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Pedosedimentary evolution of the last interglacial and early glacial sequence in the European loess belt from Belgium to central Russia

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Abstract

For more than one century, the textural B-horizon of the last interglacial soil and its cover deposits have been standing out in Europe as an important pedostratigraphic marker. The complexity of this horizon was well illustrated since the seventies, though its pedological and stratigraphic significance remained doubtful. Macro-, meso- and micromorphological data gathered by the authors at various key-sites in Europe and the sequential correlation principle have resulted in a better understanding of the high complexity of the pedosedimentary and stratigraphical evolution of the last interglacial and early glacial loess succession. The present study identifies four megacyclic pedosedimentary intervals that show a general trend towards dry and continental climatic conditions.

A consistent correlation exists between pedosedimentary evolution and vegetation, as recorded in the Grande Pile pollen record. The picture obtained in the present study is similar for both the Western and the Eastern European loess palaeosol successions. The so-called 'last interglacial soil', with three major soil-forming processes, belongs to the Eemian and Saint-Germain I (MIS substages 5e and 5c), whereas the humiferous sediments and soils on top are linked to Melisey II, Saint-Germain II and Ognon I (MIS substages 5b and 5a). The overlying loess, colluvial sediments and humiferous soils that end the palaeosol succession belong to the Ognon II and III interstadials; they record the onset of the early Pleniglacial (MIS stage 4) characterized by a significant increase in aeolian sedimentation.

Keywords: early glacial; Eemian; European loess belt; last interglacial; paleopedology; stratigraphy

Introduction

The last-interglacial soil on loess and loess-like sediments in Europe, recognized by Ladrière (1890), corresponds in general to a well developed textural B-horizon and is known as the 'Rocourt Soil' in NW Europe (Gullentops, 1954), as 'B1b of PK III' in Czechia (Demek & Kukla, 1969) and as the 'Salyn Soil' of the 'Mezin Complex' in Central Russia (Velichko, 1990). The early glacial loess sequence corresponds to a complex of humiferous loams and bears the name 'Warneton Pedocomplex' in Belgium (Paepe & Vanhoorne, 1967; Van Vliet-Lanoë, 1990a), 'B1d of PK III and PK II' in Czechia (Demek & Kukla, 1969) and 'Krutitsa Soil' of the 'Mezin Complex' in Central Russia (Velichko, 1990).

Up to now, long-distance synthetic investigations integrating regional information for this time-span mainly referred to literature data (Pécsi & Richter, 1996) or to an elementary field validation (Van Vliet-Lanoë, 1986). Yet, the complex pedosedimentary and cryogenetic succession of Remicourt (Haesaerts et al., 1999) recently led to a better understanding of the 130-65 ka time-span in Belgium and provided much more detailed information than envisaged before. The present contribution intends to assess the degree to which regional knowledge suffices to reconstruct the palaeoclimatological and environmental conditions of the last interglacial and early glacial along a West-East transect from Belgium to central Russia between 48° and 52°30′ NL. The present assessment is therefore based on fieldwork in close collaboration with local teams.

Among the thirty personally examined sections in Belgium, Germany, Austria, Czechia, Hungary, the Ukraine and central Russia, six selected key-sites provide the largest quantity and the greatest variability of qualitative soil-sedimentary information, thanks to favourable geomorphological and sedimentological conditions. In the reference regions of Belgium, Germany, Czechia and central Russia, the key-sites of Harmignies (B), Remicourt (B), Tönchesberg (G), Metternich (G), Dolni Vestonice (Cz) and Zheleznogorsk (R) function as reference sections (Fig. 1), whose chronological positions are determined by their geomorphological background, TL-dating (Frechen, 1992; Frechen et al., 1995; Zöller et al., 1994) or TL-stratigraphy (Balescu, 1988; Juvigné et al., 1996; Wansard, 1997).

Methods and materials

The interpretation of past environments on the basis of palaeosols (Ruhe, 1965) rests on the uniformitarian principle. Bearing relations between environments and present-day soil characteristics, for instance, biological activity and humiferous surface building, works reasonably well. In this case, the differentiation of the environmental background depends on the degree of humification and decomposition, as well as on the intensity and identification of faunal activity. Certain constraints, such as diagenesis do, however, exist. Clay illuviation, for example, is not ascribed to a precise climatological signal (Van Vliet-Lanoë, 1990b) but to azonal favourable leaching conditions, which are significant during the dynamic arctic/temperate transitions. The persistence of clay coatings, on the other hand, indicates a temporal continuum of temperate conditions (Van Vliet-Lanoë, 1986).

The identification of cryogenic features enables the interpretation of freeze/thaw processes, permafrost characteristics and sedimentary/erosional dynamics. In most cases the soil micromorphology of these processes proved to be critical (Van Vliet-Lanoë, 1985; Huijzer, 1993). Aeolian as well as slope deposits of local origin, containing fragmented soil material, require an unvegetated or bare surface in the source area; such a dramatical vegetation clearance therefore pinpoints an important climatic signal.

Considering the given constraints, the present study is based on interactive field description, meso- and micromorphology; it focuses on the succession of cycles recorded by sedimentary and soil characteristics during unstable and stable periods, rather than on individual palaeosols. Roman figures and suffixes referring to the examined regions indicate the regional cycles. The quantification of the palaeoclimate is based on present-day environments and annual precipitation. The correlations of the regional sequences are thus based on major soil formations and cryogenic

Fig. 1. Location map of the sections studied.
1: Harmignies; 2: Remicourt; 3: Metternich; 4: Tönchesberg; 5: Dolni Vestonice; 6: Zheleznogorsk.

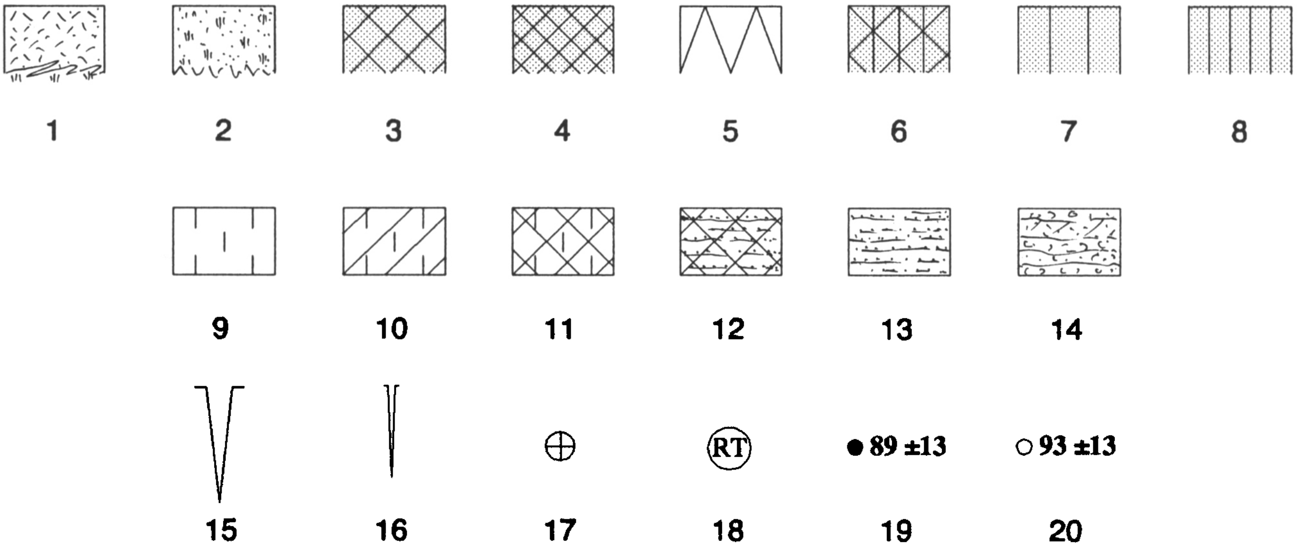

Fig. 2. Graphic symbols and abbreviations used in Figures 3-6 (profiles).

Pedology. 1: tundra gley; 2: E-horizon; 3: light humiferous soil; 4: humiferous soil (chernozem); 5: conchoidal structure; 6: greyzem; 7: brown arctic soil (B-horizon); 8: luvisol (B2t horizon).

Lithology. 9: loess; 10: reworked loess; 11: humic loam; 12: humic colluvium; 13: colluvium (sandy loam); 14: gelifluxion (loam); 15: ice-wedge pseudomorph; 16: frost wedge; 17: palaeomagnetic event; 18: Rocourt tephra; 19: TL dating on aeolian sediment (reliable date); 20: TL dating on reworked or mixed sediment (rejected date).

Sedimentary facies. L: loess-like loam; (L): reworked loess; H L: humiferous loess; Gel: gelifluxion (loam); H Gel: gelifluxion (humiferous-loam); LBS: Lehmbrockel Sande (cf. Demek and Kukla, 1969); Col: colluvium; S Col: sandy colluvium.

Palaeoclimatic environments (solid line). P: periglacial; A: arctic; SA: subarctic; B: boreal; T: temperate. MAT: mean annual precipitation (dashed line).

Abbreviations. Lith.: lithology; Ped.: pedology; Cycl.: Cycles; Palaeosols; MALP: Malplaquet Soil; V S G: Villers-Saint-Ghislain Soil; HARM: Harmignies Soil; H C R: Humiferous Complex of Remicourt; W H M: Whitish Horizon of Momalle; PARABR: Parabraunerde.

processes taking into account their palaeoclimatic signal, the position of the sites in the landscape, and the presence of geomorphological breaks in the sequences.

The relevant regional successions are described and depicted in the following section. The graphic symbols in the figures and the abbreviations used in them are explained in Figure 2.

Regional sequences

Belgium (Harmignies and Remicourt)

The compiled Belgian sequence integrates the sections of Harmignies (Haesaerts & Van Vliet, 1974; Haesaerts & Van Vliet-Lanoë, 1981) and Remicourt (Haesaerts et al., 1999). Harmignies is located on top of a cuesta that functioned as a sedimentary trap during the Late Pleistocene, whereas Remicourt presents a bottom-slope position in the Hesbaye – the classic loess region of Belgium (Fig. 3).

The Rocourt Soil: cycles I-III

The typical facies of the 'Rocourt Soil' (Gullentops, 1954) developed on the Saalian loess in Belgium comprises a complex textural B-horizon that records three soil-forming processes (Haesaerts & Van Vliet-Lanoë, 1981; Haesaerts et al., 1981). Two individualized processes of clay illuviation resembling luvisols (cycles I-II) precede a greyzem (cycle III); they are systematically separated by 'cold' events characterized by slight erosion and deep seasonal freezing (Haesaerts et al., 1999). During the first cold interval, a deep polygonal network of desiccation cracks penetrated the initial luvisol of cycle I in Remicourt.

In Harmignies, the presence of sandy-loam colluvium in between the first and the second clay illuviation reveals the complex character of what is known as the 'Harmignies Soil' (cycle I) and the 'Villers Saint-Ghislain Soil', the latter being the image of the second clay illuviation and the greyzem (cycles II-III). The soils of cycles I and II are further characterized by important bleaching processes recording further acidification of the palaeoenvironment.

The so-called 'Whitish Horizon of Momalle', which characterizes the upper part of the Rocourt Soil, represents the base of cycle IV. This layer records a major cooling as it arises from the reworking of the greyzem's upper part and from percolating or running meltwater on top of a frozen subsurface horizon (Haesaerts et al., 1999).

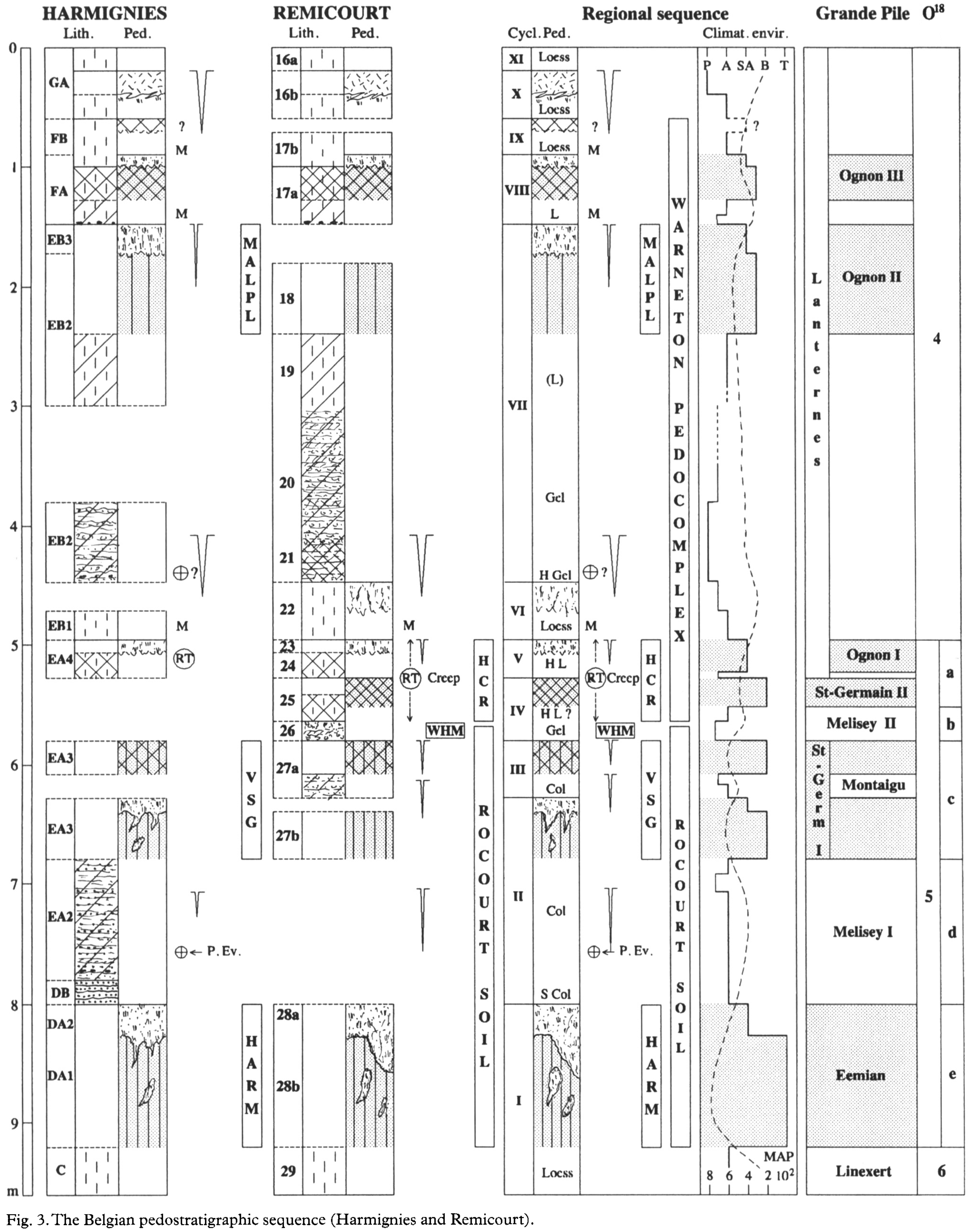

Fig. 3. The Belgian pedostratigraphic sequence (Harmignies and Remicourt).

The Warneton Pedocomplex: cycles IV-IX

On top of the Rocourt Soil lies the 'Humiferous Complex of Remicourt' incorporating the Rocourt tephra (Juvigné, 1977; Juvigné et al., 1996); it is due to two soil-forming processes separated in time by frost creep and by aeolian sedimentation reworking local humiferous loams. The lower soil resembles a chernozem (cycle IV) and the upper one a subarctic soil (cycle V). The presence of the Rocourt tephra trapped in the humiferous sediments that cover the three soil units of the Rocourt Soil, reinforces the correlation between Harmignies and the sections in Hesbaye, such as Remicourt, Rocourt and Kesselt (Juvigné et al., 1996).

The Humiferous Complex of Remicourt is covered by a well sorted allochtonous loess with a faint humiferous soil in the upper part (cycle VI). It is followed by a thick, stratified loamy sediment deposited by gelifluction, and subsequently by homogeneous, loess-like loams (cycle VII) that are mainly preserved at the bottom slopes and reflect a major geomorphological break. In Remicourt and in Harmignies, a first generation of ice-wedge pseudomorphs opens in the lower part of the stratified loams; a soil with faint clay illuviation, named 'Malplaquet Soil' in Harmignies, closes cycle VII.

The Malplaquet Soil is truncated by a major deflation surface, the geometry of which is discordant with the underlying sequence. Local aeolian loams and later allochtonous calcareous loess cover the deflation surface; two humiferous soils (cycles VIII and IX) were formed in these sediments; the upper soil is incipient and preceeds a well developed tundra gley with occasional ice-wedge pseudomorphs at the base of the early Pleniglacial loess cover (cycle X).

Germany (Metternich and Tönchesberg)

The two selected key-sites of Tönchesberg and Metternich functioned as a sedimentary trap during the Late Pleistocene (Fig. 4). The Tönchesberg section (Becker, 1990; Conard, 1992; Frechen, 1994) lies on top of a Middle Pleistocene volcanic crater dated 202±14 ka, which belongs to the Wehr phase of the East Eifel volcanism (Van den Bogaard & Schmincke, 1990). Metternich, near the confluence of the Mosel and Rhine, is in a bottom-slope position on top of the lower Mosel terrace (Boenigk et al., 1994; Frechen et al., 1995).

The interglacial parabraunerde: cycles I-III

At the base of both key-sections lies a complex textural B-horizon named 'Erbacher Boden', which is considered as a single interglacial event (Frechen et al., 1995), although a micromorphological analysis of this pedocomplex in Metternich demonstrates a succession of three soil-forming episodes separated by two 'cold' events.

A first soil development (cycle I) with strongly clay illuviation preceeds a unit reflecting deep freezing and thawing. A second soil unit (cycle II) with clay illuviation on platy peds is followed by erosion and repeated churning of the upper horizon during cold-climatic conditions. A third generation of clay illuviation with organo-mineral substances records the formation of a greyzem (cycle III). Finally, frost creep associated with percolating meltwater truncated the complex textural B-horizon (base of cycle IV).

The Mosbacher Humuszone: cycles IV-XII

In the two selected key-sites, the first cycle of the Mosbacher Humuszone (cycle IV) consists of a homogeneous, humiferous loam (probably an autochtonous aeolian deposit) bearing a subarctic soil. The second cycle starts with an aeolian input followed by a thick stratified pedisediment (cycle V), reworking the whole Erbacher soil sequence, including the calcareous Saalian loess. A soil the development of which was strongly influenced by geomorphology formed on this calcareous sediment. The result of this is a chernozem-like soil formed at topographically relatively elevated sites as in Tönchesberg, and a weakly developed luvisol induced by better leaching conditions at the bottom of the slope in Metternich.

The soils of cycle V are covered by thick, humiferous pedisediments alternating with homogeneous, humiferous loams; they record several phases of stabilization (cycles VII-IX). A chernozem-like soil with carbonate eluviation ends cycle VII; the prismatic choncoïdal pedality affecting this soil results from extreme freeze desiccation posterior to the pedogenesis; the organo-mineral translocation along vesicles and on the prismatic pedality is the result of the thawing process during a phase of stabilization (cycle VIII). A subarctic soil developed on humiferous aeolian loam ends this part of the sequence (cycle IX); it is affected by desiccation cracks in Metternich and by ice-wedge pseudomorphs in Tönchesberg.

The upper part of the Mosbacher Humuszone (cycles X and XI) is characterized by two thin calcareous loess-like layers (markers). Each of them is covered by a humiferous pedisediment. For the first generation of pedisediment, the presence of a humiferous soil is well established in Tönchesberg (cycle X).

Czechia (Dolni Vestonice)

The sequence of the Dolni Vestonice brickyard (Fig. 5A), situated at a bottom slope of the Pavlov mountain on a lower Dyje terrace, was chosen as the reference record for central Europe (Klima et al., 1961; Kukla & Koci, 1972). In the most elaborate profile of the brickyard (profile 4), the last interglacial and the early glacial are recorded in two pedocomplexes, PK III and PK II, respectively (Demek & Kukla, 1969).

PK III: cycles I-V

At the base of the sequence dating from the last interglacial and the early glacial rests a complex textural

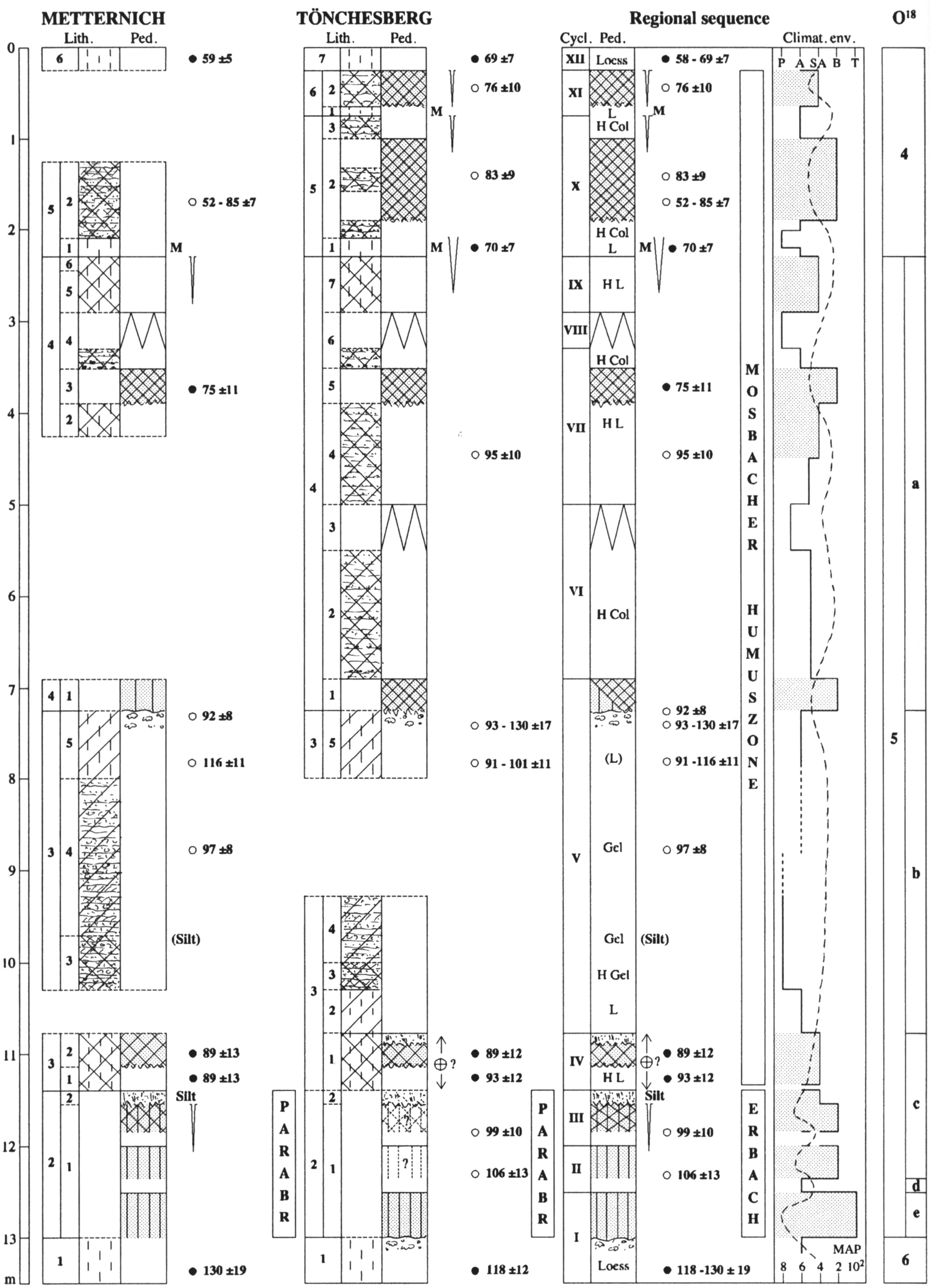

Fig. 4. The pedostratigraphic sequences of Metternich and Tönchesberg (Middle Rhine, Germany). ADD-TL dates from Frechen (1994) and Frechen et al. (1995).

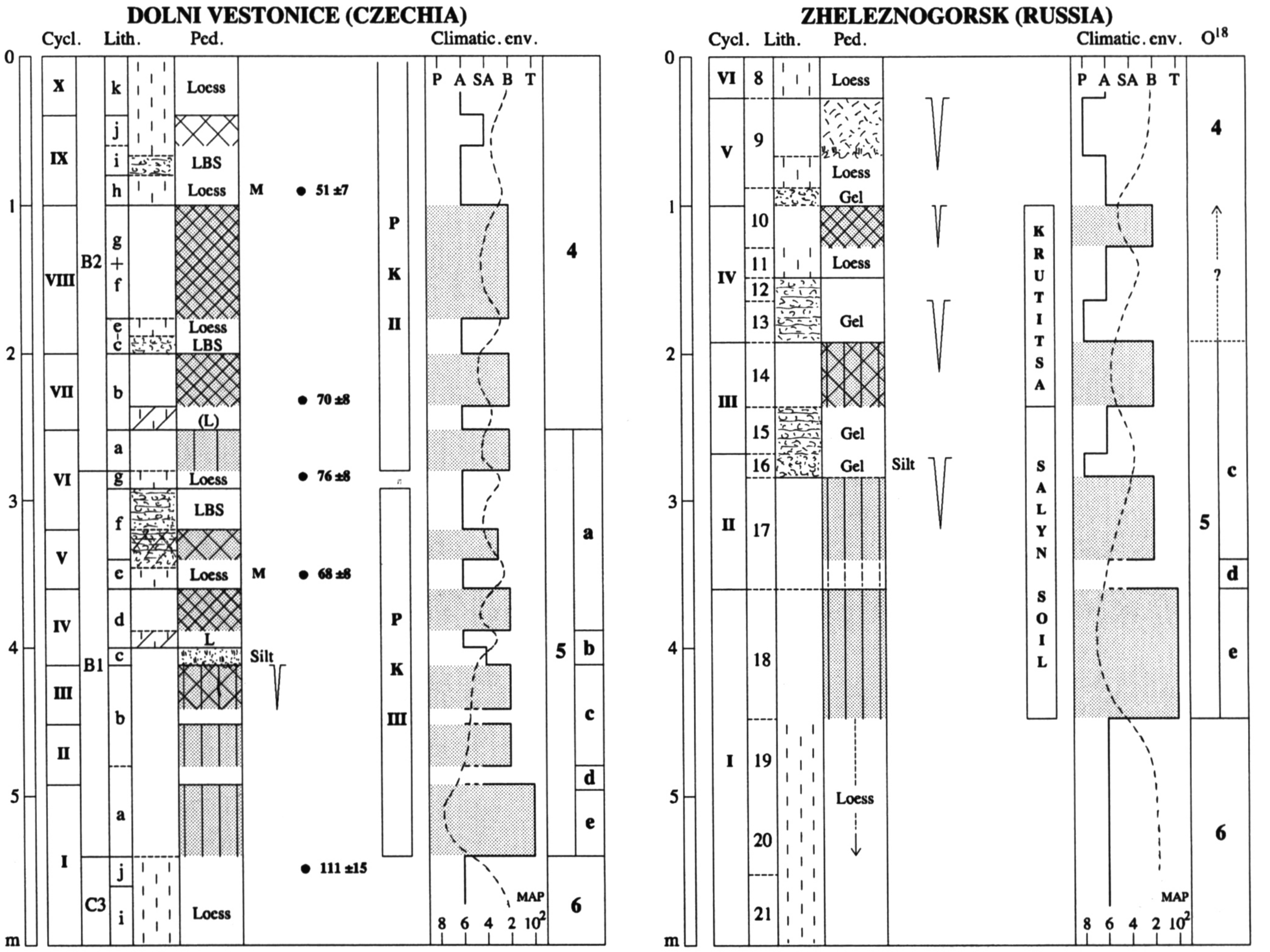

Fig. 5. The pedostratigraphic sequences of Dolni Vestonice (Czechia) and Zheleznogorsk (central Russia). TL dates from Zöller et al. (1994).

B-horizon recording three episodes of soil formation. The first one, represented by clay coatings (cycle I), has been disturbed by freezing and thawing. On the induced platy peds, a second set of clay coatings (cycle II) is recognized. Strong churning of the upper part of the textural horizon provided abundant fragmented clay coatings in the matrix. The voids of this upper horizon, as well as the platy peds, are covered by a third illuviation, characterized by organo-mineral substances (cycle III).

Following the truncation of the complex textural B-horizon by frost creep, which is attested by plastically deformed platy peds and abundant pale silt in the so-called E-horizon, a humiferous soil formed on top of a first generation of colluvium (cycle IV). This chernozem is covered by a thin, well sorted loess ('Marker', cf. Demek & Kukla, 1969) followed by a colluvial deposit containing abundant soil fragments ('Lehmbrockel Sande', cf. Demek & Kukla, 1969) bearing a distinctly bioturbated, weakly humiferous horizon indicative of a temporal surface stabilization (cycle V). The prismatic pedality, which crosses the underlying horizons, reflects the dry and cold climate during the deposition of the Lehmbrockel Sande.

PK II: cycles VI-X

A decalcified cambisol (B2a; cycle VI) described as 'Braunerde' by Kukla rests on top of primary loess covering colluvial deposits. Missing in profile 4 but occurring in profile 9 (Klima et al., 1961), this truncated cambisol is also recorded in other sections of Czechia, such as Modrice (Kukla & Koci, 1972); it is followed by two chernozems, each of them being developed on loess-like material partly accumulated by gelifluction (cycles VII and VIII). As for the chernozem of cycle IV, the prismatic pedality that crosses the underlying horizons is the result of freeze desiccation. Finally, the deposition of aeolian loess and the formation of an incipient humiferous soil (cycle IX) end PK II in the Czech sequence.

Central Russia (Zheleznogorsk)

Among the many sites in central Russia visited by the present authors, Zheleznogorsk – located between Kursk and Briansk (Velichko, 1982; Velichko et al., 1997) – was chosen as reference sequence (Fig. 5B). Although it is situated on a plateau, the presence of a shallow depression has induced a better development of the last interglacial – early glacial sequence (Sycheva, 1993).

Salyn Soil of the 'Mezin Complex': cycles I-II and III p.p.
The so-called Salyn Soil (Velichko, 1982), developed on the late Middle Pleistocene loess (Wansard, 1997), is characterized by textural banding and strong clay illuviation. It records two soil horizons separated by deep seasonal freezing inducing a platy pedality in the upper horizons of the initial luvisol (cycle I). A second set of clay coatings occurs on the platy peds (cycle II). A thick local sediment with a high concentration of pale silt was deposited by frost creep or even gelifluction, and truncates the textural B-horizon (cycle III pro parte). A first generation of ice-wedge pseudomorphs opened at this level (Sycheva, 1993).

Krutitsa Soil of the 'Mezin Complex': cycles III p.p. and IV
After the frost-creep sedimentation, a new soil resembling a greyzem and characterized by dark brown clay coatings, developed on colluvial material (cycle III). Later on, erosion and sedimentation under cold climatic conditions restarted (cycle IV) together with a second generation of ice-wedge pseudomorphs. The sedimentation was initially colluvial and later more aeolian; the lower part of this soil-sediment indicates deposition by frost creep, which gradually became more gelifluction-like.

Following the deposition of the pedisediment, a chernozem-like soil formed (cycle IV). An input of calcareous sediment occurred at the end of this interval of soil formation. Within and below this humiferous soil, void pseudomorphs of gypsum crystals indicate dry climatic conditions; these were probably formed during the input of the first calcareous sediment.

Erosion and sedimentation due to gelifluction continued and finally filled the whole depression (cycle V). This phase was characterised by deep freezing marked by a third generation of ice-wedge pseudomorphs. Finally calcareous loess belonging to the Valdai sequence covered the pedisediment (cycle VI).

Integrated scheme for Europe

In order to reconstruct a general scheme of the last interglacial and early glacial pedostratigraphic record, the regional sequences were put in parallel using the sequential-correlation principle (Haesaerts & Cahen, 1997). In other words, the distribution and correlation of the various pedosedimentary cycles shown in Figure 6 take into account their signature as well as their position regarding the morpho-sedimentary and chronological evolution. It is therefore worth mentioning that the TL datings obtained for the German and Czech loess palaeosol sequences were considered only during the final stage of the correlation, using the reliable dates on aeolian sediments as a relative time control. In general, these published TL dates fit exceptionally well with the proposed scheme.

Altogether, the general scheme achieved clearly shows a remarkable internal consistency regarding the reproducibility of the pedosedimentary cycles in relation with their geographical and relative chronological distribution. This also enables the subdivision of the integrated scheme into four distinct megacycles, labelled A-D, each of them recording specific morpho-sedimentary and palaeoclimatic dynamics.

Regarding the chronostratigraphic setting of the system, the Grande Pile pollen record (Woillard, 1975; Woillard, 1978; Woillard & Mook, 1982) is used as the main tool since it represents the most complete continental record showing a close correlation with last-interglacial and early-glacial loess/paleosol sequences of NW Europe (Haesaerts et al., 1999).

Discussion

Megacycle A: Eemian – Melisey I – Saint-Germain I

Except for a few particular geomorphological positions, megacycle A corresponds to a complex textural B-horizon that covers the time-span of 130-90 ka. A variety of cryogenic features and three main soil-forming episodes enhance this complexity, which can be unravelled in the field at a few sites only.

The first soil of megacycle A corresponds to the Eemian (130-115 ka). The pedogenesis of this soil comprehends decalcification of the Middle Pleistocene loess, clay mobilisation, acidification and hydromorphy. The soil characteristics are similar in the four regions and suggest favourable leaching conditions. The calibrated climatic signal of the Grande Pile pollen record by Guiot et al. (1992) attests a higher precipitation in autumn and winter during the early Eemian than nowadays. Summers were cooler and winters milder. The occurrence of leached soils or luvisols in the Eemian record, from the Atlantic Ocean to central Russia, confirms the above climatic data. The bleached spots with ferrugineous rims provoked by decomposing roots and an acid environment at the end of the Eemian pedogenesis are ascribed to phases 6 and 7 of the Eemian in La Grande

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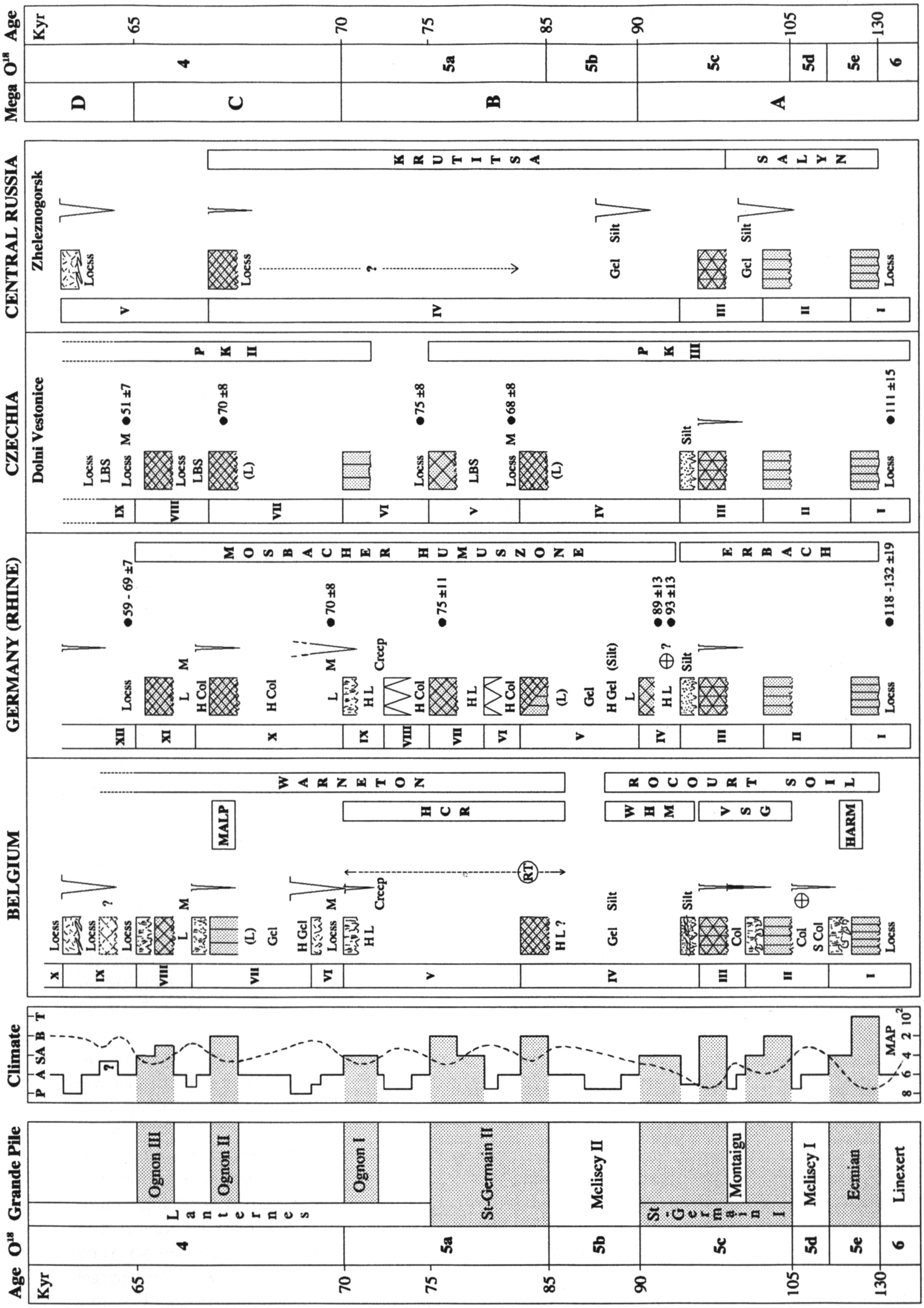

Fig. 6. Integrated pedostratigraphic scheme (from Belgium to central Russia).

Pile (Woillard, 1975; Van Vliet-Lanoë, 1986).

During Melisey I, deep freezing and thawing inducing a firm platy pedality prevailed all over Europe. Further relict features in Western Europe are desiccation cracks in a polygonal network, consolidated horizons and sandy/loamy colluvium deposits. These observations are compatible with features related to the Tardiglacial (Van Vliet-Lanoë & Langohr, 1981) and present-day active permafrost (Mackay, 1974). The depth of the permafrost layer in Belgium during Melisey I possibly varied around 1 m and the mean July and January temperatures were 7 °C and 15 °C lower than nowadays (Guiot, 1990).

The second soil-forming episode of megacycle A is attributed to Saint-Germain I-A. The reactivation of clay mobility is ascribed to a leached soil. It is likely that, during the final stages of Melisey I, thawing processes provided favourable leaching conditions for clay illuviation along the cryogenic structures. Although the soil horizon is similar in all the regional sequences, the leaching was clearly less intense in Eastern than in Western Europe.

Erosion and sedimentation correlated with the Montaigu event (Saint-Germain I-B) end the second soil horizon of megacycle A. At the end of this event, a platy pedality induced by ice lensing was generated again in all regional sequences.

The third soil horizon of megacycle A fits with Saint-Germain I-C. The soil resembles a greyzem and is characterized by black organo-mineral coatings and pupal chambers, revealing intense biological activity. Just like the older soils of megacycle A, the greyzem is attested in all the regional sequences. Since the soil probably formed during the maximum extent of the broad-leaved forest of Saint-Germain I (Woillard, 1978), the corresponding climate must have been continental and characterized by moist summers and an annual precipitation of about 600-700 mm in Western Europe (Guiot, 1990). The average winter temperature did not drop below 0 °C. (Guiot et al., 1992). Cooling of the climate intensified the occurrence of soil characteristics such as platy pedality and pale silt accumulations.

Following this cooling, humiferous aeolian loams were deposited, which have been preserved only in depressions and in bottom-slope position. This sequence confirms the calibrated palaeoclimatic evolution during Saint-Germain I, which suggests an increasing amplitude of the annual temperature curve. Average winter temperatures in Western Europe were about –7 °C, and a decrease in the annual precipitation up to not more than some 500 mm in Western Europe (Guiot et al., 1992) provided drier and therefore unfavourable leaching conditions, which were, however, ideal for humiferous surface building. Astronomical (Berger, 1978) and palynological (Woillard, 1975) data confirm the considered palaeoclimatic evolution.

Megacycle B: Melisey II – Saint-Germain II – Ognon I

At the beginning of megacycle B, the greyzem and the overlying loams were truncated by frost creep over a frozen subsurface horizon (Van Vliet-Lanoë, 1995) or by gelifluction, either of them induced by permafrost conditions. The stratified loamy sediments deposited by gelifluction represent reworked material from the sequence of megacycle A. They are attributed to moist spring seasons and to the melting of an active layer (Van Vliet-Lanoë, 1985). These characteristics are confirmed by palaeoclimatic data. Although precipitation during Melisey II was less than during Melisey I, springtime was considerably moister during the final stages of Melisey II (Guiot et al., 1992). While Melisey I was characterised by cold summers, Melisey II had colder winters (Guiot, 1990). Astronomical calculations of the January and July insolation (Berger, 1978) strengthen this information.

The upper half of megacycle B fits with Saint-Germain II and Ognon I (Woillard, 1975). During Saint-Germain II, soils in Europe became more diversified, ranging from weakly leached to humiferous soils. The existence of weakly leached soils in Western Europe is confirmed by the moist spring seasons at the beginning of Saint-Germain II (Guiot et al., 1992). They are generally formed on a variety of local sediments of colluvial or aeolian origin.

In Western Europe a period of intense freeze desiccation ended these soil-forming processes; deposition of humiferous loams followed and a subarctic soil developed that correponds to Ognon I.

These conclusions led to a reconsideration of a previous interpretation regarding the two-fold 'Humiferous Complex of Remicourt' of the Belgian loess sequence (Haesaerts et al., 1999). Considering the obvious climatic signature of the underlying 'Whitish Horizon of Momalle' and its occurrence in the Rhine sequence (Fig. 6), the Humiferous Complex of Remicourt is now ascribed to the Saint-Germain II and Ognon I interstadials.

Megacycles C and D: Ognon II and III

At the beginning of megacycle C, a thin autochtonous loess, related to stadial II of Lanterne I (Woillard, 1975), occurs as a marker. This marker is covered by stratified, loamy sediments deposited by gelifluction and associated with the first occurrence of ice-wedge pseudomorphs. On top of these sediments two soils separated by a second input of autochtonous loess occur as weakly bleached soils or humiferous soils. They belong to the climatic ameliorations known as Ognon II and III. In Western Europe, these soils are attributed to subarctic conditions, while their East European counterparts are fit with more continental environments and resemble chernozems.

During megacycle D, a so-called tundra-gley with occasional ice-wedge pseudomorphs was formed on the first allochtonous calcareous loess, marking the onset of the early Pleniglacial (MIS 4).

Conclusions

The lower part of the last-interglacial to Early-Glacial loess/paleosol sequences in Europe is characterized by a complex textural B-horizon (megacycle A) that represents three soil processes related to the Eemian and Saint-Germain I (130-90 ka). The evolution of this pedocomplex is remarkably similar in Europe. A first generation of thick clay coatings was disturbed by freezing and thawing. Along the induced cryogenic structures, a second generation of clay coatings is recorded. Following a cold period, a third illuviation, characterized by organo-mineral substances, is observed. During megacycle A, the input of sediments was considerably lower and individual soils belonging to the Eemian (130-115 ka) are therefore restricted to rare geomorphological conditions (Harmignies, Belgium). The Eemian – Saint-Germain I interval is thus characterized by a remarkable stability of landscapes and substrates leading to a distinct predominance of the pedological processes with regard to the erosion/sedimentation events.

Furthermore, the main soil characteristics of megacycle A show a low differentiation from West to East over the whole European loess belt; on the contrary, they show a strong evolution gradient through time: luvisols during Eemian, and weakly leached soils evolving towards greyzems during Saint-Germain I.

During Melisey I and Melisey II, the frost penrated deep enough to allow the formation of a permafrost even in NW Europe. Sedimentation remained local and limited to bottom-slope colluvium mostly in the western part of the European loess belt (Rhine valley and middle Belgium). The continental character of the climate was more pronounced from Melisey II on and stabilised during Saint-Germain II, as shown by chernozems developed on autochtonous aeolian loams, which are almost typical for this time-span. The sediments and soils of megacycle B (90-70 ka) belonging to Saint-Germain II and Ognon I are, indeed, related to increasingly continental and dry climatic conditions. These conditions resulted in a higher variety of soil-forming processes giving weakly leached or strongly humiferous soils. Megacycle C (70-65 ka), which corresponds to Ognon II and Ognon III, comprises two soils and the first indication of glacial loess deposition.

The loess/paleosol sequences from Western Europe to central Russia thus record a reliable and similar palaeoclimatic signal from the Eemian and early glacial. The general trend was one of increasing dry and continental conditions through time. In general, the East European soils indicate somewhat drier and therefore less favourable leaching conditions. This regional climatic variability did not lead to variable soil horizons during megacycle A (130-90 ka). Major differences between the considered regions are observed to a minor extent only during megacycle C (70-65 ka).

Palynological data from La Grande Pile (Woillard, 1978), astronomically calculated insolation rates (Berger, 1979) and calibrated palaeoclimates (Guiot, 1990; Guiot et al., 1992) sustain the recorded sequences and allow a close correlation between vegetation and pedosedimentary information.

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