Early Weichselian dust storm layer at Achenheim in Alsace, France

DENIS-DIDIER ROUSSEAU, GEORGE KUKLA, LUDWIG ZÖLLER AND JANKA HRADILOVA

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The cause of the rapid transition from lush grasslands and woodlands of the Early Glacial interstadial to Pleniglacial barrens in Europe is still a mystery. In the loess sections of Bohemia and Austria this transition is associated with thin layers of fine-grained airborne dust known as 'markers', believed to be deposited by major continental-scale dust storms. Here we present evidence that a similar, sharply delimited layer with a minimum TL age of 64.9 ± 6.9 ka separates the autochthonous humus steppe soils from abiogenic sediments of the Achenheim 1 pedocomplex in France. The soil complex has been previously correlated on pedostratigraphic grounds with marine oxygen isotope stage (MIS) 5. Given its age and stratigraphic position, the dust layer correlates with the PKII marker in Bohemia. The recognition of a marker in Achenheim suggests that the development of the Early Glacial steppe soils ended abruptly not only in central Europe, but also in Alsace, France, prior to 65 ka, possibly as a result of a single continental-scale dust storm.

Denis-Didier Rousseau, Université Montpellier II, Paléoenvironnements & Palynologie, Institut des Sciences de l'Evolution (UMR CNRS 5554), case 61, pl. E. Bataillon, 34095 Montpellier cedex 05, France & Lamont-Doherty Earth Observatory of Columbia University, Palisades, N.Y. 10964, USA; George Kukla, Lamont-Doherty Earth Observatory of Columbia University, Palisades, N.Y. 10964, USA; Ludwig Zöller, Forschungsstelle Archäometrie der Heidelberger Akademie der Wissenschaften, c/o Max-Planck Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany; Janka Hradilova, Geological Institute of the Czech Academy of Sciences, 135 Rozvojova, 16500 Praha-Suchdol, Czech Republic; *received 22nd May 1996, accepted 6th July 1998*

The ice cores from Camp Century and Dye 3 in Greenland (Dansgaard *et al.* 1972, 1982) as well as a detailed analysis of pollen content in the lake deposits (Woillard 1978, 1979; Müller 1974, 1992) indicate the existence of abrupt climatic oscillations in the Pleistocene. However, it is only recently that interest in these past episodes of anomalously rapid climatic change have come to the forefront of the paleoclimatic agenda.

Traces of recurrent massive iceberg discharges during the last climatic cycle recognized in the North Atlantic ocean sediments (Heinrich 1988; Bond *et al.* 1992; Grousset *et al.* 1993; McManus *et al.* 1994; Bond & Lotti 1995) support the notion of numerous climate oscillations inferred from the GRIP and GISP2 ice cores (GRIP, 1993; Grootes *et al.* 1993). These observations point to the ice and the oceans as key players in the mechanism of past climate changes. Relatively few studies, however, have been dedicated to records of rapid changes of environment on the European continent and to the role of the atmospheric dust in past climates.

Together with lake beds, the loess sequences in central Europe provide relatively detailed and reasonably continuous records of paleoenvironmental changes on land. Correlation of loess sequences with the moraines and terraces of Alpine glaciations and marine isotope stages, based on biostratigraphic and climatostratigraphic criteria, were proposed earlier (Kukla 1977; Lozek 1964). In the Achenheim sequence (Alsace, France), the analysis of the mollusk content resulted in the recognition of five first-order climatic cycles, and in the estimates of past temperature and precipitation based on transfer functions in the three youngest cycles (Rousseau 1991). Correlation with the marine isotope stages (MIS) was proposed based on the mollusks, geomorphology, sedimentology and TL dating (Lautridou *et al.* 1985; Rousseau 1987; Rousseau & Puisségur 1990).

Although signs of rapid environmental change were detected in sediments of the Last Glacial Maximum in Achenheim (Rousseau & Puissegur 1990), attention was not focused on the youngest Achenheim 1 pedocomplex, which is correlated with MIS stage 5. Here we present new evidence showing that rapid changes in local environment similar to those described in the PK II and PK III pedocomplexes of the central European loess belt can be detected in Achenheim as well.

Stratigraphy of the Achenheim section

The Upper Pleistocene in Achenheim is represented by two major lithological units (Sommé *et al.* 1986) (Fig. 1). The Achenheim 1 (ACH1) pedocomplex starts at the base with an interglacial Bt horizon overlain by a black steppe soil. This in turn is overlain by brown loams showing bedding structures (Sommé *et al.* 1986). Overlying the Achenheim 1 unit is the Lower Younger Loess (LYL), which includes prominent frost wedges in its upper part, and whose upper boundary is the Nagelbeek horizon (K) (Haesaerts *et al.* 1981; Juvigné *et al.* 1996). The latter horizon is found throughout parts of western Europe (Sommé *et al.* 1986) (Fig. 1). The youngest Upper Younger Loess (UYL) overlays this horizon followed by the Holocene soil at the top (Sommé *et al.* 1986). The most detailed

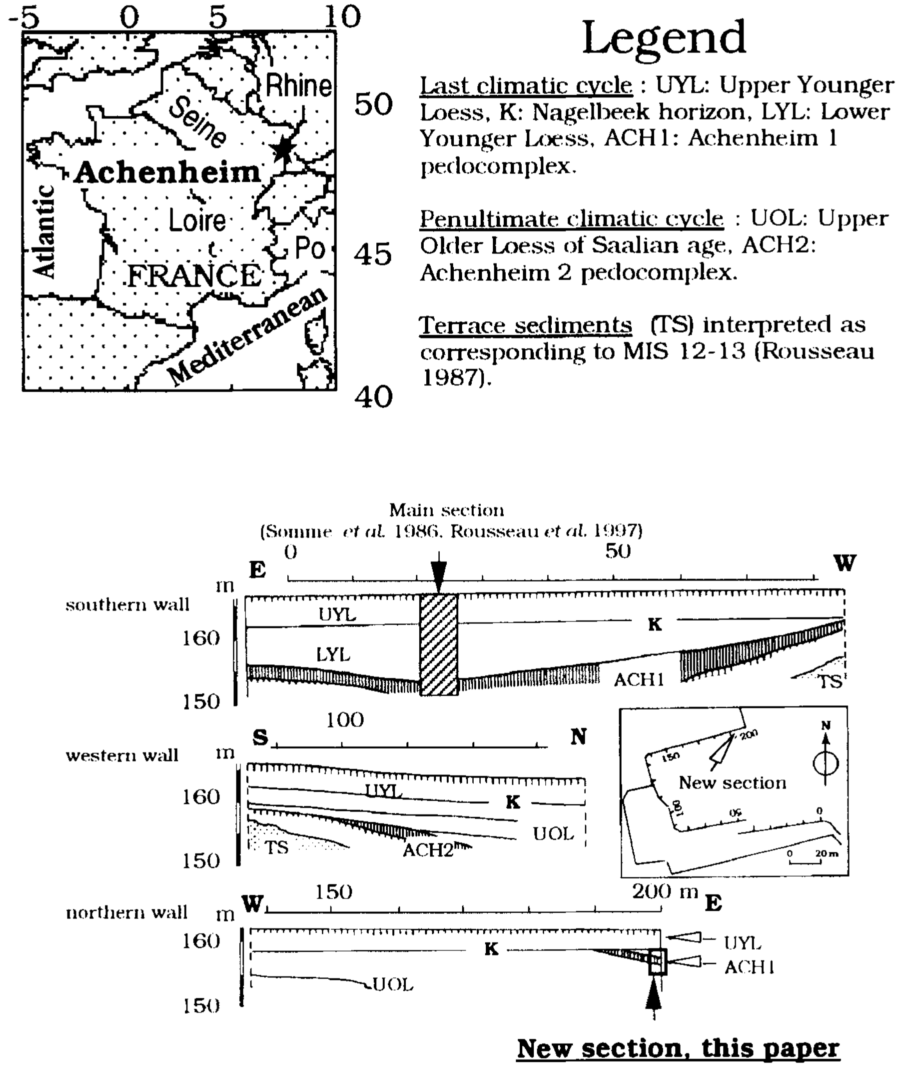

Fig. 1. Location of the Hurst brickyard in Achenheim near Strasbourg in Alsace, France (from Heim *et al.* 1982, modified). Stratigraphy in the three walls of the brickyard. The main section with detailed record of the sediments of the last climatic cycle in the paleodepression, previously studied and described by Sommé *et al.* (1986) and Rousseau *et al.* (1998), marked by a downward pointing arrow. Also showing the position sediments of the penultimate cycle (UOL and the Achenheim 2 pedocomplex). K indicates the Nagelbeek level. New section described in this paper marked by an upward arrow. Elevation in meters above sea level.

studies of the Achenheim loess were undertaken in the Hurst brickyard, where the sediments of the last and penultimate climate cycles are well exposed (Fig. 1). The sequence of the last climatic cycle is best represented in the southern exposure, where it fills a paleovalley (Rousseau *et al.* 1994, Fig. 2). The sequence is exceptionally well subdivided and complex but shows clear lithologic and pedologic parallels with other sequences in Northern France and Normandy, believed to be of the same age (Lautridou *et al.* 1985; Sommé *et al.* 1986). Detailed interregional correlation is difficult and has not yet been attempted.

In the northern wall of the Hurst brickyard, away from the paleovalley at a site referred to as a 'new section', a more typical sequence of Achenheim 1 complex was studied. The Upper Older Loess (UOL) is here overlain by the soil complex about 3 m thick (Figs. 1 and 2). A brown Bt horizon 55 cm thick with krotovinas is at the base (Fig. 2). Black, 80-cm-thick chernozemic steppe soil with abundant signs of reworking by worms follows. On top of this soil is a layer of light-colored, fine-grained silt, some 10–15 cm thick. The base of the layer is sharp and has not been reworked by pedofauna, a typical feature of markers (Kukla 1961). This silt is overlain by some 90 cm of pellet sands. The lower 30 cm is dark, consisting of well-bedded, sand-sized pellets of reworked chernozem. The remaining upper layer is brown, com-

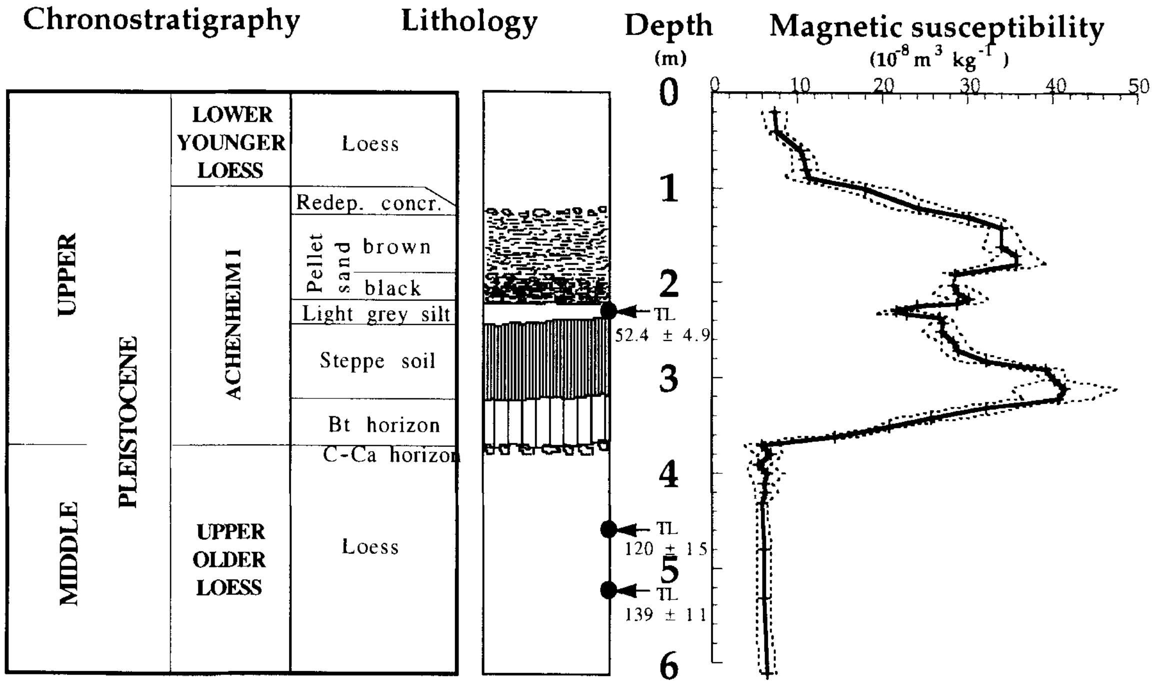

Fig. 2. General stratigraphy of the Achenheim I pedocomplex in the new section described in this paper. Lithology, thermoluminescence dates and the low field magnetic susceptibility (mean in full, range of the 10 measurements dotted). Depth below the surface of the excavation. Holocene soil was removed.

posed mainly of reworked Bt pellets. The layer is covered by a band of redeposited concretions (some up to 10 cm in diameter), which were probably derived from the reworked C-Ca horizon of the Achenheim 1 complex. The Weichselian Lower Younger Loess (LYL), follows. The sequence of black-, then brown- and finally white-spotted pellet sands, overlying the marker is in the inverse order of the pedogenic horizons underlying the marker. Obvious signs of a root network of grass or of pedofauna burrowing, both of which are common in loess, are absent in the marker.

In order to correlate this sequence with the rest of the Achenheim exposure and with other Pleistocene localities in Europe, we measured both the low field magnetic susceptibility and the thermoluminescence of the sediments.

Magnetic susceptibility (MS) permits rapid characterization of lithologic differences in eolian deposits (Begèt *et al.* 1990; Heller & Liu 1982; Kukla 1987). Correlations among individual loess sequences in China as well as of the loess with deep-sea cores (Kukla *et al.* 1988, 1990; Ding *et al.* 1995; Hovan & Rea 1991; Xiao *et al.* 1995; Kukla & Cilek 1996), and ice cores (Petit *et al.* 1990) are facilitated by the use of this parameter. The susceptibility in the soils is generally higher than in the loess layers. This is true in Europe, China, North America and Western Asia (Kukla *et al.* 1988, 1990; An *et al.* 1991; Forster & Heller 1994; Rousseau & Kukla 1994; Shackleton *et al.* 1995), but not in Alaska (Begèt *et al.* 1990).

We measured the magnetic susceptibility in Achenheim with the portable Bartington MS2 unit at the frequency of 0.58 Khz. After cleaning the section, 10 readings were obtained and averaged at each level, spaced at 10 cm intervals.

Results

The low field magnetic susceptibility shows values varying between 7 and 42×10^{-8} m^3 kg^{-1} (Fig. 3). The highest values are in the Bt horizon. In the Saalian loess (UOL), the susceptibility (MS) values are relatively stable, at around 7 units. Above the loess, in decalcified soil, the MS values increase progressively, reaching 42×10^{-8} m^3 kg^{-1} at the top of the Bt horizon. Within the chernozemic soil, MS decreases to around 27×10^{-8} m^3 kg^{-1}. The fine-grained silt of the marker is characterized by low MS with a minimum of 22×10^{-8} m^3 kg^{-1}. At the boundary between the silt and the pellet sands, the MS values climb again to around 28×10^{-8} m^3 kg^{-1}, remaining relatively stable within the dark-brown pellet sands. The average value here is almost the same as that in the top of the chernozemic soil, pointing to the common source of both materials. In the brown and reddish-brown pellet sands, the MS values increase and reach 35. Finally, the susceptibility gradually decreases in the upper part of the pellet sands and in the Lower Younger Loess

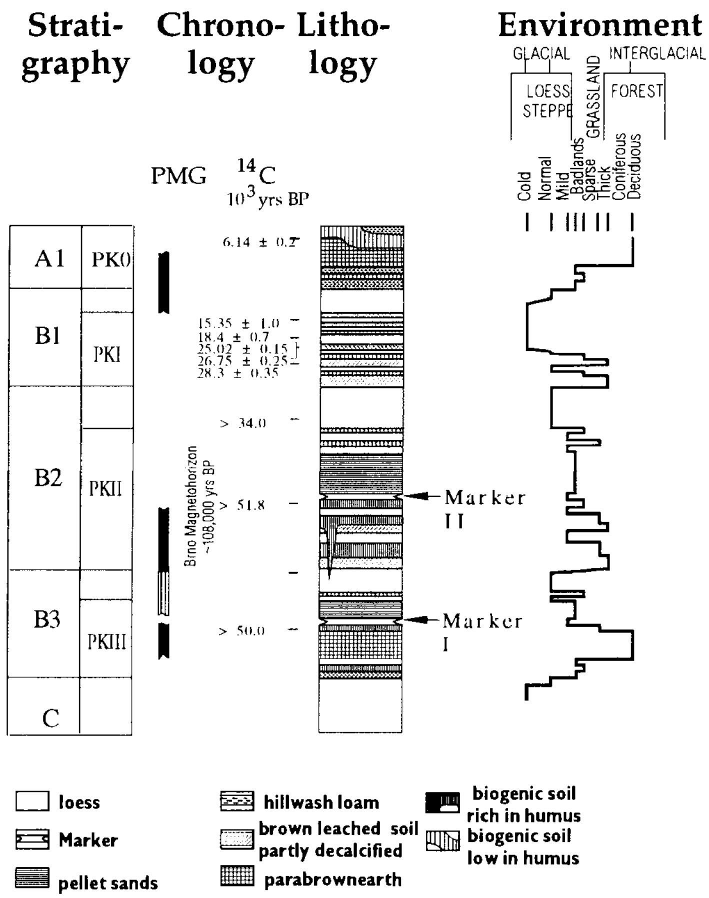

Fig. 3. Synthetic stratigraphy of the last glacial cycle in the loess sequences in the Czech Republic. Litho-pedostratigraphy, paleomagnetic (PMG) and ^{14}C determinations. Dated levels indicated by arrows. Stratigraphic position of markers I and II. Past environment reconstructed from snail assemblages and pedology (modified from Kukla 1977). A1-C: Cycles, PK0-PKIII: Pedocomplexes.

(LYL). A similar mirror-like pattern centered at the marker was also detected in the main section of the fossil gully, in the southern wall of the brickyard. There the MS values of the pellet sands are similar to those measured in the underlying Bt and the black soil horizons (Rousseau *et al.* 1998).

The loess underlying the pedocomplex (Fig. 1) yielded thermoluminescence (TL) ages of 120 ± 15 ka, 139 ± 11 ka and 133 ± 13 ka, in agreement with the Saalian age of the Upper Older Loess (Zöller *et al.* 1998). The first determination was obtained by the regeneration method, the other two by the additive dose method. Samples for TL dating were collected in light-proof steel cylinders hammered into the carefully cleaned faces. The environmental (γ) dose rate was measured using a portable gamma spectrometer. In the case of the marker in the new section, on-site measurements were taken in order to avoid non-representative data. The samples were processed in the laboratory under subdued red light. Polymineral fine grains (4–11 μm), obtained by sieving and elutriation and settled on aluminum discs using acetone, were used for TL measurements. The thermoluminescence signal was recorded at a ramp of 5 Ks^{-1} by an EMI 9635Q photomultiplier with blue-transmittent Corning 5–58 and heat-absorbing Chance Pilkington HA3 glass filters. The equivalent radiation dose absorbed since the deposition of the sediments (ED_β) was estimated using regeneration or additive dose-longest plateau (add) techniques. In the first method the regenerated TL intensity versus laboratory dose plots was fitted to a third-order polynomial curve, whereas the natural plus laboratory dose intensity versus laboratory dose plots was fitted and extrapolated using a saturating exponential curve (after Berger *et al.* 1987). Radioactivity analyses of the samples were based on thick source alpha counting, beta counting and high resolution gamma spectrometry in the laboratory. For a more detailed description of these procedures, see Zöller (1994) and Zöller *et al.* (1998) (Fig. 4).

The marker section gave an age of 52.4 ± 4.9 ka. This is a minimum age owing to the apparent secular disequilibrium in the 238-uranium decay chain. Another TL date of 64.9 ± 6.9 ka was obtained in the grey, fine-grained silt in the main section in paleovalley (Fig. 5), which corresponds to the marker which is

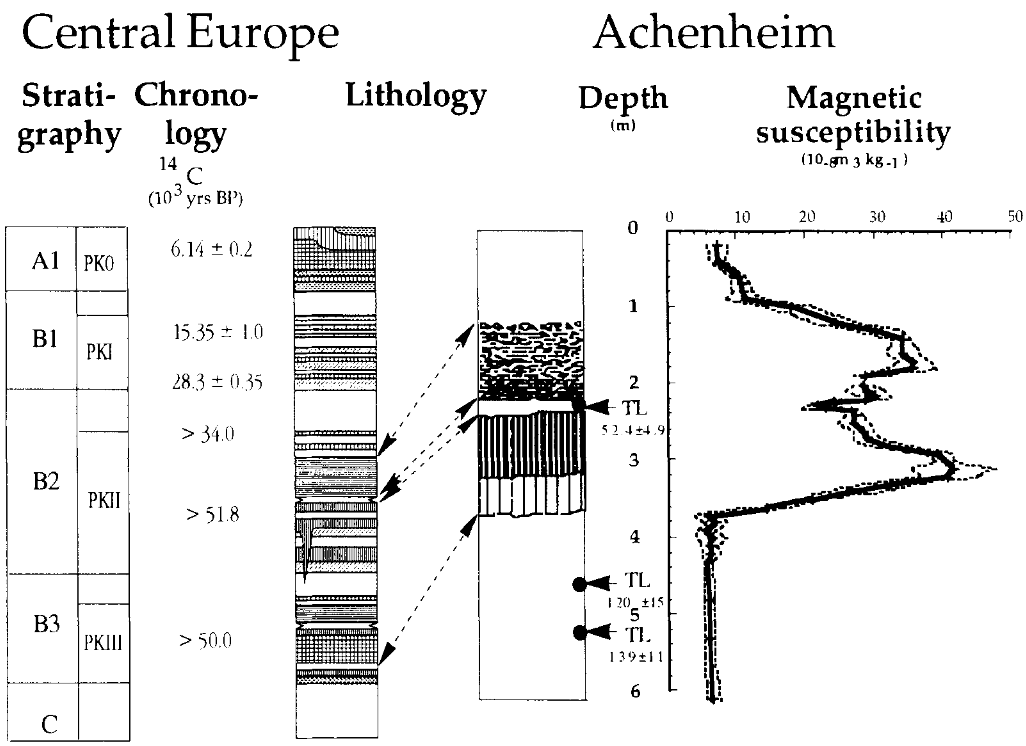

Fig. 4. Correlation between the Achenheim sequence and central European loess stratigraphy. Left: ^{14}C chronology and lithology in central Europe (see Fig. 3) Right: lithology, TL dates and magnetic susceptibility in Achenheim. Proposed correlations shown by arrows. (Otherwise same as in Figs. 2 and 3).

here partially reworked and para-autochthonous (Rousseau *et al.* 1998; Zöller *et al.* 1998). These two dates and the similar lithologic succession of the marker in Achenheim and the PKII marker in Bohemia (Kukla 1977) lead us to believe that the two may be of the same age, approximately coeval with the 5/4 boundary. Given this interpretation, the onset of the loess sedimentation in Achenheim may have occurred at the time of strong dust peaks observed in the GRIP ice-core at a level dated to the *c.* 72 ka assessed by GRIP members (1993).

Markers

Markers are thin bands of fine-grained silt which separate black humus-rich, biogenic, steppe soils from overlying detritic, basically sterile, pellet sands. They were originally described from Bohemia and Moravia (Kukla 1961). They document a sharp switch from a rich ecosystem of dense grasslands with abundant pedofauna to lifeless badlands. Although markers are generally finer than the normal loess, no significant differences were found in the mineralogic composition of bulk samples of markers as compared to the loess.

In Sedlec near Prague, the Czech Republic, the following granulometry of the PK II marker was reported by Hradilova (1994): <0.01 mm: 50.07%; 0.01–0.05 mm: 44.23%; 0.05–0.125 mm: 4.60%; and >0.125 mm: 1.10%. Kaolinite, smectite, illite, chlorite, quartz and K-feldspar made up the fine fraction below 63 μm. In the finest fraction under 20 μm, the smectite was almost absent. Gypsum was detected in the finest fraction (<2 mm) pointing to a dry source area of marker material (Hradilova & Stastny 1994).

The material composing the markers could not have originated close to the point of deposition since the surrounding ground was covered by black, mostly decalcified and degraded chernozems covered with a dense mat of grass cover. Local rivers carried mostly decalcified detritus from the surrounding woodlands. The grain composition of the marker points to its eolian origin. Micromorphological and mineralogic studies detected local components in the coarse fractions (Hradiva & Stastny 1994), but the composition of the fine fraction implies transport by dust storms of considerable magnitude, probably on a continental scale.

Up until now, the markers have only been described from the Lower Middle Rhine valley, near Koblenz, and in the Czech Republic, Austria and Slovakia. In the classical loess stratigraphy of central

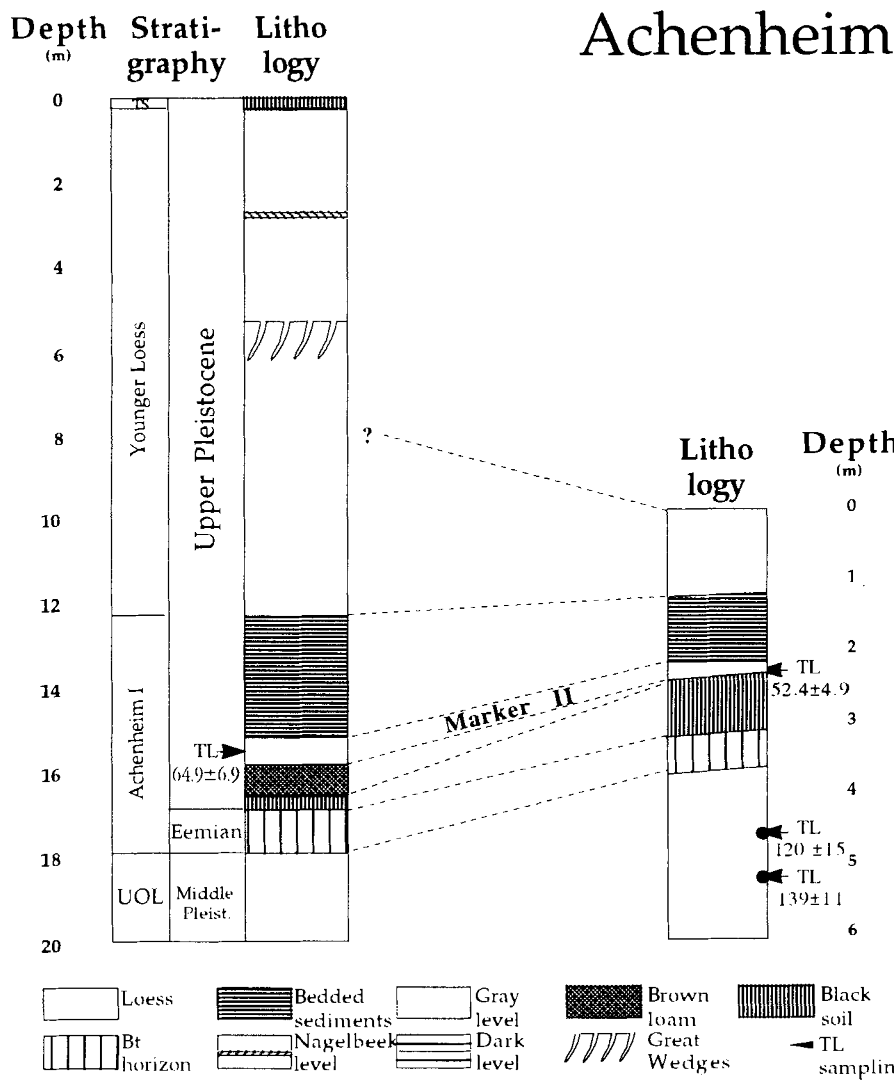

Fig. 5. Correlation of the two Upper Pleistocene loess sequences at Achenheim. On the left, the main section located in the southern wall (from Rousseau *et al.* 1995 modified. On the right the newly studied section described in the present study). The marker level has minimum thermoluminescence ages of 52.3 and 64.9 thousand years.

Europe, three major pedocomplexes have been described during the last climatic cycle. Among them Kukla & Lozek (1961) noted the occurrence of two markers in pedocomplexes PKIII and PKII. The first is believed to have occurred at around 110 ka, while the second dates to about the time of the MIS 5/4 boundary, i.e., to around 72 ka. Within the range of dating accuracy, this is also the probable level of the marker in Achenheim. The proposed land equivalent of the MIS 5/4 boundary is marked by a sharp degradation of the environment. In the loess sequences, the sharpest deterioration of the landscape occurred at the PKII marker level and coincides with the onset of the last pleniglacial largely abiotic environments in the loess belt. Pollen data indicate that this boundary coincides with the establishment of full-glacial steppes and tundras in western Europe (Kukla *et al.* 1997; Woillard 1978, 1979).

The profile from the new section of Achenheim reflects a succession from a harsh continental steppe in UOL to a forest (Bt horizon), and then to a temperate steppe (autochthonous chernozem). The Last Interglacial forest which led to the development of the Bt horizon was probably replaced by the chernozem steppe in the Early Glacial. Fine-grained silt of the marker was deposited over the autochthonous blackish chernozem unit relatively suddenly followed by the hillwash deposit of pellet sands, which reflect the action of rain downpours hitting parched dry soil. These heavy rains first removed the chernozemic and later the exposed Bt horizons. Finally, a prolonged episode of eolian sedimentation followed, represented by the loess unit LYL. This lithologic succession is, in essence, identical with others described from the central European loess belt (Kukla 1961, 1977). The 'new section' however, is the first one where the typical marker is identified in France.

Conclusions

A marker of fine-grained dust separating rich biogenic soils from overlying barren ones, lithologically similar to that found in central Europe, is identified in a newly studied section of the Achenheim 1 pedocomplex in France. The abrupt transition to the Pleniglacial bare landscape in northeastern France at or prior to 65 ka based on TL dating and correlation with marine isotope stage 5 may have been the result of a continental-scale dust storm. Marker II equivalents elsewhere in France together with additional physical datings (TL and ^{14}C) in Achenheim, should allow us to further constrain the chronology of this loess sequence.

The fact that a marker occurs in the Upper Pleistocene sequence in Achenheim is of particular interest. The layer, well known from central Europe, is almost unknown west of the Rhine. The question therefore remains whether a single hypothesized large-scale, early Weichselian dust storm affected western and central Europe at the same time or whether the Achenheim marker is the product of a separate regional west European drought episode.

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References

An, Z. S., Kukla, G., Porter, S. C. & Xiao, J. L. 1991: Magnetic susceptibility evidence of monsoon variation on the loess plateau of Central China during the last 130,000 years. *Quaternary Research 36*, 29–36.

Begèt, J. E., Stone, D. B. & Hawkins, D. B. 1990: Paleoclimatic forcing of magnetic susceptibility variations in Alaskan loess during the late Quaternary. *Geology 18*, 40–43.

Berger, G. W., Lockhart, R. A. & Kuo, J. 1987: Regression and error analysis applied to the dose-response curves in thermoluminescence dating. *Nuclear Tracks and Radiation Measurements 13*, 177–184.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., McManus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G. & Ivy, S. 1992: Evidence for massive discharges of icebergs into the North Atlantic ocean during the last glacial period. *Nature 360*, 245–249.

Bond, G. & Lotti, R. 1995: Iceberg discharges into the North Atlantic on millennial time scales during the last glaciation. *Science 267*, 1005–1010.

Dansgaard, W., Johnsen, S. J., Clausen, H. B. & Langway, C. C. 1972: Speculation about the next glaciation. *Quaternary Research 2*, 396–398.

Dansgaard, W., Clausen, H. B., Gundestrup, N., Hammer, C. U., Johnsen, S. F., Kristinsdottir, P. M. & Reeh, N. 1982: A new Greenland deep ice core. *Science 218*, 1273–1277.

Ding, Z., Liu T., Rutter, N. W., Yu, Z., Guo, Z. & Zhu, R. 1995: Ice-volume forcing of East Asian winter monsoon variations in the past 800,000 years. *Quarternary Research 44*, 149–159.

Forster, T. & Heller, F. 1994: Loess deposits from the Tajik depression (Central Asia): Magnetic properties and paleoclimate. *Earth and Planetary Sciences Letters 128*, 501–512.

GRIP members 1993: Climate instability during the last interglacial period recorded in the GRIP ice core. *Nature 364*, 203–207.

Grootes, P. M., Stuiver, M., White, J. W. C., Johnsen, S. F. & Jouzel, J. 1993: Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores. *Nature 366*, 552–554.

Grousset, F. E., Labeyrie, L. D., Sinko, J. A., Cremer, M., Bond, G., Duprat, J., Cortijo, E. & Huon, S. 1993: Patterns of ice-rafted detritus in the Glacial North Atlantic (40–55°N). *Paleoceanography 8*, 175–192.

Haesaerts, P., Juvigné, E., Kuyl, O., Mucher, H. & Roebroeks, W. 1981. Compte rendu de l'excursion du 13 juin 1981, en Hesbaye et au Limbourg neerlandais, consacrée à la chronostratigraphie des loess du Pléistocène supérieur. *Annales de la Société Géologique de Belgique 104*, 223–240.

Heim, J., Lautridou, J. P., Maucorps, J., Puisségur, J. J., Sommé, J. & Thévenin, A. 1982: Achenheim: une séquence type des loess du Pléistocène moyen et supérieur. *Bulletin Association française d'Etude du Quaternaire 10–11*, 147–159.

Heinrich, H. 1988: Origin and consequences of cyclic ice rafting in the northeast Atlantic Ocean during the past 130,000 years. *Quaternary Research 29*, 142–152.

Heller, F. & Liu, T. S. 1982: Magnetostratigraphical dating of loess deposits in China. *Nature 300*, 1169–1172.

Hovan, S. A. & Rea, D. K. 1991: Late Pleistocene continental climate and oceanic variability recorded in northwest Pacific sediments. *Paleoceanography 6*, 349–370.

Hradilova, J. 1994: New micromorphological knowledge of the last Pleistocene glacial cycle in the loess profile at Praha-Sedlec. *Journal of the Czech Geological Society 39*, 319–329.

Hradilova, J. & Stastny, M. 1994: Changes in the Clay Fraction Mineral Composition in a Loess Profile of the Last Interglacial and Early Glacial in Praha-Sedlec. *Acta Universitatis Carolinae Geologica 38*, 229–238.

Juvigné, E., Haesaerts, P., Mestgah, H., Pissart, A. & Balescu, S. 1996: Révision du stratotype loessique de Kesselt (Limbourg, Belgique). *Comptes Rendus de l'Académie des Sciences Paris 323*, série IIa, 801–807.

Kukla, G. 1961: Lithologische Leithorizonte der tschechoslowakischen Lössprofile. *Věstnik Ustredniho Ustavu Geologickeho 36*, 369–372.

Kukla, G. 1977: Pleistocene land-sea correlations. 1. Europe. *Earth-Science Reviews 13*, 307–374.

Kukla, G. 1987: Loess stratigraphy in central China. *Quaternary Science Reviews 6*, 191–219.

Kukla, G. & Cilek V. 1996: Plio-Pleistocene megacycles: record of climate and tectonics. *Palaeogeography, Paleoclimatology, Palaeoecology 120*, 171–194.

Kukla, G. & Lozek, V. 1961: Loess and related deposits. *INQUA 6th Int. Congr. Warszawa, Institut Geology Prace 34*, 11–28.

Kukla, G., An, Z. S., Melice, J. L., Gavin, J. & Xiao, J. L. 1990: Magnetic susceptibility record of Chinese Loess. *Transactions Royal Society Edinburgh: Earth Sciences 81*, 263–288.

Kukla, G., Heller, F., Liu, X M., Xu, T. C., Liu, T. S. & An, Z. S. 1988: Pleistocene climates in China dated by magnetic susceptibility. *Geology 6*, 811–814.

Kukla, G., McManus, J. E., Rousseau, D. D. & Chuine, I. 1997: How long and how stable was the last interglacial. *Quaternary Science Reviews 16*, 605–612.

Lautridou, J.P., Sommé, J., Heim, J., Puisségur, J. J. & Rousseau, D. D. 1985: La stratigraphie des loess et formations fluviatiles d'Achenheim (Alsace): Nouvelles données bioclimatiques et corrélations avec les séquences Pléistocènes de la France du Nord-Ouest. *Bulletin Association française d'Etude du Quaternaire 22–23*, 125–132.

Lozek, V. 1964: *Quatärmollusken der Tschechoslowakei*. 374 pp. Verlag der Tschechoslowakischen Akademie der Wissenschaften, Praha.

McManus, J., Bond, G., Broecker, W., Johnsen, S. F., Labeyrie, L. & Higgins, S. 1994: High-resolution climate records from the North Atlantic during the last interglacial. *Nature 371*, 326–329.

Müller, H, 1974: Pollenanalytische Untersuchungen und Jahresschichtenzaehlung an der eem-zeitlichen Kieselgur von Bispingen/Luhe. *Geologisches Jahrbuch A 21*, 149–169.

Müller, H. 1992: Climate changes during and at the end of the interglacials of the Cromerian Complex. *In* Kukla, G. J. & Went, E. (eds.): *Start of a Glacial*, 51–69. Springer-Verlag, Heidelberg.

Petit, J. R., Mounier, L., Jouzel, J., Korotkevich, Y. S., Kotlyakov, V. I. & Lorius, C. 1990: Palaeoclimatological chronological implications of the Vostok core dust record. *Nature 343*, 56–58.

Rousseau, D. D. 1987: Paleoclimatology of the Achenheim series (middle and upper Pleistocene, Alsace, France). A malacological analysis. *Paleogeography, Paleoclimatology, Paleoecology 59*, 293–314.

Rousseau, D. D. 1991: Climatic transfer function from Quaternary molluscs in European loess deposits. *Quaternary Research 36*, 195–209.

Rousseau, D. D. & Puisségur, J. J. 1990: A 350,000 years climatic record from the loess sequence of Achenheim, Alsace, France. *Boreas 19*, 203–216.

Rousseau, D. D. & Kukla, G. 1994: Climatic records from the Eustis loess section (Nebraska, USA) during the Late Pleistocene. *Quaternary Research 42*, 176–187.

Rousseau, D. D., Soutarmin, N., Gaume, L., Antoine, P., Lang, M., Lautridou, J. P., Sommé, J., Zöller, L., Lemeur, I., Meynadier, L., Fontugne, M. & Wintle, A. 1994: Histoire du dernier cycle climatique enregistrée dans la séquence loessique d'Achenheim (Alsace, France), à partir de la susceptibilité magnétique. *Comptes rendus Académie Sciences Paris 319, II*, 551–558.

Rousseau, D. D., Zöller, L. & Valet, J. P. 1998: Climatic variations in the Upper Pleistocene loess sequence at Achenheim (Alsace, France). Analysis of the magnetic susceptibility and thermoluminescence chronology. *Quaternary Research 49*, 255–263.

Shackleton, N. J., An, Z., Dodonov, A. E., Gavin, J., Kukla, G. J., Ranov, V. A. & Zhou, L. P. 1995: Accumulation rate of loess in Tadjikistan and China: relationship with global ice volume cycles. *Quaternary Proceedings 4*, 1–6.

Sommé, J., Lautridou, J. P., Heim, J., Maucorps, J., Puisségur, J. J., Rousseau, D. D., Thévenin, A. & Van Vliet-Lanoé, B. 1986: Le cycle climatique du Pléistocène supérieur dans les loess d'Alsace à Achenheim. *Bulletin Association française d'Etude du Quaternaire 25–26*, 97–104.

Woillard, G. 1978: Grande Pile peat bog: continuous pollen record for last 140,000 years. *Quaternary Research 9*, 1–21.

Woillard, G. 1979: Abrupt end of the last interglacial s.s. in north-east France. *Nature 281*, 558–562.

Xiao, J., Porter, S. C., An, Z., Kumai, H., & Yoshikawa, S. 1995: Grain size of quartz as an indicator of winter monsoon strength on the loess plateau of central China during the last 130,000 yr. *Quaternary Research 43*, 22–29.

Zöller, L. 1994: Würm- und Rißlößstratigraphie und Thermolumineszenz-Datierung in Süddeutschland und angrenzenden Gebieten. *Habilitationsschrift Fakultät für Geowissenschaften Universität Heidelberg*, 199 + VII pp.

Zöller, L., Rousseau, D. D., Jäger, K. D. & Kukla, G. 1998: Last interglacial, Lower Weichselian and Middle Weichselian; A comparative study from the Upper Rhine area and Thuringia. *Zeitschrift für Geomorphologie*.