ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT

Abh. Geol. B.-A. | ISSN 0378-0864 | ISBN 978-3-85316-043-5 | Band 62 | S. 223–229 | Wien, August 2008

Veränderter Lebensraum – gestern, heute und morgen

Hauptversammlung der Deutschen Quartärvereinigung e.V. (DEUQUA) in Wien: 31. August – 6. September 2008

Palaeoecological Investigations on the Loess Profile of Duttendorf in the Northern Alpine Foreland

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Salzburg
Oberösterreich
Quartär
Salzachgletscher
Löss
Sedimentologie
Palynologie

Österreichische Karte 1 : 50.000
Blätter 44, 45, 46

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Zusammenfassung

An Lößablagerungen der Lokalität Duttendorf, im Periglazialraum des pleistozänen Salzachgletschers (OÖ) gelegen, wurden sedimentologische, paläopedologische und paläoökologische Untersuchungen durchgeführt. In der hier präsentierten Neu-Aufnahme des Profils wurden erstmals Untersuchungen von Pollen und Makroresten unternommen. Der obere Teil des Lößprofils wurde im letzten Hochglazial abgelagert, was durch eine frühere Radiokarbondatierung an fossilen Molluskenschalen sowie neuere OSL-Datierungen belegt ist. Der Pollengehalt aus acht ausgewählten Proben zeigt das Bild eines offenen Graslandes, vor allem im oberen Teil des Profils, mit etlichen krautigen Arten. Die Anwesenheit von hygrophilen Arten deutet auf humidere Bedingungen zu hochglazialen Zeiten hin, als bisher vermutet, und die (zumindest) zeitweilige Präsenz von offenen Gewässern. Dies wird durch den sedimentologischen Befund sowie die Malakofauna bestätigt.

Abstract

Sedimentological, palaeopedological and palaeoecological investigations were carried out on the periglacial loess deposits of Duttendorf (Austria) in the forefield of the Pleistocene Salzach glacier. In the re-investigations presented here, first analysis of pollen and macro remains content of the loess deposit is presented. The upper loess section was positioned into the Last Glacial Maximum (OIS 2) by an earlier radiocarbon date of mollusc shells, which is confirmed by a recent OSL date. The pollen content of eight selected samples shows the picture of an open grassland, especially in the upper loess section, with several herbal taxa. The presence of hygrophilous plant species points to more humid high glacial conditions than previously supposed and the (at least) temporal presence of open water bodies. The sedimentological account and especially the malacofauna underpin this picture.

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1. Introduction

Loess has grown more and more important as a palaeoclimatic record during the 20th century (PYE, 1987; KUKLA & CILEK, 1996; MUHS, 2007), a fact that is underpinned by numerous studies from loess regions around the world, especially China, Central Asia and Europe.

In Europe, the period of the last glaciation seems to be best preserved (ROUSSEAU, 2007), although older Quaternary sequences are known e.g. from the classical site at Krems (Austria) (FINK & KUKLA, 1977). While recently some very detailed studies on loess sequences in Western Europe were carried out e.g. at Nussloch in Germany (ANTOINE et al., 2001), the number of new works from Europe remains limited. This is the case especially for palaeoecological works, although a number of such studies from sites around the world have shown that loess sequences can contain a sufficient amount of palynological content.

This makes it additionally interesting to perform such investigations on sediments in the Northern Alpine foreland. In the following, first palaeoecological investigations at the Loess deposits in Duttendorf (Upper Austria) are presented.

2. Loess as a Palaeoclimatic Information Source

Loess-palaeosol-sequences (LPS) are a valuable information source for Quaternary Science. They offer information about past climatic and environmental conditions and changes, which in many cases is not available from other types of terrestrial deposits (ANTOINE et al., 2001; SMALLEY et al., 2001; ROUSSEAU et al., 2007). While loess is generally produced and deposited under cold climatic conditions, palaeosols evolve under temperate and warm conditions (interstadial/interglacial). Thus, stratigraphical sequences of loess deposits and fossil soils/palaeosols represent climatic and environmental change over long time periods (KUKLA, 1977; KUKLA & CILEK, 1996).

Important efforts in loess research were made throughout Europe and other parts of the world during the 20th century, especially since the INQUA (sub)commission on loess was established under the Austrian scientist Julius FINK in 1962 (SMALLEY et al., 2001; ZÖLLER & SEMMEL, 2001). Recently, a new loess map for Europe was presented (HAASE et al., 2007). According to the simplified definition of PYE (1987, 1995), loess is a terrestrial windblown clastic sediment, which is composed predominantly by silt-sized particles (~20–40 μm diameter) of quartz, feldspar, mica and clay mineral particles. Typical loess contains up to 10 % of fine sand (>63 μm), and a clay (<4 μm) portion of up to 20 % is not unusual. Following PYE (1995), two essential criteria qualifying sediments as loess can be pointed out:

a) the deposit consists principally of wind deposited silt,
b) accumulation occurred sub-aerially.

Today, loess is considered to be highly connected with Quaternary glaciation, which, due to the distribution of land masses, in the past took place predominantly in the Northern hemisphere. Consequently, the largest loess covered areas occur in North America (Great Plains) and Eurasia (Western, Central and Eastern Europe; Central Asia and China). The largest loess areas in the Southern Hemisphere can be found in Southern South America, from La Pampa to Patagonia (SMALLEY, 1995; ROUSSEAU, 2001; MUHS, 2007).

3. European Loess

The European loess is the westernmost part of the world's largest and most voluminous loess belt that continues eastwards to Central Asia and, finally, to the Chinese Sea (PYE, 1987; ROUSSEAU et al., 2007). The first loess map for Europe was produced by GRAHMANN (1932). In a new map by HAASE et al. (2007), the loess deposits from the European part of Russia, Ukraine, the Northern Caucasus, East Europe, the Balcan region, Central and Western Europe are differentiated after thicknesses, loess types and loess-like sediments. After ROUSSEAU et al. (2007), the European loess is mainly composed of quartz, next to feldspars, carbonates and clay minerals, and generally lies outside the great Pleistocene glaciation areas of Fennoscandia and the Alps. The best preserved LPS in Europe originate from the last glacial cycle, but sequences ranging far back into the older Pleistocene (>~400 ka) can also regularly be found (e.g. BOLIKHOVSKAYA & MOLODKOV, 2006; ROUSSEAU et al., 2007). One of the best studied loess profiles in Europe is situated at Nussloch/Germany (ANTOINE et al., 2001; ROUSSEAU et al., 2002). Text-Fig. 1 gives an overview of the loess distribution in the Northern Alpine foreland of Germany and Austria and the last Pleistocene Last Glacial Maximum (LGM) extent of approx. 22 ka ago.

4. Regional Setting

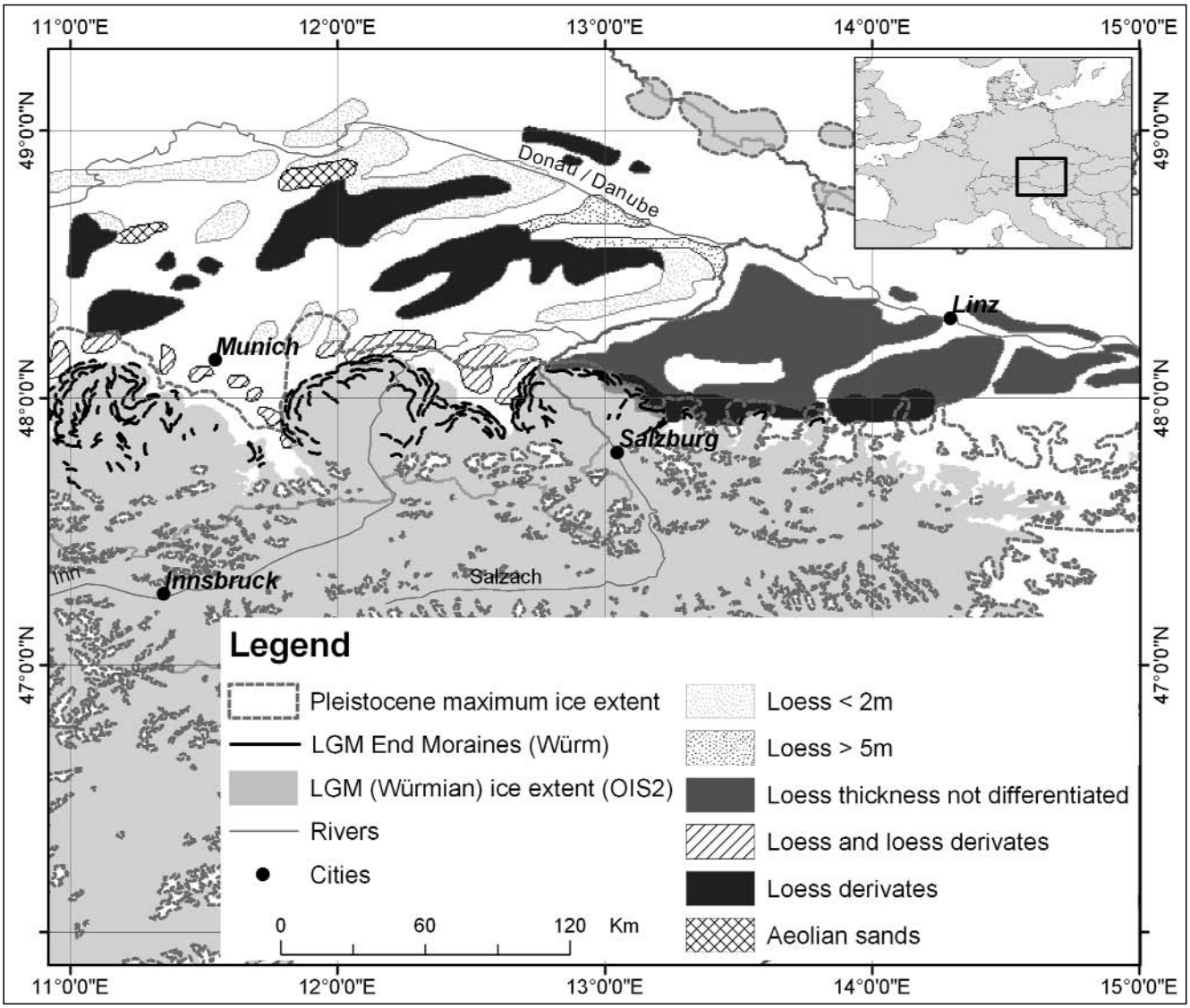
The central part of the Northeastern Alps is defined by the Inn valley, which is the largest drainage system in the Eastern Alps, as well as by the Salzach and Enns valleys (VAN HUSEN, 1997). Of all the large Pleistocene glaciers in the Northern Alpine foreland (like the Rhine, the Isar-Loisach or the Inn glaciers), the Salzach glacier was the last one to the East, followed only by relatively small glaciers. The former Salzach glacier area is situated in the present-day's bordering region between Austria and Germany and is named after the river Salzach (see Text-Fig. 2).

The loess profile of Duttendorf (Austria; 48° 09' 39" N, 12° 50' 13" W; 420 m a.s.l.) is situated approximately 40 km north of the city of Salzburg and 110 km east of Munich (Text-Fig. 1), ca. 5 kilometres north of the LGM moraines and only a few hundred meters south of the Riss moraines of the former Salzach glacier. Today's average annual mean temperature and precipitation sums are 8.6°C and 865 mm.

At this location, the river Salzach eroded up to 60 / 80 m into the Pleistocene and Miocene sediments, forming a large natural escarpment on a steep slope next to the riverbank.

5. Scientific History of the Salzach Glacier Region

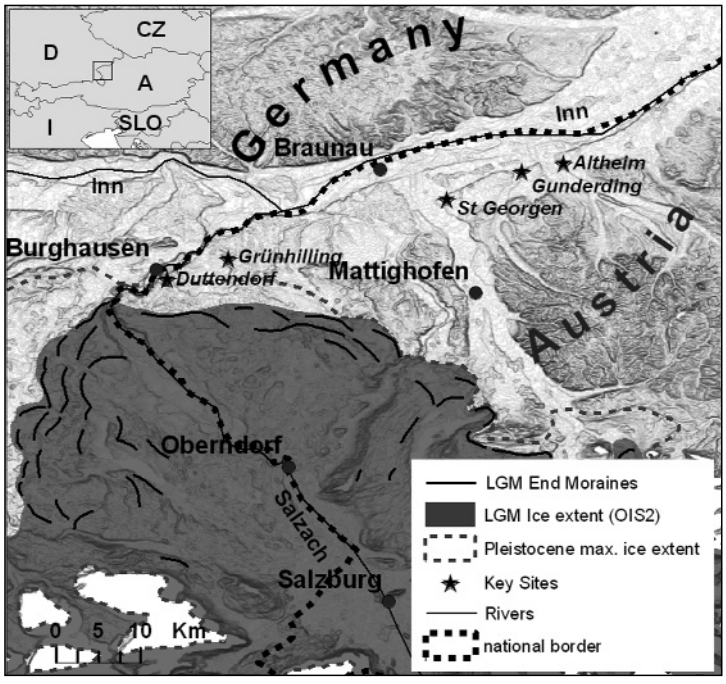
The Northern Alpine foreland in Europe has always been one of the "hot spots" for Quaternary research, and even before Albrecht PENCK and Eduard BRÜCKNER established their fundamental theory of the four major Pleistocene glaciations (Günz, Mindel, Riss, Würm) based on fieldwork throughout the European Alps and their forelands (PENCK & BRÜCKNER, 1909/11), E. BRÜCKNER wrote his PhD thesis on the Pleistocene Salzach glacier (BRÜCKNER, 1886). Since then, over a hundred years of intensive research has led to some detailed insights into the Quaternary history and landscape genesis of that area (e.g. GÖTZINGER, 1936; WEINBERGER, 1950, 1954, 1955, 1957; EBERS, 1952, 1955, 1960), cumulating in a glacio-morphological map of the Pleistocene Salzach glacier region (EBERS et al., 1966). Later, and amongst others, EICHLER & SINN (1974), GRIMM et al. (1979), DOPPLER (1980, 1982), ZIEGLER (1983) and DOPPLER & GRIMM (1983) focused on the German northwestern part of the former Salzach glacier. TRAUB & JERZ



Text-Fig. 1.
The Eastern Alps during the last glacial maximum (LGM) and today's loess distribution in their Northern foreland.
Glacial extents and end moraines after EHLERS & GIBBARD (2004); loess types and distribution after HAASE et al. (2007).

(1975) were the first to investigate the loess deposits of Duttendorf, where they could produce a LGM radiocarbon date out of fossil mollusc shells, resulting in an age of 21,650±250 years BP (uncalibrated [TRAUB & JERZ, 1975]), which after MONEGATO et al. (2007) corresponds to an age of 25,912–25,044 calibrated years BP. After KOHL (2000) and VAN HUSEN (2004) this date remained the only absolute dating for the last glacial maximum of the Salzach glacier until recent time.

The latest results of detailed investigations on the Eastern (German) part of the Salzach glacier region were presented by GRIMM et al. (1979). Some following works from the German part of the Salzach glacier region focus on small investigation areas or on specific aspects of the area (e.g. DOPPLER, 1982; ZIEGLER, 1983; DOPPLER & JERZ, 1995; STRATTNER &



Text-Fig. 2.
Overview of the Pleistocene Salzach glacier and its periglacial areas together with the position of the Duttendorf site and some other selected loess sites (Grünhilling, St. Georgen, Gunderding and Altheim; black asterisks).
Glacier extents according to EHLERS & GIBBARD (2004).

ROLF, 1995; JERZ, 1999). For the glacial and periglacial areas of the Austrian parts of the region, the investigations of WEINBERGER (1950, 1954, 1955, 1957), cumulated in a monography on the Pleistocene Salzach glacier (EBERS et al., 1966), still represent the Austrian state of the art in most cases. In recent times, re-investigations especially on the periglacial regions of the Pleistocene Salzach glacier were carried out, resulting in numerous pedostratigraphical informations and OSL datings especially on Middle and Upper Pleniglacial LPS from the Inn terraces in the periglacial area of the Salzach glacier (TERHORST et al., 2002).

All these investigations form a very good basis for further works, especially in the periglacial area of the Salzach glacier, where many questions still remain to be answered.

6. Materials and Methods

In 2005 four sediment samples from the calcareous and fossiliferous upper part of the loess profile at Duttendorf, first described by TRAUB & JERZ (1975), were tested for their palaeoecological content (pollen, NPPs and macro remains). The results of this analysis give a first insight into the vegetation composition during the accumulation phase of the Upper loess at Duttendorf (STARNBERGER et al., 2008). The encouraging results from the Duttendorf loess led to the decision to proceed with further studies in more detail and for the entire profile, including the basal loess deposits as well as the underlying fossil soil horizon (STARNBERGER et al., accepted).

6.1. Analysis of Pollen and Extrafossils

In order to analyse the representative content of pollen, extrafossils, charcoal and other botanical and zoological microremains, a selection of eight sediment samples was made (10 g each). Samples were first sieved in order to get the grain fraction between 7 and 150 μm, and were then treated with HCl, hydrofluoric acid (HF), and Acetolysis, according to the standard procedure for pollen analysis following SEIWALD (1980) and MOORE et al. (1991). In order to get insights into the concentration of all palynomorphs, marker spikes (*Lycopodium*) were added following STOCKMARR (1971). Palynological analysis was performed by using the reference collection of the Institute of Botany (University of Innsbruck) and identification literature as MOORE et al. (1991), FAEGRI & IVERSEN (1989), as well as BEUG (2004).

6.2. Macro Remains

For analysis of macro content of the loess sediment, 400 g of each sample was sieved with water in order to get the grain size fraction between 150 and 250 μm. The samples from the upper loess (DD-N-1 to DD-N-5) additionally were treated 2–3 min with ultrasound before sieving, in order to destroy anorganic aggregates.

6.3. Molluscs

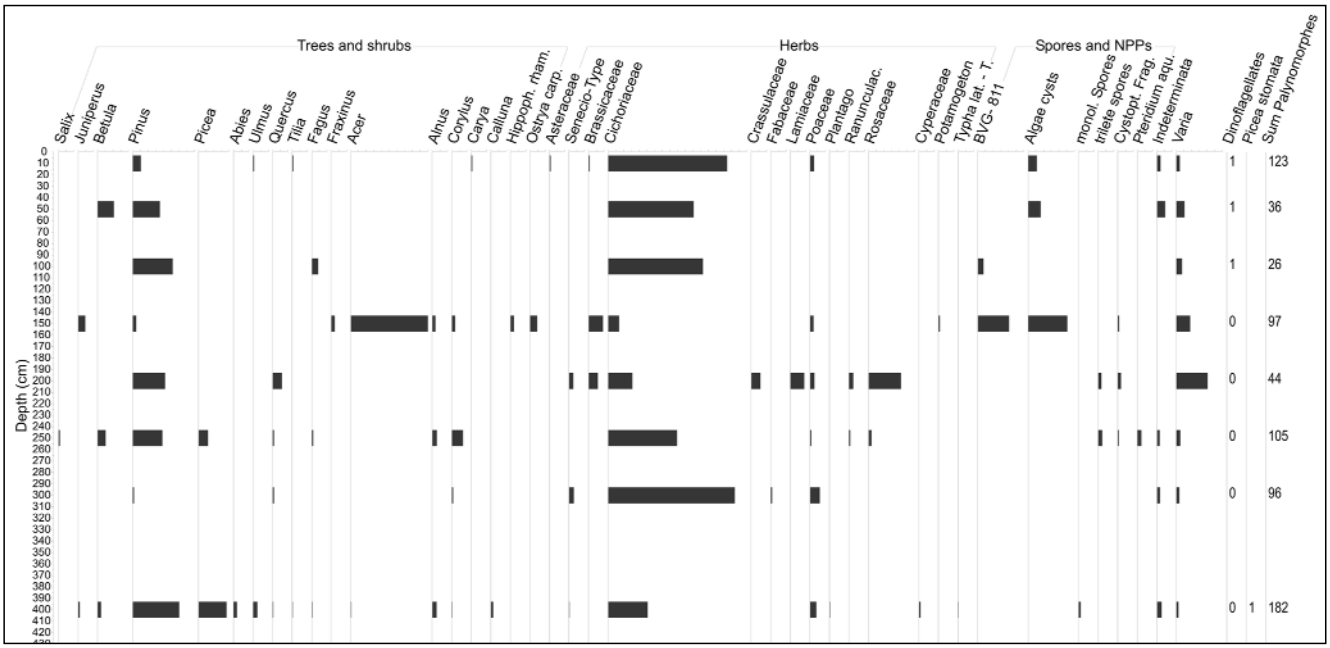
The molluscs from the fossiliferous upper loess in Duttendorf were already investigated in detail by TRAUB & JERZ (1975). Our own malacological analyses were therefore restricted to the sieving of few relatively small sediment samples from the most fossiliferous sections of the profile (STARNBERGER et al., 2008; STARNBERGER et al., accepted). Here, five mollusc species were determined to species level. Additionally and in contrast to the work by TRAUB & JERZ (1975) also *Clausilia rugosa parvula* occurred in small amounts in the sieved samples from the lower section of the upper loess. The presence of *Columella columella, Pupilla muscorum densegyrata* and *Arianta arbustorum alpicola* confirm the cold climatic conditions, under which the high glacial fauna must have lived. Classical Index taxa for interstadials were not found. However, from the molluscal taxa represented in this study, *Trochulus hispidus* (syn. *Trichia hispida*) and *Arianta arbustorum* are extraordinarily dominant. Especially the strong dominance of the relatively large mollusc *Arianta arbustorum* is quite unusual for loess faunas. On the other hand, small molluscs are relatively rare in the Duttendorf loess section, unlike in other comparable loess studies.

7. Results

The pollen concentration throughout the whole profile is relatively low, with values between 36 and 297 grains per 1 g of sediment, which is comparable to other studies performed in loess sediments (e.g. FRENZEL, 1964A; SUN et al., 1997; ROUSSEAU et al., 2001; FENG et al., 2007; see Text-Fig. 3). However, the high amounts of Cichoriaceae in most of the samples (see below) are remarkable and point to possible selective preservation conditions. In the pollen diagram, elements considered as local flora (Cichoriaceae, water plants) were excluded from the total sums in order to calculate percentage values.

The sedimentological characteristics of the loess deposits, like the repeated presence of pebbles and the deposition of the material in a channel structure leads to the interpretation that not all of the sediments are from aeolian genesis. More likely, the sediment was at least partially swept together and reworked by water, resulting in an alluvial loess. The analysis of palynomorphs, macro remains and mollusc shells underpins this idea: in the pollen diagram especially the upper section ("Upper Loess", 200 cm and above) contains water plant pollen like *Typha latifolia*-type and *Potamogeton*, besides numerous algae cysts, spores from wetland ferns like *Cystopteris fragilis* and (reworked) dinoflagellates. Further, the malacological fauna, which is also concentrated in this upper section of the profile, consists mainly of more or less hygrophilous species. According to LOŽEK (1964, 2001) a mollusc assemblage such as the one found at Duttendorf may indicate a spectrum from typical loess steppe to humid woodland habitats.

Text-Fig. 4 shows a comparison between pollen groups and molluscs: the hygrophilous *Arianta arbustorum* dominates most parts of the upper loess in the profile (from 200 cm up to 10 cm depth), with varying abundances. The lowest section of the upper loess (around 200 cm) starts with small amounts together with *Succinella oblonga* and *Trochulus hispidus*, altogether indicating rather humid conditions. The pollen information refines this picture into a mixture of *Pinus*-dominated woodland and rather diverse open grassland with some indicators of humid conditions. At about 150 cm, *Arianta arbustorum* reaches its overall highest values, connected with some amounts of *Succinella oblonga* and *Trochulus hispidus*. Also, the tree pollen percentages rise slightly, while herb values are low, and several hydrophilous taxa appear, indicating water bodies in the near surroundings. At about 100 cm the index loess species *Columella columella* appears, however in very small amounts, indicating cold and high glacial conditions, together with *Pupilla muscorum densegyrata*, another typical loess species. *Succinella oblonga* shows high percentages, and also *Trochulus hispidus* is present. The pollen spectrum changes into a rather open grassland mixed with *Pinus* communities. In the zones at 50 and 10 cm, *Columella* disappears, while *Pupilla* remains present in small numbers. *Arianta* reaches another maximum at 50 cm, together with *Trochulus hispidus*, which grows into even larger percentages at around 10 cm, whereas *Arianta arbustorum* almost disappears. The vegetation remains dominated by grasses and herbs and some scattered woodland elements from 100 to 50 cm, while the

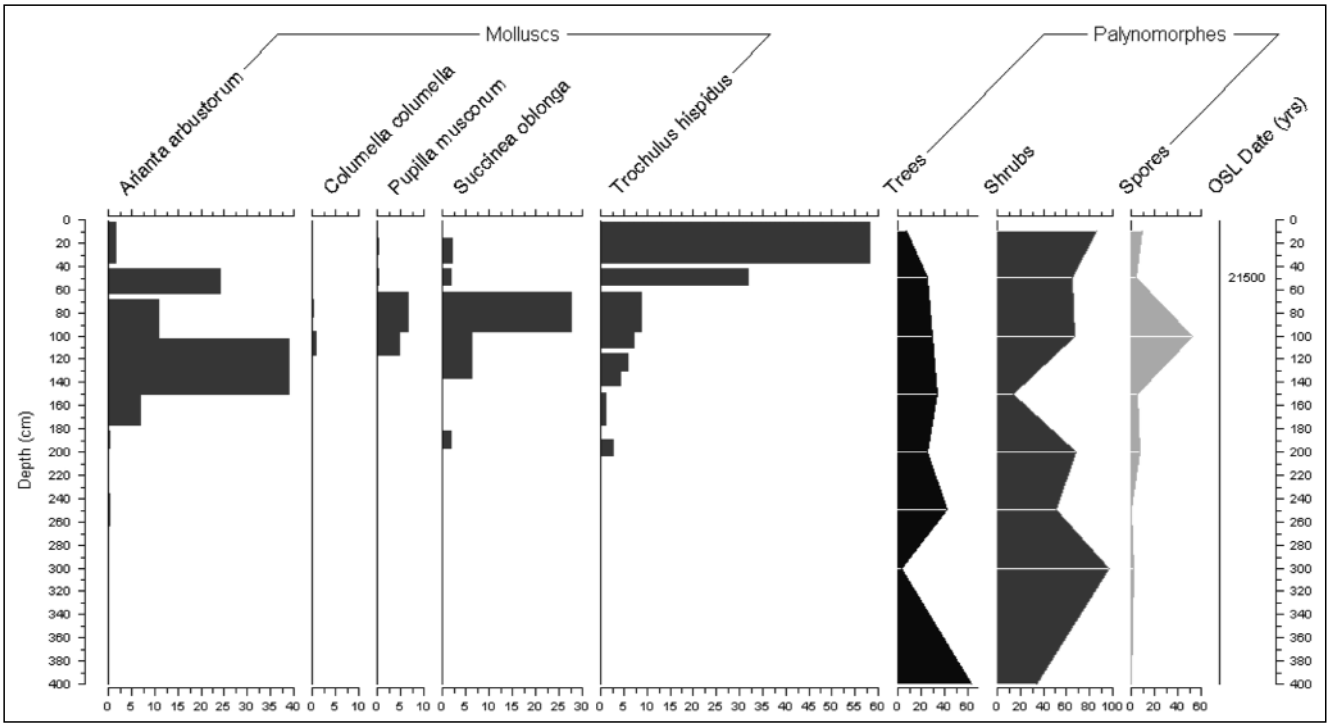


Text-Fig. 3.
Pollen data from selected loess sediment horizons from Duttendorf.
From left to right: Arboreal pollen, non-arboreal (herb) pollen, and extrafossil taxa (see text for details).

wetland indicators decrease again into smaller values. At 10 cm depth, the picture is quite the same, but with lower arboreal and higher herb percentages.

8. Discussion

The classification of the Duttendorf profile is of special interest due to the geomorphological position of the sediments. The radiocarbon dating of 21,650±250 (= 25,912–25,044 calibrated [MONEGATO et al., 2007]) years BP performed earlier (TRAUB & JERZ, 1975) on the upper part of the profile could be generally confirmed by an OSL dating from the same stratigraphical position (50 cm depth) which gives a slightly younger age of approx. 21,500 (±2,300) years BP (Prof. Dr. Manfred FRECHEN, GGA Hannover; see STARNBERGER et al. [2008]; STARNBERGER et al. [accepted]). Thus, the time of deposition of the upper part of the loess can clearly be assigned to the Last Glacial Maximum (OIS 2). Pollen, macro remains and especially the malacofauna underpin the high glacial origin of the sediment. Comparison of the dating results at Duttendorf with



Text-Fig. 4.
Comparison between the malacofauna described by TRAUB & JERZ (1975) and the pollen groups, both from the loess profile at Duttendorf.
At the right hand, the OSL date from 50 cm depth (below the upper limit of the loess) is added.

OSL dates performed on loess deposits on the nearby Innterraces shows that the time span of the deposition at Duttendorf falls into the first and older phase of loess accumulation in the larger area, with the oldest high-glacial deposits dated to 22,600±3,300 years BP in Altheim (TERHORST et al., 2002). So, the absolute datings at the Duttendorf site can be used to estimate a maximum age of the gravel outwash ("Niederterrasse") at this location.

The results of the pollen and macro remains analysis additionally contribute to the picture of a cold, open grassland, which has been drawn before e.g. by FRENZEL (1964a) for lower Austria. On the other hand, several indicators for humid conditions point to a damper climate and the (at least temporal) influence of flowing water: in the lower part of the upper loess section, the high amounts of shells from *Arianta arbustorum*, a species that indicates rather mesic to damp open landscapes, occur with a peak of algae cysts. In depths of around 100 cm, *Pupilla muscorum* is more abundant than *Columella columella*, pointing to steppe conditions (ROUSSEAU, 2001). This fits to the fact, that, in order to grow, the ice volume of a glacier requires low temperatures but also enough supply of moisture (see ROUSSEAU, 2001, p. 164). It is remarkable, that the high-glacial loess steppe sediments contain rather few Poaceae pollen (except for the sample at 10 cm depth), a fact that is hard to interpret, but is already reported e.g. by FRENZEL (1964a). Also, the presence of some arboreal pollen, mainly from *Pinus*, does not fit into the traditional picture of a treeless dry steppe landscape in central Europe during OIS 2.

The lowermost sample from the supposedly redeposited palaeosol which is to be correlated with the sediments from the last interglacial (Eemian) after TRAUB & JERZ (1975) is, as already mentioned above, not only sedimentologically, but also from the palynological point of view, very different from all other samples: It indicates a dense coniferous forest with some thermophilous, deciduous elements scattered in. Characteristic last interglacial species like Carpinus, Taxus, Hedera or Buxus, reported from other localities in the Northern Alpine foreland like Mondsee (Austria; KLAUS, 1987; DRESCHER-SCHNEIDER, 2000), Samerberg (Bavaria; GRÜGER, 1979) or Jammertal (Germany; MÜLLER, 2000) were not found. This points to a chronostratigraphical position younger than Eemian age of these Duttendorf sediments, although reworking of fossil Eemian soil material through cryoturbation cannot be excluded.

9. Conclusions

The upper pleniglacial origin of the upper loess section at the Duttendorf site was already shown by a radiocarbon date (TRAUB & JERZ, 1975) and was confirmed by a OSL dating in the present work. The sedimentological characteristics, malacofauna, pollen and macro remains from this upper loess section point to more humid conditions at the onset of OIS 2 (150 and 200 cm depth), while the OSL date of 21,500 years BP at the Profile (50 cm) is located together with pollen and molluscs who indicate cold and dry conditions.

The lower loess section, classified as middle pleniglacial formation, clearly differs in sedimentological characteristics as well as in pollen and macro remains content, showing changing climatic conditions of cold to temperate phases, without a characteristic upper pleniglacial malacofauna.

The classification of the basal fossil soil material as Eemian palaeosol by TRAUB & JERZ (1975) cannot be supported by this re-investigation.

Finally, the loess profile at Duttendorf seems to represent a special situation due to its palaeogeomorphological situation, the relative closeness to the LGM tongue of the Salzach glacier and the exceptional richness in the mollusc remains of *Arianta arbustorum alpicola*. The presented results lead to the conclusion that there might be a potential for further palaeoecological and palaeoclimatological investigations in the loess area of the western part of Upper Austria, and besides other sites already mentioned (Gunderding, Altheim), there are more locations which are worth being investigated in the future (e.g. Grünhilling and St. Georgen, see Text-Fig. 2).

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Manuskript bei der Schriftleitung eingelangt am 20. Juni 2008