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A stratigraphic concept for Middle Pleistocene Quaternary sequences in Upper Austria

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Abstract: Three profiles of loess-palaeosol sequences on top of Middle Pleistocene fluvioglacial terraces of the Traun-Enns-Plate are investigated in the region of Wels (Upper Austria), each of them representing characteristic Middle Pleistocene sequences for the northeastern Alpine Foreland. The sequences comprise thick pedocomplexes, providing the opportunity to distinguish and to classify specific interglacial palaeosols. The loess-palaeosol sequence of Oberlaab developed on top of the fluvioglacial terrace of the classical Mindel (Younger Deckenschotter) shows four interglacial palaeosols. This fact suggests that the age of the terrace is at least the fifth to last glacial period, correlative to MIS 12. The cover layers on top of classical Günz terrace (Older Deckenschotter) in Neuhofen and Wels-Aschet include five palaeosols. Both sites are characterised by intense pedogenesis in the basal pedocomplex, which is considerably more pronounced than in the overlying palaeosols. Pedostratigraphic results point out that the genesis of the studied Günz Deckenschotter can be correlated to MIS 16 (minimum age).

Ein stratigraphisches Konzept für mittelpleistozäne Quartärabfolgen in Oberösterreich

Kurzfassung: Auf den mittelpleistozänen fluvioglazialen Terrassen der Traun-Enns-Platte in der Region um Wels (Oberösterreich) wurden drei Löss-/Paläobodensequenzen untersucht. Jedes dieser Profile ist für mittelpleistozäne Abfolgen im nordöstlichen Alpenvorland charakteristisch. Die Profile umfassen mächtige Pedokomplexe, welche eine Differenzierung und Einstufung von interglazialen Paläoböden erlauben. Die Löss-/Paläobodensequenz von Oberlaab ist auf der fluvioglazialen Terrasse des Mindel-Glazials im klassischen Sinne entwickelt (Jüngere Deckenschotter) und weist vier interglaziale Paläoböden auf. Diese Tatsache macht eine Einstufung der Jüngeren Deckenschotter mindestens in die fünftletzte Kaltzeit wahrscheinlich (MIS 12). Die Deckschichten auf den Günz-Deckenschottern im klassischen Sinn (Ältere Deckenschotter) beinhalten fünf Paläoböden. Beide Lokalitäten weisen eine sehr intensive Pedogenese in ihrem basalen Pedokomplex auf, die wesentlich ausgeprägter ist, als in den überlagernden Paläoböden. Die pedostratigraphischen Ergebnisse lassen eine Einstufung der Älteren Deckenschotter mindestens ins MIS 16 zu.

Keywords: *Quaternary stratigraphy, Wels-Aschet, Oberlaab, landscape formation, palaesols, loess*

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1 Introduction

By now, numerous palaeoclimatic curves based on marine drillings give a distinct idea of the number of glacial-interglacial cycles, as well as of the palaeoclimatic evolution of the Middle Pleistocene. Terrestrial studies in Europe are unable to accomplish these targets as they lack dating methods. This is the case especially for the Middle Pleistocene time span in the northern Alpine Foreland. In this context, Habbe (2003) mentions a time gap in numerical datings between the classical Günz and the Upper Pleistocene. The palaeomagnetic boundary at the transition from Lower to Middle Pleistocene (≈780.000 yrs) is therefore of crucial stratigraphical importance as it is one of the rare opportunities to date in the middle and lower Middle Pleistocene. The stratigraphical position as well as the ages of the four classical glacial deposits (sensu Penck & Brückner 1901–1909) are still under discussion. The Quaternary sediments of the western and the eastern Alpine Foreland are hardly correlative also because of the use of different stratigraphic systems and because of the fact that terrace bodies can comprise more than one formation period (Doppler et al. 2011, Schellmann et al. 2010).

For example, on the one hand, the Matuyama/Brunhes boundary (MBB) could be proved in Günz deposits at the location Heiligenberg (Ellwanger et al. 1995) for the western Alpine Foreland in Baden-Württemberg. On the other hand, however, the palaeomagnetic reversal occurred within the Younger Deckenschotter (classical Mindel) near Basel (Zollinger 1991), which coincides with pedostratigraphical results (Bibus 1990). Actually, the stratigraphical system of the Pleistocene Rhineglacier area classifies the formation of the Mindel Deckenschotter as a terrace complex prior to and during the MBB. Furthermore, the Günz Deckenschotter are ranked as Early Pleistocene formations there (Ellwanger et al. 2011). Doppler et al. (2011) developed a stratigraphical scheme for the Bavarian Alpine Foreland, which integrates

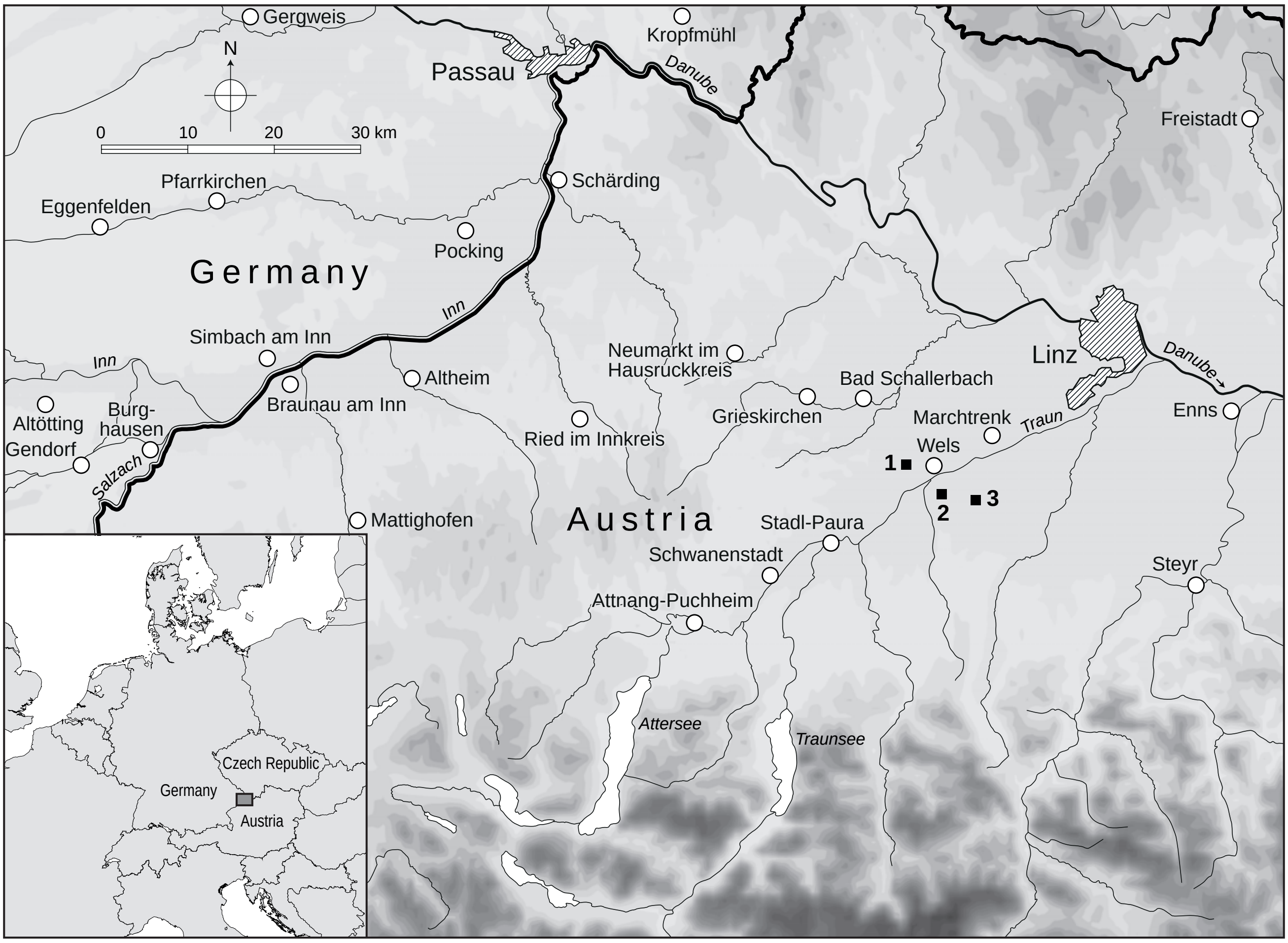

Fig. 1: Study area in Upper Austria. x1 = profile Oberlaab, x2 = profile Wels-Aschet, x3 = profile Neuhofen.

Abb. 1: Untersuchungsgebiet in Oberösterreich. x1 = Profil Oberlaab, x2 = Profil Wels-Aschet, x3 = Profile Neuhofen.

Mindel into the Brunhes-Epoch and Günz sediments mainly to the Matuyama-Epoch. The authors do not exclude that Günz sediments in parts belong to the Brunhes-Epoch. Single datings in the Bavarian foreland obtained with cosmogenic nuclides resulted in 0.68+0.23/−0.24 Ma for a Mindel deposit and 2.35+1.08/−0.88 Ma for a Günzian site (Häuselmann et al. 2007). The error rate for the datings are remarkable high. Furthermore, it has to be mentioned that the formation period of Günz, respectively Mindel sediments in Bavaria do not correspond to those in Baden-Württemberg, in general (Doppler et al. 2011).

In the northeastern Alpine Foreland of Austria the "Günz complex" is assumed slightly above the MBB (Van Husen 2000, Van Husen & Reitner 2011b), as the transition from reverse to normal magnetisation was not yet verified in any sequence, and the studied sediments show positive magnetisation throughout (cf. Kohl 2000).

A stratigraphic classification of Quaternary forms and sediments in the northern Alpine Foreland above the MBB remains problematic. Absolute ages of Middle Pleistocene deposits are ambiguous (cf. Preusser & Fiebig 2009), and detailed subdivisions are still impossible. This eventually results in the difficulty that even comparably complete Quaternary sequences are not available for a correlation on a supraregional scale. As a consequence, this is also shown in the stratigraphic chart of the German Stratigraphic Commission (Deutsche Stratigraphische Kommission 2002), which displays large uncertainties below the Riß complex within the chronostratigraphic correlation of glacial complexes between the northwestern and northeastern Alpine Foreland. The problem further becomes evident in the Austrian stratigraphic chart (Österreichische Stratigraphische Kommission 2004).

For these reasons, palaeopedological/pedostratigraphical studies represent an important factor for the study area in assessing the stratigraphic position of the Younger and Older Deckenschotter. Scholger & Terhorst (this volume) proposed a stratigraphic scheme for the loess-palaeosol sequence of Wels-Aschet, which is situated on top of the Günz Deckenschotter. The authors proved Middle Pleistocene palaeomagnetic excursions and classified them on the base of pedostratigraphy. According to the mentioned study, the uppermost section of the Günz Deckenschotter is older than 570–560 ka (Emperor - Big Lost - Calabrian Ridge 3 excursion) and thus is correlated with MIS 16 (Scholger & Terhorst, this volume). The palaeomagnetic approach was applied for the first time in loess sequences in order to establish a chronological framework for Middle Pleistocene in the study area. In this context, it has to be mentioned that Markovic et al. (2009, 2011) applied rock magnetic parameters to build up a Middle Pleistocene stratigraphy for palaesols and loess sediments of the Middle Danube Basin. The authors were able to correlate their results to marine isotopic curves (see also Bronger 1970).

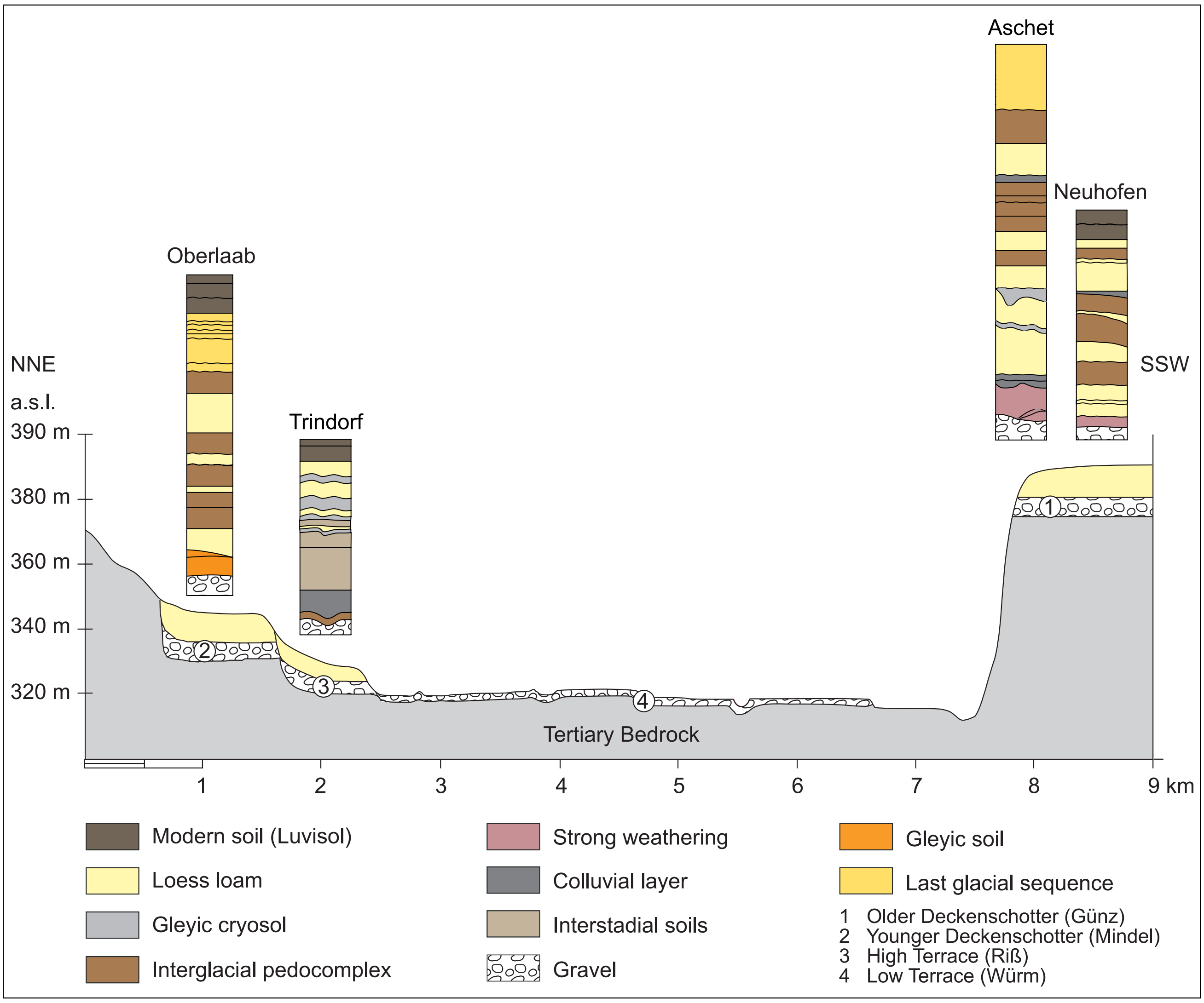

Fig. 2: Geomorphological situation of the presented profiles close to the river Traun/Wels. The uppermost interglacial pedocomplex of all profiles corresponds most probable to the Eemian interglacial soil (see also Scholger & Terhorst, this volume).

Abb. 2: Geomorphologische Situation der präsentierten Profile in der Umgebung der Traun bei Wels. Der oberste interglaziale Pedokomplex entspricht mit hoher Wahrscheinlichkeit jeweils dem Eem-Interglazialboden (vgl. Scholger & Terhorst, dieser Band).

In general, Middle Pleistocene terrestrial stratigraphy is still at its starting point and detailed research with palaeopedological and magnetostratigraphical methods as well as with new luminescence approaches is crucial for the development of a regional terrestrial stratigraphic framework as a first step. Moreover, for future research there is a need i) to correlate terrestrial regional results with each other and ii) to link to results of global palaeoclimatic archives.

This study is intended to propose a Middle Pleistocene stratigraphic framework for Quaternary sediments in the region of Wels.

1.1 Study area

The study area is situated on the Traun-Enns plate between Wels and Linz (Fig. 1). The mean annual air temperature is at 9.1°C, precipitation accounts for 821 mm per year. Holocene soils as developed in terraces, loess and loess-like sediments are Luvisols (Parabraunerde) with transitional stages to Stagnosols (Pseudogley).

The sequence of fluvioglacial terraces is presented in Figure 2. It shows the spatial situation of the classical morphostratigraphic elements (cf. Penck & Brückner 1901–1909). In the lowermost position, two Würmian terraces are present close to the present day floodplain of the river Traun. The Riß terrace in Figure 2 occurs at the left hand side, separated only by a small step to the next higher terrace level of the Younger Deckenschotter (~340m a.s.l.). The position of the Older Deckenschotter in Wels is at ~380 a.s.l. covered by a loess palaeosol sequence of up to 10 m thickness. Profile Neuhofen on top of the Older Deckenschotter is situated 15 km to the east.

For the maximum advances of the younger main glacial phases of Riß and Würm, marine isotopic stages MIS 6 and 2 are correlative (Terhorst et al. 2002). Most probably, Günz and Mindel occur simultaneously with phases of massive global climate decrease during MIS 16 and MIS 12 for the study area (van Husen & Reitner 2011b).

The studied Younger and Older Deckenschotter are covered with loess and loess loams, reaching a thickness up to 12 m and comprising extensive palaeosols and pedocomplexes.

Studies on Quaternary deposits in the study area are avail-

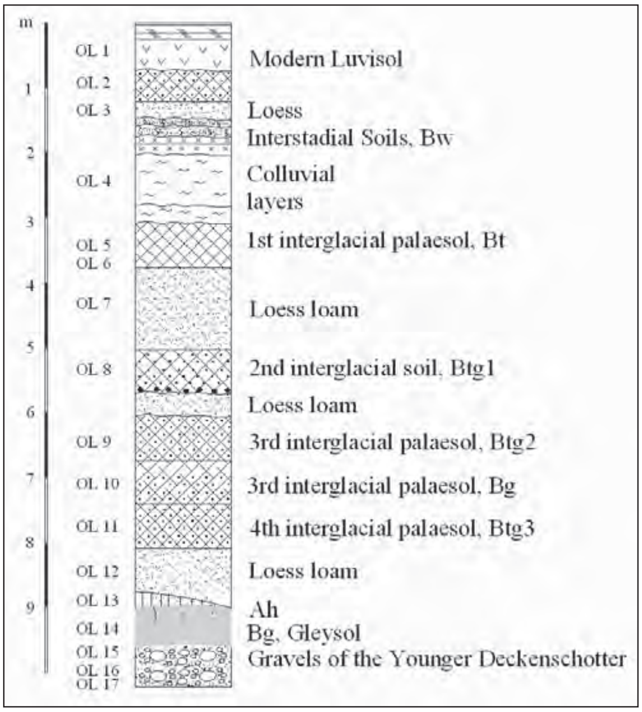

Fig. 3: Detailed palaeopedological profile of the Quaternary sequence Oberlaab on top of the Younger Deckenschotter (Mindel).

Abb. 3: Detailliertes paläopedologisches Profil der quartären Abfolge in Oberlaab auf den Jüngeren Deckenschottern (Mindel).

able by Kohl & Krenmayr (1997), Stremme et al. (1991) and Fink et al. (1978). Analyses on the sedimentological and mineralogical composition of the cover layers were performed by Terhorst et al. (2003) and Terhorst et al. (2011a, b).

In total, three Middle Pleistocene loess-palaeosol sequences of the Traun-Enns plate are presented, of which one profile is situated on top of the Younger Deckenschotter, while two evolved in the Older Deckenschotter. In general, the studied loess sediments are decalcified loess loams, undergone weathering processes and later redeposition. All described palaesols have been affected by polygenetic pedogenesis and thus, correspond to pedocomplexes, although the expression partly palaesol is used.

In order to give the complete view of Quaternary sequences in the study area, the Upper Pleistocene sequence is involved in the stratigraphic scheme, however, not described in detail here (see Terhorst et al. 2002).

2 Palaeopedological Results

2.1 The cover layers of the Younger Deckenschotter in profile Oberlaab

The loam pit Oberlaab, which is still being quarried, is located about 1.5 km north of Wels and belongs to Pichler brickyard. It represents the only pit currently accessible in the study area, in which the Younger Deckenschotter with superimposed cover layers is exposed.

The walls have been investigated several times and the situation in 2001 is presented by Terhorst (2007). Detailed field analyses were conducted in form of an international cooperation in the year 2003, of which the most complete sequence is presented in Solleiro-Rebolledo et al. (this volume).

In 2003, excavated material showed relatively unweathered gravels and sands of the Younger Deckenschotter (Fig. 3, OL 15–17). The terrace gravels are carbonate-free in this location (Fig. 3), and debris from sedimentary rocks is weakly weathered, while crystalline debris shows almost no signs of weathering. However, Kohl (2000) also mentions the occurrence of highly weathered gravels at a former profile section. The terrace deposits are interspersed with distinct bands of iron and manganese.

In the eastern part of the pit on top of the Younger Deckenschotter an intensely greyish Gleysol (OL 14) is encountered, which shows an extraordinarily high number of root traces, and even remains of relic roots occur in places. Immediately on top of it an Ah horizon of up to 60 cm thickness appears locally (OL 13).

The gleyic horizons are covered by a silty, redoximorphic, and also weathered loess loam, which can be traced all over the exposure (OL 12).

The studied wall exhibited before 2003 showed a pedocomplex on top of the above described loess loam with a thickness of up to 2 m (OL 11–OL 9). The latter consists of the basal horizons of two single Stagnic Luvisol pedocomplexes, which were in parts multiply transformed by pedogenesis and correspond to two interglacial phases. Conspicuously, the horizon boundaries are very sharp and linear in some places and could therefore represent erosional surfaces. Interestingly, the single soil horizons (OL 11–OL 9) can be traced by their characteristic features over the entire exposure, which emphasises the independence of each palaeosol. In general, the third Btg horizon is characterised by its intense manganese precipitations and coatings. Additionally, a zone of reduced weathering intensity occurs between the third and fourth fossil soil, which is noticeable by lower clay content with simultaneously higher silt content.

On top of the third Btg horizon a loess loam (OL 8a) follows in some parts of the exposure, which is separated by a stone line from horizon OL 8. OL 8 corresponds to the second well developed Btg horizon and therefore indicates a further interglacial.

The pedocomplex is covered by a loess loam of up to 2 m thickness, which partly was affected by stagnic conditions (OL 7). Based on its stratigraphic position in the profile, the sediment most probably represents a Rißian loess loam.

On top of it the Eemian interglacial soil in form of a Bt horizon is developed (cf. Sedov et al., this volume).

The western wall of the exposure shows a characteristic sequence of Würmian loess of up to 2 m thickness above the Eemian interglacial soil, which can be compared, even though strongly shortened in this place, to the loess-palaeosol sequences of the Last Glacial, which are present on top of the ‘Hochterrasse’ (classical Riß) in the study area. At the base colluvial layers are encountered (OL 4). On top of these, weakly redeposited residuals of Middle Würmian interstadials are preserved, covered by thin loess (OL 3).

The modern soil is a Stagnic Luvisol with a thickness of more than 1 m (OL 2, 1).

In conclusion, at least four interglacial pedocomplexes (OL 5/6 and OL 8 to OL 11) can be identified in the cover layers of the presented profile.

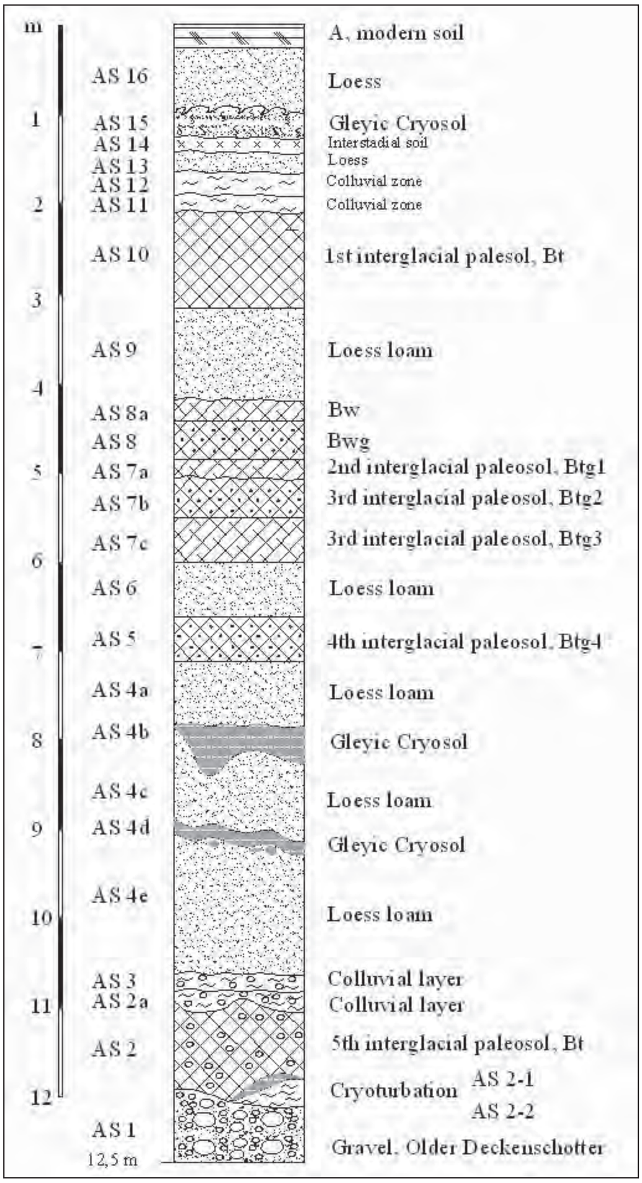

Fig. 4: Detailed palaeopedological profile of the sequence Wels-Aschet on top of the Older Deckenschotter (Günz).

Abb. 4: Detailliertes paläopedologisches Profil der quartären Abfolge in Wels-Aschet auf den Älteren Deckenschottern (Günz).

2.2 The cover layers of the Older Deckenschotter in profile Wels-Aschet

Profile Wels-Aschet was dug up and documented anew in 2003 by a working group headed by Prof. Dr. Dirk van Husen. Older studies on the loam pit of Pichler brickyard in Wels-Aschet are available by Kohl & Krenmayr (1997), Kohl (2000) and Stremme et al. (1991).

Recently, detailed descriptions are available in the study of Terhorst (2007), Terhorst et al. (2011a, b). Stratigraphical concepts have been presented by Preusser & Fiebig (2009) and Scholger & Terhorst (this volume).

The loess-palaeosol sequence of the studied profile reaches a thickness of 12.5 m. It is mostly decalcified while gravel deposits of the Older Deckenschotter show high lime contents.

The basal section of the profile displays an intensely reddish, strong weathering (Fig. 4, AS 2) with dark red clay cutans in the gravels of the Older Deckenschotter (AS 1). Fine earth shows the highest clay content of the profile. In places, the palaeosol is slightly disturbed by cryoturbations.

Above the palaeosol, which represents at least one interglacial, redeposited, gravel-bearing layers are present, which were covered by a 3.5 m thick loess loam (AS 4a–4e), which is disturbed twice by cryoturbation structures. These structures correspond to relic Cryosols and show an intense greyish brown colouring. This double subdivision of the lower loess loam of the Older Deckenschotter was already described by Kohl (2000) for Wels-Aschet, as well as for the former exposure Linz/Grabnerstraße (Fink et al. 1978). Within the loess loam AS 4a a palaeosol developed, which is proved by an intensely stagnic, dark yellowish brown Btg horizon of interglacial intensity (AS 5). The soil texture is characterised by silty clay, and clay cutans are widely distributed across the entire horizon. The former topsoil is eroded.

A further, thin and unstructured layer of loess loam (AS 6) overlies palaeosol AS 5. Above this loam a multiply layered pedocomplex is developed (AS 8a–7c). The basal Btg horizons (AS 7b, 7c) are silty clays and contain distinct reddish brown clay coatings on aggregate surfaces. These two lower horizons of the pedocomplex can be clearly distinguished from the overlying second interglacial palaesol (Btg horizon, AS 7a) by an erosional unconformity (wavy horizon boundary) and a change in grain sizes. Above all, the difference appears in the enhanced clay content. Additionally, the hydromorphic soil features are significantly weaker. Horizons 8 and 8a above the pedocomplex cannot be interpreted clearly. They show intensive stagnic conditions along former root channels, in which greyish reduced areas are visible.

On top of the pedocomplex loess loam with 1 m thickness is deposited, which is not subdivided any further (AS 9).

Within the loess loam an interglacial soil is developed, which is represented by an intense, 1.10 m thick, dark brown Bt horizon of a former Luvisol (AS 10), in which only weak hydromorphic features are observed. The interglacial soil corresponds largely with the first Bt horizon of the profile Oberlaab described above (Terhorst et al. 2003, Sedov et al., this volume). This palaeosol horizon is correlative with the MIS 5e (Preusser & Fiebig 2009, Terhorst et al. 2011b).

A Würmian sequence, which in comparison to other profiles is highly shortened, covers the last-mentioned palaeosol. The basal Würmian sediments of profile Wels-Aschet (AS 11, AS 12) correspond to colluvial layers. They are equally interspersed with charcoal as well as rests of the Bt-material of the underlying palaeosol. In the middle section a shortened equivalent of the "Lohne Soil" (acc. to Semmel 1968) (AS 14) can be documented, which is preserved as the youngest Middle Würmian interstadial in almost every Upper Austrian loess sequence (Terhorst et al. 2002). In its upper section the "Lohne Soil" is transformed by an intense Cryosol (Reductaquic). The overlying loess (AS 16) is represented by a decalcified, shallow deposit. The recent soil is missing in this profile section of the former loam pit.

Altogether, profile Wels-Aschet contains five palaeosols of interglacial intensity, while strong weathering of the lowermost palaeosol would support also the idea of six interglacial phases recorded in Wels-Aschet.

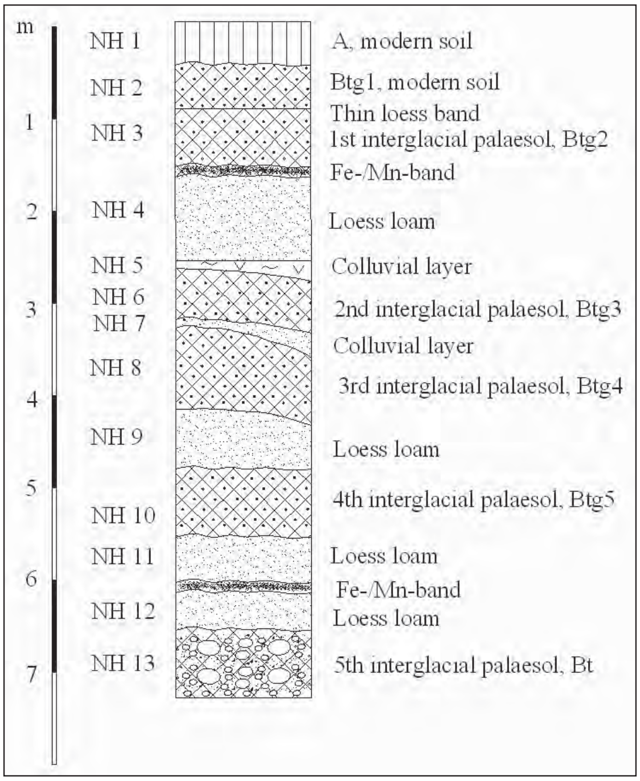

Fig. 5: Detailed palaeopedological profile of the sequence Neuhofen on top of the Older Deckenschotter (Günz).

Abb. 5: Detailliertes paläopedologisches Profil der quartären Abfolge in Neuhofen auf den Älteren Deckenschottern (Günz).

2.3 The cover layers of the Older Deckenschotter in profile Neuhofen

The cover layers of the Obermair loam pit in Neuhofen are on average 6.5 m thick, while in places they can reach a thickness of up to 10 m. They lead into a palaeochannel position with a stratified channel filling in northwestern direction. On the southeastern part the lower, extremely weathered Older Deckenschotter was exposed during the past years (Fig. 5).

The lowermost, intensely weathered pedocomplex has developed in the gravels and corresponds to the fifth palaeosol (Fig. 5, NH 13). Judging from its weathering status the soil horizon has to be classified as interglacial, while a formation during more than one interglacial is also probable (cf. Terhorst et al. 2003). Its surface is eroded and covered by a stagnic loess loam of about 1 m thickness (NH 12, NH 11). A distinct iron/manganese band separates this horizon.

Above the loess loam a stagnic Btg horizon has developed (NH 10). Interestingly, this horizon contains locally dark brown to black humic clay cutans, which indicate the former presence of a distinct A horizon in a superimposed position, which is not preserved to date. This Btg horizon within the presented profile corresponds to the fourth interglacial palaeosol.

On top, another loess loam was deposited (NH 9), inside of which a further interglacial palaeosol (NH8) is developed. This soil horizon is also eroded in its uppermost section. However, the overlying redepositional zone (NH 7) can also be interpreted as marginally redeposited residue of a former E horizon.

Above, NH 6 represents another interglacial palaeosol horizon, which is in places covered by a thin redepositional zone containing soil sediment (NH 5).

A loess loam horizon of up to 1.5 m thickness follows, which is limited to the top by an iron/manganese band in some places of the profile. This band dips into the direction of the channel filling.

The uppermost section of profile Neuhofen is represented by a pedocomplex, which consists of two different superimposed Btg horizons (NH3, NH 2). Both horizons are at the maximum 1.5 m thick. The pedocomplex is locally separated by a layer of loess loam; therefore two individual soils are recognisable.

3 Discussion of stratigraphic results

A highly differentiated structure of the cover layers is present in all Middle Pleistocene sequences presented here. Below a mostly shallow, characteristic Würmian sequence, which is only absent in Neuhofen, the Eemian soil is preserved as uppermost interglacial soil (Fig. 2). This soil usually is substantially less dense and stagnic than the older palaeosols of the warm stages. Underneath, at least three further, in parts highly stagnic, Btg horizons follow in all profiles. Moreover, on top of the Older Deckenschotter, a strongly weathered reddish palaeosol is present.

In general, the palaeosols are developed as pedocomplexes and represent different phases of pedogenesis and geomorphodynamics. The polypedogenetic transformation is in most cases clearly visible macromorphologically.

3.1 Younger Deckenschotter

The loam pit in Oberlaab exposes one of the best structured profiles of cover layers of the Younger Deckenschotter in the entire northern Alpine Foreland. Overall four distinctly developed interglacial soils indicate a minimum age for the gravel surface of the fifth to the last glacial (MIS 12).

On the Younger Deckenschotter in Oberlaab a basal, intensely weathered Gleysol occurs in addition to the existent interglacial soils (cf. Ottner & Sedov, this volume). However, the palaeoclimatic meaning of this soil remains unclear. An interglacial formation cannot be fully excluded in this case, however a formation in pre-weathered flood deposits must also be discussed.

Classical ideas according to Penck & Brückner (1909) of a formation of the Younger Deckenschotter (Mindel) in the third glacial do not apply for every case in the presented profile; however, a categorisation into the fourth to the last glacial also underestimates their age. Kohl already described three fossil interglacial soils (Kohl & Krenmayr 1997). Therefore, the classical view on the age of the Younger Deckenschotter being set in the third to the last glacial period was already in question at that time.

Our results support the classification of Mindel Deckenschotter in the Austrian Alpine foreland as belonging to MIS 12, which is in agreement with the palaeogeographical studies of Van Husen & Reitner (2011a) and palaeomagnetic results of Scholger & Terhorst (this volume).

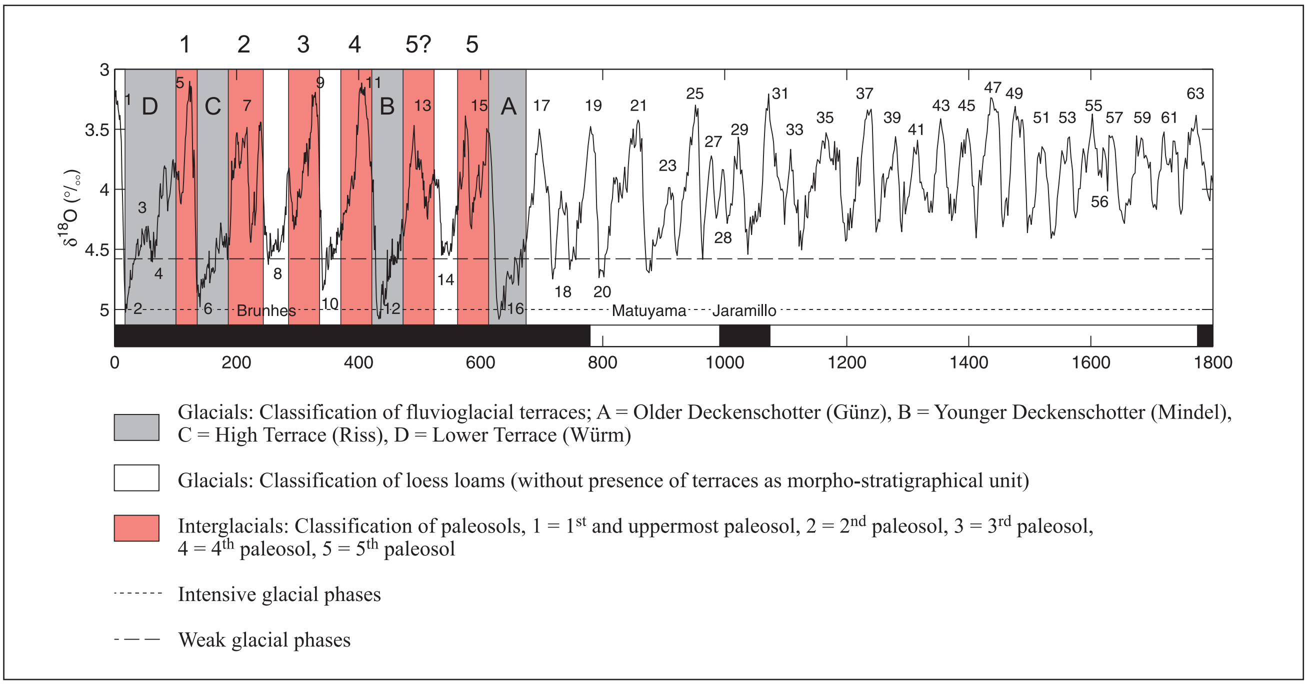

Fig. 6: Classification and correlation of palaeosols, fluvioglacial terraces and loess loams on the base of the marine oxygen isotope curve according to Lisiecki *&* Raymo *(2005), modified (source:* Terhorst *et al. 2011b).*

Abb. 6: Einstufung und Korrelation von Paläoböden, fluvioglazialen Terrassen und Lösslehmen im Vergleich mit der marinen Sauerstoffisotopenkurve nach Lisiecki *&* Raymo *(2005), modified (source:* Terhorst *et al. 2011b).*

3.2 Older Deckenschotter

The cover layers of the Older Deckenschotter in Wels-Aschet and Neuhofen contain one more interglacial palaeosol than in the Younger Deckenschotter profile of Oberlaab and consequently have to be classified as at least one glacial age older. It can be assumed that the intensely weathered basal palaesol of both profils contains not just one interglacial phase. The high degree of weathering in the Bt horizon of the oldest palaeosol (AS 2) is reflected in the intense red clay cutans as well as in the high clay content of about 60.0%. Furthermore, only stable minerals, such as quartz, are present. The clay fraction is dominated by mixed layer minerals, and in this palaesol vermiculites and illites are completely weathered (Terhorst et al. 2011b).

Thus, the minimum age for the Older Deckenschotter is assumed to belong to the sixth to seventh to the last glacial phase. In this context the fact that the MBB could not yet be proved within the cover layers, leads consequently to a classification in the Brunhes epoch (Scholger & Terhorst 2011). The proof of distinct palaeomagnetic excursions designated to the pedogentic phase of the basal intensely weathered palaeosol of AS 2 might be assigned to MIS15, towards whose end the geomagnetic excursion E-BL-CR3 (Emperor - Big Lost - Calabrian Ridge 3; 570–560 ka) occurs (Scholger & Terhorst, this volume). Therefore, the classification according to van Husen (2000) can be confirmed by our pedostratigraphical results.

Findings of *Carya* and *Pterocarya* pollen in Wels-Aschet (Kohl 2000) yield a further stratigraphic indicator below the loess loam, which was by the author classified as Rißian. These pollen occur until the Holsteinian Interglacial, which can be parallelised with MIS 11 according to Sarnthein et al. (1986, among others). The results imply a comparably old age of the basal profile sections. This fact as well as palaeopedological results were not considered in the study of Preusser & Fiebig (2009). The above-discussed stratigraphic findings are in contrast to the stratigraphic approach of Preusser & Fiebig (2009), who discuss much younger ages on the base of luminescence dating (IRSL). In this study, ages >200 ka do not significantly increase in the basal parts of the sequence, reflecting that the applied luminescence method can be problematic above 200 ka (cf. Preusser & Fiebig 2009). Recently, methodological studies were able to extend the range of the luminescence method to 300 ka using a new post-IR IRSL protocol (290 °C) (Thiel et al. 2011), an approach not yet applied to the sequence of Wels-Aschet.

At present the Older Deckenschotter are classified as seventh to the last glacial in the Austrian Stratigraphic Chart (Österreichische Stratigraphische Kommission 2004).

Kohl (2000) describes already four interglacial soils in Neuhofen and therefore, also in this case, assumes one interglacial more than in classical stratigraphy (acc. to Penck & Brückner 1909).

Alltogether, the gravel surface of the Günz gravel body is younger than the MBB. This study classifies it at least to belong to MIS 16 (c.f. Van Husen & Reitner 2011b, Scholger & Terhorst 2011).

3.3 Comparison of cover layers in the northern Alpine Foreland

Overall, at the present state-of-the-art it is impossible to compare stratigraphic results of the eastern Alpine Foreland with the western area in Baden-Württemberg. The most recent stratigraphic approach and nomenclature of Baden-

Württemberg deviates strongly from the Bavarian and Austrian stratigraphic system (Doppler et al. 2011). This fact complicates all attempts to correlate terracesm of the eastern with those of the western Alpine Foreland. Furthermore, it has to be taken into account that the described single terrace bodies have to be regarded as terrace complexes, which include groups of terraces (Schellmann et al. 2010). Thus, it is highly probable to obtain different ages in one terrace body.

Bibus (1995) describes cover layers on the Iller-Lech plate and discusses the fourth or fifth to the last glacial as minimum age for the Younger Deckenschotter. Based on palaeosols in the cover layers of the Younger Deckenschotter in Allschwil brickyard near Basel he even assumes a minimum age of sixth to seventh to the last glacial (Bibus 1990), which was later confirmed by Zollinger (1991) in the verification of the MBB within the Younger Deckenschotter (cf. also discussion in Bibus 1995). For the Upper Austrian study area no indication for a classification of the Younger Deckenschotter into seventh to the last glacial could be found so far. Thus, they are presumably younger than in the Rhine glacier area.

A comparison of the Older Deckenschotter in Upper Austria and studies on the Iller-Lech plate (Bibus 1995) appears difficult because of the differentiated morphological structure of the terraces in the western Alpine Foreland. The Younger Deckenschotter cover layers in Roßhaupten brickyard are best compared to the sequences of the Older Deckenschotter presented here. Bibus (1995) classifies the Younger Deckenschotter based on at least five to sixthe palaeosols into the seventh to the last glacial. Also the eighth to the last glacial period could be possible in this place, as the MBB could be proved above the gravels (cf. Jerz 1993). Consequently, a younger age of the Upper Austrian terraces seems to show here, too.

The classification according to pedostratigraphic investigations is consistent with glacial morphological studies in the northern Alpine Foreland by Doppler & Jerz (1995) and Doppler et al. (2011). However, it has to be taken into account critically that the sequence of the presented profiles is not preserved completely. According to Doppler & Jerz (1995) the lower boundary of the Günz complex has to be classified in the MIS 24 (Jaramillo), while the upper boundary is set at the transition of MIS 16 to MIS 15 based on results from the former glacial areas. Regarding the pedostratigraphic results presented here, the Older Deckenschotter of the Traun-Enns plate appear to belong to the youngermost section of the Günz complex.

3.4 Correlation with marine curves

Regarding the marine oxygen isotope curve according to Lisiecki & Raymo (2005), around eight interglacial soil formations respectively eight glacials are possible after the MBB, starting with MIS 19 (Fig. 5). However, based on the number of palaeosols in the studied profiles the Older Deckenschotter can be classified at the maximum into MIS 16. The generally intensive, ferretto-like weathering of the Older Deckenschotter in Upper Austria (fifth/basal palaesol) should therefore correspond to the following interglacial (MIS 15), which is recorded in the palaeomagnetic studies as well (Emperor - Big Lost - Calabrian Ridge 3; 570–560 ka) (Scholger & Terhorst, this volume). According to the results of the palaeomagnetic analyses, loess loams deposited on top of the MIS 15 palaesol can be correlated to MIS 14. Subsequently, five interglacials are recorded in marine curves, which should result in a sequence of five palaeosols, respectively, only four of which are clearly present in the study area on the Older Deckenschotter. If we assume that the fifth palaesol of Wels-Aschet and Neuhofen includes the two interglacials of MIS 15 and 13, the superimposed loess sediment could also belong to MIS 12. The present stage of investigation does not allow a clear classification (Scholger & Terhorst, this volume).

Pursuing these stratigraphical considerations for the Younger Deckenschotter, which also occur consistently in Oberlaab, and additionally regarding the number of palaeosols on the Younger Deckenschotter, MIS 12 or 14 can consequently be considered as probable times of origin for the Younger Deckenschotter. However, it has to be taken into account that MIS 14 is not as pronounced as the other glacials (cf. Fig. 6) and therefore may not be suitable for extensive deposition of gravel in form of an individual morphostratigraphic unit (acc. to Penck & Brückner 1909). Further, the age classification of the younger Mindel complex can be brought into accordance with the stratigraphy by Doppler & Jerz (1995), who rank classical Mindel to MIS 12. In the study area four interglacial soils are still recorded on the Younger Deckenschotter, whose age of formation has to be assigned to MIS 11, 9, 7 and 5, according to the previous considerations. The intermediary glacial phases apparently did not induce the formation of independent, morphologically visible fluvioglacial terraces in the study area. Only MIS 6 is distinctly present in Rißian upper terrace deposits. The latter has to be classified as Younger Rißian stage according to datings and pedostratigraphic studies (Terhorst et al. 2002). The two older glacials MIS 8 and 10 are not represented by individual morphostratigraphic terraces here. However, during both stages sedimentation of loess loams was active. These are mostly preserved as deposits of more than 1 m thickness. According to the glacial stratigraphy for the northern Alpine Foreland (Doppler 2003, Doppler & Jerz 1995) the Riß complex can be divided into three glacial phases: Older, Middle and Younger Riß, corresponding to two terrace bodies in the western area of the Pleistocene Salzach glacier.

In this context it is remarkable, that datings by Stremme et al. (1991) in Wels-Aschet below the Eemian soil yielded ages between 136 ka (±13 ka) and 128 ka (±15 ka). The age of the loess loam below the second palaesol is stated in the same work as 233 ka (±35 ka) and 245 ka (±51 ka).

4 Conclusions

The cover layers of the studied profiles allow for the conclusion that Younger and Older Deckenschotter have to be assessed differently than it is assumed in the scope of the classical morphostratigraphic classification. The pedostratigraphic documentation over many years further proves an older formation age of the Deckenschotter than it has been reported in literature so far. The gravel surface of the Older Deckenschotter in the study area seems to be younger than the MBB and corresponds at least to MIS 16.

The Younger Deckenschotter in Oberlaab are one to two glacial/interglacial cycles younger than the Older Deckenschotter and can, after detailed discussion, be classified at least as corresponding to MIS 12. The studies further confirm that a largely complete record of palaeosol sequences on the Traun-Enns plate can be expected.

At a supraregional level both conformities and discrepancies become obvious in the stratigraphic classifications. For basic correlations existent dating methods, such as optically stimulated luminescence (OSL), have to be further expanded, and magnetostraphic methods have to be applied systematically in further loess sequences.

In future it is desirable and absolutely necessary to establish a chronostratigraphy for the terrestrial Middle Pleistocene all over European loess sequences. This is the only way to enable supraregional or even global correlations. Furthermore, a reliable stratigraphy enables to decode regional landscape formation as well as the response of geosystems to climate change.

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