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Charcoal and wood remains for radiocarbon dating Upper Pleistocene loess sequences in Eastern Europe and Central Siberia

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ABSTRACT

The present paper concerns long Upper Pleistocene loess sequences from Eastern Europe with multiple Upper Palaeolithic occupations, rich in charcoal, as well as loess sequences from Central Siberia with abundant wood remains. These complementary records have allowed establishing a high-resolution climatic sequence integrating 24 interstadial episodes between ca 42.5 and 10 kyr BP. Here, we discuss the methodology of dating used to fix the chronological framework of this climatic sequence, based on a set of 240 available radiocarbon dates, mainly produced on charcoal and wood remains.

Special attention is paid to the strategy of sampling charcoal and wood material in strict accordance with stratigraphy, as well as to the preparation process in the laboratory for extraction, cleaning, identification and selection of the best fragments to date. Careful stratigraphic drawing and detailed positioning of the samples for each geological layer are also considered in order to clarify the relationship of the obtained dates with respect to any sedimentary, pedological or archaeological event to be dated. The reliability and accuracy of the dates obtained from loess sequences are further controlled by the internal consistency with regard to stratigraphy. Palaeoenvironmental implications are also discussed.

1. Introduction

Until recently, the radiocarbon chronology of the climatic events recorded on the Eurasian continent for the Upper Pleistocene, especially the pleniglacial, was still uncertain (Shackleton et al., 2004), despite the high number of radiocarbon dates on bone, charcoal and peaty deposits available from different archives which have been used more or less successfully (van der Hammen, 1995; Djindjan et al., 1999; Conard and Bolus, 2003; Noiret, 2004; van Andel and Davies, 2004; Joeris and Street, 2008).

The interest in loess deposits relates precisely to the possibility of investigating long sedimentary records combining aeolian inputs and palaeosols with high-resolution climatic signals for the period between 42.5 and 10 kyr BP delimited by reliable radiometric dating. The most favourable situations were encountered in Eastern Europe along the Dniester and the Pruth rivers, with the multi-stratified Upper Palaeolithic sites rich in charcoal of Molodova V, Mitoc and Cosautsi, but also in Central Siberia along the Yenisei, with the middle pleniglacial record of Kurtak which contains abundant wood remains. By combining detailed stratigraphy and radiocarbon dates, the integration of these 4 complementary sequences has led to the reconstruction of a well documented climatic record for the period between 42.5 and 10 kyr BP. It encompasses some 24 interstadial episodes, with a strong chronology based on some 240 available radiocarbon dates, mainly on charcoal and wood remains (Haesaerts et al., 2003, 2005, 2009).

In the present paper we discuss the fundamental question regarding the reliability and reproducibility of the dates which have contributed to establishing the chronological framework of the above mentioned 4 key loess records. Special attention is paid to each step of the dating process, from field work to measurements, implementing adequate laboratory treatment. Moreover, identification of the charcoal and wood remains provides not only useful information on the past environment but also a means for controlling the homogeneity of the material to date. The reliability and accuracy of the dates gained from loess sequences is further controlled by the internal

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consistency of their distribution with regard to stratigraphy. Another important aspect lies in the discussion of the relationship between the age of the dated material and the geological or archaeological occurrences to be dated, an approach mainly taken into consideration during the last decade (Oliva, 2000; Bertran, 2004; Texier et al., 2004). This point also relates to the chronological framing of the pedo-sedimentary and climatic markers which reinforce the proxy-correlation schemes linking the climatic signatures of the loess and the Greenland ice records (Haesaerts et al., 2009).

2. Materials and methods

2.1. Sampling charcoal and wood from loess for dating

Material selected for dating was mainly macrocharcoal (from 0.25 mm up to a few cm) and wood considered as the most suitable material for radiocarbon dating (Mook and Waterbolk, 1985; Bird, 2007; Carcaillet, 2007). Charcoal in loess deposits was found in two situations. In the first one, charcoal was associated with archaeological occurrences, either *in situ* or derived from hearth. Focus was placed on charcoal concentrations in order to better control the homogeneity and stratigraphic position of the sample with a minimal risk of mixing material from different stratigraphic levels. In the second situation, the fossil material was found as non-reworked cluster(s) in geological layers without any trace of human activity. Such material has been interpreted as the result of wildfires (Damblon and Haesaerts, 2002; Haesaerts et al., 2003). In both situations, sample collection was done on vertical sections in order to track any feature of the lithology and geometry of the deposits, and thus to ensure the precise positioning of the sample within the stratigraphy. In various cases, collecting charcoal at the top, middle and bottom of a humic layer was shown to be very informative about the time-slice of the recorded event as exemplified in Section 3.3.3. In this way, working on vertical sections enabled thorough understanding of the sedimentary dynamics and the connection between the pedosedimentary event and the material to date.

2.2. Laboratory handling

In the perspective of achieving the best dating possible, handling loess samples with charcoal or wood in the laboratory had different aims: 1) extract charcoal or wood fragments from the sediment sample and clean them from the mineral matrix; 2) detect and remove any visible contaminant, mainly rootlets; 3) identify and count the taxa to control the homogeneity of the sample; 4) estimate the preservation state of the fragments; 5) select the best fragments for dating.

The procedure for charcoal extraction involves drying the bulk sample before dispersion in water, potentially with pyrophosphate, sieving at 1, 1/2 and 1/4 mm, chemical treatment by HF, HCl, and rinsing in distilled water (Damblon et al., 1996, Damblon and Haesaerts, 2002). For some charcoal material, a supplementary attack with aqua regia ($HNO_3 + HCl$) was necessary to remove iron oxides and hydroxides. Many contaminants, mainly rootlets, were detected under the binocular and microscope, leading to removal of the contaminant or exclusion of the contaminated pieces (Damblon et al., 1996; Damblon and Haesaerts, 2002).

The homogeneity of a sample was centred on conifers and boreal taxa (*Betula*, *Salix*) in order to avoid any possible intrusive mixing with Holocene material. Only well identified fragments were used for dating. Usually, a large number of fragments were selected from the charcoal concentrations collected in the field. In addition to wood charcoal, charred remains of seeds, fruits, needles and grass epidermis were also recovered locally.

The amount of selected fragments depends on the sample size and the dating method. Naturally, for conventional dating with a gas proportional counter, the number of fragments must be high in order to contain a minimum of 2.5–3 g of carbon. For AMS dating, we tried to obtain a minimum of 100 mg of carbon. In general, small fragments (0.5–5 mm) were selected as they were easier to control for purity than the biggest ones. Considering the sites and the material in stake, three laboratories (Groningen, Oxford, Novosibirsk) contributed to dating good quality charcoal material.

Concerning the samples of wood found exclusively in the sequence of Kurtak (Central Siberia), their preservation state was very good so that preparation of the material for dating was limited to strong washing in distilled water and removing rootlet contaminants, leaving all further steps of chemical pre-treatment to the ^{14}C laboratories (Acid–Base–Acid procedure in the Novosibirsk and Groningen laboratories).

All of the radiocarbon dates are presented in ^{14}C years BP with 1σ measurement uncertainty, but without any calibration. This does not prevent from establishing correlation with the climatic sequence of the Greenland ice record which is actually disconnected from ^{14}C time scale calibration (Reimer et al., 2004; Blockley et al., 2008; Haesaerts et al., 2009; Reimer et al., 2009).

3. The East Carpathian Area

3.1. General setting

Unlike North-western Europe where charcoal is seldom preserved in the loess (Haesaerts et al., 1981; Haesaerts, 1985; Schirmer, 1990; Bosinski, 1995; Antoine et al., 1999, 2003), multi-stratified Palaeolithic sites rich in charcoal are frequent in Central and Eastern Europe (Otte, 1981; Kozlowski, 1986). For the Middle Danube Basin (Fig. 1), the best documented sites are known in Lower Austria (Neugebauer-Maresch, 1999; Haesaerts et al., 2007; Nigst and Haesaerts, in press) and Moravia (Valoch, 1976; Svoboda et al., 1994; Svoboda and Bar-Yosef, 2003; Valoch, 2008; Richter et al., 2009). They provide a reference sequence for the period between ca 43 and 25 kyr BP, with at least four interstadial episodes (Haesaerts et al., 1996; Svoboda et al., 1996). However, in this area solifluction processes often hamper the positioning of the charcoal occurrences with regard to the climatic events to be dated (Klima, 1963, 1995; Oliva, 2000; Haesaerts et al., 2004). Furthermore, the chronological context of the late pleniglacial loess cover is poorly documented due to the limited number of Palaeolithic sites as well as the lack of charcoal after 23 kyr BP (Svoboda et al., 1996; Neugebauer-Maresch, 1999; Haesaerts et al., 2004, 2007).

The best conditions were found east of the Carpathians, on the Moldavian Plateau, where Palaeolithic settlements are abundant in the loess cover along the Pruth and Dniester valleys (Morosan, 1938; Chernysh, 1959, 1973; Bogutski and Lanczont, 2002; Noiret, 2004, 2009) which represented one of the main migration routes for large herbivores between the Baltic Area and the steppe plains around the Black Sea during the last glacial period (Haesaerts et al., 2003). On the other hand, the proximity of the Carpathian foothills generated the conditions needed for persistence of wooded corridors along the main rivers, even during the late pleniglacial (Ivanova, 1977, 1987; Pashkevich, 1987; Velichko, 1992). This specific landscape, together with access to high-quality flint, was most probably one of the main reasons for the semi-continuous occupation of this region by Palaeolithic hunter-gatherers during middle and late pleniglacial (Ivanova, 1987; Haesaerts et al., 2003, 2007). In the early 1990s, three key sites with long loess sequences and multi-stratified Palaeolithic occupations were still easily accessible along the Dniester and Pruth valleys. Located on the external part of the terrace systems, these sites acted as sediment traps at different periods of the Upper Pleistocene (Figs. 2 and 3). Molodova, on a 20 m terrace along the Ukrainian bank of the Dniester, provided a detailed sequence for the Upper Pleistocene (Ivanova, 1987). Mitoc-Malu Galben, on the second

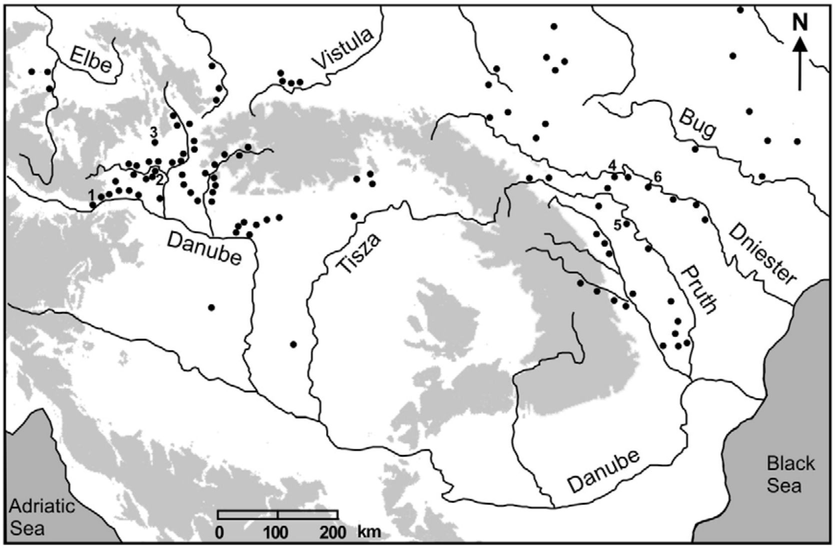


Fig. 1. Distribution of the main Upper Palaeolithic sites in Central and Eastern Europe and location of the sites discussed in the text: 1) Willendorf; 2) Dolni Vestonice; 3) Bohunice and Stranska Skala (Brno); 4) Molodova; 5) Mitoc-Malu Galben; 6) Cosautsi.

terrace of the Pruth in North-eastern Romania, recorded the final part of the middle pleniglacial and the first half of the late pleniglacial (Chirica, 2001; Otte et al., 2007). Finally, Cosautsi, on top of the first terrace along the Moldavian bank of the Dniester, provided a high-resolution stratigraphic succession encompassing the second part of the late pleniglacial and the Lateglacial (Borziac, 1993).

3.2. Stratigraphic background

Each of these Palaeolithic sites gives access to a ±15 m thick stratigraphic succession with numerous cultural layers rich in charcoal (Fig. 3). They were excavated over large surfaces, and allowed strict control of the lateral continuity of most of the loess layers and pedologic horizons over long distances. In this context, the palaeoclimatic approach is based on diagnosis of sedimentary and pedologic processes, with special attention to periglacial features, as well as pollen and faunal data when available. Bleached horizons of tundra gley type were related to episodes of deep frost or permafrost conditions (Haesaerts and Van Vliet-Lanoë, 1981; Antoine et al, 2002). On the other hand, humic horizons, from chernozem-type to incipient bioturbated type, were ascribed to interstadial episodes ranging from boreal to subarctic conditions (Ivanova, 1987; Gubin, 1987; Pashkevich, 1987; Adamenko, in Borziac, 1993; Haesaerts et al., 2003; Becze-Deak et al., 2007).

By comparing the loess sequences of Molodova, Mitoc-Malu Galben and Cosautsi, it was possible to draw correlation links between them and to establish a synthetic regional climatic sequence (Haesaerts et al., 2003, 2007). This approach was based on the distribution of the main lithological bodies and on the sequential distribution of pedological markers, the consistency of the system being reinforced by the long series of radiocarbon dates at disposal (Haesaerts et al., 2003). As shown in Fig. 3, at Molodova and Mitoc both sequences cover the period between ca 33 and 20 kyr BP, whereas the second half of the late pleniglacial and the Lateglacial are recorded at Cosautsi.

3.2.1. The middle pleniglacial (between ca 45 and 26 kyr BP)

At Molodova, the period prior to ca 33 ka BP, is recorded by two loess bodies (units 7 and 9) framing the lower pedocomplex (unit 8) which consists of three humic horizons from reddish brown chernozem-type to para rendzina-type (subunits 8.1 to 8.3). The chronological context of units 7 to 9, probably between ca. 45 and ca. 33 kyr BP, could not be precisely established due to a lack of suitable organic material for radiocarbon dating. The upper part of the middle

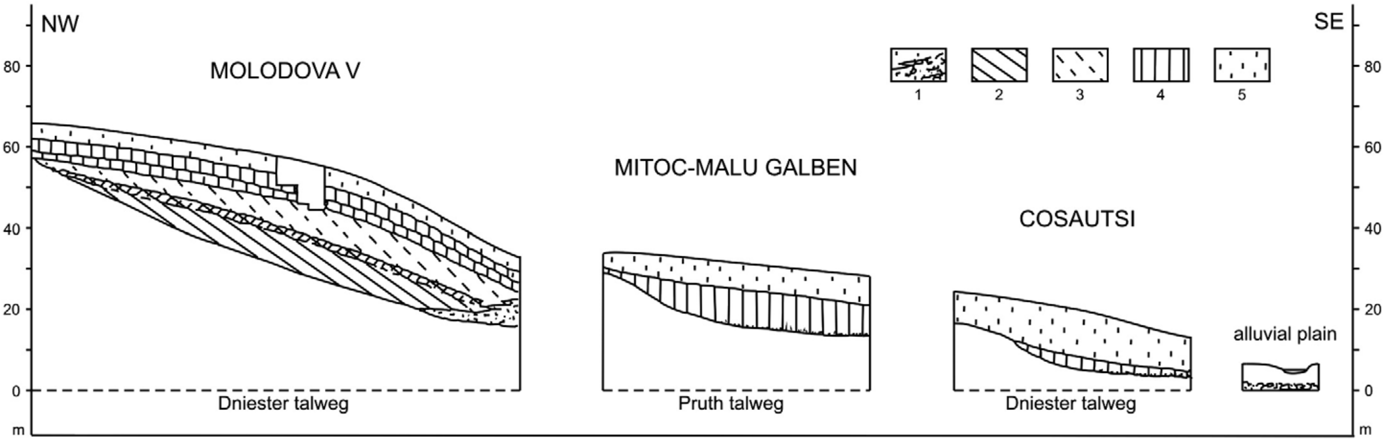


Fig. 2. Geomorphological background of Molodova V, Mitoc-Malu Galben and Cosautsi (East Carpathian Area). Graphic symbols: 1) fluviatile gravels; 2) early glacial deposits (Molodova V: units 1 to 4); 3) early pleniglacial loamy loess (Molodova V: unit 5); 4) middle pleniglacial loess–palaeosols (Molodova V: units 6 to 10; Mitoc: units 13 to 7); 5) late pleniglacial and Lateglacial loess (from Haesaerts et al., 2003).

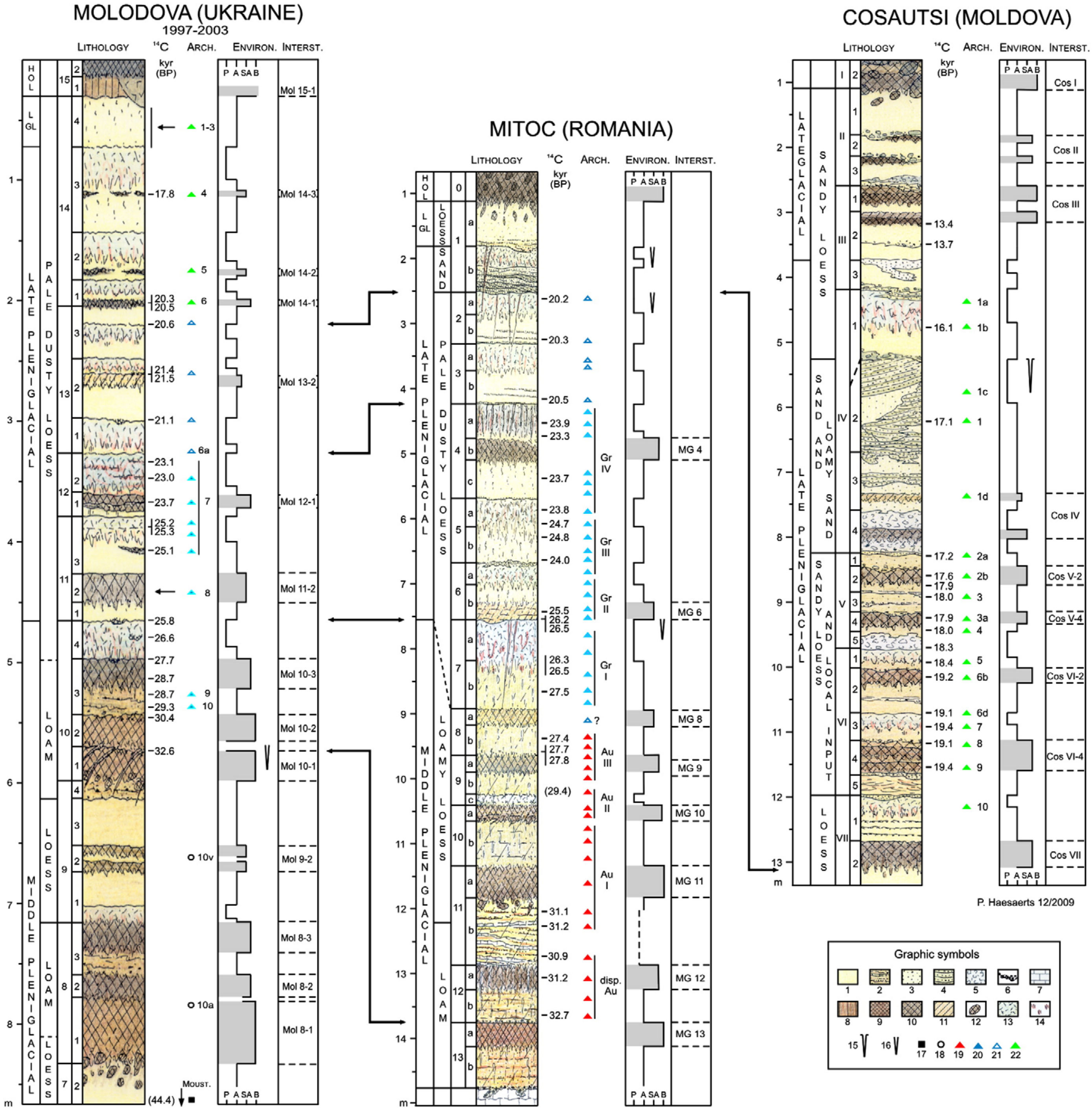


Fig. 3. Main stratigraphic sequences of the East Carpathian Area. Graphic symbols for Figs. 3 to 9: 1) loess; 2) loam; 3) silty sand; 4) sand; 5) chalky flow; 6) gravel; 7) limestone; 8) illuviated horizon (B2); 9) strong humic horizon; 10) weak humic horizon; 11) yellowish brown bioturbated horizon; 12) krotovinas; 13) bleached horizon (tundra gley): 14) iron staining; 15) ice wedge cast; 16) frost wedge; 17) Mousterian; 18) transitional industries; 19) Aurignacian; 20) Gravettian; 21) poorly documented Upper Palaeolithic 22) Epigravettian. Abbreviations: Arch: archaeology; Environ: environment; P: periglacial, with deep frost or permafrost conditions; A: arctic; SA: subarctic; B: boreal; interst: interstadials; Mol: Molodova; MG: Malu Galben; Cos: Cosautsi; Gr: Gravettian; Au: Aurignacian; disp Au: dispersed Aurignacian; Molodova: upper half of the sequence (modified from Haesaerts et al., 2007).

pleniglacial is best recorded at Mitoc-Malu Galben at the bottom of a steep talus (Figs. 2 and 3). Here, a set of loamy and loess-like deposits well-dated from 32.7 to 26 kyr BP, shows a succession of six humic horizons ranging from brown chernozem-type (top of unit 13) to incipient bioturbated type (top of unit 8). The upper loess-like deposit (unit 7) is capped by a thick tundra gley (dated around 26 kyr BP) which occurs as a marker horizon underneath the first late pleniglacial loess cover (units 6 to 4). In this sequence, Aurignacian cultural layers are almost equally distributed from the base of unit 12, to the mid part of unit 8, the first Gravettian assemblages occurring at the base of unit 7. At Molodova, the 1.5 m thick pedocomplex of unit 10, with a consistent set of radiocarbon ages from 32.6 to 25.8 kyr BP, records two brown chernozem-type horizons (sub-units 10-1 and 10-2) and a para rendzina horizon (sub-unit 10-3) caped by a tundra gley (sub-unit 10-4). This succession appears to be coeval to units 13 to 7 at Mitoc. At Molodova, no Aurignacian has been encountered, and cultural layers 10 and 9 related to subunit 10-3 have been ascribed to the Gravettian.

Table 1
Charcoal taxa identified in the loess sequences investigated in the East Carpathian Area and Central Siberia. Legend. Countries, Ro: Romania; Mo: Moldavia; Uk: Ukraine; Ru: Russia. Basins. Pr: Pruth; Dn: Dniester; Y: Yenisei. Materials. W*: wood; C: charcoal; N: needle; F: fruit; S: seed; L: leaf; R: root. Periods. Up: upper pleniglacial; Mp: middle pleniglacial.

		East Carpath.			Central Sib.	
	Countries	Uk	Ro	Mo	Ru	
	Basin	Dn	Pr	Dn	Y	
Material	Sites	Molodova V	Mitoc-Malu Galben	Cosautsi	Kurtak Kammini Log	Kurtak Chani P31
C/W*	*Picea sp.*	Mp Lp	Mp Lp	Lp	Mp	Mp*
N	*Picea obovata*	–	–	–	Mp	Mp
C	*Picea/larix*	Mp	–	Lp	Mp	–
C	*Larix/picea*	Mp Lp	–	–	Mp	–
C	*Larix* sp.	–	–	–	Mp	–
C	*Juniperus* sp.	–	Mp	–	–	–
C	*Pinus t. cembra*	Mp Lp	Lp	Lp	Mp	Mp
C	*Pinus t. sylvestris*	Mp Lp	–	–	–	–
C	*Pinus sp.*	–	–	–	–	–
C	*Betula sp.*	–	Mp Lp	–	–	Mp
C	*Salix sp.*	–	–	Lp	Mp	Mp
C	*Populus sp.*	–	–	–	–	Mp
C	*Alnus / Duschekia*	–	Mp Lp	–	–	–
C	*cf. Rubus*	–	–	Lp	–	–
F	Apiaceae	–	Lp	–	–	–
F	*Galium*	–	Lp	–	–	–
S	Caryophyllaceae	–	Lp	–	–	–
F	*Polygonum aviculare*	–	Lp	–	–	–
S	*Medicago*	–	Mp	–	–	–
F, L	Poaceae	Lp	Mp Lp	–	Mp	Mp
F	cf. Cyperaceae	–	Mp Lp	–	–	Mp
R	unidentified	–	Mp Lp	–	–	–

Legend
Countries. Ro: Romania; Mo: Moldavia; Uk: Ukraine; Ru: Russia.
Basins. Pr: Pruth; Dn: Dniester; Y: Yenisei.
Material. W*: wood; C: charcoal; N: needle; F: fruit; S: seed.
L: leave; R: root.
Periods. Lp: late pleniglacial; Mp: middle pleniglacial.

3.2.2. The first part of the late pleniglacial (26 to 20.5 kyr BP)

This period encompasses two bodies of pale loess: respectively units 11 to 13 at Molodova and units 6 to 2 at Mitoc. The first loess body, related to the main Gravettian occupations between ca 25.5 and 23 kyr BP, records a cold but still rather humid climatic context. It shows two distinct humic horizons (subunits 11-2 and 12-1 at Molodova and subunits 6a and 4b at Mitoc) alternating with several tundra gleys. The upper gley shortly after 23 kyr BP occurs as a second marker horizon at both sites. The second loess body (respectively unit 13 and units 3 and 2) dated between ca 22 and ca 20.5 kyr BP, reflects a much drier environment (Motuz, 1987; Prepelitza, 2007), with several light tundra gleys which frame an incipient bioturbated horizon at Molodova (subunit 13-2). At both sites, only scattered poorly documented lithic assemblages are related to this period.

3.2.3. The second part of the late pleniglacial and the Lateglacial (20.5 to 10 kyr BP)

At Molodova, the upper part of the loess cover (unit 14) with a thin para rendzina-type horizon at the base, dated around 20.4 kyr BP (subunit 14-1), makes the link with the Cosautsi sequence preserved on top of the first terrace of the Dniester. The first part of this sequence (cycles VII to V) records a 5-meter thick succession of sandy loess, local loamy deposits with rill-wash structures and chalky flows, indicative of a rather humid climatic environment, including a unique set of 15 Epigravettian cultural layers well-dated between 19.4 and 17.2 kyr BP. This succession encompasses a para rendzina-type horizon slightly prior to 19.4 kyr BP (subunit VII-2), followed up by two doublets of humic horizons of decreasing intensity (subunits VI-4, VI-2, V-4 and V-2) which frame a cold episode with tundra gley and chalky flow dated around 18.4 kyr BP (subunits VI-5 and V-1). The middle part of the Cosautsi sequence (unit IV) shows a clear trend to extreme climatic conditions preceded by two weakly developed para rendzina-type horizons subunits IV-4 and IV-3). This drastic change is illustrated by the predominance of sandy deposits partly fed by the Dniester alluvial fan, as well as by two episodes of permafrost marked respectively by ice-wedge casts (top of subunit IV-2) and a well-developed tundra gley slightly posterior to 16 kyr BP (top of subunit IV-1). Finally, subunits III and II which record the Lateglacial, are

Table 2
Molodova V. The radiocarbon dates distributed by lithological sub-unit. Abbreviations: C.L.: cultural layer, ch.: charcoal. Double dating on the same sample is indicated by vertical line.

Number	Lithol. subunit	C.L.	Number date	^{14}C age (BP)	Material/ taxon
Dates 1997–2003					
1	14-3	4	GrA-9433	17,770 ± 110	bone
2	14-1	6	GrA-22904	20,470 ± 110	*Pinus ch.*
3	14-1	6	GrN-23575	20,320 ± 210	*Pinus ch.*
4	13-3	–	GrA-13857	20,610 ± 110	*Pinus ch.*
5	13-3	–	GrA-22904	20,630 ± 110	*Pinus ch.*
6	13-2	–	GrA-22905	21,410 ± 110	*Pinus ch.*
7	13-2	–	GrA-13858	21,540 ± 120	*Picea ch.*
8	13-1	–	GrA-13860	21,070 ± 120	*Picea ch.*
9	13-1	–	GrN-24483	20,840 ± 310	Bone
10	12-2	–	GrN-27614	23,120 ± 330	*Pinus ch.*
11	12-2	7	GrA-9443	21,070 ± 150	Horse bone
12	12-2	7	GrN-23801	150 ± 80	Carbonates
13	12-2	7	GrA-9455	23,000 ± 170	*Pinus ch.*
14	12-1	7	GrA-22909	23,650 ± 140	*Picea ch.*
15	11-3	7	GrA-9457	25,170 ± 210	*Pinus ch.*
16	11-3	7	GrA-9458	25,280 ± 210	*Pinus ch.*
17	11-3	7	GrA-9564	25,130 + 220–200	*Picea ch.*
18	10-4	–	GrN-23577	25,730 ± 200	*Pinus ch.*
19	10-4	–	GrA-9435	25,760 ± 150	*Pinus ch.*
20	10-4	–	GrN-23574	26,640 ± 300	*Picea ch.*
21	10-4	–	GrA-13299	27,700 + 270–260	*Picea ch.*
22	10-3	–	GrN-23578	28,730 ± 250	*Picea ch.*
23	10-3	–	GrA-9438	28,590 ± 170	*Picea ch.*
Dates 1997–2003					
24	10-3	9	GrN-27613	28,700 + 580–540	*Larix/Pic.ch.*
25	10-3		GrA-23198	29,370 ± 280	*Larix-t. ch.*
26	10-2	–	GrN-23576	30,420 ± 300	*Picea ch.*
27	10-1	–	GrN-24714	32,590 + 580–540	*Larix/Pic.ch.*
Dates Ivanova 1987					
28	14	1	GIN-54 a	10,940 ± 150	Colloïds
29	14	1a	GIN-54 b	10,590 ± 230	Bone
30	14	2	GIN-8	11,900 ± 230	Bone
31	14	2	GIN-56	12,300 ± 140	Colloïds
32	14	3	GIN-9	13,370 ± 540	Charcoal
33	14	4	GIN-147	17,000 ± 1400	Charcoal
34	14	5	GIN-52	17,100 ± 180	Charcoal
35	14	6	GIN-105	16,750 ± 250	Charcoal
36	12	7	Mo-11	23,000 ± 800	Charcoal
37	12	7	GIN-10	23,700 ± 320	Charcoal
38	11	8	LG-14	> 24,000	Charcoal
39	10	9	LG-15	28,100 ± 1000	Charcoal
40	10	9	LG-15	29,650 ± 1320	Charcoal
41	6	11a	LGU	> 35,000	Charcoal
42	6	11	GrN-4017	> 40,300	Charcoal
43	6	12	LG-17	> 45,600	Charcoal

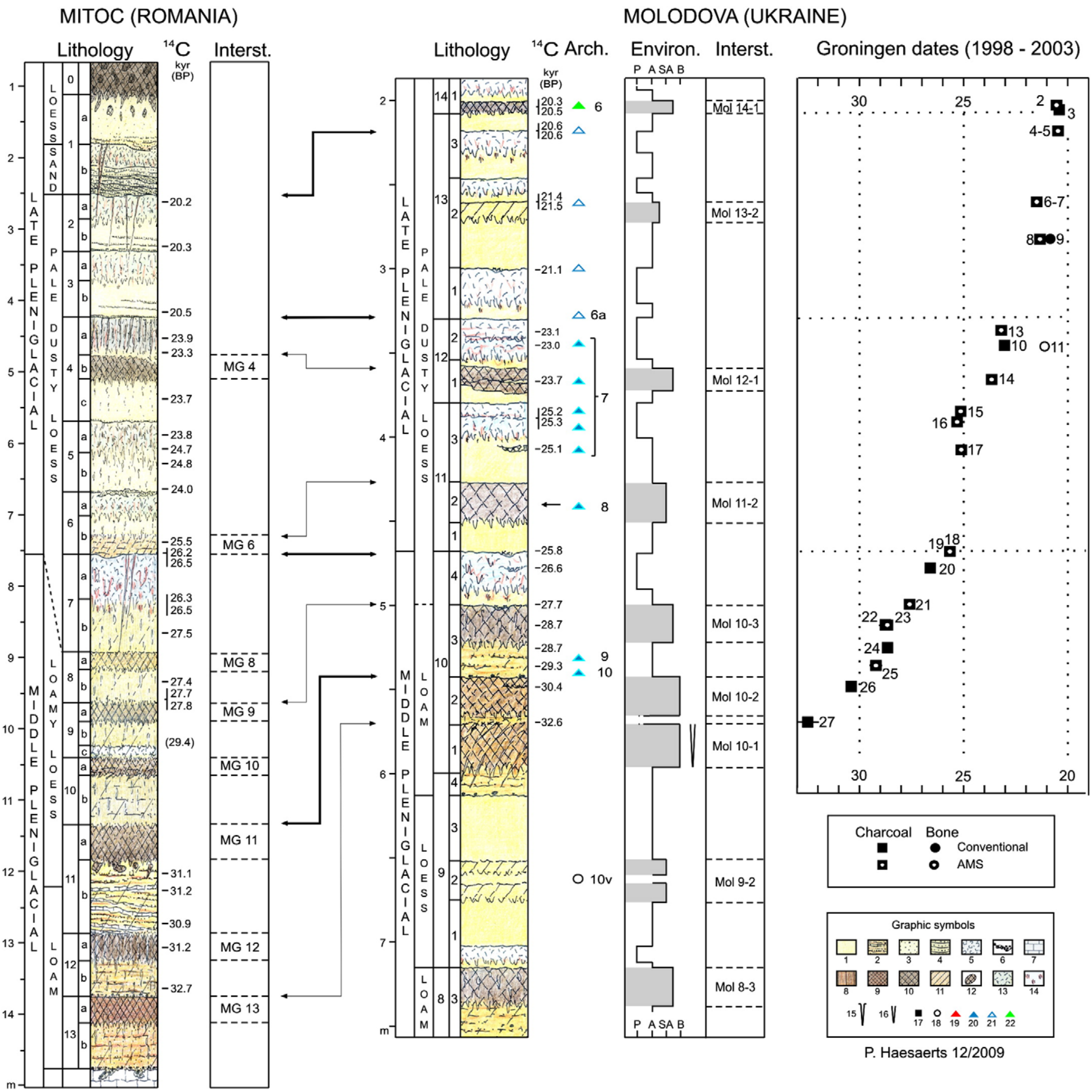


Fig. 4. Molodova V. Distribution of the radiocarbon dates with respect to stratigraphy and time scale and comparison with Mitoc-Malu Galben.

Table 3
Molodova V. Different parallel dating on the same sample (A) or the same layer (B).

Litholog. sub-unit	Number Sample	Number date	^{14}C age (BP)	Taxon	Number Sample	Number date	^{14}C age (BP)	Taxon
A) conventional and AMS dating on the same sample								
10-4	18	GrN-23577	25,730 ± 200	*Pinus*	19 du	GrA-9435	25,760 ± 150	*Pinus*
10-3	22	GrN-23578	28,730 ± 250	*Picea*	23 du	GrA-9438	28,590 ± 170	*Picea*
B) dating different samples from the same layer								
14-1	2	GrA-22904	20,470 ± 110	*Pinus*	3	GrN-23575	20,320 ± 210	*Pinus*
13-3	4	GrA-13857	20,610 ± 110	*Pinus*	5	GrA-22904	20,630 ± 110	*Pinus*
13-2	6	GrA-22905	21,410 ± 110	*Pinus*	7	GrA-13858	21,540 ± 120	*Picea*
11-3	15	GrA-9457	25,170 ± 210	*Pinus*	16	GrA-9458	25,280 ± 210	*Pinus*

characterized by the restart of semi-continuous aeolian sedimentation, shortly prior to 13.8 kyr BP, with the deposition of two bodies of sandy loess framing a set of four para rendzina-type horizons (subunits III-2, III-1, II-3 and II-2).

3.3. Molodova V (South-western Ukraine)

3.3.1. The site

Molodova is situated ca 50 km to the east of Chotin, on the southern slope of the deep valley cut by the Dniester through Cretaceous chalk and Palaeozoic bedrock. Excavated by a Russian team from 1965 to 1985 (Chernysh, 1973, 1987; Ivanova and Tzeitlin, 1987), the Palaeolithic site of Molodova V has provided a ca 25 m thick Upper Pleistocene sequence preserved on the 20 m terrace, encompassing a complex series of Middle and Upper Palaeolithic layers. The excavation pit covers an area of 40 × 20 m and cuts through the upper part of the loess cover to a depth of 12 m; it records a complex stratigraphy overlying ca 4 m of early pleniglacial loamy loess encountered in test pits (Figs. 2 and 3). This succession described in 1987 by Ivanova and Gubin consists of seven sandy loess bodies (units 6 to 14) and 2 humic pedocomplexes (units 8 and 10). From 1997 to 2002, a nearly identical pedo-sedimentary succession was recorded by our team at the site, together with complementary sampling for radiocarbon dating, after cleaning of the remaining sections (Haesaerts et al., 2003).

3.3.2. Charcoal data

The diversity of taxa appears rather low in the sequence of Molodova (Table 1). Only charcoal of *Picea, Larix/Picea and Pinus* (*cembra*- and *sylvestris*-types) were found in the middle and late pleniglacial deposits with spruce somewhat more frequent in the pedocomplex of unit 10. Some scattered charred fragments of grass were also found in the upper part of the loess cover (base of unit 14). All charcoal concentrations in the late pleniglacial loess bodies were taken from archaeological layers (Haesaerts et al., 2003). Charcoal was present both in tundra-gleys and in humic horizons. On the contrary, charcoal in the middle pleniglacial pedocomplex of unit 10 formed clusters free of artefacts, except in colluvium 10-3 that contained a few shifted remains from Gravettian layers 10 and 9 (Chernysh, 1987; Ivanova, 1987). We thus assume that the charcoal clusters in the pedocomplex 10 were the consequence of wildfire. From this it follows that no fundamental difference between the charcoal assemblages from human occupations and wildfire traces really exists.

3.3.3. Radiocarbon dates

Some 43 radiocarbon dates are available for the loess sequence of Molodova V (Table 2). An initial set of 16 dates was published by Ivanova (1987) on unidentified charcoal, bone and colloids. These were obtained essentially from units 10 to 14 and range from 30 to 10.9 kyr BP. Between 1997 and 2003, a large set of charcoal and bone samples was recovered from the late pleniglacial loess cover (units 11 to 14) and from the middle pleniglacial pedocomplex (unit 10), providing 27 new radiocarbon dates. Here, only these 27 dates will be taken into account because some doubt subsist on the precise stratigraphic origin and the quality of the previous dates (Haesaerts et al., 2003). The new radiocarbon ages range from 32.6 kyr BP on top of subunit 10-1 to about 17.8 kyr BP in subunit 14-3. The distribution of the ages in the time scale (Figs. 3 and 4) shows a progressive and consistent trend almost without inversion of dates. In the pedocomplex of unit 10, the ages grade from 32.6 to 25.8 kyr BP. The grading of the ages is also progressive for the late pleniglacial, between 25.3 and 17.8 kyr BP, but increases in relation to loess deposition. It should be noted in Table 2 that the ^{14}C age on a horse bone (date number11) in subunit 12-2 appears ca 2000 yr younger than the ^{14}C ages on charcoal. This is probably due to some contamination of collagen by humics (Lanting and van der Plicht, 1994; Bronk Ramsey, 2008) or to possible interaction with secondary carbonates (date number12).

It is worth pointing out the reproducibility of the ^{14}C ages at different levels. Six examples in the Molodova V sequence are discussed in order to demonstrate the quality of the results (Table 3). Initially, it was useful to test the dates by conventional and AMS dating on the same sample composed of a large number of charcoal fragments (duplos). As shown in Table 3a (dates number 18–19duplo and 22–23duplo), the results are very conclusive within the limits of 1σ uncertainty. On one hand, this confirms that conventional and AMS dating give the same results on good charcoal material and on the other hand, the homogeneity of the charcoal samples regarding the radiocarbon age of the fragments is attested.

In a second step, the opportunity to test the reproducibility of dating charcoal of different concentrations from the same layer was found in subunits 14-1, 13-3, 13-2 and 11-3, each of these subunits providing two charcoal clusters at a distance of around 10 m (Table 3b, dates number 2–3, 4–5, 6–7 and 15–16). These tests show three facts: 1) AMS dates on the same taxon from the same layer (number 4–5 and 15–16) give similar ages; 2) AMS dates on different taxa from the same layer (number 6–7) give comparable ages; 3) both AMS and conventional dates on the same taxon from the same layer (number 2–3) give similar ages. The conclusion lies in the reliability and accuracy of the ^{14}C dates obtained for the sequence of Molodova V during the campaign 1997–2002. The reliability of the results is further ensured by the distribution of the charcoal concentrations which appear clearly separated by sterile loess layers.

In the sequence of Molodova V, most of the dated charcoal clusters within the pedocomplex 10 appear independent of any human activity and are rather the result of wildfire. Their distribution enables a consistent approach of the time succession of the different events consisting in four sedimentary episodes, each of them being followed by the development of a pedological horizon. In the present situation, we may consider that charcoal clusters preserved inside the pedological horizons of subunits 10-2, 10-3, 10-4 belong to the sedimentation phase while charcoal clusters at the top of the pedological horizons of subunits 10-1, 10-3 and 10-4 probably relate to wildfire at the end of the soil development. Consequently, the radiocarbon dates available for pedocomplex 10 allow the distribution of the pedosedimentary events through time to be determined. The pedogenesis of brown chernozem-type in subunit 10-1 probably ends around 32.6 kyr BP. It is followed by a cold episode marked by frost wedges. The second pedogenesis of brown chernozem-type developed from the top of subunit 10.2 in between 30.4 and 29.3 kyr BP. Similarly, the para rendzina-type soil in subunit 10.3 developed shortly after 28.7 up to 27.7 kyr BP. Finally, the development of tundra gley on top of 10.4 is probably bracketed between 26.6 and 25.8 kyr BP. Altogether, the distribution of the ^{14}C ages in the pedocomplex 10 does not provide a precise evaluation of duration of the pedogeneses, but enables them to be placed in time spans of about 1–2 millennia.

By contrast, the duration of the climate events appears shorter during the late pleniglacial as suggested by the distribution of the dates in the successive layers of Molodova. Examples are given by the position of the dates in the tundra-gleys in subunits 11-3, 12-2, 13-1 and even in the succession of the dates which occur close together from 13-1 upward. This appears as a result of rapid accumulations of loess bodies followed by short stabilization phases of a few centuries under cold and wet conditions.

3.4. Mitoc-Malu Galben (North-eastern Romania)

3.4.1. The site

Mitoc is situated ca 90 km south of Molodova, along the Romanian bank of the Pruth (Fig. 1). The Palaeolithic site Malu Galben, located on the second terrace, acted as a sediment trap during part of the middle and late pleniglacial. This situation gave way to the deposition

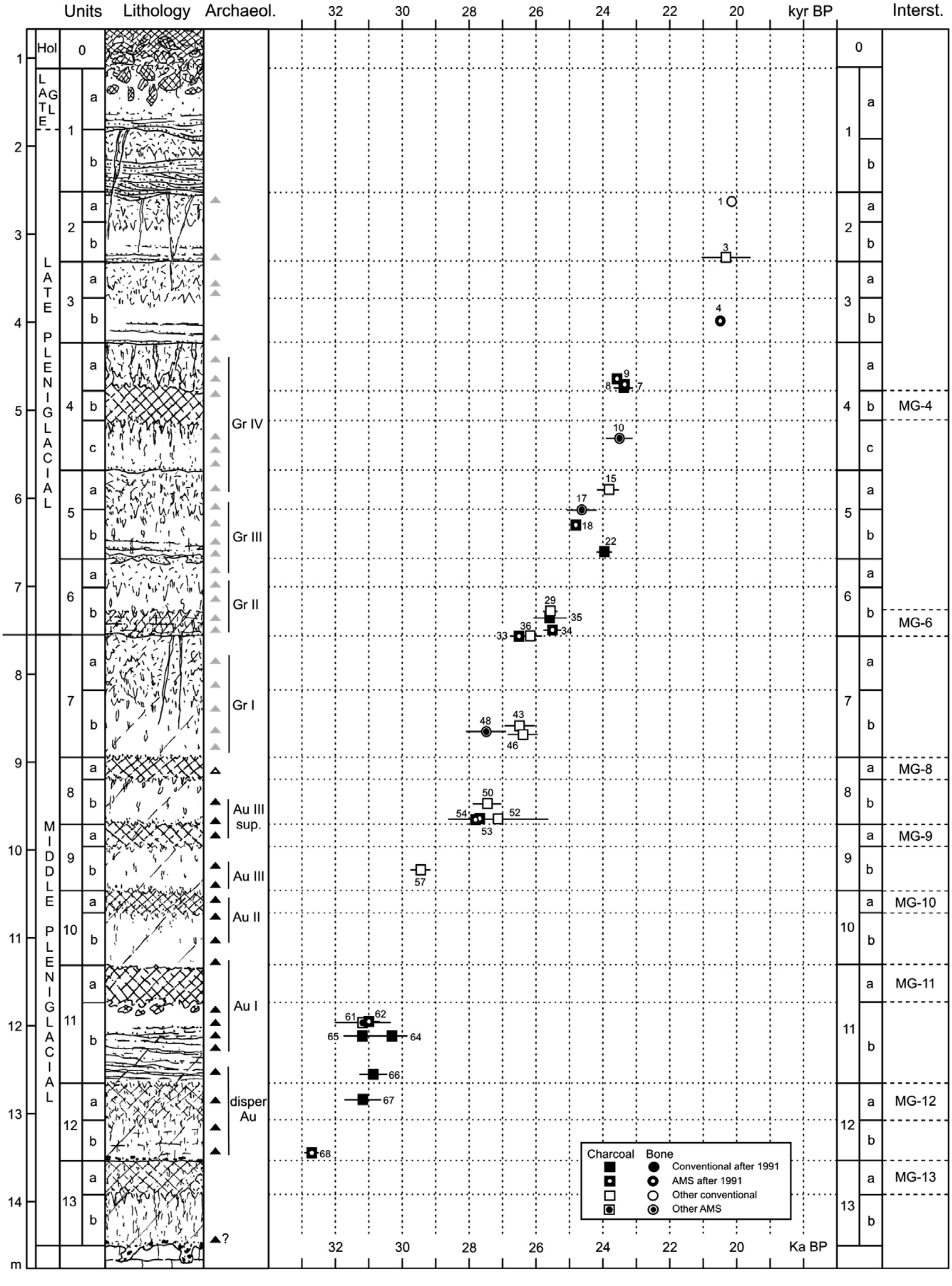


Fig. 5. Mitoc-Malu Galben. Distribution of the selected radiocarbon dates with respect to stratigraphy and time scale.

Table 4
Mitoc-Malu Galben. Radiocarbon dates distributed by lithological unit. The dates are presented in two sets following the excavations made by archaeologists before 1991 and after 1991 under stratigraphic and anthracological control. Abbreviations, bef.: before, aft.: after. Numbers in brackets: dates not kept after screening. Vertical lines: dating on the same sample; only the oldest date was taken into account.

				Dates before 1991		Dates after 1991		
Number bef.91	Number aft.91	Litholog. subunit	Number date	^{14}C age (BP) ± 1σ	Dated material	^{14}C age (BP) ± 1σ	Dated material	Taxon
1	–	2a	GrN-13765	20,150 ± 210	Bone	–	–	–
–	(2)	2b base	GrA-8399	–	–	17,460 + 140–130	Bone	Unidentifiable
3	–	2b base	GrN-14031	20,300 ± 700	charcoal	–	–	–
–	4	3b	GrA-5000	–	–	20,540 ± 110	tine	*Rangifer*
–	(6)	3b base	GrA-8243	–	–	19,100 ± 120	Bone	Unidentifiable
–	7	4a base	GrA-14671	–	–	23,290 ± 100	Charcoal	*Picea*
–	8	4a base	GrN-20438	–	–	23,390 ± 280	Charcoal	*Picea*
–	9	4a base	GrA-1353	–	–	23,850 ± 100	Charcoal	*Picea*
10	–	4c	OxA-1779	23,650 ± 400	Ch. bone	–	–	–
15	–	5a	GrN-14034	23,830 ± 330	Charcoal	–	–	–
(16)	–	5a	GrN-12635	27,150 ± 750	Charcoal	–	–	–
17	–	5a	OxA-1780	24,650 ± 450	Bone	–	–	–
–	18	5b up.	GrA-14670	–	–	24,780 ± 120	Charcoal	*Betula*
–	22	5b base	GrN-20439	–	–	23,990 ± 250	Charcoal	*Picea*
29	–	6b	GrN-15450	25,610 ± 220	Charcoal	–	–	–
–	33	6b base	GrA-1354	–	–	26,450 ± 130	Charcoal	*Picea*
–	34	6b base	GrA-13298	–	–	25,540 ± 210	Charcoal	*Picea*
–	35	6b base	GrN-20440	–	–	25,610 + 500–470	Charcoal	*Picea*
36	–	6b base	GrN-18811	26,180 ± 290	Charcoal	–	–	–
40	–	7b	GrN-14913	25,330 ± 420	Charcoal	–	–	–
(41)	–	7b	GrN-18880	26,020 + 650–600	Charcoal	–	–	–
(42)	–	7b	GrN-18881	26,380 + 600–500	Charcoal	–	–	–
43	–	7b	GrN-18815	26,500 + 460–440	Charcoal	–	–	–
(44)	–	7b	GrN-18882	25,080 + 500–470	Charcoal	–	–	–
(45)	–	7b	GrN-18883	26,110 + 1050–930	Charcoal	–	–	–
46	–	7b	GrN-18879	26,300 + 450–430	Charcoal	–	–	–
48	–	7b	OxA-1778	27,500 ± 600	Bone	–	–	–
(49)	–	7b	GrN-12636	28,910 ± 480	Charcoal	–	–	–
50	–	8b	GrN-14914	27,410 ± 430	Charcoal	–	–	–
(51)	–	8b	GrN-12637	31,850 ± 800	Charcoal	–	–	–
52	–	8b base	GrN-15453	27,100 ± 1500	Charcoal	–	–	–
–	53	8b base	GrA-27261	–	–	27,700 ± 180	Charcoal	*Juniperus*
–	54	8b base	GrA-27268	–	–	27,750 ± 160	Charcoal	*Betula*
(56)	–	9b up.	GrN-15451	26,530 ± 400	Charcoal	–	–	–
57	–	9b up.	GrN-15454	29,410 ± 310	Charcoal	–	–	–
(59)	9b base	GrN-14037	26,910 ± 450	Charcoal	–	–	–	
61	–	10b base	OxA-1646	31,100 ± 900	Charcoal	–	–	–
–	62	10b base	GrA-1648	–	–	31,000 ± 330	Charcoal	*Picea*
(63)	–	11 up.	GrN-15456	25,930 ± 450	Charcoal	–	–	–
–	64	11 up.	GrN-20443	–	–	30,240 + 470–440	Charcoal	*Picea*
–	65	11 up.	GrN-20770	–	–	31,160 + 570–530	Charcoal	*Picea*
–	66	11 base	GrN-20442	–	–	30,920 ± 390	Charcoal	*Picea*
–	67	12a	GrN-20444	–	–	31,160 + 550–510	Charcoal	*Picea*
–	68	12b	GrA–1357	–	–	32,730 ± 220	Charcoal	*Picea*

of a 14 m thick loamy loess cover which is preserved against a steep talus developed in the Cenozoic limestone (Figs. 2 and 3). The site was excavated over an area of 20 × 30 m, down to the terrace, by Chirica (Iasi) from 1982 to 1991 and together with Belgian teams from 1992 to 1998 (Chirica, 1989, 2001; Otte et al., 2007). This resulted in a complex pedo-sedimentary succession recorded along the three walls of the excavation field with a gentle dip to the Pruth (Haesaerts et al., 2003; Becze-Deak et al., 2007; Haesaerts, 2007). The recurrent presence of humic horizons and tundra gleys throughout the sedimentary succession has led to a subdivision of the Malu Galben sequence into 13 units, each one recording an episode of sedimentation followed by pedogenesis. Malu Galben is further characterized by the overabundance of Aurignacian and Gravettian lithic material. Charcoal, associated with the archaeological occupations, was rather abundant, making possible the large series of radiocarbon dates to be used as a basis for a detailed chronology of the sequence between 32.7 and ca 20 kyr BP (see Section 3.4.3).

3.4.2. Charcoal and other plant remains

As at Molodova, the diversity of taxa is low with a large majority of conifer charcoal, mainly *Picea* and *Pinus cembra*-type (Table 1). Some scattered charcoal particles of boreal malacophylls (*Betula* sp., *Alnus*/*Duschekia*) were found in association with the conifers. These do not change the climatic signature of the charcoal assemblages at Mitoc. Moreover, many conifer charcoal particles were found not only in humic layers, but also in pale loess layers and tundra-gleys. Such occurrences, which provided a consistent succession of radiocarbon dates, mean that boreal trees never disappeared completely from the landscape of the Pruth valley during the late pleniglacial. Various

Table 5
Mitoc-Malu Galben. Reproducibility of dates from the same layers, on different samples with the same taxon, by AMS and conventional dating (number 7, 8, 9), on different taxa from the same sample (number 53, 54), on different samples with possibly different taxa (number 62, 63).

Number	Lithol. subunit	Number date	^{14}C age (BP)	Taxon
7	4a inf	GrA-14671	23,290 ± 100	*Picea*
8	4a inf	GrN-20438	23,390 ± 280	*Picea*
9	4a inf	GrA-1353	23,850 ± 100	*Picea*
53	8b inf	GrA-27261	27,700 ± 180	*Juniperus*
54	8b inf	GrA-27268	27,750 ± 160	*Betula*
62	10b inf	OxA-1646	31,100 ± 900	Charcoal
63	10b inf	GrA-1648	31,000 ± 330	*Picea*

charred seed and fruit remains of herbaceous plants were found in the Aurignacian layer of subunit 11b and the Gravettian layer of subunit 6b, both derived from hearths.

3.4.3. The radiocarbon dates

The site of Malu Galben provided a total of 68 radiocarbon dates on charcoal, bone and burnt bone retrieved only from archaeological

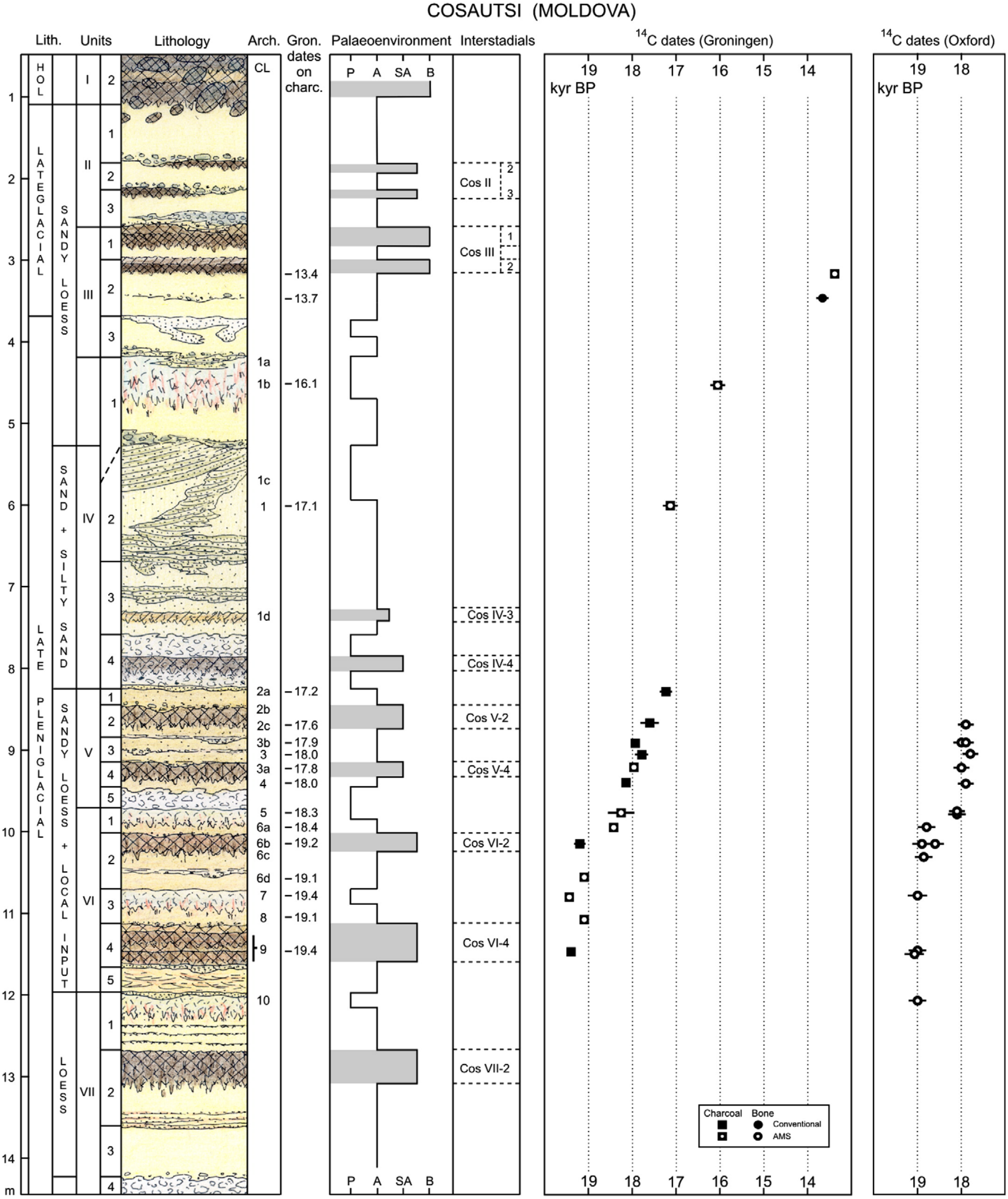


Fig. 6. Cosautsi. Distribution of the radiocarbon dates on charcoal and bone, with respect to stratigraphy time scale.

layers. Some 46 dates were obtained before 1991 by V. Chirica and his team (Chirica, 1986, 1989; Honea, 1993, 1994) while 22 dates were obtained on materials, mainly charcoal, excavated by the RBINS team and by the team of the University of Liège between 1992 and 1998 (Damblon et al., 1996; Damblon and Haesaerts, 2007). This long sequence required a strong selection of the radiocarbon dates due to various sources of biases and errors that hindered establishment of a reliable chronology. As a matter of fact, the set of 46 dates obtained before 1991 was quite dispersed with respect to the stratigraphy. This distribution has led to careful screening of the results and documentation by V. Chirica which showed various sources of biases linked to the uncertain stratigraphic origin of some samples, the lack of identification and selection of charcoal and the low quantities of carbon in some samples submitted to dating (Damblon and Haesaerts, 2007). After screening, about 25 dates could be taken into consideration for the discussion (Table 4, column number bef. 91). From the set of 22 dates produced after 1991, three were excluded due to a test on secondary carbonate, one labelling error and a bad duplicate. This resulted in 19 dates for discussion (Table 4, column aft. 91).

In a second step, the remaining 44 dates (Table 4) were scrutinized with regard to stratigraphy and the trend line of the dates in the sequence (Damblon and Haesaerts, 2007). It followed that 7 dates from the first set obtained before 1991 appeared clearly too young due to contaminants (number 41, 42, 44, 45, 56, 59, 63) while 3 other dates from the same set (number 16, 49, 51) were much too old and interpreted as the result of possible error of positioning in the stratigraphy or possibly of local gathering of driftwood by Palaeolithic people (Théry-Parisot, 2001; this volume). In these cases, the intrusion of older material by run-off was not possible because the loess inputs were not disturbed. This is verified notably in subunit 8b where two taxa (*Juniperus*, *Betula*) in a single sample (dates number 53–54) were dated to 27,700 ± 180 (GrA-27261) and 27,750 ± 160 BP (GrA-27268) respectively. Finally, no dating problems occurred with well-identified charcoal material precisely positioned in the stratigraphy during the investigations after 1991 (Damblon, 2007). Only the dates on bone number 6 and 2 appear too young with regard to the general trend of the ages, probably due to contamination of collagen by humics.

At Mitoc, as at Molodova, it is also worthwhile to note the reproducibility of the ^{14}C dates in three key levels (Table 5). In subunit 4a, at the base of the tundra gley, three charcoal samples of spruce have yielded ^{14}C ages between 23.9 and 23.3 kyr BP. As at Molodova, the homogeneity in age of a sample from the base of subunit 8b clearly appears by dating two taxa, *Juniperus* and *Betula*, in parallel. Another example is given in subunit 10b where the new date on spruce charcoal (31,100 ± 900 BP) seems very close to the previous one (31,000 ± 330 BP).

After this last selection, the distribution of the 32 remaining reliable dates in the time scale is given in Fig. 5 with regard to depth and stratigraphy. The trend line of the ^{14}C ages is clearly in agreement with the stratigraphic sequence and progressively grades from 32.7 to 23.3 kyr BP, with a chronological break at the base of unit 3, dated to 20.5 kyr BP.

Two groups of radiocarbon data may be distinguished in this sequence. One set of dates between 32.7 and 26.3 kyr BP belongs to the middle pleniglacial succession (units 12 to 7). The second set of consistent dates from 25.5 to 20.2 kyr BP belongs to the late pleniglacial loess cover (units 6 to 2). In the middle pleniglacial deposit, each charcoal sample comes from the sedimentary units and brackets the pedological horizons. As for Molodova, the distribution of the dates enables the six climatic ameliorations to be situated within time spans of about 1 to 2 millennia. By contrast, in the late pleniglacial deposit, the dates in units 6 to 4, between 25.5 and 23.3 kyr BP, allow a highly detailed and accurate framing of climatic events shorter than one millennium, with two interstadial episodes dated around 25.5 and 23.5 kyr BP (subunits 6a et 4b). A clear break appears between the tundra gley 4a slightly after 23.3 and the overlying loess of unit 3 and 2 dated around 20.5 and 20.2 kyr BP.

Table 6

Cosautsi. The radiocarbon dates distributed by lithological sub-unit. The first set of dates comes from unidentified charcoal material collected in the cultural layers and dated before 1993. The second set comes from identified charcoal dated after 1993 and the third from bone dated after 1993, both sets being carefully recovered during the stratigraphic field investigation. Abbreviations, ch.: charcoal, Pinus c.: *Pinus cembra*-type.

Cosautsi: radiocarbon dates				
Lithological subunit	Cultural layer	Number date	^{14}C age (BP)	Material before 1993
–	1	GIN-4146	17,200 ± 300	Charcoal
–	2 a	LE-3304	16,860 ± 770	Charcoal
–	2 a	SOAN-2452	16,940 ± 1215	Charcoal
–	2 b	LE-3305	15,520 ± 800	Charcoal
–	2 b	GIN-4148	18,200 ± 500	Charcoal
–	2 b	SOAN-2461	19,620 ± 925	Charcoal
–	3 b	LE-3307	17,390 ± 580	Charcoal
–	3 b	SOAN-2462	17,840 ± 550	Charcoal
–	3	GIN-4149	16,160 ± 250	Charcoal
–	3	LE-3306	17,400 ± 340	Charcoal
–	4	GIN-4150	17,100 ± 250	Charcoal
–	4	LE-3308	17,640 ± 830	Charcoal
–	5	GIN-4152	17,030 ± 180	Charcoal
–	6 a	A-1862	18,140 ± 165	Charcoal
–	6 c	A-1864	18,935 ± 160	Charcoal
Lithological subunit	Cultural layer	Number date	^{14}C age (BP)	Material after 1993
III-2 soil	–	GrA-9565	13,380 ± 80	*Picea ch.*
III-3	–	GrN-23582	13,660 ± 140	Bone
IV-1 gley	1 b	GrA-4209	16,050 ± 170	*Pinus c. ch.*
IV-2 mid.	1	GrA-5217	17,130 ± 180	*Pinus c. ch.*
V-1 top	2 a	GrN-21792	17,230 ± 140	*Picea ch.*
V-2 base	2 c	GrN-21793	17,620 ± 210	*Picea ch.*
V-3 top	3 b	GrN-21360	17,910 ± 80	*Picea ch.*
V-3 base	3	GrN-21359	18,030 ± 150	*Picea ch.*
V-4 soil	3 a	GrA-7554	17,780 ± 90	*Picea ch.*
V-4 base	4	GrN-21794	17,950 ± 100	*Picea ch.*
VI-1 top	5	GrN-23581	18,150 ± 100	*Picea ch.*
VI-1 top	5	GrA-5218	18,260 ± 210	*Picea ch.*
VI-1 base	6 a	GrA-13291	18,430 ± 100	*Picea ch.*
VI-2 soil	6 b	GrN-21361	19,200 ± 130	*Picea ch.*
VI-2 base	6 d	GrA-7555	19,120 ± 100	*Pinus c. ch.*
VI-3 top	7	GrA-6746	19,440 ± 100	*Picea ch.*
VI-3 base	8	GrA-7557	19,070 ± 100	*Picea ch.*
VI-4 soil	9	GrN-21795	19,410 ± 100	*Picea ch.*
V-2	2 c	OxA-5233	17,900 ± 200	Bone
V-3	3 b	OxA-5234	17,900 ± 180	Bone
V-3	3 b	OxA-5235	18,000 ± 180	Bone
V-3	3	OxA-5236	17,840 ± 180	Bone
V-4	3 a	OxA-5237	18,000 ± 180	Bone
V-4	4	OxA-5257	17,840 ± 180	Bone
VI-1	5	OxA-5238	18,060 ± 180	Bone
VI-1	5	OxA-5247	18,140 ± 200	Bone
VI-1	6 a	OxA-5248	18,780 ± 200	Bone
VI-2	6 b	OxA-5256	18,560 ± 200	Bone
VI-2	6 b	OxA-5249	18,940 ± 220	Bone
VI-2	6 c	OxA-5255	18,860 ± 200	Bone
VI-3	7	OxA-5250	18,980 ± 220	Bone
VI-4	9	OxA-5251	19,060 ± 220	Bone
VI-4	9	OxA-5252	19,060 ± 200	Bone
VI-4	9	OxA-5253	19,080 ± 220	Bone
VII-1	10	OxA-5254	18,980 ± 200	Bone

Here it is worthwhile to consider the tundra-gley in subunit 7a which yielded the ages 26.5 and 26.3 kyr BP at the base and nearly the same dates at the interface with subunit 6b dated to 25.5 kyr BP. These dates were obtained from Gravettian occupations. The very slight difference between the dates from underneath and on top of the tundra gley could point to a very short phase of climatic cooling. On the other hand, the dates of 26.2 and 26.5 kyr BP could be related to a human occupation during the formation of the tundra-gley. However, these

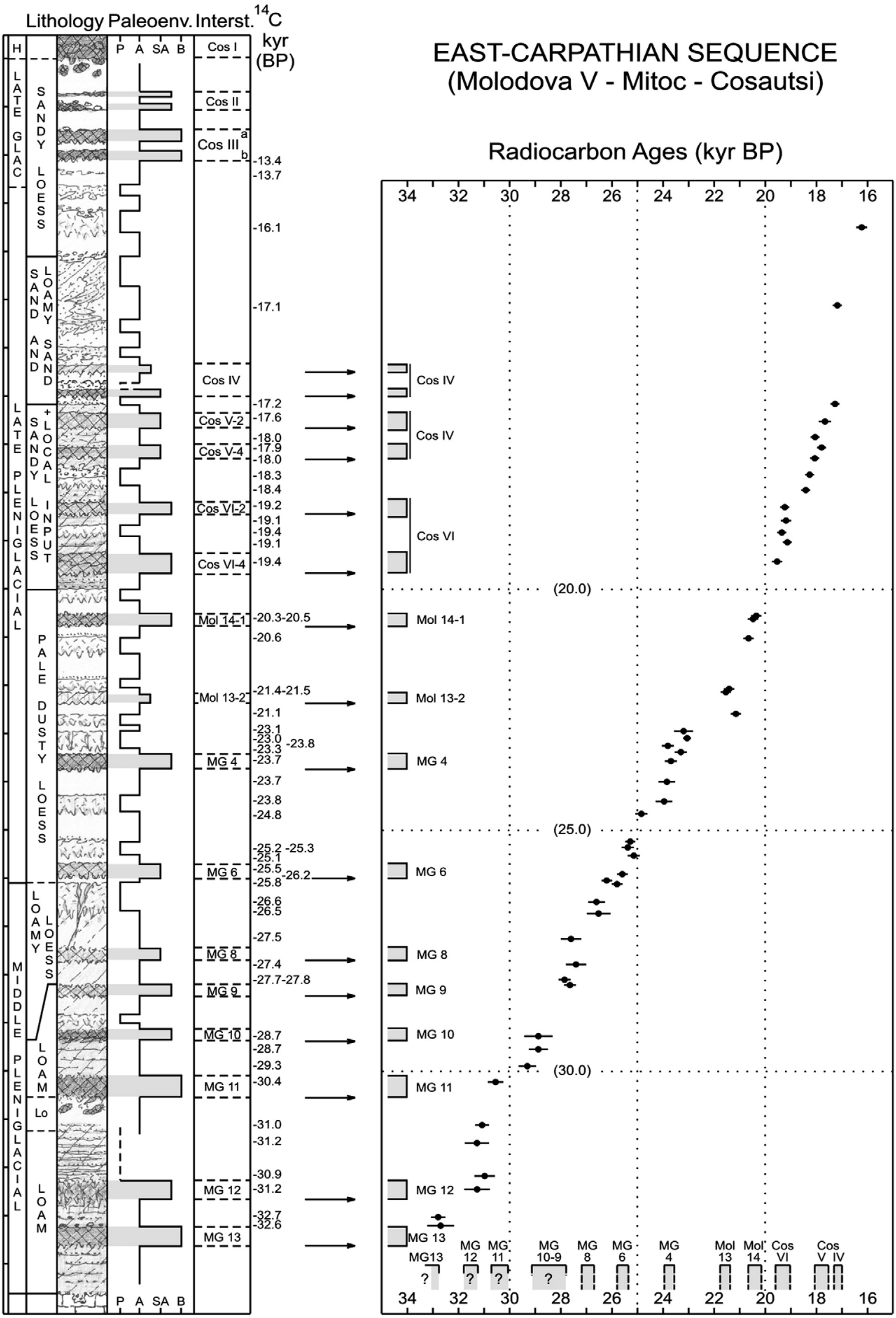


Fig. 7. The East Carpathian sequence: distribution of the interstadial events through time, with respect to the radiocarbon dates. Shortenings as in Fig. 3 (from Haesaerts et al., 2009).

dates could also derive from gathering driftwood. In each case, however, the duration of the climatic cooling remains shorter than one millennium.

3.5. Cosautsi (Moldavian Republic)

3.5.1. The site

The Upper Palaeolithic site Cosautsi is situated along the Moldavian bank of the River Dniester ca 120 km downstream of Molodova (Fig. 1). It contains an exceptional Epigravettian settlement within a long stratigraphic succession encompassing a large number of cultural layers with abundant charcoal and bone remains. This high-quality material provided a double set of radiocarbon dates between 19.4 and 13.4 kyr BP produced in the Groningen and Oxford laboratories (Otte et al., 1996; Haesaerts et al., 1998, 2003). The geomorphologic location of the site on the first terrace (Fig. 2), along the valley slope close to a chalky outcrop, induced specific sedimentary dynamics providing a high-resolution climatic and environmental record based on a complex succession of sandy loess, loamy deposits and chalky flows separated by tundra gleys and humic horizons (Fig. 6). The stratigraphy of the site was established by Adamenko during the 1982–1989 excavations, following a subdivision of the sequence into nine sedimentary cycles (Borziac, 1993); it was completed by us in 1994 and 1996 along a set of long trenches across the gentle slope to the Dniester (Haesaerts et al., 2003).

3.5.2. Charcoal data

As at Molodova and Mitoc, conifers form the main taxa throughout the sequence, with *Picea* most abundant while *Pinus cembra*-type is limited to late pleniglacial subunits IV-2 and IV-1 (Table 1). Some scattered debris of *Salix* and *cf. Rubus* were also found in this unit IV, probably due to the position of the site on the river bank of the Dniester. The continuous occurrence of conifer charcoal throughout the sequence of Cosautsi in both the loess and humic layers is worthy of note because it strongly suggests the persistence of boreal tree populations on the river bank, even during the Last Glacial Maximum.

3.5.3. The radiocarbon dates

Cosautsi has yielded 50 radiocarbon dates on charcoal and bone remains collected within some 21 occupation layers in an exceptional late pleniglacial sandy and loamy loess sequence (Table 6; Fig. 6). In this sequence, an initial set of 15 dates on unidentified charcoal (Table 6, upper part) was obtained before 1993 from cultural layers 6c to 1 (Borziac, 1993). Although they range from 19.6 to 15.5 kyr BP, their distribution in time with regard to the successive cultural layers was in disagreement with the stratigraphy. A new set of charcoal and bone samples covering the entire sequence (Fig. 6) was thus collected during the 1994–96 campaigns (Haesaerts et al., 1998, 2003). Each charcoal concentration comes from remains of hearths. The result produced 17 dates on identified charcoal, essentially spruce or pine, and 16 dates on bone (Otte et al., 1996; Noiret, 2004). Both sets between subunits VII-1 and V-1 show the same trend line delimiting the sequence between 19.4 and 17.2 kyr BP with a clear break in the distribution of dates around 18.5 kyr BP. In Fig. 6, the dates on charcoal appear slightly older than the ones on bone, especially around 19.4 kyr BP. This phenomenon may be attributed to minor contamination of bone collagen, leading to a concentration of dates between ca 19 and 18 kyr BP, rather than an old wood effect on charcoal, which is probably undetectable for this time period, and taking the ^{14}C measurement uncertainty into account.

At any rate, in Fig. 6, the dates on charcoal from the Groningen laboratory are used as the most reliable tool in agreement with the stratigraphy. With regard to the three doublets of humic horizons dated between 19.4 and 17.1 kyr BP (respectively units VI-4 and VI-2, subunits V-4 and V-2 and subunits IV-4 and IV-3), the delimiting of each successive climatic amelioration during this time span suggests very short events lasting around one or two centuries, and the break in chronology at ca 18.5 kyr BP appears related to the permafrost episode on top of unit VI. By contrast, for the upper part of the sequence, the limited number of radiocarbon dates prevents a detailed chronological delimitation of the three cold snaps with permafrost conditions in units IV and III between 17.1 and 13.4 kyr BP. Increasing aeolian activity and limited Palaeolithic occupations characterize this period prior to the two doublets of humic horizons (subunits III-2 and III-1 and subunits II-3 and II-2) ascribed to the Lateglacial.

3.6. The East Carpathian chronology

This East Carpathian sequence based on the loess records of Molodova, Mitoc-Malu Galben and Cosautsi provides a semi-continuous pedo-sedimentary record with high-resolution climatic signature and strong radiocarbon chronology for the period ca 33 to 16 kyr BP. The integrated distribution of the dates from the 3 sites with regard to the regional sequence (Fig. 7) shows a straight trend line from 32.7 to 16.1 kyr BP and allows the transfer of the climatic events from a metric scale into the radiocarbon time scale. In such a system, most of the late pleniglacial interstadial episodes occur as short time intervals with duration of a few centuries, taking the dating uncertainties into account. By contrast, the dates available for the middle pleniglacial at Mitoc and Molodova down to 32.7 kyr BP, which come mainly from sedimentary units, delimit the pedologic horizons related to the interstadial events Malu Galben 12 to Malu Galben 8 within time slices of around one millennium or more.

Furthermore, no radiocarbon dates are available for the sequence between 32.7 and 44.4 kyr BP. In order to overcome these constrains, we had the opportunity to complete the middle pleniglacial record in Central Siberia with the loess sequence of Kurtak, along the Yenisei River, which provided a semi-continuous climatic record well-dated between ca 42.5 and 26 kyr BP on wood remains and charcoal (Haesaerts et al., 2005).

4. Siberia

4.1. Background

In Siberia, wood remains are rather common in Pleistocene fluviatile deposits, usually in permafrost conditions. Such remains occur also in southern Siberia along the Ob River and its tributaries (Zykin et al., 2000) where stumps and conifer trunks have provided dates around 40, 32 and 30 kyr BP, unfortunately related to discontinuous sedimentary sequences and often disconnected from the loess records along the valley slopes. In this respect, specific conditions were encountered at Kurtak, south of Krasnoyarsk, where a semi-continuous middle pleniglacial loamy sequence with abundant wood remains is directly related to the Upper Pleistocene loess cover (Haesaerts et al., 2005).

4.2. Kurtak

4.2.1. Stratigraphic setting

The studied area is located along the Yenisei Valley, close to the Minusinsk depression and to the outlet of the river across the Sayan Range, a situation which has favoured the deposition of a thick loess cover on the western slope of the valley during the Pleistocene. At Kurtak, this loess cover is widely exposed along the banks of the Krasnoyarsk Reservoir, in a slope-edge position at the point of contact with the plateau, ca 65 m above the bottom of the valley. Here, the ca 25 m thick Upper Pleistocene cover encompasses two main loess bodies ascribed to the early and late pleniglacial, with a succession of middle pleniglacial loess and loamy deposits in between (Drozdov et al., 1999; Chlachula, 2003; Zander et al., 2003).

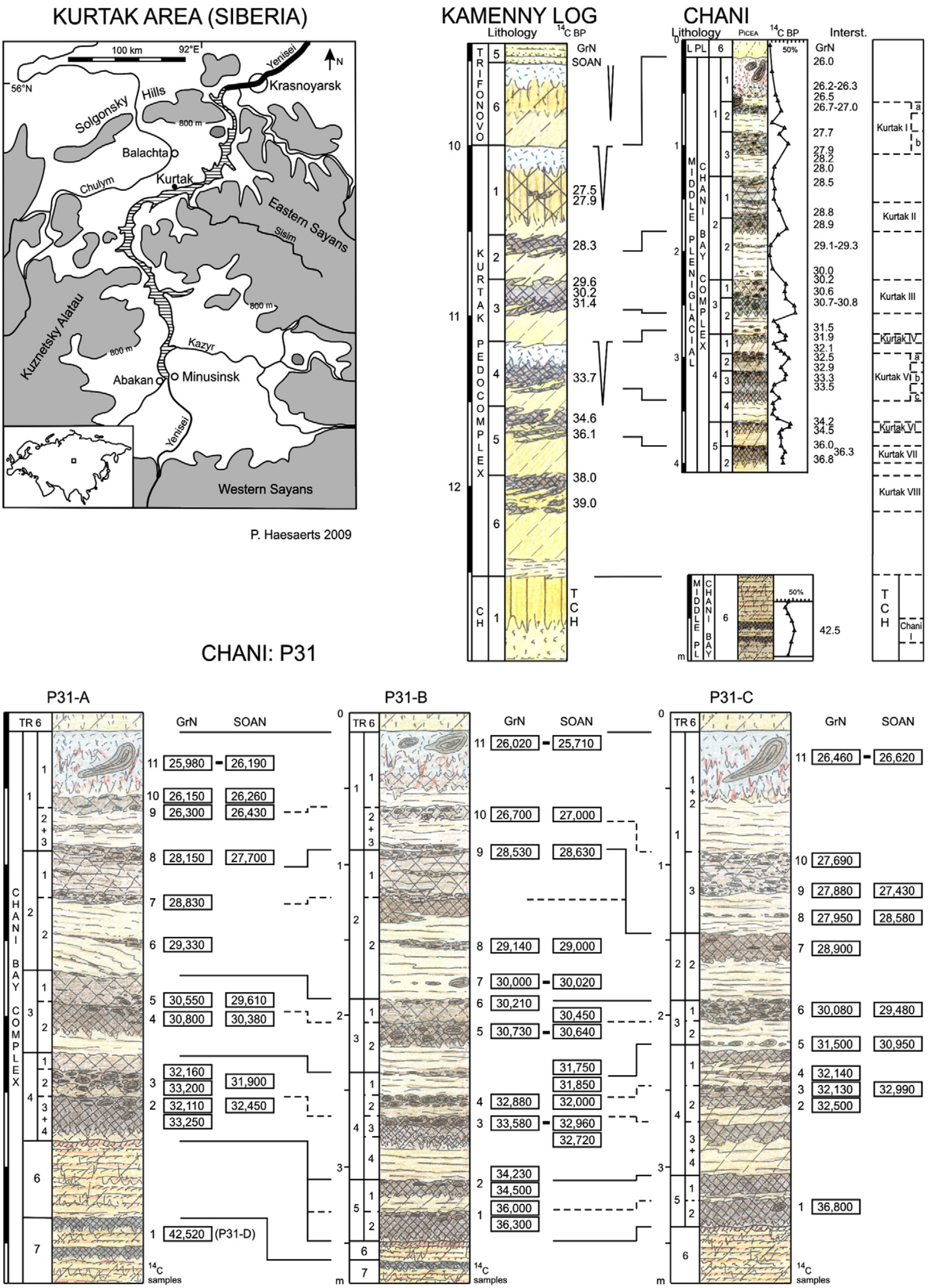


Fig. 8. Middle pleniglacial stratigraphic succession of the Kurtak region along the Upper Yenisei River (Siberia) and distribution of the radiocarbon dates in the section P31-A, P31-B and P31-C at Chani. Abbreviations: GrN: Groningen radiocarbon dates (kyr BP); SOAN: Novosibirsk radiocarbon dates (kyr BP). (modified from Haesaerts et al., 2005).

Table 7
Kurtak. The radiocarbon dates distributed by lithological subunit. The table is presented in two parts. The first gives the dates obtained from the loess cover on the plateau. The second gives the dates from three close sections (P31/A, B, C) in the depression of Chani. GrN: Groningen conventional; SOAN: Novosibirsk conventional. Double dates on the same sample are given in parallel. See Figs. 8 and 9.

Lithol. subunit	Sample	Number date gron.	^{14}C age (BP)	Number date Nov.	^{14}C age (BP)	Material/taxon
Kaminny Log, Kashtanka			Plateau			
1	Ku 1	–	–	SOAN-3276	27,460 ± 230	Unid. charc.
1	KL 1	GrN-21895	27,920 ± 260	–	–	Picea charc.
2	Ka 2	GrN-24481	28,320 ± 190	–	–	Larix charc.
3	KL 3	GrN-21896	29,580 + 400–460	–	–	Picea charc.
3	KL 3	GrA-13286	30,190 ± 350	–	–	Picea charc.
3	KL 3	–	–	SOAN-3275	31,410 ± 465	Unid. charc.
4	KL 4	GrN-21358	33,740 + 500–480	–	–	Picea charc.
5	KL 5	GrN-24478	34,570 + 1150–1000	–	–	Picea charc.
5	Ka 5	GrN-24482	36,130 ± 310	–	–	Salix charc.
6	KL 6	GrA-9246	38,000 + 4200–2800	–	–	Picea charc.
6	KL 6	GrN-24479	39,020 + 710–650	–	–	Picea charc.
P 31/A			Chani depression			
K1-1	A-8	GrN-24182	25,980 ± 180	SOAN-3862	26,190 ± 170	Picea wood
K1-2	A-7 sup	GrN-24181	26,150 ± 160	SOAN-3861	26,260 ± 170	Picea wood
K1-2	A-7 inf	GrN-24180	26,300 ± 160	SOAN-3860	26,430 ± 355	Picea wood
K1-4	A-6	GrN-24472	28,150 ± 170	SOAN-3859	27,700 ± 150	Picea wood
K1-4	A-5	GrN-24179	28,830 ± 210	–	–	Picea wood
K1-5	A-4	GrN-24471	29,330 ± 390	–	–	Picea wood
K1-6	A-3	GrN-24470	30,550 ± 180	SOAN-3857	29,610 ± 245	Picea wood
K2-1	A-2	GrN-24469	30,800 ± 150	SOAN-3856	30,380 ± 360	Picea wood
K3-K4	A-1	GrN-24468	32,160 ± 190	SOAN-3855	31,900 ± 295	Picea wood
K3-K4	A-1	GrN-25034	33,200 ± 360	–	–	Picea wood
K4-1/K5-1	A-0	GrN-24467	32,110 ± 40	SOAN-3274	32,450 ± 360	Picea wood
K4-1/K5-1	A-0	GrN-25033	33,250 ± 310	–	–	Picea wood
Tch.1	A-G3	GrA-6866	42,520 + 730-670	–	–	Picea charc.
P 31/B						
K1-1	B-10	GrN-24193	26,020 ± 180	SOAN-3874	25,710 ± 455	Picea wood
K1-3	B-9	GrN-24192	26,700 ± 200	SOAN-3873	27,000 ± 270	Picea wood
K1-4	B-8 sup	GrN-24,191	28,530 ± 200	SOAN-3872	28,630 ± 525	Picea wood
K1-5	B-7	GrN-24190	29,140 ± 210	SOAN-3871	29,000 ± 540	Picea wood
K1-5	B-6 sup	GrN-24188	30,000 ± 280	SOAN-3870	30,020 ± 305	Picea wood
K1-5	B-6 inf	GrN-24189	30,210 ± 260	–	–	Picea wood
K2-1	B-5	–	–	SOAN-3868	30,450 ± 650	Picea wood
K2-1	B-5	GrN-24187	30,730 ± 300	SOAN-3869	30,640 ± 395	Picea wood
K3-3	B-4	GrN-24186	32,880 ± 340	SOAN-3865	31,750 ± 270	Picea wood
K3-3	B-4	–	–	SOAN-3867	31,850 ± 340	Picea wood
K3-3	B-4	–	–	SOAN-3866	32,000 ± 350	Picea wood
K4-1	B-3	GrN-24185	33,580 ± 360	SOAN-3863	32,960 ± 455	Picea wood
K4-1	B-3	–	–	SOAN-3864	32,720 ± 575	Picea wood
K5-1	B-2	GrN-24184	34,230 ± 300	–	–	Picea wood
K5-1	B-2	GrN-25032	34,500 ± 470	–	–	Picea wood
K6-1	B-1	GrN-24183	36,000 ± 360	–	–	Picea wood
K6-1	B-1	GrN-25031	36,300 ± 500	–	–	Picea wood
P 31/C						
K1-1	C-11	GrN-24199	26,460 ± 180	SOAN-3880	26,620 ± 250	Picea wood
K1-4	C-10	GrN-24477	27,690 ± 180	–	–	Picea wood
K1-4	C-9	GrN-24476	27,880 ± 160	SOAN-3879	27,430 ± 340	Picea wood
K1-4	C-8	GrN-24475	27,950 ± 180	SOAN-3878	28,580 ± 450	Picea wood
K1-4	C-7	GrN-24474	28,900 ± 240	–	–	Picea wood
K2-1	C-6	GrN-24473	30,080 ± 180	SOAN-3877	29,480 ± 300	Picea wood
K2-2	C-5	GrN-24198	31,500 ± 280	SOAN-3876	30,950 ± 430	Picea wood
K3-2	C-4	GrN-24197	32,140 ± 320	–	–	Picea wood
K3-2	C-3	GrN-24196	32,130 ± 350	SOAN-3875	32,990 ± 300	Picea wood
K3-3	C-2	GrN-24195	32,500 ± 200	–	–	Picea wood
K6-1	C-1	GrN-25035	36,800 ± 470	–	–	Picea wood

On the plateau, a first middle pleniglacial sandy loess body is capped by a brown boreal soil (Tcherniakovsky Soil) overlain by the Kurtak Pedocomplex (Fig. 8); the latter consists of ca 2 m of loamy loess encompassing a set of five humic horizons dated between 39 and 27.5 kyr BP on charcoal and capped by a thick tundra gley with large ice wedge pseudomorphs at the contact with the late pleniglacial loess cover (Haesaerts et al., 2005). Laterally the Tcherniakovsky Soil and the Kurtak Pedocomplex are connected with the Chani Bay Complex preserved in a large depression at the edge of a small tributary. This complex encompasses ca 4 m of loess-like silts and humic loamy layers with abundant wood remains (units 1 to 5) overlying ca 2 m of laminated silts (units 6 and 7). The main interest of the Chani sequence lies in its sedimentary succession as well as the good state of preservation of the plant remains (Figs. 8 and 9). In particular, this sequence provides a remarkable pollen record which links the deposition of most of the humic loams to interstadial episodes with extension of the spruce population in the depression, and the loess-like silts to cold episodes with extension of the steppe cover (Fig. 8). Furthermore, at Chani the chronology of this system is exceptionally coherent and is based on 63 dates obtained in most cases on wood debris which allows a precise chronological delimitation of 10 interstadial episodes (Chani I and Kurtak VIII to Kurtak Ia) between 42.5 and 26 kyr BP.

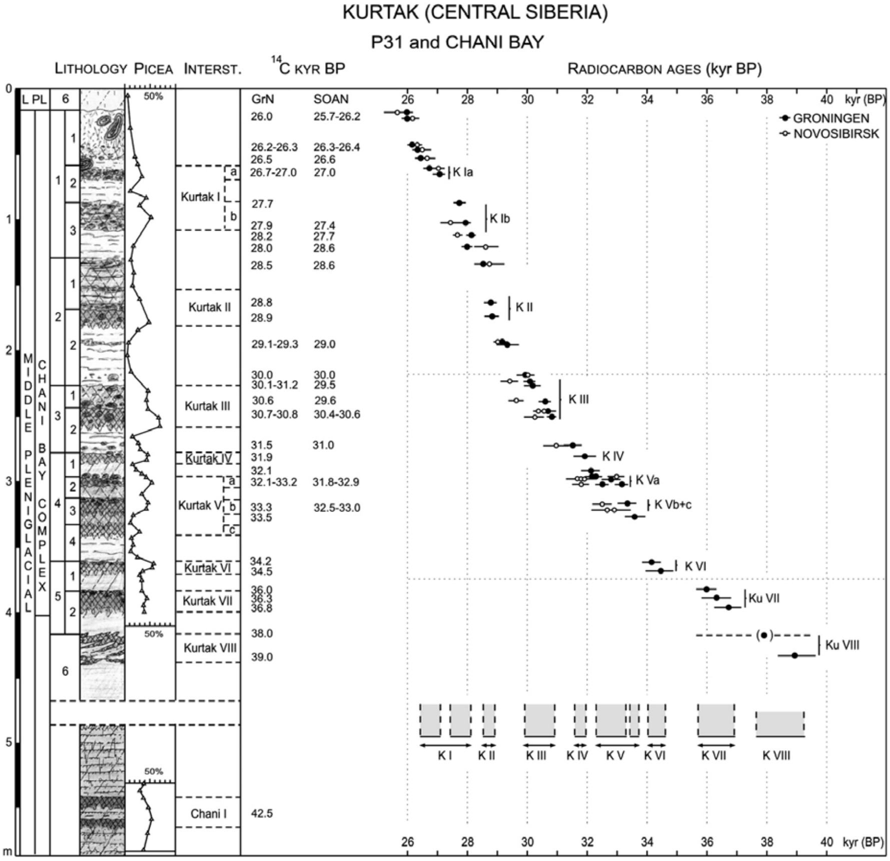


Fig. 9. Kurtak. Integrated middle pleniglacial succession with distribution of the interstadial events through time with respect to the radiocarbon dates (from Haesaerts et al., 2005).

4.2.2. Wood and charcoal data

The botanical remains at Kurtak are made of charcoal, wood remains and charred fragments of stems, leaves and achenes. Most of the charcoal fragments were found in the loess deposited on the plateau (Kamenny Log, Kashtanka), but were also found in the Chani Bay depression (Table 1). By contrast, large wood remains were well-preserved in various successive layers of Chani Bay. Overall, the spectrum of taxa is largely dominated by conifers, mainly *Picea* and *Pinus cembra*-type (probably *P. sibirica*), but debris of *Betula*, *Salix* and *Populus* were also recovered locally. The limited finds of birch, willow and poplar are probably linked to the vicinity of the Yenisei River. The entire set of wood pieces belongs to *Picea*, probably *P. obovata* judging from needles found in the record of Chani. The preservation state of the wood (remains of trunks, branches and roots) was very good due to the action of permafrost during the pleniglacial and part of the Holocene. Tree rings have been counted on certain pieces, showing up to 160 rings, presently under study.

4.2.3. The radiocarbon dates

From the entire Kurtak Area, 74 radiocarbon dates should be taken into consideration with regard to their reliable stratigraphic origin (Haesaerts et al., 2005). An initial set of 11 dates was obtained for charcoal clusters found in the Kurtak Pedocomplex at various places on the plateau, notably at Kamenny Log and Kashtanka (Table 7). Their coherent distribution between 39 and 27.5 kyr BP in the Kurtak Pedocomplex allows dating of six successive units (Fig. 9). A second set of 63 dates (Table 7) was produced on wood remains, mainly spruce, from 14 sedimentary sub-units of the Chani Bay Complex. These 63 dates show a very good concordance between the ^{14}C ages and the stratigraphy (Figs. 8 and 9). Regarding the state of preservation and the distribution of the numerous conifer wood remains consisting of debris of trunks, roots, branches, splinters and bark lying flat in the layers at Chani, a large sampling was achieved in three complementary sections (Fig. 8) about 10 m apart for dating in two different laboratories, Groningen and Novosibirsk (Table 7).

The occurrence in different successive layers of a large number of wood pieces was an opportunity for testing different approaches to dating this material with the aim of better controlling the chronology

Table 8

Kurtak. Reproducibility of dates from the same layers from the P31 sections of Chani. Comparative dating was made in two laboratories for three kinds of *Picea* wood samples: a) dating a single piece of wood sawn in two parts, b) dating two distinct wood pieces lying flat in a single layer, c) dating several wood pieces of small size from the same layer. GrN: Groningen conventional; SOAN: Novosibirsk conventional.

Section	Lithol.	Number date GrN	^{14}C age (BP)	Number date SOAN	^{14}C age (BP)
P31	a) Same piece of wood				
B	2.2	GrN-24188	30,000 ± 280	SOAN-3870	30,020 ± 305
B	3.2	GrN-24187	30,730 ± 300	SOAN-3869	30,640 ± 395
B	4.3	GrN-24185	33,580 ± 360	SOAN-3863	32,960 ± 455
P31	b) Two distinct wood pieces lying in the same layer				
C	1.1	GrN-24199	26,460 ± 180	SOAN-3880	26,620 ± 250
B	1.2	GrN-24192	26,700 ± 200	SOAN-3873	27,000 ± 270
A	1.3	GrN-24472	28,150 ± 170	SOAN-3859	27,700 ± 150
B	2.1	GrN-24,191	28,530 ± 200	SOAN-3872	28,630 ± 525
C	3.1	GrN-24473	30,080 ± 180	SOAN-3877	29,480 ± 300
C	3.2	GrN-24198	31,500 ± 280	SOAN-3876	30,950 ± 430
A	4.2	GrN-24468	32,160 ± 190	SOAN-3855	31,900 ± 295
A	4.3	GrN-24467	32,110 ± 40	SOAN-3274	32,450 ± 360
P31	c) Several elements of small size extracted from the same layer				
A	1.1	GrN-24180	26,300 ± 160	SOAN-3860	26,430 ± 355
C	1.3	GrN-24476	27,880 ± 160	SOAN-3879	27,430 ± 340
B	2.2	GrN-24190	29,140 ± 210	SOAN-3871	29,000 ± 540

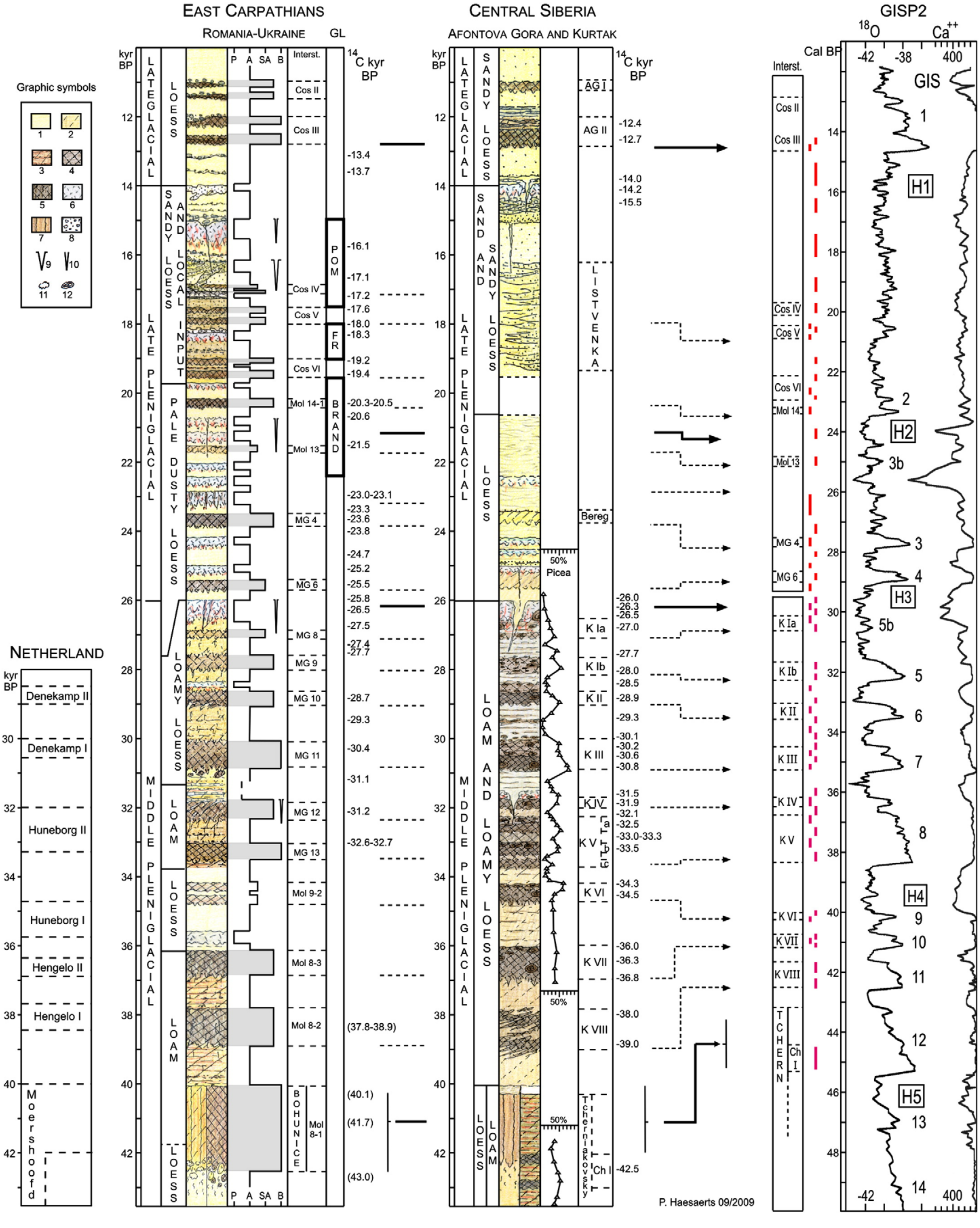


Fig. 10. Correlation between the Netherlands (van der Hammen, 1995), the East Carpathians Area and Central Siberia (The upper part of the sequence refers to Drozdov and Artemiev, 2005). Graphic symbols; 1) loess; 2) loam; 3) silty sand; 4) weak humic horizon 5) strong humic horizon; 6) bleached horizon (tundra gley): 7) B horizon; 8) gravel; 9) ice wedge cast; 10) frost wedge; carbonate concretion; 12) wood remain. Abbreviations as in Figs. 3 and 8; GL: Glacial extensions (Northern Europe): POM: Pomeranian; FR: Frankfurt; BRAND: Brandenburg; K: Kurtak; Ch: Chani. Full horizontal lines: markers; dotted lines: lower limit of the interstadial episodes. The red vertical bars along the GISP2 sequence show the degree of uncertainty of inferred position of the dated samples from the loess into the climatic record of Greenland ice (modified from Haesaerts et al., 2009).

of the system (Damblon et al., 1996; Haesaerts et al., 2005). Table 8 shows good agreement between conventional dates obtained in parallel in both laboratories on equivalent wood remains collected in successive layers: a) a single large piece of wood sawn into two parts for each laboratory, b) two distinct pieces of wood found flat in the same layer, and c) two batches of several small-sized fragments of wood collected from the same layer. In the first case, the concordance between dates from the same wood elements appears very good when taking the ^{14}C measurement uncertainty. Similarly, double dating on distinct wood pieces from successive layers also yielded concordant results. Moreover, even the batches of small wood remains provided satisfying dates. In this way, we may assume and confirm that different laboratories working on good material can give truly concordant ^{14}C results as already shown by the international radiocarbon inter-comparison programs (Scott, 2003). Furthermore, the distribution of the ^{14}C dates from both laboratories seems very consistent through each of the three sections, following the stratigraphic correspondences established in the field between these sections, but also regarding the position of the dated wood fragments at the base, middle and top of the main humic layers (Figs. 8 and 9).

In other words, the consistent distribution of the radiocarbon ages of the Chani Bay Complex attests to very low reworking of the wood remains along the slope of the depression probably resulting from progressive sediment accumulation together with deep frost or permafrost conditions. Each humic accumulation is the consequence of a minor climate change and can be the result of the slipping of fallen spruce debris downslope during the summer season. On the other hand, the concentrations of large pieces of trunks and broken stumps, recorded in the upper part of sub-units 4-2 and 3-1 (Fig. 8), are probably related to intense run-off during rainy storms as they presently occur in the Kurtak region at the end of the summer. Then, the input of loess and loam contributed to sealing the humic layers so that the succession of such accumulations appears derived from the alternation of interstadial and stadial episodes also marked by variations in the spruce pollen curve (Figs. 8 and 9).

Taken together, the pedo-sedimentary records and the series of radiocarbon dates recorded from Chani Bay and Kurtak complexes evidence a semi-continuous succession of ten interstadial episodes with precise chronological framing between ca 42.5 and 26 kyr BP during the middle pleniglacial (Fig. 9). The first main interstadial is related to the brown boreal-type Tcherniakovsky Soil on the plateau and to the laminated silts dated 42.5 kyr BP at Chani. Following interstadial episodes Kurtak VIII (ca 39 to 38 kyr BP), Kurtak VII (ca 37 to 36 kyr BP), Kurtak V (ca 33.5 to 32.2 kyr BP) and Kurtak III (ca 30.8 to 30 kyr BP) correspond to major interstadials of one millennium or longer duration, taking the ages obtained for the lower part, middle part and top of the corresponding humic layers into account. By contrast, the episodes Kurtak VI (34.5 to 34.2 kyr BP) and Kurtak IV (around 31.9 kyr BP) are of shorter duration, of only a few centuries. This is also the case for episodes Kurtak II (28.9 to 28.5 kyr BP), Kurtak Ib (28.0 to 27.5 kyr BP) and Kurtak Ia (around 27 kyr BP) which precede the major cooling dated around 26 kyr BP on large stumps preserved *in situ* in the tundra gley capping the sequence at Chani (Figs. 8 and 9).

5. Discussion

5.1. The charcoal and wood record

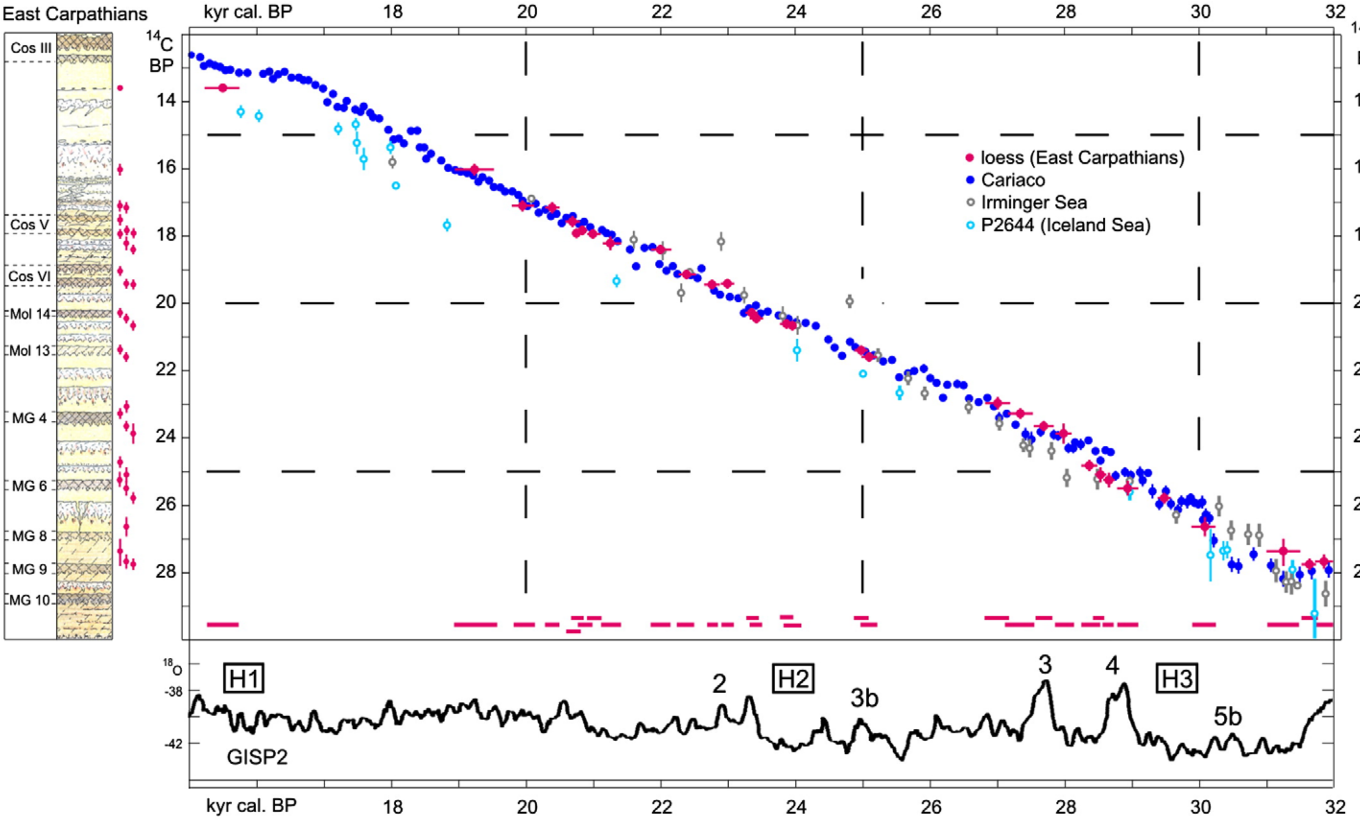
In the East Carpathian Area, as well as in Central Siberia, the diversity of taxa appears rather low with regard to the number of samples analysed in the investigated area (Table 1). Conifers clearly form the most common taxa in the charcoal and wood assemblages with often one taxon in a sample independent of sample size (Damblon, 1997; Damblon and Haesaerts, 1997; Haesaerts et al., 1998; Damblon and Haesaerts, 2002). Among the other taxa, only boreal and pioneer deciduous malacophylls (*Betula*, *Salix*, *Populus*, *Alnus*/*Duschekia* and cf. *Rubus*) are present. As in East Carpathian Area, most of the charcoal samples come from archaeological layers, the question arises if the very low diversity in taxa could be the result of fuel selection by humans (Théry-Parisot, 2001; Théry-Parisot et al., 2010-this volume). This might be possible if we consider the combustible quality of conifer wood (Boulton and Jay, 1946). Nevertheless, the availability of a limited number of tree species during the pleniglacial has also to be taken into consideration (Théry-Parisot, 2001; Théry-Parisot et al., 2010-this volume) as well as other factors like faster burning of soft woods such as birch, poplar and willow (Rossen and Olsson, 1985; Smart and Hoffman, 1988).

However, two arguments at least argue in favour of non-selective gathering of wood fuel. First, the charcoal concentrations from archaeological layers in the East Carpathian Area show the same low diversity of taxa, mainly conifers, than in the natural charcoal concentrations at Molodova (Unit 10) as well as at Kurtak where wood and charcoal remains are preserved outside any archaeological context. The same observation was made at Hungarian sites where natural "spruce forest" developed and was burnt around 28,000 BP on Kopash Hill (Sümegi and Rudner, 2001). In 21 sites of this region, from 32,500 to 15,900 BP, the charcoal spectra appear clearly composed of conifers (*Picea*, *Picea*/*Larix*, *Larix*/*Picea*, *Pinus sylvestris*, *P. cembra*, *Juniperus*) and scattered amounts of *Betula* and *Salix*.

A second argument lies in the pollen records of the Molodova and Kurtak sites. At Molodova V, the tree pollen dominance is shared by *Picea*, *Pinus* and *Juniperus* while *Larix* appears absent (Pashkevich, 1987). Boreal deciduous taxa are mainly represented by *Alnus*/*Duschekia* and *Betula*. Up to the top of the pollen record, the rising but low amounts of *Quercus*, *Ulmus*, *Tilia* and *Corylus* strongly suggest contamination from the Holocene soil. At Kurtak, clear alternations between *Picea* and *Pinus* curves prevail in the tree pollen record, suggesting a clear dominance of these conifers in the arboreal component of the Upper Pleistocene local steppe vegetation (Haesaerts et al., 2005). No mesophilous taxon is observed in the pollen spectra. At this point, the complete lack of mesophilous taxa in the charcoal assemblages suggests the absence of refuges for temperate trees during the pleniglacial in the investigated loess fields. For the preceding reasons, the over-dominance of conifer charcoal in the East Carpathian Area and Central Siberia is understood as directly deriving from the available tree component of the vegetation in the considered areas.

5.2. The inter-regional loess sequence

The investigated loess sequences of the East Carpathian Area and Central Siberia form two complementary high-resolution climatic and chronological records which cover the entire period between 42.5 and 10 kyr BP. The correlation between these records was founded on sequential comparison of the regional pedo-sedimentary and palaeoclimatic signatures, the internal consistency of the system being strengthened by the radiocarbon data (see Section 3.2). The connection between East-Carpathian and Kurtak sequences focuses first on the thick tundra gley that points to the important permafrost episode dated around 26 kyr BP in both regions where it precedes the late pleniglacial loess cover (Fig. 10). On this basis, the interstadial episode Kurtak III, well-dated between 30.8 and 30 kyr BP, is correlated with the interstadial episodes Molodova 10-2 and Malu Galben 11, within the same time slice. This leads to situate the episodes Kurtak II, Kurtak Ib and Kurtak Ia in parallel with the succession of Malu Galben 10, 9 and 8 in the East Carpathian Area. Finally, the brown boreal-type Tcherniakovsky Soil, ca 42.5 kyr BP, lies in a comparable position to the reddish brown chernozem of the lower pedocomplex at Molodova (subunit 8-1), and also to the Bohunice Soil and the Willendorf Interstadial dated between ca 43 and 40 kyr BP in the Middle Danube Basin (Haesaerts et al., 1996; Valoch, 2008; Richter et al., 2009; Nigst and Haesaerts, in press).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● loess (East Carpathians)
● Cariaco
○ Irminger Sea
○ P2644 (Iceland Sea)
Cos III
Cos V
Cos VI
Mol 14
Mol 13
MG 4
MG 6
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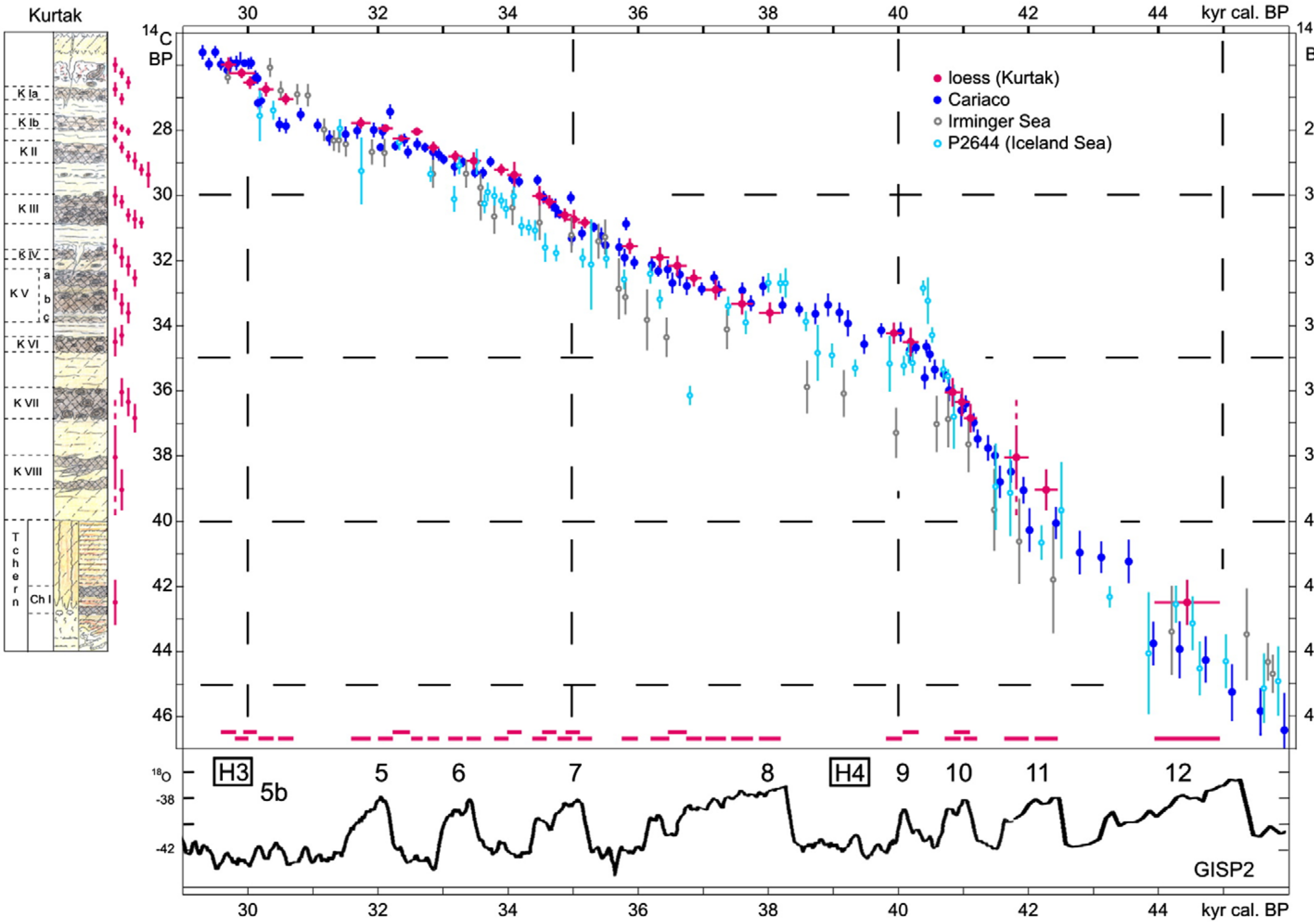
Kurtak
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40
42
44
kyr cal. BP
14C BP
28
30
32
34
36
38
40
42
44
46
● loess (Kurtak)
● Cariaco
○ Irminger Sea
○ P2644 (Iceland Sea)
K Ia
K Ib
K II
K III
K IV
K V
a
b
c
K VI
K VII
K VIII
Tchern
Ch I
18O
-38
-42
H3
5b
5
6
7
8
H4
9
10
11
12
GISP2

Within the inter-regional loess sequence, the distribution of the radiocarbon dates provides an accurate chronological framing of the climatic events between ca 42, 5 and ca 12 kyr BP (Fig. 10). It points to a duration of a few centuries for almost all interstadial events between 30 and 12 kyr BP, whereas most of the interstadial events prior to 30 kyr BP lasted at least 1 millennium or longer, as recorded at Kurtak.

The middle pleniglacial sequence of Kurtak also shows a number of similarities with the climatic record proposed by van der Hammen (1995) for the alluvial deposits of the Dinkel Valley in the Netherlands. This reinforces the reproducible character of most climatic episodes identified between ca 43 an 26 kyr BP across the entire Eurasian loess domain from Central Siberia to North-western Europe (Fig. 10). On the other hand, the late pleniglacial sequence of the East Carpathian Area occurs as a unique dataset for the period between 26 and 16 kyr BP, a time span including the Last Glacial Maximum (Kozarski, 1980) usually poorly documented in the loess domain of Central and North-western Europe (Djindjan et al., 1999; Street and Terberger, 2000; Haesaerts, et al., 2007). Taken together, the distribution of the main late pleniglacial loess bodies clearly points to a cyclic pattern (Figs. 7 and 10), as most of the loess layers are followed by an episode of stable surface with pedogenesis, whereas the thickness of the loess varies from site to site depending on the geomorphological context.

The high-resolution climatic record at disposal for the loess of Eastern Europe and Siberia combined with long series of consistent radiocarbon dates for the period between ca 42.5 and 10 kyr BP, has been linked with the climatic signature of the GISP2 isotope record (Grootes and Stuiver, 1997; Meese et al., 1997) and with the carbonate dust supposed to be a marker of aeolian sedimentation on the continent (Ram and Koenig, 1997). This scheme, based on the principle of sequential correlation (Fig. 10), relies on the hypothesis that loess interstadials correspond to positive peaks of $\delta^{18}O$ in the ice whilst rigorous episodes with deep frost or permafrost conditions are equivalent to low values of $\delta^{18}O$ (Haesaerts et al., 2009). The proxy-correlation scheme is further constrained by a set of markers related to specific climatic events. Among these, the permafrost episode that marks the end of the middle pleniglacial around 26 kyr BP is connected to the cold episode between GIS 4 and GIS 5b, associated with the Heinrich event H3 (Heinrich, 1988; Bond et al., 1992). In the same line, the Tcherniakovsky Soil and its equivalent in Eastern and Central Europe which record a major interstadial, are correlated to GIS 12. Furthermore, the late pleniglacial loess cover between 26 and 20.5 kyr BP may be connected with the high concentrations of carbonate dust between GIS 5b and GIS 2, whereas the loess body prior to 33 kyr BP at Molodova (subunit 9-3) would correspond to the cold phase between GIS 8 and GIS 9.

On this basis, when considering the succession of events between the different markers, each interstadial of the loess has its equivalent in the Greenland ice sequence. In the same way, the main tundra gleys of the loess are equivalent to the cold episodes of GISP2 reported to Heinrich events H1 to H3. In this procedure, the atmospheric derived radiocarbon ages from the loess are mainly used as an external dataset for improving the proxy-correlation scheme linking the loess climatic sequence to the Greenland ice record (Figs. 10 and 11). They were compared to the distribution of the uncalibrated ages obtained for the marine records of Cariaco (Hughen et al., 2004, 2006), Iberian Margin (Shackleton et al., 2004), Iceland Sea (Voelker et al., 2000) and Irminger Sea (van Krefeld et al., 2000), both set of continental and marine ages being positioned independently with regard to the GISP2 climatic record (Haesaerts et al., 2009).

6. Conclusion

The detailed study of long loess sequences in Eastern Europe and Siberia, most often associated with multi-stratified Palaeolithic sites, allowed analysis of various key factors which are used for establishing a fine radiocarbon chronology of the climatic events in the period from ca 42.5 to 10 kyr BP. This chronology is based on long series of atmospheric-derived radiocarbon dates obtained on charcoal and wood remains. A preliminary condition for obtaining reliable and accurate results is the careful positioning of the samples for dating within the stratigraphy. Another condition is determining the relation between the charcoal or wood samples and the pedo-sedimentary, climatic or archaeological events that are to be dated, a goal achieved by micro-stratigraphic observations. An important aspect of the problem lies in the necessity of selecting the dates on the basis of qualitative criteria, in particular regarding the dates published in the literature. Such criteria notably deal with the quality of the materials, preparation in the laboratory, selection of the best fragments for dating and also the final consistensy of the distribution of the radiocarbon ages in the stratigraphic sequences. Along the same lines, it is worth pointing out the importance of taxonomic identification in order to verify the homogeneity of a sample, mainly charcoal concentrations, and contribute as well to palaeoenvironmental reconstruction. Moreover, working on charcoal or wood concentration also enables cross-dating of a single sample or possibly on different samples from the same layer. By combining radiocarbon dates and detailed stratigraphy, it becomes possible to verify and strengthen correlations between the loess sequences on the basis of the sequential analysis of the pedo-sedimentary and climatic signatures.

On the whole, the implementation of these approaches in the study of the loess sequence has led to the establishment of long semi-continuous climatic and chronological sequences for the period between 42.5 and ca 10 kyr BP by integrating some 24 interstadial episodes with a resolution degree of centuries. In this way, the conjunction of the climatic signals in loess and the associated radiocarbon dates have led to the development of a proxy-correlative scheme with the Greenland ice sequence that allows the positioning of the long series of atmospheric derived radiocarbon dates from loess with respect to the isotopic signatures in the ice record. This approach provides an argument in favour of the reproducible and global character of the long series of short climatic events recorded in loess at the scale of the boreal hemisphere, from Siberia up to Greenland via Eastern and North-western Europe, as a complement to the north-south trend linking Greenland to the climatic records of Northern Atlantic, Iberian Margin and Cariaco.

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Fig. 11. Distribution of the atmospheric-derived ^{14}C dates from the East Carpathian Area (above) and Kurtak (below) regarding the GISP2 climatic sequence (as in Fig. 10), compared to the distribution of the radiocarbon dates from the marine sequences of Cariaco (Hughen et al., 2004, 2006), Irminger Sea (van Krefeld et al., 2000) and Iceland Sea (Voelker et al., 2000). Graphic symbols as in Fig. 10. The red vertical bars along the loess sequences correspond to radiocarbon dates (kyr BP) with 1σ uncertainty. The red horizontal bars along the GISP2 sequence show the degree of uncertainty of inferred position of the dated samples from the loess into the climatic record of Greenland ice as in Fig. 10 (modified from Haesaerts et al., 2009).

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