Investigating the chronostratigraphy of prominent palaeosols in Lower Austria using post-IR IRSL dating

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Abstract: The age of most Lower Austria loess deposits is unknown; this is especially true for Middle Pleistocene loess because there is no generally applicable dating method available. Recently it has been shown that infrared stimulated luminescence (IRSL) signals measured at elevated temperatures after an infrared (IR) stimulation are more stable than the standard IRSL signal measured at 50°C. These signals offer new opportunities to extend the datable age range by minimising or circumventing the undesirable anomalous fading correction. In this study we apply, for the first time, two post-IR IRSL single-aliquot regenerative (SAR) dating protocols to polymineral fine-grain samples from three loess/palaeosol sequences in Lower Austria. The luminescence characteristics and ages derived from these protocols are compared with the IRSL results obtained at 50°C. Recycling ratios, recuperation and dose recovery tests show that these protocols are applicable to the loess under investigation. Fading rates for the post-IR IRSL signals are significantly smaller than for the IRSL at 50°C; the differences in fading rates between post-IR IRSL at 225°C and post-IR IRSL at 290°C are less obvious. Significant fading corrections are needed for the ages derived from the IRSL signal at 50°C. From our study we conclude that the fading corrected post-IR IRSL at 225°C and the fading uncorrected post-IR IRSL at 290°C provide the best age estimates; we prefer the latter because no fading correction is apparently needed. Our data strongly suggest that the pedocomplex ‘Paudorfer Bodenbildung’ developed during marine isotope stage (MIS) 5, whereas the pedocomplex ‘Göttweiger Verlehmungszone’ is significantly older (≥ 350 ka) than has been suggested in former studies.

Keywords: post-IR IRSL; fading; loess; Middle Pleistocene; Lower Austria

1 Introduction

Loess/palaeosol sequences contain detailed archives of terrestrial palaeoenvironmental changes and landscape evolution. Unfortunately, most loess sequences lack a reliable absolute chronology and hence these changes are difficult to constrain in time. Especially for Middle Pleistocene loess deposits, geochronological information is scarce because there is, as yet, no generally applicable and reliable instrumental dating method which can be used for this age range. Luminescence dating has proved to be a useful tool to date loess deposits (Roberts, 2008), not only because of the wide age range covered by this technique (from a few years to, theoretically, several hundred thousand years; Atkyn, 1998) but also because of the long sub-aerial transport of the particles which make up loess; this is confidently expected to have bleached any luminescence signal prior to deposition. Loess is also made up almost entirely of quartz and feldspar, both of which are suitable dosimeters for luminescence dating. The main drawback in the optically
stimulated luminescence (OSL) dating of quartz extracted from loess is the low saturation level of ~200 Gy; this is equivalent to ~50–70 ka assuming a dose rate of between 3 and 4 Gy/ka (typical for loess, e.g. Frechen et al., 1997; Novothny et al., 2002, 2009; Wang et al., 2006; Buylaert et al., 2007; Lai et al., 2010; Thiel et al., 2011a, b). In contrast, feldspar infrared stimulated luminescence (IRSL) signals have a much higher saturation dose (~1500–2000 Gy; equivalent to ~500–700 ka) but, on the other hand, most feldspars suffer from athermal signal loss, referred to as anomalous fading (Wintle, 1973; Spooner, 1994). Because of this phenomenon, IRSL ages tend to significantly underestimate the depositional age. Huntley & Lamothe (2001) have presented a model that can be used to correct the age underestimation, but these corrections are theoretically only applicable to the linear part of the growth curve, i.e. to young samples. Approaches which allow for correction beyond the linear region have been proposed by Lamothe et al. (2003) and Kars et al. (2008); in principle these models can be used for older material (in case of loess >50 ka), but there is little or no testing of these models available in the literature. Although fading corrections can give apparently accurate ages (Huntley & Lamothe, 2001; Buylaert et al., 2011) it seems more advisable to make use of IRSL signals that show less or no fading (Thiel et al., 2011a, submitted) because all correction models involve untestable assumptions, including that the fading rate observed on a laboratory timescale is relevant to geological time. In addition, there are examples where feldspar IRSL ages underestimate when compared with independent age control, even after fading correction (e.g. Wallinga et al., 2007).

Recent developments in luminescence dating offer the potential to circumvent the problem of anomalous fading, and thus to extend the reliable dating range to the Middle Pleistocene (126 to 781 ka; Head et al., 2008). The post-IR IRSL signal (IR stimulation at 50°C and subsequent IRSL measurement at 225°C, blue detection; Thomsen et al., 2008) seems to have great potential; in the laboratory, this signal fades more slowly than conventional IRSL measured at 50°C. Buylaert et al. (2009) tested the applicability of this post-IR IRSL signal to dating sand-sized potassium feldspar grains; the fading rate of the post-IR IRSL signal was two times smaller than the one of the IRSL signal measured at 50°C. Thiel et al. (2011a) used a preheat of 320°C (60 s), IR stimulation at 50°C (200 s) and subsequent post-IR IR stimulation at 290°C (200 s) for polynuclear fine grains (4–11 μm). They measured the natural signal and dose response curve of a sample from below the Brunhes/Matuyama boundary (~780 ka, expected natural dose >2700 Gy), and found the natural signal in saturation on the laboratory regenerated growth curve; from that they concluded that for their samples they were unable to detect any evidence for anomalous fading in the field using post-IR IRSL at 290°C.

Even though post-IR IRSL dating in its different forms has now been applied in several studies (Buylaert et al., 2009; Thiel et al., 2010, 2011a, accepted; Reimann et al., 2011) no study has compared the performance of the two different post-IR IRSL dating protocols now in use. In this paper we compare the ages derived from the IR signal at 50°C and two post-IR IRSL signals (post-IR IR stimulation at 225°C, Buylaert et al., 2009; post-IR IR stimulation at 290°C, Thiel et al., 2011a) for three loess/palaeosol sequences in Lower Austria: i) Joching, ii) Paudorf, and iii) Göttweig. These sites have a long scientific history, starting with the investigations of Bayer (1927) and Götzinger (1936). Nevertheless the ages of the pedocomplexes ‘Paudorfer Bodenbildung’ and ‘Göttweiger Verlehmungszone’ are still controversial (Fink, 1976; Noll et al., 1994; Zöller et al., 1994; Smolíková et al., 1994) due to discontinuities as the result of intensive erosional phases (cf. Havlíček et al., 1998), and illustrate the need for a more reliable numerical dating method. We first demonstrate that our measurement pro-

Fig. 1: Map of the study area, showing the locations of Göttweig (Furth and Aigen), Paudorf, and Joching.

Abb. 1: Karte des Untersuchungsgebiets mit den Lokalitäten Göttweig (Furth und Aigen), Paudorf und Joching.
tocols are applicable to these samples, by examining recuperation, recycling ratios and the ability of these protocols to measure a known dose given in the laboratory. Subsequently the luminescence characteristics, the equivalent doses and laboratory fading rates for the various signals are compared and the derived ages (corrected and uncorrected) are discussed in terms of their reliability. Finally, the most reliable set of IRSL ages is used to unravel the chronostratigraphy of the prominent palaeosols in Lower Austria.

2 Site descriptions and sampling

The loess/palaeosol sequences investigated in this study are located in the Kremser Feld in Lower Austria (Fig. 1); this region is covered by up to 30 m of loess deposits. Three sites exhibiting the prominent palaeosols ‘Paudorfer Bodenbildung’ and ‘Göttweiger Verlehmungszone’ were investigated; samples for luminescence dating were taken by hammering metal tubes into the freshly cleaned profile. Samples for dosimetry measurements (~1000 g) were taken from immediately around the luminescence samples.

2.1 Joching

The village of Joching is located on the left bank of the Danube (Fig. 1) and is the furthest upstream of our sites. The loess/palaeosol sequence has a total thickness of about 10 m, with at least two distinct palaeosols (Fig. 2). Below silty yellowish-brown loess (unit J1) a zone of Cryosol horizons (unit J2) is underlain by stratified loamy pellet sands (‘Bröckelsande’; unit J3) of up to 4 m thickness. These sands cover a palaeosol horizon with interstadial intensity (J4). About 1.0 m of silty yellowish-brown loess rich in secondary carbonates and with few mollusc fragments (unit J5) is exposed below this soil. The loess is underlain by a pedocomplex (units J6–8) which intensity implies interglacial conditions. Loess (unit J9) is exposed below this pedocomplex.

At this site three luminescence samples were taken (Fig. 2). Sample 1398 was taken from the loess unit J1 1.3 m below top ground surface. The ‘Bröckelsand’ (unit J3) was sampled (sample 1399) 0.2 m below the Cryosol complex (unit J2), and sample 1400 was taken in the loess unit J9 0.7 m below the pedocomplex, i.e. ~8.3 m below top ground surface.

2.2 Paudorf

The village of Paudorf is located on a right bank tributary of the Danube. The loess/palaeosol sequence is exposed in a former brickyard and is the type locality of the ‘Paudorfer Bodenbildung’ sensu Götzinger (1936). The outcrop, last described by Fink (1976) and thermoluminescence (TL) dated by Zöller et al. (1994) and Noll et al. (1994), is about 9.5 m thick (Fig. 3). At least two well-developed pedocomplexes are preserved at this site; the uppermost soil complex is the prominent ‘Paudorfer Bodenbildung’ (Fig. 3).
The luminescence sampling points are shown in Figure 3; two adjacent profiles were sampled (Paudorf I and II). The uppermost sample 1404 was taken in loess (unit PI-2) 0.3 m above the ‘Paudorfer Bodenbildung’ (unit PI-3), which is here developed as a reddish-brown, clay-rich palaeosol with crotovina. The loess unit PI-4 below the ‘Paudorfer Bodenbildung’, was sampled 2.9 m below top ground surface (sample 1403).

In profile Paudorf II, the 4 m thick loess (PII-3) was sampled below the ‘Paudorfer Bodenbildung’ at a depth of 4.2 m (sample 1402); because of induration, this sample had to be taken as a block. The loess deposit is underlain by alternating Cryosol and loess horizons (PII-4 to PII-7). In its lower parts a weak brownish palaeosol is exposed (PII-8). A loess layer (PII-9) bracketing the weak palaeosol and the basal pedocomplex (PII-10), originally correlated with the ‘Göttweiger Verlehmungszone’ (GÖTZINGER, 1936), was sampled at a depth of 7.8 m (sample 1401).

2.3 Göttweig

Two different sections were investigated near the monastery of Göttweig, just north of the loess sequence at Paudorf (Fig. 4). Section I (Fig. 4a) is the classical site of the ‘Göttweiger Verlehmungszone’ sensu BAYER (1927) and GÖTZINGER (1936), located near the town of Furth in a sunken path. The pedocomplex ‘Göttweiger Verlehmungszone’ (unit GI-4) and the overlying up to 6 m thick loess is exposed horizontally over several hundred meter and lies on a Danube terrace; the correlation with other terraces is unclear. A continuous thin layer (unit GI-2) can be identified in the loess package; preliminary magnetic analysis suggest that this layer is a tephra (pers. comm. U. HAM-BACH), whose origin and age is unfortunately unclear.

The luminescence sampling points at Section I are shown in Figure 4a. Sample 1406 comes from silty loess (unit GI-1) 0.6 m above the tephra (unit GI-2), and sample 1405 was taken in sandy-silty yellowish-brown loess (unit GI-3) 0.3 m below the tephra. Another sample (1407; not shown in Fig. 4) was taken 300 m upslope 30 cm below re-worked loess which includes pebbles and sandy layers; the position of this sample with respect to the other samples is not unambiguously established but the sampling point definitely lies above the tephra layer.

Section II is located in the hollow way near the village of Aigen (between Göttweig and Paudorf), where a pedocomplex correlated with the ‘Paudorfer Bodenbildung’ is exposed (FINK, 1976; Fig. 4b). However the pedocomplex (unit GII-3) is eroded at this site, deduced from the lack of an A horizon and a package of 30 cm thick reworked soil sediment (unit GII-2) covering the soil. The fine-silty yellowish-brown loess (unit GII-1) was sampled 0.7 m below top ground surface and 0.6 m above the ‘Paudorfer Bodenbildung’ (sample 1408); due to induration the sample had
to be taken as a block. Sample 1409 was taken in carbonate rich silty loess (unit GII-4) 0.6 m below the ‘Paudorfer Bodenbildung’ (i.e. 2.5 m below top ground surface).

### 3 Sample preparation and analytical facilities

In the laboratory, all samples for equivalent dose (D<sub>e</sub>) determination were treated under subdued red light. The outer ends (~1 cm) of the samples might have been exposed to daylight during sampling; these were discarded and the remaining sample treated with hydrochloric acid, sodium oxalate, and hydrogen peroxide. Between each treatment step the sediment was washed with distilled water. Special attention was paid to samples 1402 and 1408 (taken as blocks); all surfaces were scraped off to a depth of >1 cm before chemical treatment. The fine-silt fraction (4–11 μm) of the samples was extracted by repeated settling and washing (Frechen et al., 1996). The polymineral fine-grains were then deposited on aluminium discs (diameter 9.7 mm) from a suspension in acetone (2 mg/ml). Luminescence measurements were made with automated Risø TL/OSL readers (DA-15 and DA-20, respectively; Bøtter-Jensen et al., 2003; Thomsen et al., 2006) fitted with calibrated ⁹⁰Sr/⁹⁰Y beta sources calibrated using fine-grained quartz on aluminium discs. The feldspar signal of the polymineral samples was stimulated with infrared light diodes emitting at 870 nm, and the luminescence was detected in the blue-violet region (325–450 nm) through a Schott BG39/Corning 7–59 filter combination.

### 4 Dosimetry

The concentrations of U, Th and K were determined by high-resolution gamma-ray spectrometry equipped with a high-purity germanium detector. 700 g of each sample of
dried material was homogenised and packed in Marinelli beakers, sealed and stored for at least one month to ensure equilibrium between radon and its daughter nuclides before counting. Details about the procedures for dosimetry measurements at the Leibniz Institute for Applied Geo-physics (LIAG) laboratory in Hannover are given by Kunz et al. (2010).

The dose rates were derived using the conversion factors of Adamiec & Aitken (1998). For all samples a water content of 15 ± 5% was used (Frechen et al., 1997) to allow for possible changes in water content throughout time, and a mean a-value of 0.08 ± 0.02 was assumed (Rees-Jones, 2009). Calculation of the cosmic dose rate is based on Prescott & Hutton (1994).

The dosimetry data are summarised in Table 1. The total dose rates range from 2.1 ± 0.1 Gy/ka to 3.8 ± 0.2 Gy/ka. The rather low dose rate of 2.1 ± 0.1 Gy/ka for samples 1400 and 1409 originate in the relatively low Th (~7 ppm) and K (<1%) contents. Nevertheless, all dose rates are within the range expected for European loess (Zöller et al., 1994; Frechen et al., 1997) to allow results back to ~600 ka. Again they observed a low fading rate in the laboratory (1.1 ± 0.2%/decade; n=15) but argued that no fading correction was necessary.

In the following sections we compare the results obtained using the post-IR IRSL protocol described by Buylaert et al. (2009) (post-IR IRSL at 225°C) with those of Thiel et al. (2011a) (post-IR IRSL at 290°C) (Table 2). For comparison the results of the IRSL signal at 50°C (measured as part of the post-IR IRSL at 225°C protocol) are also discussed.

### S Post-IR IRSL dating

Since Thomsen et al. (2008) first identified reduced laboratory fading rates from various feldspar signals, several studies have tested or made use of elevated temperature post-IR IRSL signals (e.g. Buylaert et al., 2009; Thiel et al., 2010, 2011a, by; Reimann et al., 2011). Buylaert et al. (2009) used a preheat of 250°C for 60 s (used in many studies in the past), and their post-IR IR stimulation temperature was chosen to be 225°C. Because Murray et al. (2009) showed for sand-sized grains of potassium feldspar that there is no systematic increase in equivalent dose measured at 50°C for preheat temperatures ranging from 80°C up to 320°C (60 s duration), Thiel et al. (2011a) adopted a more stringent preheat of 320°C for 60 s to date their polymineral fine-grains with a post-IR IRSL protocol. This allowed them to use post-IR IR stimulation at significantly higher temperatures. They chose to investigate the use of stimulation at 290°C and observed the natural signal of a polymineral fine grain extract from below the Brunhes/Matuyama boundary (~780 ka, i.e. ~2700 Gy) in saturation on a laboratory growth curve. Based on these observations, they concluded that there is no detectable anomalous fading in nature of the post-IR IRSL signal at 290°C, even though they were able to measure a finite laboratory fading rate of ~1-1.5%/decade. Thiel et al. (submitted) have since compared ages obtained using the same post-IR IRSL at 290°C protocol with independent age control based on both fission track and radiocarbon dating as well as quartz OSL at two loess sites in Japan (Watanuki et al., 2005) and obtained very consistent results back to ~600 ka. They observed a low fading rate in the laboratory (1.1 ± 0.2%/decade; n=15) but argued that no fading correction was necessary.

### S.1 Post-IR IRSL measurements at 225°C

For these post-IR IRSL measurements we used the same temperature and stimulation conditions as Buylaert et al. (2009). After a preheat of 250°C for 60 s, we bleached the polymineral fine-grains (six aliquots per sample) with IR diodes at 50°C for 100 s to recombine the near-neighbour trap/centre pairs which fade most rapidly (discussed in e.g. Poolton et al., 2002; Thomsen et., 2008, 2011), and then held the aliquot at 225°C while measuring the IRSL for 100 s. The response to a test dose (~70 Gy) was measured in the same manner (Table 2), and an IR illumination at 290°C for 40 s was inserted at the end of each SAR measurement cycle to reduce the effect of any recuperation (based on Murray & Wintle, 2003). The initial 2.4 s of the decay curve were used for D0 determination after subtracting a background from the last 60 s.

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| Sample | K [%] | U [ppm] | Th [ppm] | Cosmic dose rate [Gy/ka] | Total dose rate [Gy/ka] |
|--------|-------|---------|----------|--------------------------|------------------------|
| 1398   | 1.2 ± 0.1 | 3.0 ± 0.1 | 10.6 ± 0.3 | 0.18 ± 0.02 | 3.1 ± 0.1 |
| 1399   | 1.7 ± 0.1 | 3.2 ± 0.1 | 11.5 ± 0.4 | 0.14 ± 0.02 | 3.5 ± 0.2 |
| 1400   | 0.8 ± 0.1 | 2.3 ± 0.1 | 7.3 ± 0.3 | 0.08 ± 0.01 | 2.1 ± 0.1 |
| 1401   | 2.2 ± 0.1 | 2.8 ± 0.2 | 11.4 ± 0.4 | 0.13 ± 0.01 | 3.8 ± 0.2 |
| 1402   | 1.4 ± 0.1 | 2.5 ± 0.1 | 9.4 ± 0.3 | 0.15 ± 0.02 | 2.9 ± 0.1 |
| 1403   | 1.5 ± 0.1 | 2.5 ± 0.1 | 9.9 ± 0.3 | 0.17 ± 0.02 | 3.0 ± 0.1 |
| 1404   | 1.6 ± 0.1 | 2.8 ± 0.1 | 10.9 ± 0.4 | 0.20 ± 0.02 | 3.3 ± 0.1 |
| 1405   | 1.6 ± 0.1 | 2.9 ± 0.1 | 11.0 ± 0.4 | 0.09 ± 0.01 | 3.2 ± 0.2 |
| 1406   | 1.4 ± 0.1 | 2.8 ± 0.1 | 9.8 ± 0.3 | 0.10 ± 0.01 | 2.9 ± 0.1 |
| 1407   | 1.5 ± 0.1 | 2.9 ± 0.1 | 12.9 ± 0.3 | 0.11 ± 0.01 | 3.4 ± 0.2 |
| 1408   | 1.3 ± 0.1 | 2.9 ± 0.1 | 10.1 ± 0.3 | 0.20 ± 0.02 | 3.0 ± 0.3 |
| 1409   | 0.9 ± 0.2 | 2.2 ± 0.1 | 6.9 ± 0.2 | 0.16 ± 0.02 | 2.1 ± 0.1 |
The laboratory fading rate was measured on three aliquots per sample as the IRSL signal decreased over time using artificially irradiated aliquots; this is expressed in terms of the percentage decrease of signal intensity per decade of time (the g-value; Aitken, 1985, Appendix F). After a final IR illumination at 290°C for 40 s, the same aliquots as for equivalent dose measurements were given doses of ~50 Gy (‘young samples’) and ~200 Gy (‘old samples’), respectively, to monitor anomalous fading using the SAR protocol outlined in Table 2. The storage times after irradiation and preheating (Auclair et al., 2003) varied from as brief as experimentally possible (‘prompt’) to delays of up to ~10 hours. The g-values, calculated using Equation 4 of Huntley & Lamothe (2001), were normalised to a measurement time delay of 2 days after irradiation.

The dose response curves and the post-IR IRSL decay curves of samples 1399 (a ‘young’ sample) and 1407 (an ‘old’ sample) are shown in Figure 5; they are representative of all the other samples presented in this study. The sensitivity-corrected natural of the post-IR IRSL signal of sample 1399 lies on the relatively linear part of the dose response curve, whereas the natural post-IR IRSL signal of sample 1407 (Fig. 5b) clearly lies beyond the linear region, which thus reduces the accuracy of the Huntley & Lamothe (2001) fading correction.

The ability of a measurement protocol to reproducibly measure the response to a laboratory dose given after repeated heating of the sample is represented by the recycling ratio, which ought to yield values indistinguishable from unity. The recycling ratios for the samples vary between 0.99 ± 0.01 (n=6; sample 1407) and 1.05 ± 0.02 (n=5; sample 1399) (Table 3 and Fig. 6a). Recuperation is well below 5% of the natural signal for all except the uppermost sample of the Joching profile (sample 1398), which shows a recuperation of 8.8 ± 0.5% (n=6) (Fig. 6b).

Satisfactory recycling ratios do not necessarily mean that doses given before any heating can also be measured accurately (which is the closest we can come to reproducing natural conditions). We therefore carried out a dose recovery test. Three natural aliquots of samples 1399 (Joching), 1401 (Paudorf) and 1405 (Göttweig) were bleached for 4 hours in a Hönle SOL2 simulator (sample to lamp distance ~1.2 m to avoid heating of the aliquots). The aliquots were then given a beta dose similar to the measured D_e for each sample and the given dose was measured in the usual manner. The results of the dose recovery test are shown in Fig. 7a. For all samples, measured/given doses are within 10% of unity. Because of the residual signals (and hence doses) observed for the post-IR IRSL signal at 225°C in other studies (Thomsen et al. 2008; Buylaert et al., 2009) we measured the residual signal after bleaching on separate aliquots of the same samples (three per sample). These residual signals were equivalent to a dose of 4.7 ± 0.5 Gy (n=9). After subtraction of these residual doses the measured/given dose ratios vary between 0.97 ± 0.01 (n=5; sample 1404) and 1.02 ± 0.04 (n=3; sample 1399). Both the measured to given ratios before and after residual subtraction are very close to unity (Fig. 7), demonstrating the accuracy of the measurement protocol when measuring an artificial beta dose given prior to any heating.

5.2 Post-IR IRSL measurements at 290°C

Following Thiel et al. (2011a), after preheating the samples (six aliquots per sample) at 320°C for 60 s we bleached the polynmineralline fine-grains with IR diodes at 50°C for 200 s and subsequently measured the IRSL at 290°C for 200 s. The response to a test dose was measured in the same manner, and an IR illumination at 325°C for 100 s was inserted at the end of each SAR measurement (Table 2). The light sum of the initial 2.4 s of the post-IR IRSL signal was used for D_e determination, less a background derived from the last 100 s. The fading rates on three aliquots per sample were measured in exactly the same way as for the IR at 225°C signal but using the preheating and stimulation conditions of the post-IR IRSL at 290°C protocol.
The dose response curves and the post-IR IRSL signals at 290°C of two samples (1399 and 1407) are shown in Figure 8. Whereas the natural post-IR IRSL signal of sample 1399 lies in the linear region of the dose response curve, the natural post-IR IRSL signal of sample 1407 is well above and is approaching saturation. Recycling ratios are very close to unity for all samples (Table 3 and Fig. 6a), and recuperation varies between 0.9 ± 0.02% (n=6; sample 1407) and 7.2 ± 0.2% (n=6; sample 1398). The high recuperated signal of sample 1398 is unusual compared to the other values, which are all below 5% (Fig. 6b).

The residual signals are equivalent to 1.5 ± 0.2 Gy (n=9). Without subtraction of the residual signals the measured to given dose ratios vary between 1.09 ± 0.02 (n=3; sample 1399) and 1.11 ± 0.04 (n=3; sample 1409; Fig. 7a), whereas after subtraction the ratios lie between 1.08 ± 0.02 (n=3; sample 1399) and 1.10 ± 0.04 (n=3; sample 1409; Fig. 7b). Although the results are within 10% of unity there does seem to be a systematic tendency to overestimate the given dose. Nevertheless, we consider these results acceptable, because they are within the 10% range.

6 Comparison of the fading rates and ages derived from the different signals

The laboratory fading rates for all samples and signals are listed in Table 3 and plotted in Fig. 10. The mean fading rate for IRSL at 50°C is 3.3 ± 0.4%/decade (excluding the two outliers 1398 and 1400), 2.1 ± 0.3%/decade for post-IR IRSL at 225°C, and 1.0 ± 0.4%/decade for post-IR IRSL at 290°C, confirming that post-IR IR stimulation at higher temperatures reduces fading (Thomsen et al., 2008).

The fading rates for the IRSL measurements at 50°C vary between 1.0 ± 0.7%/decade (sample 1401) and 9.9 ± 0.5%/decade (sample 1400) and are much higher than for the post-IR IRSL measurements, with the exception of sample 1401; the latter has a fading rate comparable to those of the post-IR IRSL signals (Fig. 10). If this sample indeed does not fade significantly, then the various (uncorrected) D<sub>e</sub> values should be similar, and ages should be indistinguishable. This, however, is not observed; the D<sub>e</sub> values for the post-IR IRSL signals are significantly higher than for the IRSL measurement at 50°C and as a result the ages do not agree (Table 3 and Fig. 11). Unexpectedly, for sample 1405 the laboratory fading rate of the IRSL signal at 50°C is slightly lower (3.4 ± 0.3%/decade) than that of the post-IR IRSL signal at 225°C (4.3 ± 0.5%/decade); the post-IR IRSL at 290°C fading rate is much lower (0.8 ± 0.4%/decade) than for both the other signals. Given the fact that our aliquots are made up of many hundreds of thousands of grains, which ought to result in homogeneous luminescence behaviour, the variability observed in the fad-
For details about the bleaching conditions and residual measurements see text.

Fig. 7: Results of dose recovery tests a) without residual subtraction, b) with residual subtraction. The residual signal is 1.5 ± 0.2 Gy (n=9) for the IRSL measurements at 50°C, 4.7 ± 0.5 Gy (n=9) for the post-IR IRSL measurements at 225°C, and 13 ± 2 Gy (n=9) for the post-IR IRSL measurements at 290°C. For details about the bleaching conditions and residual measurements see text.

Abb. 7: Ergebnisse der Dose Recovery Tests a) ohne das Restsignal abzuziehen, b) mit Subtraktion des Restsignals. Das Restsignal ist 1.5 ± 0.2 Gy (n=9) für die IRSL-Messungen bei 50°C, 4.7 ± 0.5 Gy (n=9) für die post-IR IRSL-Messungen bei 225°C, und 13 ± 2 Gy (n=9) für die post-IR IRSL-Messungen bei 290°C. Siehe Text für Details zu den Belichtungsexperimenten und Messungen.

ing rates, especially for the IR at 50°C signal, is surprising and difficult to explain; although it could originate from e.g. a change in source area, it seems more likely that it reflects some unknown laboratory source of variability.

Thiel et al. (2011a) measured fading rates of 1–1.5%/decade using the post-IR IRSL signal measured at 290°C for their polynmineral fine-grain samples; they argued that because the natural signals from these samples were in saturation on a laboratory growth curve, it was unlikely that the natural signal had faded significantly. In addition, they also measured a fading rate of ~1%/decade for fine-grained quartz dominated by a fast OSL component; it seems clear that at the very least their post-IR IRSL signal did not fade any more than the blue-stimulated OSL signals from quartz. It may be that fading rates below 1%/decade are not meaningful, and in fact reflect systematic errors in laboratory fading measurements.

We have confirmed that for the higher temperature signals smaller fading rates are obtained and as a consequence it is expected that the fading uncorrected ages of the IRSL signal at 50°C ought to be younger than for any post-IR IRSL measurement. If fading measurements and fading corrections are applicable (Huntley & Lamothe, 2001), and if post-IR IRSL at 290°C does not show significant anomalous fading as suggested by Thiel et al. (2011a, accepted), fading corrected IRSL ages at 50°C and fading corrected post-IR IRSL ages at 225°C should be indistinguishable from fading uncorrected ages for the post-IR IRSL at 290°C, at least over the dose range for which the Huntley & Lamothe (2001) correction may be applicable in practice (~200 Gy; Buylaert et al., 2011). The fading uncorrected and fading corrected ages are listed in Table 3 and shown in Figure 11. We assume that the post-IR IRSL at 290°C gives the most accurate age estimates because there is evidence that these signals do not fade in nature (Thiel et al., 2011a, accepted); this can also be concluded from sample 1405, which is in or close to saturation, since laboratory saturation in feldspar is only possible when fading is negligible.

As expected, the fading uncorrected ages of the IRSL signal at 50°C (showing the largest fading rates) underestimates compared to the post-IR at 290°C (Fig. 11a); the age underestimation is most evident for the older samples. On the other hand, uncorrected post-IR IRSL at 225°C ages only slightly underestimate compared to post-IR IRSL at 290°C (Fig. 11b). The measured post-IR IRSL at 225°C laboratory fading rates (0.6 to 4.3%/decade; Table 3), at least when >1%/decade, are probably significant, and it seems clear that the post-IR IRSL at 225°C needs fading correction. A similar observation was made by Buylaert et al. (2009) for their Eemian samples (see supplementary table in Buylaert et al., 2009). The fading corrected ages for post-IR IRSL at 225°C are plotted against corrected ages for post-IR IRSL at 290°C in Figure 11c, and against uncorrected ages for post-IR IRSL at 290°C in Figure 11d. It is recognised that the correction model is theoretically not applicable at higher doses, but such qualifications become of second order importance when the correction is so small. The fading correction for post-IR IRSL at 290°C is, on average, < 10% of the age and so Figures 11c and 11d are very similar. In both figures the agreement between the ages derived from the two signals is satisfactory with one exception (sample 1403), for which either post-IR IRSL at 225°C underestimates, or post-IR IRSL at 290°C overestimates.

The agreement between the fading corrected ages for IRSL at 50°C with the fading uncorrected (or corrected) ages for post-IR IRSL at 290°C is slightly poorer, especially for the older samples (~ 100 ka; Fig. 11e). Sample 1400, which has a fading rate of 9.9 ± 0.5%/decade resulted in a significantly overestimated age after correction of 679 ± 74 ka (Table 3). This sample is well outside the applicable range of the Huntley & Lamothe (2001) correction model, but this should result in an underestimate, not overestimation; however, it is most likely that the fading rate for this sample is overestimated. A depositional age of >600 ka for this sample is unlikely not only from a stratigraphical point of view but also when compared with the post-IR IRSL age estimates. The overestimation is consistent with the observations of Reimann et al. (2011) using Holocene coastal sediments (to which the correction model is defi-
nitely applicable); they show that fading correction of the IRSL signal at 50°C for g-values >6 %/decade overestimates their depositional ages for which independent age control is available.

In most post-IR IRSL dating studies (e.g. Buylaert et al., 2009; Thiel et al., 2011a, b; Reimann et al., 2011) it has been observed that a significant residual post-IR IRSL signal is present after daylight or solar simulator bleaching in the laboratory. Thomsen et al. (2008) showed in a bleaching experiment that there is no obvious difference in signal resetting between the IRSL at 50°C signal and the post-IR IRSL signal at 225°C. Nevertheless, using the same post-IR IRSL signal, Buylaert et al. (2009) found apparent residuals of up to 2 Gy for modern samples while residuals measured using IR at 50°C were ~0.5 Gy; either the two signals bleach to different degrees, or there are differences in thermal transfer. In contrast, Thiel et al. (2011a) measured laboratory residuals equivalent to 15–20 Gy for the post-IR IRSL signal at 290°C. For their samples it was difficult to decide on the relevance of these residual measurements to naturally bleached samples because there were no modern analogues available at their site. Again, some or all of the residual doses may have arisen through thermal transfer following the higher preheat temperature of 320°C. Thus it remains unclear to what degree the post-IR IRSL signals bleach more slowly than the IR at 50°C for these samples, or whether the differences are a result of the different preheat temperatures used (i.e. thermal transfer).

None of the ages presented here have had a residual dose subtracted. From laboratory bleaching experiments, apparent residuals can vary between 1.5 ± 0.2 Gy (n=9) for IRSL at 50°C and 13 ± 2 Gy (n=9) for post-IR IRSL at 290°C. In nature bleaching is likely to be episodic and take place over much longer times than is typical for laboratory bleaching experiments. One can test the size of any residual by determining the luminescence age of material of independently known young age, or by examining the dose in recently transported modern material (modern analogues). Unfortunately, there are no modern analogues available at our sites. To test the bleachability of the different IRSL signals the ages of the younger (~70 ka) samples are compared (Fig. 11f). The IRSL at 50°C ages are taken as reference because there is good evidence in the literature that the signal can be bleached to very low levels (e.g. Huntley & Clague, 1996) and in this age range the fading correction is generally expected to yield accurate results (Huntley & Lamothe, 2001; Buylaert et al., 2011). For the youngest sample (sample 1398; IRSL at 50°C D2; 15 ± 2 Gy), which might be expected to be significantly affected by residual doses, the post-IR IRSL ages are slightly older than the corrected IRSL age at 50°C. However, for this sample the corrected IRSL age at 50°C of 10 ± 1 ka seems, from a geological point of view too young, since there was no loess deposition in Lower Austria during the Holocene. The post-IR IRSL ages are thus closer to the expected age. This gives confidence that the post-IR IRSL signals are bleachable in nature, and as a result we do not subtract any residual from any of our ages. Nevertheless this assumption needs further testing using modern analogues and/or very young samples.

In summary, for young samples, for which the fading correction of the 225°C signal is likely to be accurate, both the fading corrected ages for post-IR IRSL at 225°C and the fading uncorrected ages for post-IR IRSL at 290°C seem to yield comparable results. For older samples any fading correction is likely to be increasingly inaccurate, and we favour the age estimates from the post-IR IRSL at 290°C, which apparently do not require significant fading correction (Thiel et al., 2011a, accepted). The following discussion on the chronological framework of the palaeosols is hence based on this IRSL signal unless otherwise stated.

### 7 Chronostratigraphy of the palaeosols

In Joching the loess unit J1 above the Cryosol complex (sample 1398) was dated to 16 ± 2 ka, whereas the 'Bröckelsand' (sample 1399) was dated to 47 ± 3 ka. This allows for formation of the Cryosol complex sometime between ~45 ka and ~20 ka. Cryosols in Lower Austria were described at Stratzing and luminescence dated to ~27–33 ka (Thiel et al., 2011a). This is in agreement with Hæséarts et al. (1996), who have...
presented several radiocarbon ages (charcoal) from various sites in Lower Austria pointing to formation of the Cryosols between 27 and 39 ka. The loess unit J9 underlying the pedocomplex (sample 1400) was dated to 170 ± 16 ka (MIS 6); it is therefore likely that the pedocomplex (unit J6–J8) developed during MIS 5; however, an unequivocal attribution to a sub-stage is not possible. Because the pedocomplex is composed of three horizons, it is possible that it comprises the entire MIS 5 with its sub-stages. The pedocomplex in Joching might thus be correlated with the ‘Paudorfer Bodenbildung’ (unit PI-3; Fig. 3), which at its type locality in Paudorf develop

d during MIS 5. This is shown by the age of the loess unit PI-2 above the ‘Paudorfer Bodenbildung’ of 106 ± 12 ka (sample 1404), whereas the loess below (unit PI-4) gives an age of 159 ± 20 ka (post-IR IRSL at 225°C; sample 1403). Here, it has to be noted that the age of 299 ± 33 ka derived from post-IR IRSL at 290°C seems to be an overestimate; this is likely because the ratio of D$_0$‘s obtained (post-IR IRSL at 290°C/post-IR IRSL at 225°C) is for all samples <1.5, whereas for sample 1403 it is 2.1. Hence, for sample 1403, the fading corrected post-IR IRSL at 225°C age of 159 ± 20 (Table 3) seems the most reliable result and is, within errors, in agree-
Tab. 3: Recycling ratios, equivalent doses (De), fading rates, and fading uncorrected and fading corrected ages for the three (post-IR) IRSL signals. For all samples six aliquots were measured for De determination. The fading uncorrected ages for the post-IR IRSL signal at 290°C (in bold) are considered the most reliable (apart from sample 1403 for which the corrected age of post-IR IRSL at 225°C is considered the most reliable estimate). For details see text.

| Location | Sample | Signal | Recycling ratio | D_e [Gy] | Fading rate [%/decade] | Fading uncorrected age [ka] | Fading corrected age [ka] |
|----------|--------|--------|----------------|---------|------------------------|-----------------------------|--------------------------|
| Joching  | 1398   | IRSL at 50°C | 1.03 ± 0.02 | 15 ± 2 | 8.0 ± 0.5 | 5 ± 1 | 10 ± 1 |
|          | pIR IRSL at 225°C | 1.02 ± 0.01 | 33 ± 3 | 2.8 ± 0.2 | 11 ± 1 | 13 ± 1 |
|          | pIR IRSL at 290°C | 1.02 ± 0.01 | 50 ± 5 | 1.3 ± 0.5 | 16 ± 2 | 18 ± 2 |
|          | IRSL at 50°C | 1.07 ± 0.07 | 140 ± 15 | 4.3 ± 0.5 | 40 ± 4 | 58 ± 8 |
|          | pIR IRSL at 225°C | 1.05 ± 0.02 | 148 ± 11 | 1.8 ± 0.1 | 42 ± 2 | 49 ± 4 |
|          | pIR IRSL at 290°C | 0.99 ± 0.01 | 163 ± 10 | 0.9 ± 0.5 | 47 ± 4 | 50 ± 5 |
|          | IRSL at 50°C | 1.01 ± 0.02 | 329 ± 34 | 9.9 ± 0.5 | 157 ± 17 | 679 ± 74 |
|          | pIR IRSL at 225°C | 1.00 ± 0.01 | 337 ± 32 | 2.7 ± 0.2 | 160 ± 17 | 201 ± 19 |
|          | pIR IRSL at 290°C | 1.00 ± 0.01 | 356 ± 32 | 1.0 ± 0.3 | 170 ± 18 | 183 ± 19 |
| Paudorf  | 1400   | IRSL at 50°C | 1.02 ± 0.02 | 474 ± 37 | 2.2 ± 0.6 | 119 ± 6 | 141 ± 13 |
|          | pIR IRSL at 225°C | 0.99 ± 0.01 | 596 ± 20 | 1.2 ± 0.2 | 157 ± 10 | 172 ± 15 |
|          | pIR IRSL at 290°C | 1.00 ± 0.01 | 714 ± 58 | 1.1 ± 0.2 | 189 ± 16 | 204 ± 20 |
|          | IRSL at 50°C | 1.03 ± 0.01 | 344 ± 15 | 2.2 ± 0.6 | 119 ± 6 | 141 ± 13 |
|          | pIR IRSL at 225°C | 1.00 ± 0.01 | 427 ± 44 | 0.6 ± 0.6 | 147 ± 16 | 154 ± 20 |
|          | pIR IRSL at 290°C | 0.99 ± 0.01 | 538 ± 34 | 0.7 ± 0.5 | 187 ± 12 | 195 ± 20 |
|          | IRSL at 50°C | 1.01 ± 0.04 | 353 ± 19 | 4.3 ± 0.6 | 118 ± 7 | 172 ± 19 |
|          | pIR IRSL at 225°C | 1.00 ± 0.01 | 414 ± 44 | 1.8 ± 0.1 | 138 ± 15 | 159 ± 20 |
|          | pIR IRSL at 290°C | 0.98 ± 0.01 | 897 ± 97 | 0.7 ± 0.3 | 299 ± 33 | 315 ± 41 |
|          | IRSL at 50°C | 1.03 ± 0.03 | 234 ± 20 | 3.7 ± 0.6 | 71 ± 6 | 97 ± 12 |
|          | pIR IRSL at 225°C | 1.01 ± 0.01 | 225 ± 19 | 1.5 ± 0.2 | 68 ± 6 | 77 ± 9 |
|          | pIR IRSL at 290°C | 1.01 ± 0.01 | 351 ± 40 | 1.5 ± 0.4 | 106 ± 12 | 120 ± 16 |
|          | IRSL at 50°C | 0.99 ± 0.01 | 728 ± 51 | 3.4 ± 0.3 | 228 ± 17 | 304 ± 30 |
|          | pIR IRSL at 225°C | 0.99 ± 0.01 | 1295 ± 83 | 4.3 ± 0.5 | >300 | >300 |
|          | pIR IRSL at 290°C | 0.99 ± 0.01 | 1845 ± 483 | 0.8 ± 0.4 | >350 | >350 |
|          | IRSL at 50°C | 1.04 ± 0.02 | 440 ± 47 | 4.6 ± 0.6 | 152 ± 16 | 230 ± 34 |
|          | pIR IRSL at 225°C | 1.00 ± 0.00 | 537 ± 30 | 2.3 ± 0.3 | 185 ± 12 | 233 ± 19 |
|          | pIR IRSL at 290°C | 1.00 ± 0.01 | 503 ± 115 | 1.2 ± 0.3 | 173 ± 40 | 190 ± 46 |
| Göttweig | 1405   | IRSL at 50°C | 1.00 ± 0.01 | 847 ± 125 | 3.2 ± 0.3 | 249 ± 38 | 327 ± 53 |
|          | pIR IRSL at 225°C | 0.98 ± 0.01 | 1149 ± 96 | 2.9 ± 0.5 | >280 | >280 |
|          | pIR IRSL at 290°C | 1.00 ± 0.01 | 1265 ± 78 | 0.9 ± 0.3 | >300 | >300 |
|          | IRSL at 50°C | 0.99 ± 0.05 | 75 ± 6 | 3.3 ± 0.4 | 25 ± 2 | 33 ± 4 |
|          | pIR IRSL at 225°C | 1.00 ± 0.01 | 83 ± 6 | 2.0 ± 0.5 | 28 ± 3 | 32 ± 4 |
|          | pIR IRSL at 290°C | 1.00 ± 0.01 | 101 ± 8 | 0.9 ± 0.4 | 34 ± 3 | 36 ± 4 |
|          | IRSL at 50°C | 1.00 ± 0.01 | 244 ± 16 | 3.1 ± 0.3 | 116 ± 8 | 151 ± 13 |
|          | pIR IRSL at 225°C | 1.00 ± 0.01 | 294 ± 23 | 1.3 ± 0.4 | 140 ± 13 | 155 ± 15 |
|          | pIR IRSL at 290°C | 0.99 ± 0.01 | 263 ± 53 | 0.7 ± 0.3 | 124 ± 25 | 132 ± 30 |

*The equivalent doses of the IRSL signal at 50°C are derived from the same measurement cycle as the post-IR IRSL (225°C) results, i.e. preheat of 250°C. The same applies to the measured fading rates.*
gemessen. Die geringsten Fading-Raten wurden für das post-IR IRSL-Signal bei 290°C für alle Proben bei Anwendung der verschiedenen (post-IR) IRSL-Signale. Abb. 10: Vergleich der experimentell ermittelten Fading-Raten [%/Dekade] fading measurements see text.

Fig. 10: Comparison of laboratory fading rates [%/decade] for all samples using the different (post-IR) IRSL signals. Lowest fading rates are observed for the post-IR IRSL measurements at 290°C. For details about laboratory fading measurements see text.

ment with the age of sample 1402 (unit PII-3), which also originates from below the ‘Paudorfer Bodenbildung’ (Fig. 3) and was dated to 187 ± 12 ka. The individual soils of the ‘Paudorfer Bodenbildung’ might thus have formed during sub-stages of MIS 5. Originally the formation of the soil was attributed to a Würmian interstadial by Götzinger (1936); at that time it was not recognised as being a pedocomplex. Ložek (1976) revised the attribution of Götzinger (1936), because an interglacial mollusc fauna was found in the lowermost part of the ‘Paudorfer Bodenbildung’, i.e. the lower part of this pedocomplex developed most likely during MIS 5e. This is in agreement with our dating results and with the TL results of Zöller et al. (1994), who state that their age of 103 ± 11 ka below the ‘Paudorfer Bodenbildung’ at its type locality should be regarded as a minimum age. The attribution of the ‘Paudorfer Bodenbildung’ to MIS 3 as suggested by Noll et al. (1994) can clearly be dismissed. At profile Paudorf II, the BC horizon, i.e. the weakly developed palaeosol (unit PII-8, Fig. 3) is younger than 189 ± 16 ka (sample 1401); a correlation with other soils in this area remains unclear and needs further investigations. For the underlying pedocomplex (unit PII-10), which has been correlated with the ‘Götweiger Verlehmungzone’, it can only be concluded that it has to be older than 189 ± 16 ka. Hence further investigations are needed to address the question whether this soil is equivalent to the ‘Götweiger Verlehmungzone’, which is dated to ≥350 ka (sample 1405; minimum age based on 2°Dc for post-IR IRSL at 290°C; Wintle & Murray, 2006) at its type locality in Göttweig/Furth (Fig. 4a). Originally the ‘Götweiger Verlehmungzone’ (unit GI-4) was attributed to MIS 5e (Götzinger, 1936), but Zöller et al. (1994) observed natural TL signals from above and below the ‘Götweiger Verlehmungzone’ close to saturation and concluded that their ages of ~200 ka have to be interpreted as minimum ages. Furthermore, the alle/Ile ratio of Pupilla shells taken from loess immediately above the ‘Götweiger Verlehmungzone’ soil is too high to be from penultimate glacial loess (Zöller et al., 1994). Smolíková (1994) suggest that this pedocomplex is perhaps of Holsteinian age, which at present is correlated with MIS 11 or MIS 9. Our minimum age is consistent with these findings. This age model is also supported by the dating of the loess sample 1407 above the tephra, 300 m upslope of Section I, which yielded ≥300 ka; the loess sample 1406 above the tephra was dated to 173 ± 40 ka, clearly showing a hiatus in the sequence. It has to be noted that the tephra, if found in other sequences, might be a useful Middle Pleistocene marker, dated to ≥300 ka.

At Section II (Götweig/Aigen; Fig. 3b) the loess unit GI-1 above the reworked loess (unit GI-2) and the pedocomplex (unit GI-3) is dated to 34 ± 3 ka (sample 1408), and is thus in good agreement with Zöller et al.’s (1994) TL results of 28 ± 3 ka. They dated the loess below the pedocomplex to 107 ± 10 ka (regenerative dose method) and 119 ± 13 ka (additive dose method) and concluded that the soil formation lasted about 90 ka. Even though we have obtained a very similar age of 124 ± 25 ka for the loess from below the soil (sample 1409), we argue that there is certainly some break in the sedimentary record, rather than a long pedogenetic phase, because the pedocomplex is clearly eroded (indicated by the lack of an A horizon and a covering of soil sediment). Nevertheless, the age suggests that the pedocomplex exposed in Göttweig/Aigen corresponds with the ‘Paudorfer Bodenbildung’ at its type locality (Götzinger, 1936).

8 Conclusions

We have used two recently suggested post-IR IRSL dating protocols (Bulyaert et al., 2009; Thiel et al., 2011a) to compare ages and so unravel the chronostratigraphy of prominent palaeosols in Lower Austria. In addition, we have compared the fading rates and ages derived from post-IR IRSL dating with IRSL at 50°C (measured as part of the post-IR IRSL measurements at 225°C).

The samples behave satisfactorily in the two post-IR IRSL SAR protocols, i.e. recycling ratios and dose recoveries are close to unity and recuperation is well below 5% for most of the samples. The lowest laboratory fading rates are observed using the post-IR IRSL signal at 290°C, followed by post-IR IRSL at 225°C, and fading rates for IR at 50°C tend to be the highest. The fading rates of the post-IR IRSL at 290°C are in most cases below 1%/decade, and based on the observations of Thiel et al. (2011a) we conclude that fading for this signal is probably negligible over geological time and so we do not attempt any fading correction of this signal. Good agreement between the ages derived from the post-IR IRSL signals and those from IRSL at 50°C on young samples shows that the post-IR IRSL signals are bleachable. Nevertheless it remains unclear whether the residual dose observed following laboratory bleaching, or some part of it, needs to be subtracted from the Dc. The fading corrected ages for post-IR IRSL at 225°C are in generally good agreement with the uncorrected ages for post-IR IRSL at 290°C. Both post-IR IRSL signals could be used for dating; we prefer the post-IR IRSL at 290°C because no fading correction seems to be needed, and so there are no dose/age limitations imposed by the use of a correction model. However, one 290°C age appeared significantly overestimated in the stratigraphical context, which has to be a matter of future investigations.
Fig. 11: Comparison of ages for all samples using the different (post-IR) IRSL signals. The ages shown are without subtraction of the residuals. a) Fading uncorrected ages for IRSL at 50°C against fading uncorrected ages for post-IR IRSL at 290°C, b) fading uncorrected ages for post-IR IRSL at 225°C against fading uncorrected ages for post-IR IRSL at 290°C, c) fading corrected ages for post-IR IRSL at 225°C against fading corrected ages for post-IR IRSL at 290°C, d) fading corrected ages for post-IR IRSL at 225°C against fading uncorrected ages for post-IR IRSL at 290°C, e) fading corrected ages for IRSL at 50°C against fading uncorrected ages for post-IR IRSL at 290°C, and f) young (<70 ka) fading corrected ages for post-IR IRSL at 225°C (grey circles) against corrected ages for IRSL at 50°C, to show the relative bleachability of the post-IR IRSL signals. Minimum ages are shown with open error bars. Solid line is a 1:1 line, and dashed lines represent ±10%.

Abb. 11: Vergleich der Alter für alle Proben unter Verwendung der verschiedenen (post-IR) IRSL-Signale. Die angeführten Alter sind ohne Subtraktion des Restsignals. a) Nicht-korrigierte Alter für IRSL bei 50°C gegen nicht-korrigierte post-IR IRSL-Alter bei 290°C, b) nicht-korrigierte post-IR IRSL-Alter bei 225°C gegen nicht-korrigierte post-IR IRSL-Alter bei 290°C, c) korrigierte post-IR IRSL-Alter bei 225°C gegen korrigierte post-IR IRSL-Alter bei 290°C, d) korrigierte post-IR IRSL-Alter bei 225°C gegen nicht-korrigierte post-IR IRSL-Alter bei 290°C, e) korrigierte Alter für IRSL bei 50°C gegen nicht-korrigierte post-IR IRSL-Alter bei 290°C, und f) junge (<70 ka) korrigierte Alter für post-IR IRSL bei 225°C (graue Punkte) und nicht-korrigierte Alter für post-IR IRSL bei 290°C (schwarze Punkte) gegen korrigierte IRSL-Alter bei 50°C, um die relative Zurücksetzung der post-IR IRSL-Signale zu zeigen. Minimale Alter sind mit offenen Fehlerbalken gezeigt. Die durchgezogene Linie zeigt die 1:1-Linie, und die gestrichelten Linien repräsentieren ±10%.
We assign the ‘Paudorfer Bodenbildung’ at its type locality in Paudorf to MIS 5. It is furthermore very likely that the pedocomplex in Göttweig/Aigen developed during the same time and can hence be correlated with the ‘Paudorfer Bodenbildung’. The same is true for the pedocomplex exposed in Joching. The absolute age of the ‘Göttweiger Verlehmungszone’ remains unclear due to saturation of the sample above this soil; the saturation implies an age >350 ka for the ‘Göttweiger Verlehmungszone’. The discontinuities in sedimentation observed at these sites are hence significant. It has to be noted that sampling at higher resolution is needed to draw final conclusions on the extent of the discontinuities. The correlation of Lower Austrian loess deposits and their interlaided palaeosols thus remains problematic. Advances in absolute dating techniques such as post-IR IRSL dating are of importance to address the many remaining open questions on loess stratigraphy in the future.

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