.1. In general, the section could be subdivided into four units, beginning at the top with a darkish decalcified part in which the Holocene soil is developed. The decalcification boundary at about 2 m is the lowermost limit of this unit. The underlying calcareous loess is characterized by a light yellowish colour and a typical porous fabric. This unit is composed of pure loess and resorted loess derivates wherein some darkish or reddish parts could be detected and are seen as interstadial soil features. During the deposition of this unit, huge ice wedges were formed reaching even into the subjacent unit (Fig. 2.3). The unit beneath is dominated by solifluction processes which generated different smaller layers. The whole unit shows markedly stronger colouring. The base is composed of material which seems to have undergone strong soil redeposition. The lowest unit is subdivided into two parts. The upper part shows a strong lamination with platy fabric including sandy bands indicating abluation processes; the lower part is less laminated and has a weaker structure. We assume that

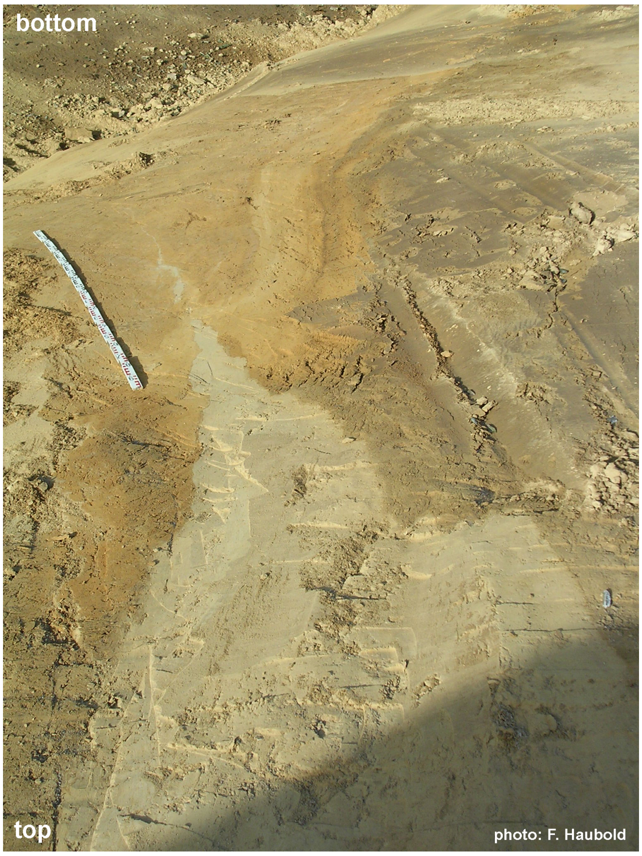

Figure 2.3: Big ice wedges at the Leippen section (photo is upside down)

the lowest unit is already composed of Saalian deposits. A sample from the lower part of layer 18 shows an IRSL age of 139 ± 14 thousand years (ka). Combining this IRSL age with the increase of clay and sand in layer 16 and 17 and the increase of Fe-ratio, we suspect a significant hiatus in this section. This hiatus is the result of an erosion phase which hits the Eemian soil and the Early Weichelian deposits.

The geochemical analyses (Fig. 2.2) support the division into these units.

Table 2.1: Description of Leippen section

Layer	Label	Description
1	Ap	humic dark horizon with a clear lower boundary
2	Bt	reddish brown clay enriched compact loam, weak pinprick structure and sporadically hydromorphic features (rust stains)
3	Bt+Cv	less clay than layer 2, oval bleached patches (diameter 5 mm), pinpricks
4	LFZ	lamellar line-like structure between brownish clay-enriched (10Y5/6) and yellowish coarse silt (10Y6/4)
5	Bv	homogeneous light brownish grey, non calcareous silt, typical loosely packed loess structure with sporadic fine Manganese concretions, old backfilled earthworm burrows
6	NB	bedded light greyish calcareous loess with iron hydroxide lines, undulated lower boundary, old backfilled earthworm burrows (current term in work: bio-traces)
7	fAh	pale slightly dark loess
8	fAh/fBv	brown greyish homogeneous loess with pseudomycelia and sporadic big Mn-stains
9		slight lamellar structure, light brown, big Mn-stains
10	fAh/fBv	brown greyish homogeneous loess with pseudomycelia, undulating lower limit
10-11		laminated loess with big Manganese stains
11	fAh/fBv?	pale dark homogeneous loamy loess
12	NB	grey brownish loam with a typical iron-oxide grid
13		loamy, brown greyish loess derivate, numerous Mn-concretions (solifluction layer)
14		loam, grey, brown with some little stones
15	fBv	(soil sediment) stony (pebbles) layer, dark grey brown, numerous Mn-concretions, dense layering
16	fG	bleached grey layer with rosty tubes, hydromorphic features
17	fBv	reddish sandy material with cryoturbation features, parts with microstructure
18		clearly laminated material with sandy, loamy and silty layers (10YR5/6, 5/4, 6/8, 5/6), platy microstructure
19	fG	grey-(light purple)-bleached loam
20	NB/fG	grey-(light purple)-bleached loam, iron-oxides
21		Manganese enriched loam
22		thin layer of sand
23	fG	grey-(light purple)-bleached loam
24	fBv	(soil sediment) clay enriched, reddish brown soil sediment
25		yellowish loess
26	fG	grey-(light purple)-bleached loam
27	fBv	(soil sediment) stained silt, grey brown yellowish

2.3.2 Seilitz section (Tab. 2.2; Fig. 2.4)

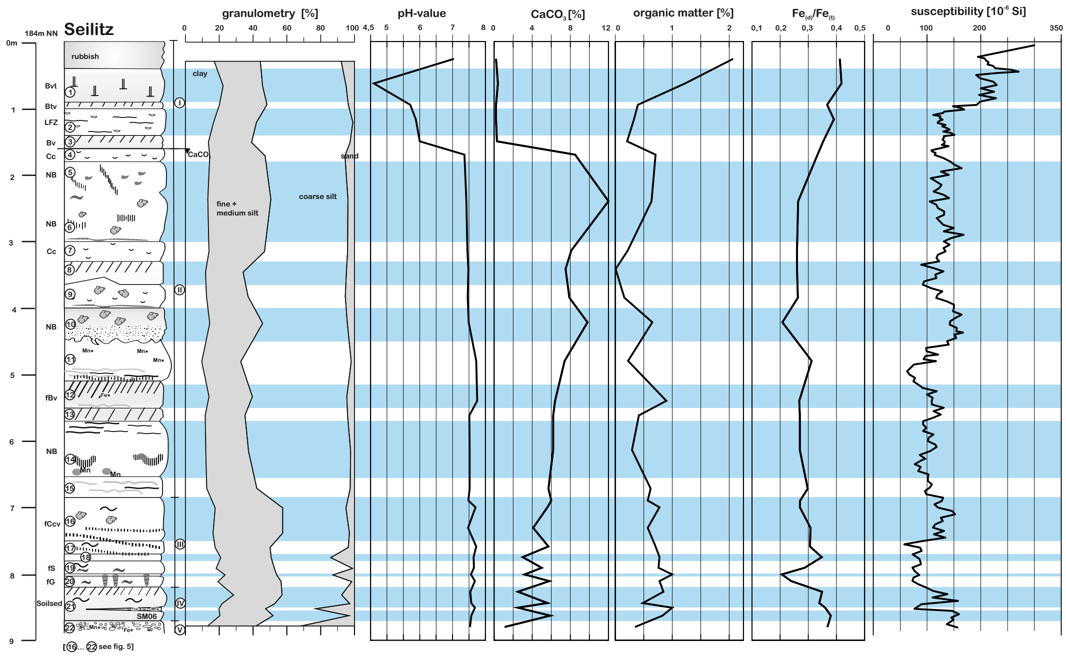

Figure 2.4: Seilitz section with geochemical results

The section is located close to the village of Seilitz (GK R 5388260, H 5673750) in a kaolin pit 1.5 km southwest of the recent course of the river Elbe. A detailed description is given in Table 2.2. The loess record covers a thick kaolin horizon derived from strong alteration processes of the monzodiorite. In between, a small sandy gravel layer is developed which is interpreted as remnants of moraine material of Saalian age. This stratigraphical situation makes a Weichselian loess deposition most likely. Following the different features within the whole loess section, we propose to subdivide the Weichselian loess deposits into three units. According to the Leippen section the uppermost unit, a decalcified loess, correlates to the late Weichselian with the recent soil at the top. The following unit is about 5 m thick and contains several interstadial soils with the upper soil showing strong hydromorphic features (Fig. 2.4; layer 5 and 6). A dark grey horizon (layer 10) is seen as the strongest palaeosol-(sediment) in this section. The lower brownish palaeosol forms layer 12. The lower unit III is characterized by layers indicating strong solifluction, which are also recognizable at the section of Leippen (Fig. 2.2). Geochemical analyses such as the increased content of sand and clay (Fig. 2.4) show congruent results. For

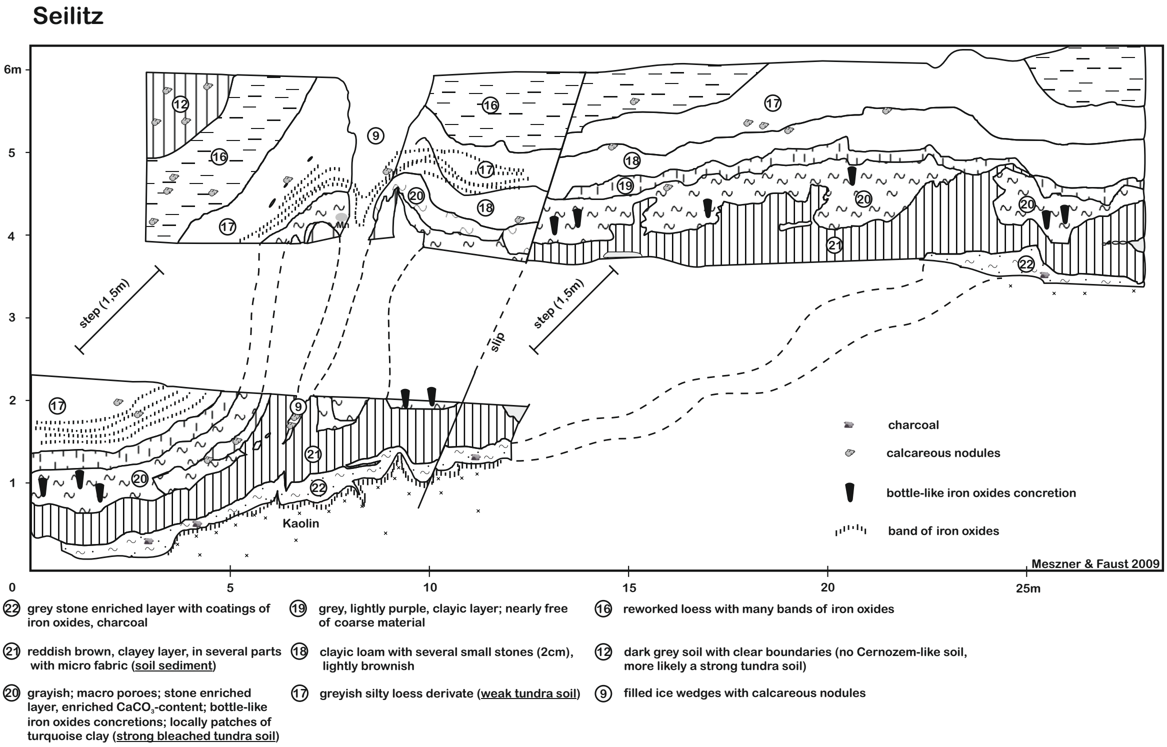

Figure 2.5: Lower part of the Seilitz section

example the dark grey horizon (layer 10) shows enrichment of carbonate and of SOM. The pH-value marks the carbonate free parts of the Holocene soil development and fits well with the analyses of the carbonate content.

Table 2.2: Description of Seilitz section

Layer	Label	Description
1	Bvt	brown illuvial horizon with weak hydromorphic features, in the lower part prismatic structure
2	LFZ	a very typical expression of lenticular horizon!; lamellar line-like structure between brownish clay-enriched and yellowish coarse silt, pores increasing with depth
3	Bv	light brown homogeneous horizon, decalcified, some fine pores
4	Cc	light yellow calcareous loess; bio-traces, small Mn-concretions
5	NB	Concentric iron oxide rings around root channels, pseudomycelia, bleached grey stains, scattered fine pores
6	NB	light brown loess, diffuse iron oxide patches, pseudomycelia, small Mn-concretions, stained
7		loess
8		reddish loess (fine dispersed iron oxides)
9		weak linear iron oxides on a pale matrix, calcareous nodules, lower limit marked by a strong line of iron oxides
10	NB	calcareous nodules, dark grey, many fine pores, loamy, 10% calcium carbonate, molluscs, soil structure, iron oxide stains, clearly limited, undulating lower boundary
11		bedded loess derivate with calcareous nodules and small Mn-concretions
12	fBv	no stratified loess, homogenous material, small globules of iron oxides, greyish brown colour, many pseudomycelia, undulating lower boundary
13		stratified material, hydromorphic features
14	NB	iron oxides diagonally ruled, big Mn-stains in the lower part
15		stratified loess derivates, strong reworked material
16	fCcv	some calcareous nodules, sporadically little stones
17		massive slight pale yellow calcareous loess with fine iron oxide bands
18		loess derivate with many Mn- and iron oxide concretions
19		grey brownish loam, bands of iron oxides and small calcareous concretions
20	fG	grey, bleached material, locally patches of turquoise clay, bottle-like iron oxide concretions (often formed like a sugar loaf)
21	(fBv)	(soil sediment) reddish brown loam, compact bedding, sometimes with weak platy microstructure
22		very massive layer, many stones, grey matrix with interfacial skins of iron oxides

2.3.3 Zehren section (Tab. 2.3; Fig. 2.6)

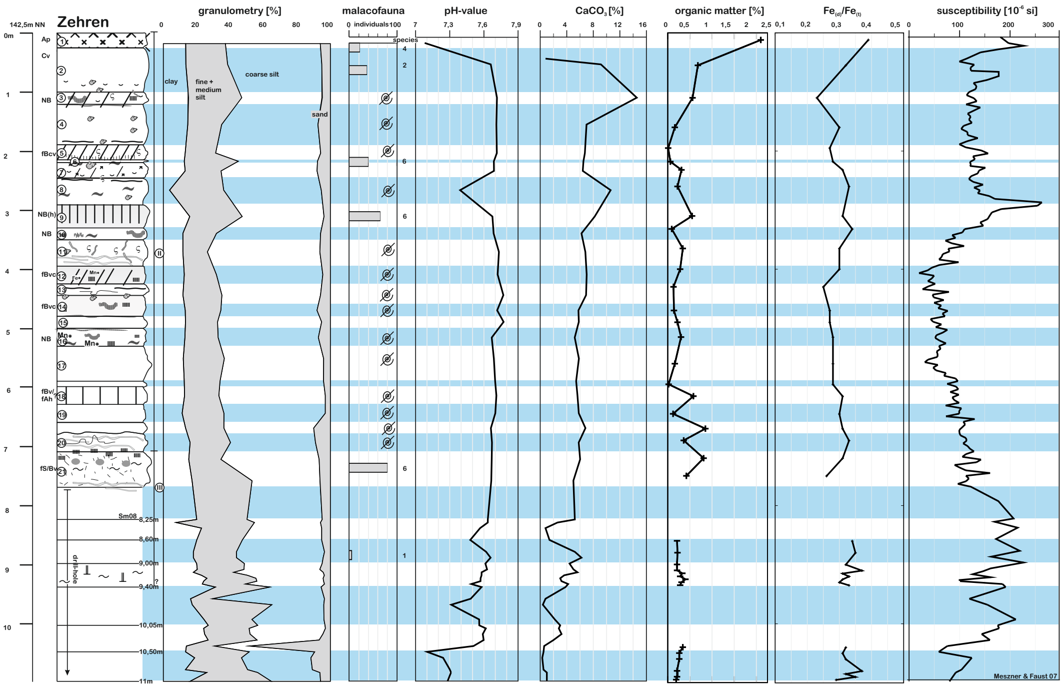

Figure 2.6: Zehren section with geochemical results

The Zehren section (GK R 4597625 H 5675325) is situated about 1.5 km to the north of the Seilitz section. Table 2.3 contains a summarized description. At the top of the section a weak humic calcareous horizon is developed which indicates strong erosion processes in former times. We assume that at least 2 m of soil and loess material is lacking. Therefore the described unit from the top of the Seilitz and Leippen section is not preserved in the Zehren section. At about 3 m depth we detected a notable humic horizon with remarkable dark greyish colouring (layer 9) which has not been described in former studies. The main features of this horizon are the strong colour and the distinct lower and upper boundary. The base of this unit (layer 20) marks the boundary between loess and loess sediment (Fig. 2.6). From a depth of 7 m (layer 21) the section is composed of strongly reworked loess derivates up to a depth of 11 m. Considering the fact that at the top of this section 2 m of loess is missing, we believe that this section represents the thickest loess accumulation of the study area.

Table 2.3: Description of Zehren section

Layer	Label	Description
1	Ap	calcareous humic dark grey plough horizon
2		calcareous light yellow loess
3	NB	carbonate enrichment, some light grey bleached stains, patches and bands of iron oxides, biotraces
4		loess with calcareous nodules
5	fBvc	light brown yellowish loess, the upper boundary is marked by clearly visible and shredded layer of yellow material
6		band of iron oxides on a grey yellowish bleached matrix
7		light brown yellowish loess, lower boundary is also marked by a shredded layer, pseudomycelia
8		loess with a fine layer of bleached patches, some pseudomycelia and iron oxides stains in the lower part
9	NB	dark grey loamy material, clear lower and upper boundary, some iron oxides and a very fine angular structure
10		stains of iron oxide, bleached root channels
11		laminated loess with biotraces, in the lower part Mn-concretions
12	fBvc	light brown greyish material (not laminated!), small nodules of iron oxides
13		laminated loess with microcryoturbation
14	fBvc	brown greyish homogeneous material, iron and Mn-concretions, pseudomycelia, biotraces, clear iron oxide bands on the lower boundary
15		loess
16	NB	lightly grey bleached loess with iron oxide stains, clearly band of iron oxide
17		material showing weak lamination
18		light brown colouring
19		weakly laminated loess derivates
20		loess with distinct lamination and some iron oxides stains in the lower part, cryoturbation features
21	fS/Bv	brownish grey loam with iron oxide grid, big Mn-patches

2.3.4 Ostrau section (Tab. 2.4; Fig. 2.6)

This section is situated close to the town of Ostrau (GK R 4582462 H 5675008) in a limestone pit of the Ostrauer Kalkwerke GmbH and contains the most complete Weichselian loess sequence including the last interglacial palaeosol (Eemian). Table 2.4 shows a detailed description of the Ostrau section. According to the sections of Leippen and Seilitz, we are able to subdivide the sequence from the Ostrau section into three upper units as well. As the section reaches into the last interglacial palaeosol, we added a fourth unit at the bottom of this section. From the top we observe the typical sequence starting with decalcified loess which includes the first three layers (Fig. 2.7). Unit II starts with layer 4 and ends at about 5 m depth with layer 8. In layer 5, a slightly reworked but strong soil is developed which we correlate with the strong soil at the Zehren section (Fig. 2.6, layer 9). This soil formed after a stronger phase of reorganization of the surface as evidenced by deep gullies which are filled up (layer 5). A detailed draft (Fig. 2.8) of the upper part of the section shows the incision into layer 6. The lowermost unit begins with layer 9 in which big ice wedges could be observed. Stratigraphically they belong to layer 8 (unit II). The lowermost unit III is composed of several derived loess layers and soil sediments indicating several environmental changes during this time. The grey solifluction layer (11) and the reddish loam (layer 12) mark the boundary between unit III and unit IV. Of particular interest is the humic horizon in layer 13 and the bleached lower part rich in charcoal remnants (layer 14). In Ostrau this stratigraphically lowest unit is composed of Saalian deposits in which two in situ horizons were formed (Eemian soil; layer 15/16).

Table 2.4: Description of Ostrau section

Layer	Label	Description
1	Bt	lower part of truncated Bt-horizon of the Holocene Luvisol, spare hydromorphic features (iron oxide stains)
2	LFZ	short brown bands of loamy clayish material alternating with pale yellow loessic stains (lenticular horizon)
3	Bv	homogeneous pale brown material, some diffuse cloud-like Mn-stains
4	NB	NB = Nassboden [germ] = Gelic Gleysol; typical microstructure of loess, slightly brown colour, some parts show pale dark discolouration when the surface is drying; these discolourated parts look like filled earthworm burrows (current work determination: bio-traps), sporadic Mn-concretions
5	NB	dark grey bleached loamy material with rust stains and a clear microstructure (rough section surface after preparation), $CaCO_3$ -concretions make crunching noise when cleaning the section, calcareous nodules horizontally bedded
6		laminated loess derivate, sparely iron oxides stains
7	fBv	light dark, pale brown (slightly purplish) colour; calcareous nodules, very distinct lower and upper boundary (undulating), rust stains, pseudomycelia, Mn-concretions; cryoturbation features
8		laminated loess derivate, in the lower part big Mn-stains
8-9		stronger reworked material - clear changes in texture
9	fS/Bv	thick layer; brown, slightly reddish (10YR6/4); in the upper part stains of iron oxides (leopard skin-like), in the lower part increase of bleaching and iron oxides, fissures are lined with iron oxides skins, sporadically pseudomycelia; loamy, mixed with coarse fragments
10		bright yellow silt, without any features of pedogenesis, filled ice wedge
11		clear boundary, grey matrix (10YR5/4) with fragments of reddish brown clayic material, relative high content of coarse material and calcareous concretions, solifluction features
12	reworked Bt	dark yellowish (reddish) brown (10YR4/4) loam, sporadically angular structure, in the lower part strong hydromorphic features (grey bleached)
13	HZ	HZ - Humuszone (humic horizon) dark pale grey brown silt (mottles), least compacted
14	fS(e)w	conspicuous bright grey material; loose structure; charcoal; big fibril Mn-concretions
15	fSw/Bt	mottled yellow reddish orange horizon, bleached grey root channels subangular structure, in-situ Bt-horizon of a Luvisol with hydromorphic features
		buried stone layer
17		sand with clay coatings and a prismatic structure, intense reddish colour

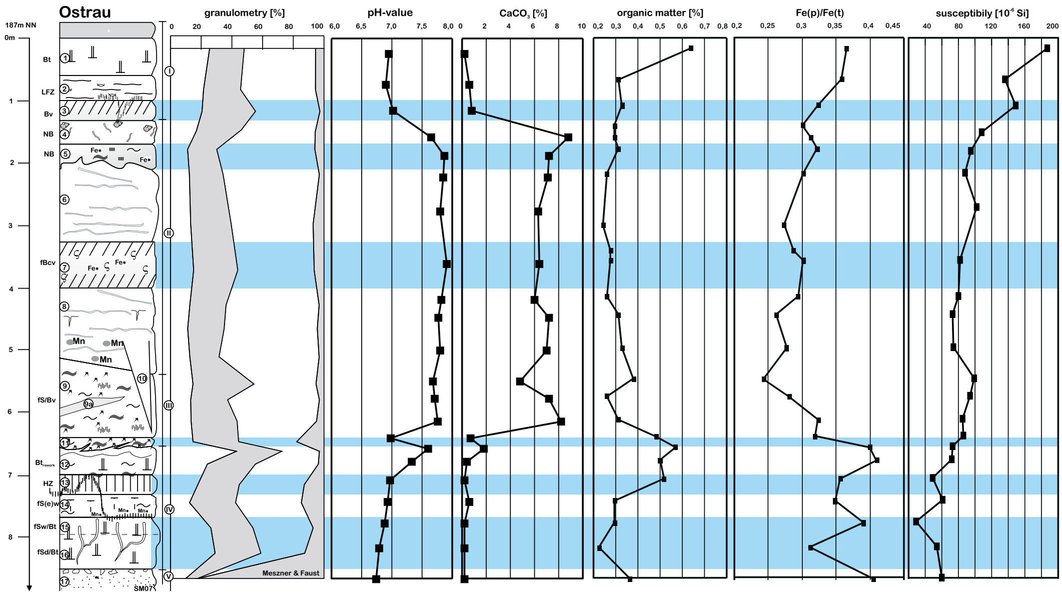

Figure 2.7: Ostrau section with geochemical results

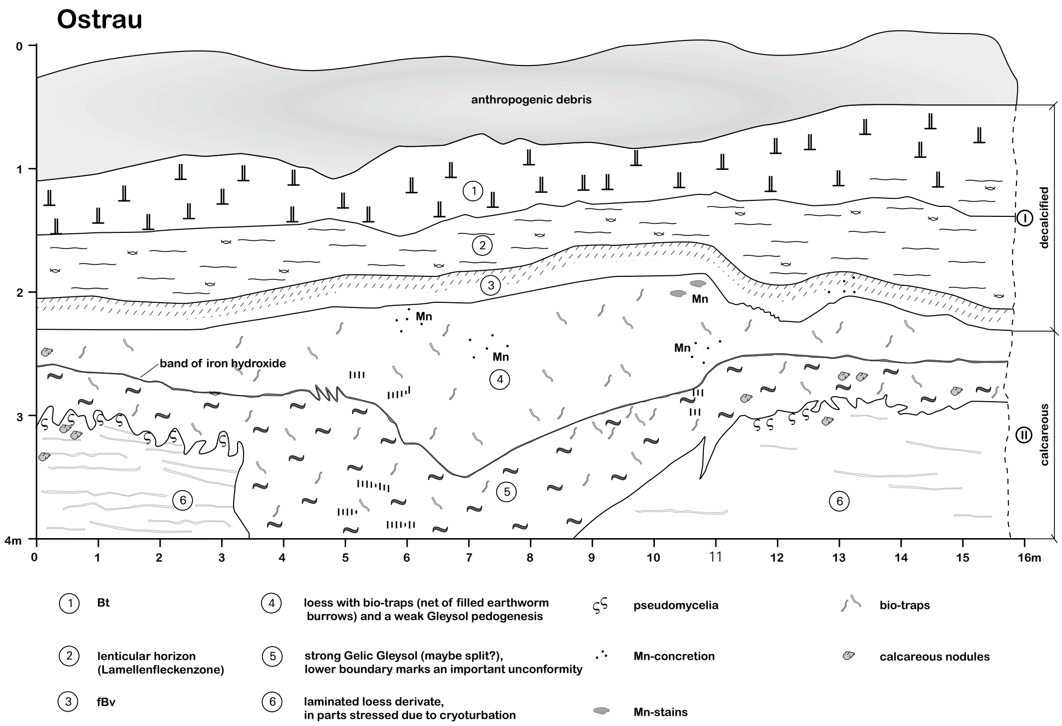

Figure 2.8: Detailed draft of the upper part of Ostrau section

2.3.5 Zschaitz section (Tab. 2.5; Fig. 2.9)

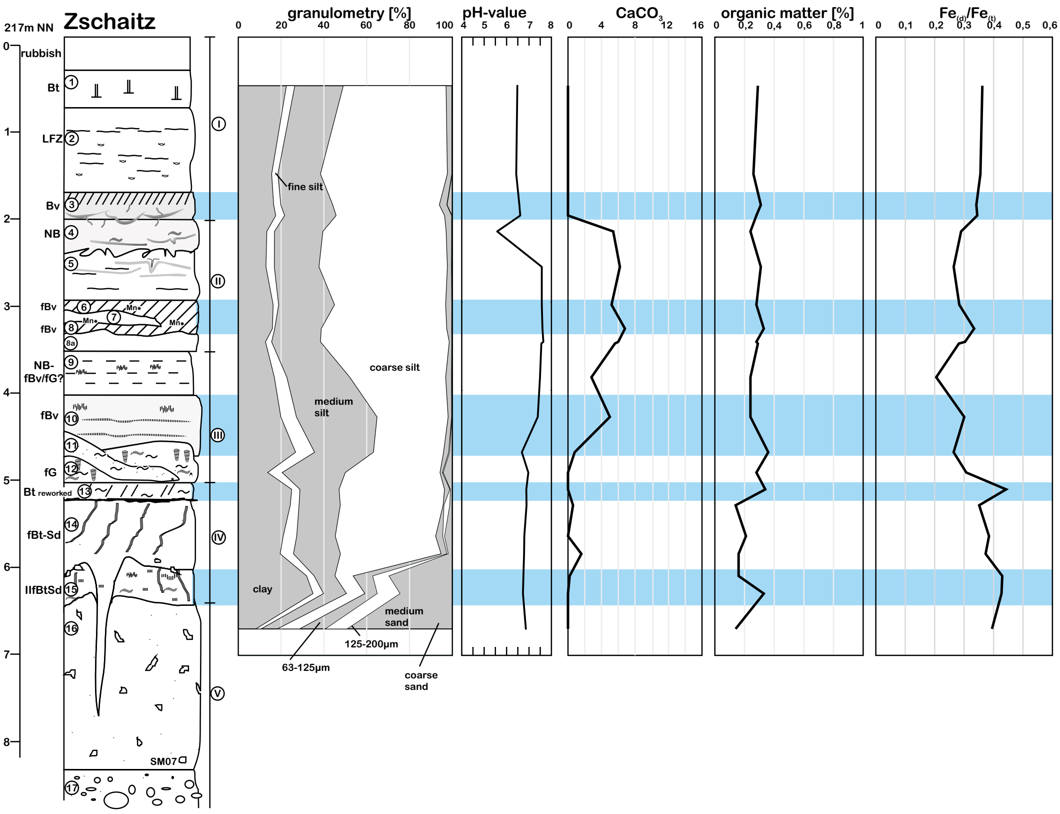

Figure 2.9: Zschaitz section with geochemical results

At the Zschaitz section, deposits of an ancient river branch of the Mulde river (Eissmann 1964) are exposed in a gravel pit (GK R 4580416 H 5669191). These fluvial deposits are covered by loess sediments from two glacial periods. Four units could be identified in this section. Details are given in Table 2.5. Unit I is composed of decalcified sediment layers which could be correlated with almost all the other sections described in the present study. The lower boundary of this unit is marked by the boundary of the decalcified layer into the calcareous loess. Unit II is not as distinct as in the other sections and composed of the layers 4 to 8a. Unit III contains several soil sediments and solifluction layers. Its boundary to unit IV is distinct and clear. Unit IV has on its top remnants of the last interglacial soil. The deeper part shows big ice wedges and strongly reworked loess derivates with little gravel content. Within this deepest layer (16) close to the contact to the gravel deposits (layer 17) some stone artefacts (small flakes) were found but have not been investigated

Table 2.5: Description of Zschaitz section

Layer	Label	Description
1	Bt	reddish brown clay enriched compact loam, weak pinprick structure and sporadically hydromorphic features (rust stains)
2	LFZ	lamellar lined structure between brownish clay-enriched and yellowish coarse silt; in the upper part large and in the lower part narrow bedding, lenticular horizon
3	Bv	homogeneous light brownish grey, non calcareous silt, loose loess structure; several dark greyish curved structures (banana-like) crossing the boundary into the calcareous loess; boundary between non-calcareous and calcareous loess
4	NB	grey material, hydromorphic features, undulated lower limit
5		laminated material with small frost cracks
6	fBv	platy structure, Mn-concretions, pale grey-brown
7		loess
8	fBv	Mn-concretions, pale grey-brown
8a		slightly reworked loess, laminated
9	NB fBv/fG?	homogeneous greyish material; increase content of fine to medium silt and clay; deoxidation in the lowest part of this layer
10	fBv	brown loessic material with fine dispersed iron-oxides
11		light yellow greenish layer with fibered Mn- (2-5 mm) and iron-oxide concretions
12	fG	grey, bleached material, locally patches of turquoise clay, bottle-like iron oxide concretions
13	Bt reworked	reddish layer with high content of clay; constant thickness; microstructure; the lower limit is marked by a crusted band of iron oxide; nearly no Mn-concretions; thin horizontal patches of bleached material
14	fBt-Sd	brown reddish, slightly purple material; well developed microstructure; bleached root channel, ice wedges are filled with fBt-Sd-material
15	IIfBtSd	vario-coloured horizon, orange reddish and grey parts, many stones, grey bleached channels
16		very coarse material, many stones
17		gravel from a palaeochannel of the Freiberger Mulde river

yet.

2.3.6 Klipphausen section (Tab. 2.6; Fig. 2.10)

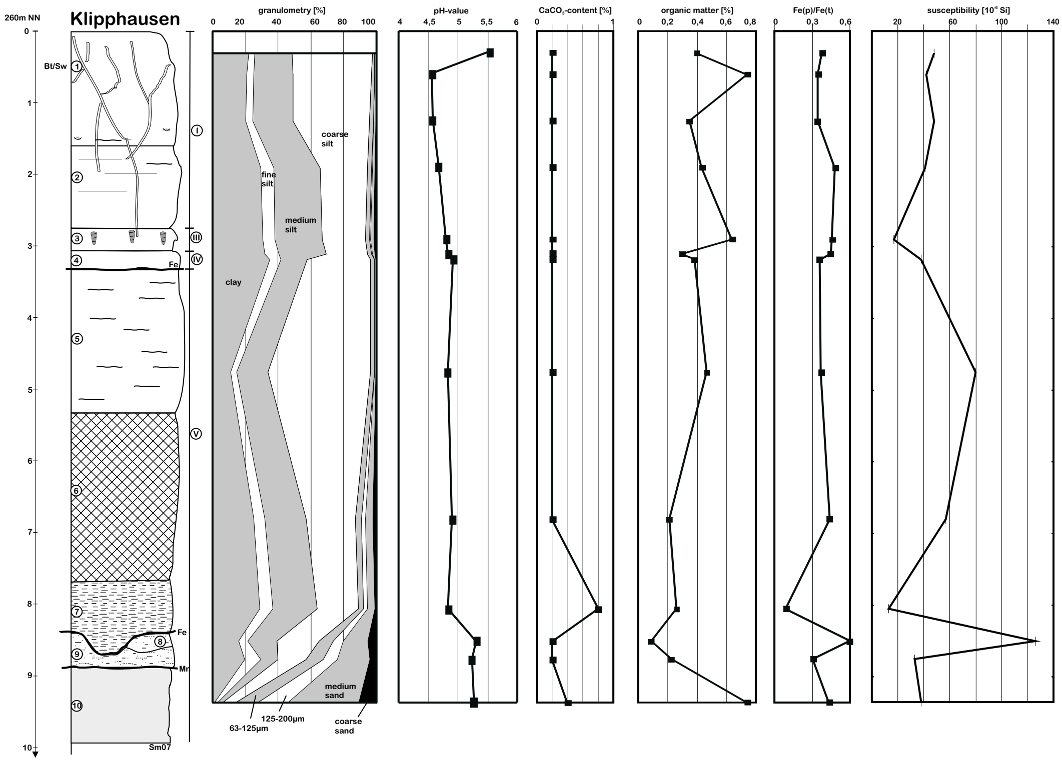

Figure 2.10: Klipphausen section with geochemical results

Differing hachures from Fig. 2.16 in layer 6-10

6 – clayic loam; 7 – light grey loam; 8 – silty loam; 9 – sandy loam; 10 – bedded sand

This section is situated close to the village of Klipphausen (GK R 4605947 H 5660667). It is not accessible anymore because it existed only for a short period of time during house construction. The Klipphausen section is characterized by an additional pattern, not identified in the above described sections. The material of the upper three meters is loamy (20%-60% clay; fine and medium silt) and shows a low pH-value. This is due to the fact that this section is located in the southern part of the study area close to the connecting slope into the southern mountain range (Erzgebirge). It is a typical position for the transition zone from the loess plateau with aeolian dominated processes into the mountain landscape which was dominated by solifluction processes. The section is composed of different layers including loess derivates and solifluction layers. We only see similarities according to the other sections in the upper part of this sequence. There, gleyic features are found in a loess derivate

Table 2.6: Description of Klipphausen section

Layer	Label	Description
1	Bt/Sd	checkered loam with clay filled root channels; bleached clay
2		yellowish loam with numerous Mn-concretions
3		deoxidized greyish loam with bottle-like iron-oxide structures
4		reddish, grey-brown clayish loam
5		loessic laminated silty loam, platy microstructure
6		homogeneous brown clayish loam, compacted
7		light grey loam; in the upper part some patches of iron-oxide; the lower limit is marked by crusted band of iron oxides
8		silty loam, yellow matrix with rusty coatings
9		sandy loam with grey bleached patches in a reddisch oxidized matrix
10		bedded sand, upper limit is marked by a distinctive Mn-band

(layer 3) which we correlate with layer 16 of the Leippen section (Fig. 2.2) and layer 20 of the Seilitz section (Fig. 2.4).

2.3.7 Gleina section (Tab. 2.7; Fig. 2.11)

Table 2.7: Description of Gleina section

Layer	Label	Description
1	Bt	lower part of the truncated Bt-horizon
2	LFZ	lenticular horizon
3	Bv	homogeneous pale brown decalcified horizon
4		bleached stains (root channels), biotraps, at the lower part slightly brown with Mn-stains
5	NB	high porosity, many bleached stains, bright orange iron oxide rings around filled root channels loess with many iron hydroxide stains
6	NB	many small calcic nodules (Loesskindl); bleached, the lower part shows many Mn-dots loess, scattered small Mn-concretions, scarcely iron hydroxide stains
7	NB	calcareous nodules, strong bleaching; scattered rust stains, platy structure, clear boundaries
8		laminated loess derivate, loose density
9	NB	weak bleaching; homogeneous (not laminated), iron hydroxide stains, pseudomycelia

Table 2.7: Description of Gleina section

Layer	Label	Description
10		laminated material with small frost cracks, loess derivates
11	fBv	homogeneuos, diffuse distributed iron hydroxide stains, pseudomycelia; loamy, weak structure, many pores
12		weak laminated material with features of cryoturbation stress
13	fBv	pseudomycelia; no lamination, gathering of Mn-stains, small iron hydroxide concretions
14		upper boundary is marked by some slightly yellow undulating and thin layers of loess material, distort layers, big Mn-stains, small frost cracks
15		transition zone between weakly modified and strongly reworked loess, above: many oval Mn-stains; beneath: bigger Mn-stains, compact structure, loamy, typical iron oxide grid (leopard skin-like)
15-16		increasing of medium and fine silt with depth, big Mn-stains with diffuse boundaries
16		Mn-stains and calcareous nodules, location of big (15cm) horizontal bedded calcareous nodules
17		increasing clay content with depth, scattered iron hydroxide stains, in the depth of 10.30 m gradual increase of carbonate, small admixture of coarse fragments; the lowest part is represented by a brown greyish clayish layer
18	fG	non calcareous, intense bleached, grey horizon (10BG 6/1); the lower boundary is marked by intense lines of iron hydroxides
19	fBv	reddish brown horizon, platy structure, bands of iron hydroxide that end abruptly at the upper boundary
20		gradually decrease of carbonate, bedded structure with embedded sandy lenses
21	HZ	dark pale grey brown silt, least compacted
22	fS(e)w reworked	bright grey bleached material, weak coherence, big Mn-concretions (0.5-1 cm) often with fibril structure; charcoal!
23	IIfS(e)w	intense mottles of reddish brown iron hydroxides, most parts are bleached, subangular structure
24	fBtSd	intense bleached root channels, clearly subangular structure, decrease of colouring, in the lower part more reddish, more darkish at the top

Table 2.7: Description of Gleina section

Layer	Label	Description
25	IIfBt (Sand) & IIIfG (Silt)	mixed layer with reddish clay and light grey silt
26		light ochre sand

The Gleina section is located at the northern loess boundary (Lössrandstufe) at the western edge of the village Gleina (GK R 4586889 H 5678057). This former brick yard is the type locality for the so called "Gleinaer Bodenkomplex" which is an interstadial soil complex (Lieberoth 1964b). The Gleina section was reopened by us in 2009. Figure 2.11 shows the main stratigraphical units. The thick loess sequence of Gleina has comparable units which correlate well with the previously described profiles. The four important units already described are present in this section. The section also shows the "Gleinaer Bodenkomplex", which is easy to identify because of its intense colour changes from grey to reddish. In addition, this soil complex is characterized by its decalcified horizon between the top of the complex and the following interglacial soil below. However, in all the other sections, there is no clear evidence of this complex. According to Neumeister (1966) who reported the thickest Weichselian loess layers in the northern boundary (Lössrandstufe), our findings show a similar pattern. The northernmost sections (Gleina and Zehren) show the thickest, and in the case of Gleina, most complete Weichselian loess deposits. In contrast, the Klipphausen section, situated at the southern boundary of the loess plateau, shows only Weichselian loess deposits of 3 m thickness.

2.4 Interpretation and discussion

The main lithological and pedogenical features of all studied sections are used to establish a standard-LPS for the SLR. In five sections (Leippen, Seilitz, Ostrau, Zschaitz, Gleina) the uppermost 2 m look almost similar. The material is decalcified and in the uppermost part a Luvisol was formed during the

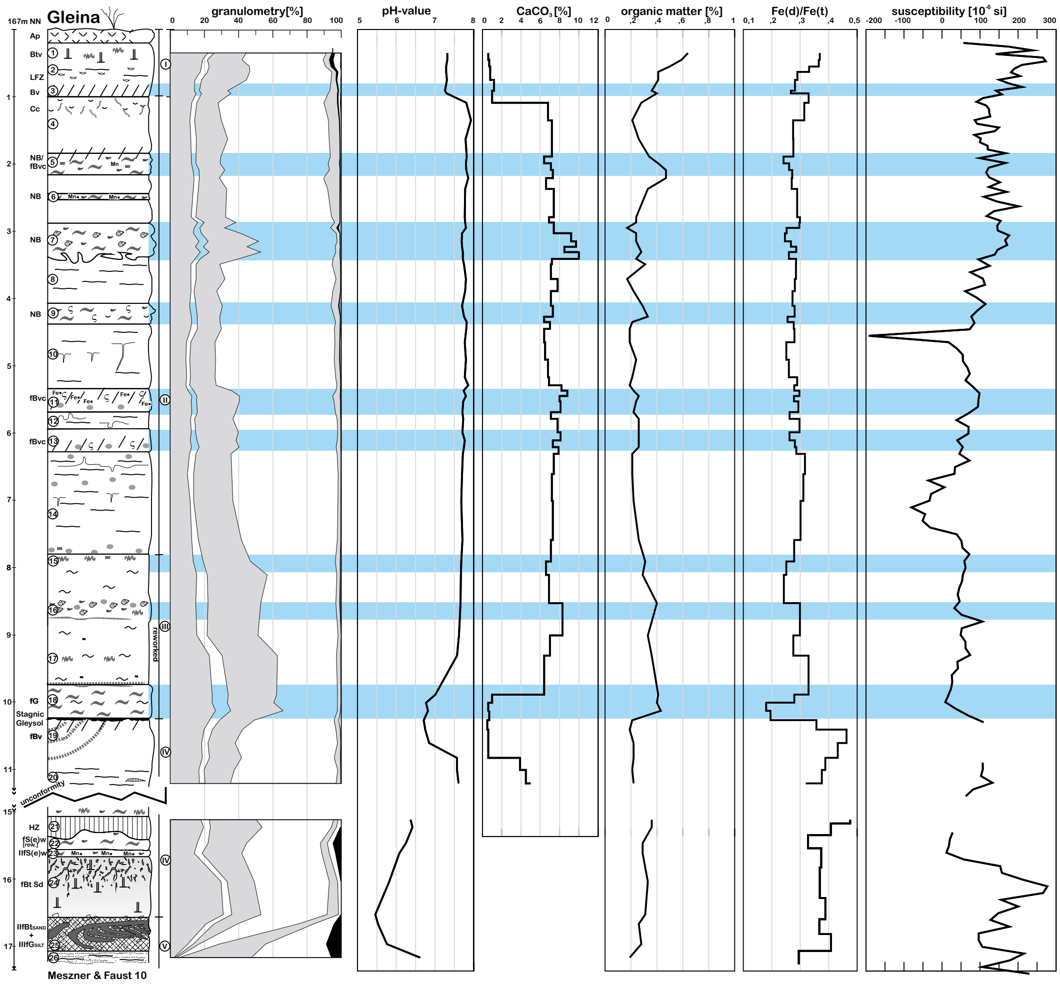

Figure 2.11: Gleina section with geochemical results

Holocene. Below a well-developed Btv-horizon a lenticular horizon ("Lamellenfleckenzone"after Lieberoth (1959) can be observed in all sequences. In some cases ice wedges just below the recent surface were formed and their infilling show lenticular structure even if they reach into the underlying horizon. We assume that this widespread lenticular horizon was formed after a strong cooling which generated these ice wedges. The features of lenticular structure point to a pedogenesis which can be explained by alternations between frozen and unfrozen conditions, resulting in clear band shaped structures of different grain sizes. The underlying horizon is not affected by this process and shows no banded features (Fig. 2.12). We suggest a taiga-like environment to form such features. Below the lenticular horizon of the former permafrost horizon a brownish palaeosol is preserved. At the lower boundary

Figure 2.12: Close up view of the lenticular (2) and underlying Bv-horizon (3) from the Seilitz section (Photo: S. Meszner)

of the brownish palaeosol there is a change from decalcified to calcified loess. This distinct change in the carbonate content represents a clear horizontal boundary, which is hard to identify in the sections. All these findings belong to **unit I** (Fig. 2.14) and are consistent with former studies (G. Haase et al. 1970; Lieberoth 1962a,b; Lieberoth 1959, 1963).

Unit II is a loess layer up to 7 m thick. Except for some palaeosols within this unit, the loess shows only minor evidence of reworking. Unit II contains at least four palaeosols, including two weak soils showing Gelic Gleysol features. One of the strong soils can be characterized as a Cambisol, the other ones are reworked greyish Gelic Gleysols with elevated humic content (Fig. 2.4, 2.6). At the Zehren section mollusk analyses were conducted showing a high number of individuals of several species in the reworked humic Gelic Gleysol. In contrast to the pedological features showing gleyic conditions, the mollusk analyses point to a steppic palaeoenvironment. The occurrence of *Cecilioides acicula* indicates drier climatic conditions during the formation of this horizon (Hamann 2010). This horizon is most likely of polygenetic origin, assuming humid conditions which led to the formation of a Gelic Gleysol. Later this Gelic Gleysol was reworked, also documented in the Ostrau section with features of deep gullying. Schirmer (2000) described a similar situation from the lower Rhine loess region and termed this layer "Eben-Zone". It is possi-

Figure 2.13: Bottle-like iron oxide concretion in the Seilitz section

ble that erosion and redistribution of sediments were widespread during this period. A IRSL sample from the top of this Gelic Gleysol in the Leippen section is dated to an age of 21.6 ±2,5 ka (Fig. 2.2). In a next stage, subsequent soil formation under drier conditions took place. A humic horizon was formed within the material of the reworked Gelic Gleysol in which the mollusk assemblage developed. ANTOINE et al. (2009b) describe comparable processes. The humic soil formation correlates to a short interstadial with slightly drier climatic conditions. At Zehren and Seilitz section these soil horizons have higher magnetic susceptibility values. These two strong palaeosols can be identified in five out of seven profiles and interpreted as characteristic marker soils. The more weakly developed palaeosols can be observed in three sections (Seilitz, Zehren, Gleina). In contrast, former studies by G. HAASE et al. (1970) and LIEBEROTH (1962a) and LIEBEROTH (1959, 1963) describe only one weak soil within this unit II instead of two strong and one weak palaeosol which we could identify for Unit II of the composite Saxon loess sequence. Numerical dating at the base of Unit II in the Leippen section shows an IRSL age of 26.4 ± 3 ka (Fig. 2.2).

The structure of **unit III** is complex but differs significantly from the overlying unit because of a shift in terms of granulometric composition from silt dominated material in the overlying unit II to more loamy material in unit III. This unit shows clear evidence of reworking processes. Coarse silt decreases whereas clay, fine silt, and medium silt as well as the sand fraction increase. Some parts of unit III are also characterized by a certain content of small pebbles of 1 cm in diameter as seen in the sections of Leippen, Seilitz, Zehren and Ostrau (Fig. 2.2, 2.4, 2.6, 2.7). In the upper part of the transition zone large dark manganese spots (lowest part of unit II) could be observed. Iron oxide patterns are abundant in the lower part (uppermost part of unit III). In terms of climatic conditions, it is assumed that the transition shows a climatic change from more arid conditions (unit II) to more humid conditions (upper part of unit III). Unit III shows in the part beneath very clear features of solifluction with incorporated small pebbles in an unsorted material. According to G. HAASE et al. (1970) and KOCH & NEUMEISTER (2005) the material shows properties of loess derivates that is varicoloured. Beneath the varicoloured loess derivate we observe a grey hydromorphic solifluction layer that shows clear features of cryoturbation with bottle shaped structure (Fig. 2.13). These features named "Roströhrengley" by LIEBEROTH (1963) can be seen in every section. The formation of this "Roströhrengley" is supposed to have been taken place during a cold and moist climate. This soil-like material (Roströhrengley) is integrated in the "Gleina Soil Complex" (LIEBEROTH 1963). The Gleina Soil Complex contains furthermore an arctic brown soil below the gley soil that indicates slightly better climatic conditions. This complex is easy to identify by studying the graph of the iron-oxides ratio. The gley soil is marked by a profile-wide minimum of the $Fe_{(d)}/Fe_{(t)}$- ratio as can be seen in the sections Seilitz, Gleina, and Leippen. In contrast, the underlying arctic brown soil is characterized by an increase of this ratio (Seilitz 21, Zschaitz 13, Ostrau 12, Gleina 19, Leippen 17). In the sections Gleina and Ostrau the values of iron-oxide ratios exceed in the reddish brown soil (arctic brown soil) the values of the Holocene and Eemian interglacial soils. Comparing these data, we suppose a high activity of iron oxides caused by high oxidation-reduction potential during the formation of this interstadial complex. In all sections, the arctic brown soil shows a reworked structure, whereas at the Gleina section this brown arctic soil was formed "in situ" however superimposing a reworked brown arctic soil sediment. This is proved by the fact that a distinct platy soil structure is developed. Lieberoth (1962a) assumed that the "Gleina Soil Complex" was formed at the same time as the "Lohne Soil" (Semmel 1968) respectively the "Paudorf Soil" (Fink 1964). We do not support this interpretation because our findings point to a much older formation of the lower part of the "Gleina Soil Complex". This is supported by the observation that the lower part of unit III and the upper part of unit IV shows changes in terms of granulometric composition even between the "Roströhrengley" and the reworked arctic brown soil. Unconformities between unit III and IV in some sections indicate that prior to the formation of the "Roströhrengley" erosion and sedimentation took place. Finally it suggests a correlation of this soil complex ("Roströhrengley" and reworked arctic brown soil beneath) with the "Niedereschbacher Zone" described by Semmel (1968). It seems that processes of landscape disturbances and redistribution of soil material are typical for the Middle Weichselian in Saxony.

Unit IV is only exposed at the sections of Ostrau, Gleina and with some modifications at the setting of Zschaitz. Compared to the unit above, we observe only in the upper part reworking of soils in this unit. The reworked arctic brown soil is the result of a period of soil formation, followed by a period of solifluction. The increase of clay content and pedogenetic iron content (Fe_d/Fe_t) denote this soil formation. Obviously the arctic brown soil formed within material most probably eroded from the Eemian soil (OIS-5e). In the Gleina section (Fig. 2.11) we observe a gradually increase of colour to the top of the arctic brown soil (layer 19) and a clear unconformity to the overlaying redeposited "Roströhrengley". Most of the soils of unit IV are formed in situ. However, some (soil-) sediments show weak features of a short relocation. After deposition this material underwent soil formation. At the Ostrau section, the upper part of unit IV contains a humic soil that is preserved as well as at the section of Zschaitz, however slightly reworked. Lieberoth (1963) did not mention humic soils in this stratigraphic position although he described many profiles in Saxony. The occurance of such humic soils was reported from drier regions (e.g. Thuringian Basin and Harz foreland) by Ruske et al. (1962), Ruske & Wünsche (1964a) and Ruske & Wünsche (1964b), Semmel

(1968), and SCHÖNHALS et al. (1964). In line with these findings we postulate drier conditions during the formation of this humic soil in our study area. Below the humic soil a pale soil sediment is present which can be observed in all sections, even if no humic horizon has been found. This layer is supposed to be the earliest Weichselian deposit. The most obvious feature of this layer is the abundance of large manganese concretions. At sections Seilitz, Ostrau and Gleina this lowest part of unit IV is intermingled by these concretions and charcoal pieces. Macro remnant analyses of 25 pieces indicate, that only *Larix deciduas* Mill. was found. It seems that at the end of the Eemian Interglacial and during the transition time towards the Early Weichselian a larch forest covered the landscape. In the study area an Eemian soil (Pseudogley) is preserved below the Weichselian loess deposit at the sections of Ostrau, Zschaitz and Gleina. At all other profiles the lower boundary of the Weichselian loess can hardly be defined. The differences between an early Weichselian rebedding or a late Saalian rebedding is almost impossible because both layers show similar colouring and grain size distribution. Especially the grain size distribution varies in these layers in short intervals (e.g. profile Leippen).

2.5 Conclusions

In order to develop a reliable stratigraphy, seven LPSs were studied in detail and further profiles were discussed for comparison. Based on these investigations a high-resolution composite profile was compiled.

2.5.1 Local correlation

Fig. 2.14 shows an overview of all studied sections. The colour-bars represent correlations between the individual sections, based on lithological and palaeopedological analyses. Three IRSL ages are provided for a first chronostratigraphic interpretation. Most of the sections to the north of the studied Saxon loess plateau (Gleina, Zehren, Seilitz) are characterized by thick accumulations of loess with intercalated palaeosols. The sections Leippen and Zschaitz situated in the south of the Saxon loess plateau show less accumulations of loess, representing the general north-south trend of loess thickness.

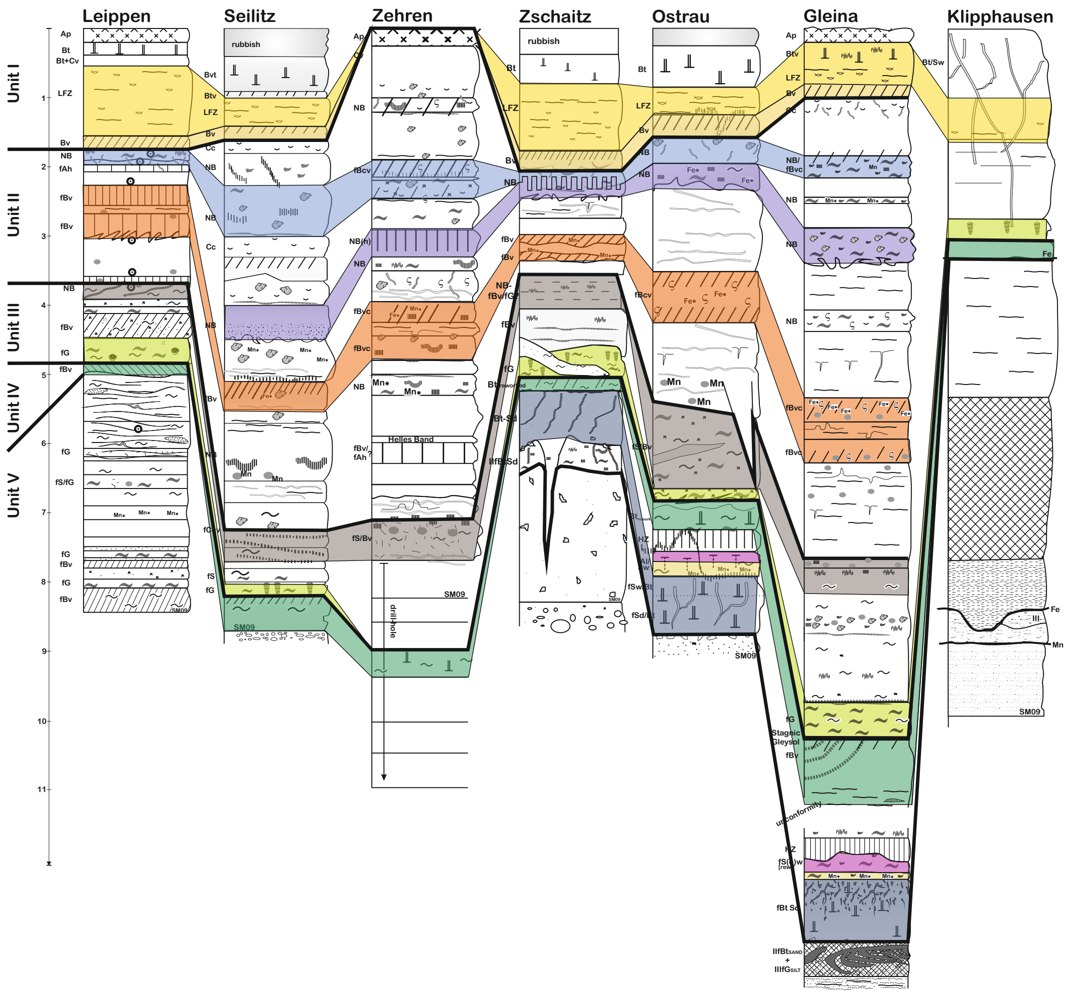

Figure 2.14: Local correlation of all studied sections (the coloured bars accent similar stratigraphic positions in different sections)

2.5.2 Composite profile (Fig. 2.15)

According to our results a detailed composite profile (Fig. 2.15) for the SLR is proposed. Main contributions to the findings of G. Haase et al. (1970) and Lieberoth (1963) are two strong soils and two weak soils formed within unit II. We consider the Gleina Soil Complex not to be correlated with the Lohne Soil Complex as proposed by Lieberoth (1962a) and Lieberoth (1963) and Ricken (1983). Another important feature that was not described in former studies is the humic horizon just above the Eemian soil complex. We correlate this humic horizon with one of the “Mosbacher Humuszonen” as described by Semmel (1997a) and Semmel (1997b) and with the humic parts

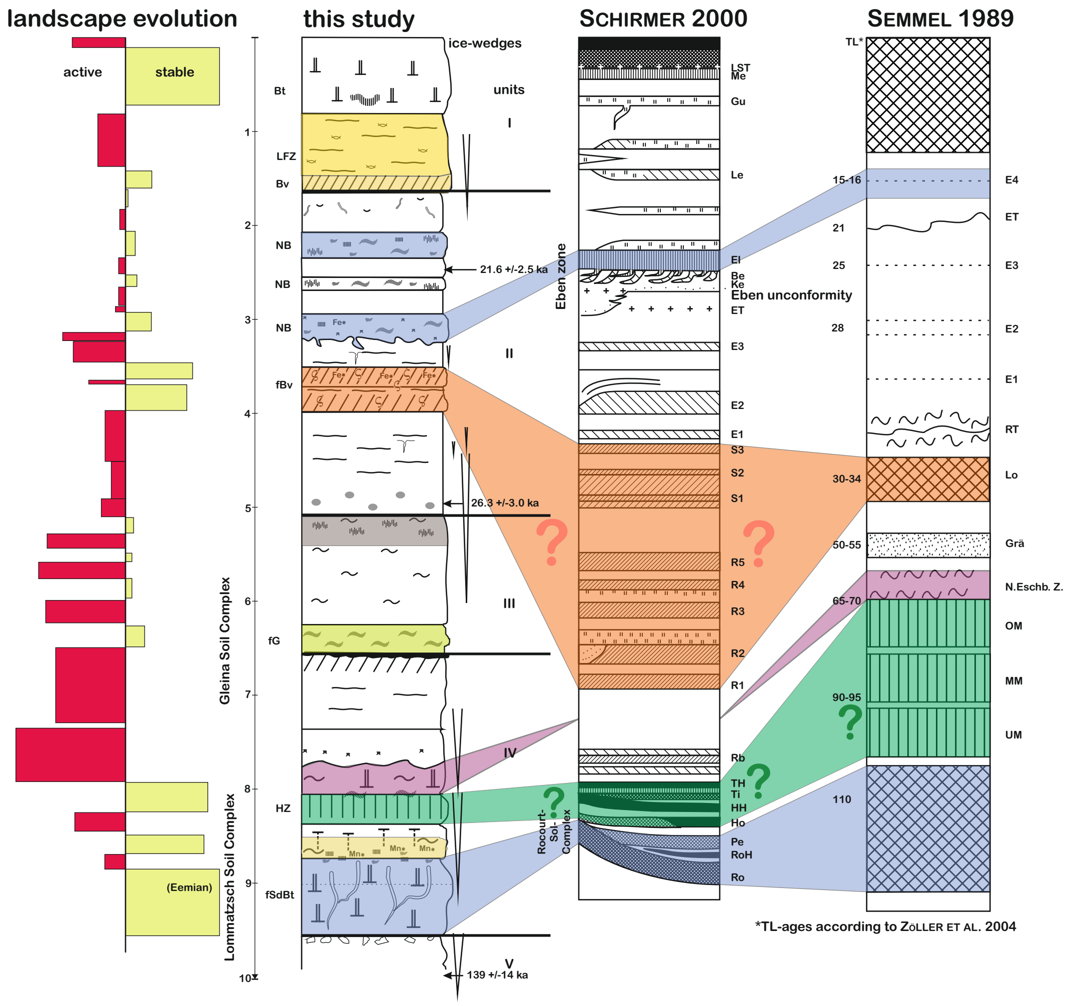

Figure 2.15: Composite profile of Saxony and regional correlation with other loess areas in central Europe

of the Rocourt-Sol-Complex by SCHIRMER (2000), respectively. Ice wedges point to strong cold events without thick snow cover. Some of the ice wedges are even incised into lower units. In unit II the big ice wedges show a marginal bulge that indicate a longer phase of very cold winters. To form a marginal bulge of the ice wedge frequent changes of melting and strong freezing are necessary. The sequence is characterized by changes of soil formation, loess deposition and solifluction. These features are interpreted (left graph of Fig. 2.15) in terms of geomorphic conditions and landscape evolution. Stable conditions coincide with periods of soil formation, whereas geomorphic activity can be attributed to loess deposition or solifluction. The latter takes place in transition phases in terms of climatic conditions. Ice wedges indicate strong dry cooling events. Two composite profiles of the western part of Germany Schirmer (2000, 2004), Semmel (1989), and Zöller et al. (2004) are added to the Saxon composite profile in order to correlate similar findings into a chronostratigraphic approach. The very detailed analyses of the Nussloch section (Antoine et al. 2001; Bibus et al. 2007) are considered as well. However, because of its high resolution, it does not serve as overview comparison.

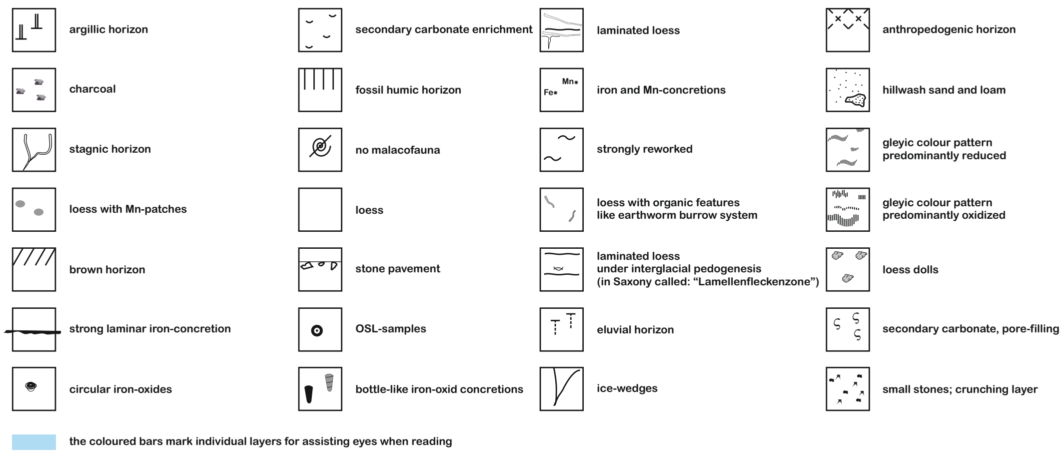

Figure 2.16: Legend for all profile drawings presented in this study

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Chapter 3

Study II: Identifying depositional and pedogenetic controls of Late Pleistocene loess-palaeosol sequences (Saxony, Germany) by combined grain size and microscopic analyses

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Field work	95%	-	-	5%
Lab work	100%	-	-	-
Stratigraphy	80%	5%	5%	10%
Manuscript preparation	90%	5%	-	5%

Abbreviations are the authors' initials.

Abstract

Late Pleistocene LPS often consist of complex layers of aeolian or reworked loess-like sediments or both. Additionally, they may have been overprinted by pedogenetic processes. In the present paper we demonstrate, how combined analyses of high-resolution grain-size distributions and microscopic analysis can be used to discriminate depositional and pedogenetic features of loess-palaeosol profiles from the SLR. Grain size analysis was conducted by classical pipette and sieve procedures and eight grain size classes (coarse, medium, fine and very fine sand; coarse, medium and fine silt; clay) were distinguished. Generally, it was observed that an increase of coarse material is linked with an increase of the mineralogical components which refers to slope processes. Rounded shapes of Mn- and Fe-precipitates, mostly found in Early Weichselian humus layers, indicate strong interstadial soil development modified by subsequent redeposition. Further observations suggest that the class of medium sand is dominated by secondary precipitates. The varying amount of very fine sand shows that sequences are cyclically built up of pure loess comparable to the Nussloch section. Studying coarse grain size fractions by microscopic analysis, a differentiation between loessic layers formed by periglacial slope processes and layers overprinted by pedogenetic processes is possible. Furthermore, an increase of fine material and secondary Mn- and Fe-precipitates can be attributed to soil forming processes (clay formation, redoximorphic processes, and illuviation). The results reveal similar temporal and lithogenetic pattern of Weichselian aeolian dynamics of the study area and other records from the European continent. Furthermore, grain size results independently confirm the luminescence chronology of the studied sections. Reworked loess-like sediments show varying OSL age estimates; aeolian loess shows a systematic change of OSL ages. Therefore, we advocate a detailed grain size interpretation as a basis for further investigations on LPS.

3.1 Introduction

Grain size analyses have always been part of standard analyses in applied geomorphology, sedimentology, and soil sciences. Several methods are employed to determine grains size distribution of soils and sediments (e.g., Pfeffer 2006). According to Leser (1977) grain size distribution is the key property of soils and deposits because of its effects on water and nutrient cycling, aeration, and habitat functions. In turn, grain size distributions can be used to identify whether sediments were deposited by aqueous, aeolian, or glacial surface processes. Geomorphological and sedimentological studies increasingly include more recently developed methods to elucidate palaeoenvironmental conditions. For example, alkane-analyses on a Hungarian loess section were used to reconstruct vegetation change during Late Pleistocene (Schatz et al. 2011), frequency-dependent magnetic susceptibilitiy of Chinese loess palaeosols was conducted to estimate the duration of soil formation periods (Vidic et al. 2004), and stable isotope studies on limnic sediments from Central Germany served to reconstruct temperature regime and the water balance of a palaeolake during Late Weichselian and Early Holocene (Böttger et al. 2002). In this context, the study of sediment texture appears to have become of minor importance. Still, in particular in the case of studying loess and loess-derived deposits texture analysis has proved as a valuable tool to uncover changes in either aeolian sedimentation dynamics, exposure to weathering and pedogenesis and/or redepositional processes. For example, previous studies on loess and loess-like sediments used grain size analysis to classify several types of loess and loess derivates (Altermann & Fiedler 1975, G. Haase et al. 1970, Koch & Neumeister 2005, Neumeister 1966, Pécsi & G. Richter 1996, Fig. 30 & Pye 1995).

It is established knowledge that well sorted and uni-modal grain size distributions reflect the aeolian origin of loess. According to Muhs (2013) loess is characterized by a mean particle size smaller than windblown sand (~130 µm to 2000 µm) but coarser than medium silt (<20 µm). Pye (1995) determines a modal grain size of about <30 µm for aeolian loess deposits. Common grain size frequencies for typical loess as suggested by Koch & Neumeister (2005) are: <12% sand, <20% clay, >68% silt. Medium and coarse silt grains are transported close to the earth surface and in short-term suspension. In contrast, particles with a diameter <20 µm even could be transported in the higher troposphere in long-term suspension (Muhs 2013; Pye 1995). However, in periglacial settings loess is often reworked by processes of surface wash, soil creep or other periglacial processes following its initial deposition. Such reworked loess-like sediments show often an enrichment of particles coarser than ~130 µm which originate from underling deposits. Finest loess particles are transported and deposited as silt- or sand-size aggregates held together by electrostatic forces, salts, or organic matter (Pye 1995). Moreover, LPS with clay content >20% may point to the effects of secondary enrichment because of pedogenetic and/or redepositional processes. For example, Vandenberghe et al. (1998) interpret the variable clay contents of LPS as an indicator of pedogenesis. Similarly, varying clay contents in fluvial deposits are interpreted as proxies of soil development in fluvial deposits (Wolf et al. 2013). Over the last decade, much attention has been devoted to interpret the aeolian component of LPSs (Antoine et al. 2009b; Bokhorst et al. 2011; Rousseau et al. 2011; Vandenberghe & Nugteren 2001; Vandenberghe et al. 1998). Technological progress (e.g., Diffraction Particle Size Analyzer, Laser Particle Sizer) allowed processing much larger sample quantities and revealing grain size distributions with more than 80 grain size classes ranging from 0.1 µm to 1000 µm. In this context the calculation of ratios based on grain size distribution seems to be meaningful. Vandenberghe et al. (1998) and Bokhorst et al. (2011) subdivide several profiles using a silt ratio (u-ratio) and estimate mass accumulation rates for Weichselian Pleniglacial LPSs. The u-ratio has been used to describe sedimentary processes without being modified by pedogenetic effects. For example, Antoine et al. (2009b) used continuous sampling at 5-cm-intervals to single out pulses of aeolian activity in the Late Pleistocene based on a so-called grain size index (GSI; Rousseau et al. 2007). These loess events represent stratigraphic markers that further subdivide an otherwise seemingly homogeneous stack of Pleniglacial Weichselian loess. Moreover, Antoine et al. (2009b) show that the "loess events" found in the Nussloch section correlates with atmospheric dust concentration in the northern hemisphere during the Weichselian glaciation. Meanwhile, the GSI was applied to several loess profiles such as Eustis (Rousseau et al. 2007), Nussloch (Antoine et al. 2009b), Surduk (Antoine et al. 2009a), Stayky (Rousseau et al. 2011), and Dolní Věstonice (Antoine et al. 2013). This development is paralleled by improved physical dating methods delivering a higher chronological resolution of Weichselian sediments (Preusser et al. 2008) allowing to reconstruct atmospheric dynamics of the last glaciation (Porter & Zhisheng 1995).

Accordingly, during the past decade a number of studies on European LPSs have been published (Antoine et al. 2013, 2009a,b; Bibus et al. 2007; Fischer et al. 2012; Jary & Ciszek 2013; Marković et al. 2008; Marković et al. 2013; Rousseau et al. 2011; Schirmer 2012; Vandenberghe et al. 1998). Unfortunately, this does not account for the central German loess regions where Saxon loess sequences have been rarely investigated for about 30 years (G. Haase et al. 1970; Lieberoth 1963; Meszner et al. 2011, 2013).

In this paper we present grain size distribution patterns from nine LPSs sections in Saxony. Our approach is to use grain size distribution patterns as proxy to identify aeolian, pedogenetic, and/or geomorphological processes controlling the formation of the LPSs. Next to that, we compare our records to general depositional conditions prevailing in the northern European loess belt during last glacial cycle. This includes the review of spatial changes of grain size distribution in the SLR and a discussion of palaeowind directions.

3.2 Geographical setting

The SLRis situated in the east of Germany and characterized by a smooth topography with gently rolling hills. The landscape is divided by small rivers, which are deeply incised down to bedrock. The study area is located in the transition zone between the Upland of Erzgebirge and the northern European Lowland. Elbe and Mulde rivers, bordering the main loess area, are deeply incised into the hilly landscape by approximately 100 m. The SLR has an average elevation of 200-250 m above sea level and inclines to the north. Loess deposits reach a total thickness of up to 16 m and cover all parts of the landscape with the exception of steep west-facing slopes and the floodplains (Fig. 3.1). Loess deposits reach maximum thickness at the northern boundary forming a low scarp in the landscape (named "Lössrandstufe " , ~"loess scarp "). This boundary is characterized by a sudden decrease in loess thickness from approximately 20 m up to complete disappearance of loess within a 100 m distance.

Bedrock geology is formed by plutonic rocks of the Meissen Complex in the eastern part (Pälchen & Walter 2008; Pietzsch 1951). Late Permian and

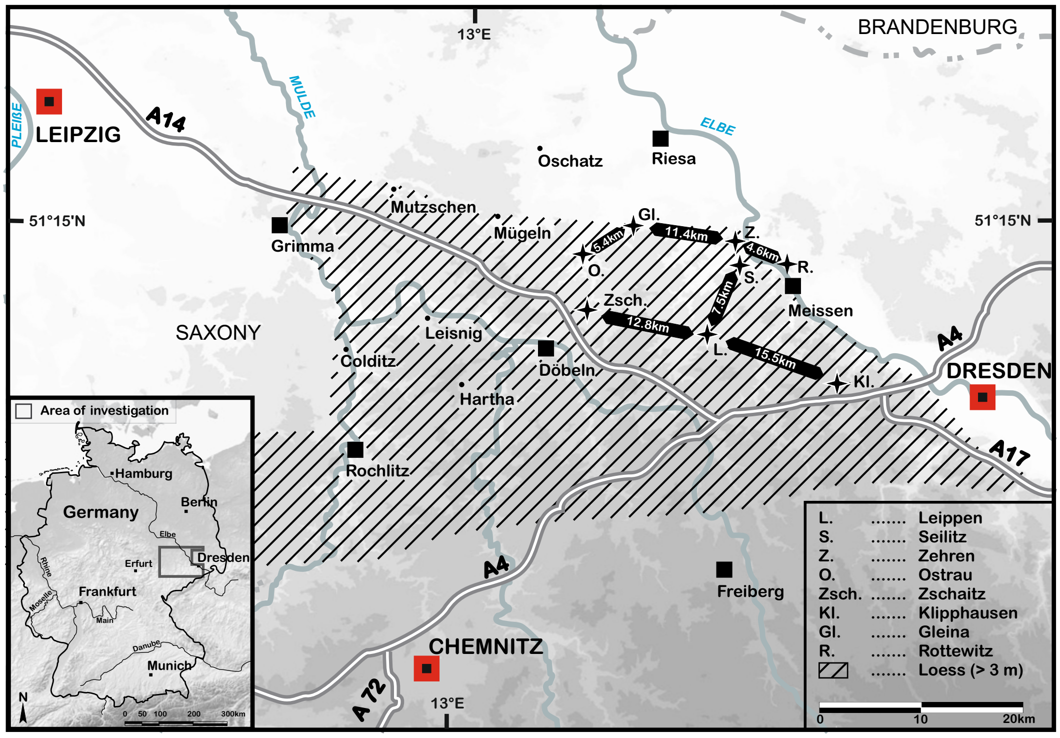

Figure 3.1: Study area

Triassic sediments are found in the central and western part and are nowadays mined, for example in a limestone quarry where the loess section Ostrau is located. During Early to Middle Pleistocene, the study area was covered by ice from the Elsterian and Older Saalian glaciation (Eissmann 1994). During the last glaciation the SLR remained ice-free. Periglacial processes and deposition of loess prevailed. The study area is part of the northern branch of the European loess belt. However, periglacial processes have induced secondary redeposition causing a relatively bad preservation of original aeolian sediments (Frechen et al. 2003; Pécsi & G. Richter 1996). Many sections show slightly or strongly reworked loess due to redeposition by surface runoff or other slope processes like solifluction and cryoturbation (Meszner et al. 2011).

The standard profile of the SLR as revised by Meszner et al. (2013) is divided into five major units. Unit I represents the uppermost part of the loess sequences, which is superimposed by Holocene and Late Weichselian soil formation. Unit II can be subdivided into an upper homogeneous loess and a lower weakly stratified loess derivate. The stratification of the lower loess (unit II b) points toward sedimentation of loess in combination with snow covering (Antoine et al. 2001; Dijkmans 1990), which causes resorting by short-distance runoff processes during thawing seasons. According to Vandenberghe et al. (1998) a correlation of unit IIb loess with "Middle silt loam II" is likely.

Unit III is characterized by abundant loess derivates (partially soil sediments from weak interstadial brown soils) with intercalated hydromorphic soils. The lowest part of unit III is a strongly bleached Gelic Gleysol (upper part of the Gleina Complex). Unit IV represents the entire sequence of first Weichselian loess sediments spanning a time from approximately 110 ka to 35 ka. At the base, relicts of Early Weichselian humic horizons can be found which are covered by a sequence of almost pure loess. This sequence is rarely preserved in Saxony and could be investigated in the Rottewitz section only (Fig. 3.11, layer 15-22). Unit V is composed of pre-Weichselian sediments, which were superimposed by Eemian and Early Weichselian soil formation. At present, the study area is characterized by a variable soil pattern showing a mosaic of Luvisols which are more or less truncated due to long-term agricultural activities since about 7,500 BP (cf. Oexle 2000). The valley bottoms are filled with hillslope-derived material up to a thickness of ca. 4 m (Wolf & Faust 2011). Today the mean annual temperature is about 8.8°C[1], as determined by the nearby climate station Döbeln. The mean annual precipitation is about 600 mm[1] with its maximum in summer months.

3.3 Methods

For this study samples were taken from 9 large LPS located in the SLR. The sampling resolution varies between 5 cm (Fig. 3.9) and a layer specific sampling (Fig. 3.8) with a resolution of about 35 cm. Grain size analyses were conducted by classical pipette and sieve procedures after KÖHN. The samples were not decalcified before analysis. Carbonate grains are an important component of grain size distributions and were deposited almost synsedimentarily. However, Antoine et al. (2009b, Fig. 4) and Steininger et al. (2012) demonstrated that decalcification does not have a significant effect on the measured grain

[1]sources: Deutscher Wetterdienst

size results or on the indices, calculated on the basis of grain size distributions. Furthermore, ANTOINE et al. (2009b) reported a correlation coefficient of 0.962 between decalcificated and non-decalcificated samples. STEININGER et al. (2012) calculated correlation coefficients between 0.91 and 0.943. Additionally carbonate content, pH-value, organic matter, and different iron oxide fractions (see: MESZNER et al. 2011, rock magnetic properties (BAUMGART et al. 2013), and *n*-alkane biomarkers (ZECH et al. 2013) were determined to create an area-wide correlation of all sections (MESZNER et al. 2013). On the basis of OSL age estimates a robust chronology was established for this region (KREUTZER et al. 2012; MESZNER et al. 2013). For classical grain size analysis after KÖHN, 10 g of air-dried fine material (<2 mm) was mixed with 25 ml sodium hexametaphosphate ($(NaPO_3)_6$ - 39 g/l H_2O) and 250 ml de-ionized water and shaken for two hours. Subsequently, this suspension was diluted with de-ionized water in an Atterberg's cylinder up to the mark of 1000 ml and stored for another 12 hours. The fine fractions (>63 µm) were determined after strong reshuffling by pipetting. In a defined depth and at a given time, 10 ml of suspension was extracted via pipette, followed by drying and weighing of the residuum. Afterwards, the remaining suspension containing material greater than 63 µm was analyzed by wet sieving. All sieve residua were weighed after drying. In this study sieves with mesh sizes of 630 µm, 200 µm, 63 µm, and in some cases 125 µm were used. Sand fractions (<63 µm) of several samples were examined under the microscope to estimate general composition. A reflected-light microscope (HUND, V-Reihe) with a total magnification of 20x and 40x (objective 2X and 4X; eyepiece 10X) was used. All components (mostly mineralogical components, Fe and Mn precipitates, and carbonate nodules or grains; rarely charcoal or remnants of plants and molluscs) were classified by their relative frequency into five categories (first category = absent; fifth category = component dominates this fraction). Afterwards the weight of the whole fraction, determined during standard grain size analysis, was divided by the estimated amounts of the components. The data are presented in the coloured columns to the right of the profile sketches in Fig. 3.2, 3.6 and figs. 3.9-3.11. The authors are well aware that the estimation of the mineralogical composition is a rough and contestable method. Nevertheless, it has to be underlined that changes of the composition especially in the medium and coarse sand fraction are clearly visible. The composition of the fine sand fraction is more difficult to estimate but a declaration of dominant or absent components is still possible.

3.4 Results and discussion

3.4.1 Description of general grain size distribution

The main purpose was to examine the characteristics and changes of grain size distribution of Saxon LPSs. When comparing all studied profiles, several recurrent patterns of grain size distributions can be identified at similar stratigraphic levels (units according to MESZNER et al. 2013):

1. The lower parts of all investigated LPS (unit V and lower parts of unit IV) show strong fluctuations in granulometry, and sand as well as clay contents are significantly high. A further result of microscope investigations is that layers composed of reworked soil material (soil sediments) are mostly characterized by a huge amount of Fe-precipitates, which additionally show a high degree of roundness (Fig. 3.11).

2. Unit III shows a significantly higher homogeneity in the grain size distribution compared to unit IV and V and considerably less coarse silt when compared with unit II. Unit III is characterized by an increase in finer material especially medium silt (20 µm to 6.3 µm) and clay (<2 µm).

3. The granulometry of unit II is dominated by coarse silt (approximately 60%). According to LIEBEROTH (1963) and G. HAASE et al. (1970) unit II represents the purest form of Weichselian loess deposits. Usually, there is an upward increase in the very fine sand fraction (63-125 µm) with a double peak maximum at the top of unit II. These generalized grain size patterns of unit II are modified by intercalated palaeosols (Gelic Gleysols). Gelic Gleysols, also called tundra gley soils (ANTOINE et al. 2001), are interpreted as layers of reworked material which formed during periods of decreased dust deposition. Such layers of redeposited material can be identified by an increase in the fine and mainly medium silt fraction (Fig. 3.9 - Ostrau, Fig. 3.2 - Gleina).

4. The upper sections of the profiles (unit I) show an increase in clay content. This increase is mainly based on clay illuviation into Bt-horizons during Late Pleistocene/Holocene Luvisol formation. In our study the

highest amount of clay in unit I never exceeds 22% (in the Bt-horizon of the Eemian Luvisol a clay content of 30% is typical).

The sand fractions are composed of different groups of components. Coarse fine sand, medium sand and coarse sand mainly consist of secondary precipitates as Fe- and Mn-concretions or calcium carbonate. Only layers of unit V show an increase of the mineral fraction. In contrast, the fraction of very fine sand is dominated by mineral grains. These findings correspond to observations described by Muhs (2013) and Tsoar & Pye (1987) which indicate that a grain diameter of about 130 µm marks the upper boundary of material transported as air suspension. Another typical grain size distribution pattern can be observed in the Ostrau and Gleina section. There, a maximum of medium silt and a minimum of very fine sand can be identified in unit I between the upper part of the lenticular horizon ("Lamellenfleckenzone" (LFZ) according to Lieberoth 1959) and the Bt-horizon (Fig. 3.4: layer 3, Fig. 3.5: layer 1-2, Fig. 3.9: layer 1-2, Fig. 3.2: layer 2). Beneath, a strong decrease in the very fine sand and coarse silt is apparent. Taking into account that coarse silt and very fine sand represents high energy aeolian deposits (according to Muhs 2013: short-term suspension) and fine and medium silt represents low energy aeolian deposits (long-term suspension), the uppermost 1 m or 1.5 m loess in Saxony has to be classified as a low energy aeolian deposit. This sequence of low energy aeolian deposits directly overlies a sequence that consists of highest energy aeolian deposits of the Late Weichselian. Apparently, after a maximum of wind speed during the Last Glacial Maximum (LGM) (Kasse 2002), a rapid shift from coarse-grained to finer-grained loess sedimentation occurred. In the Ostrau, Seilitz, Gleina, and Leippen sections an increase of coarse sand in the uppermost parts of the recent Bt-horizon (unit I) was noticed. This increase is connected with pedogenetic formation of Fe-precipitates during (obviously also hydromorphic) soil formation (Fig. 3.2). In the following chapters detailed descriptions of the individual grain size fractions are presented and discussed. Finally, in Fig. 3.12 a conceptual model summarizes our results to interpret trends and changes of selected grain size fractions in LPSs from areas where redeposition due to slope processes have been taken into account. It has to be mentioned that studies dealing with grain size analyses are often based on data derived from one investigated site only (Shi et al. 2003). But loess sections are terrestrial archives for landscape evolution processes at specific geomorphological positions and should not be interpreted as undisturbed and continuous climate records. Therefore, in loess areas, where secondary translocation processes cannot be excluded, an area-wide approach should be preferred rather than a single-site approach.

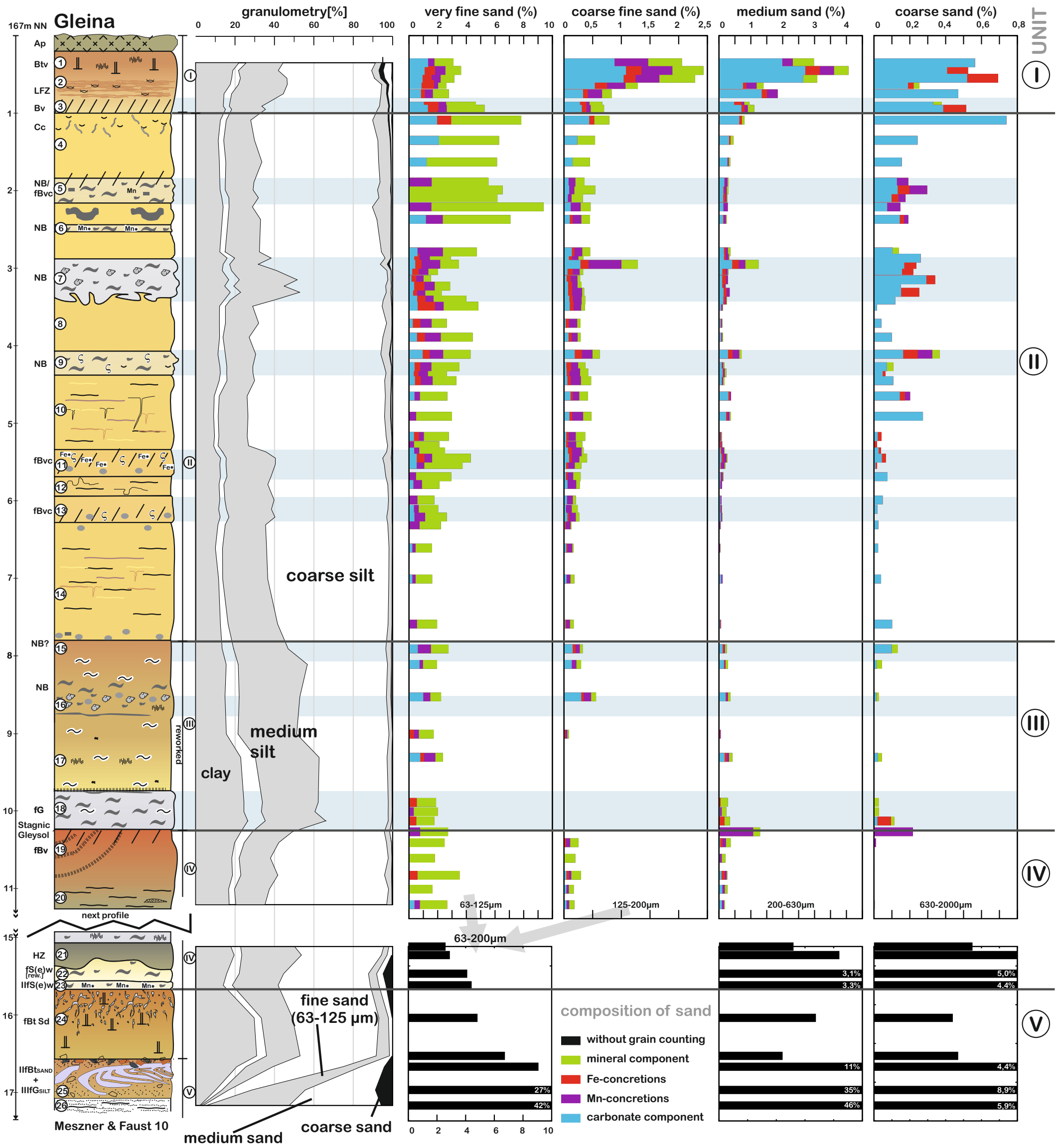

Figure 3.2: Grain size distribution of the Gleina section (modified after Meszner et al. 2011, for legend see Fig. 3.11)

Asynchronous distributions are observable in unit II and unit I when comparing very fine and medium sand. The fine sand component is mainly derived from aeolian deposition. The coarser sand fractions are forced by re-deposition processes (due to alternation) or hydromorphism (due to pedogenetic formation of Fe and Mn-precipitates).

3.4.2 Coarse sand

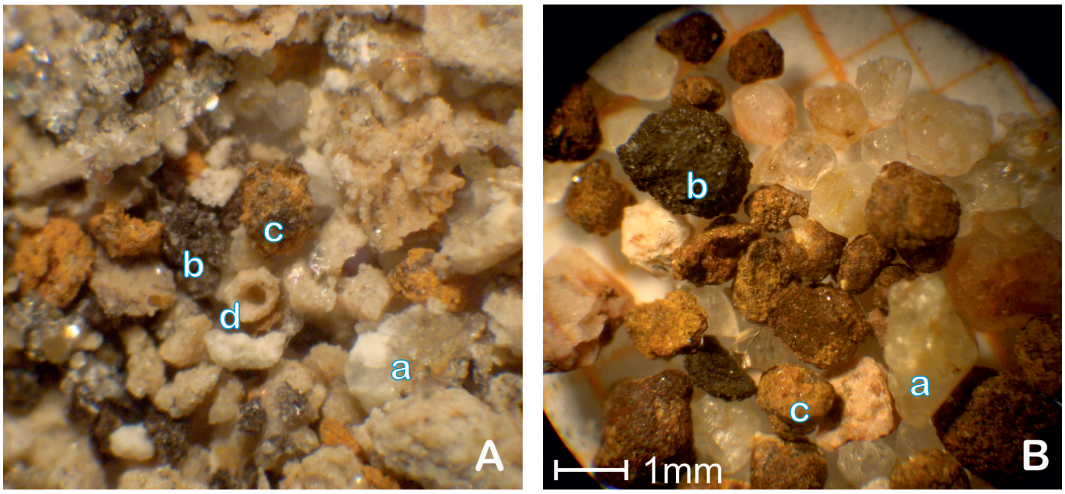

Figure 3.3: Photo of coarse sand fractions

A: Coarse sand fraction of a calcareous interstadial soil from unit II (layer 8), section Seilitz,
B: Coarse grain fraction of a reworked decalcified humic enriched horizon of the Rottewitz section (layer 22),
a: mineral grain (quartz), b: Mn concretion, c: Fe concretion, d: carbonate nodule (dominant in picture A).
It is noticeable that Fe- and Mn-concretions show different degrees of roundness. The significantly rounded concretions in image B point to redeposition after soil development.

As a result of sorting due to the eolian transport processes, the amount of coarse sand should be low in loess sediment. According to Tsoar & Pye (1987, p. 142), material deposited by short-term suspension in wind is normally finer than approximately 130 µm (also Muhs 2013). This means that all material found in LPSs coarser than 130 µm has been transported by processes others than those that are normally used to explain loess formation. An enrichment of coarse particles caused by sedimentological processes shows another composition in the coarse sand fraction than an enrichment caused by soil formation. Obviously, LPSs located on the northern European loess belt often show features of hydromophism (Jary & Ciszek 2013; Meszner et al. 2011; Vandenberghe et al. 1998) which are accompanied by the formation of Fe- and Mn-precipitates. In contrast, quality and quantity changes of mineral grains (mainly quartz, feldspar, or mica grains) indicate sedimentological processes. In the investigated LPSs the content of the coarse sand (2000-630 µm) is generally small (almost below 1%). In most samples, especially in unit II, almost no coarse sand was found (Fig. 3.4, 3.5, 3.7, 3.9 & 3.10). However, in other units in all investigated LPS of SLR a coarse sand fraction was found. This fraction consists of varying ratios of rounded or angular mineral grains, carbonates, iron-oxides, and manganese-oxide concretions. It is dominated by mineral components, consisting of quartz, feldspar, and mica grains (Fig. 3.3). Macro remnants of plants, charcoal, and fragments of snails or insects are rarely preserved. Studies on malacofauna in LPS from Saxony were done but did not yield suitable results useful for palaeoenvironmental reconstruction. Studies on charcoal (coarse sand fraction and larger) from five LPS were done by A. SEIM[2]. All pieces of charcoal were found at the bottom of unit IV, and due to their stratigraphical position they seem to have been incorporated in the deposit during the Early Weichselian. In total 83 pieces of charcoal were investigated. From that, 48% can be classified as *Larix sp.*, 51% as *Pinus sp.*, and only one piece from the Ostrau section can be determined as *Quercus sp.* These results suggest that a dry and continentally influenced boreal forest (Taiga) that was exposed to wild fire activity temporarily developed in Central Germany during the Early Weichselian.

Two different coarse sand samples with their typical composition are shown in Fig. 3.3. In contrast to picture **A** (Fig. 3.3), picture **B** was taken from a non-calcareous soil, lacking carbonate coatings and clustered carbonate concretions. Thus, a differentiation of components using an optical microscope is easier for sample **B** than for sample **A**. Moreover, comparing the structure of iron and manganese oxide concretions in Fig. 3.3, there are differences in the degree of roundness. Sample **B**, which is taken from a layer which is enriched within humus material in the lower part of the Rottewitz section (layer 20), shows well-rounded concretions. The rounded shape of precipitates can be interpreted as an indicator for secondary deposition after primary formation during water-influenced pedogenesis.

Generally, a high proportion of the coarse sand fraction can be identified

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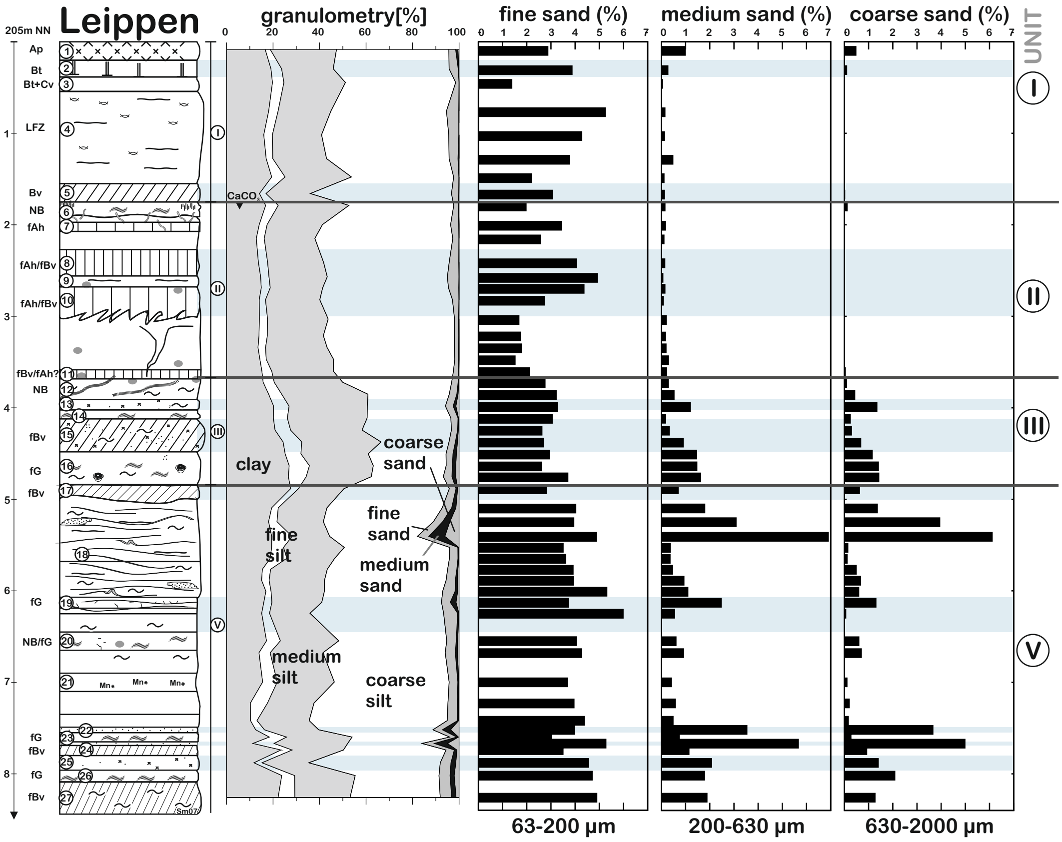

Figure 3.4: Grain size distribution of the Leippen section (modified after Meszner et al. 2011, for legend see Fig. 3.11)

at the top and at the base of the investigated LPS (Fig. 3.4: layer 1, 2, 12 and deeper; Fig. 3.5: layer 1 & 18 and deeper; Fig. 3.8: layer 9 and deeper; Fig. 3.9: layer 1; Fig. 3.10: Layer 11 and deeper; Fig. 3.2: layer 1-4, layer 7, layer 19, layer 21 and deeper; Fig. 3.11: layer 13, 21 & 22). Based on these stratigraphical similarities the following typical patterns for the Saxon LPS are proposed:

- A maximum of coarse sand near to the recent surface is mostly located in the (Sd)Bt-horizon of the Holocene soil.

  The decalcified Holocene Luvisol (unit I) often shows weak features of hydromorphism in the form of Fe- and Mn-concretions. These pedogenetic precipitates (compare Fig. 3.9 layer 1 and Fig. 3.2 layer 1-3) cause the maximum amount of coarse sand in the Holocene and Late Pleistocene surface soil. Additionally, horizons of the Holocene topsoil often show an

enrichment of coarse mineral grains, too. We suppose that coarse sand grains were mixed into the topsoil because of agricultural land use. A sedimentological input of coarse sand during the Late Glacial period (for example Younger Dryas period) is also possible, but further evidence of aeolian input of coarse sand (sand sheets or dune sands) during the Late Glacial period is missing in this region.
As an exception, the Gleina section shows higher values of coarse sand in layers without hydromorphic features (Fig. 3.2: layer 4). Microscope analysis shows that glutinous metabolites aggregate single grains to bigger peds and causes this enrichment. It has to be taken into account that any increase in the coarse sand fraction in the near surface horizons may be caused by recent biological activity. The "biological" concretions look similar to coatings of calcium carbonate; the use of HCl verified that such concretions are free of carbonates.

- A second maximum is located at the base of most sections and is related to a strong interglacial soil development (Eemian soil). Due to the fact that relicts of (truncated) last interglacial soil development show features of different soil formations (clay illuviation, strong hydromorphism) as well as secondary overprinting (platy and lenticular aggregation with Mn-enrichment on peds surfaces related to Early Weichselian ice lensing), it has to be classified as a polygenetic soil complex. In particular, the grain size results of the Gleina profile (Fig. 3.2) and the Rottewitz profile (Fig. 3.11) may help to understand the complex development of the lower parts of the Saxon LPS. There is a significant increase in coarse sand in unit V and the basal part of unit IV compared to material seen in overlaying units. Otherwise in most sections there is a clear increase of coarse grained material in the substrate underneath the Eemian Soil, too (Fig. 3.11: layers 25 & 26).

The typical grain size distributions in unit V and in the basal part of unit IV are controlled by three factors.

1. Changes in the sedimentation processes:
   The material below the Eemian Soil is the result of completely dif-

ferent formation processes than the loess layers above (Fig. 3.11 layers 25 & 26). In the case of the Rottewitz section there are solifluction layers that are dominated by granite grit.

2. Soil formation, which forms coarse sand concretions (Mn and Fe): Saalian loess-like material was modified by interglacial soil formation (Fig. 3.11 layer 24).

3. Relocation of material in a loess landscape (solifluction in loess, cryoturbation, abluation): Early Weichselian loess has been modified by Early Weichselian stadial soil formation and was afterwards reworked by slope processes (Fig. 3.11 layers 20-22).

The non-loess character of the lowermost two layers in the Rottewitz section is clearly visible in grain size distribution. Looking at the layers and horizons above, the increase in coarse sand in layer 24 (Fig. 3.11) is mainly caused by an increase of Fe- and Mn-precipitates which are products of soil formation. There are also some mineral components mixed into the substrate, but the main increase is induced by an interglacial more or less hydromorphic soil formation. A gradual increase from the bottom to the top of the horizon (Fig. 3.11 layer 24, fBt) underlines its pedological formation. The maximum amount of concretions is located in the charcoal-enriched (Fig. 3.11: layer 23) and humus-enriched layers (Fig. 3.11: layer 20-22) above the Eemian soil. Microscopic investigations show that pedogenetical precipitates of these layers (20 to 22, Fig. 3.11) have a well-rounded shape compared with rough angular-shaped precipitates from layer 24 (Fig. 3.11). These findings indicate soil reworking. Further support for this assumption comes from the distribution of precipitates within the layer. Figure 3.11 (layer 22) showing no gradual increase or decrease of precipitates from the bottom to the top. In our opinion the homogeneous texture results from mixing by slope processes (solifluction or creep).

- Another enrichment of coarse sand fraction was found in strong Gelic Gleysols ("Nassböden"; Fig. 3.6: layers 5 & 8; Fig. 3.2: layers 7 & 9). In this case, carbonate concretions provide the main component of the coarse sand and determine its maximum. In particular, the strongest

Gelic Gleysol (e.g., Fig. 3.2: layer 7) that developed in the upper Pleniglacial (unit II) is characterized by the enrichment of loess dolls and smaller carbonate nodules. The longitudinal axes of loess dolls are often oriented in a downslope direction and indicate a redeposition in an active layer during Gelic Gleysol formation. Carbonate nodules that are smaller than loess dolls may have also been formed after Gelic Gleysol formation. The distribution of calcium carbonate (dissolution and secondary precipitation) forces mainly the coarse sand distribution in unit I and unit II.

An enrichment of the coarse sand fraction, comparable to the overlying unit II, can be detected in unit III (figs. 3.2 & 3.7). After examining this fraction with a microscope, mineral grains could be identified as the main component of the coarse sand fraction. Because there is no evidence for cover sand layers or other types of eolian sand deposits, a delivery of sand due to saltation processes (Pécsi & G. Richter 1996 or Tsoar & Pye 1987) is considered as negligible. An admixture of underlying coarse material is even more likely. Therefore, deposits of unit III cannot be described as pure loess but rather as a strongly reworked loess-rich material or loess derivate. The primary eolian material was re-sorted by cryoturbation and solifluction and underlying coarse material was mixed into the sediment during redeposition. We conclude that the increase of mineralogical grains in the coarse sand fraction in unit III is a proxy for strong erosion, redeposition, and intense reworking of surface material during a period of intense landscape transformation. Varying thickness of unit III and features of different types of soil formation processes (brunification, strong bleaching, big Mn-stains) point to the fact that not only slope processes influence this material, but also different interstadial soil formation processes. Meszner et al. (2013) shows that unit III sediments date to the end of MIS 3. This supports the interpretation that unit III sediments were influenced by interstadial soil formation processes.
Furthermore, the coarse sand decreases from the bottom of unit III up to its top. We interpret the gradual fining up as indication of reduced slope processes and a re-strengthening of loess deposition in this area. The first pure aeolian deposits (basal part of unit II) yield a fine grain quartz OSL age of ca. 28 ka (further OSL ages published in Meszner et al. 2013 and Kreutzer et al. 2012). The idea that the high values of coarse sand in unit III provide evidence

for strong redeposition fits well to the OSL age estimates. The high-resolution sampled OSL age estimates show a hiatus between unit IV and unit III spanning approximately 35 ka from 70 ka to 35 ka (Meszner et al. 2013). It is most likely that material which was accumulated between 70 ka and 35 ka was reworked and eroded completely during a period of strong erosion, redeposition, and intense reworking of surface material.

In addition to angular mineral grains, we repeatedly observed layers consisting of well-rounded grains of the coarse sand fraction, which suggest that in the source areas fluvial and/or glaciofluvial material was available. Especially in Early Weichselian humic sediments a syngenetic enrichment with rounded particles can be observed. It seems that sediments of the Early Weichselian represents rapidly alternating conditions of loess deposition, cover sand development, solifluction, and soil development. However, it has to be underlined that Early Weichselian sediments represent a long period of glacial history, which are recorded in one or one and a half meter sediment, only. OSL-ages according to Kreutzer et al. 2014a and Meszner et al. 2013 suggest low sedimentation rates for this period. These results are in accordance to microparticle concentrations in NORTHGRIP ice cores according to Ruth et al. (2003).

Such evidence of coarse sand transport due to saltation was found in Early Weichselian deposits only.

In summary, we propose that loess with more than 10% sand content has to be attributed as loess derivate or loess-like sediment. There is no soil formation in loess investigated in our study which can create such a high amount of coarse sand due to pedogenetic overprinting. However, loessic sediments with more than 10% coarse sand are likely formed during strong reworking and redeposition due to solifluction and abluation processes. Gelic Gleysols (Nassböden) are characterized by an increase in carbonate-, Fe- and Mn- concretions especially in the medium sand fraction (Fig. 3.2 layer 7; Fig. 3.6 layer 8; Fig. 3.9 layer 5). In contrast to strong Weichselian interstadial soils such as humic horizons (Fig. 3.11, layer 20 & 22) or brown soil horizons (Fig. 3.11, layer 18) or interglacial soils (Eemian soil complex), with concretions up to coarse sand size. Fe- and Mn-concretions of weak Weichselian Gelic Gleysols are of medium sand size only (Fig. 3.11: layer 16). Therefore the medium sand fraction is a useful proxy to identify weak soil formations in LPSs rather than being a proxy for redeposition. In the Leippen (Fig. 3.4), Seilitz (Fig. 3.5 & 3.4), Ostrau (Fig. 3.8), Gleina (Fig. 3.2), and Rottewitz (Fig. 3.11) sections, medium sand and coarse sand show similar content behavior but to a different degree (e.g., Fig. 3.4). The similarities of both fractions are most obvious in units that are dominated by stronger reworked deposits such as unit III, IV, and V. However, very fine sand must have been triggered by another process since it does not show a similar trend compared to the coarse sand fractions (also visible in Fig. 3.9). We therefore conclude that in the SLR the coarse and the very fine sand fraction are controlled by different formation processes.

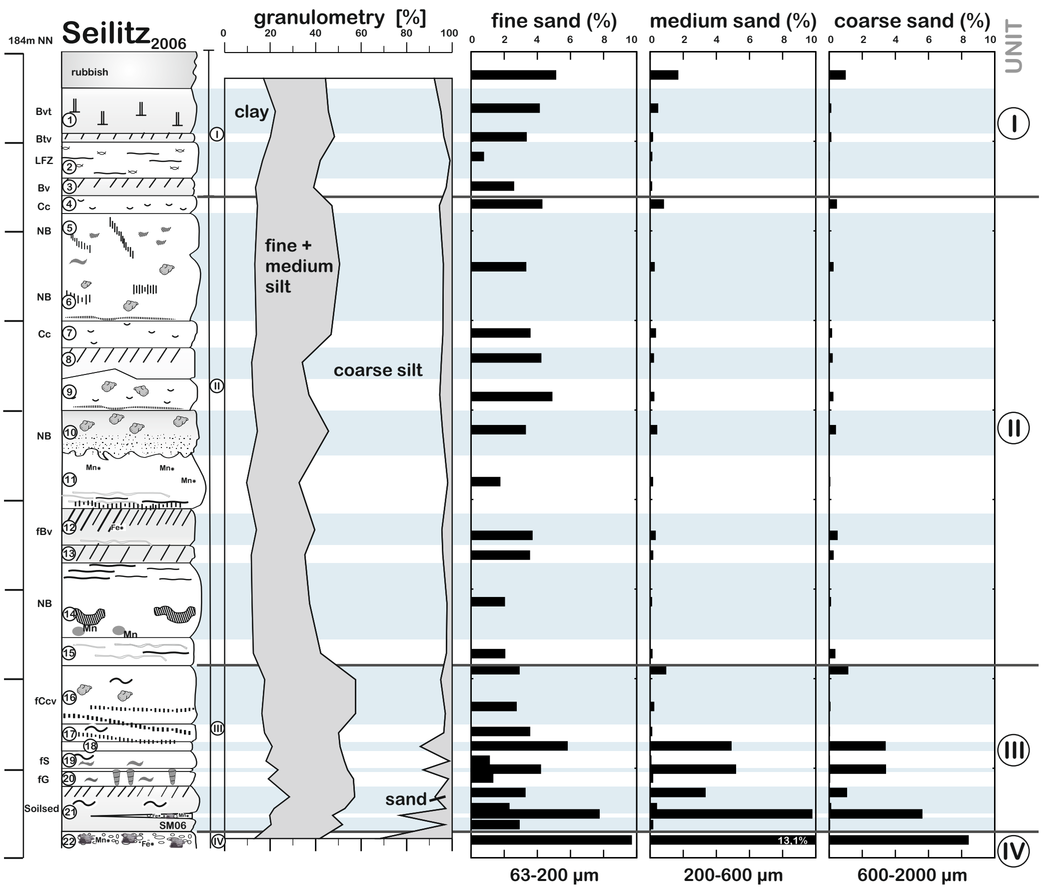

Figure 3.5: Grain size distribution of the Seilitz section (first survey from 2006, modified after Meszner et al. 2011, for legend see Fig. 3.11)

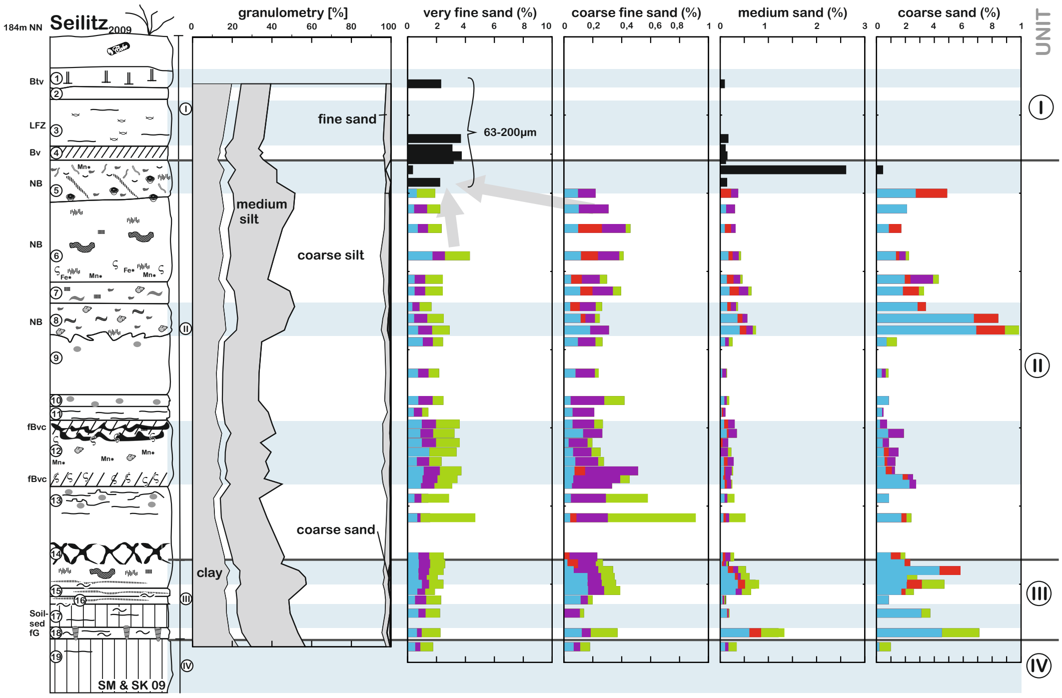

Figure 3.6: Grain size distribution of the Seilitz section (second survey from 2009, for legend see Fig. 3.11)

3.4.3 Very fine sand

The largest amount of the entire sand fraction (>63 µm) represents the fraction of the very fine sand (63-125 µm). In pure aeolian loess from Saxony, the average amount of very fine sand varies from 2 to 3%. The composition of very fine sand is dominated by mineral grains. Concretions of Fe, Mn, or carbonate have negligible amounts (Fig. 3.9 & 3.11). As mentioned previously, the distribution of very fine sand is different to the behaviour of coarse-fine sand (125-200 µm), medium sand, and coarse sand fraction. The distribution of very fine sand is more comparable with the distribution of the coarse silt fraction. In this context the Rottewitz section is an exception (Fig. 3.11). The record of coarse fine sand indicates a high amount of mineral grains analogue to the very fine sand. This may have been caused by the short distance to the local source area, the Elbe valley (Fig. 3.1). These findings correspond favourably with the concept of a proximal loess accumulation adjacent to a dust source according to Pye (1995, Fig. 11A). In particular, numerous authors in recent years have sought information about the aeolian dynamics recorded in LPSs.

It is therefore another purpose of this paper to verify whether similar patterns related to former aeolian dynamics can be recorded in Saxon LPSs, too. We interpret the content of the very fine sand in weakly redeposited units (mainly unit IV, especially in the Rottewitz section, II, and I) as being transported via air suspension, and finally we use the amount of very fine sand as an indicator for palaeowind speed. Vandenberghe & Nugteren (2001) associated coarse-grained loess with strong winds and cold conditions, while fine-grained sediments were related to low-energy deposition under warmer conditions. In unit IIa a general increase of very fine sand is observed from the bottom to the top. The increase is visible in profiles, investigated using a high resolution sampling method. Here a cyclical increase is detected with two maximum peaks at the top of unit II (Fig. 3.2: layer 4-6) and in the lower part of unit I (Fig. 3.9: layer 2-4). This can also be observed in the Leippen (Fig. 3.4), Zehren (Fig. 3.7 layer 4-8), Ostrau (Fig. 3.9), and Gleina (Fig. 3.2) profiles. Similar results have been described by Antoine et al. (2009b) from the Nussloch section. The cyclicity (so called "loess events") found in the Nussloch section is comparable with the variation of very fine sand in unit II and I of the Saxon LPSs. When discussing the very fine sand increase, not only intensification of palaeowind speed should be considered. Additionally, a change in distance between dust source and sedimentation area is conceivable. A coarsening up of aeolian sediments related to a nearby source has been described by Prins et al. (2007), Pye (1995), Pye & Sherwin (1999), Schönhals (1955), Smalley et al. (2006), and Wang et al. (2006). The climatically forced extension of an Arctic desert during the Upper Pleniglacial might have caused local dust sources (e.g., local river floodplain) where surface winds could upload aeolian dust. However, since the coarsening of younger Weichselian loess can be detected all along the northern European loess belt (Antoine et al. 1999, 2009b; Bibus et al. 2007; Jary 2007; Schirmer 2000, 2003; Vandenberghe et al. 1998), it becomes evident that a general increase in wind speed was a fundamental cause of this phenomenon. We suggest that varying very fine sand content in profiles located in the SLR is mainly linked to the changes in palaeowind speed. The maximum of very fine sand (transition unit II to unit I) seems to represent the LGM and can be observed above the strong Gelic Gleysol on the Ostrau (Fig. 3.9), Leippen (Fig. 3.4), and Gleina sections (Fig. 3.2). Other studies often show arithmetical means and ratios of grain sizes distributions. This is useful in loess areas where accumulation of pure aeolian silt is the dominant process. However, loess sequences located on the northern branch of the European loess belt (like the SLR) contain several sequences dominated by different deposition processes (several types of redeposition, erosion, and other overprintings). In this contribution we renounce showing arithmetical means and ratios, because only unit II is dominated by more or less pure aeolian deposits.

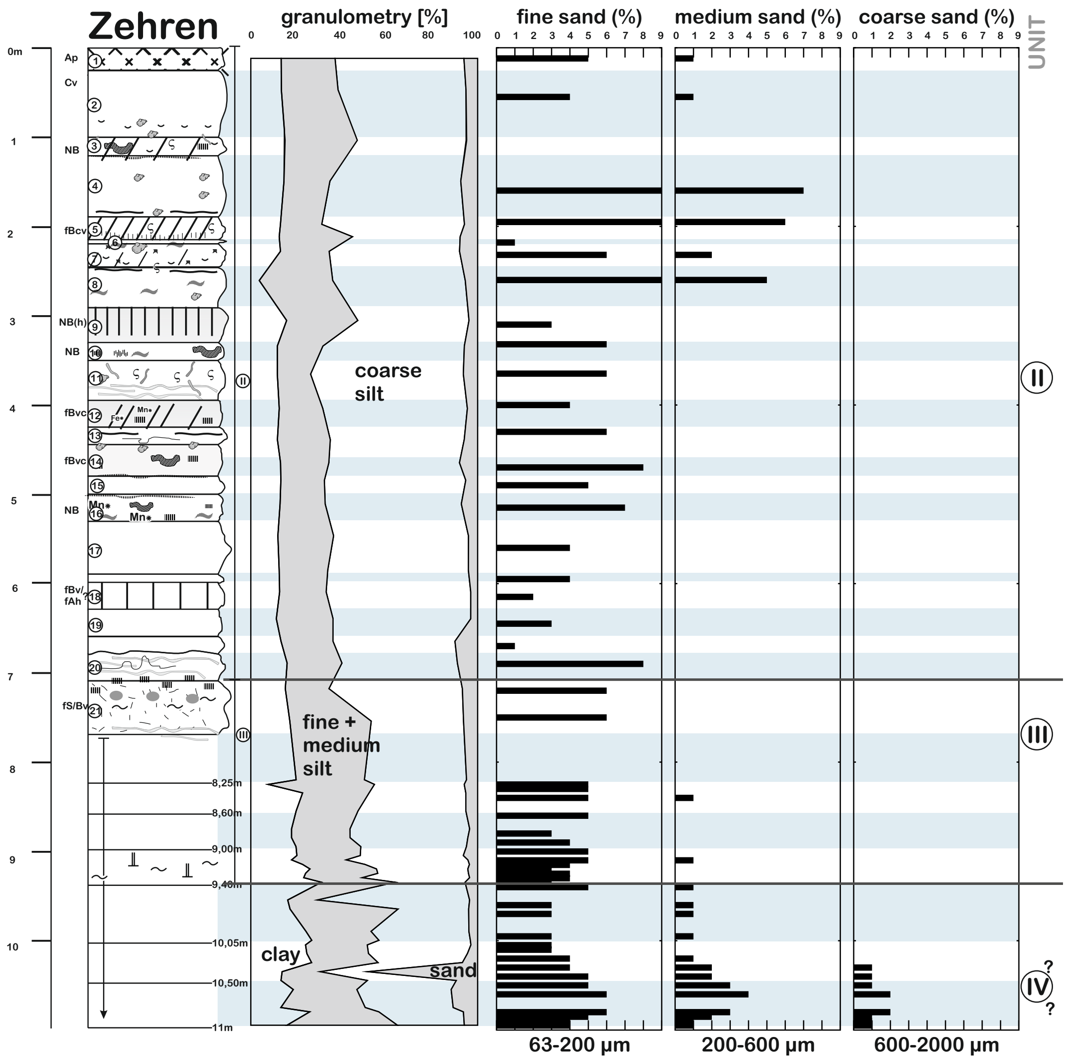

Figure 3.7: Grain size distribution of the Zehren section (modified after Meszner et al. 2011, for legend see Fig. 3.11)

3.4.4 Silt

Coarse silt typically dominates weakly reworked or pure loess deposits from unit I and II with an overall proportion of approximately 55%. This fraction shows a clear decline in Gelic Gleysols (tundra gley soils). Simultaneously with the decrease in the coarse silt, an increase in clay, fine, and medium silt content occurs in Gelic Gleysols (Fig. 3.2 layer 7; Fig. 3.4 layer 6; Fig. 3.5 layer 10; Fig. 3.6 layer 7 & 8; Fig. 3.7 layer 9; Fig. 3.9 layer 5). Such a behaviour of grain size distribution seems to be typical for tundra gley soils in LPS and was also mentioned by ANTOINE et al. (2009b) from the Nussloch section. But what is the reason for this fining? As described above, in Saxon LPSs Gelic Gleysols show features of redeposition, which refer to its formation as an active layer. Due to the deposition during the active layer period, the easily erodible coarse silt fraction could be preferentially washed out and caused the refinement of the material. In addition, increased physical weathering caused by repeated freezing and thawing is capable of generating a higher amount of fine material down to a grain size of fine silt. Both processes explain a reduction in the mean grain size in Gelic Gleysol sediments, but it is doubtful that they are capable of reducing the coarse silt fraction by 20%. As an additional explanation we propose a decrease in palaeowind speed and assume that the decrease enabled the formation of Gelic Gleysol. A reduction in wind speed limited potential (local) source areas and may be linked to a decline in aeolian input. Therefore the amount of long-term suspension particles (diameters >20 µm, MUHS 2013) increased in comparison with short-term suspension particles deposited during soil formation periods.

Without high sedimentation rates the profile growth is slowed down and the uppermost material is not buried continuously. We assume that slower sedimentation rates are associated with the increase of exposure time. The longer the material is exposed to surface, the more intensively the material is weathered. During this long period of exposition as surface soil, features of Gelic Gleysol could have developed. Conversely, fast sedimentation went along with the coarsening up of loess. In the case of fast sedimentation, features of Gelic Gleysol cannot develop due to being quickly covered with fresh material. As a result, pure loess with less features of hydromorphism was formed (like unit IIa, for example Fig. 3.6 layer 6). Thus, we suggest that climate probably plays a minor role during Gleysol formation. In contrast, available sediment supply is a more important regulation factor.

Wang et al. (2006) gave an alternative explanation for the occurrence of finer-grained material in stadial soils developed in loess compared to coarser-grained material in pure loess. They argued that during periods of soil formation, denser vegetation cover and a wetter surface of soils increase the dust trapping efficiency. The dust trapped during periods of soil formation consists of finer grained material because there are slower surface winds, a dense vegetation cover, and less local dust sources than in periods of pure loess sedimentation. Periods of pure loess formation are characterized by coarser-grained material but a lower sedimentation rate due to the reduction in dust trapping efficiency (sparse vegetation cover and dry surface soil) (Wang et al. 2006). In Saxony the authors did not find clear evidence for higher sedimentation rates in soils. OSL ages of Late Glacial loess sequences (Meszner et al. 2013) may indicate a lower sedimentation rate during Gelic Gleysol formation and a higher sedimentation rate in pure loess. Additionally, features of Gelic Gleysol formation are sporadically distributed in pure loess sequences, too. We suppose that conditions for Gelic Gleysol formation exist more or less over the entire Late Glacial period and the sedimentation rate triggers the intensity of Gelic Gleysol features in the loess sequence. Similar to Gelic Gleysols (for example: Fig. 3.4: layer 6; Fig. 3.6: layer 8; Fig. 3.7: layer 9), deposits of unit III show tendencies toward fining. It is likely that the primary aeolian sediment of unit III, compared to deposits of unit II, has a finer mean grain size distribution due to reduced sediment input during decreased wind speed. In contrast to Gelic Gleysols, the coarse sand fraction is also increased in deposits of unit III (cf. Fig. 3.4, 3.5, 3.6 & 3.9). This may be interpreted as an indication of secondary redeposition due to solifluction processes of unit III substrates (section 3.4.2). These sediments have to be characterized as loess derivates or weathered loess according to the classification of Koch & Neumeister (2005) or Pye (1995). Additionally, unit III sediments were also overprinted during weak interstadial soil formation. Similar patterns of fining due to soil formation are observed in unit I. Comparing the distribution of medium silt and clay content in unit I, clay shows a linear increase from bottom to top and could be interpreted as a pedological process. In contrast, medium silt reaches a maximum in the lenticular horizon and decreases above. The asynchronous behavior of both fractions underlines the fact that they were not forced by similar processes. The clay content indicates soil formation and weathering processes, whereas medium and coarse silt are forced by sedimentological processes (most likely palaeowind speed).

In the past, concepts of dust deposition and loess accumulation in several environments and landscapes were discussed (Pye 1995; Pye & Sherwin 1999). Such models are mainly based on grain size distribution and thickness of the loess cover. Nugteren & Vandenberghe (2004) and Bokhorst et al. (2011) have shown that grain-size differentiation enables to reconstruct the palaeowind direction for the Central Loess Plateau (China) and Central and Eastern Europe. Pye (1995) described a relationship between grain size distribution, loess thickness and the distance to the source area. Our data show how the geomorphological position of the sections in the loess area influences its grain size distribution. For example, similar stratigraphic positions (e.g., unit I and II) could be easily correlated by the vertical distribution of the very fine sand. The sequences show similar trends, but they are clearly distinguishable from each other by their amounts of very fine sand. The Ostrau section (located in the central part of the loess area) and the Seilitz section (located west of the Elbe valley) show very fine sand concentrations of 2% (max. 4%) on the average. In contrast, the Gleina section, located directly on the northern boundary of the loess area (Fig. 3.1) shows a very fine sand content of 3% (max. 8-9%) on the average. Considering the spatial position of these sections in the SLR (Fig. 3.1) a palaeowind direction from the north may be assumed. Coarse-grained dust particles transported by wind are accumulated at the northern margin of the loess area. Further south, in the central part of the loess area, mainly fine-grained loess was accumulated. Taking into account the very fine sand data from the Rottewitz section (located directly on the eastern slope of Elbe valley), a second palaeowind direction from west can be reconstructed. The Rottewitz section shows a very fine sand content of 6% (max. 9-10%) on the average. Particularly the comparisons of sections close to the Elbe valley (Seilitz and Rottewitz section; Fig. 3.1) clearly illustrate the influence of the Elbe valley on grain size distributions. The eastern profile (Rottewitz) has a higher amount of very fine sand than the western profiles (Seilitz).

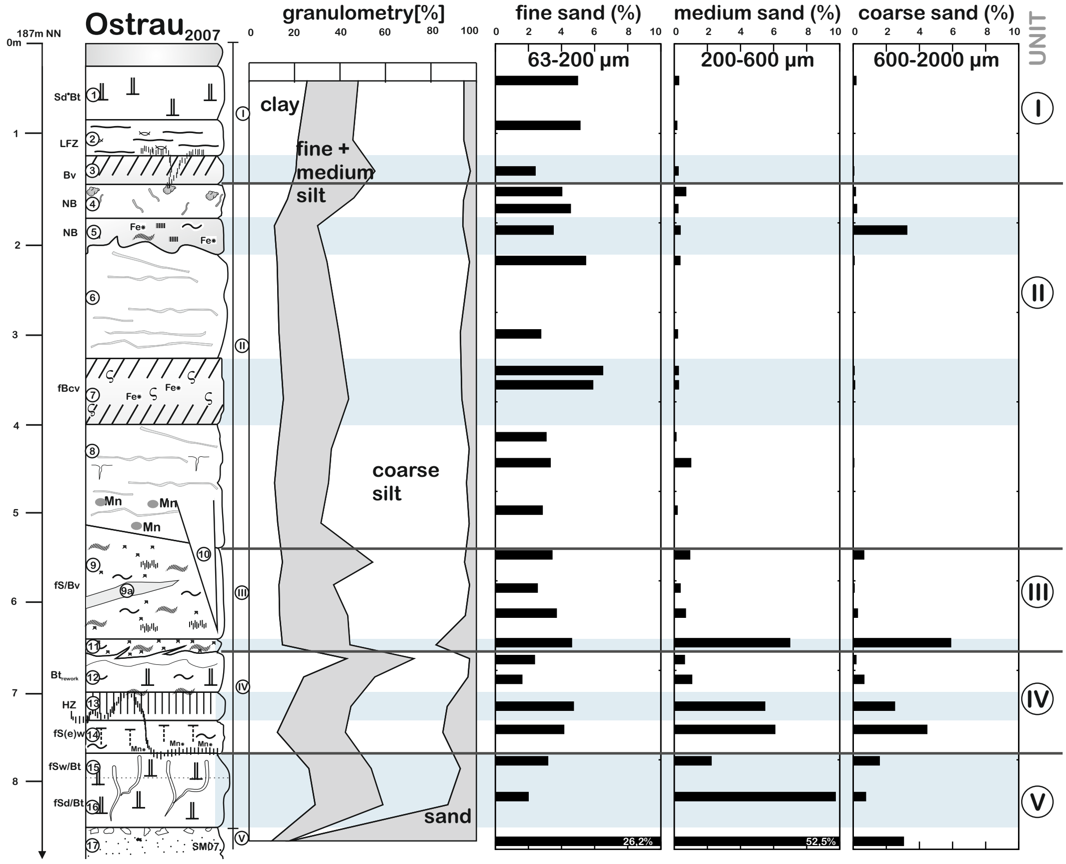

Figure 3.8: Grain size distribution of the Ostrau section (modified after Meszner et al. 2011), first survey in 2007 (for legend see Fig. 3.11)

3.4.5 Brown Gelic Gleysol

Two weakly developed brown soils or rather soil sediments with hydromorphic features (Fe-concretions) were found in our investigated LPS. The upper brown soil (Fig. 3.2: layer 11, 13, Fig. 3.4: layer 8, 10; Fig. 3.5: layer 12, 13; Fig. 3.6: layer 12; Fig. 3.8: layer 7; Fig. 3.10: layer 6, 8) can be found in most profiles of the SLR. Especially in the Gleina, Leippen, Ostrau, and Seilitz sections it reaches a thickness of up to 1 m. This brown Gleysol can be recognized by typical features: pale brown colour, pseudomycelia, Fe-concretions in the upper part, and a homogeneous structure. This layer is classified as a brown Gelic-Gleysol complex because in most LPSs the layer is subdivided into two horizons and the grain size distributions show recurring patterns in

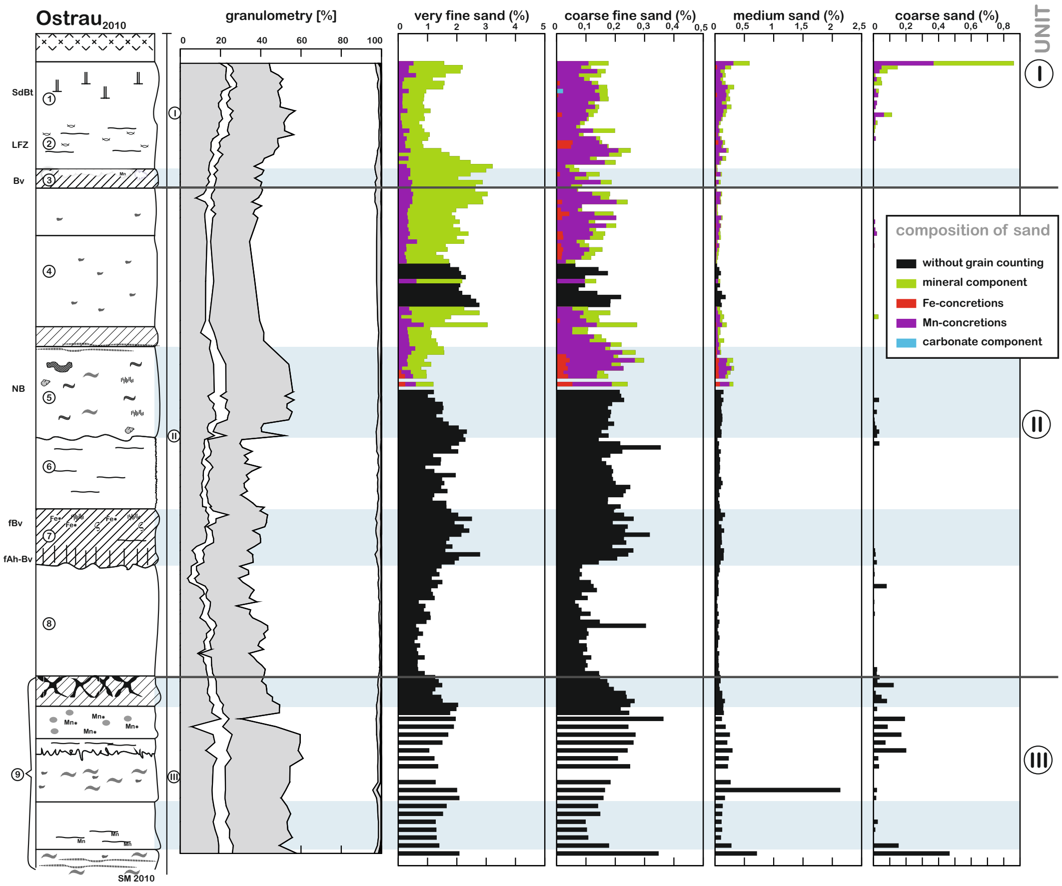

Figure 3.9: Ostrau section, survey 2010 (for legend see Fig. 3.11)

The column headed with "granulometry" shows the grain size distribution of the Ostrau site. The fraction <63 µm was decalcified using HCl, the fraction >63 µm was not decalcified.

all sequences. In contrast to the underlying material the clay content rises by another 2-3% on average. More distinctive are the changes in the medium silt fraction that increases by another ca. 4%, whereas the coarse silt decreases by ca. 8%. Additionally, there is an increase in the coarse sand fraction. The maximum of coarse sand is reached within the complex, where hydromorphic features are dominant (at the top of this soil). Figure 3.6 shows that the amount of Fe- and Mn-concretions increases with the increase in the coarse sand and coarse fine sand fraction. The fining of soil parent material can be related to weathering processes during the period of soil development. A decrease in very fine sand and coarse silt in the center of this weak interstadial soil complex emphasizes sedimentation of primary finer-grained loess due to reduced eolian dynamics (more long-term suspension material). It might be

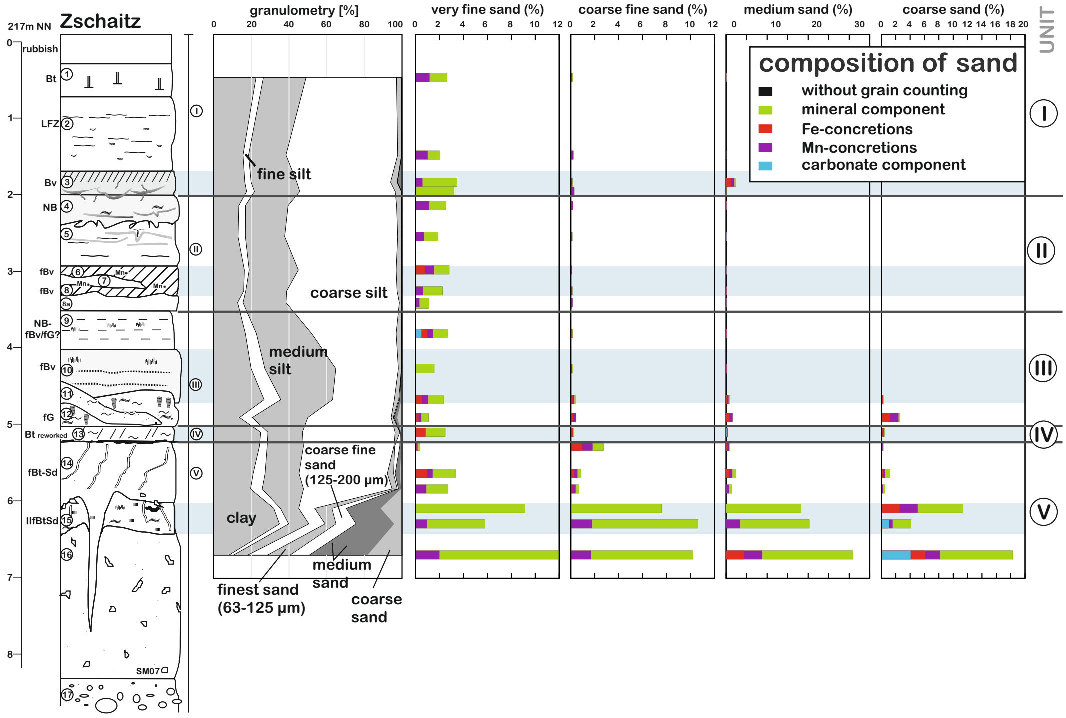

Figure 3.10: Grain size distribution of the Zschaitz section (modified after Meszner et al. 2011, for legend see Fig. 3.11)

reasonable to assume that this soil was decalcified during formation. After being covered with fresh material the brown soil was affected by recarbonation. Compared to pure loess, this material is finer-grained and induces a lower rate of percolation of soil water and air. Therefore the formation of pseudomycelia during recarbonation is a result of the grain size distribution with dominating fine-grained material. Another interpretation of pseudomycelia in soils is that they were formed during soil formation in the material bordering to directly living plant roots. According to Verrecchia (2011) secondary carbonates could be precipitated as hypercoatings of root channels due to desiccation and/or root suction. It has to be mentioned, that during dry conditions the formation of hydromorphic features which could also be found in this horizon is not possible. However, it must be taken into account that weathering (brunification), hydromorphism and the formation of pseudomycelia describe a climatically succession from wetter conditions at the beginning of soil formation period to finally dryer conditions. It is most likely that pseudomycelia were formed just during transition between interstadial and stadial conditions.

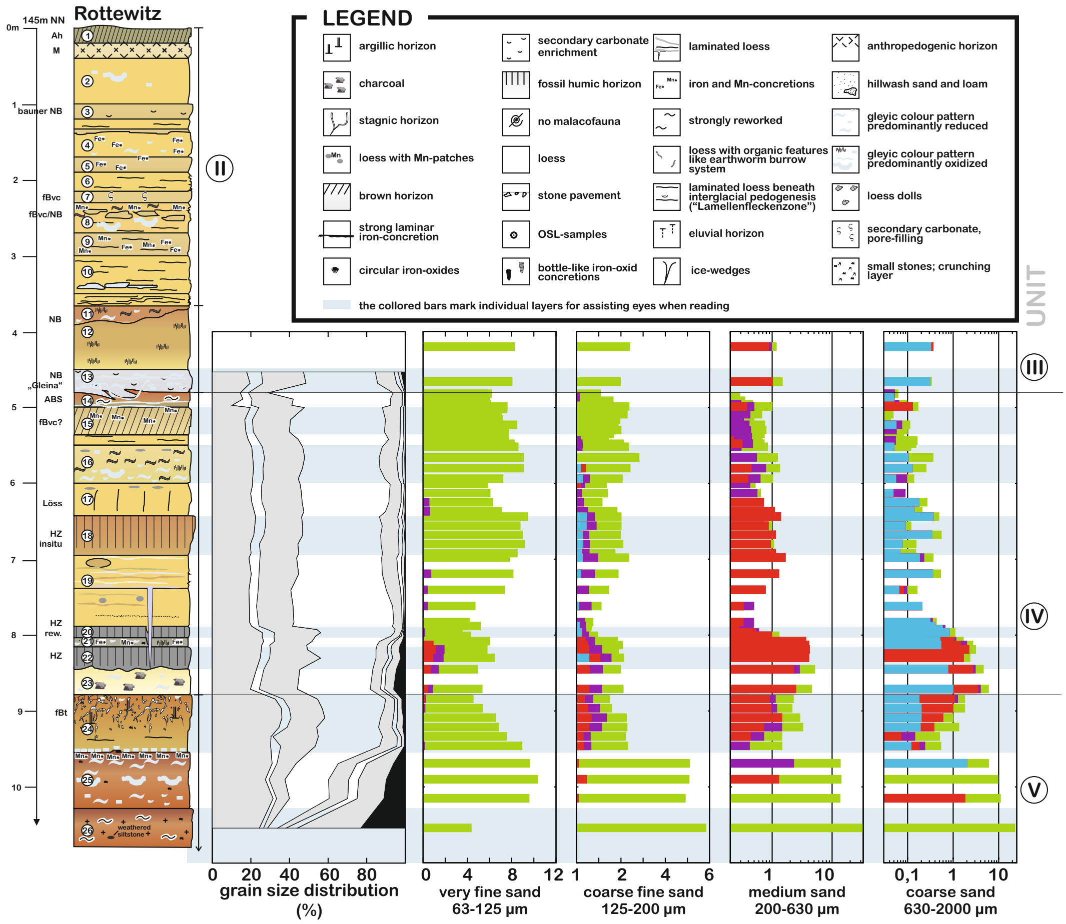

Figure 3.11: Grain size distribution of the Rottewitz section. Note the logarithmic scale of medium and coarse sand distributions. For legend of composition see Fig. 3.10.

In summary, this complex composed of two weak interstadial soil horizons represents a short decrease in aeolian dynamics during a soil formation period within the Upper Pleniglacial. This complex is noteworthy because normally grey and not brown Gelic Gleysols represent short interstadial conditions during the Upper Pleniglacial only. Its pale brown-grayish colour is a singularity for this stratigraphic position. OSL age estimates of 28-26 ka according to Meszner et al. (2013) show that the complex was formed during the Late Pleniglacial.

3.5 Summary

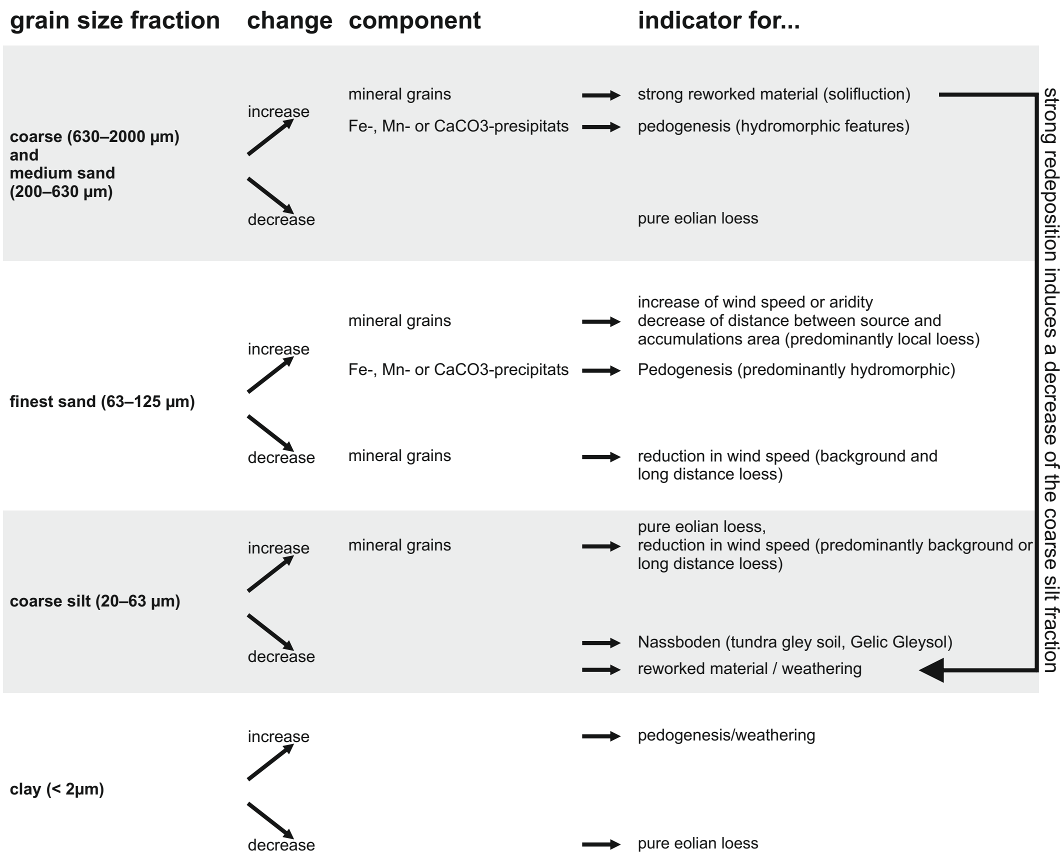

Figure 3.12: Selected grain size fractions and potentially palaeoenvironmental interpretation for LPSs

A number of studies have been published in the last decade on European LPSs for reconstructing palaeoenvironmental conditions. Much attention has been devoted to recent methods, for example, biomarker, isotopic, or magnetic investigations (e.g. Böttger et al. 2002; Schatz et al. 2011; Vidic et al. 2004. Most studies, showing grain size data from LPS have focused on the reconstruction of aeolian dynamics (Antoine et al. 2013, 2009a,b; Bokhorst et al. 2011; Marković et al. 2008; Marković et al. 2013; Rousseau et al. 2011; Shi et al. 2003; Vandenberghe et al. 1998). This contribution highlights the interpretation of grain size data to conclude on geomorphological processes. An enrichment of coarse particles caused by sedimentological processes show another composition of the coarse sand fraction than an enrichment caused by soil formation. Obviously, LPSs located on the northern

European loess belt often show features of hydromorphism (Jary & Ciszek 2013; Meszner et al. 2011; Vandenberghe et al. 1998) which are accompanied by the formation of Fe- and Mn-precipitates. In contrast, quality and quantity changes of mineral grains (mainly quartz, feldspar, or mica grains) indicate sedimentological processes. In particular, basal strata of the LPSs provide examples demonstrating the usefulness of microscopic analysis. In complex loess profiles which were affected by severe redepositional processes the approach allows to distinguish between sedimentary and pedogenetic origin of coarse-grained subfractions (e.g., sections of Zschaitz and Seilitz, figs. 3.10 and 3.5, respectively). The results described above indicate that especially the individual sand fractions are forced by a minimum of three processes (Fig. 3.12):

1. Coarsening due to strong redeposition during solifluction with embedding of allochthonous material (mainly influencing coarse and medium sand).

2. "Pedogenetic" coarsening caused by the formation of Fe- and Mn-precipitates due to hydromorphism (strong soil formations create medium and coarse sand; weak interstadial soil formations create fine and medium sand precipitates only).

3. "Sedimentological" coarsening due to an increase in wind speed (aeolian dynamics). Generally the very fine sand fraction is a useful proxy for estimating palaeowind speed. In addition, in close proximity to a local source area (e.g., valley margin of larger rivers) coarse-fine (125-200 µm) and medium sand (200-630 µm) may indicate wind speed too.

Thus not only the composition of the coarse sand fraction but also the shapes of precipitates (Fig. 3.3) carry important information about formation processes. Rounded Fe- and Mn-precipitates are typical features for Early Weichselian soil-derived sediment. A second major finding is that comparable stratigraphic units of different sections show similar grain size distributions. Additionally, a correlation on the basis of grain size distributions of stratigraphically different, but genetically identical units was possible. A 65-ka Gelic Gleysol (Fig. 3.11: layer 16) shows properties similar to that of a 22-ka-old Gelic Gleysol (Fig. 3.9: layer 5). Similar formation processes causes similar

grain size distributions in loess.
Another important point raised by this contribution is that the depth of the decalcification boundary is not related to a specific loess or loess-like sediment. Late Pleistocene/Holocene soil formation modifies the parent material, which was at the surface when soil formation started. Thus, loess-like material of different ages can be the parent material for Late Pleistocene/Holocene soil formation. A useful marker to distinguish or delimit stratigraphical units of near surface substrates is the bimodal very fine sand distribution at the transition from unit II to I. In this study no calculated arithmetic mean or median (e.g., Stevens et al. 2011 or Antoine et al. 2001) of grain size distribution was used. A mathematical value that combines several grain size classes is useful to describe a general trend. However, a differentiation between the grain size class that causes the shift of arithmetic mean or median is possible only if raw grain size results are considered.

Finally, grain size data help to identify hiatuses in LPSs. Loess has a mean particle size that is smaller than windblown sand, but coarser than long-term suspension dust (typically 10-20 µm) (Muhs 2013). Without disturbance during deposition, vertical grain size distributions of LPSs should show smooth transitions from layer to layer. Unit II is an example for a more or less undisturbed aeolian deposit. However, it is shown above that at unit-boundaries the grain size distribution changes abruptly and significantly. These shifts are a result of mass wasting slope processes, which caught and modified primary aeolian deposits. During downslope movement the material was usually enriched by coarse sand and degraded in coarse silt. These shifts in grain size distribution help to identify hiatuses in LPSs. Grain size distribution analysis, furthermore, helps to distinguish between soils and soil sediments. Soils show a gradual change of properties (e.g., in organic and carbonate content) from parent material to soil horizons or within horizons. In contrast, soil sediments are clearly distinguishable by grain size distribution influenced by non-in-situ material.

Another fundamental objective of the presented study was to revive loess research in this region. As mentioned above, much attention has been devoted to the aeolian component of the sand fraction (>130 µm). The grain size

data show clear evidence of two periods dominated by aeolian loess sedimentation and relatively high accumulation rates. The older period is preserved in the Rottewitz section (unit IV) and the younger period is preserved in most profiles as unit II. Unit II loess shows a clear cyclicity in very fine sand concentration which is interpreted as variations in aeolian activity. These results agree with observations from other European loess regions (Antoine et al. 2013, 2009b; Bokhorst et al. 2011; Jary & Ciszek 2013; Rousseau et al. 2011; Schirmer 2012; Vandenberghe et al. 1998) and lead to the assumption that this cyclicity is a European wide feature in LPSs. A further result comparable to investigations from other regions is that both aeolian periods are separated by a phase (unit III ~Middle Pleniglacial) of less loess conservation and most likely dominated by low sedimentation rates, interstadial soil formation, and widespread erosion (Antoine et al. 1999; Frechen et al. 2001; Jary & Ciszek 2013; Schirmer 2012; Vandenberghe et al. 1998). Taking this into account, loess sequences located on the northern branch of the European loess belt show a similar internal structure and have been controlled by supraregional depositional conditions. These findings conform to dating results from the SLR (Kreutzer et al. 2012; Meszner et al. 2013). Sequences marked by slope process are characterized by variable OSL age estimates that differ from layer to layer. By contrast, sequences derived from aeolian deposition show gradual increase or decrease of OSL ages.
This study has shown several limitations of the approach that has been applied. First, distinguishing the typical grain size distribution of each layer requires high resolution sampling. We propose a maximal distance between two samples of 7 cm up to 10 cm. More robust data will be achieved by using continuous column sampling described by ANTOINE (2009) who used a sample resolution (column high) of about 5 cm (applied at the Ostrau section, Fig. 3.9). Secondly, the study only uses simple mineralogical analyses which, for example, did not distinguish different minerals. Further analysis (for example heavy minerals) should allow identifying source areas of the dust. Furthermore, the reconstruction of palaeowind was only based on nine LPSs. It has to be noted that a higher spatial resolution might be useful to double-check our preliminary findings on palaeowind directions.

In summary, this study shows that a variety of depositional conditions can be derived from a detailed interpretation of grain size distribution only. In addition, applied numerical dating helps to reconstruct palaeoenvironmental conditions and allows for supraregional comparison of loess records. All results discussed in this paper are integrated in a comprehensive reconstruction of palaeoenvironment and landscape evolution published by Meszner et al. (2013).

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Chapter 4

Study III: Late Pleistocene landscape dynamics in Saxony, Germany: Palaeoenvironmental reconstruction using loess-palaeosol sequences

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	SM	**SK**	**MF**	**DF**
Field work	90%	5%	-	5%
Lab work	100%	-	-	-
OSL sampling	50%	50%	-	-
OSL dating	-	100%	-	-
Stratigraphy	80%	5%	5%	10%
Manuscript preparation	70%	20%	5%	5%

Abbreviations are the authors' initials.

Abstract

Loess archives are of paramount importance for reconstructing regional palaeoenvironmental conditions of past glacial periods. The SLR is an area of transition between the western and the eastern European loess belt. With this contribution, a documented loess-palaeosol composite profile for the SLR is extended, and a new chronostratigraphy, established by high-resolution OSL dating of two profiles, is described. In addition, for the first time OSL age estimates for the loess palaeosol sequence at Seilitz are presented for the quartz and polymineral fine grain fraction. Based on the presented composite profile climatic and environmental conditions (e.g. wind speed, temperature) are deduced. Based on high-resolution OSL dating it is possible to identify a hiatus spanning ca. 30 ka. This gap is located in the Gleina Complex where an underlying layer shows an age of ca. 60 ka and the upper layer an age of ca. 30 ka. Additionally, two periods of strong loess accumulation with ages of ca. 70–60 ka and 30–18 ka could be identified. There is a general trend of grain size coarsening-up towards the Late Glacial which shows a maximum at ca. 21 ka. Correlations with French, western German and Polish loess sections are discussed.

4.1 Introduction

Loess sequences are important terrestrial archives for better understanding palaeoenvironmental dynamics of the last glacial-interglacial cycle. As a terrestrial archive, in loess, landscape evolution dynamics are recorded by the progression of sediments, soils and soil sediments. In contrast to other palaeoclimate archives (e.g. ice cores; ANDERSEN et al. 2004) loess-palaeosol sequences reflect not only climatic signals, but represent archives of local landscape and environmental evolution (e.g. MARKOVIĆ et al. 2008). Processes that force the landscape evolution during the last glacial cycle were mainly driven by palaeoclimatic conditions that are expressed differently in respect to local palaeoenvironments.

Every loess region in central Europe provides global and regional palaeoclimatic information, which can be deduced from loess, loess derivatives, soils and soil sediments. To allow for a general view, it is necessary to collect an adequate amount of stratigraphical and chronological data from neighbouring loess areas. As a contribution to the European loess research, this work reports a high-resolution chronostratigraphy for the SLR and presents detailed field analyses of seven large exposures. The SLR is located between western European (ANTOINE et al. 2003a, 1999, 2009b; ANTOINE et al. 2003b; HAESAERTS et al. 1999; HUIJZER & VANDENBERGHE 1998; ROUSSEAU et al. 2002; SCHIRMER 2000; SEMMEL 1999; VANDENBERGHE et al. 1998; VLIET-LANOË 1989) and eastern European loess regions (GERASIMENKO 2006; HAESAERTS et al. 2010; JARY 2009; JARY 2010; ROUSSEAU et al. 2011), raising the opportunity for combining findings from both regions. JARY (2010) presented a transect of loess-palaeosol sequences for the eastern European loess belt and proposed correlations of Late Pleistocene loess-palaeosols from Poland, NW Ukraine, and Russia; however numerical age estimations are scarce. Recently, first OSL age estimates from the site Biały Kościół (MOSKA et al. 2011, 2012) south of Wrocław were published, providing an opportunity for correlations with western European loess areas.

For the site Stayky, located in Middle Ukraine, ROUSSEAU et al. (2011) provided a stratigraphic overview accompanied by several numerical age estimations in an adequate chronological resolution using infrared light stimulated luminescence (IRSL) dating methods. The work showed similarities in the variation of the grain-size index with western European loess profiles. Such correlation of grain sizes over Europe has to be done carefully, and it may be helpful to consider results of an intermediate loess area to confirm these assumptions. The presented results from the SLR may serve as a link between these loess areas located on the northern branch of the European loess belt.

In the southeastern European loess provinces, loess sections preserve information back to the MIS 21 (Fitzsimmons et al. 2012). Additionally, loess palaeosol sequences preserve independent palaeoenvironmental information, such as vegetation history (Schatz et al. 2011; Zech et al. 2009), soil development (magnetic susceptibility; Marković et al. 2008) or proxy data for the palaeowind speed (grain size distribution; Vandenberghe et al. 1998).

The first studies of loess sequences from Saxony date back to the beginning of the last century (Gallwitz 1937). In the 1960s, the SLR has been investigated by stratigraphical and palaeopedological methods to establish a standard profile e.g. G. Haase et al. 1970; Lieberoth 1963.

Since 2008, the loess in Saxony has been intensively reinvestigated, and efforts have been undertaken to better understand the environmental (Zech et al. 2013) and climatic conditions during the late Pleistocene (Meszner et al. 2011, 2014). For example, Baumgart et al. (2013) used rock magnetic properties of loess sections from this area to subdivide several sequences of different rock-magnetic characteristics. The reported subunits are in accordance to the sedimentological units found during fieldwork and the interpreted grain size results (Meszner et al. 2014).

Meszner et al. (2011) introduced a new composite profile for the SLR based on seven newly opened loess sections for the last glacial. This composite profile consisted of five main units. New findings have extended the existing composite profile. By establishing a high-resolution chronostratigraphy with ages obtained from the profiles Ostrau (Kreutzer et al. 2012) and Seilitz, the composite profile is re-evaluated and further discussed here.

For the first time, OSL ages from the loess section in Seilitz are presented. The quartz and polymineral fine grain (4–11 µm) fraction were used, applying standard methods for quartz dating (Murray & Wintle 2000) and the post-

IR IRSL (pIRIR) protocol for the polymineral fraction (Thiel et al. 2011; Thomsen et al. 2008). Furthermore, on the basis of geomorphological and pedological findings, palaeoclimatic parameters (i.e. temperature, wind speed, precipitation) were derived for the Late Pleistocene. Landscape evolution dynamics (i.e. redeposition and landscape stability) are determined by interpreting sedimentological features (grain size analyses, Meszner et al. 2014) and specific structural conditions of soils, soil sediments and loess layers.

4.2 Study area

All profiles discussed in this article belong to the SLR, which is located on the northern foothills of the Erzgebirge between 150 m and 250 m a.s.l. (Fig. 4.1). A significant feature of the SLR is an abrupt change from loess deposits to glacial or glaciofluvial sediments at the northern boundary. The thickness of the loess deposits increases from south to north and reaches an area-wide maximum on the northern boundary. A smooth step in the landscape marks this boundary and represents the transition zone from loess to glacial or glaciofluvial sediments in the north. Loess deposits cover the entire undulating topography of the study area with a 4–8 m thick layer, excluding steep slopes (predominantly western slopes of river and creek valleys) and alluvial floodplains.

Grain size distributions at a section on the eastern side of the river Elbe show a higher amount of coarse grain fractions than profiles located on the western river side. Due to these sedimentological patterns, it is concluded that dominantly westerly winds were responsible during the time of loess deposition. Today, the area is characterized by a mean annual temperature of 8.8 °C (station Döbeln) and ca. 590 mm of total precipitation per year (average of stations Zehren and Ostrau, data from 1961 to 1990).

The investigated profiles Ostrau (51°12’10” N, 13°10’48” E) and Seilitz (51°11’11” N, 13°24’02” E) are located on the western side of the river Elbe (Fig. 4.1). The profile Ostrau is characterized by the interglacial soil (Eemian) at the base followed by 3 m of strongly reworked loess derivatives and soil sediments (unit IV and III) and 6 m of dominant barren loess with intercalated tundra gley soils (unit II and I). The profile Seilitz consists of several loessic

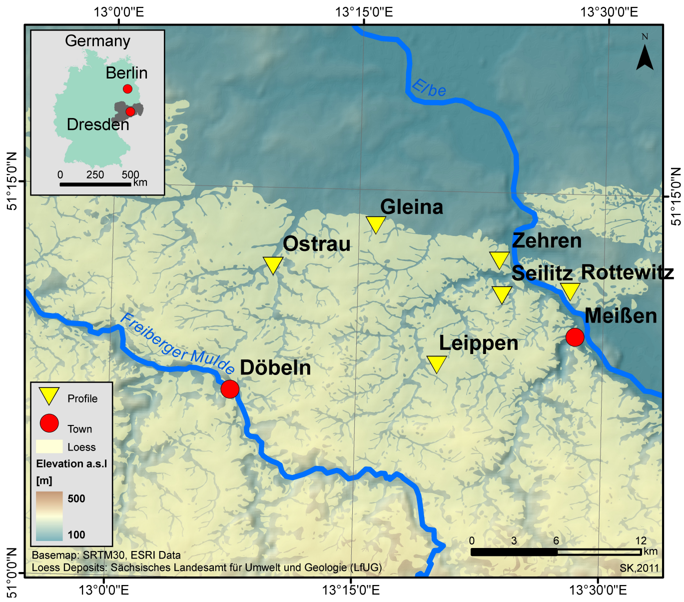

Figure 4.1: Study area with profile locations in Saxony (Germany)

solifluction layers (unit IV and III) at the base, without the conservation of the Eemian soil. The upper part (unit II and I) of the profile is dominated by barren loess and is comparable with the upper part (unit II and I) of profile Ostrau. For further details, see Meszner et al. 2014.

4.3 Material and methods

4.3.1 Field work and sedimentology

Soil and sediment samples were analysed using routine methods described in detail by Meszner et al. 2011. The following parameters have been determined: (a) total organic content (TOC), (b) pedogenetic (dithionite-soluble) and (c) total Iron, (d) pH-value, (e) carbonate content, (f) magnetic susceptibility, and (g) grain size distribution. For further information concerning the grain size analysis, see Meszner et al. 2014. Since 2008, total organic carbon was detected by using the suspension method (DIN EN 15936). The results of both methods are found to be similar.

4.3.2 Luminescence dating

Measurement setup

OSL samples for the profile Seilitz were taken during night time after carefully cleaning the section. Samples for dose rate determination were taken from the surrounding 30 cm of the sampling positions. All samples were prepared using standard procedures for the polymineral and quartz fine grain (4–11 µm) fraction. Carbonates and organic material have been removed by HCl and H_2O_2 treatment respectively. The fine grain quartz samples were etched for six days in three day pre-treated H_2SiF_6 (34 %) and subsequently washed in HCl (Berger et al. 1980; Fuchs et al. 2005). The purity of the quartz extracts were tested by IR stimulation (IRSL/OSL ratio $< 1\,\%$). The sample preparation was done under subdued red light ($\lambda = 640\ \Delta\ 20$ nm).

For the measurements, the samples were mounted on aluminium discs (ca. 2 mg of sample/disc). At least 12 aliquots of the fine grain extracts were measured. The quartz fraction was measured using a standard single-aliquot regenerative-dose (SAR) protocol according Murray & Wintle (2000) with a cutheat of 160 °C and read temperature of 125 °C. The preheat temperature of 220 °C was deduced from test measurements. For D_e determination the integral of the first 0.2 s was used after subtracting the background from the last 4 s of the shine down curve. For sample pre-treatment of the two coarse grain quartz samples (BT594, BT707) see Kreutzer et al. (2012). In addition, five polymineral fine-grain samples were measured for comparison, applying the pIRIR protocol described by Thomsen et al. (2008). The protocol parameters (preheat 250 °C for 60 s, read temperature 50 °C (IR_{50}) and 225 °C ($pIRIR_{225}$) were taken from Buylaert et al. (2009) and confirmed with a dose-recovery test on two samples. Therefore the aliquots have been first artificially bleached in a solar simulator for 12 h. The resetting of the latent luminescence signal was proved by IR stimulation at 50 °C and 225 °C following a preheat of 250 °C for 60 s previous the β-irradiation. The first 2 s from the 100 s IR decay curve were used for signal integration and the last 10 s for background subtraction.

After passing the rejection criteria of 10 % for recycling ratio, maximum palaeodose error and the test dose error the D_e for each sample was obtained using the mean and standard error of the measured aliquots. The recuperation rate was almost $< 5\,\%$. It is assumed that the measured luminescence signal of the polymineral fine grain fraction in the blue band, using infrared light stimulation, is dominated by emissions from feldspar. Since it is well known that the luminescence signal deduced from feldspar suffers from an anomalous signal loss with time (Spooner 1994; Wintle 1973) a fading test and a fading correction was carried out using the procedure described by Huntley & Lamothe (2001) and Auclair et al. (2003). Due to machine time restrictions the g-value was measured for only one sample (BT711) using the IR_{50} and the $pIRIR_{225}$ signal on five aliquots. The g-values were normalized to the prompt measurement. The OSL and IRSL measurements were carried out on two Risø TL/OSL DA-15 readers fitted with EMI 9235QB15 UV sensitive photomultiplier tubes and $^{90}Sr/^{90}Y$ β-sources (2.7 Gy min^{-1} and 9.1 Gy min^{-1}). Stimulation was done using blue LEDs ($\lambda = 470\ \Delta\ 30$ nm) for the quartz fraction and infrared light LEDs ($\lambda = 875\ \Delta\ 80$ nm) for the polymineral fraction. A 7.5 mm Hoya U-340 filter and a 3 mm Chroma Technology D410/30x filter were used for detection in the UV and blue band respectively.

Dosimetry

Dose rate determination was carried out using thick source α-counting (U, Th) and ICP-MS (K) as well as low-level high-resolution γ-ray-spectrometry (U, Th, K content). The dose rates were calculated using the conversion factors from Adamiec & Aitken (1998) and the cosmic dose rate was calculated after Prescott & Hutton (1994). The mean a-values for six fine grain quartz samples were determined following the procedure suggested by Mauz et al. (2006) and Lai et al. (2008) after optical bleaching for 6 h (Osram Duluxstar 24W/827). On the polymineral fine grain fraction the a-values were measured for the IR_{50} and the $pIRIR_{225}$ signal after heating the prepared discs to 450 °C for ca. 45 min. For further details concerning the a-value measurement of the polymineral fine grain fraction using the $pIRIR_{225}$ protocol the reader is referred to Kreutzer et al. (2014b). A water content of $20 \pm 5\,\%$ was used.

4.4 Reconstruction of landscape evolution parameters

The reconstruction of palaeoenvironment and landscape evolution shown in Fig. 4.5 is mainly deduced from field observation and sedimentological analyses. The reconstruction based on comparison of layers (sediments or soil sediments) or horizons (soils) with adjacent stratigraphical items. Considering that every boundary may include an extensive hiatus, in Fig. 4.5 no continuous curve of palaeoproxy is drawn. Each stratigraphical item is attributed by its own palaeoproxy succession.

Using all detected similarities and differences, a quantitative estimation of changes of the climatic conditions during its genesis was determined. The derived climatic parameters, including temperature, precipitation, and wind speed are combined with a proxy of redeposition to provide an estimation of the stability or the fragility of Saxon loess landscape during the last glacial. In the following sections, all proxies containing valuable palaeoenvironmental information are explained.

4.4.1 Soils

Soils and soil sediments combine major information about palaeoenvironmental and palaeoclimatic conditions: (a) The particular type of soil development provides information of climatic conditions during pedogenesis at specific sites in the landscape. Most of the soils and soil sediments that found in similar stratigraphical positions in loess sections show an identical type of soil formation, but are localized in various geomorphological positions of the former landscape (e.g. section Seilitz is located at the lower backslope; section Ostrau is located at transition between an upper backslope and a plateau). This is an indication that climate plays an important role leading the palaeopedogenesis. (b) The second important type of information provided by soils is the degree of conservation or redeposition. A well-preserved in situ soil indicates stable landscape conditions. A subsequent onset of loess accumulation would bury the soil and preserve it.

In contrast, soil sediments imply a succession of further processes. First, there have been conditions for soil formation in a stable landscape. After that, a period of redeposition due to solifluction, cryoturbation or surface runoff processes activates slopes and modifies soils to truncate soils. In some sections, structures of downslope creeping (downslope hooklike bending) are preserved in the transition between in situ and deposited material. In such a case, it is possible to deduce the direction of mass movement.

Some deposited material is completely mixed and homogenized. To achieve such a homogenization, an intensive movement of wet and completely thawed material must have occurred. Soil sediments on slopes, for example in a palaeodell, are preserved as a stack of thin horizontal layers of different colours and materials. It indicates an increased movement of a former active layer at this geomorphological position.

A summary of soils and palaeosols found in the investigated loess sections, their appended pedofeatures and derived palaeoclimatic and palaeoenvironmental interpretation is given in Tab. 4.1. Based on types of overprinting which additionally modified soils, scenarios of landscape dynamics can be reconstructed. Several soil sediments, mainly tundra gley soils, show a sharp lower limit. Therefore, subsequent redeposition of soil horizons can also be recognized by investigating the characteristics of the lower and upper boundaries.

If a complete part of a loess section including several palaeosols was eroded and no residual is preserved, the only way to detect this gap is to compare several sections. Such periods of erosion are hard to identify. Sometimes, hiatuses may detectable by interpreting the grain size distribution. Rapid changes in the substrate qualities especially an increase of coarse and medium sand indicates gaps formed by erosion. Following the assumptions, a scenario of palaeoenvironmental development during the last glacial cycle in the SLR is developed below (Tab. 4.3).

4.4.2 Temperature

The reconstruction of palaeotemperatures is based on information derived from palaeosols, soil sediments or sedimentation features, found in loess palaeosol sequences. Climate plays a dominant role in palaeoenvironmental evolution. Following this assumption, interpretation of palaeoenvironmental remains al-

Table 4.1: Soils on loess and possible palaeoenvironmental interpretations

Soil type	**Typical features**	**Palaeoclimatic interpretation, site ecology**	**Landscape evolution dynamic**
Tundra gley soil or Nassboden (NB) or Gelic Gleysol	Greyish-bleached, calcareous, pedo-chemical parameters follow no vertical patterns, horizon/ layer boundaries are undulating	Wet conditions and very high soil moisture during summer months above frozen ground (summertime thawed active layer), continuous anaerobe periods (therefore strong bleaching); cold temperatures and low rates of evaporation	Period of erosion previous to tundra gley soil development; during unfrozen period often saturated soil → bleaching; increase of dust sedimentation → profile growing
Chernozem-like soil, Humuszone (HZ)	Enrichment of organic carbon, often decalcificated, pedo-chemical parameters follow no vertical patterns, in mixed pieces of charcoal	Very cold winters, dry and warm summers, steppe vegetation with intermittent groups of trees, wild fire ecology	drought causes increasing of aeolian dynamic, often wild fire, subsequently redeposited
Luvisol	Strong soil development with clay illuviation, decalcified, often hydromorphic imprinting, upper part of Bt-horizon is reworked, Pedo-chemical parameters follow horizons	Interglacial (moderate) climate, finally increased soil moisture	Stable surface
Cambisol	Reddish brown colour, pedo-chemical parameters follow vertical patterns; often crotovinas	Temperate and humid period	Active soil fauna, stable landscape surface; finally often reworked
Grey forest soil, Sols lessivè	Grey-bleached upper soil horizon with charcoal remains (Larix and Pinus) and big Fe- and Mn-concretions, decalcified	Widespread wildfire → drought, temperate climate, cold winter, almost enough precipitation for clay illuviation, bleaching the upper horizon, and tree growing	Fast change between wet and dry soil moisture; clay illuviation need stable surface but finally strongly reworked

lows a derivation of a rough palaeoclimatic reconstruction. Accounting for the fact that loess-palaeosol sequences are not continuous archives (because of erosion or interrupted dust input) a qualitative estimation of palaeotemperature regimes, by comparing with neighbored stratigraphic units, is suggested. In several cases, a succession of temperature is derivable from pedofeatures, which point to a later overprinting. For example, a last interglacial soil complex shows features of clay illuviation, related to a forested landscape under temperate conditions and a strong hydromorphism. In contrast to the formation of Luvisols, hydromophic features are related to root channels and a laminated fabric. The microstructure arises from ice lensing and other periglacial processes after Luvisol formation.

Brownish soils or soils with clay illuviation indicate temperate climatic conditions. Humic enriched soils suggest hot and dry summers followed by cold winters.

Most structures in loess are associated with palaeofreezing. They provide information of temperature during winter seasons. Ice wedge casts indicate very cold glacial periods with widespread development of continuous permafrost.

During very low temperatures, frost penetrates near-surface substrates and causes ruptures due to thermal contraction. At the time of strong thermal contractions the surface could not be covered by thick snow layers, because snow's insulating effect prevents deep freezing of the substrate. Plate or lenticular structures indicate fluctuations of the permafrost table and associated segregation ice. Further information on frost action in Late Pleistocene loess-palaeosol sequences is described by Vliet-Lanoë (1989).

4.4.3 Wind speed

Palaeowind speed is estimated by the amount of the finest sand fraction (63–125 µm) in the loess sections. The sketch of wind speed with regard to the composite profile (Fig. 4.3) is composed of two loess profiles. Wind speed estimations below the Gleinaer Complex (starting at ca. 10 m depth) are based on data measured at Rottewitz, and estimations of the upper part are based on data measured in Gleina. The general trend of finest sand in unit III to unit I, and the highest amount of finest sand in unit IIa, is found in four out of seven loess-palaeosol sequences. Layers composed dominantly of reworked material are inadequate for palaeowind speed estimations, because during redeposition a distorting of the substrate destroys former aeolian signals.

4.4.4 Redeposition

The index of redeposition combines results from grain size analysis with findings from fieldwork. If intercalated sand sheets could be exclude as a reason for increased coarse material ($> 630\,\mu m$) in loess-palaeosol sequences, coarse sand indicates solifluction and other downslope processes. In periods of dust sedimentation, only deposits finer than medium sand were accumulated. Therefore coarse sand is a useful proxy of redeposited loess-derived sediments (Meszner et al. 2014). However, significant changes in substrate characteristics in loess sediments are mostly attributed to periods of erosion and resulting unconformities. In addition, in the field, observed layer- and horizon boundaries give evidence for reposition of this layer. Several layer boundaries show hooklike downslope bending, suggesting postsedimentary translocation.

4.4.5 Landscape evolution dynamics index

The previously mentioned parameters are combined in a qualitative landscape evolution dynamics (LED) index. The index is considered as an attempt to reconstruct palaeoenvironmental landscape conditions and illustrate how several climatic and environmental conditions correlate with periods of activated or stabilized landscapes. Stable landscapes imply closed vegetation cover, soil development, reduced erosion, and low input of aeolian material. Active landscapes imply a reorganisation of the land surface, associated with strong erosion and sedimentation, aeolian sediment input, and patches of vegetation only.

Table 4.3: Nuclide concentration and dose rates.

Sample	α-counting		ICP-MS[1]	γ-ray-spectrometry[2]			Fraction	Mineral	Stimulation	a-value[3]	$DR_{cosm.}$	DR_{total}[4]
	U	Th	K	U	Th	K	[µm]				[Gy/ka]	[Gy/ka]
	[ppm]	[ppm]	[%]	[ppm]	[ppm]	[%]						
BT706	2.66 ± 0.27	11.36 ± 0.90	2.09 ± 0.10	NV	NV	NV	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.21 ± 0.01	3.62 ± 0.23
BT707	3.68 ± 0.24	7.12 ± 0.79	2.11 ± 0.11	NV	NV	NV	90-200	Quartz	blue OSL@125 °C	NV	0.19 ± 0.01	3.05 ± 0.17
							4–11	Quartz	blue OSL@125 °C	0.044 ± 0.001		3.58 ± 0.19
							4–11	Polymineral	IRSL@50 °C	0.079 ± 0.001		3.92 ± 0.21
							4–11	Polymineral	post-IRSL@225 °C	0.118 ± 0.002		4.29 ± 0.24
BT708	3.30 ± 0.26	9.05 ± 0.86	2.12 ± 0.11	3.2 ± 0.11	10.65 ± 0.12	2.05 ± 0.04	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.19 ± 0.01	3.65 ± 0.22
BT709	3.10 ± 0.28	8.56 ± 0.93	2.00 ± 0.10	NV	NV	NV	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.18 ± 0.01	3.41 ± 0.22
BT710	3.27 ± 0.29	8.40 ± 0.91	1.96 ± 0.10	3 ± 0.12	10.31 ± 0.13	1.95 ± 0.04	4–11	Quartz	blue OSL@125 °C	0.046 ± 0.001	0.16 ± 0.01	3.51 ± 0.17
BT711	3.37 ± 0.18	8.79 ± 0.59	1.84 ± 0.09	3.25 ± 0.15	10.73 ± 0.15	1.84 ± 0.04	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.15 ± 0.01	3.46 ± 0.21
							4–11	Polymineral	IRSL@50 °C	0.073 ± 0.001		3.80 ± 0.19
							4–11	Polymineral	post-IRSL@225 °C	0.107 ± 0.002		4.17 ± 0.21
BT712	2.70 ± 0.28	12.08 ± 0.93	1.80 ± 0.09	3.04 ± 0.16	10.4 ± 0.15	1.75 ± 0.04	4–11	Quartz	blue OSL@125 °C	0.040 ± 0.003	0.14 ± 0.01	3.32 ± 0.18
BT594	3.73 ± 0.29	10.66 ± 0.95	1.87 ± 0.09	NV	NV	NV	90-200	Quartz	blue OSL@125 °C	NV	0.13 ± 0.01	2.92 ± 0.16
							4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012		3.58 ± 0.24
BT713	3.58 ± 0.29	9.28 ± 0.93	1.82 ± 0.09	NV	NV	NV	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.13 ± 0.01	3.40 ± 0.22
							4–11	Polymineral	IRSL@50 °C	0.072 ± 0.001		3.72 ± 0.21
							4–11	Polymineral	post-IRSL@225 °C	0.108 ± 0.002		4.10 ± 0.23
BT714	3.80 ± 0.30	8.23 ± 0.98	1.97 ± 0.10	NV	NV	NV	4–11	Quartz	blue OSL@125 °C	0.041 ± 0.012	0.13 ± 0.01	3.50 ± 0.23
							4–11	Polymineral	IRSL@50 °C	0.075 ± 0.001		3.85 ± 0.22
							4–11	Polymineral	post-IRSL@225 °C	0.112 ± 0.001		4.23 ± 0.24
BT715	3.93 ± 0.31	8.95 ± 1.02	1.91 ± 0.10	3.26 ± 0.11	12.1 ± 0.13	1.86 ± 0.04	4–11	Quartz	blue OSL@125 °C	0.030 ± 0.001	0.11 ± 0.01	3.43 ± 0.17
							4–11	Polymineral	IRSL@50 °C	0.072 ± 0.002		3.91 ± 0.20
							4–11	Polymineral	post-IRSL@225 °C	0.104 ± 0.002		4.26 ± 0.22

Notes:

[1] *An error of 5 % was used.*

[2] *If nuclide concentrations were measured with γ-ray-spectrometry these values were taken for dose rate calculation.*

[3] *The a-value for the polymineral fraction was measured for all of the samples. For the quartz fraction, four samples were measured and for the remaining (unmeasured) samples the mean and the 2-σ uncertainties from these measurements were taken as a-value.*

[4] *A water content of 20 ± 5 % was used to calculate the total dose rate*

4.5 Results

4.5.1 Luminescence dating

Dosimetry

The obtained dose rates of ca. 3.5 Gy ka^{-1} for fine grain quartz and ca. 3.8 Gy ka^{-1} to 4.2 Gy ka^{-1} (Tab. 4.3) for the polymineral fraction are typical for loess (Kreutzer et al. 2012; Thiel et al. 2011). No radioactive disequilibrium was detected in the Uranium decay chain. The obtained a-values range from 0.03 ± 0.001 to 0.046 ± 0.001 for the quartz fraction, 0.072 ± 0.002 to 0.079 ± 0.001 for the polymineral IR_{50} signal and 0.104 ± 0.002 to 0.118 ± 0.002 for the $pIRIR_{225}$ signal respectively. The quartz a-values are in general in accordance with the previous findings in Saxony (Kreutzer et al. 2012). For detailed results and discussion of the IR_{50} and $pIRIR_{225}$ a-values the reader is referred to Kreutzer et al. (2014b).

Luminescence characteristics

To reveal the overall significance of the identified pedo- and lithostratigraphic units a numerical chronology was established by luminescence dating on two mineral fractions (polymineral and quartz). Routine dose recovery tests for different preheat temperatures carried out for two coarse and two fine grain quartz samples showed a reproducibility within 10 % of the given dose for temperatures from 200 °C to 260 °C (supplementary material Fig. 1S). The preheat plateau test of one coarse grain and one fine grain sample showed a plateau at least between 200 °C and 220 °C (supplementary material Fig. 2S). In addition, for the polymineral fine grain fraction the protocol parameters taken from the literature have been proved on two polymineral fine grain samples using five aliquots for each sample. The given dose was reproducible within 10 % for the IR_{50} and $pIRIR_{225}$ signal with low scatter between the aliquots (supplementary material Fig. 3S). Our results indicate that the D_e can be adequately determined with the chosen protocol parameters. A typical shine-down curve, growth curve and D_e distribution for the sample BT711 is shown in Fig. 4.2 for the quartz and the polymineral fraction.

The different mineral fractions consist of a sufficient bright luminescence

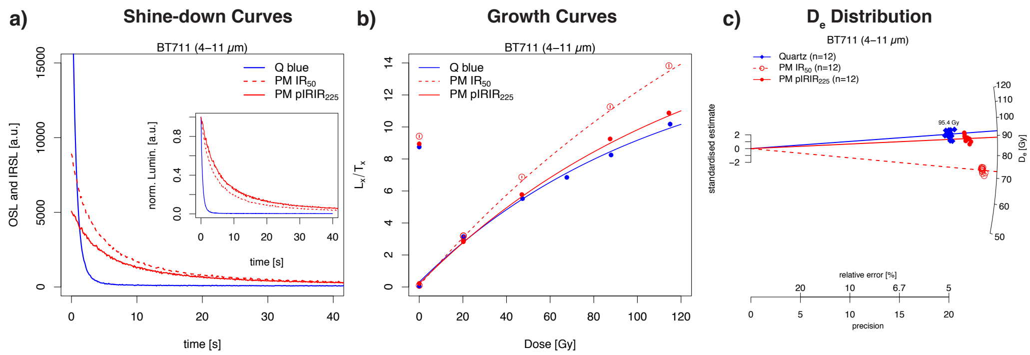

Figure 4.2: Luminescence characteristics: Shine-down curve, growth curve and D_e distribution of BT711 quartz and polymineral fine grain. The inset of the left plot shows the normalized shine-down curves

signal. The quartz signal decreases much faster than the IR_{50} and $pIRIR_{225}$ signal with a lower signal of the $pIRIR_{225}$ emission. The latter one is consistent with the findings from Tsukamoto et al. (2012) and indicates that the signal from the polymineral fraction is dominated by sodium feldspar. For the dose response curves (Fig. 4.2b) of the $pIRIR_{225}$ and quartz curve we observe similar behaviour. In contrast, the IR_{50} curve consists of a more linear shape. The D_e distribution is comparable for all measured signals with a high precision ($c_v \sim 5\%$) but lower D_e values for the IR_{50} than for the $pIRIR_{225}$ signal. The obtained g-values in %/decade (BT711: IR_{50}: 3.1 ± 0.4, $pIRIR_{225}$: 2.2 ± 0.7, supplementary material Fig. 4S) are in accordance with previous findings for the polymineral fine grain fraction from loess (Thiel et al. 2011). These g-values were assumed for all other polymineral fine grain samples.

Luminescene ages

Age results were obtained on quartz coarse and fine grain and polymineral fine grain separates. The results are listed in Tab. 4.4. In general the findings from the profile Seilitz confirm the results obtained in a similar stratigraphic position from the profile Ostrau (Kreutzer et al. 2012). All samples were dated using the fine grain quartz fraction. The ages slightly increase with depth from 18.3 ± 2.2 ka at the top (BT706) to 72.8 ± 7.6 ka at the base of the profile (BT715). As previously observed in Ostrau (Kreutzer et al.

Table 4.4: D_e values and luminescence ages estimates.

No	Depth [m]	M.[1]	Grain S.[1] [µm]	n	Fit[2]	Stimulation	D_e [Gy]	Age[3,4] [ka]
BT706	0.4	Q	4–11	24/24	EXP+LIN	blue OSL@125 °C	66.07 ± 1.75	18.3 ± 2.5
BT707	0.4	Q	90–200	14/24	EXP	blue OSL@125 °C	56.02 ± 3.16	18.6 ± 2.9
		Q	4–11	11/12	EXP+LIN	blue OSL@125 °C	64.20 ± 0.74	17.9 ± 2.0
		PM	4–11	12/12	EXP	IRSL@50 °C	59.78 ± 0.23	21.0 ± 2.6 (15.3 ± 1.6)
		PM	4–11	12/12	EXP	post-IRSL@225 °C	74.13 ± 0.45	21.4 ± 2.3 (17.3 ± 1.1)
BT708	1.7	Q	4–11	22/24	EXP+LIN	blue OSL@125 °C	77.59 ± 1.34	21.3 ± 2.6
BT709	2.1	Q	4–11	9/12	EXP+LIN	blue OSL@125 °C	74.11 ± 1.16	21.7 ± 2.8
BT710	3.8	Q	4–11	9/12	EXP	blue OSL@125 °C	71.67 ± 1.21	20.4 ± 2.1
BT711	4.7	Q	4–11	12/12	EXP+LIN	blue OSL@125 °C	92.55 ± 0.78	26.7 ± 3.3
		PM	4–11	12/12	EXP	IRSL@50 °C	72.72 ± 0.33	26.2 ± 3.0 (19.1 ± 2.0)
		PM	4–11	12/12	EXP	post-IRSL@225 °C	88.20 ± 0.62	26.5 ± 3.4 (21.2 ± 2.1)
BT712	5.9	Q	4–11	12/12	EXP+LIN	blue OSL@125 °C	83.27 ± 1.12	25.1 ± 2.6
BT594	6	Q	90-200	17/24	EXP	blue OSL@125 °C	64.81 ± 3.83	22.2 ± 3.5
		Q	4–11	12/12	EXP	blue OSL@125 °C	79.69 ± 1.10	22.3 ± 3.0
BT713	6.95	Q	4–11	12/12	EXP+LIN	blue OSL@125 °C	105.18 ± 1.83	31.1 ± 4.1
		PM	4–11	12/12	EXP	IRSL@50 °C	75.22 ± 0.36	27.7 ± 3.4 (20.2 ± 2.2)
		PM	4–11	12/12	EXP	post-IRSL@225 °C	93.14 ± 0.77	28.4 ± 3.7 (22.7 ± 2.6)
BT714	7.6	Q	4–11	12/12	EXP+LIN	blue OSL@125 °C	101.45 ± 1.09	29.1 ± 3.6
		PM	4–11	12/12	EXP	IRSL@50 °C	78.68 ± 0.51	28.0 ± 3.4 (20.4 ± 2.3)
		PM	4–11	12/12	EXP	post-IRSL@225 °C	94.82 ± 0.67	28.0 ± 4.2 (22.4 ± 2.6)
BT715	9.7	Q	4–11	12/12	EXP+LIN	blue OSL@125 °C	250.22 ± 4.79	73.0 ± 7.6
		PM	4–11	12/12	EXP	IRSL@50 °C	195.09 ± 0.90	69.5 ± 8.1 (50.0 ± 5.1)
		PM	4–11	12/12	EXP	post-IRSL@225 °C	245.07 ± 1.06	72.3 ± 9.6 (57.5 ± 5.8)

Note:

[1] *M. = Mineral: Q = Quartz, PM = Polymineral; Grain S. = Grain Size*

[2] *Used function for growth curve fitting. EXP: exponential, EXP+LIN exponential plus linear.*

[3] *Ages given with 2σ uncertainties.*

[4] *Ages from the polymineral fraction with fading correction. For the fading correction a g-value of 3.1 ± 0.4%/decade (IR_{50}) and 2.2 ± 0.7 %/decade ($pIRIR_{225}$) was assumed. Uncorrected age estimates are given in brackets. For further details see main text.*

2012) the profile is divided into two parts and divided by a hiatus with ages < 30 ka (BT714) above and > 70 ka (BT715) below the hiatus. For the quartz fraction from sample BT707 and sample BT594 the coarse as well as the fine grain fraction were measured. We found that both quartz grain size fractions yield similar ages within errors with a low variance between the mean ages. This is in accordance to our findings from the profile Ostrau where the coarse and fine grain quartz ages match within errors. In contrast, in Ostrau the different quartz grain sizes showed a markedly variance within the mean ages, which was not observed here. We therefore assume that the bleaching and the luminescence behaviour of the different grain sizes fractions in Seilitz are quite similar for the investigated samples.

To our surprise, sample BT594 yields slightly younger ages for both grain size fractions than the above situated sample BT712. Our findings may indicate that (a) sample BT711 and BT712 were incomplete bleached during transport, (b) contaminated by older grains during secondary translocation or (c) dosimetric inhomogeneities especially below a partially water saturated layer (BT711). However, the reasons for these slightly (mean) age inversions are unknown but they are still in accordance within errors.

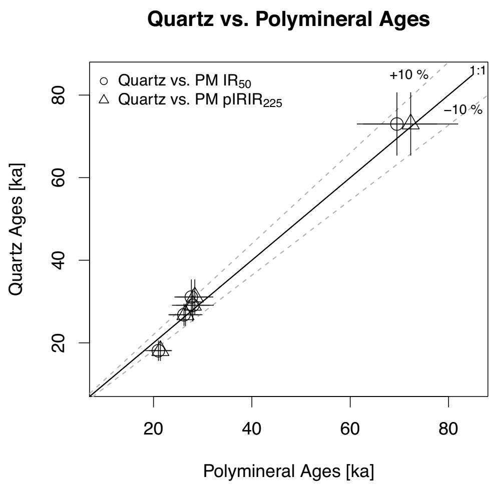

Figure 4.3: Quartz vs. polymineral post-IR IRSL ages estimates

The polymineral fraction was chosen to obtain luminescence ages on a different mineral fraction. For five samples, ages were determined for the IR_{50} and the $pIRIR_{225}$ signal. Without fading correction the polymineral fine grain ages are significantly younger than the quartz ages indicating that the polymineral fraction might suffer from anomalous fading. For all samples we observed that the uncorrected and corrected IR_{50} ages are slightly younger than the $pIRIR_{225}$ ages. This in accordance with published data, where the $pIRIR_{225}$ signal is believed to be less affected by fading (THOMSEN et al. 2008). Although a fading measurement has been carried out on only one sample (BT711) the obtained g-values for the IR_{50} and $pIRIR_{225}$ are assumed to be applicable for all other polymineral samples. After the fading correction the polymineral fine grain ages are in accordance with the (fine grain) quartz ages (Fig. 4.3), except sample BT707 that overestimates the quartz age. The latter is believed as artefact from the deduced g-values for only one sample. Because of consistent age estimates from all of the different grain size and mineral fractions, we conclude that the deduced sedimentation ages are correct. For further details and discussions on the age results and the stratigraphic implications see Sec. 4.5.2 and 4.6.

4.5.2 Stratigraphy

The complete newly revised standard profile (Fig. 4.4) combines all observed stratigraphical items from seven investigated loess profiles in Saxony. The fine grain quartz age estimates of the profile Seilitz and the profile Ostrau are in accordance within errors with the stratigraphy and listed along the sketch of standard profile.

The combined Saxon LPS is divided into five distinct pedo-stratigraphical units. This subdivision is not only performed on the basis of varying sedimentation characteristics (such as for example unit IIa, IIb or IV), but also accounting for differing postsedimentary pedogenic superimpositions. For example, unit I is not considered as a separate sedimentation unit, but marks the part of the loess sequence where late Weichselian and Holocene soil formation processes have altered the loess sediments. As the sequence of unit I, based on its strong pedogenetic superimpositions, is significantly distinguishable from unit IIa, a designation as a separate unit and not as a sub-unit of unit II is reasonable.

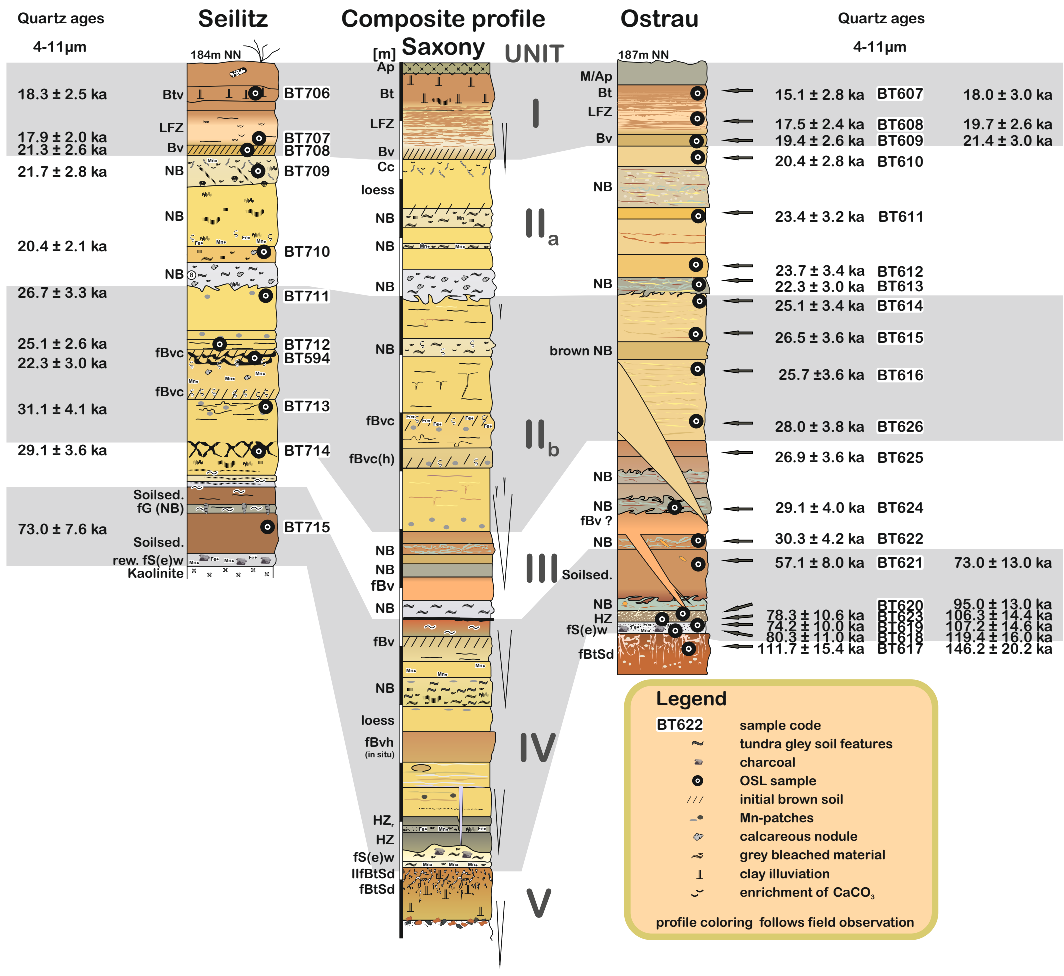

Figure 4.4: Profile Seilitz, Ostrau and a composite profile for the SLR with fine grain quartz OSL age estimates. The maximum fine grain quartz ages for Ostrau are given in brackets. For further details on the given ages for Ostrau the reader is referred to Kreutzer et al. (2012).

Horizons and layers are labeled using German soil nomenclature except for loess-specific terms: HZ- Humus Zone; LFZ- lenticular horizon or banded Bt; (French: "doublets horizon"; German: "Lamellenfleckenzone"); NB- tundra gley soil (Nassboden)

In contrast to the former version of the standard profile (Meszner et al. 2011), the presented unit-boundaries have shifted:

In this contribution, the lowermost sediments in the composite profile are an independent unit (unit V) and do not belong to unit IV. Unit V represents pre-Weichselian sediments (often Saalian loess- derived sediments), overprinted by last interglacial and early Weichselian soil formation. If the 1–1.5 m thick sequence of unit V is preserved undisturbed (as in Ostrau and Gleina), a buried stone line could frequently be preserved at the basis of the Eemian soil formation.

The uppermost part of the Eemian fBt-horizon shows a high amount of Fe- and Mn-concretions. The oxide precipitates have a diameter up to 2 mm and show a clearly higher degree of roundness than precipitates from underlying horizons. The oxide concretions formed during hydromorphic processes in the end of Eemian interglacial and were rounded during Early Weichselian deposition. Despite the angular structure and dark-brown humic clay coatings on aggregates, this reworked material is only marginally distinguishable from the in situ fBt-horizon with prism structure in the lower parts. As a result of these findings, the border between unit V (pre-Weichselian sediments) and unit IV (Weichselian sediments) is located inside the last interglacial fBt-horizon.

Above this soil sediment a strongly grey-bleached soil sediment with intermixed pieces of charcoal (Meszner et al. 2011) and large Fe- and Mn-concretions (fS(e)w-horizon) is developed. In the profile Seilitz this charcoal intermingled soil sediment directly lies above the kaolinite (basement rock), and all other interglacial soil horizons, usually located beneath, are missing. These soil sediments that presumably originated from deposition of upper grey forest soil horizons have been dated at ca. 74–80 ka (profile Ostrau). The upper part of this layer is enriched by humic material (HZ). For the humic enriched horizon ("Humuszone") an OSL age of 78 ± 11 ka was obtained (BT623, Ostrau). A sharply delimited grey-bleached tundra gley soil (also referred to as "Nassboden" or Gelic Gleysol) lies between the Humus Zone and a reddish-brown soil sediment above. The reddish-brown soil sediment have a sedimentation age of about 73 ± 13 ka (BT621, Ostrau, maximum age). This soil sediment found in the profiles Ostrau and Seilitz and has a clay content between 20 % and 40 %. This sediment is substantially composed of reworked

Eemian or Early Weichselian soil material with an age ranging at least from 57 ± 8 ka (BT621, Ostrau) to 73 ± 8 ka (BT715, Seilitz). In most profiles the upper part of unit IV is characterized by several solifluction layers with intercalated grey-bleached tundra gley soils, always capped by a rusty reddish-brown redeposited layer (uppermost layer of unit IV).

In the profile Rottewitz, the upper sequence of unit IV is preserved with a higher resolution. Rottewitz contains the following pedostratigraphic sequence: Truncated Luvisol of Eemian age with hydromorphic imprints (fBtSd), grey-bleached soil sediment including remnants of charcoal (fS(e)w), humic enriched horizon (HZ), clear bounded grey tundra gley soil (NB), and dark brown soil sediment (HZr = reworked humic enriched horizon). Exclusively preserved are the layers and soils above: Following a sequence of laminated loess, a strongly developed, maroon-brown soil (fBvh) is preserved (in situ) and is covered by another loess sequence. This upper loess sequence is separated by a grey tundra gley soil, which looks very similar to tundra gley soils imbedded in late Weichselian loess sequences.

The uppermost part of unit IV from section Rottewitz is represented by a weakly developed truncated soil, directly covered by rusty- reddish-brown soil sediments. It is assumed that this soil sediment in section Rottewitz originated from re-deposition of a subjacent weak soil. The sequence has never been previously investigated in Saxony. Thus, the basal part of Rottewitz was integrated into the standard profile without further modification. In summary, a detailed and complete pedostratigraphy of the post-Humus Zone-period on a southwestern exposed slope of the Elbe valley in Saxony is preserved.

On the bottom of the following unit III, a strong tundra gley soil yielding an OSL age of 30.3 ± 4.2 ka (BT622, Ostrau) is developed. This tundra gley soil is situated directly above the rusty-reddish-brown soil sediment from the top of unit IV and has been referred to as 'Gleinaer soil complex' according to Lieberoth 1963. Above the tundra gley soil from the bottom of unit III, a homogeneous yellow red-brown zone is observed and represents a residue of a weak brown soil development. An OSL age in the layer above of 29.1 ± 4.0 ka (BT624, Ostrau) was obtained. This was followed by a sequence of several tundra gley soils (at least two) imbedded in brown-greyish loess derivatives (which might have originated from weak interstadial brown soils). In addition, frequently, this unit shows evidence of relocation or disturbance due to ice wedge pressure. In summary, unit III represents a sequence of altered loess derivates, showing features of Gelic Gleysols and brownish soils and spanning a time between 30–35 ka to 28 ka.

In unit II, only marginally altered loess followed, showing sedimentation ages between 28.0 ± 3.8 ka (BT626, Ostrau) and 29.1 ± 3.6 ka (BT714, Seilitz) on its basis. This transition between reworked and altered loess derivatives (unit III) and foliated, nearly barren loess (unit IIb), can be found in all investigated loess sequences. The loess package of unit IIb is characterized by a laminated loess facies with an intercalated brown tundra gley soil (mostly split in two parts) that shows ages older than 26.5 ± 3.6 ka (BT615) and 25.1 ± 2.6 ka (BT712). The boundary between unit IIb and IIa is marked by a strongly developed tundra gley soil. In the section Ostrau, this tundra gley soil redraws the surface of a palaeodell. Therefore, we assume a strong period of erosion prior to tundra gley soil formation. The following loess of unit IIa is homogeneous, and foliated or laminated loess facies are observed rarely. Above this (basic)-tundra gley soil of unit IIa, OSL ages of 20–23 ka have been determined. This confirms the assumption that homogeneous loess sediments deposited during the LGM. Additional weaker-developed tundra grey soils are imbedded in this loess package. The top of unit II is marked by the boundary of the late glacial and Holocene decalcification. For all stratigraphic units, unit IIa and IIb reach the greatest thickness, often more than 4 m.

Unit I is completely decalcified, showing a weak brown horizon (Bv) at the base. Above the so-called Lamellenfleckenzone (Lieberoth 1959) is situated, gradually mixed with a Bt-horizon. The Holocene soil is frequently truncated at the Bt-horizon due to an intensive agricultural usage and has been overlain by a colluvium. The OSL ages obtained in the Holocene Bt-horizon were ca. 15 ka (BT607) and 18 ka (BT706).

However, the obtained OSL ages continuously decrease from the stratigraphic lowest towards the uppermost layers and, respecting the given margins of errors, no age inversion is observed. The determined chronostratigraphies for the two loess profiles (Seilitz and Ostrau) are consistent and offer a reliable age model for the Saxon loess sequences. Particularly striking is an age hiatus between unit IV and unit III. The loess or loess-derived sediments in the period between ca. 60 ka to 30 ka are poorly preserved only.

4.6 Discussions

4.6.1 Unit V & IV (>120 ka to ca. 60 ka)

Both units represent the base of Saxon loess sequences ranging from the Eemian interglacial to the early Weichselian at about 60 ka. Typical for this sequence is that every layer shows evidence of distinct palaeoenvironment conditions, which differ substantially from layer to layer.

During the Eemian interglacial, a Luvisol was developed in the Saalian loess derivatives. This Luvisol was superimposed by hydromorphism (strong grey-bleached root channels and Mn- and Fe-precipitates), indicated by clay infiltration during the Luvisol formation and a resulting increase of substrate density in the Bt-horizon. This dense subsoil horizon tends to saturated conditions due to a slowdown of soil water circulation. These findings also imply cooler and more humid climate conditions at the end of the Eemian interglacial.

In a first phase of erosion at the beginning of the Weichselian glacial period, the upper Luvisol soil horizons were eroded and accumulated as soil sediment. During this redeposition, Fe- and Mn- concretions, created during previous hydromorphism, were rounded. This sediment and the underlying fBtSd-horizon were subjected to a new pedogenesis (albic Luvisol) and dark fine material was infiltrated into subsoil horizons and covered surfaces of voids and peds. When the following erosion phase occurred, the upper parts of the soil were displaced again and Larix- and Pinus- charcoal remnants, created during widespread forest fires, were mixed into this soil sediment (fS(e)w). A humus-enriched zone (HZ), located above the charcoal-enriched layer, is separated by a small tundra gley soil from another reworked humus-enriched zone (HZr) above. As described from nearby loess regions, massive humus-enriched zones follow the Eemian interglacial soil (e.g. Ruske & Wünsche 1968, Saxony-Anhalt). Such well-preserved thick humus-enriched soils have not been discovered in Saxony.

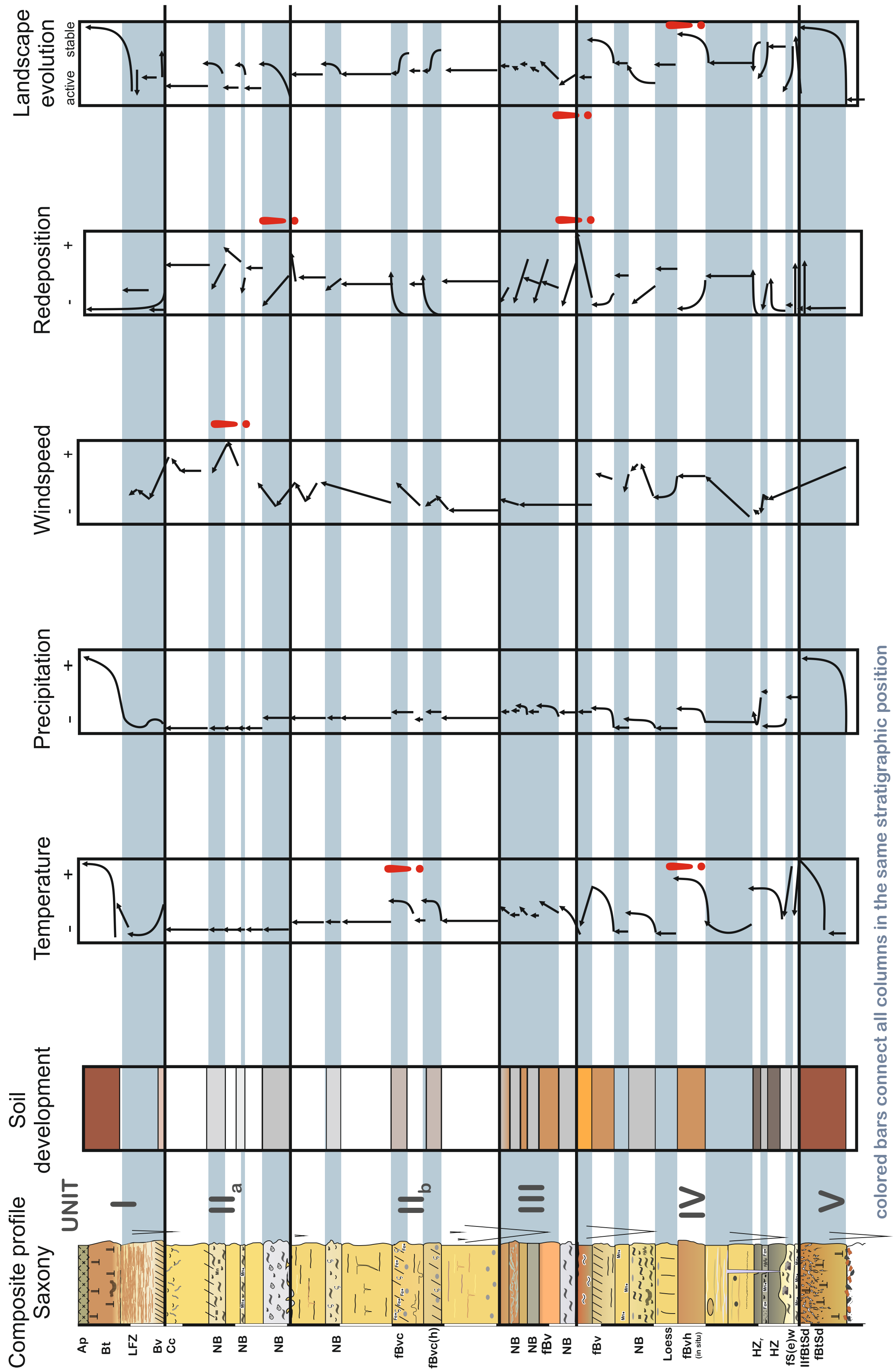

Figure 4.5: Estimation of landscape evolution dynamics. An attempt to a palaeo-environmental reconstruction based on a composite profile and environmental proxies.

We propose that the humus-enriched zones found in Saxony are residuals from Chernozem-like soils. Probably they are equivalents of three humus-enriched zones described by Demek & Kukla (1969) or Semmel (1968). Following Semmel (1998), these humus-enriched zones represent a typical interstadial pedogenesis. Pinus and non-tree pollen maxima at the beginning and at the end surround a warm climate period, where the amount of Abies and Picea pollen exceeds non-tree pollen.

These significantly differing signals from the beginning of the glacial period are summarized in Fig. 4.5. The climatic parameters describe a step-by-step process of climatic development starting with stable interglacial conditions and change to a finally very dry steppe climate, represented by humus-enriched zones (Antoine et al. 2001). The early Weichselian climate was characterized by stable conditions, which were recurrently interrupted by periods of redeposition and erosion and increasing continentality. The early Weichselian segment covers a period of at least 45 ka (unit V and unit IV until the humus-enriched zones) but rarely reaches thicknesses of more than 3 m in the Saxon loess profiles. Therefore, it is assumed that in the whole SLR, loess older than 75 ka was accumulated only rarely, or was immediately eroded or intermixed into soil sediments. A low dust concentration was found in ice cores from Antarctica (interpreted as a global dust signal), where dust has not been verified until 70 ka (Petit et al. 1990).

Similar pedostratigraphic characterizations are known from the French loess region described by Antoine et al. (2003a, 1999) and Antoine et al. (2003b). In the Somme valley, three soils were found at the Weichselian base, indicating vertical relocation of clay and fine silt. The Eemian Bt- horizon (Rocourt soil) at the Somme basin is superimposed by two soils. In the first soil above the Eemian Bt-horizon, the so-called Bettencourt soil, and in the second soil sediment, the so-called Saint-Sauflieu 1 soil is developed. The color (dark-greyish) of these soils is paler with increasing age. In addition, the vertically relocated fine material has a higher amount of organic material than found in the Eem-Bt-horizon. Therefore, the associated horizon is a Bth-horizon. Above the illuvial horizons, a hydromorhic horizon (glossic) is developed. Antoine et al. (2003a) point out that this soil, classified as a grey forest soil, indicates a climate shift towards continental conditions. Similar multi-phase developments, where the last interglacial and early-Weichselian soil complex has been preserved, have been described for German loess outcrops. Schirmer (2010) and Schirmer (2000) reported four different Bt- and Bth-horizons with associated Ah-horizons (Humuszone) at Garzweiler (Rocourt soil; Pesch soil; Holz soil and Titz soil), with intensity decreasing upward and clay shift to clay-humus coatings. Schirmer (2000) deduced that the amplitude of the warm period during the Recourt soil development was the longest and the range of climatic fluctuation decreased upwards in the sediments. Haesaerts et al. (1999) described the same phenomena for the profiles of Remicourt and Rocourt in Belgium: multi-phased expression of Eemian and early-Weichselian soil development. Considering these findings from western and central Europe, there is evidence for a complex story of different soil developments, starting with the Eemian interglacial up to the early Weichselian, with several interruptions due to periods of erosion and redeposition. In Saxony, only in the profile Rottewitz thicker loess sedimentation (3 m loess) between 60 ka and 70 ka is preserved.

In all other investigated Saxon loess profiles, a more detailed description of layers above the humus-enriched zones is hardly possible, because only a homogenized reddish-brown solifluction layer is preserved. This redeposited layer has been dated to 57.1 ± 8.0 ka (BT621, Ostrau) and 73.0 ± 7.6 ka (BT715, Seilitz) and represents the uppermost layer of unit IV. This demonstrates that in many cases in Saxony the Eemian and early Weichselian sediments have been either completely eroded, or only sediments containing their soil material (such as in Seilitz), still exist. The difficulties in dating these sediments (Kreutzer et al. 2012) may originate in their composition. As a soil sediment, this layer is a mixture of many materials with different ages and varying stages of alteration, and therefore incomplete bleaching of gains is likely.

However, there is much evidence for a substantial phase of extensive erosion and landscape reorganisation between 30 ka and 60 ka. This long hiatus is also described in other loess profiles in Europe. According to OSL age estimates from Stayky (Middle Ukraine), only the lower 2.5 m of the whole section are older than 30 ka (Rousseau et al. 2011). In the loess profile Koblenz-Metternich (Boenigk & Frechen 1999) TL-dating in similar stratigraphic positions shows a jump from 32 ka to 55 ka. Moska et al. (2012) reported from the site Biały Kościół in southwest Poland an increase of OSL ages deeper than unit "Gi/LMd" (sample BK5). In contrast, samples above this complex (Gi/LMd = Komorniki, Dubno or Bryansk soil complex) show marginally differences of OSL age estimates with narrow probability density functions. We suggest a stratigraphic analogy between the Gi/LMd-complex and the boundary of unit VI and III.

The age estimates of unit IV and V decrease in accordance with the stratigraphy, and constitute a solid validation for the pedostratigraphical framework. Due to the problems of dating early Weichselian deposits (Kreutzer et al. 2012), only a rough classification of the oldest part of the profile can be given.

On the basis of the findings, the period of Early Weichselian represents all post-Eemian sediments up to the humus-enriched zones and their relocated equivalents. The boundary of MIS 5/MIS 4 (Wright 2000) is proposed to be between the humus-enriched zones and the overlying loess sediments of unit IV.

4.6.2 Unit III (ca. 30 ka)

In the lower part of unit III, a very strong tundra gley soil is found. Lieberoth (1963) described this soil as the upper part of the Gleinaer soil complex. The lower boundary of this soil marks an important discordance between unit IV and III and is recognized in all investigated loess profiles in Saxony. In Ostrau, the substrate of tundra gley soil has an age of 30.3 ± 4.2 ka (BT622) and in the underlying layer, belonging to unit IV, an age of 57.1 ± 8.0 ka (BT621) was measured. The succession of this reddish soil (sediment) in unit IV and the grey tundra gley soil at the base of unit III is discovered in all Saxon loess profiles.

Lieberoth (1963) and G. Haase et al. (1970) interpret this sequence as a middle Weichselian soil complex (Gleina soil Complex). Based on our dating results, the interpretation according to G. Haase et al. (1970) that this complex is dominantly formed due to pedogenesis, cannot be supported. This complex marks an important gap in the loess sedimentation between 30 ka and 60 ka in Central Europe. Therefore, this sequence is designated as the "Gleina Complex" (without "soil"), combining the established stratigraphical nomenclature with new findings.

However, in Saxony unit III covers a range of only ca. 2 ka. In between, short periods of weak soil formation and periods of reworking occurred and at least two tundra gley soils were preserved. The findings demonstrate a strong overprinting of this sequence by pedogenesis and weathering which is in contrast to the nearly barren loess sediments of unit IIa and IIb. Comparing these results with Antoine et al. (2003a), unit III can be correlated with the lower sequence of the Upper Pleniglacial, which has also been dated to ca. 30 ka. Nevertheless, the sedimentation and/or the preservation of loess is significantly higher in unit III than in unit IV.

The sedimentological gap between unit IV and III is interpreted as one of the strongest periods of reworking and erosion (Fig. 4.5). The overlying loess-derived sediments are interpreted as soil sediments or sediments, which are touched by alteration and implicit warmer and wetter conditions changing with periods of loess sedimentation.

4.6.3 Unit IIb & IIa (<30 ka to >20 ka)

Loess of unit II often represents more than half of all Weichselian deposits in the Saxon loess profiles and therefore dominates the profiles. Consistently, with the dating results, unit II contains sediments < 30 ka to > 22, representing a period of high loess sedimentation and conservation rates. Frechen et al. (2003) showed that the major parts of European loess sequences are younger than 28 ka and that the preservation of older loess is rare. This unit can be subdivided into IIa and IIb. Unit IIb consists of foliated loess sediments, and unit IIa is dominated by homogeneous loess. Antoine et al. (2009b) also described such a foliated loess facies in France and Western Germany. Dijkmans (1990) observed these structures in Greenland's sand-sheet areas and was able to give evidence for their niveo-aeolian genesis. Following the assumption that foliated loess was created through niveo-aeolian sedimentation, dust sedimentation in unit IIb probably happened primarily during winter. With the thawing of the intercalated snow layers, typical structures of foliated loess appeared. However, the homogeneous loess in unit IIa is expected to have accumulated mainly during snow-free seasons without any processes of micro- segmentation during snow melting. As the ages roughly indicate the age bracket of unit-IIa-loess is the LGM. This homogeneous loess may be a hint that the period of the LGM was very cold and dry. In comparison with unit IIb, significantly less snow was covering the surface during loess accumulation. Alternatively, loess deposition occurred mostly during snowless seasons.

Frequently, barren loess is interrupted by grey tundra gley soils associated with characteristic patches and bands of iron oxides. These tundra gley soils from the Pleniglacial resulted from periods with reduced dust sedimentation. Combined with a predominant stable temperature, the profile stopped growing and the thawed surface (active layer above permafrost) developed repeatedly in the same material during aestival thawing periods. Caused by continuously low temperatures and accompanied by sparse vegetation cover, aestival evaporation stayed at a low level and the active layer was constantly water-saturated in the thawed season. Such conditions intensified the process of soil bleaching during the Pleniglacial summers.

With the onset of aeolian dynamics, sedimentation rates increased strongly. Hence, the active permafrost layer was not developing for a longer period in the same material and therefore the process of bleaching was not able to influence the sediment dominantly. The alternation between onset (formation of loess) and offset (formation of tundra gley soil) of dust sedimentation in unit II is expressed in the column of redeposition (Fig. 4.5) while temperature and precipitation remain constant.

The strong tundra gley soil at the lower boundary of unit IIa shows a very undulating lower limit in profile Ostrau, tracing a surface of a palaeodell. Apparently, strong erosion events occurred previously to the formation of tundra gley soil. Antoine et al. (2001) link such strong erosion phases with thermokarst, where permafrost thawed due to a rise in temperature. Along zones of weaknesses (e.g. polygon edges of older ice wedge networks), gully erosion takes place. This process possibly explains the great extent of erosion that happened between unit IIa and IIb. No other evidence for thermokarst (with humic material filled channel) was found in all investigated profiles.

In unit IIb, a two-part brown tundra gley soil is developed. In comparison to other grey tundra gley soils, here it is likely that low dust accumulation and higher temperatures forced dominantly aerobic soil formation. In the profiles Ostrau and Seilitz unit IIb is approximately 3 m thick and covers a period of ca. 3 ka. Comparable results apply for unit IIa. Frechen et al. (2003)

reported the highest accumulation rates in Europe during MIS 2. Such high accumulation rates imply high aeolian dynamics with sufficient source areas under (cold) arid conditions. These assumptions fit to large ice wedges that were repeatedly found in unit IIb. These observations indicate constant and very cold temperatures with little precipitation for this period only (Fig. 4.5). Typical for this unit is a twin peak of fine sand (63–125 mm), with the highest amount ever found in Saxon loess sections, which could be a result of high wind speed (Fig. 4.5). This is similar to findings from the section Nussloch (Antoine et al. 2009b) where the grain size $> 63\,\mu m$ shows the highest amount in comparable stratigraphic situations (loess Event 5 and 6).

4.6.4 Unit I

This unit represents that part of the Saxon loess sequence which was affected and decalcified during the late Weichselian and Holocene soil development. In the northern part of the SLR, the late Weichselian and Holocene soil development superimpose the uppermost sediments of unit IIa. In the southern part of the SLR, the thickness of loess sediments decreases over all units. The thickness of unit IIa and IIb decreases, and surface soil formation affected deeper stratigraphical layers. In the profile Leippen, the tundra gley soil from the base of unit IIa was incorporated in unit I.

A typical feature of unit I is the lenticular horizon ("Lamellenfleckenzone" or "limon à doublets") below the Bt-horizon (for detailed description see Meszner et al. (2011)). According to Vliet-Lanoë (1998), this sequence gives evidence for several different developments, which were interfering in the recent surface soil. She describes a compacted horizon (Fragipan) at the base of the pedocomplex and proposes that this is a result of the last continuous permafrost in Central Europe during the late glacial.

The major period of clay illuviation happened during the Bölling interstadial and should be a result of very strong mechanical processes that were very active in the last phases of the late glacial. According to the findings of Vliet-Lanoë (1998), only discontinuous permafrost existed during the Younger Dryas in the Central Europe lowlands. In addition, Kühn (2003) observed clay illuviation ca. 4 ka before the beginning of the Holocene, but in contrast to Vliet-Lanoë (1998) he gives no specific age bracket for this clay illuviation.

In two profiles in Saxony, filled ice wedge casts are located in the lenticular horizon. The infillings of the ice wedge casts show illuviated bands of clay but clearly much lesser bands of illuviated clay than in the surrounding material (unaffected lenticular horizon). It is possible that this feature is evidence for a two-part late Weichselian clay illuviation similar to that described by Vliet-Lanoë (1998). The first illuviation of clay affected the entire lenticular horizon and was disrupted by a period of ice wedge formation (perhaps during Younger Dryas). After filling the ice wedge casts with sediment, a second clay illuviation started and again affected the lenticular horizon and the freshly filled ice wedge casts. Due to the different time periods affected by clay illuviation, more bands of clay were developed in the loess outside the ice wedge casts than in the sediment inside. Following Vliet-Lanoë (1998) the major clay illuviation is connected with strong hydraulic potential and suction during springtime.

4.6.5 Sedimentation

Based on our results, we observed two periods of strong loess sedimentation during the Weichselian Glacial in Saxony. However, during periods of strong erosion, possible traces of loess accumulation were eliminated. In summary, we assume that the first appearance of remarkable Weichselian aeolian dust accumulation occurred around ca. 60–70 ka. The loess was deposited after the development of several humic-enriched layers. A further period of strong sedimentation ranges from 30 ka to at least ca. 18 ka and took place after a very strong phase of erosion and tundra gley formation (Gleina complex). This defines the beginning of unit III.

Seelos et al. (2009) describe similar findings on the basis of maar lake investigations and report from two main periods of dust sedimentation (60–71 ka and 32–13 ka). The first Weichselian dust recorded in maar lakes yielded an age of ca. 118 ka (Seelos & Sirocko 2007). Similar maximum ages were measured in the light grey charcoal enriched layer (fSew) above the last interglacial Bt-horizon (Ostrau, 119.4 ± 16 ka). Kasse et al. (2003) dated the first Weichselian fluvial deposit in the open cast mine Nochten (Eastern Germany) to 122 ± 19 ka (IRSL age). These similar ages (ca. 120 ka) are repeatedly described from different parts of the landscape (river sediments, aeolian sediments) and may be evidence for deposits formed during the first reorganization of the landscape after the Eemian interglacial.

4.7 Conclusions and outlook

The loess-palaeosol sequences from the SLR are of paramount interest for reconstructing the landscape of the last glacial cycle. We reported more than 35 stratigraphical units, palaeosols and other soil or sediment features, which were formed mainly during the Weichselian glaciation under different climatic conditions. In addition, OSL age estimates from two profiles using different mineral and grain size fractions were presented and a new composite profile for this loess region was developed.

This provides the opportunity to correlate the SLR with other European loess regions. The high accumulation rates of upper glacial loess in Saxony are similar to many other loess regions in Europe. Additionally, we identified another loess package of ~ 3 m thickness in a time bracket between 70 ka and 60 ka in a section close to the valley of the Elbe River.

It is possible to compare the granulometry-derived wind speed data from the upper Weichselian (unit I, II and III) with a section in Ukraine (ROUSSEAU et al. 2011) and Western Germany (ANTOINE et al. 2009b). Similar to the sections Nussloch and Stayky, two maxima of coarse loess fraction are preserved in the Late Glacial deposits. This grain size trend is probably a typical pattern that could be found in many loess sequences over whole Europe. There is also a good comparability, especially with Polish loess regions (JARY 2007).

Typical for the SLR is the poor preservation of early Weichselian humuic enriched zones. Only thin layers of reworked humic material are preserved. The Upper Weichselian units reach a thickness up to 9 m and could be subdivided in two loess facies. The upper homogeneous and the lower stratified loess facies are also known from loess sections in France (ANTOINE et al. 2009b), Belgium (ANTOINE et al. 2009b), Western Germany (ANTOINE et al. 2009b), and Poland (JARY 2007).

The revised composite profile consists of five units:

1. **Unit V** ($>$ 120 ka) covers pre-Eemian sediments and Eemian soil formation.

2. **Unit IV** ($<$ 120 ka to 60 ka) consists of highly compacted pedostratigraphic layers with low resolution probably due to poor loess sedimentation and preservation. These findings indicate different environmental conditions preserved in each of the observed layers in the early Weichselian.

3. **Unit III** ($<$ 30 ka): The lower part is dominated by the upper tundra gley soil of the Gleinaer Complex covering a hiatus of at least 30 ka. The following onset of loess sedimentation (Pleniglacial) shows a pedogenic imprinting. The OSL ages are overlapping and so no age bracket is given. Due to the hiatus it is not possible to further assess the palaeoenvironmental conditions.

4. **Unit II**

   (a) Unit IIb ($<$ 30 ka to $>$ 22 ka): The unit is dominated by a stratified loess facies formed during high aeolian dynamics with an intercalated brownish tundra gley soil.

   (b) Unit IIa ($<$ 22 ka): This unit consist of homogeneous loess and covers the LGM with the highest loess accumulations rates. The granulometry shows a shift to the highest amount of the finest sand fraction. The base of this unit is represent by a strong gelic Gleysol.

5. **Unit I** ($<$ 18 ka) represents the top of the profiles containing the surface soil and the underlying lenticular horizon.

On the basis of high resolution sampled OSL data from Seilitz and Ostrau, a hiatus in the loess sedimentation with a time range of ca. 30 ka was identified. Nearby loess sections from Poland suggest that this hiatus exists there also. Probably this gap is a feature that can be found in many loess profiles located on the European loess belt. Nevertheless, further investigations are needed.

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Chapter 5

Extended summary

5.1 Characterisation of Saxon loess-palaeosol sequences

Most of the presented results were based on findings obtained during fieldwork and could be reconfirmed with secondary data measured in the laboratory. The described profiles have a thickness between 8 and 17 m. Most profiles at watershed or upper slope positions show a thickness of 6 m to 8 m and only at special geomorphological positions, for example at the Zehren and Gleina section more loess were accumulated or rather were preserved more efficiently after its accumulation compared with other sections. The thickness of the loess cover increases from the south to the north and culminates at its very northern distribution boundary. For example, the Gleina section located directly on the northern loess boundary is 17 m thick. The carbonate content in the upper Weichselian loess (unit II) is relatively consistent across all sections with about 6 to 7 % in the SLR. Higher values are mostly connected with an enrichment due to an interglacial soil development. Further variations are attributed to internal carbonate movement of a lower order (formation of small or greater carbonate nodules). Our observations show that the formation of carbonate nodules is not necessarily linked with an interglacial soil formation. In the SLR they are often connected with strong Gelic Gleysol formation during Upper Weichselian (unit II). The Zeuchfeld section (Fig. A.3) in the north-east of Freyburg (Saxony-Anhalt) shows higher values of carbonate content (ca. 10 %)

in the Upper Weichselian loess. These results support the assumption according to NEUMEISTER (1966) and G. HAASE et al. (1970) that the carbonate content increases in proximity to carbonate bearing bedrock. It underlines the idea that loess deposits in Central Europe include a strong local dust component. ROUSSEAU et al. (2014) propose a similar assumption on the basis of investigations on trace element concentration. They found strong evidence that each loess region has its own trace element fingerprint and is distinguishable from other loess areas. In this study, samples from the Leippen, Gleina, Seilitz, Zehren, Ostrau, and Zeuchfeld sections were also analysed. It has to be noted that Saxon samples show similar concentrations, and just the results from Zeuchfeld differ slightly (Fig. A.4). However, this study documented that the loess from Saxony has a strong local component. A differentiation between loess from Saxony and Saxony-Anhalt (Zeuchfeld section) is also possible (ROUSSEAU et al. 2014, see supl. material: TabS1, FigS2 & FigS3). The hypothesis that loess from a distinct area has a uniform mineral composition is supported by our own results from rare earth element (REE) investigations. Figure 5.1-(d) shows the REE concentrations of 24 samples from 3 Saxon LPSs. The concentrations have low variability, suggesting that the deposits seem to originate from the same source area.

Further variations of the carbonate content are observed due to the formation of interstadial soils. For example, at the Gleina section the Gleina complex is decalcified, whereas the above lying and subjacent sediments are calcified. The author interprets this feature not as a period where decalcified dust has been deposited but rather that the Gleina complex represents a long period where several interstadial soil formations were able to decalcify the sediment (Fig. 5.3). The fact that an interstadial soil formation was able to decalcify the loess in Saxony could also clearly be observed in the Rottewitz section (Fig. A.1: No. 18). Here an in situ palaeosol is excellently preserved and shows a decalcified upper part, whereas the carbonate content increases downwards. The TOC behave oppositely and show an increase upwards with a maximum of 0.7 % at the top of the palaeosol. Generally, in all investigated LPSs from Saxony we could never find higher values of TOC connected with a palaeosol formation. That SOM could be preserved in LPSs in higher concentration than found in Saxony, is documented in the section of Zemechy (CZ).

This LPS is located in the north of Prague and was investigated in summer 2012. Here, Early Weichselian Chernozem-like palaeosols were predominantly preserved in situ and an increased content of SOM up to 1.5 % at the top of the palaeosols could be observed (Fig. A.2). In Saxon LPSs such high values of SOM could not be found. This suggests that such strongly developed interstadial soils were not preserved in Saxony and the reworked Humus zone at the base of the profiles should only be interpreted as a relict of stronger soils.
In chapter 3 the grain size distribution of LPSs from Saxony was discussed. It could be demonstrated that grain size fractions were differently forced either by several geomorphological or pedogenic processes (Fig. 3.12). For example, the aeolian dynamics are expressed by the coarse silt and very fine sand fractions. Coarser fractions were linked with secondary overprinting weather of pedogenic or depositional origin. Such knowledge is important for further investigations such as OSL dating. If OSL investigations were obtained on coarse grains due to some methodical advantages, the results have to be scrutinised. Coarse grains were mostly not represented as an aeolian component of the loess and could be incorporated by mass wasting slope processes. During downslope movement, coarse grains originating from a stratigraphically underlying sediment could incorporate and falsify the OSL age.
Additionally, stratigraphical units could be identified on the basis of their typical grain size distributions (Sec. 3.4.1). Therefore, interpreting grain size data is a suitable method to reconfirm a stratigraphical subdivision established on the basis of other results.

5.2 The revised Saxon standard profile

A standard profile can never be complete. Every new outcrop stimulates advancements and extends the succession. The results presented here are on the current state of knowledge and have to be continued and advanced by future work. A further dilemma of a standard profile is its inflexible nature. A combination of all information carried out from a specific area can only be realised with difficulties. For example, most results are attributed to a specific geomorphological position. The position affects not only the thickness of a deposit but rather the edaphic moisture, vegetation cover, slope processes, the type of soil

formation and finally the preservation due to covering with younger material. For example, our study on biomarkers shows that the n-alkane concentration varies at the same stratigraphic layer but in different profiles (Zech et al. 2013, Fig. 5). This is interpreted as a feature triggered by the exposition of the profile. High n-alkanes concentrations were connected with a high edaphic moisture at a north facing slope (Gleina section). Low n-alkanes concentrations indicate dryer edaphic conditions with an increased re-mineralization of organic matter at a south-west facing slope (Rottewitz section).
A standard profile, however, can only be an approximation of all information combined in one archive (area).
The revised Saxon standard profile is subdivided into five units. Each unit represents a more or less homogeneous formation due to its pedogenic and sedimentological properties as well as its soil/palaeosol assemblage. The units were independently derived during previous fieldwork and represent a stratigraphical frame of a higher order. As defined in Sec. 4.5.2 the following subdivision is proposed (see Tab. 5.1).

Summarizing the stratigraphical results, Saxon LPSs are characterized by strongly reworked layers at the profile base representing the last interglacial and the Early Weichselian, indicating different environmental conditions. This long period was followed by a first strong aeolian activity producing a cover of unweathered loess, interrupted by a short warm interstadial period with soil formation on a stable surface. This period of aeolian activity was replaced by a period of stronger reposition due to slope processes and a low aeolian activity. It was terminated with a strong Gelic Gleysol formation. Afterwards, a second aeolian period produced a huge loess cover at all geomorphological positions in the loess area. At the beginning, a more or less synsedimentary profile growing was co-occurring together with a weak soil formation. Later, unweathered loess interrupted by weak Gelic Gleysol was deposited.

Table 5.1: Subdivision of Saxon LPS

unit V	pre-Weichselian sediments modified by the Eemian soil formation
unit IV	This is a complex unit spanning over a long period. It contains deposits from the beginning of the Weichselian glaciation up to the lower part of the Gleina complex. Typically, this unit starts with the first Weichselian deposit, a bright-greyish Mn- and Fe-precipitates enriched layer with an aggregation of charcoal at its top. This layer is covered by a greyish, humus-enriched and reworked relict of a Chernozem-like soil. After a Gelic Gleysol and a reddish-brownish soil sediment, both reworked, a loess package with an embedded interstadial Cambisol-like soil is preserved. The top of the unit is represented by another brownish soil sediment which forms the lower part of the Gleina complex. With the exception of the Rottewitz section, unit IV is characterized by stronger reworked layers and soil sediments. The Rottewitz section is located on the south-west facing upper eastern slope of the Elbe river valley and shows obvious suitable preservation conditions. Comparing all investigated profiles located in Saxony, this older loess package is preserved only in the Rottewitz section.
unit III	This unit represent the reactivation of aeolian sedimentation. In all profiles the base of this unit is built by the upper part of the Gleina complex (strong Gelic Gleysol). The deposits of this unit are mostly pedogenically overprinted and show features of at least two Gelic Gleysols.
unit II	This unit achieve major proportions with regards to the profile thickness and is dominated by unweathered loess. Its lower part (unit IIb) is built of a more stratified loess facies whereas the upper part (unit IIa) is built of a homogeneous loess facies. They are separated by a strong Gelic Gleysol.
unit I	Unit I represent the upper part of the loess section, which is modified by the Holocene and Late Pleistocene soil development. Mostly the soil formation overprints deposits belonging to unit IIa but in some cases also deposits of unit IIb are involved.

5.2.1 Internal differentiation of the Weichselian loess

One challenge of this project was to identify different deposition periods during Weichselian glaciation and verify whether they have either a similar or different mineralogical composition. This was related to the question as to whether the dust source changed during Weichselian. For that reason, REEs and Yttrium concentrations were measured on 24 samples from the Ostrau, Gleina, and Rottewitz sections. The analyses were done on the grain size fraction $<125\,\mu m$ to be sure to investigate the aeolian components. Figure 5.1 (a-c) shows the trace element concentrations normalised to the arithmetical mean of a distinct section. The coloured lines express specific stratigraphical positions where the samples were taken. The Gleina section shows a high internal variability of REE concentration compared with the Rottewitz section. But when comparing all sections, there is no clear evidence to show that older loess layers have a trace element composition different from that of younger loess layers. The author interprets this feature as evidence that the source area did not change during Weichselian loess deposition. In Figure A.5 the concentrations were normalized to the arithmetical mean of all measured samples. It indicates that Rottewitz has an increased concentration of trace elements compared to Gleina and Ostrau sections. It can be supposed that this enrichment is caused by the proximity to the Elbe river. As mentioned in Sec. 3.4.4, grain size results point to a palaeo-wind direction coming from the north-west. Such winds could deposit fresh material from the river banks of the Elbe river up to the Rottewitz section (see Fig. 3.1). These findings are consistent with results from grain size investigations, where the Rottewitz section shows an increased short-term transport fraction ($<125\,\mu m$).

Additionally, the concentration of heavy minerals was investigated on samples from the Gleina and Ostrau sections (Bachelor thesis by Starke, L. & M. Tessmer, 2011). The results from the Ostrau section indicate a differentiation between loess younger than the Gleina complex and loess older than the Gleina complex. The variation mainly regards the concentration of chlorite. In the Ostrau section, chlorite could only be found in units II and III. In older deposits no chlorite was detected. We do not interpret this as varying source of the dust during Weichselian glaciation. In fact, we suppose that this signal represents the degree of weathering. The material older than the Gleina complex is more strongly weathered so that chlorite is completely destroyed.

Another remarkable finding due to heavy mineral investigations is that the amount of heavy minerals in unit II loess of the Gleina section is at least double that of unit II loess from Ostrau. Due to the fact that in both sections unit II loess is completely dominated by the aeolian deposition, a contamination resulting from slope processes has neglected. This finding supports the hypothesis that the main wind direction comes from the north-west. The Gleina section is directly located at the northern loess boundary (Fig. 4.1). If the dust comes from the north-west, heavy components should be deposited similar to the coarse grain size fractions proximate to the source area. However, this high concentration of heavy minerals indicates a short-term transport of dust only and agree with observations discussed above, in that at least the coarse components of Saxon loess come mostly from a local dust source.

We conducted rock magnetic analysis from Saxon LPSs (published by BAUMGART et al. 2013) which indicates that the magnetic characteristics differ significantly with the depth. We worked out that variations on rock magnetic properties are mainly triggered by secondary processes such as climatically controlled water-logging, weathering or reworking. On the basis of rock magnetic analysis there is no evidence for subdividing Saxon LPSs into different sedimentary/mineralogical units. However, a subdivision on the basis of rock magnetic with regard to secondary overprinting due to weathering and relocation is strongly recommended and correlates well with the established units (Sec. 5.2):

Unit I and IIa show an increase of magnetic susceptibility going along with an increase of frequency dependent susceptibility, which is typical for interglacial soil formation on loess and known from Chinese loess. Unit IIb shows the opposite magnetic behaviour, because magnetic and frequency depending susceptibility does not follow a similar trend. This behaviour increase in unit III, that magnetic and frequency depending susceptibility follow opposite trends. The lower parts of unit IV and unit V (Eemian soil) show very low values of magnetic susceptibility, which is not typical for a soil development of interglacial order. We interpret this as evidence for strong secondary degradation of this soil and its upper horizons.

Summarizing all results discussed in this section, LPSs from Saxony show variations on several properties over Weichselian glaciation. The changes are mostly based on the age and the duration of secondary overprinting processes but not on fluctuating origin areas of the primary dust.

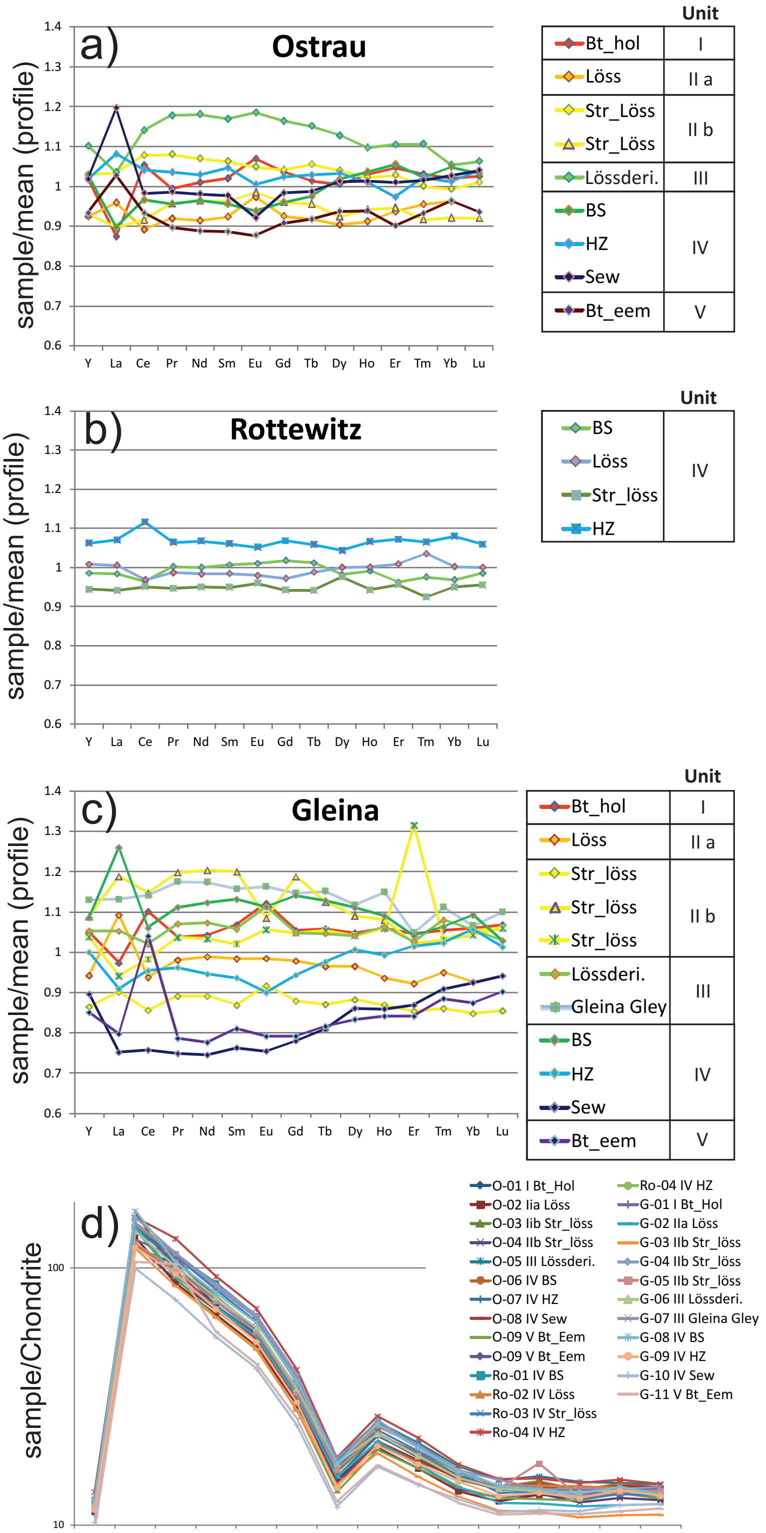


Figure 5.1: REE and Yttrium concentration of Saxon LPSs

a) - c): REE and Yttrium concentration of different sections. The concentrations are normalized to the arithmetical mean of the distinct profile;

d) all measured concentrations normalized to a carbonaceous chondrites after McDonough & S. Sun (1995)

5.2.2 Local correlation to previous work done on loess in Saxony

On the basis of mainly 8 profiles from the SLR a revised Saxon standard profile is established (Fig. 4.4). According to the scheme of LIEBEROTH (1963) or Fig. 1.3 (b) several improvements could be added:

- The Eemian soil is not preserved with its uppermost horizons up to the Aeh-horizon. In fact, this interglacial soil is truncated and hardly overprinted by several soil formations during the Early Weichselian period. Results of grain size analysis indicate that the bright layer (fS(e)w) and the underlying II fBtSd horizon are not composed of the same material (Fig. 3.2 and 3.11). It is supposed that the upper layer is reworked material (soil sediment) of Early Weichselian soil formations. The Ah-horizon of the Eemian soil (Fig. 1.3) according to LIEBEROTH (1963) seems to be a relict of an Early Weichselian steppe soil formation. These assumptions are supported by results of OSL dating, showing Early Weichselian ages (Fig. 4.4 & 5.2). Furthermore *n*-alkane analyses (ZECH et al. 2013) show an extremely low concentration in the truncated Eemian Interglacial palaeosol. This can also be attributed to the erosion of the Eemian topsoil.

- In principle, what LIEBEROTH 1963 summarized as W β is typically found in Saxon LPS. But fortunately we found it in the Rottewitz section. Here, a period of loess sedimentation, including an in situ interstadial Cambisol-like palaeosol and a Gelic Gleysol, has been preserved and this has improved the standard profile. In Figure 5.2 this loess is labelled as "Unit IV loess".

- The "Gleina soil complex" according to LIEBEROTH (1963) must be reinterpreted rather as a complex which within holds a hiatus of around 30 ka than a soil complex of successional soil formation. In Figure 5.2 this complex is labelled as "Upper" and "Lower Gleina". From our point of view the discussion about how to interpret this complex is not finished but we do reluctantly attribute it as an interstadial soil corresponding with a Greenland interstadial (GIS). It seems that processes of landscape disturbances and redistribution of soil material are typical for this period in Saxony.

- Lieberoths Wγ1' loess corresponds to our unit III. We could add at least two more Gelic Gleysols.

- Wγ1"-loess, corresponding with our unit IIb, could be extended by a weak brownish interstadial palaeosol (Fig. 4.4: fBvc). Wγ1"' represented our unit IIa and is characterized by a homogeneous loess facies. According to results by Baumgart et al. 2013, unit IIa and unit IIb could also be separated by their rock magnetic characteristics. Unit IIa shows a magnetic behaviour known from the Chinese loess area. Here, the magnetic susceptibility increases together with the frequency dependent susceptibility. In contrast, unit IIb seems to reflect a different model of magnetic behaviour known from colder loess areas (compare Sec. 1.3)

- We did not find evidence requiring a subdivision into Wγ 1 and Wγ2. But we did find sections where the Holocene soil formation modifies older deposits for example of unit IIb. This could be observed when the uppermost loess is absent or builds a thin layer only. Therefore, the parent material of the Holocene soil formation could differ. In some cases, also an Upper Pleistocene Gelic Gleysol could be the parent material for Holocene soil formation.

5.3 Chronostratigraphy of Saxon loess-palaeosol sequences

The chronological results based on OSL datings obtained from Leippen (Meszner et al. 2011), Seilitz, Ostrau (Meszner et al. 2013), Zehren, Gleina, and Rottewitz sections (Kreutzer 2012). Due to the fact, that we obtained OSL dating form a distinct stratigraphical position but in several sections, a robust chronology can be established (Fig. 5.2). The results improve and reconfirm the stratigraphical scheme mentioned above.
The OSL ages presented by Kreutzer (2012), Kreutzer et al. (2012), and Meszner et al. (2013) indicate huge variations from layer to layer during

periods of stronger redeposition (older unit IV and transition III/IV). Contrastingly, a consistent age development, matched with the profile growth, can be found during periods dominated by loess deposition (unit II, III and younger IV). In the Figure 5.2 most OSL dating results are shown. The first Weichselian deposits directly above the Eemian soil are aged between 110 and 120 ka (adjusted ages). The uppermost part of unit IV shows ages between 55 and 75 ka. This indicates that unit IV spans a time period of ca. 35-65 ka. It has to be noted that unit IV also includes the older loess package which has a much better chronostratigraphical resolution and is spanning the time period between 60 to 75 ka. The older loess package documented that LPSs are able to record climactically triggered fluctuation which initiate a soil formation with decalcification and brunification processes. These processes running that fast that their chronology can only hardly be resolved by OSL dating techniques within their errors, if they occur in the Middle Weichselian (see Fig. 5.2: unit IV loess).

Furthermore, the dating results indicate a huge hiatus between unit III and unit IV (see 4.6.2). These support assumptions derived on grain size or rock magnetic data that this was a long-lasting period including soil formation and weathering, landscape reorganisation and strong redeposition.
A high resolution of OSL data could be obtained from unit III and II. The data indicate a reactivation of aeolian sedimentation between 30 and 40 ka (Fig. 5.2, "Upper Gleina"). The highest resolution regarding OSL ages could be presented for unit II. This is caused by the thickness of this unit. In most profiles unit II represents more than half of the profile thickness although spanning a time of only 10 ka (18-28 ka).

The results of this study demonstrated that it is possible to generate a standard loess profile with high pedological and sedimentological resolution (Fig. 4.4). Such profiles indicate a high density of palaeoenvironmental information, as can be seen in Fig. 4.5. Such drawings suggest a comprehensive view over the whole glaciation. However, a crucial finding of this study that has to be emphasized is that there is a high variation in the chronostratigraphical resolution found in Saxon LPSs (Fig. 5.2). In periods dominated by aeolian deposition and subsequent preservation, LPSs records a lot of information. In contrast, in periods with slowed down aeolian deposition, LPSs

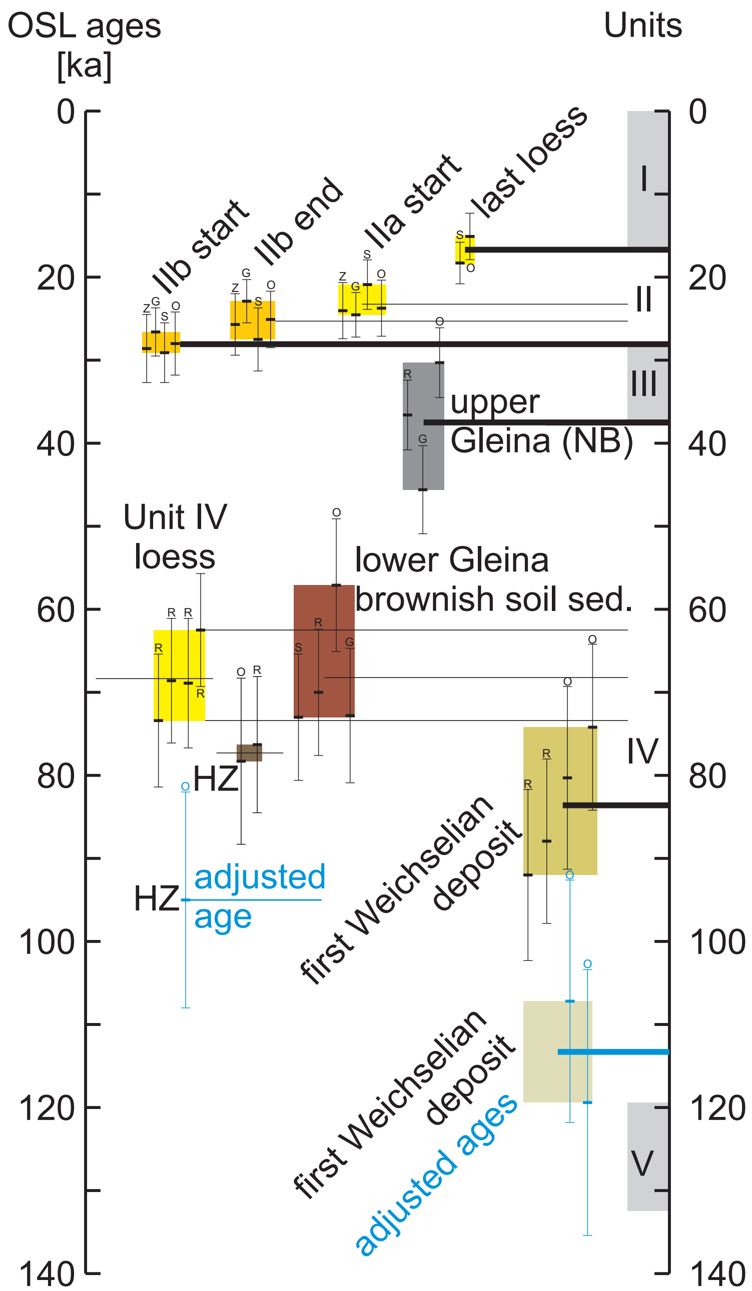


Figure 5.2: Major units plotted to OSL ages according to KREUTZER (2012) and MESZNER et al. (2013)

Colours are in accordance with Fig. 5.3 & 4.4.

Upper case letters beside the error bars refer to the profile where the OSL samples was obtained; S: Seilitz, O: Ostrau, G: Gleina, Z: Zehren, R: Rottewitz;

horizontal line marks the mean or the youngest/oldest OSL age of a unit; blue coloured bars are adjusted OSL ages according to KREUTZER et al. (2012) and Fig. 4.4 (right column).

records only minimal or no information. This is obviously demonstrated in Figure 5.3 where major units of Saxon LPSs, plotted against their OSL age, were contrasted with more or less continuous palaeotemperature and palaeo-dust concentration data derived from other archives. A high pedo-sedimentological resolution in loess archives could only be developed during main loess periods. In Saxony the first one was between ca. 62 and 73 ka and the second one between 16 and 30 ka.

5.4 Chronostratigraphical comparison with other European loess-palaeosol sequences

Comparing results presented in this study with other European loess profiles (see Fig: A.6), several similarities could be identified.

The upper half of most Weichselian loess profiles in Europe is built of a thick, only slightly weathered loess package with ages ranging between ca. 30 and 20 ka. This package represents the Upper Weichselian and could be subdivided based on several Gelic Gleysols. This type of weak soil formation is described for this unit across Europe – from France to the Ukraine (Jary & Ciszek 2013) and further to Russia (Velichko 1990). The strongest one, in Saxony defined as the boundary between unit IIb and IIa loess, is also described in other regions. In the Netherlands and France (Antoine et al. 2003a; Juvigné & Wintle 1988) it is labelled as "Nagelbeek" soil, in Belgium as "Tongued Horizon " (Frechen et al. 2001). In the Rhineland it is documented as "Eben-Zone" (Schirmer 2000). A strong Gelic Gleysol in the Upper Weichselian loess is also described in the Zlota profile (Moska et al. 2015). In Russia a comparable soil is labelled as "Truchevsk soil" (Velichko 1990).

Antoine et al. (2009b, 2001) found on the basis of grain size investigations in the Upper Weichselian loess a cyclicity of wind speed and interpret this as an influence of the North Atlantic wind regime. These are comparable findings to our results (see Fig. 3.11). The amount of very fine sand in Saxony also increases in unit II loess and reaches a profile-wide maximum in the upper parts of unit IIa. Rousseau et al. (2014) mentioned that this cyclicity is also documented based on grain size fluctuations in Ukrainian loess sections. This important aeolian period was also investigated by Frechen et al. (2003), who calculated high accumulation rates for several sections from Europe. They mentioned that the accumulation rate is mainly connected to the proximity to huge river systems and does not follow a west-east trend.

The beginning of this period is dated to ca. 30 ka (Antoine et al. 2009b; Kreutzer et al. 2014a; Moska et al. 2015; Schirmer 2000). In Saxony, we have clear evidences that the pure loess sedimentation starts ca. 28 ka (unit IIb). We suppose that unit III has to be interpreted as a transition, where the aeolian reactivation starts but was in line with weak soil formations. The Middle Pleniglacial is characterized in most profiles in Figure A.6 by greater steps between neighboured OSL ages. This points to slower aeolian deposition as well as hiatuses due to periods of erosion. Figure 5.2 also shows great variations of OSL ages obtained from the same stratigraphical unit from Saxon LPSs. We interpret this as an indication that such layers are composed of reworked materials from different units. Antoine et al. (2014) describe for the Middle Pleniglacial in the Havrincourt (F) section a Gelic Gleysol with an underlying complex of Arctic soils (Gelic Cambisol). It seems that this is stratigraphically comparable with the Gleina complex from Saxony. But also the underlying boreal Cambisol shows similarities with the fBv-horizon from the Gleina section. The author proposes that during Middle Pleniglacial the condition of surface preservation must have a high spatial variation. Results from the SLR, particularly from upper unit IV and unit III, are stratigraphically and chronostratigraphically not uniform. Further observations have to be done to improve the understanding of this period.

However, many sections over Europe show similar results concerning a hiatus or a time gap in-between the Gleina complex. Such a hiatus is documented for example in the following sections (see Tab. 5.2):

It has to be underlined that one similarity of many loess sections from the whole European continent is that the Middle Pleniglacial is characterized by greater stratigraphical gaps.

The same results were found in the Zeuchfeld section in Saxony-Anhalt (Kreutzer et al. 2014a). Here, a hiatus of ca. 40 ka is documented. This section is worth mentioning because it is located at a slope, where older material, for example gravel of a Saalian glacifluvial outwash plain, is exposed to the surface at the high slope position. Slope processes were indicated throughout

Table 5.2: Selected profiles with equivalent formations comparable to the Gleina complex

Country	section	upper age	lower age	duration of gap	formation name	Reference
France	Saint Sauflieu	18.8±0.4 ka	55.0±4.9 ka	ca.35 ka		FRECHEN et al. 2001
Belgium	Veldwezelt	-	-	-	Kesselt Suite	VANCAMPENHOUT et al. 2008, p. 148
Belgium	Harmignies	>23.6 ka	53.4±10.4 ka	<ca. 30 ka	-	FRECHEN et al. 2001
Germany	Schatthausen	38.5±4.0 ka	51.6±5.2 ka	ca.13 ka	Böckinger Boden	FRECHEN et al. 2007
Poland	Bialy Kosciol	25.9±0.8 ka	41.5±1.6 ka	ca. 15.6 ka	Gi/LMd or Komorniki	JARY & CISZEK 2013; MOSKA et al. 2011
Poland	Krakow Spadzista	32.5±2.8 ka	65.4±5.9 ka	ca. 30 ka	-	ŁANCZONT et al. 2014
Czech Rep.	Zemechy	37.3±4.8 ka	66.2±12.6 ka	20 - 45 ka	-	ZANDER 2000
Czech Rep.	Dolni Vestonice	30.589 cal BP	44.95±1.87 ka	ca. 13 ka	Middle-Upper Weich-selian transition	ANTOINE et al. 2013
Russia	East European Plain	29.3±3.0 ka	>70.0±7.0 ka	ca. 40 ka	Bryansk Palaeosol	LITTLE et al. 2002

the glaciation in an increase of coarse material coming from the upper slope positions. Figure A.3 shows results of the grain size analysis. This section draws a simplified picture of the major Weichselian periods: Stronger relocation at the beginning of the glaciation and during the Middle Pleniglacial. The period of relocation during the Middel Pleniglacial separates an older and a younger loess package.

The older loess package in Saxony includes a well preserved in situ palaeosol showing ages between ca. 62 to 73 ka. This palaeosol is of high interest because in situ soil formations from this period in LPSs are rare. HAESAERTS et al. (1999) described similar features from the Remicourt and Harmignies sections (BE). They propose an age of >75 ka for these formations. On the basis of our OSL dating results from the Rottewitz section, we suppose an age of ca. 70 ka.

It has to be noted that the clay content of the older loess package is higher, with ca. 5-7% compared to the Upper Weichselian loess (Zeuchfeld and Rottewitz section). Similar results are documented by Haesaerts et al. (1999) from Belgium loess. The same feature can be found in the Zemechy section (Fig: A.2) too. In this profile, there is an increase of clay content in a depth of ca. 4 m. Between 5 and 7 m depth a loess package showing a clay content of ca. 25%. Zander (2000) analysed 16 samples from the Zemechy section using different OSL and TL techniques and found a hiatus of between 20 and 45 ka in the depth between 4 and 5 m. The author proposes that in the Zemechy section the Upper Weichselian loess is directly deposited on the older unit IV loess package and the Middle/Upper Weichselian transition is represented only by the loamy greyish-brown material between 4.5 and 5 m depth.

From other European LPSs it is known that the Lower Weichselian is characterized by at least three Humic soils. Such Chernozem-like formations are documented for example at Saint Sauflieu (F) (Antoine 1998; Frechen et al. 2001), Mainz-Weisenau (D) (Bibus et al. 2002), and Dolni Vestonice (CZ) (Antoine et al. 2013) section. In Saxon LPSs the Lower Weichselian is badly preserved and only relicts of Humic soil could be found. In Rottewitz (Fig. A.1: No 20 & 22) two humic enriched layers are preserved. Looking at Figure A.6, a subdivision of Early Weichselian Humic soils is documented in Western European loess areas (France), Central European loess areas (Kappler 2013; Ruske & Wünsche 1968), and southern-central European loess areas (CZ). In eastern Central and East Europe, only one humic soil, mostly slightly modified due to gelisolifluction, is described. However, it has to be mentioned that near to Saxony (Zemechy or Bad Kösen section) Early Weichselian soils were preserved. It seems to be unlikely that the palaeoclimate varied that much that in the Zemechy section three strong Chernozem-like soils could develop and in Saxony no soil formation occurred. It is more likely that this feature is forced by different preservation conditions. Therefore, it is conceivable that in Saxony and other eastern European loess areas the dust input was not enough to separate the Early Weichselian variations into distinct Chernozem-like soil formations.

From Czech LPSs it is known that the Early Weichselian soils are separated not by loess deposit but rather by "marker silts" (Antoine et al. 2013; Demek & Kukla 1969). Rousseau et al. (2013) mentioned that marker silts are generally finer grained than normal loess, but no significant differences are found in the petrological content. They propose a formation during dust storm events and on the basis of its fine granulometry that marker silt were deposited over long distances (not local material). Similar observations were described by Seelos & Sirocko (2007) from Eifel maar sediments. They suppose that the first Weichselian aeolian input after the Eemian, found in Eifel maar lakes, show features of single dust storm events and not continuous loess sedimentation.

A last feature, described from many LPSs over the whole of Europe is an enrichment of charcoal in Early Weichselian sediments (e.g. Vancampenhout et al. 2008). Also in Saxon LPSs charcoals were found in all sections. On the basis of found charcoal remnants, during the Early Weichselian period Central Europe was forested with coniferous trees. The fact that bushfires appear on a continental scale, the climate must have been characterized by extreme dryness during summer. Sirocko et al. (2005) report numerous layers of charcoal in Eifel maar lakes between 103 and 112 kyr BP (varve-counted age) too.

Generally, Saxon LPSs seems to show more similarities with eastern European loess sections than with western European loess areas. Therefore, the investigations in Saxony are important to help connect the knowledge derived from LPSs over the whole of Europe.

5.5 Chronostratigraphical comparison with other archives

> " It appears that loess sedimentation in Germany was not a constant process during the last glacial cycle, but rather occurred in distinct pulses, the most effective one being during the LGM."

This is a statement from Zöller & Semmel (2001). The results of the current study agree with this assumption. Furthermore, we could extend this statement for the eastern German region, that there were two distinct periods of loess deposition.

Such results are in accordance with data presented by SEELOS et al. (2009) from Eifel lake sediments (Fig. 5.3: D). The first loess package correlates with the cold marine isotope stage (MIS) 4 according to LISIECKI & RAYMO (2005) and the older Weichselian dust concentration maximum detected in Greenland ice cores (RUTH et al. 2007). The younger loess package occurred during MIS 2 with the sedimentation of unweathered loess during the LGM.

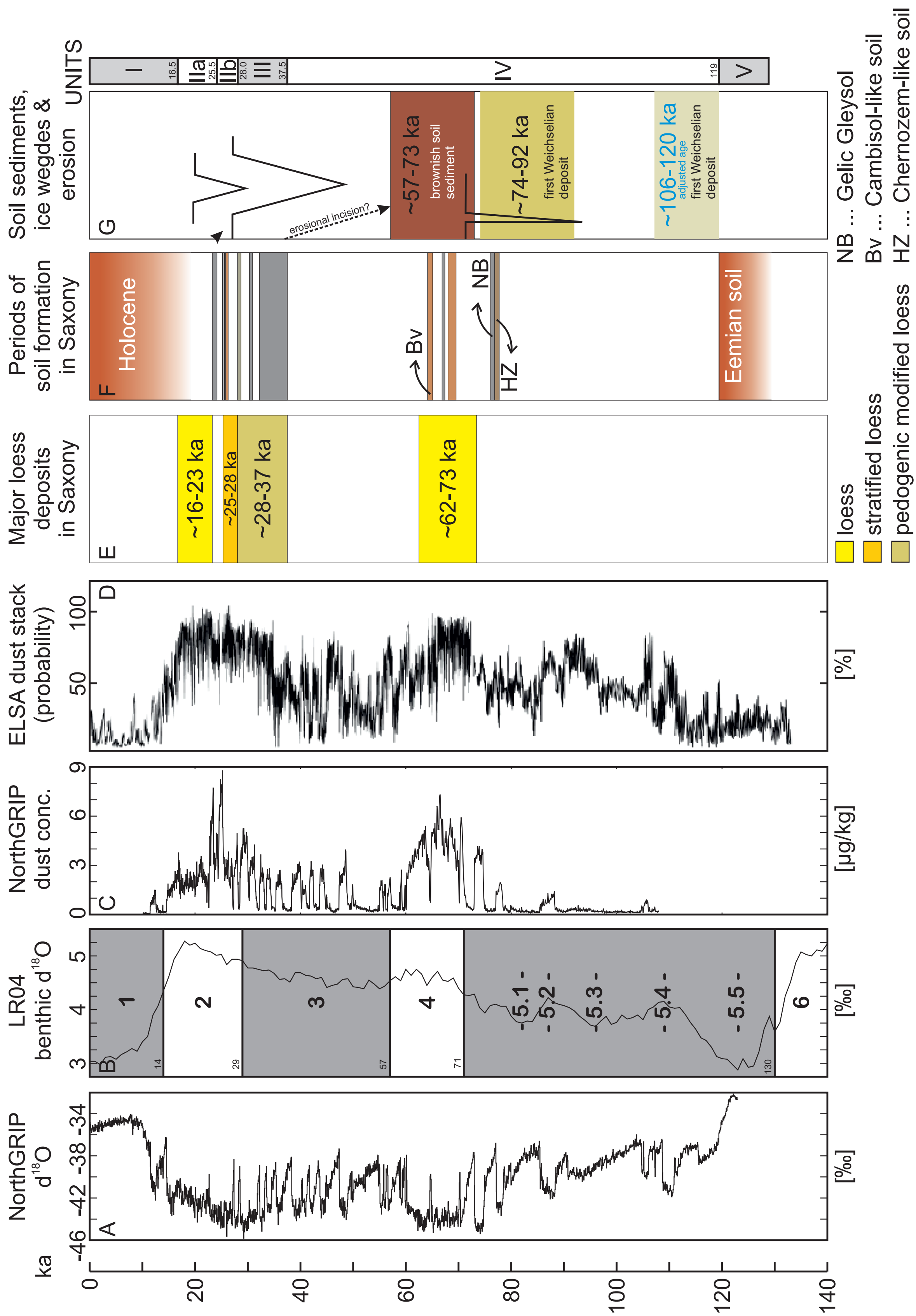
These results are surprising because Saxon LPSs shows evidence of being influenced locally, as mentioned above. But the general dynamic follows the northern hemispheric macroclimate.

The results are surprising for a second reason. When looking at the interstadials derived from ice cores (GIS), it is hard to imagine that such short fluctuation can have a significant influence on LPSs. But data presented in Fig. 5.3 demonstrates that in periods of huge loess sedimentation most of the fluctuation could be expressed in a LPS, for example as a Gelic Gleysol (MIS 2) or as a (Gelic) Cambisol (MIS 4).

Warmer periods of the glaciation (MIS 3) with a slower loess accumulation are in Saxon LPS represented as hiatuses or as reddish-brown soil sediments. It has to be discussed whether clay enriched soil sediments, often described and interpreted as reworked Eemian soil material (MESZNER et al. 2011), are the result of multiple interstadial soil formations on the same material.

Figure 5.3 *(following page)*: Comparative consideration of dust tracing archives from the Northern Hemisphere with own results.

A) NGRIP stable oxygen isotopic record according to ANDERSEN et al. (2004); B) LR04 benthic $\delta^{18}O$ stack with Marine Isotope Stages (MIS) according to LISIECKI & RAYMO (2005); C) NGRIP dust concentration according to RUTH et al. (2007); D) ELSA dust detection stack as a normalized probability record according to SEELOS et al. (2009); E) major loess deposits found in Saxon LPSs; F) soils and Palaeosols detected in Saxon LPSs; G) soil sediments and geomorphological remnants detected in Saxon LPSs; E-G) units are plotted against OSL ages according to KREUTZER (2012) and MESZNER et al. (2013), for details see Fig. 5.2


ka
NorthGRIP
d18O
[‰]
LR04
benthic d18O
[‰]
NorthGRIP
dust conc.
[µg/kg]
ELSA dust stack
(probability)
[%]
Major loess
deposits
in Saxony
~16-23 ka
~25-28 ka
~28-37 ka
~62-73 ka
Periods of
soil formation
in Saxony
Holocene
Bv
NB
HZ
Eemian soil
Soil sediments,
ice wegdes &
erosion
erosional incision?
~57-73 ka
brownish soil
sediment
~74-92 ka
first Weichselian
deposit
~106-120 ka
adjusted age
first Weichselian
deposit
UNITS
I
IIa
IIb
III
IV
V
loess
stratified loess
pedogenic modified loess
NB ... Gelic Gleysol
Bv ... Cambisol-like soil
HZ ... Chernozem-like soil

The initial position, before the project started, was that we only had a vague idea about the potential of this archive in Saxony. We had no idea about the temporal resolution or gaps within this archive.

Now, several years later, we have a broader understanding of the processes and dynamics forcing this archive. We now also have more experience of identifying and classifying palaeosols or the interpretation of some features caused by frost action. Comparing our knowledge with the initial position several years ago, we have to acknowledge that we now can subdivide the loess of the Weichselian glaciation in periods where we know almost nothing and in periods where we know that they have the potential to serve as a temporal high-resoluted archive for landscape reconstruction.

Appendix A

Appendix

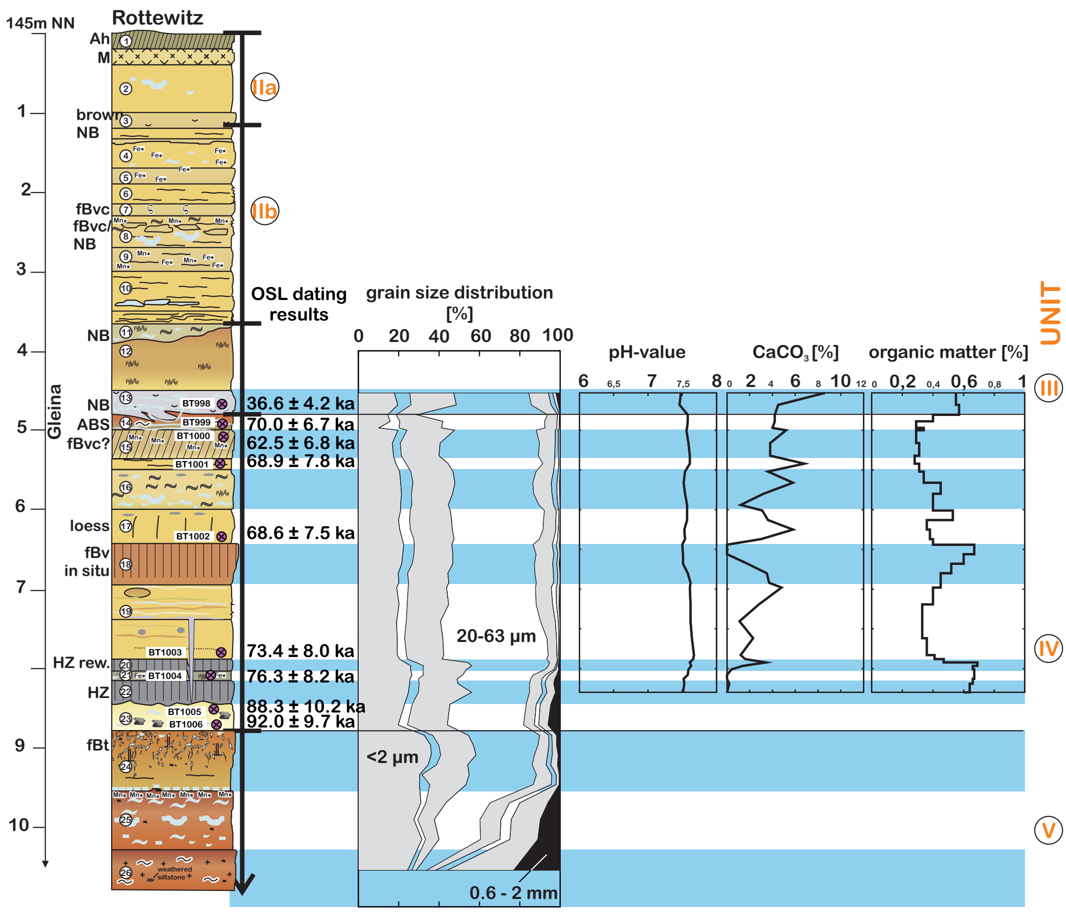


Figure A.1: Rottewitz section with geochemical results. OSL dating results according to KREUTZER (2012, p. XXVI).

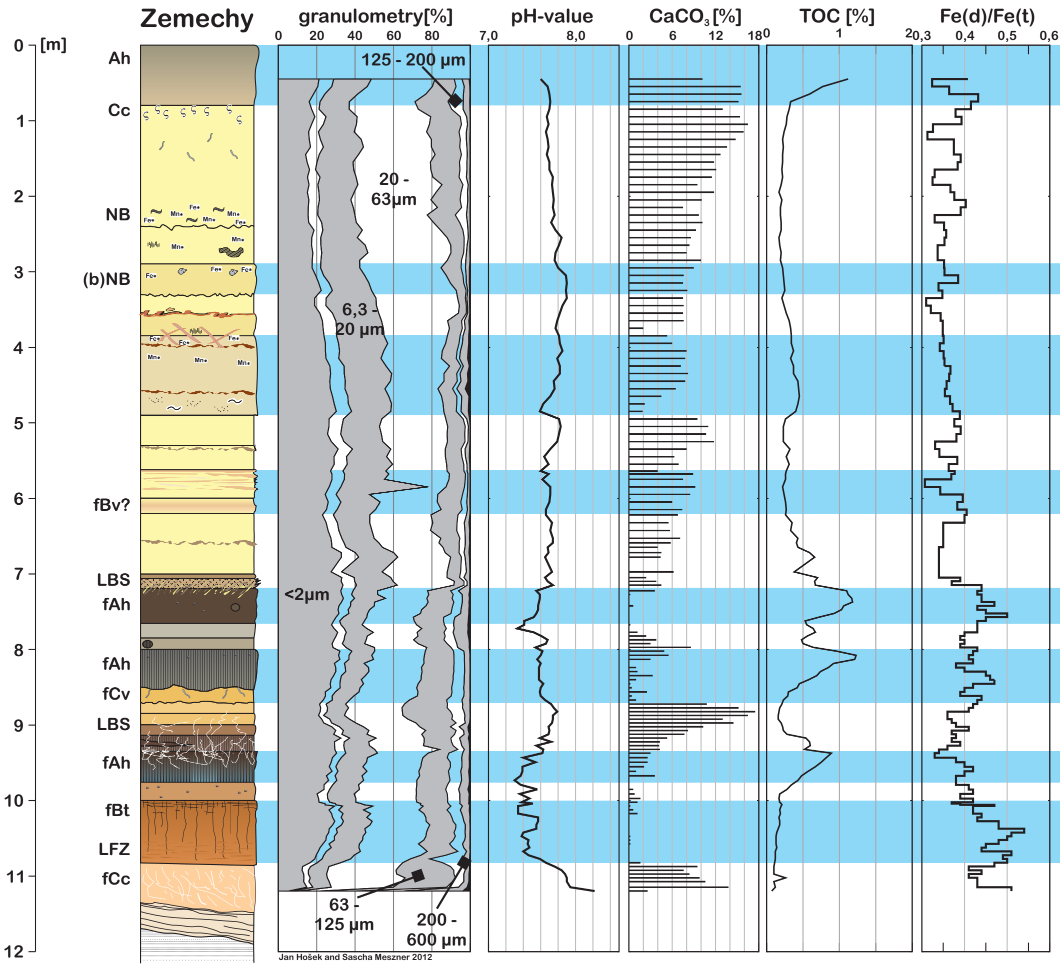


Figure A.2: Zemechy section (CZ) with geochemical results

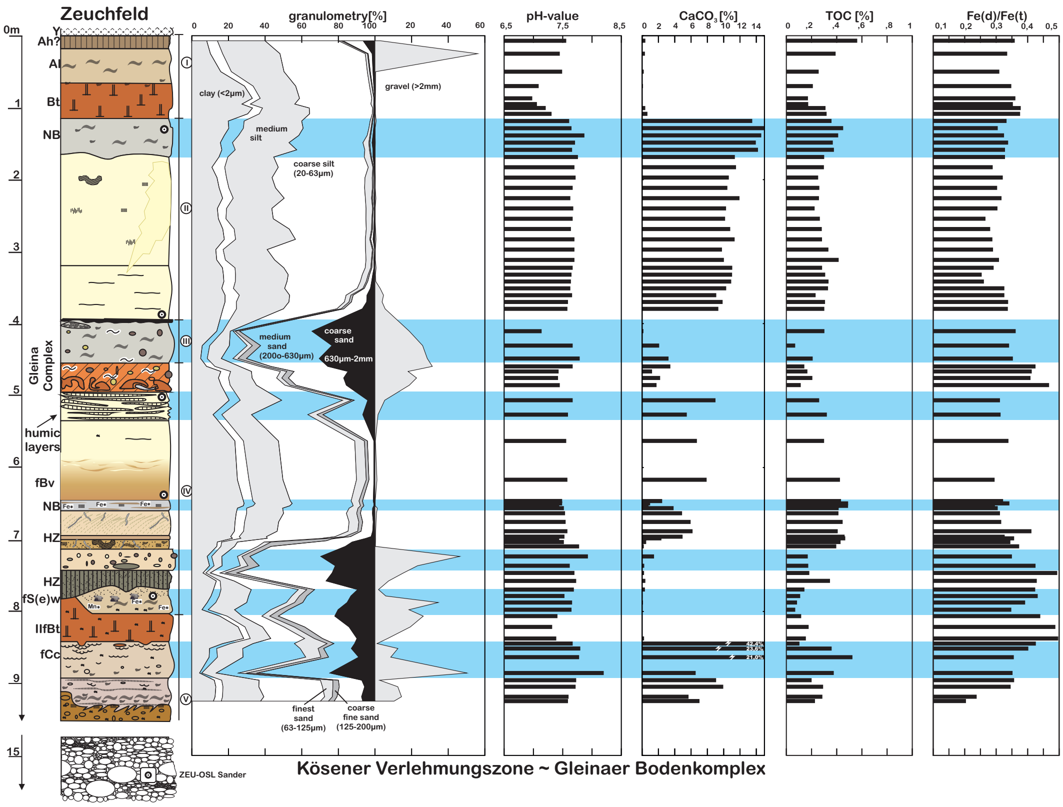


Figure A.3: Zeuchfeld section with geochemical results. For OSL dating results of this section see Kreutzer et al. (2014a) or Kreutzer (2012, p. XXVII).

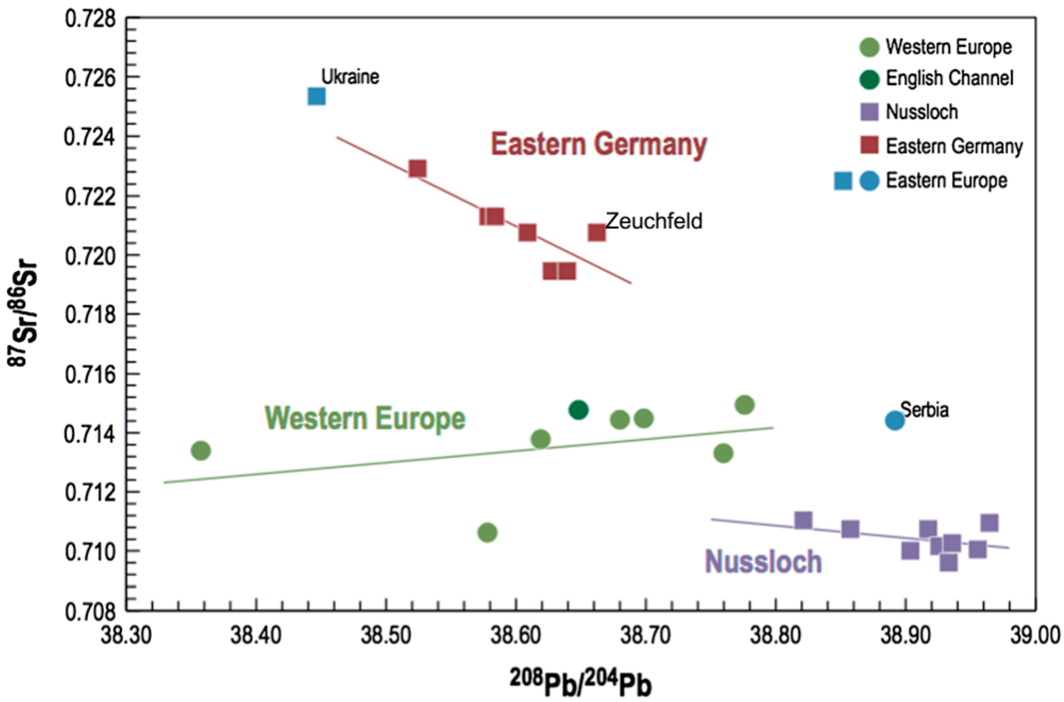


Figure A.4: Isotope ratios ^{87}Sr/^{86}Sr plotted versus ^{208}Pb/^{204}Pb; errors on measurements are smaller than the symbols. Samples from Western Europe, Nussloch, and Eastern Germany define groups that can easily be distinguished. For each geographical group linear regressions are shown.
Slightly modified according to Rousseau et al. (2014, Fig. 3).

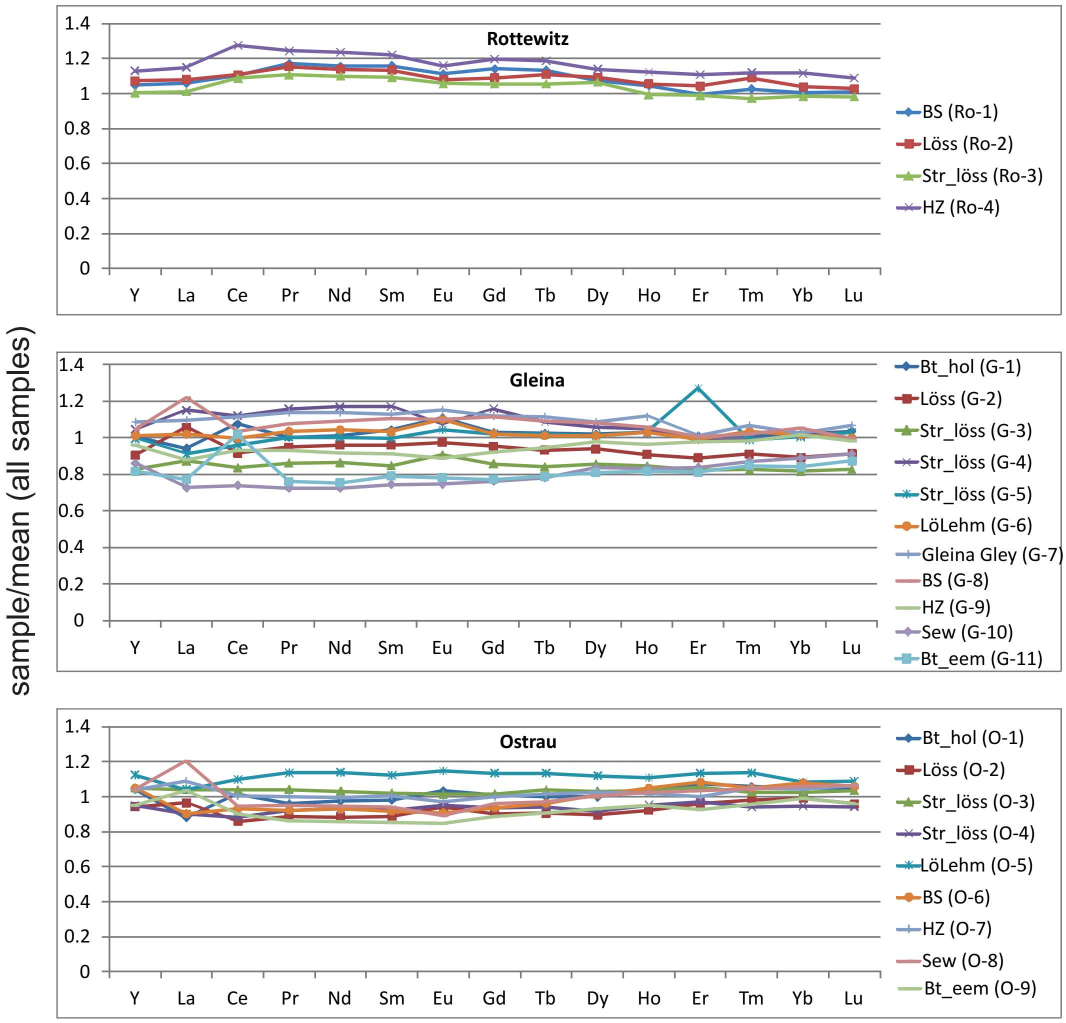


Figure A.5: REE and Yttrium concentration of Saxon LPSs normalised to arithmetical mean of all measured samples

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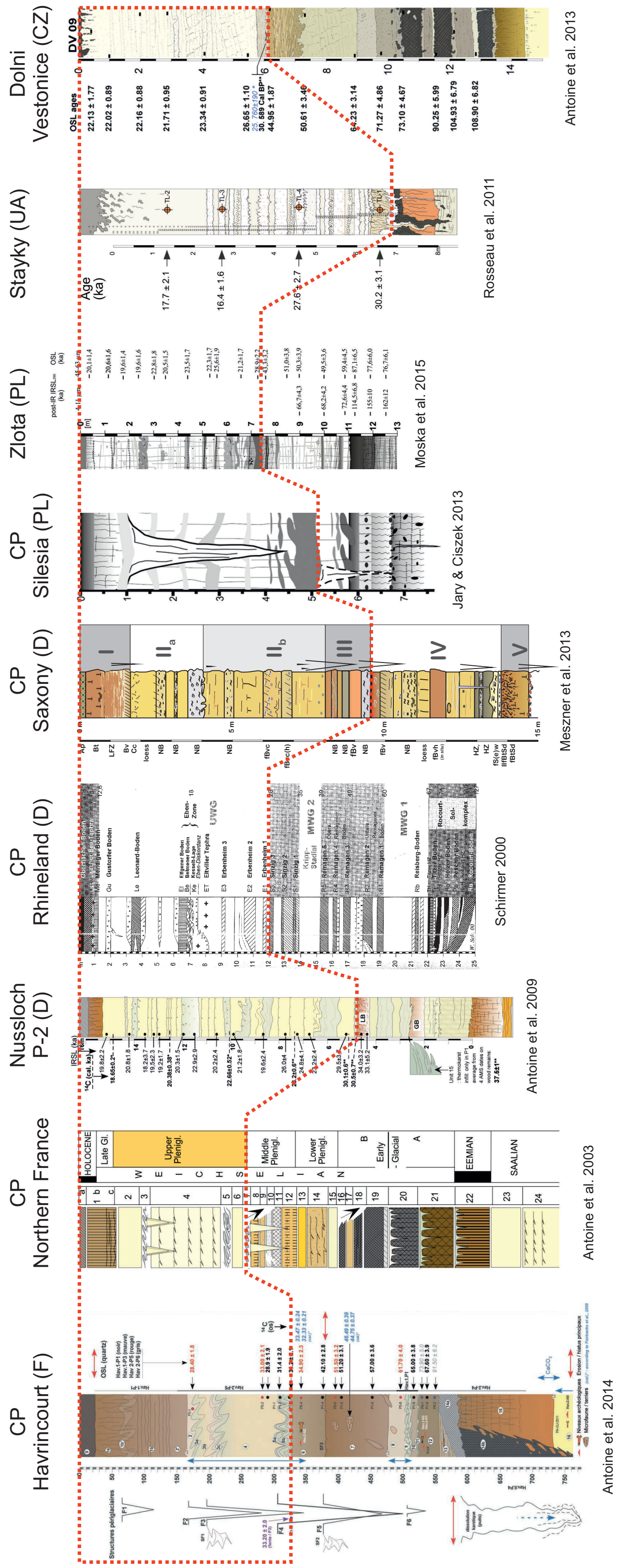
Figure A.6 *(following page)*: Comparative consideration of LPSs from Europe

CP = Composite Profile; the red dotted line circuit the upper Weichselian loess deposits younger ca. <30 ka.

The author is aware of having used the too small figures. However, this scheme should give a overview. For details consult the primary sources or the digital version of this thesis.



CP Havrincourt (F)
Antoine et al. 2014
CP Northern France
Antoine et al. 2003
Nussloch P-2 (D)
Antoine et al. 2009
CP Rhineland (D)
Schirmer 2000
CP Saxony (D)
Meszner et al. 2013
CP Silesia (PL)
Jary & Ciszek 2013
Zlota (PL)
Moska et al. 2015
Stayky (UA)
Rosseau et al. 2011
Dolni Vestonice (CZ)
Antoine et al. 2013

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