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Geochronological reconsiderations for the Eastern European key loess section at Stayky in Ukraine

A. Kadereit and G. A. Wagner

Heidelberger Lumineszenzlabor, Geographisches Institut, Universität Heidelberg,
Im Neuenheimer Feld 348, 69120 Heidelberg, Germany

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Correspondence to: A. Kadereit (annette.kadereit@geog.uni-heidelberg.de)

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Abstract

Event-stratigraphical correlations between local/regional terrestrial sedimentary archives and marine or ice-core records providing the global climate history and time-scale are highly desirable for a deeper understanding of the effects of global climate change on a local/regional (palaeo-)environment. However, such correlations are not trivial, as the terrestrial records tend to be floating and fragmentary and usually show varying sedimentation rates. Therefore, a reliable chronometric framework is a necessary prerequisite for any event-stratigraphy involving terrestrial archives. In this respect, the age-model underlying the event-stratigraphical approach for the Eastern European key loess section at Stayky in Ukraine appears to need revision. Here we explain, why it is highly unlikely that the Middle Pleniglacial Vytachiv Soil developed during Greenland interstadial (GIS) 8, and why the embryonic soils in the upper part of the Upper Pleniglacial part of the loess section most likely post-date Heinrich 2 event. As a consequence, the revised age-model challenges the earlier suggested correlation of the suite of incipient soils above the Vytachiv Soil with Greenland Interstadials, which was supposed to start with GIS7 but for which matching from after GIS5 seems more likely. The revised chronology suggests that the transition from Middle to Upper Pleniglacial environmental conditions at the Eastern European key section occurred during the final phase of marine isotope stage (MIS) 3. Thus, the picture appears to be in accordance with that of the Western European key section at Nussloch in Germany pointing to a common driver of palaeo-environmental change in both regions, such as early Late Glacial Maximum (LGM) advances of the Arctic ice-shield or changes of the North Atlantic circulation and sea-ice distribution leading also to relevant changes of the palaeowind field.

1 Introduction

Loess-palaeosol sequences are most important archives recording and storing the environmental history of terrestrial landscapes during glacial and interglacial periods (e.g. Marković et al., 2009; Buggle et al., 2009). Over the last decades, loess-palaeosol sections covering the last glacial-interglacial cycle were studied intensively from Western to Eastern Europe (e.g. Antoine et al., 2001; Rousseau et al., 2011). Thus a stratigraphic pattern of loess deposits with less intensively developed palaeosols covering loess deposits with more intensively developed palaeosols, earlier described by Schönhals et al. (1964), was well-supported (e.g. Antoine et al., 2001; Rousseau et al., 2001; Fuchs et al., 2008). Ideally, the lower section is terminated by a well recognizable palaeosol, regionally called the Lohne Soil (Germany, Austria), Vytachiv Soil (Ukraine), Surduk Soil (Serbia) etc., which at the top is truncated due to discordant erosion. Thus, the terminal palaeosol may function as a pedostratigraphic marker horizon for over-regional stratigraphic correlation of loess sections in the different parts of Europe. The significant change in the pedosedimentary stratigraphy indicates correspondent changes in the palaeo-environmental conditions of the respective terrestrial landscapes during the milder climate excursions of the last glacial period (Dansgaard–Oeschger warm events or Greenland interstadials, GIS, respectively) during which soils developed and for which some authors assume a recurrence interval of ca. 1500 yr (e.g. Schulz, 2002; Rousseau et al., 2002). This marked change is attributed to the transition from the Middle to the Upper (Younger) Wurmian ("Mittelwürm" to "Jungwürm" after Schönhals et al., 1964), following the original terminology, or to the Weichselian Middle to Upper Pleniglacial boundary (e.g. Antoine et al., 2009), following the modern stratigraphic classification for Western and Northern Europe (e.g. Törnqvist et al., 2000; van Huissteden and Kasse, 2001). Therefore, the marker horizons indicate a point in time after which environmental conditions apparently changed significantly throughout Europe.

Environmental changes for the Middle Pleniglacial/Upper Pleniglacial transition are best reconstructed at sections which show the least chronometric gap between an uppermost preserved Middle Pleniglacial (MPG) soil and a preserved lowermost Upper Pleniglacial (UPG) loess deposit. In this respect, a site like Nussloch (e.g. Antoine et al., 2009) with apparently only little truncation of the MPG part is preferable to the Dolni Vestonice (DV09) section in the Czech Repubic (Antoine et al., 2013) or the Ostrau section in eastern Germany (Kreutzer et al., 2012), of which MPG parts were eroded down to ca. 45 ka or even ca. 70 ka old deposits, respectively. In the most complete sections, the marked transition in the terrestrial archives occurred somewhere near the transition from marine isotope stage (MIS) 3 to MIS2 (e.g. Antoine et al., 2009; Schirmer, 2012). However, it should be noted that the MPG/UPG-boundary was variably attributed to the termination of GIS3, i.e. the MIS3/MIS2 boundary (e.g. Huijzer and Vandenberghe, 1998; Törnqvist et al., 2000; Guiter et al., 2003), or to the termination of GIS5, i.e. within the final phase of MIS3 (e.g. van Huissteden and Kasse, 2001).

Palaeopedological and stratigraphical investigations at the loess-palaeosol sections nowadays usually go along with more or less intensive dating of the pedosedimentary archives. The datings serve to determine the time when respective environmental conditions prevailed or changed at a site. They also help to clarify whether the stratigraphically apparently matching terminal palaeosols developed at the same time and whether environmental conditions hence changed isochronically at the different terrestrial locations. It is prudent to intensify such investigations at well developed key sections, which each serve as a reference profile for a greater region. Thus, the Nussloch section in southwestern Germany which contains a well developed Lohne Soil is regarded as a key section for Western Europe (Antoine et al., 2009), while the section at Stayky in Ukraine which contains the Vytachiv Soil is regarded as a key section for Eastern Europe (Rousseau et al., 2011; Fig. 1).

It is essential to develop especially reliable chronologies for the key sections, as results from these sites are routinely transferred to other sections to achieve a better understanding of their stratigraphy and chronometry. Only recently, the well developed loess-palaeosol section Schwalbenberg II in the Middle Rhine Valley in Germany (Fig. 1) was compared with the Nussloch section (Schirmer, 2012). Following the Nussloch chronology, the upper two Middle Pleniglacial palaeosols at the Schwalbenberg II section (Sinzig Soils, S2 and S3) were correlated with GIS7 (S2) and GIS6 (S3), although ^{14}C-dating at the site itself would allow their correlation with GIS6 (S2) and GIS5 (S3), respectively (cf. Supplement – Figs. S1 and S2). Therefore, it cannot be excluded that possible misinterpretation of a master profile might lead to wrong interpretation of other loess-palaeosol sections in the greater area. This makes it necessary to re-evaluate the data of the key sections carefully as scientific knowledge progresses.

In recent years, ^{14}C- and luminescence dating has brought about a wealth of chronometric data for important loess sections (Fuchs et al., 2012; Haeserts et al., 2010; Terhorst et al., 2011; Stevens et al., 2011; Timar et al., 2010; and many more). But methodological progress in dating techniques has shown also that ^{14}C-ages beyond ca. 35 ^{14}C ka BP, corresponding to ca. 40 ka cal BP, might have to be interpreted carefully (e.g. Briant and Bateman, 2009). This holds especially for ages that were gained from bone collagen or charcoal that tend to underestimate the true ages, unless samples were subject to special pretreatment (e.g. Higham, 2011). For a comprehensive review of that topic confer to Talamo et al. (2012). It has also been argued that ^{14}C-dating of loess organic matter may underestimate the age of loess deposition, if postsedimentary contamination with younger organic matter occurred by deep rooting plants (e.g. Gocke et al., 2013). Luminescence dating, too, has shortcomings. Apart from age overestimation due to incomplete bleaching of the latent luminescence signal prior to sediment deposition, age underestimation is also possible. This was reported for infrared-stimulated luminescence (IRSL) dating of feldspars or the feldspar component of polymineral fine-grains, respectively, if measurements were performed using inadequate detection filters (e.g. Lang and Wagner, 1996; Wallinga et al., 2000). However, also a carefully chosen measurement setup can produce IRSL-ages which are suspicious of underestimating the true ages by ca. 3 ka for ca. 30 ka old samples (Lomax

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et al., 2012). Yet, it should be noted that although midpoints of the IRSL-ages of the latter study tended to be slightly too low, the expected ages were met within error margins (1 sigma). This finding is relevant for the interpretation of IRSL-ages in the present study (see Sect. 3).

Rapid progress in the dating of terrestrial sediment archives nowadays allows matching of the local/regional terrestrial archives with marine and ice-core records (e.g. Antoine et al., 2009; Rousseau et al., 2011). Such correlations are relevant, as the latter are regarded to record the global climate signals. Thus they may be interpreted to reflect the pacemakers of the environmental changes in the local/regional parts of earth's palaeolandscapes, as documented in the terrestrial pedosedimentary archives. The resolution and understanding of the global records are also improving (cf. Fig. 2 and literature quoted therein), requiring a re-evaluation of earlier correlations between them and the terrestrial archives.

Thus, re-evaluation of the Western European key section at Nussloch has recently led to a modified interpretation of the chronology (Kadereit et al., 2013). The investigation showed that the likely period for the evolution of the Lohne Soil matches GIS7 – GIS5. It is noteworthy that this interpretation is in accordance with an alternative interpretation of the Schwalbenberg II chronology for the time period close to the MIS3/MIS2-boundary (cf. Supplement – Figs. S1 and S2). Another outcome of the Nussloch study was that the MPG/UPG-boundary as observed in the Western European loess-palaeosol section does not seem to conform to the MIS3/MIS2-transition. Rather, it appears that the Western European terrestrial environment responded earlier, i.e. already at the termination of GIS5.

As also the Eastern European key section at Stayky in Ukraine was correlated with the Nussloch section (Rousseau et al., 2011), we here reinvestigate the stratigraphic and chronometric data available for the Ukrainian master section. For our study we revert to data published by Rousseau et al. (2011) in Clim. Past (Vol. 7, 221 pp.). Our aim is to check whether the earlier interpretation of the Stayky chronology can be regarded as robust or whether adaptations seem necessary for the Eastern European key section.

2 Data and philosophy

Rousseau et al. (2011) constructed a paleowind-record for the Stayky loess section in Ukraine, using a ratio of coarse silt to fine and medium silt plus clay, the so called grain-size index (GSI[1]), as a proxy. The proxy record was correlated with the GSI-record from the Western European master loess section at Nussloch in Germany (Antoine et al., 2001, 2009). Both terrestrial records were correlated with the global ice-core time-scale GRIP_ss09sea (Johnsen et al., 2001) (cf. Fig. 1e) and a dust record for the Greenland ice-core, most likely based on Ruth et al. (2002, 2003) and Ruth (2005). Matching occurred with an event-stratigraphical approach based on visual similarity between records. While periods of high wind strength are supposed to be represented by high GSI-values, periods of low wind strength are approximated by low GSI-values. Usually, cool Greenland stadials and cold Heinrich events are associated with periods of high and very high wind strength, respectively, while the warmer Greenland interstadials are periods of low wind strength. Likewise, the colder excursions are the times of dominantly loess accumulation, while the warmer periods are the times of soil formation. This way, millennial-scale Dansgaard–Oeschger events were recognized to be recorded and archived in loess-palaeosol-archives (cf. Rousseau et al., 2002). The event-stratigraphical approach resulted in the correlation of a suite of embryonic soils (ES1 to ES8) in the upper part of the Stayky profile between ca. 630 cm and 230 cm b.g.l. (below ground level) with GIS7 to GIS2, based on the assumption that the underlying Vytachiv Soil at ca. 650 cm b.g.l. matches GIS8. But such correlation is not supported by the chronometric data provided by Rousseau et al. (2011).

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[1] ([63.4–20.7 µm]/< 20.7 µm) for Stayky (Rousseau et al., 2011); [50–20 µm]/< 20 µm resp. [52.6–26]/< 26 µm] for Nussloch (Antoine et al., 2009)

A necessary prerequisite for the event-stratigraphy is a solid chronometrical framework, to first of all place the part of the terrestrial loess record that shall be correlated with the global ice-core record in the most likely time-window. This is essential as the terrestrial records are usually neither complete nor continuous nor do they show constant sedimentation rates. Instead, the terrestrial pedosedimentary archives are rather floating, likely exhibiting stratigraphical gaps and varying sedimentation rates along the time-axis. Therefore, the placement of the time-markers is most essential and has to be carried out with special care.

For the Stayky loess sequence, Rousseau et al. (2011) provide four infrared stimulated luminescence (IRSL-) ages. These serve as the necessary chronometric tie-points. The results of the dating are presented by the authors in Table 1 and Figs. 3 and 4, but they differ slightly in the figures as compared to the table. The samples (from bottom to top) BT 31, BT 34, BT 33 and BT 32 from 650, 450, 270 and 150 cm b.g.l. yielded ages of 30.1 ± 2.3 ka[2]/30.2 ± 3.1 ka[3], 27.6 ± 2.0 ka[2]/27.6 ± 2.7 ka[3], 16.4 ± 1.2 ka[2]/16.4 ± 1.6 ka[3] and 17.6 ± 2.0 ka[2]/17.7 ± 2.1 ka[3]. The ages vary mainly in the given errors which are mostly about 30 % larger in the figures, as compared to the table. We assume that the ages are quoted on the 1 sigma error level, which is usual practice for luminescence dating.

3 Results and discussion

The ages for the samples from 270 and 150 cm are identical within error margins, with the midpoints showing slight age inversion. Thus sedimentation rates in the upper part were probably too high for sufficient chronometric resolution with luminescence dating. The most important time-marker is the IRSL-age for sample Bt 31, which is from the horizon of the Vytachiv Soil. Rousseau et al. (2011) argue that the chronometry

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[2] data from Table 1 of Rousseau et al. (2011)

[3] data from Figs. 3 and 4 of Rousseau et al. (2011)

supports a correlation of the Vytachiv Soil at the Stayky loess site in Ukraine with the Lohne Soil at Nussloch in southwestern Germany (for a recent review on the Nussloch section see Antoine et al., 2009). They argue further that the chronometry supports a correlation of the Vytachiv Soil with GIS8. However, for the Nussloch site Kadereit et al. (2013) showed that a correlation of the Lohne Soil with GIS8 must be excluded. The possible chronometric time-window for the palaeosol formation at Nussloch is GIS7 to GIS5. Further stratigraphical considerations point to GIS5 as a likely period, in which the Lohne Soil developed – or rather reached its climax state, in the likely case that soil development had commenced already during the preceding or the two preceding Greenland interstadials.

Luminescence dating determines the time when a mineral grain was last exposed to daylight. Therefore, luminescence ages for samples from soil horizons do not determine the time of soil formation, but the time (cold stadial) when the sediment (loess) was deposited prior to the time when the soil developed therein (subsequent warm interstadial). Thus, IRSL-dating determines the Greenland stadial before the Greenland interstadial, which matches the period of soil formation. If, however, bioturbation is significant during the period of soil formation, mineral grains may be bleached sufficiently to determine the time of soil formation (e.g. Kadereit et al., 2010). If the Vytachiv Soil matches GIS8, as proposed by Rousseau et al. (2011), the IRSL-age for sample BT 31 should correspond either to the Greenland stadial[4] between GIS9 and GIS8 (no bioturbation or other post-depositional bleaching of mineral grains), or to GIS8 (sufficient bleaching during the period of soil formation). In order to test this hypothesis, we compiled the most commonly used global ice-core time-scales and plotted them together with the IRSL-age for sample Bt 31 in Fig. 2. The GRIP_ss09 time-scale (Johnsen et al., 1995) (Fig. 2d) is regarded as inadequately calibrated to calendar years, as it lacked necessary corrections for δ^{18}O-variations of the ocean water, which were applied later

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[4] As there exist differing systems for the numbering of Greenland stadials (e.g. Björk et al., 1998 *versus* Rousseau et al., 2006, we address a respective stadial as “a stadial between GIS$_{\#}$ and GIS$_{\#\text{-}1}$”).

and published as the GRIP_ss09sea time-scale (Johnsen et al., 2001) (Fig. 2e). For the correlation of palaeorecords in the period 15–42 ka, the INTIMATE group recommended to use the NGRIP_CICC05 time-scale (Andersen et al., 2006; Svensson et al., 2006) as the relevant standard time-scale (Hoek et al., 2008) (Fig. 2b). Therefore, we included Heinrich events (H1–H3) on the NGRIP_CICC05 time-scale in Fig. 2b, at least tentatively. We did not use the IRSL-age as presented in Table 1 by Rousseau et al. (2011), but used the slightly older age with the larger error as given in Figs. 3 and 4 of that publication. This way, we avoid bias the data to better suit our arguments. We plotted the IRSL-age both with the 1 sigma and the 2 sigma error bars, respectively. On the 1 sigma error level, the age covers the period 27.1–33.3 ka (brown squares with shorter error bars in Fig. 2a and i), on the 2 sigma error level it covers the period 24.0–36.4 ka (brown squares with longer error bars). From Fig. 2 it becomes clear that the age-model for the Vytachiv Soil does not include GIS8 – unless one refers to the obsolete GRIP_ss09 time-scale and argues on the 2 sigma error level. The IRSL-age for the level of the Vytachiv Soil covers at maximum GIS7 (2 sigma), while a later period (GIS5) is the more likely period on the 1 sigma error level. Therefore, a start of the event-stratigraphy for the suite of embryonic soils with GIS7 as proposed by Rousseau et al. (2011) is not supported by the chronometry. Based on the IRSL-dating of the underlying Vytachiv Soil the lowermost embryonic soil (ES8) in the hanging wall could possibly be parallelized with GIS4. It is interesting to note that this interpretation would correspond to the independently revised age-model and correlation of palaeosols with Greenland interstadials as suggested for the Nussloch site by Kadereit et al. (2013), if one accepts a correlation between the Lohne Soil and the Vytachiv Soil, as suggested by Rousseau et al. (2011). Regarded for itself, the IRSL-age of sample Bt 31 could also point to soil formation during GIS4 and/or GIS3. This interpretation, however, is unlikely, when the dating result for sample Bt 32 is taken into account.

The IRSL-age for Bt 32 from 450 cm b.g.l. originates from ES5. As embryonic soil number 6 occurs threefold (ES6c–ES6a), ES5 is the sixth embryonic soil detected above the Vytachiv Soil. For ES6c a positive excursion of the GSI-record is observed

(Fig. 4 of Rousseau et al., 2011), which the authors attribute to Heinrich 3 event. As Heinrich 3 dates around 31 ka (Hemming, 2004; Skinner, 2008) just predating GIS4, this would conform to a formation of the Vytachiv Soil at Stayky during (or until) GIS5. On the 1 sigma error level, ES5 could match GIS4 or GIS3 (see yellow squares with short error bars for Bt 32 in Fig. 2a/i). If this interpretation is accepted, the lowermost five embryonic soils represent the final part of MIS3, i.e. the period postdating GIS5. MIS3, and Oxygen isotope stage (OIS) 3, respectively, end with the termination of GIS3 (e.g. Anderson et al., 2006). As mentioned above, the Middle to Upper Pleniglacial boundary for terrestrial archives has been variably defined, either corresponding to the termination of GIS3 (e.g. Törnqvist et al., 2000; Pirson et al., 2012), so that the Middle Pleniglacial compares to MIS3, or to the peak of GIS5 (cf. van Huissteden and Kasse, 2001). Considering the remarkable change from a Middle Pleniglacial to an Upper Pleniglacial habitus of the loess-palaeosol-sequence at the top of the Vytachiv Soil, as documented by Rousseau et al. (2011), the latter scheme appears more appropriate for the Stayky section. Otherwise, the MPG/UPG-boundary would have to be placed further up in the Stayky profile than proposed by Rousseau et al. (2011, Fig. 4), either between ES5 and ES4b, or further up in the hanging wall. However, it does not seem wise to obtrude marine and ice-core schemes onto terrestrial archives. Rather it is worth noticing that the regional terrestrial pedosedimentary archive does not seem to accord to the global archive.

Whether or not ES5 postdates Heinrich 3, as suggested by Rousseau et al. (2011) cannot be decided on the 1 sigma error level of the chronometric data, as the error-range of Bt 34 includes the time period of Heinrich 3. Yet, it is likely if one follows the above interpretation that the formation of the Vytachiv Soil matches GIS5 and ES5 matches GIS3 or GIS4.

Heinrich 2 dates around 24 ka (Hemming, 2004; Skinner, 2008), a period which is not adequately resolved by the IRSL-record. The uppermost but one embryonic soil (ES2a) at 270 cm b.g.l. yields an age around 16.4 ka, which could correspond to the time of Heinrich 1 event (cf. Hemming, 2004; Skinner, 2008), and/or to the Late Glacial

Maximum (LGM), respectively.[5] A similar age of 17.7 ± 2.1 ka was found for sample Bt 32 from 150 cm b.g.l., supporting a likely LGM-age for the upper half of the Stayky profile (both IRSL-ages in Fig. 2a and i as light blue squares). In contrast to that, Rousseau et al. (2011) attribute a GSI-peak ca. 150 cm b.g.l. to Heinrich 2 event. Therefore, the necessary chronometric backbone for the event-stratigraphy seems to be disregarded. It is noteworthy that the new interpretation is supported independently by the Nussloch chronology and a GSI-correlation between the two loess sections at Stayky and Nussloch. Thus, Rousseau et al. (2011) compare the GSI-peak at ca. 150 cm b.g.l. at Stayky with a GSI-peak between gley/CRha[6] 6b (unit 33) and gley/CRha 7 (unit 35) at Nussloch. The chronometry at Nussloch is supported for unit 34 and unit 38 by ^{14}C-data, which are considered as especially reliable by Antoine et al. (2009). These data place gley/CRha 5 to gley/CRha 8 from Nussloch in the LGM-period ca. 21–18 ka ago[7], clearly post-dating Heinrich 2 event (cf. Fig. 6 in Kadereit et al., 2013). If the level of ca. 150 cm b.g.l. at the Stayky section corresponds to the GSI-peak just below gley/CRha 7 at the Nussloch section, as suggested by Rousseau et al. (2011, Fig. 4), the upper part of the Stayky loess section should correspond to the cold stadial between Heinrich 2/GIS2 and Heinrich 1/GIS1, and would not predate Heinrich 2.

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[5] Here we define the LGM, not as sometimes done for ice-core records, i.e. as the stadial period of minimum δ^{18}O values between GIS3 and GIS2 ca. 27.5–23.5 ka before present (e.g. Svensson et al., 2006), but as appropriate for European loess-palaeosol-archives, i.e. as the time after Heinrich 2 event until the onset of termination 1 ca. 21–18 ka ago (cf. also “LGM sensu lato” in Sommer and Zachos, 2009 and considerations in Kadereit et al., 2013).

[6] According to IUSS Working Group (WRB, revised edition, 2007) the Pleniglacial tundra-soil remains at Nussloch are mostly Haplic Cryosols (Reductaquic, Siltic). The recommended code for the soil reference group and the prefix qualifier is “CRha”.

[7] ^{14}C-data for sample GifA-99014 from unit 34 (3.8 m b.g.l.) and for GifA-96221 from unit 38 (1.6 m b.g.l.) at the Nussloch loess section are 17 250 ± 140 ^{14}C BP and 15 260 ± 110 ^{14}C BP, respectively (Hatté et al., 2001). These correspond to 21 150–20 150 and 18 750–18 040 cal BP, respectively (95.4 %) (OxCal 4.1, Bronk Ramsey, 2012; IntCal09, Reimer et al., 2009).

Therefore, the Stayky event-stratigraphy seems to be questionable, both in its lower and in its upper part, where the IRSL-chronometry is not sufficiently considered. The discrepancies could be partly due to the inferior temporal resolution of the Ukrainian loess section (only ca. 4.5 m vertical resolution of the Weichselian pedosedimentary archive between the Vytachiv Soil and the uppermost embryonic soil (ES1) at Stayky as compared to ca. 10 to 12 m between the Lohne Soil and gley/CRha 8/9b at Nussloch (cf. Fig. 2 in Antoine et al., 2009). Further problems with a dust-event stratigraphy may be caused by a possibly distorted, non linear time-axis due to varying sedimentation rates. Events in the ice-core records show (almost) undistorted peaks, as the time-scales are reasonably well calibrated to calendar years. For visual correlation with the global record, however, the different sections of the terrestrial record are manually variably squeezed or stretched (cf. Fig. 7 of Rousseau et al., 2011). The same holds for an event-stratigraphy between two loess-palaeosol-records, which for the visual correlation are manually adapted in profile length, i.e. along the time-axis. Therefore, the occurrence and size of events in the terrestrial record is partly a result of the pretreatment of the data-record. The a priori placement of time-markers and the application of computer-aided time-series analyses could help to objectify such non-trivial correlation procedures.

As no results from tests of anomalous fading of the IRSL-signal are given for the Stayky chronometry, one could argue that the IRSL-ages possibly systematically underestimate the true sediment ages (e.g. Wallinga et al., 2000). However, assuming hypothetical age-underestimation for the IRSL-chronometry at Stayky, would not change the interpretation for the base of the suite of embryonic soils. As may be derived from Fig. 2, it would need a severe underestimation of at least ca. 2.5 ka (missing difference for the 2 sigma error bar to reach beyond the base of GIS8, i.e. into the stadial between GIS9 and GIS8) or even ca. 5.5 ka (1 sigma error bar) to justify on grounds of the chronometry a matching of the Vytachiv Soil with GIS8. Hypothesizing such large age-underestimation would outrange, e.g., the slight discrepancies between IRSL fine-grain ages and blue-light stimulated luminescence (BLSL) quartz ages as observed for the loess section at Krems-Wachtberg in Austria, where, however, the slightly lower IRSL-ages were on the 1 sigma error level still in agreement with the BLSL-ages as well as with the ^{14}C-age for the Palaeolithic find layer (Lomax et al., 2012). From this it follows that IRSL-ages probably give reasonably correct ages not leading to erroneous interpretation in the lower part of the Stayky loess section.

The situation is slightly different for the IRSL-age for ES5. Slight age-underestimation of 1 or 2 ka could place the embryonic soil before GIS3, or even before GIS4. Yet this would not change the general correlation of the lower embryonic soils with the final phase of MIS3, i.e. the period after GIS5. Therefore, the chronometric considerations suggest a trisection of the loess section containing the suite of embryonic soils, which places

1. ES8 to approximately ES5/ES4b into the final and still warmer/more humid MIS3,
2. approximately ES4b and ES4a into the more moderate early MIS2 and
3. approximately ES2a/ES1 or only the loess above to at least 150 cm b.g.l. into the cold and dry LGM towards the end of MIS2.

The general trend in decreasing temperature and humidity in the greater region from MIS3 to MIS2 is reflected by the pollen record of the Arapovichi loess section (Molodkov and Bolikhovskaya, 2009 and literature quoted therein; cf. Fig. 1). At Stayky, the trisection is not reflected by the pedosystem, which – compared to the millennial-scaled climate-oscillations – seems to possess relatively long reaction and relaxation times as well as due time to reach a respective climax stadium. All the observed soils were addressed uniformly as incipient or embryonic soils and the late LGM-period above ca. 230 cm b.g.l. does not seem to show any macroscopically observable pedogenic features at all (Rousseau et al., 2011, Fig. 3). Only for two levels of the likely end-MIS3 section, i.e. between ES5 and ES6a as well as in the basal part of ES6c, stagnic conditions were observed (Rousseau et al., 2011). However, the faster adaptable vegetation-system shows a clear trisection (Rousseau et al., 2011):

1. the lowermost part of the so called pollen-unit “bg1” (cf. Fig. 8 of Rousseau et al., 2011) between 635–390 cm b.g.l, including ES4b, shows more humid boreal and arcto-boreal forest-steppe alternating with forest-tundra as well as higher counts of mesophytic herbs and arboreal pollen and a higher diversity of arboreal pollen; pollen of Quercus was present in ES7, while Corylus was detected in ES8, ES6c and E5; the spore inventory of ES6c and ES6a point to excessive ground moisture in a cold climate; for ES7 and ES5 the absence of cryophytes is striking; this could support a correlation of these soils with GIS4 and/or GIS3 (and ES6a/c with the stadial in between) towards the end of MIS3;

2. the upper part of pollen-unit “bg1” between 390–230 cm b.g.l., with considerably higher counts of grasses of up to 42 % and a typical grass steppe; these could reflect the dryer conditions of a beginning MIS2;

3. the upper part of the Stayky profile between 230–70 cm b.g.l. corresponding to pollen-unit “bg2”, for which counts and composition of arboreal pollen are much poorer than in the underlying “bg1” and which is characterized by typical periglacial steppe; this increase in aridity could reflect the terrestrial LGM-conditions in the second half of MIS2, as suggested by the revised age-model.

Thus, the changes in the vegetation history observed at Stayky seem to support the age-model as suggested in the present paper, whereas the GSI-based event-stratigraphy shows major unexplainable discrepancies with the IRSL-chronology.

In order to substantiate the revised age-model, additional chronometrical investigations would be desirable. For Stayky a validation of the IRSL-dating could be performed by including OSL-dating of quartz and ^{14}C-dating of loess organic matter. As however, the stratigraphical resolution is much better at the reference profile at Nussloch, further dating should be considered also for the Western European master profile. Also, careful bio- and other stratigraphical comparison with other well analyzed profiles from the region, as e.g. the loess-section at Arapovici (Molodkov and Bolikhovskaya, 2009; and literature quoted therein), could help to substantiate the chronostratigraphy for the

Stayky loess section and to put a correlation with Greenland interstadials (GIS) on solid footing. Presently, long-distance correlations between the loess sites at Nussloch and Stayky should better be regarded as working hypotheses.

Our results are in excellent agreement with findings of Haeserts et al. (2010) who compiled uncalibrated ^{14}C-data from loess-palaeosol sections containing Upper Palaeolithic occupations in Eastern Europe and central Siberia and who deduced from these composed profiles, one for each region. The MPG/UPG-transition, i.e. from loess containing loamy soils in the lower part to generally dusty and pale, partly sandy loess in the upper part, is between 26.5 and 25.8 ka BP (East Carpathians) and 26.3 and 26.0 ka BP (central Siberia), respectively. The transition at ca. 26 ka BP corresponds to ca. 30.6–31.3 ka cal BP (Danzeglocke et al., 2013). Thus it matches (the end of) the milder excursion in the Greenland stadial between GIS5 and GIS4 prior to Heinrich 3 event (cf. Fig. 2b), which is not pronounced enough to qualify as a separately classified interstadial, but is sometimes designated GIS4.1 in terrestrial speleothem records (e.g. Fleitmann et al., 2009) or GIS5b in the ice-core records. Climate changes from more humid to more arid conditions are often accompanied by more accentuated rainfall–runoff events leading to geomorphodynamic sediment reworking (e.g. Unkel et al., 2007). Comparable palaeoenvironmental conditions at the transition from a more humid GIS5 resp. GIS5b (MPG termination) to a drier period with increased dust input (beginning UPG) could possibly explain the often observed MPG/UPG erosional discordance.

One last issue shall be addressed: The charm of the global marine and ice-core records is that they are quasi-continuous. As long as no (significant number of) ice-layers are missing, the $^{18}\delta$O-variations are quasi-continuously recorded and archived. If, however, the dust accumulation over the Arctic ice-shield is taken as a reference proxy, the record loses its original character and becomes (more like) an ordinary terrestrial archive, with all possible complications involved in sediment transport from source to sink. The reason is that the Greenland dust-input is a semi-quantitative proxy for wind strength and dust mobilization in the East Asian deserts (e.g. Ruth, 2005), which may or may not be recorded completely (number of events/frequency) and adequately (intensity of individual events/magnitude) in the ice-layers. Apart from that, it seems that the Greenland dust-record is more appropriate for correlations with the Asian loess deposits, as they both might share the same source areas in East Asian deserts in Western China and Inner Mongolia (e.g. Bory et al., 2002)[8] – unless the intention is to correlate the European loess sections via the vehicle of the Greenland ice-shield dust-proxy with the Asian loess deposits. From this latter consideration it follows, that if future research can substantiate a correlation of the European loess sites with the Greenland dust-record, then the European and the Asian loess deposits should also show such parallelizable signatures. Matching of central Asian loess records with dust records of Greenland ice cores was recently supported by Machalett et al. (2011, 2012).

4 Summary and conclusion

The event-stratigraphy for the Stayky loess section is supported by four IRSL-ages (Rousseau et al., 2011). If the IRSL-ages are accepted, correlation of the suite of embryonic soils above the Vytachiv Soil presumably does not start with GIS7 but probably after GIS5. The lowermost incipient soils, likely encompassing ES8 to ES5/4b, probably developed during the final phase of MIS3. In that case, the transition from the terrestrial Middle to Upper Pleniglacial would have occurred during MIS3, i.e. likely at the termination of GIS5. Therefore, the major pedozones, which include more mature and loamy soils in the Middle Pleniglacial and solely incipient soils in the Upper Pleniglacial, would not accord to the major isotope stages of the marine and ice-core archives. In this respect the general picture at the Eastern European key loess section at Stayky in

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[8] For ongoing investigations of sediment deposits of the Yellow River as likely source areas for loess on the Chinese Loess Plateau cf. Stevens et al. (2012).

Ukraine seems to resemble that of the Western European master section at Nussloch in southwestern Germany.

The western, more oceanic site (Nussloch: ca. 9° E, ca. 49° N) and the eastern, more continental site (Stayky: ca. 31° E, ca. 50° N) are located at similar latitude. Therefore, it is imaginable that a common shift in palaeoecological conditions might have been correlated with respective advances of the Northern European ice margin and corresponding changes in the North Atlantic climate circulation. Such early LGM ice advances at < 34 ka (maximum luminescence age of glaciofluvial outwash deposits) were recently suggested for the Brandenburg ice marginal position in northeastern Germany (Lüthgens, 2011). As, however, terrestrial palaeoenvironmental MIS3 oscillations were apparently more susceptible to variations of the North Atlantic sea-surface temperature and corresponding sea-ice distribution than to the extent of the northern ice-shield (Barron and Pollard, 2002), changes in the oceanic system might have been the actual trigger, probably together with self-reinforcing effects of the northern hemispheric climate system triggered in turn by varying atmospheric dust load from the central Asian terrestrial sources (e.g. Machalett et al., 2011, 2012).

Since local/regional wind trajectories and vectors respond highly sensitive in a changing glacial climate, as e.g. documented by the GSI-variations in the Nussloch and Stayky records (Antoine et al., 2001, 2009; Rousseau et al., 2011), wind might have been significant for the marked change from MPG to UPG palaeosol character. This assumption is based on a model by Zech (2013), which states that the intensities of soil development are not merely a function of soil formation rates, but that increased dust input may "dilute" intensities whereas decreased dust input may mimic increased soil formation rates. The Nussloch data allow a rough estimate of upper MPG versus lower UPG sedimentation rates. These are consistent with the Zech model, as they suggest sedimentation rates of ca. $\leq 0.5\,\mathrm{m\,ka^{-1}}$ before GIS5 (cf. unit 15/Huneborg II-unit 20/Denekamp) but ca. $1.5\,\mathrm{m\,ka^{-1}}$ thereafter (cf. unit 21-unit 24). Therefore it seems plausible that GIS4 and GIS3 are represented by soils which are less intensively developed than underlying MPG soils. The relatively high GSI values (ca. 1.3–1.6) of the likely GIS4 (unit 23) and GIS3 (unit 26) soils as compared to the Lohne Soil (unit 20; GSI ca. 0.6) are in agreement with increased aeolian input. Thus the Zech model could help explain why the terrestrial environments at Nussloch and Stayky seem to respond earlier (MPG/UPG-boundary) than the marine and ice core records (MIS3/MIS2 transition).

The uppermost part of the Stayky loess section, possibly reaching down to 270 cm b.g.l. and in this case including ES2a/1, could date into the LGM, i.e. the MIS2-period post-dating Heinrich 2 (MIS2b/2c). It is interesting to note that the revised age-model for Stayky conforms to the independently revised age-model for Nussloch (cf. Kadereit et al., 2013). For Nussloch, the necessity for a revision is even more obvious, as at the master section in Western Europe GIS8 matches a well datable thermokarst infilling which clearly predates the Lohne Soil. Due to the limited number of available ages, the revised interpretation for Stayky should be regarded as a working-hypothesis, which – however – could help guide future investigations along west-eastern loess transects through Europe and into Asia. It is essential that the terrestrial, and therefore highly incomplete, discontinuous and floating records are supported by solid chronometries as a necessary prerequisite for successful event-stratigraphical correlations. This way, the brilliant approaches to (1) link loess-palaeosol-sequences with millennial-scale Dansgaard–Oeschger cycles (Rousseau et al., 2002) and to (2) use a grain-size index (GSI) for the correlation of (distant) loess-palaeosol-sections (Rousseau et al., 2011) could become most powerful tools advancing European loess research.

Supplementary material related to this article is available online at: http://www.clim-past-discuss.net/9/2629/2013/cpd-9-2629-2013-supplement.pdf.

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References

Alley, R. B., Meese, D. A., Shuman, C. A., Gow, A. J., Taylor, K. C., Grootes, P. M., White, J. W. C., Ram, M., Waddington, E. D., Mayewski, P. A., and Zielinski, G. A.: Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas event, Nature, 362, 527–529, 1993.

Andersen, K. K., Svensson, A., Johnsen, S. J., Rasmussen, S. O., Biglera, M., Röthlisberger, R., Ruth, U., Siggaard-Andersen, M.-L., Steffensen, J. P., Dahl-Jensen, D., Vinther, B. M., and Clausen, H. B.: The Greenland Ice Core Chronology 2005, 15–42 ka, Part 1: constructing the time scale, Quaternary Sci. Rev., 25, 3246–3257, 2006.

Antoine, P., Rousseau, D.-D., Zöller, L., Lang, A., Munaut, A. V., Hatté, C., and Fontugne, M.: High-resolution record of the Last Interglacial–Glacial cycle in the loess palaeosol sequences of Nussloch (Rhine Valley – Germany), Quatern. Int., 76/77, 211–229, 2001.

Antoine, P., Rousseau, D.-D., Moine, O., Kunesch, S., Hatté, C., Lang, A., Tissoux, H., and Zöller, L.: Rapid and cyclic aeolian deposition during the Last Glacial in European loess: a high-resolution record from Nussloch, Germany, Quaternary Sci. Rev., 28, 2955–2973, 2009.

Antoine, P., Rousseau, D.-D., Degeai, J.-P., Moine, O., Lagroix, F., Kreutzer, S., Fuchs, M., Hatté, C., Gauthier, C., Svoboda, J., and Lisá, L.: High-resolution record of the environmental response to climatic variations during the Last InterglacialeGlacial cycle in Central Europe: the loess-palaeosol sequence of Dolní Vestonice (Czech Republic), Quaternary Sci. Rev., 67, 17–38, 2013.

Barron, E. and Pollard, D.: High-resolution climate simulations of oxygen isotope stage 3 in Europe, Quaternary Res., 58, 296–309, 2002.

Björck, S., Walker, M. J., Cwynar, L. C., Johnsen, S., Knudsen, K.-L., Lowe, J. J., Wohlfahrt, B., and INTIMATE Members: An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group, J. Quaternary Sci., 13, 283–292, 1998.

Bory, A. J.-M., Biscaye, P. E., Svensson, A., and Grousset, F. E.: Seasonal variability in the origin of recent atmospheric mineral dust at NorthGRIP, Greenland, Earth Planet. Sc. Lett., 196, 123–134, 2002.

Briant, R. M. and Bateman, M. D.: Luminescence dating indicates radiocarbon age underestimation in late Pleistocene fluvial deposits from eastern England, J. Quaternary Sci., 24, 916–927, 2009.

Bronk Ramsey, C.: OxCal Program v4.1, https://c14.arch.ox.ac.uk/oxcal/OxCal.html (last access: 1 July 2013), 2012.

Buggle, B., Hambach, U., Glaser, B., Gerasimenko, N., Markovic, S., Glaser, I., and Zöller, L.: Stratigraphy, and spatial and temporal paleoclimatic trends in southeastern/eastern European loess-palaeosol sequences, Quatern. Int., 196, 86–106, 2009.

Clausen, H. B.: The Greenland Ice Core Chronology 2005, 15–42 ka, Part 1: constructing the time scale, Quaternary Sci. Rev., 25, 3246–3257, 2006.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjörnsdottir, A. E., Jouzel, J., and Bond, G.: Evidence for general instability of past climate from a 250 kyr ice-core record, Nature, 364, 218–220, 1993.

Danzeglocke, U., Jöris, O., and Weninger, B.: CalPal-2007online/quickcal2007 ver. 1.5, http://www.calpal-online.de (last access: 14 May 2013), 2009.

Fairbanks, R. G., Mortlock, R. A., Chiu, T.-C., Cao, L., Kaplan, A., Guilderson, T. P., Fairbanks, T. W., and Bloom, A. L.: Marine radiocarbon calibration curve spanning 0 to 50 000 yr BP based on paired ^{230}Th/^{234}U/^{238}U and ^{14}C Dates on pristine corals, Quaternary Sci. Rev., 24, 1781–1796, 2005.

Fuchs, M., Rousseau, D.-D., Antoine, P., Hatté, C., Gauthier, C., Markovic, S., and Zöller, L.: Chronology of the Last Climatic Cycle (Upper Pleistocene) of the Surduk loess sequence, Vojvodina, Serbia, Boreas, 37, 66–73, 2008.

Fuchs, M., Kreutzer, S., Rousseau, D.-D., Antoine, P., Hatté, C., Lagroix, F., Moine, O., Gauthier, C., Svoboda, J., and Lisá, L.: The loess sequence of Dolní Vestonice, Czech Republic:

a new OSL-based chronology of the Last Climatic Cycle, Boreas,doi:10.1111/j.1502-3885.2012.00299.x, in press, 2012.

Gocke, M., Peth, S., and Wiesenberg, G. L. B.: Lateral and depth variation of loess organic matter overprint related to rhizoliths – revealed by lipid molecular proxies and X-ray tomography, Catena, doi:10.1016/j.catena.2012.11.011, in press, 2013.

Greenland Ice-Core Project (GRIP) Members: Climate instability during the last Glacial period recorded in the GRIP ice core, Nature, 364, 203–208, 1993.

Guiter, F., Andrieu-Ponel, V., de Beaulieu, J.-L., Cheddadi, R., Calvez, M., Ponel, P., Reille, M., Keller, T., and Goeury, C.: The last climatic cycles in western Europe: a comparison between long continuous lacustrine sequences from France and other terrestrial records, Quatern. Int., 111, 59–74, 2003.

Haase, D., Fink, J., Haase, G., Ruske, R., Pécsi, M., Richter, H., Altermann, M., and Jäger, K.-D.: Loess in Europe – its spatial distribution based on a European Loess Map, scale 1:2 500 000, Quaternary Sci. Rev., 26, 1301–1312, 2007.

Haesaerts, P., Borziac, I., Chekha, V. P., Chirica, V., Drozdov, N. I., Koulakovska, L., Orlova, L. A., van der Plicht, J., and Damblon, F.: Charcoal and wood remains for radiocarbon dating Upper Pleistocene loess sequences in Eastern Europe and Central Siberia, Palaeogeogr. Palaeocl., 291, 106–127, 2010.

Hatté, C., Pessenda, L. C., Lang, A., and Paterne, M.: Development of accurate and reliable 14C chronologies for loess deposits: application to the loess sequence of Nußloch (Rhine Valley, Germany), Radiocarbon, 43, 611–618, 2001.

Hemming, S.: Heinrich events: massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42, 1–43, 2004.

Higham, T.: European Middle and Upper Palaeolithic radiocarbon dates are often older than they look: problems with previous dates and some remedies, Antiquity, 85, 235–249, 2011.

Hoek, W. Z., Yu, Z. C., and Lowe, J. J.: INTegration of Ice-core, Marine, and Terrestrial records (INTIMATE): refining the record of the Last Glacial–Interglacial Transition, Quaternary Sci. Rev., 27, 1–5, 2008.

Huijzer, B. and Vandenberghe, J.: Climatic reconstruction of the Weichselian Pleniglacial in northwestern and central Europe, J. Quaternary Sci., 13, 391–417, 1998.

IUSS Working Group: World Reference Base for Soil Resources, WRB, revised edition, World Soil Resources Reports, 103, Rome, 1–128, 2007.

Johnsen, S. J., Dahl-Jensen, D., Dansgaard, W., and Gundestrup, N.: Greenland palaeotemperatures derived from GRIP bore hole temperature and ice isotope profiles, Tellus, 47, 624–629, 1995.

Johnsen, S. J., Clausen, H. B., Dansgaard, W., Gundestrup, N., Hammer, C. U., Andersen, U., Andersen, K. K., Hvidberg, C. S., Dahl-Jensen, D., Steffensen, J. P., Shoji, H., Sveinbjornsdottir, A. E., White, J., Jouzel, J., and Fisher, D.: The δ^{18}O record along the Greenland Ice Core Project deep ice core and possible Eemian climate instability, J. Geophys. Res., 102, 26397–26410, 1997.

Johnsen, S. J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J. P., Clausen, H. B., Miller, H., Masson-Delmotte, V., Sveinbjornsdottir, A. E., and White, J.: Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP, J. Quaternary Sci., 16, 299–307, 2001.

Kadereit, A., Kühn, P., and Wagner, G. A.: Holocene relief and soil changes in loess-covered areas of south-western Germany: the pedosedimentary archives of Bretten-Bauerbach (Kraichgau), Quatern. Int., 222, 99–119, 2010.

Kadereit, A., Kind, C.-J., and Wagner, G. A.: The chronological position of the Lohne Soil in the Nussloch loess section – re-evaluation for a European loess-marker horizon, Quaternary Sci. Rev., 59, 67–86, doi:10.1016/j.quascirev.2012.10.026, 2013.

Kreutzer, S., Fuchs, M., Meszner, S., and Faust, D.: OSL chronostratigraphy of a loess-palaeosol sequence in Saxony/Germany using quartz of different grain sizes, Quat. Geochronol., 10, 102–109, 2012.

Lang, A. and Wagner, G. A.: Infrared stimulated luminescence dating of archaeosediments, Archaeometry, 38, 129–141, 1996.

Lomax, J., Fuchs, M., Preusser, F., and Fiebig, M.: Luminescence based loess chronostratigraphy of the Upper Palaeolithic site Krems-Wachtberg, Austria, Quatern. Int., doi:10.1016/j.quaint.2012.10.037, in press, 2012.

Lüthgens, C.: The Age of Weichselian Main Ice Marginal Positions in North-Eastern Germany Inferred from Optically Stimulated Luminescence (OSL) Dating, PhD thesis Freie Universität Berlin, http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_000000022882, 2011.

Machalett, B., Oches, E., Haam, E., Lai, Z. P., and Endlicher, W.: Late Pleistocene aeolian dust dynamics in central Asia and their teleconnection with short-term climate oscillations and abrupt climate events in the Northern Hemisphere, Quaternary Sciences – the view from the mountains, 21–27 July 2011, XVIII INQUA Bern, Abstract 3073, 2011.

Machalett, B., Oches, E., Haam, E., Lai, Z. P., and Endlicher, W.: Long term seasonality changes and short term climate variability recorded in Eurasian Loess: examples from Serbia, Romania, Kazakhstan, and China, EGU General Assembly 2012, Geophys. Res. Abstr., 14, EGU2012–13305, 2012.

Markovic, S. B., Hambach, U., Catto, N., Jovanovica, M., Buggle, B., Machalett, B., Zöller, L., Glaser, B., and Frechen, M.: Middle and Late Pleistocene loess sequences at Batajnica, Vojvodina, Serbia, Quatern. Int., 198, 255–266, 2009.

Meese, D. A., Gow, A. J., Grootes, P. M., Mayewski, P. A., Ram, M., Stuiver, M., Taylor, K. C., Waddington, E. D., and Zielinski, G. A.: The accumulation record from the GISP2 core as an indicator of climate change throughout the Holocene, Science, 266, 1680–1682, 1994.

Molodkov, A. and Bolikhovskaya, N.: Climate change dynamics in Northern Eurasia over the last 200 ka: evidence from mollusc-based ESR-chronostratigraphy and vegetation successions of the loess–palaeosol records, Quatern. Int., 201, 67–76, 2009.

Pirson, S., Flas, D., Abrams, G., Bonjean, D., Court-Picon, M., Di Modica, K., Draily, C., Damblon, F., Haesaerts, P., Miller, R., Rougier, H., Toussaint, M., and Semal, P.: Chronostratigraphic context of the Middle to Upper Palaeolithic transition: recent data from Belgium, Quatern. Int., 259, 78–94, 2012.

Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggaard-Andersen, M.-L., Johnsen, S. J., Larsen, L. B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.-E., and Ruth, U.: A new Greenland ice core chronology for the last glacial termination, J. Geophys. Res., 111, D06102, doi:10.1029/2005JD006079, 2006.

Rasmussen, S. O., Seierstad, I. K., Andersen, K. K., Bigler, M., Dahl-Jensen, D., and Johnsen, S. J.: Synchronization of the NGRIP, GRIP, and GISP2 ice cores across MIS 2 and palaeoclimatic implications, Quaternary Sci. Rev., 27, 18–28, 2008.

Reimer, P. J., Baillie, M G. L., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Burr, G. S., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., McCormac, F. G., Manning, S. W., Reimer, R. W., Richards, D. A., Southon, J. R., Talamo, S., Turney, C. S. M., van der Plicht, J., and Weyhenmeyer, C. E.: Intcal09 and Marine09 Radiocarbon age calibration curves, 0–50,000 yr cal BP, Radiocarbon, 51, 1111–1150, 2009.

Rousseau, D. D., Gerasimenko, N. P., Matviischina, Z., and Kukla, G. J.: Late Pleistocene environments of the Central Ukraine, Quaternary Res., 56, 349–356, 2001.

Rousseau, D.-D., Antoine, P., Hatté, C., Lang, A., Zöller, L., Fontugne, M., Ben Othman, D., Luck, J. M., Moine, O., Labonne, M., Bentaleb, I., and Jolly, D.: Abrupt millennial climatic changes from Nussloch (Germany) Upper Weichselian eolian records during the Last Glaciation, Rapid Communication, Quaternary Sci. Rev., 21, 1577–1582, 2002.

Rousseau, D.-D., Kukla, G., and McManus, J.: What is what in the ice and the ocean?, Quaternary Sci. Rev., 25, 2025–2030, 2006.

Rousseau, D.-D., Antoine, P., Gerasimenko, N., Sima, A., Fuchs, M., Hatté, C., Moine, O., and Zoeller, L.: North Atlantic abrupt climatic events of the last glacial period recorded in Ukrainian loess deposits, Clim. Past, 7, 221–234, doi:10.5194/cp-7-221-2011, 2011.

Ruth, U.: Mineral dust records from Greenland ice cores, PAGES Newsletter, 13, 17–18, 2005.

Ruth, U., Wagenbach, D., Bigler, M., Steffensen, J. P., Röthlisberger, R., and Miller, H.: High-resolution microparticle profiles at NorthGRIP, Greenland: case studies of the calcium-dust relationship, Ann. Glaciol., 35, 237–242, 2002.

Ruth, U., Wagenbach, D., Steffensen, J. P., and Bigler, M.: Continuous record of microparticle concentration and size distribution in the central Greenland NGRIP ice core during the last glacial period, J. Geophys. Res., 108, ACL 1-1–ACL 1-12, 2003.

Shackleton, N. J., Hall, M. A., and Vincent, E.: Phase relationships between millennial-scale events 64 000–24 000 yr ago, Paleoceanography, 15, 565–569, 2000.

Shackleton, N. J., Fairbanks, R. G., Chiu, T., and Parrenin, F.: Absolute calibration of the Greenland time scale: implications for Antarctic time scales and for Δ^{14}C, Quaternary Sci. Rev., 23, 1513–1522, 2004.

Schirmer, W.: Rhine loess at Schwalbenberg II – MIS 4 and 3, Eiszeitalter und Gegenwart, Quaternary Sci. J., 61, 32–47, doi:10.3285/eg.61.1.03, 2012.

Schönhals, E., Rohdenburg, H., and Semmel, A.: Ergebnisse neuerer Untersuchungen zur Würmlößgliederung in Hessen, Eiszeitalter und Gegenwart, 15, 199–206, 1964.

Schulz, M.: On the 1470 yr pacing of Dansgaard–Oeschger warm events, Paeleoceanography, 17, 1–9, doi:10.1029/2000PA000571, 2002.

Skinner, L. C.: Revisiting the absolute calibration of the Greenland ice-core age-scales, Clim. Past, 4, 295–302, doi:10.5194/cp-4-295-2008, 2008.

Sommer, R. and Zachos, F. E.: Fossil evidence and phylogeography of temperate species: “glacial refugia” and post-glacial recolonization, J. Biogeogr., 36, 2013–2020, 2009.

Sowers, T., Bender, M., Labeyrie, L., Martinson, D., Jouzel, J., Raynaud, D., Pichon, J. J., and Korotkevich, Y. S.: A 135 000 yr Vostok-SPECMAP common temporal framework, Paleooceanography, 8, 737–766, 1993.

Stevens, T., Markovic, S., Zech, M., Hambach, U., and Sümegi, P.: Dust deposition and climate in the Carpathian basin over an independently dated last glacial–interglacial cycle, Quaternary Sci. Rev., 30, 662–681, 2011.

Stevens, T., Bird, A., Carter, A., Vermeesch, P., Watson, T., Lu, H., Andò, S., Garzanti, E., Cottam, M., Sevastjanova, I., and Rittner, M.: Rivers of dust – loess deposition and major rivers, oral presentation and section in written form in book of abstracts, 36. Hauptversammlung, DEUQUA 16–20 September 2012, Bayreuth, 2012.

Svensson, A., Andersen, K. K., Bigler, M., Clausen, H. B., Dahl-Jensen, D., Davies, S. M., Johnsen, S. J., Muscheler, R., Rasmussen, S. O., Röthlisberger, R., Steffensen, J. P., and Vinther, B. M.: The Greenland Ice Core Chronology 2005, 15–42 ka, Part 2: comparison to other records, Quaternary Sci. Rev., 25, 3258–3267, 2006.

Svensson, A., Andersen, K. K., Bigler, M., Clausen, H. B., Dahl-Jensen, D., Davies, S. M., Johnsen, S. J., Muscheler, R., Parrenin, F., Rasmussen, S. O., Röthlisberger, R., Seierstad, I., Steffensen, J. P., and Vinther, B. M.: A 60 000 year Greenland stratigraphic ice core chronology, Clim. Past, 4, 47–57, doi:10.5194/cp-4-47-2008, 2008.

Talamo, S., Hughen, K. A., Kromer, B., and Reimer, P.: Debates over Palaeolithic chronology – the reliability of ^{14}C is confirmed, J. Archaeol. Sci., 39, 2464–2467, 2012.

Terhorst, B., Thiel, C., Peticzka, R., Sprafke, T., Frechen, M., Fladerer, F. A., Roetzel, R., and Neugebauer-Maresch, C.: Casting new light on the chronology of the loess/paleosol sequences in Lower Austria, Eiszeitalter und Gegenwart/Quaternary Sci. J., 60, 270–277, 2011.

Timar, A., Vandenberghe, D., Panaiotu, C. E., Panaiotu, C. G., Necula, C., Cosma, C., and van den Haute, P.: Optical dating of Romanian loess using fine-grained quartz, Quat. Geochronol., 5, 143–148, 2010.

Törnqvist, T. E., Wallinga, J., Murray, A. S., de Wolf, H., Clevering, P., and de Gans, W.: Response of the Rhine–Meuse system (west-central Netherlands) to the last quaternary glacio-eustatic cycles: a first assessment, Global Planet. Change, 27, 89–111, 2000.

Unkel, I., Kadereit, A., Mächtle, B., Eitel, B., Kromer, B., Wagner, G., and Wacker, L.: Dating methods and geomorphic evidence of palaeo-environmental changes at the eastern margin of the South Peruvian coastal desert (14°30′ S) before and during the Little Ice Age, Quatern. Int., 175, 3–28, 2007.

van Huissteden, J. and Kasse, C.: Detection of rapid climate change in Last Glacial fluvial successions in the Netherlands, Global Planet. Change, 28, 319–339, 2001.

Wallinga, J., Murray, A., and Duller, G.: Underestimation of equivalent dose in single-aliquot optical dating of feldspars caused by preheating, Radiat. Meas., 32, 691–695, 2000.

Wang, Y. J., Cheng, H., Edwards, R. L., An, Z. S., Wu, J. Y., Shen, C.-C., and Dorale, J. A.: A high-resolution absolute-dated late Pleistocene Monsoon Record from Hulu Cave, China, Science, 294, 2345–2348, 2001.

Weninger, B. and Jöris, O.: ^{14}C age calibration curve for the last 60 ka: the Greenland–Hulu U/Th timescale and its impact on understanding the Middle to Upper Paleolithic transition in western Eurasia, J. Hum. Evol., 55, 772–781, 2008.

Zech, R.: Loess is the accumulation of dust, not evidence for aridity, EGU General Assembly 2013, Geophys. Res. Abstr., 15, EGU2013–11263, 2013.

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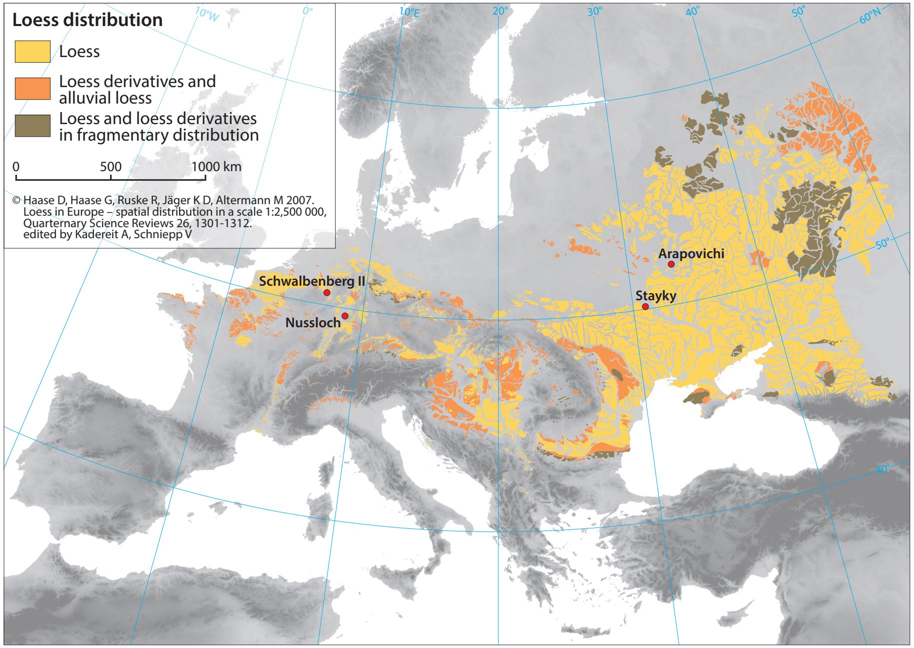

Fig. 1. Location of the well developed loess sections Nussloch (key section for western Europe), Schwalbenberg II, Stayky (key section for eastern Europe) and Arapovichi within the European loess belt (map based on Haase et al., 2007).

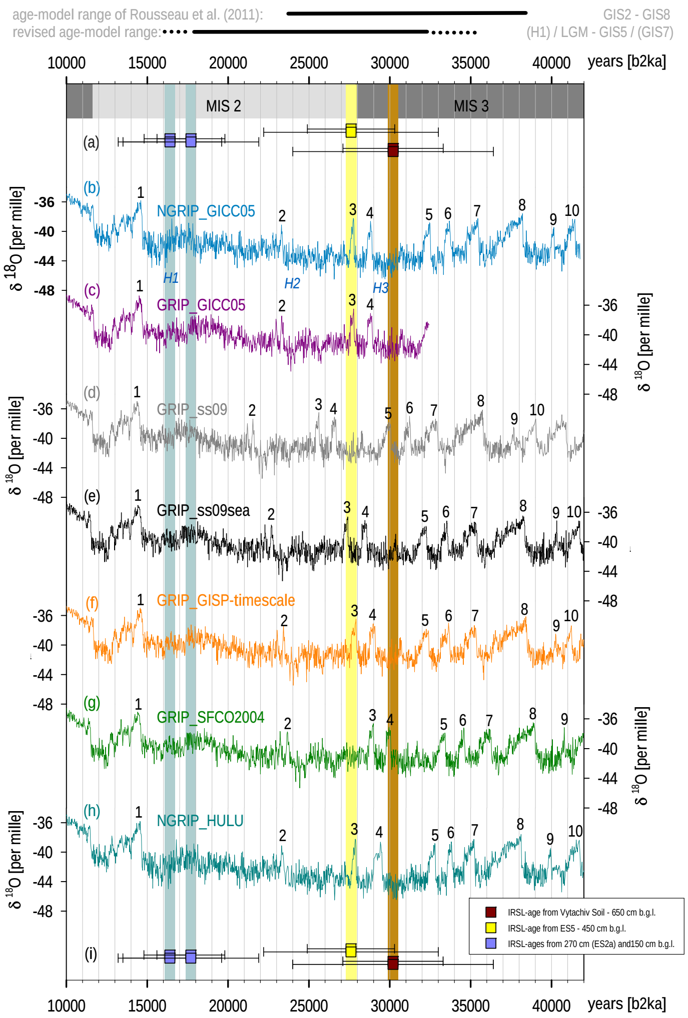
age-model range of Rousseau et al. (2011):
GIS2 - GIS8
revised age-model range:
(H1) / LGM - GIS5 / (GIS7)
10000 15000 20000 25000 30000 35000 40000 years [b2ka]
MIS 2
MIS 3
(a)
(b)
NGRIP_GICC05
1 2 3 4 5 6 7 8 9 10
δ 18O [per mille]
-36 -40 -44 -48
H1
H2
H3
(c)
GRIP_GICC05
1 2 3 4
(d)
GRIP_ss09
1 2 3 4 5 6 7 8 9 10
(e)
GRIP_ss09sea
1 2 3 4 5 6 7 8 9 10
(f)
GRIP_GISP-timescale
1 2 3 4 5 6 7 8 9 10
(g)
GRIP_SFCO2004
1 2 3 4 5 6 7 8 9
(h)
NGRIP_HULU
1 2 3 4 5 6 7 8 9 10
(i)
IRSL-age from Vytachiv Soil - 650 cm b.g.l.
IRSL-age from ES5 - 450 cm b.g.l.
IRSL-ages from 270 cm (ES2a) and150 cm b.g.l.

Fig. 2. IRSL-chronology for the loess section at Stayky/Ukraine reflected in global ice-core time-scales. The age-model of Rousseau et al. (2011) starts with GIS8 for the Vytachiv Soil, and terminates prior to Heinrich 2 for the uppermost embryonic soil ES1 (early and short chronology). The IRSL-data, however, cover an age-range from GIS5 (GIS7 at the utmost on a 2 sigma error-range) to the late LGM during the second half of the Greenland stadial between GIS2 and GIS1 (later and longer chronology). Please note that for Fig. 2 data were taken from Figs. 3 and 4 of Rousseau et al. (2011), which tend to be slightly older than the data given in Table 1 of the same publication, and which have significantly larger errors than the table-values. For recent criticism on the CICC05 time-scale – with respect to a bias towards younger ages of few hundred years especially between GIS2 and GIS6 and to the placement of Heinrich events, which in the marine time-scales usually directly precede the beginning of a GIS as documented in respective debris layers – see Skinner (2008). Therefore, the positions for H1 to H3 in Fig. 2b should be regarded as tentatively designated, meant only as an aid to follow our argumentation.
(a) IRSL-ages after Rousseau et al. (2011, Figs. 3 and 4). The data in the figures tend to be slightly older and they have larger errors than the ages given by the authors in Table 1.
(b)–(f) data from the Centre for Ice and Climate/Niels Bohr Institute/University of Copenhagen: http://www.iceandclimate.nbi.ku.dk/; the δ^{18}O-data are as based on Dansgaard et al. (1993), GRIP Members (1993) and Johnsen et al. (1997) (for more details see below).
(b) NGRIP with Greenland Ice Core Chronology 2005 (GICC05) (Andersen et al., 2006; Svensson et al., 2006) released 10 September 2007; file name "GICC05_NGRIP_20y_10sep2007"; the NGRIP-data for the time-window of 10 to 42 ka, as presented here, are all from core NGRIP2 only.
(c) GRIP with Greenland Ice Core Chronology 2005 (GICC05) (Andersen et al., 2006; Svensson et al., 2006) released 27 November 2006; file name "GICC05_NGRIP_GRIP_20y_27nov2006"; prior to 11.7 ka the NGRIP-GICC05-timescale has been transferred to GRIP by the use of volcanic marker horizons and the linear interpolation in between Rasmussen et al. (2006, 2008).
(d) ss09-timescale (Johnsen et al., 1995) released 23 November 2000 by I.A. Mogensen; file name "gripdelta.dat" (GRIP, oxygen isotopes, 20 yr averages on GISP2 time scale, 375–103 000 yrs BP), colums 1–2.
(e) ss09sea or GRIP2001-chronology (Johnsen et al., 2001); ASCII-file (GRIP, oxygen isotopes, 20 yr averages back to 122 kyr BP.

(f) GISP-timescale as based on Alley et al. (1993), Meese et al. (1994) and Sowers et al. (1993) released 23 November 2000 by I.A. Mogensen; file name "gripdelta.dat" (GRIP, oxygen isotopes, 20 yr averages on GISP2 time scale, 375–103 000 yr BP), colums 2–3.
(g) data of SFCO2004-timescale from the Pole-Ocean-Pole Project, Department of Earth Sciences, University of Cambridge: http://www.esc.cam.ac.uk/research/research-groups/pop/pop-project-data/pop-project-grip-data-on-sfcp2004-timescale; file name "GRIP data on SFCP2004 timescale"; the SFCP2004-timescale (Shackleton et al., 2004) is based on the matching between the GRIP δ^{18}O-record and the δ^{18}O-record of planktonic foraminifera of piston core MD95–2042 (Shackleton et al., 2000) that is ^{14}C-dated by the use of a correction-curve based on paired ^{230}Th/^{234}U/^{238}U and ^{14}C dates on pristine coral samples Fairbanks et al. (2005).
(h) Greenland–Hulu U/Th timescale: Greenland NGRIP stable oxygen isotope record from Andersen et al. (2006, 2008) and Svensson et al. (2006) tuned to the Hulu Cave U/Th chronology and δ^{18}O-stratigraphy from Wang et al. (2001). Data-record from Weninger and Jöris (2008).
(i) like **(a)**.