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The Upper Palaeolithic site Doroshivtsi III: A new chronostratigraphic and environmental record of the Late Pleniglacial in the regional context of the Middle Dniester-Prut loess domain (Western Ukraine)

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ABSTRACT

A multidisciplinary study of the Upper Palaeolithic site Doroshivtsi III (Western Ukraine) allows the establishment of a high-resolution chronostratigraphic and environmental record of short climatic oscillations during the Late Pleniglacial (from ca. 23 ka uncal BP to the Late Glacial). Chronostratigraphic records, radiocarbon dating, palynology and anthracology were used in parallel with archaeological studies. Palaeoenvironmental interpretations based on pedostratigraphy and pollen data show a remarkable concordance. The Doroshivtsi III sequence provides a succession of 12 short-time interstadial events. In the lower part of the sequence, they are separated by very cold and wet stadials, represented by tundra gleys. In the middle part of the sequence, interstadial events are separated by episodes of loess accumulation under cold and dry climate, whereas the upper part of the sequence almost completely consists of loesses. The sum of pollen of arcto-alpine and arcto-boreal plants was the largest during the periods of tundra gley formation, whereas few pollen grains of broad-leaved taxa occurred during formation of some soil horizons. The latter allows the preliminary suggestion that during the Late Pleniglacial some temperate trees persisted to the south from the Middle Dniester Valley. The Doroshivtsi III sequence is well correlated with the other East Carpathian records (Molodova, Mitoc and Cosautsi), and allows the establishment of a very complete record of climatic oscillations in this area from 33 ka BP to the beginning of the Holocene. It also provides a link for the correlation with the interstadial events 8 to 1 of the Greenland Ice Sequence.

1. Introduction

In Ukraine, the thickest and most stratigraphically complex loess-palaeosol sections are located near the valleys of large rivers (Veklitch, 1968). In the studied case of the loess of the last glaciation, they are the sections in the middle reaches of the River Dniester (Ivanova, 1977, 1982; 1987; Haesaerts et al., 2003, 2010; Kulakovska et al., 2015; Klasen et al., 2017) and the River Dnieper (Gerasimenko, 2006; Gerasimenko and Rousseau, 2008; Rousseau et al., 2011, 2017; Veres et al., 2018). Late Pleniglacial and the Late Glacial sediments show a frequent alternation of loesses, tundra gleys and incipient soils, and, thus, reflect short-period environmental oscillations.

The middle reaches of the Dniester is a unique area for the high-resolution study of the Late Pleniglacial as its sedimentary sequences here are very complete. They are also multi-layered Upper Palaeolithic sites, rich in charcoal and palaeontological material – both being indicators of palaeoenvironments and a source for radiocarbon dating. The remarkable archaeological potential of this region, particularly the Upper Palaeolithic sites, has been known since the beginning of the 20th century (Morosan, 1938; Chernysh, 1959). The best documented sites are those of Molodova I and V, Korman IV and Cosautsi on the right bank of the Dniester (Fig. 1).

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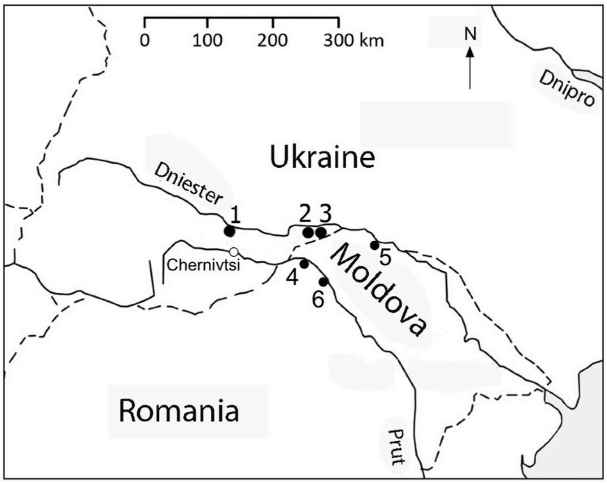

Fig. 1. Map of the sites location. 1: Doroshivtsi III; 2: Molodova V; 3: Korman IV; 4: Mitoc-Malu Galben; 5: Cosautsi; 6: Ripiceni-Izvor.

The first multidisciplinary palaeoenvironmental research on these archaeological sites was fulfilled under the leadership of I.K. Ivanova: Korman IV (1977), Molodova I (1982) and Molodova V (1987); it included geological-geomorphological study of the area, pedostratigraphy, radiocarbon chronology, clay mineralogy, palaeosol micromorphology, palynology, fauna and molluscs, geomagnetic excursions and secular variations in the deposits. The climate of the Late Pleniglacial (the Upper Valdai, between ca 23.5 uncal ka BP and 13.0 ka BP) has been shown to be periglacial, with two slightly warmer phases (the first, at the very beginning of the period, and the second, between 17.1 and 16.8 ka BP). The warming at ca 12.3-11.9 ka was correlated with the Late Glacial interstadials. The principal pedostratigraphical refinement for Molodova V was provided by Haesaerts et al. (2003, 2010). The pollen data from the three sites (Pashkevich, 1977, 1987; Bolikhovskaya and Pashkevich, 1982) indicate the predominance of periglacial tundra-steppe (or tundra-forest-steppe) evidenced by the presence of palynomorphs of arcto-alpine and arcto-boreal species in combination with pollen of xeric herbs. At Molodova I and V, the interstadial is revealed at about ca 17 ka, by a significant spread of forest and a strong reduction of cryophytes against a background of steppe predomination. After this episode, the periglacial steppe with cryophytes included a few clusters of pine, associations of shrub birches and sedges.

Important loess-palaeosol sequences were also recorded at Mitoc-Malu Galben along the Pruth River in Romania and at Cosautsi along the Dniester in Moldova (Fig. 1). All the sites concerned are located on the western slope of the river, close to the outlets of tributaries, and they acted as sedimentary traps. These sediments record different time spans in varying positions in the topography (Ivanova, 1982, 1987; Haesaerts et al., 2003, 2010). Together, they provide a synthesized sedimentary sequence covering the long period between ca 33 ka and the start of the Holocene, whose chronology is based on a large number of radiocarbon dates on charcoal, mainly from cultural layers. This regional loess-palaeosol sequence encompasses a complete set of 18 interstadial events which are marked by humiferous horizons ranging from para-rendzinas in the lowermost part of the sequence to incipient bioturbated horizons higher up. Such a record may be ascribed to specific favourable conditions which existed from the Carpathians to the Dniester plain also reported by Velichko and Isayeva (1992), who pointed out that this area was occupied by vegetation dominated by wooded steppe cover during the Late Pleniglacial.

In this paper, the complete stratigraphic record of the upper part of the Late Pleniglacial, ranging from ca. 23.5 ka to the Late Glacial, has been documented at Doroshivtsi III site along the Dniester, north of Chernivtsy (Kulakovska et al., 2011, 2015). This sequence, which combines high-resolution pedostratigraphic and pollen records, is an important source for exploring environmental dynamics during this time period in south-eastern Europe.

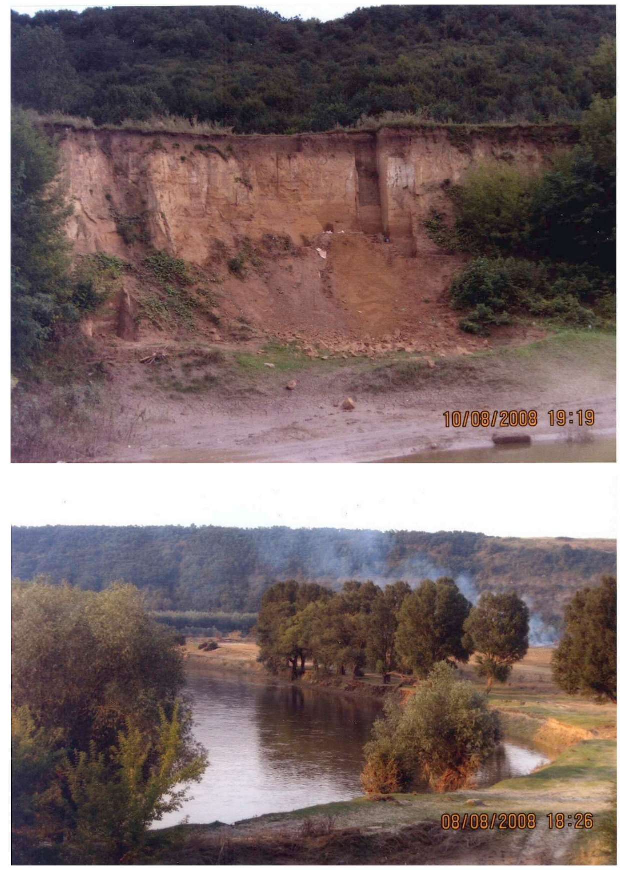

Fig. 2. The Doroshivtsi III site. Upper: the site to the west in 2008 (the trench is ca 6 m high); below: the Dniester valley from the site to the east.

2. Regional settings

The Doroshivtsi site is located in the Dniester Valley (N 48° 35′ 38"; E 25° 52′ 11″), ca 100 km to the west of Molodova I and V (Fig. 1). In this area, the river developed a valley deeply cut into Neogene and Cretaceous deposits, down to the Palaeozoic basement (Ridush, 2008; Kulakovska et al., 2015). To the west, the Middle Dniester Basin joins the Moldavian Plateau, which extends to the Carpathians via the Pruth Valley. At Doroshivtsi III, the subaerial Upper Pleistocene sequence is preserved along the western side of the valley (Fig. 2). Its base is positioned ca. 10 m above the present-day alluvial plain and 17 m above the thalweg of the Dniester (Fig. 3). The 10 m-thick cover deposits (Fig. 4), related to the first and second terrace complex, were cleaned and recorded over a distance of ca 30 m during the excavations, between 2006 and 2012, by the team of the Institute of Archaeology of the National Academy of Sciences of Ukraine (Kulakovska et al., 2015).

At present, the studied area is located in the Eastern European broad-leaved geobotanical province, whose natural vegetation shows a predominance of oak-hornbeam forest (Barbarych, 1977). *Fraxinus excelsior* L., *Acer platanoides* L, *A. campestre* L., *Tilia cordata* Mill., and *Betula pendula* Roth. frequently occur as admixtures; and *Corylus avellana* L., *Cornus mas* L., *Frangula alnus* Mill., *Rhamnus cathartica* L., *Euonymus* sp. and arboreal Rosaceae (*Crataegus* sp., *Rosa canina* L., *Prunus spinosa* L., *Rubus* sp.) form the undergrowth. The ground cover consists of mesophytic herbs and grasses. Forests of *Alnus glutinosa* (L.) Gaertn., meadows of mesophytic and hygrophytic herbs, grasses and sedges, and willow groups grow on the floodplain.

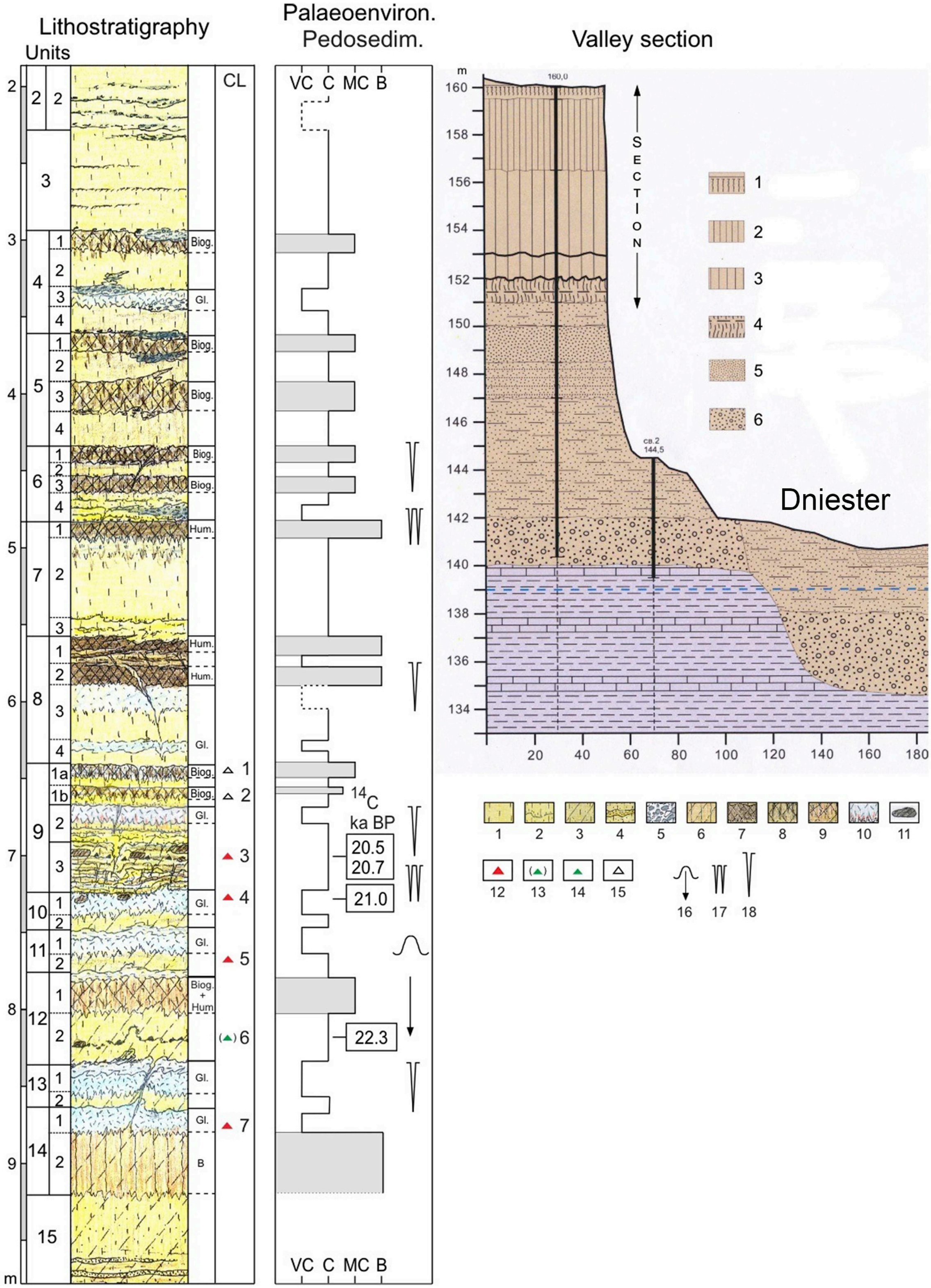

Fig. 3. Doroshivtsi III: Right: position of the site versus the Dniester alluvial plain (modified from Ridush, 2008; Kulakovska et al., 2015, Fig. 2). Graphic symbols: 1: soil; 2: loess; 3: loess with humic layers; 4: tundra gley horizons; 5: sand; 6: pebbles. Left: the sequence of the subaerial deposits at the site, radiocarbon dates, and palaeoenvironmental data. Graphic symbols: 1: silt; 2: sandy silt; 3: loam; 4: sand; 5: gravels; 6: B horizon; 7: light humic horizon; 8: dark brown humic horizon; 9: bioturbated horizon; 10: tundra gley with iron staining; 11: bones; 12: Gravettian; 13: cultural layer with some epigravettian components; 14: Epigravettian; 15: poorly documented cultural layer; 16: cryogenic disturbance; 17: wedges in a row; 18: isolated large wedges. Palaeoenvironment: VC: very cold; C: cold; MC: medium cold; B: boreal. Abbreviations: Biog.: biogalleries; Hum.: humic horizons; Gl.: tundra gley; B: B horizon; CL: cultural layer. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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Fig. 4. Doroshivtsi III: the upper part of the section in 2009: units 1 to 8.

3. Materials and methods

3.1. The radiocarbon dates

Charcoal and charred bone remains were collected at Doroshivtsi III from cultural layers 3, 4 and 6 by PH and the Ukrainian team in subunits 9-3, 10-1 and 12-2, respectively. The charcoal material is mainly represented (94%) by *Picea* (spruce). The obvious consequence of this fact was to select well preserved fragments of *Picea* charcoal as the basis material for radiocarbon dating. However, most charcoal fragments appeared obliterated by minerals, mainly secondary carbonates and silicates. Therefore it was useful treating the material with acids in order to remove such minerals. A first treatment with HCl 10% aimed at eliminate carbonates. After rinsing with distilled water, a second attack with HF 40% destroyed silicates. The material was then rinsed with HCl 10% and distilled water to obtain clean charcoal fragments for microscope examination and for radiocarbon dating. A last examination of the charcoal fragments under the microscope aimed at removing any traces of rootlets and other possible contaminants (see Damblon and Haesaerts, 2002; Haesaerts et al., 2010). The charcoal material was submitted to the Groningen and Cologne radiocarbon laboratories in order to favour comparison of the results. Samples were prepared following the ABA pre-treatment method in both laboratories. In the present paper, all radiocarbon ages are given in years uncal BP, including when abbreviated in ka.

Finally the dates, between 22.3 and 20.5 ka (Table 1), provide safe chronological markers in good agreement with the local pedostratigraphy.

3.2. Charcoal record

Charcoal and charred bone remains were collected from cultural layers 3, 4 and 6 in subunits 9-3, 10-1 and 12-2, respectively. All carbonized fragments were found only in association with Gravettian (CL4 and CL4) and Epigravettian (CL6) artefact concentrations. Consequently, the carbonized wood and bone remains appear to be the result of human activity.

The carbonized wood is attributed to *Picea* (spruce), *Pinus* indeterm., *Pinus cembra*-type (stone pine), *Larix*-type (larch), and there are fragments of unidentified charred bone (Table 1). Clearly *Picea* is dominant, with 94%, whereas *Pinus cembra* L. is around 3%. The other taxa of *Pinus* and *Larix* show very low amounts and *Pinus sylvestris* L. (Scots pine) is not represented among the charcoal material, but it is the main component in the pollen record. No fragment of small-leaved trees was found in the charcoal assemblages, though *Alnus* and *Betula* are significant in the pollen diagram.

All fragments of charcoal appear rather melted, with various signs of wood degradation such as cell shrinkage of the tracheids, local detachment of the cell walls and enlargement of the cell corners. Moreover, some pieces of conifer charcoal still bear other markers of degradation, like traces of bacteria and mycelium (Fig. 5). Such traces on charcoal are often interpreted as indications of the gathering of deadwood for fuel (Asouti, 2001; Moskal-del Hoyo et al., 2010; Henry and Théry-Parisot, 2014).

Some charcoal fragments of *Pinus cembra*-type and *Picea* from CL6 and CL3 at Dorochivtsi showed numerous bacterial rods in axial and radial cross-field tracheids and parenchyma cells (A-2397, Fig. 5). Bacterial degradation of wood has been described by Blanchette (1995) and Singh et al. (2003, 2016). Bacterial attacks are also occasionally noticed on archaeological charcoal, especially of pine (Badal et al., 2012; Carrion-Marco et al., 2012). Clearly, bacterial action contributed to cell degradation of the wood before burning.

Moreover, bacteria are held responsible for most of the decay of wood in both freshwater ecosystems and anaerobic aquatic habitats (Crawford and Sutherland, 1979; Holt and Jones, 1983; Schmit and Liese, 1994; Clausen, 2010; Kielak et al., 2016). Thus we may suspect that dead wood had lain for some time in a waterlogged environment. In any case, the charcoal fragments of *Pinus cembra* from sample A-2397 from CL 6 at Dorochivtsi III show clear characteristics of compression wood with twisted axial tracheids and with numerous bacteria eroding the secondary cell-wall microfibrils (Fig. 5). Traces of bacteria are also visible in charcoal fragments of spruce, such as in sample A-2395 (Fig. 5). Such degraded state of the structures suggests that Man collected dead, rather than green, pine and spruce wood and possibly at least a part of the wood had stayed temporarily waterlogged.

3.3. Pollen data

Almost all subunits of the section have been sampled for pollen (including sampling at 5 cm intervals in its lower part). Pollen samples were prepared following this method: boiling in a 10% solution of HCl, disaggregation in a solution of sodium pyrophosphate ($Na_4P_2O_7$), a second treatment with HCl to remove the carbonates which appeared after disaggregation, boiling in a 10% solution of KOH, separation in a heavy liquid (CdI_2 and KI) of specific gravity 2.0 and 2.2, and cold treatment with HF to dissolve sand particles.

All samples show very good preservation of palynomorphs, and those re-deposited from the Neogene or Early Pleistocene deposits differ clearly in their colour and exine thickness. The upper beds (Unit 3 − Subunit 8-4) are relatively rich in palynomorphs amongst loess-palaeosol sections (100–200 pollen grains were counted in each sample). The lower beds are poorer in palynomorphs (though not less than 100 pollen grains were counted). Re-deposited old pollen grains occur in the upper beds (11–30% of the sum of original palynomorphs). The majority of these consist of Pinaceae which are resistant to dynamic sedimentation. High percentages of re-deposited pollen indicate intense colluviation of silt particles during deposition. Almost complete absence of re-deposited pollen in the lower beds is evidence that they were accumulated without erosion of the underlying Neogene. Diatoms and spores of the microalga *Pseudoshizaea circula* (an indicator of wet ground), *Pediastrum* and fungal spores occur. Pollen has been identified with the use of spore-pollen atlases (*e.g.* Kuprianova and Alyeshina, 1972, Kuprianova and Alyeshina, 1978; Bobrov et al., 1983; Reille, 1995, 1998).

4. Results

4.1. The pedostratigraphic sequence (from top to bottom)

The Doroshivtsi III sequence has been subdivided in 15 units, most of them recording a succession of sedimentation and episodes of pedogenesis under a stable surface (Figs. 3 and 4). The geometry of the system remains almost sub-horizontal, with the exception of the lower

Table 1
Doroshivtsi III: Radiocarbon dates on charcoal and comparison with corresponding pollen data. Abbreviations − n: high number of small, not counted charcoal fragments.

Charcoal							Pollen	
Stratigr.subunit	Depth m	Cultural layer	taxa	nb fragm.	Presence of	14C age BP	Pollen Zones PZ / Pollen spectra PS	taxa %
9–3	6.78	CL 3	*Picea*	58		20,504 ± 80	PZ 11	*Picea*: <2%, *Pinus sylvestris*: 13–28%
9–3	6.84	CL 3	*Picea*	80	bacteria	20,740 ± 80	PS 22	*Pinus cembra*: <2%
10–1	7.10	CL 4-1	*Picea*	17		20,976 ± 76		
			Pinus	1				
							PZ 10	*Picea*: 3–4%
10–1	7.10	CL 4-1	*Picea*	17		–		*Pinus sylvestris*: 43%
			Pinus t. cembra	7			PS 23	*Pinus cembra*: 3–4%
			t. Larix	1				
			ch. bone	1				
10–1	7.20	CL 4-inf.	Picea (small fragm.)	n	mycelium	–		
12–2	7.83	–	*Picea*	n		–	PZ 5b	*Picea*: 3–8%
								Pinus sylvestris: 11–24%
12–2	8.01	CL 6	*Picea*	40	bacteria	22,330 ± 100	PS 31-30	*Pinus cembra*: 1–7%
			Pinus t. cembra	2	bacteria			*Larix*: < 1%
			ch. bone	2				

Total charcoal fragments		nb	%
	Picea	212	93.8
	Larix	1	0.4
	Pinus	1	0.4
	P. cembra	9	4.0
	ch. bone	3	1.3
	very small pieces	n	0.1
	total:	226	100.0

part of the sequence where some units were locally truncated by erosional processes.

Unit 1 (0.00–1.30 m; not on Fig. 3)

Dark grey silt with crumbly structure; abundant krotovinas in the lower part and gradual transition to unit 2.

Unit 2 (1.30–2.30 m)

Pale yellowish homogeneous sandy silt (2-1) with, in the lower part, several thin discontinuous layers of small limestone fragments, slightly dipping to the east (2-2).

Unit 3 (2.30–2.95 m)

Pale yellowish homogeneous sandy silt with some thin light grey layers in the middle part. The base of unit 3 is slightly discordant on top of underlying unit 4 with some lenticular concentration of limestone gravels.

Unit 4 (2.95–3.60 m)

Pale yellowish sandy silt (4-2), wearing on top a decimetric light grey-brown crumbly horizon with brown biogalleries and scattered charcoal fragments (4-1). The middle part is a decimetric continuous light grey horizon with iron staining along small root casts (4-3) passing laterally to involuted lenses of gravels (4-3), which are capping the sandy silt 4-4. As for unit 3, the base of unit 4 is slightly discordant on top of underlying unit 5.

Unit 5 (3.60–4.35 m)

This unit encompasses two light yellowish sandy silt layers (5-2 and 5-4) capped by pale yellowish brown layers with abundant brown biogalleries extending downwards (5-1 and 5-3), both layers being locally upturned.

Unit 6 (4.35–4.85 m)

It occurs as a duplication of unit 5, with two pale grey-brown bioturbated decimetric horizons (6-1 and 6-3) separated by sandy silt (6-2). The lower part of unit 6 is fairly heterogeneous, including thin layers of yellowish sand and large lenses of gravels (6-4) with a set of wedged in a row. Locally, isolated deep wedges also open on top of 6-1.

Unit 7 (4.85–5.55 m)

Thick pale yellowish grey homogenous sandy silt (7-2) with a decimetric dark brown bioturbated horizon on top (7-1). The lower part of unit 7 is sandy with thin lenses of gravels (7-3).

Unit 8 (5.55–6.40 m)

The upper part of this unit consists of two dark brown horizons (8-1 and 8-2) with in between thin layers of pale yellowish silt and isolated deep wedge-like features. The upper horizon (8-1) is strongly stretched whilst the lower one (8-1) is rather homogenous with abundant thin root casts. The main part of unit 8 consists of two layers of pale yellowish grey homogeneous sandy silt (8-3 and 8-4) wearing a light grey horizon on top.

Unit 9 (6.40–7.20 m)

On top, this unit encompasses two thin bioturbated pale yellowish brown horizons (9-1a and 9-1b) related to cultural layers 1 and 2, developed on yellowish sandy silt. Subunit 9-2 consists of yellowish grey sandy loam with thin sandy layers, grading into a grey horizon with iron staining and isolated wedges on top. Subunit 9-3 is a heterogeneous stratified sandy loam with several sets of thin wedges in a row; its upper part contains cultural layer 3.

Units 10 and 11 (7.20–7.75 m)

Duplicated yellowish grey sandy loam (10-2 and 11-2) capped by well-developed light grey horizons with iron staining (10-1 and 11-1). Cultural layers 4 and 5 are respectively positioned on top of 10-1 and in 11-2.

Unit 12 (7.75–8.10 m)

The main part of this unit consists of a homogeneous pale yellowish ochre sandy loam (12-2). It contains cultural layer 6, locally up-turned by a disturbance starting from higher up (probably 11-1). The upper part of the unit is marked by a pale ochre-brown horizon (12-1) with abundant thin humic biogalleries.

Unit 13 (8.10–8.60 m)

Yellowish grey sandy loam (13-2); to the east its base truncates 14-1

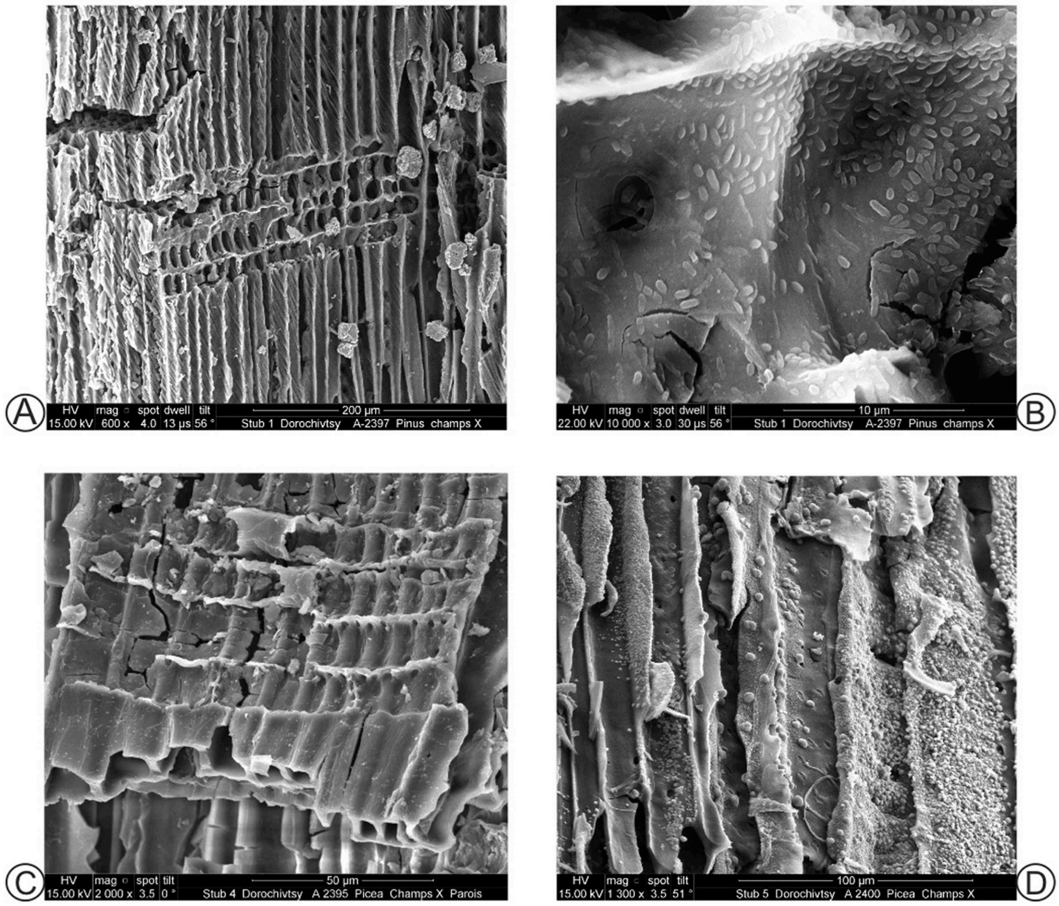

Fig. 5. Doroshivtsi III: charcoal remains. A: *Pinus t. cembra*, radial section with a ray, fenestrate pits on parenchyma cells, SU 12-2. B: *Pinus t. cembra*, radial section, ray cells with numerous bacteria on the cell walls, SU 12-2. C: *Picea* sp., radial section showing a cross-field with small simple pits, presence of bacteria on the vertical tracheid walls, SU 9-3. D: *Picea* sp., radial section showing a cross-field with small simple pits, presence of a mycelium remain in the lower part of the field, granules of fluorite are artefact residues of HF treatment, SU 10-1.

and rests on top of 14-2. All over section 13-2 is capped by a compact grey loamy horizon (13-1) with abundant iron staining. Locally the top of 13-1 is up-turned and penetrated by deep wedges.

Unit 14 (8.60–9.20 m)

This unit consists of two distinct horizons. The lower one (14-2) is a light yellowish ochre sandy loam with gradual lower limit, discordant on top of unit 15 with a thickness varying from 0.30 to ca 0.60 m. The upper horizon (14-1) occurs as a compact light grey loam with iron staining along root casts. Cultural layer 7 is located in the lower part of 14-1.

Unit 15 (9.20 down to ca 10 m)

Pale yellowish homogeneous sandy silt with several layers of coarse sand to the base.

4.2. Pedosedimentary signature

This approach combines the study of sedimentary and pedological processes recorded at a high degree of resolution over a distance of ca 25 m, allowing to observe their lateral variability.

The lower part of the sequence (units 14 to 9) consists mainly of poorly sorted sandy loam (Fig. 3). This type of sediments may be connected with colluvial processes reworking some part of the slope deposits preserved along the valley slope. It could be related to cold and rather humid conditions with poor vegetation cover. At the opposite, the upper part of the sequence (units 8 to 2) is characterized by a set of well sorted silty deposits of "loess type" in cold and dry conditions.

Within the Doroshivtsi III sequence, there are two dark brown horizons are of para-rendzina type (8-2 and 7-1). They point to boreal conditions with dense herb cover, also characteristic for the stretched humic horizon of 8-1 and for the B horizon of 14-2. These four horizons are reported to first order interstadial events (Figs. 3 and 4). In a similar way, light brown horizons with abundant brown biogalleries record medium cold conditions. These horizons well-documented in the upper part of the sequence (units 6 to 4), as well as on top of units 9 and 12, may be related to second order interstadials.

A special point deals with the light grey horizons with iron staining, often connected with cryogenic features (involutions and deep wedges). They show the signature of arctic soils of tundra gley type (Haesaerts and Van Vliet-Lanoë, 1981; French, 1976, 196–201; Van Vliet-Lanoë, 1985). Well documented in the lower part of the sequence, they record very cold climate with long periods of deep frost (subunits 14-1, 13-1, 11-1, 10-1 and 9-2).

4.3. The pollen record

Surface pollen samples from adjacent areas in the Chernivtsi region reflect well the composition of the modern vegetation (Gerasimenko et al., 2019a, 2019b), though pollen of *Pinus sylvestris* L. is over-represented. Even under the canopy of broad-leaved forest its pollen percentages are still 14–21%. This fits well with previous conclusions (Arap, 1972; Bolikhovskaya, 1986; Bezus'ko et al., 2011; Gerasimenko, 2019a, b) on over-representation of pine pollen in palynospectra. Surface pollen samples from Molodova I (Bolikhovskaya, 1986) have been also used in palaeoenvironmental interpretation of the Doroshivtsi III

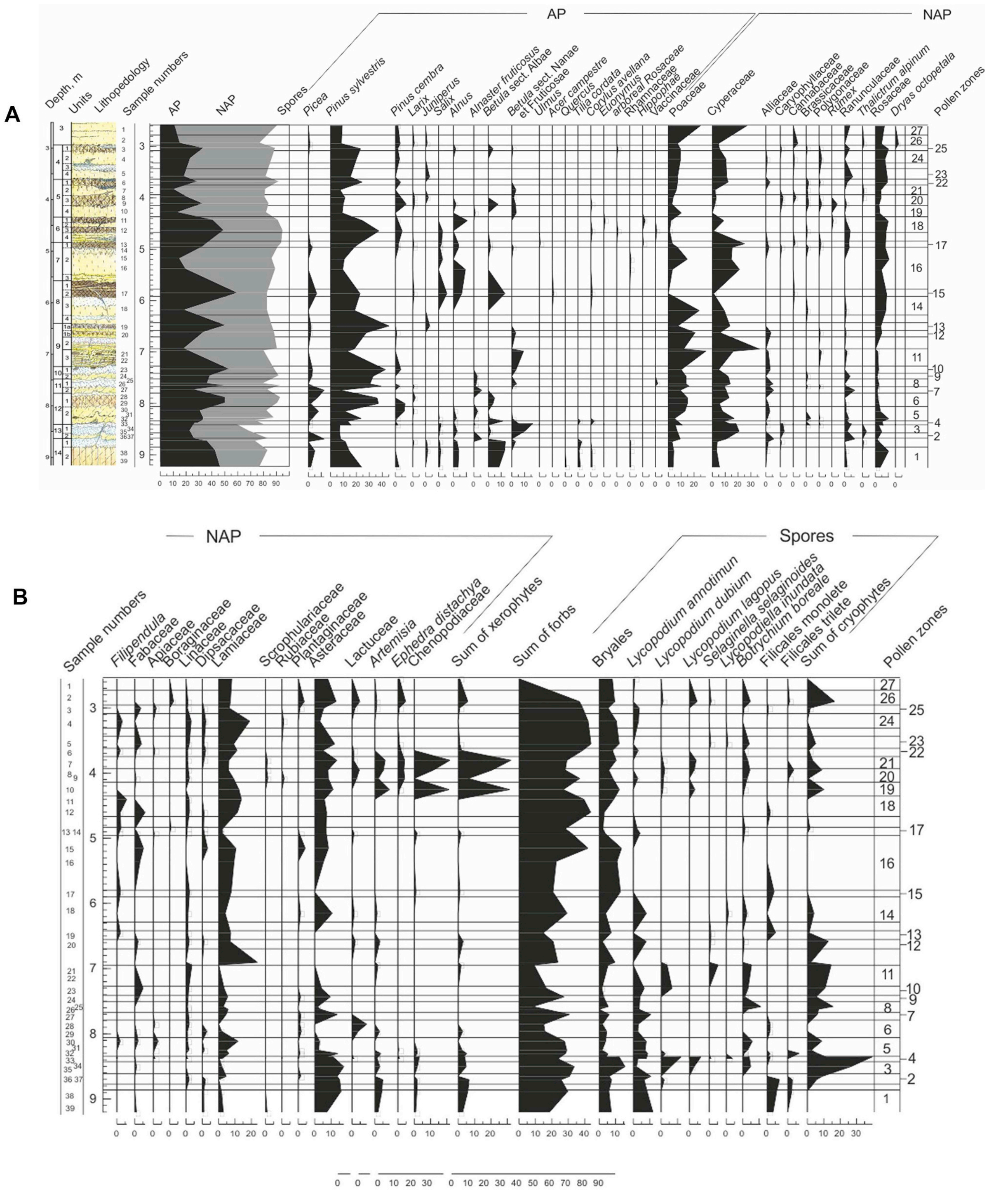

Fig. 6. a)Doroshivtsi III: pollen diagram, part 1. b)Doroshivtsi III: pollen diagram, part 2.

fossil spectra. The principal approaches to palaeovegetational reconstruction based on fossil pollen data follow those of Grichuk (1989) and Bolikhovskaya (1995). In the text and diagrams, the sum of palynomorphs of arcto-alpine and arcto-boreal species have been regarded as the sum of cryophytes (plants that can grow under low annual temperatures). Thus, this index was used for the tentative estimation of cold climatic conditions.

The results of pollen study in detail and pollen zonation are shown in the diagram (Fig. 6), in Table 2 and in the Supplementary Data to the paper.

In general, the main component of pollen assemblages of the Doroshivtsi III sequence is pollen of forbs, especially Lamiaceae,

Table 2
Summary of pollen stratigraphy and vegetational history of the Doroshivtsi III section. See Fig. 6 for the pollen diagram and Supplementary Data for its description.

StratiUnit	Litho-pedology	Pollen Zones	Pollen spectra	Main pollen features	Vegetation reconstruction
3	Loess (the middle part)	27	1	Almost complete domination of NAP. No pollen of cryophytes.	Boreal grassland. Cyperaceae near the water course.
3	Loess (the lower part)	26	2	NAP dominates. Forbs are prominent. *Ephedra distachya* L. and *Artemisia* sp. are present. *Pinus cembra* L. and a few *Picea abies* (L.) Karst. and *Larix* Mill. appear in AP. Cryophytes include *Dryas octopetala* L., *Selaginella selaginoides* (L.) Link., *Botrychium boreale* J. Milde and microthermal Lycopodiales.	Mosaic pattern of periglacial vegetation: mesophytic steppe with tundra elements (including *Dryas octopetala* L.), xeric coenoses on dry grounds, a few stands of *Pinus sylvestris* L., *Larix* Mill. and *Juniperus* L., with small admixture of dark conifers in the wetter places.
4–1	Biological horizon	25	3	Almost complete disappearance of cryophytes. NAP is dominant, with forbs most common. Increase in *Pinus sylvestris* L. and *Betula* sect. Albae.	Boreal forest-steppe: mesophytic herbal associations (Cyperaceae near the river) and sparse birch-pine woods with small admixture of *Pinus cembra* L. and *Picea abies* (L.) Karst.
4–2	Loess	24	4	NAP is significantly dominant, with diverse forbs. Cryophytes (*Selaginella selaginoides* L. and *Botrychium boreale* J. Milde) are present. AP is infrequent.	Cold mesophytic steppe with tundra elements. Cyperaceae frame the river course. A few bushes of *Juniperus* L.
4–4	Loess	23	5	NAP dominates, with significant increase in xerophytes (*Artemisia* sp., Chenopodiaceae, *Ephedra distachya* L.). Cryophytes are common (*Betula* sect. Nanae et Fruticosae, microthermal Lycopodiaceae and *Botrychium boreale* Milde). *Pinus cembra* L. and *Larix* Mill. appear in AP.	Mosaic pattern of periglacial vegetation: tundra-like mesophytic associations (with shrub *Betula*) alternate with xeric coenoses. A few *Pinus cembra* L., *Larix* Mill. and *Juniperus* L. occur in better protected localities.
5–1	Biological horizon	22	6	Forbs dominate in abundant NAP. Cryophytes decrease, AP slightly increases. Alongside with *P. cembra* L. and *Larix* Mill., *Betula* sect. Albae, *Alnus glutinosa* (L.) Gaertn, and a few *Corylus avellana* L. appear.	Boreal forest-steppe: mesophytic steppe, with a few cryophytes, and sparse pine-birch woods, with admixture of *Larix* Mill. and a few *Corylus avellana* L. (few *Alnus glutinosa* (L.) Gaertn.) near the river).
5–2	Loess	21	7	NAP dominates, with strong increase in xerophytes (Chenopodiaceae, *Artemisia* sp., *Ephedra distachya* L.). Cryophytes pollen is diverse and rather abundant (*Betula* sect. Nanae et Fruticosae, microthermal Lycopodiaceae, *Botrychium boreale* J. Milde).	Periglacial tundra-steppe: tundra plants (including clusters of shrub *Betula*) in wetter localities, xeric coenoses on drier grounds. No trees.
5–3	Biological horizon	20	8 9	Disappearance of cryophytes. Forbs dominates in abundant NAP, which also includes Poaceae and Cyperaceae. AP consists only of *Pinus sylvestris* L. and *P. cembra* L.	Boreal mesophytic steppe (diverse forbs dominate) and a few pine stands with Bryales and *Lycopodium annotinum* L. in ground cover.
5–4	Loess	19	10	NAP dominates, with xerophytes more abundant than forbs. Cryophytes include *Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb., microthermal Lycopodiaceae and *Botrychium boreale* J. Milde.	Periglacial tundra-steppe: xeric coenoses, with *Artemisia* sp., Chenopodiaceae and *Ephedra distachya* L., alternate with tundra associations, with shrub *Betula, Alnaster fruticosus* Ledeb, arcto-alpine species of lycopods and *Botrychium boreale* J. Milde. No trees.
6-1 6-3	Humus horizons	18	11 12	Increase in AP, which is rather diverse: *Pinus sylvestris* L., *P. cembra* L., *Salix* sp., *Alnus glutinosa* (L.) Gaertn., *Hippophaë* L. and a few *Corylus avellana* L. and *Euonymus* sp. Increase in forbs and disappearance of cryophytes.	Boreal forest-steppe – pine woods with small admixture of *Corylus avellana* L. and *Euonymus* sp., *Salix* sp., and *Alnus glutinosa* (L.) Gaertn. grew near the water. Mesophytic steppe with scattered *Hippophaë* L. bushes.
7–1	Humus horizon	17	13 14	NAP consisting of diverse forbs and Cyperaceae dominates. AP includes *Pinus sylvestris* L. and *P. cembra* L., *Picea abies* (L.) Karst., *Larix* Mill., *Salix* sp., *Betula* sect. Albae, and a few *Ulmus* sp. and *Hippophaë* L.	Boreal forest-steppe – mesophytic herbal associations alternate with sparse pine woods with admixture of arboreal *Betula, Picea abies* (L.) Karst, and *Larix* Mill. (a few *Ulmus* sp. in better protected localities). *Alnus glutinosa* (L.) Gaertn., *Salix* sp. and Cyperaceae grow near the water.
7–2	Loess	16	15 16	Strong increase in NAP (forbs, Cyperaceae and Poaceae). *Alnus glutinosa* (L.) Gaertn., *Salix* sp. and a few Rhamnaceae in AP.	Boreal steppe from forbs (dominate) and grasses. *Alnus* (L.) Gaertn., *Salix* sp., a few Cyperaceae and Rhamnaceae (cf. *Frangula alnus* Mill.) grow along the river course.
8–2	Humus horizon	15	17	Strong increase in AP (*Pinus sylvestris* L., arboreal *Betula, Picea abies* (L.) Karst., *Alnus glutinosa* (L.) Gaertn., *Salix* sp., *Larix* Mill., a few *Acer campestre* L. and *Corylus avellana* L. NAP is completely dominated by forbs.	Boreal forest-steppe: birch-pine woods, with admixture of *Picea abies* (L.) Karst., *Larix* Mill. and a few *Acer camperstre* L. and *Corylus avellana* L., alternate with mesophytic herbal association. *Alnus glutinosa* (L.) Gaertn. and *Salix* sp. frame the river.
8–3	Loess	14	18	The strongest increase in NAP, consisting only of Cyperaceae, Lamiaceae and Poaceae.	Cold meadow-steppe: Cyperaceae on wet grounds and Lamiaceae-Poaceae coenoses in drier localities.
9-1a	Biological horizon	13	19	AP increase, in which *Pinus sylvestris* L. dominates, *Picea abies* (L.) Karst. and *Juniperus* L. are present. NAP mainly consists of forbs and Cyperaceae.	Boreal forest-steppe: pine woods, with admixture of *Picea abies* (L.) Karst. and *Juniperus* sp., alternate with associations from sedges and forbs.
9-1b	Biological horizon	12	20	Increase in NAP (Poaceae, forbs, Cyperaceae) and cryophytes (*Betula* sect. Nanae et Fruticosae, a few *Selaginella selaginoides* L. and *Botrychium boreale* J. Milde). AP includes *Pinus sylvestris* L, a few *P. cembra* L. and *Picea abies* (L.) Karst.	Mosaic vegetational pattern: cold steppe from grasses and forbs with tundra elements (mainly shrub *Betula*) and sparse stands of *Pinus sylvestris* L., with a few dark conifers.
9–3	Cryoturbated gley beds	11	21 22	Strong increase in cryophytes (*Betula* sect. Nanae et Fruticosae, *Selaginella selaginoides* L., *Lycopodium dubium* Zoega and *Botrychium boreale* Milde). NAP (Poaceae, Cyperaceae and forbs) dominates over AP (*Pinus sylvestris* L. and a few *P. cembra* L. and *Picea abies* (L.) Karst).	Tundra: clusters of shrub *Betula*, cryophytic spore plants in association with grasses, sedges and forbs.
10–1	Tundra gley	10	23	Cryophytes are prominent (the same as in the above- described pollen zone). AP significantly increases – *Pinus sylvestris* L. strongly dominates over *P. cembra* L. and *Picea abies* (L.) Karst. Composition of NAP is similar to the PZ 11.	Forest-tundra: treeless ground, with arcto-alpine and arcto-boreal species, sedges, grasses and diverse forbs, alternates with sparse stands of *Pinus sylvestris* L. with a few dark conifers.

(*continued on next page*)

Table 2 (*continued*)

StratiUnit	Litho-pedology	Pollen Zones	Pollen spectra	Main pollen features	Vegetation reconstruction
10–2	Sandy silt	9	24	NAP dominates (mainly forbs). Decrease in cryophytes (few *Alnaster fruticosus* Ledeb. and *Botrychium boreale* J. Milde). AP includes *Pinus sylvestris* L. with a few *Picea abies* (L.) Karst.	Cold mesophytic steppe, with few cryophytes including clusters of *Alnaster fruticosus* Ledeb., alternate with sparse stands of pine with small admixture of *Picea abies* (L.) Karst.
11–1	Tundra gley	8	25 26	Increase in cryophytes (*Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb. and *Botrychium boreale* Milde. Dark conifers decrease sharply. Increase in Poaceae and Cyperaceae.	Wooded tundra: open grounds, with cryophytes (including clusters of microthermal shrubs), sedges and grasses, alternate with small patches of *Pinus sylvestris* L. with a few *P. cembra* L. and *Picea abies* (L.) Karst.
11–2	Sandy silt	7	27	NAP (mainly forbs) dominates. In AP *Picea abies* (L.) Karst. dominates over *Pinus sylvestris* L. Cryophytes include *Alnaster fruticosus* Ledeb. *Lycopodium annotinum* L. is abundant.	Cold mesophytic steppe with tundra element *Alnaster fruticosus* Ledeb. In wet places, *Picea abies* (L.) Karst. stands with boreal lycopods in the ground cover.
12–1	Humus horizon	6	28 29	AP dominates (*Pinus sylvestris* L., *P. cembra* L., *Picea abies* (L.) Karst., *Betula* sect. Albae and *Larix* Mill.). Forbs and Poaceae dominate NAP. Cryophytes are not present.	Boreal forest-steppe: woods from *Pinus sylvestris* L., with admixture of dark conifers, *Larix* Mill. and arboreal *Betula*, alternate with mesophytic steppe.
12–2	Light silt layer	5	30 31	Arcto-boreal plants (*Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb., *Lycopodium dubium* L. and *Botrychium boreale* Milde) appear and increase in the upper subzone (5b). *Pinus sylvestris* L. and *Betula* sect. Albae dominate the AP. *P. cembra* L., *Picea abies* (L.) Karst., *Alnus glutinosa* (L.) Gaertn., and (in the lower subzone 5a) a few *Tilia cordata* L. and *Corylus avellana* L.occur. Forbs dominate the NAP. Arcto-alpine spore plants are less frequent than boreal.	5b – wooded tundra-steppe: mesophytic herbal associations, with tundra elements (including *Alnaster fruticosus* Ledeb. and a few shrub *Betula*), and small patches of dark conifers and *Alnus glutinosa* (L.) Gaertn. in better protected localities.
			32		5a − boreal forest-steppe: pine-birch woods with admixture of *Picea*, a very few *Tilia* and *Corylus* and *Lycopodium annotinum* in ground cover, alternate with mesophytic steppe.
13–1	Top layer of tundra gley	4	33	Increase in NAP (forbs, Cyperaceae and Poaceae). Cryophytes are abundant (*Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb., *Selaginella selaginoides* (L.) Link.	Tundra: open grounds with diverse forbs, Cyperaceae, Poaceae, microthermal lycopods, and clusters of shrub *Betula* and *Alnaster fruticosus* Ledeb.
13–1	Bottom layer of tundra gley	3	34 35	The maximum increase in cryophytes (arcto-alpine Lycopodiaceae, *Betula* sect. Fruticosae et Nanae, *Botrychium boreale* Milde). Cyperaceae and forbs dominate NAP. Few *Alnus glutinosa* (L.) Gaertn., *Salix* sp. and arboreal *Betula* occur.	Tundra: shrub *Betula*, cryophytic lycopods, *Botrychium boreale* J. Milde and Cyperaceae on wet grounds, forbs in the drier places. A very few trees occur near the river.
13–2	Sandy silt	2	36	Decrease in arcto-alpine species (*Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb., *Botrychium boreale* Milde, *Lycopodium dubium* Zoega). NAP includes forbs, Cyperaceae and Poaceae. AP from the lower beds (subzone 2a) is more diverse (*Betula* sect. Albae, *Alnus glutinosa* (L.) Gaertn., *Larix* Mill.,a few *Tilia cordata* L. and *Frangula alnus* Mill.) than from the upper one (subzone 2b), which includes only *Pinus sylvestris* L.and *Picea abies* (L.) Karst.	Mozaic pattern of vegetation: 2b − tundra-like coenoses, with shrub *Betula*, *Alnaster fruticosus* Ledeb., arcto-boreal lycopods, Cyperaceae and forbs, and patches of boreal trees (*Picea abies* (L.) Karst. and *Pinus sylvestris* L.);
			37		2a – boreal forest-steppe with a few arcto-alpine plants. Pine-birch woods, with admixture of *Larix* Mill., a few *Tilia cordata* L., *Frangula alnus* Mill., and mesophytic steppe. *Alnus glutinosa* (L.) Gaertn. and Cyperaceae grow near the river.
14–2	Brown soil	1	38 39	Arboreal *Betula* dominates AP, *Picea abies* (L.) Karst and *Alnus glutinosa* (L.) Gaertn. are noteworthy. A few *Quercus robur* L., *Tilia cordata* L. and *Corylus avellana* L. Forbs dominate NAP, Filicales, *Lycopodium annotinum* L. are abundant among spores.	South-boreal sparse *Pinus*-*Betula* woods with admixture of *Picea abies* (L.) Karst., a few *Quercus robur* L., *Tilia cordata* L. and *Corylus avellana* L., with rich ground cover from forbs, in places, club-mosses and ferns. *Alnus glutinosa* (L.) Gaertn. grows near the water.

Asteraceae and Rosaceae (though the total number of forbs taxa in some humus and biological horizons reaches sixteen). The second important component is pollen of boreal trees and bushes, particularly *Pinus sylvestris* L., but also *P. cembra* L.*, Picea abies* (L.) Karst.*, Larix* sp.*, Juniperus* sp.*, Betula* sect. Albae, *Alnus glutinosa* (L.) Gaertn.*, Salix* sp.*, Hippophaë* sp.*,* and Vacciniaceae. The NAP is larger in the upper part of the sequence than in the lower part. The pollen percentages of *Picea abies* (L.) Karst. and *Lycopodium annotinum* L. (which is coenotically connected with *Picea),* and the sum of arcto-alpine and arcto-boreal plants are higher in the lower part of the sequence. The ratio of AP and NAP percentages changes in a cyclical pattern. Larger AP percentages correspond to humus and biological horizons. An important characteristic is the cyclic occurrence of cryophytes palynomorphs (*Betula* sect. Nanae et Fruticosae, *Alnaster fruticosus* Ledeb.*, Thalictum alpinum* L.*, Dryas octopetala* L.*, Botrychium boreale* Milde*, Selaginella selaginoides* (L.) Link*, Lycopodium lagopus* (Laest.) Zinzerl.*,* and *Lycopodium dubium* Zoega) which are more abundant in tundra gleys. The very low percentages of pollen of xeric herbs (and frequently their complete absence) and a rather significant presence of Cyperaceae pollen are the other important characteristic of the sequence's pollen record. Pollen of xeric herbs – *Ephedra distachya* L.*, Artemisia* sp. and particularly Chenopodiaceae − became prominent only in some loess units in the upper part of the sequence. Pollen of broad-leaved taxa (*Corylus avellana* L.*, Tilia cordata* Mill.*, Acer campestre* L.*, Ulmus* sp.*, Quercus* sp.), as well as bushes which are associated with temperate climate (*Frangula alnus* Mill.*, Euonymus* sp.), occur in small percentages and very rarely (mainly in the humus and biological horizons).

4.4. Doroshivtsi III archaeological assemblages

There are seven Upper Palaeolithic cultural layers present at Doroshivtsi, all located in units 9 to 14 of the stratigraphic sequence (Fig. 3). Cultural layers 1, 2 and 7 are represented by only very small assemblages of artefacts (n < 20) not allowing any more detailed analyses, while the assemblages of cultural layers 3 (n = 3981), 4 (n = 604), and 6 (n = 23,286) are sufficient for detailed technological and typological analyses (Kulakovska et al., 2015). In technological terms, cultural layers 3 and 4 are characterized by parallel, uni- and bidirectional core reduction. The abundant presence of lipped platforms suggests the use of soft hammer percussion. Retouched toolkits of both assemblages contain endscrapers, burins, retouched blades, backed bladelets, backed microblades, and rectangles, which are typical for the Gravettian technocomplex. Cultural layers 2 and 5 can be attributed to the Gravettian as well, despite the small assemblage of tools.

Cultural layer 6 is represented by 23,286 lithic artefacts. Reduction strategy is focused on the production of bladelets and microblades from the small-size uni- and bi-directional cores by hard hammer percussion. Punctiform and linear platforms are dominating, while lipped platforms are rare. Additionally, the assemblage of cultural layer 6 has its own typological characteristics. The tool-kit contains the tool-types characteristic for the Gravettian technocomplex such as backed microliths and shouldered points. At the same time, the burin-endscraper ratio is unusual for the Gravettian technocomplex. In the assemblage of cultural layer 6 end-scrapers are clearly dominating and the representation of burin types is untypical as well with dihedral burins and burins on truncation completely missing. The non-lithic assemblage of cultural layer 6 includes points made on mammoth ivory and bone, and one artefact, which is decorated with geometric ornamentation and zoomorphic images (Kulakovska et al., 2015).

On the other hand, cultural layer 6, dated to 22.3 ka BP, is low in the stratigraphic sequence (subunit 12-2, Fig. 3). The lithic assemblage of this layer bears little resemblance to the overlying, typical Gravettian materials. It is quite difficult to find any analogy of cultural layer 6 in the Middle Dniester Basin. Obviously, our conclusions are not final, since only a part of the site was excavated, and we do not exclude that the excavated area could have influenced the current typological composition of the assemblage. However, we want to stress the lack of typical Gravettian attributes in the primary blank production as well as the toolkit. Most likely the collection of cultural layer 6 at Doroshivtsi represents the result of an intrusive tradition with prominent Epigravettian features, which has practically no similarities in the local Gravettian.

5. Discussion

5.1. The pollen versus charcoal records

The charcoal record at Doroshivtsi shows the prevalence of *Picea* remains (Table 1), but this conifer exhibits low percentages in the pollen diagram. Conversely, *Pinus sylvestris*-type is not represented in the charcoal record, but it appears as the main arboreal component of the pollen assemblages (Fig. 6). On its own, *Pinus cembra*-type is represented by a few charcoal fragments.

Such disagreements are obvious in Table 1, showing the dominance of *Pinus sylvestris* pollens in stratigraphic units 9-3, 10-1 and 12-2, which contain cultural layers 3, 4 and 6 with a high dominance of *Picea* charcoal, but no *Pinus sylvestris* material.

This suggests that spruce-wood was probably more abundant and more easily available than pine wood in the gathering area of the site. But the relatively low pollen percentages of *Picea* speak in favour of spruce populations not very close to the site. In this scenario, we may assume that a part of spruce wood material collected and burnt by the Gravettians could have been imported from the Carpathians by the river Dniester, or more probably from regional forest galleries along the River Dniester and upstream tributaries like the rivers Seret and Strypa.

The apparent mismatch between the charcoal and pollen proportions observed in the fossil record of Dorochivtsi is not surprising when we consider the frequent over-representation of pine pollen in various open landscapes like some steppe, meadow-steppe and tundra, notably in the Hungarian Plain (Magyari et al., 2014), in Russia (Grichuk, 1989; Bolikhovskaya, 1995; Novenko et al., 2017), Ukraine (Arap, 1972; Bezus'ko et al., 2011; Gerasimenko et al., 2019a, 2019b), and Tibet (Xu et al., 2014; Ma et al., 2017).

Such disagreements between the charcoal and pollen records are also apparent in various archaeological and natural loess sequences (Haesaerts et al., 2010). At Molodova V, for example, the pollen record shows a dominance of *Pinus sylvestris* over other trees and shrubs (Pashkevich, 1987) while charcoal of this species is present in one layer only (tundra gley in SU 11-3 dated to 25.3 ka BP: Damblon et al., 1996).

Moreover, considering the very large set of charcoal samples analysed in the Dniester Basin, it appears that charcoal of Scots pine is often weakly represented relative to spruce, both in natural and archaeological concentrations. A good example of this is given by the sequences of Mitoc-Malu Galben and Cosautsi, where charcoal of *Pinus sylvestris* is observed in one layer only, but charcoal of *Picea* is present in every archaeological layer (Damblon, 2006; Damblon et al., 1996). Consequently, we may consider that Scots pine might be over-represented in the pollen records though it appears most often subordinate to spruce in the charcoal assemblages of that region, in particular at Dorochivtsi.

Another matter is the significance of the small percentages (≤1%) of pollen of various broad-leaved temperate trees (*Quercus* sp.*, Ulmus* sp.*, Tilia cordata, Corylus avellana, Acer campestre, Frangula alnus*) in the humus and biological horizons in the Doroshivtsi III sequence. In some cases (for example, in light silt layer SU 13-2), their presence is in disagreement with pedostratigraphical interpretation. Moreover, no one piece of charcoal of such taxa was found in the assemblages at Doroshivtsi III. Most probably the pollen input of these taxa may have come from refugia located to the south of the studied site. Nevertheless, the large piece of oak wood (determination of V. Sukachev) had been found in the cultural layer 8 (between 28 and 23 ka) at Molodova V, and no cold-tolerant snails were revealed from this level (Ivanova,

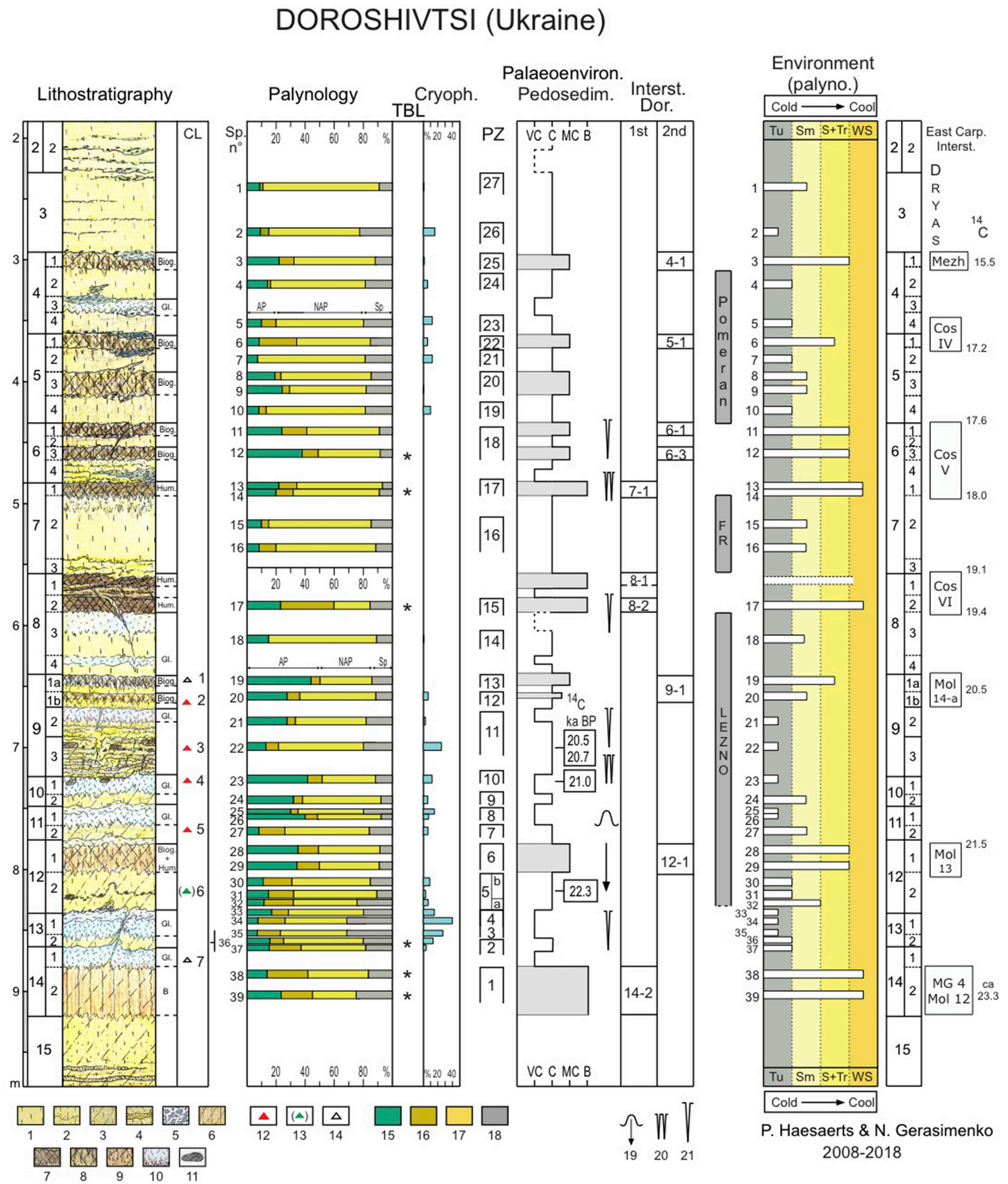

Fig. 7. Doroshivtsi III: pedostratigraphy, archaeology, pollen, chronological, palaeoenvironmental data and the synthesis. Graphic symbols and abbreviations: see Fig. 3; palynology; green (15): *Pinus sylvestris*; light ochre (16): other trees; yellow (17): herbs and forbes; grey (18): spores; TBL: temperate broad-leaved taxa. PZ: pollen zones. Palaeoenvironments derived from pedosediments; VC: very cold; C: cold; MC: medium cold; B: boreal. Palaeoenvironments derived from pollen data; Tu: tundra; Sm: mesophytic steppe; S + tr: steppe with trees; WS: wooded steppe (forest-steppe). Sites: Mezh: Mezhyrich; Cos: Cosautsi; Mol: Molodova V; MG: Mitoc-Malu Galben. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

1987, p. 114). A macroscopic charcoal of *Carpinus betulus* (26,962 ± 657 ^{14}C yr BP) and few pollen of *Quercus* sp., *Corylus avellana, Ulmus* sp. and *Carpinus betulus* which were revealed in the East-Hungarian Plain enabled the suggestion on the existence of micro-environment "oases", where thermophilous flora and mollusc fauna persisted during the full-glaciation (Willis et al., 2000). The similar refugia could have existed in the Dniester River basin on the other side of the Carpathians.

5.2. Palaeoenvironmental reconstructions on the basis of pollen data

The following environmental changes have been reconstructed on the basis of pollen data (Fig. 6) from the Doroshivtsi III section. They correspond well with those derived from pedosedimentary sequence studied (Fig. 7).

The brown soil at the base of the section (**Subunit 14–2**) formed under a light pine-birch cover with an admixture of spruce, *Pinus cembra* and a few occurrences of *Quercus robur* and *Tilia cordata* (PZ 1). At present, these broad-leaved taxa spread farther north and east than the other temperate climate tree. Hazelnut, buckthorn and juniper grew probably in association. The ground cover consisted of mesophytic herbs, ferns, green mosses and *Lycopodium annotinum* L. The river was flanked by alder and willow during a relatively warm interstadial.

Pollen data (PZ 2) from the overlying sandy silt (**Subunit 13–2**) indicate a colder climate than that during the formation of the brown soil. It is reflected in the appearance of arcto-alpine species (shrub birches, *Alnaster fruticosus* Ledeb., *Lycopodium dubium Zoega, Botrychium boreale* J. Milde*)*, the reduction in woodland and the impoverishment of their composition through the entire phase. At its beginning (PZ 2a), a sparse pine-birch cover existed with an admixture of larch, juniper, and, rarely, *Tilia cordata* Mill. and *Frangula alnus* Mill. Evidently, warmth-loving taxa have not yet disappeared completely from the Dniester River basin, being preserved to the South in refugia on the protected valley slopes. At the same time, arcto-alpine species had already occupied colder habitats. The vegetational cover had a mosaic pattern typical for subperiglacial environments (Bolikhovskaya and Pashkevich, 1982). At the end of the phase (PZ 2b), only few stands of spruce existed. Mesophytic herbs, sedges and grasses occupied open ground. Green mosses and boreal club-mosses (and at the beginning of the phase also ferns) grew in the woods.

The cooling progressed strongly during the next phase (**Subunit 13–1**). Low percentages of pine pollen (PZ 3) show that it disappeared from the site, and so did the other trees. Only a few alder and willow grew near the river. Tundra gley developed under a vegetation from arcto-boreal and arcto-alpine species of birches and club-mosses, *Thalictrum alpinum* L.*,* green mosses and sedges. A large proportion of mesophytic herbs were plants from the Rosaceae and Caryophyllaceae families, which are common at present in the Chukotka tundra (Polozova, 1983). The abundance of Asteraceae might be connected with the sandy substrata. The very high percentages of cryophyte palynomorphs indicate a periglacial climate. Such a climate also existed during formation of the top of Subunit 13-1. At that time, shrub birches and *Alnaster fruticosus* Ledeb. spread to the habitats that were earlier occupied by arcto-boreal spore plants (PZ 4). The low AP percentages indicate the spread of open areas, covered by sedges, grasses, and diverse forbs.

The lower part of the sandy silts (the base of **Subunit 12–2,** below the AH 6, ^{14}C dated to 22.3 BP) accumulated under a mesophytic steppe with wooded patches (PZ 5a). On the southern slopes, sparse pine-birch stands included a few *Tilia cordata* Mill. and *Corylus avellana* L.; on the northern slopes, spruce and shrub birches grew rarely. The infrequent occurrence of other arcto-boreal species (*Lycopodium dubium* Zoega and *Botrychium boreale* J. Milde*)* indicates the mosaic pattern of vegetation under a slightly warmer climate than during the preceding phase. The ground cover in the forest included ferns and boreal club-mosses. The next phase (the main part of Subunit 12-2, PZ 5b), which took place during and after formation of the AH 6, was marked by co-existence of tundra vegetation elements (*Botrychium boreale* J. Milde, a few shrub birches and *Alnaster fruticosus* Ledeb.) with patches of dark-conifer trees (*Picea abies* (L.) Karst. and *Pinus cembra* L., and boreal club-mosses in the ground cover). Alder, willow and dropwort (*Filipendula* sp.) framed the river. On the steppe, plants of the Lamiaceae became more abundant than those of the Asteraceae family. As the latter includes many psammophytes, this might indicate an increase in the surface stability.

During formation of the incipient soil (**Subunit 12–1**), a reduction of steppe occurred, and the terrace was covered by sparse pine wood, with an admixture of spruce*,* stone pine, larch, arboreal birches, and ferns and boreal club-mosses in the ground cover (PZ 6). Sedges grew near the water. The absence of arcto-boreal species indicates a cool and relatively wet interstadial climate.

A cyclic pattern in vegetational development is reflected in the new spread of mesophytic steppe, with a tundra element *Alnaster fruticosus* Ledeb*.*, during accumulation of sandy silts (**Subunit 11–2**, PZ 7, AH 5). Judging from low percentages of its pollen, pine did not occur near the site. Moisture-loving spruce and club-mosses grew in relief depressions. Xeric herbs disappeared from the vegetational cover during this cold climate phase.

A tundra gley (**Subunit 11–1)** was formed under cryophytic vegetation (shrub birches, *Alnaster fruticosus* Ledeb.*, Botrychium boreale* J. Milde) and sedges (PZ 8). Nevertheless, sparse pine stands with a small admixture of spruce*,* stone pine, larch, and boreal club-mosses in the ground cover occurred. It was the forest-tundra of a periglacial climate.

The overlying sandy silt (**Subunit 10–2**) formed under herbal coenoses, with the prevalence of plants of the Asteraceae (PZ 9). This might indicate an income of sand particles and a decrease in the surface stability. The cryophytes (*Alnaster fruticosus* Ledeb and *Botrychium boreale* J. Milde) were not abundant, and that indicates a drier climate than during the preceding phase.

The tundra gley (**Subunit 10–1,** AH 4, ^{14}C 20.9 ka BP) developed under the wooded tundra of a wet periglacial climate (PZ 10). The spread of cryophytes (shrub birches, arcto-alpine club-mosses and *Botrychium boreale* J. Milde) increased. The sparse pine woods had a small admixture of spruce and stone pine.

Gleyed beds and the tundra gley (**Subunit 9–3,** AH 3, ^{14}C 20.7 and 20.5 BP, and **9–2)** formed under tundra coenoses, with shrub birches, *Lycopodium dubium* Zoega*, Selaginella selaginoides* (L.) Link and *Botrychium boreale* J. Milde (PZ 11). Sedges, grasses, mesophytic herbs and a few *Artemisia* also constitute the important part of the vegetation. A few dark conifers might have grown on the southern slopes of the Dniester valley under this periglacial climate.

A biological horizon (**Subunits 9-1b,** AH 2**)** developed under the steppe from forbs (mainly plants from the Asteraceae and Rosaceae) and grasses (PZ 12). Sedges, club-mosses and horse-tails framed the river. A few pines and some dark conifers occurred, as well as arcto-boreal species (shrub birches, *Botrychium boreale* J. Milde and *Selaginella selaginoides* (L.) Link. A decrease in the extent of cryophytes indicates a less cold climate than during the preceding phase. The next biological horizon (**Subunits 9-1a,** AH 1**)** formed under a warm and wet interstadial climate. Sparse pine woodlands spread (PZ 13), with an admixture of spruce and juniper, mesophytic herbs, green mosses and ferns in the ground cover. Only a few *Selaginella selaginoides* (L.) Link occurred. Sedges and dropwort grew near the water.

A very different environment existed during the next phase, with deposition of a typical loess (**Subunit 8–3*).*** Steppe (mainly from grasses and Lamiaceae) occupied the terrace (PZ 14). Sedges grew near the river, though they became less abundant than earlier. The area was treeless, but the local herbal vegetation in the valley was not xeric. Thus, loess accumulation indicates regional aridity and strong dust storms. The boundary between Units 9 and 8 marks the end of the humid part of the Late Pleniglacial (a cryohygrophytic stage of Grichuk, 1972, 1989) and the beginning of its arid part (a cryoxerophytic stage) (Fig. 7).

The humus horizon (**Subunit 8–2**), on the contrary, developed under wooded steppe from birch, spruce, pine, few larches and the rich herbal ground cover (PZ 15). The spread of spruce and the expansion of alder and willows indicate an increase in humidity. The interstadial warming is also evidenced in the disappearance of cryophytes, the increase in ferns, and, supposedly, in the initial pollination of *Acer campestre* L. and *Corylus avellana* L. It is tentatively suggested that the last taxa might have grown in refugia within the valleys of the Dniester and its tributaries.

The overlying loess (**Subunit 7–2)** was deposited under steppe where forbs and grasses grew (PZ 16). Abundant sedges, green mosses, as well as some alders, willows and a few buckthorns grew only near the river. The cold climate became also arid.

During formation of the humus horizon (**Subunit 7–1**), mesophytic steppe vegetation also prevailed (PZ 17), but woods appeared, which included pine, stone pine, spruce, larch, arboreal birch, a few sea-buckthorn and elm. Alder, willow, sedges and dropwort grew near the river. In the herbal coenoses, the diversity of forbs became much larger and the proportion of grasses significantly decreased as compared to the preceding phase of loess formation. All of these features indicate the interstadial climate.

Similar interstadial forest-steppe environments existed during the formation of biological horizons (**Subunits 6–3 and 6–1**). Pine woods had undergrowth formed by arboreal Rosaceae, Vaccinaceae and a few pioneer elements of broad-leaved forest – hazelnut and spindle-tree (PZ 18). Sea-buckthorn occurred at the edge of woods. Alder, willow, dropwort and dock grew near the river. Forbs dominated the steppe coenoses, and the proportion of grasses and sedges was not significant.

The overlying loess (**Subunit 5–4**) accumulated under the very different vegetation of a treeless tundra-steppe (PZ 19), with abundant forbs, grasses, green mosses and cryophytes (shrub birches, *Alnaster fruticosus* Ledeb., *Thalictrum alpinum* L.*,* and arcto-alpine spore plants). This indicates the dry and cold climate of a stadial.

Forest-steppe with a significant prevalence of open landscapes (PZ 20) existed during the formation of the biological horizon (**Subunit 5–3**). A very few pine and stone pine stands occurred, with green mosses and club-mosses in the ground cover. Mesophytic herbs on the steppe were very diverse and predominated over grasses, whereas xerophytes and cryophytes almost disappeared. Abundant sedges grew near the river. This soil formed during the weak interstadial under a more humid climate than that of the preceding phase.

The overlying loess bed (**Subunit 5–2**) was deposited in a treeless steppe with tundra vegetation elements (PZ 21). The cryophytes (shrub birches, arcto-alpine club-mosses, *Thalictrum alpinum* L. and *Botrychium boreale* J. Milde) grew in wet habitats. Steppe coenoses occupied the drier ground, consisting of xerophytes (Chenopodiaceae, *Artemisia* sp. and *Ephedra distachya* L.), herbs (mainly Asteraceae) and grasses. The periglacial climate of this stadial was very dry.

The next biological horizon (**Subunit 5–1**) developed under forest-steppe (PZ 22). Pine-birch woods, which included stone pine, had an admixture of larch and a few hazel (a pioneer element of broad-leaved forest). Green mosses and boreal club-mosses formed the ground cover. The mesophytic steppe was marked by a large diversity of forbs (Lamiaceae and Asteraceae plants dominated). The role of grasses, sedges, and xerophytes was much smaller. Arcto-boreal plants (shrub birches, and *Botrychium boreale* J. Milde) persisted in the colder habitats. These features indicate the climate of a rather cool interstadial.

The overlying loess (**Subunit 4–4**) was deposited beneath a steppe (PZ 23) that had a mosaic pattern of vegetational cover with both xeric and mesophytic associations. The former consisted of Chenopodiaceae, *Artemisia* sp. and *Ephedra distachya* L.*;* the latter were rather diverse in their composition. An important feature was the appearance of cryophytes (*Lycopodium dubium* Zoega*, L. lagopus* (Laest.) Zinzerl. and *Botrychium boreale* J. Milde). Few pines (including stone pine), junipers and larches were scattered on the northern slopes. There existed a periglacial continental climate.

The next loess bed (**Subunit 4–2)**, which was formed under a mesophytic steppe with cryophytes (PZ 24), whereas xeric herbs were almost absent (*Ephedra distachya* L. occurred rarely). Cryophytes (*Botrychium boreale* J. Milde, *Lycopodium lagopus* (Laest.) Zinzerl. and *Selaginella selaginoides* (L.) Link) also were not particularly abundant. The area was treeless (only few juniper bushes occurred). This indicates the cold climate of a stadial.

The last biological horizon in the section (**Subunit 4–1**) developed under a wooded-steppe (PZ 25). Birch-pine stands included a small admixture of stone pine, spruce, larch, juniper and arboreal Rosaceae. Green mosses and boreal club-mosses formed the ground cover. The mesophytic steppe was marked by a large diversity of forbs (Lamiaceae, Rosaceae and Asteraceae plants dominated). The role of grasses, sedges, and xerophytes was much smaller. Arcto-boreal plants (a few shrub birches and *Botrychium boreale* J. Milde) were preserved in the colder habitats during this relative cool interstadial.

During deposition of the lower part of **Unit 3** (PZ 26), only a few scattered trees were in the area: *Pinus sylvesrtis* L.*, P. cembra* L.*, Picea abies* (L.) Karst*, Larix* sp. and *Juniperus* sp. On the mesophytic steppe, forbs significantly dominated over grasses and xerophytes (*Ephedra distachya* L. and *Artemisia* sp.). The two last associated with the cryophyte *Dryas octopetala* L. are typical for the Dryas stadials. Pollen of arcto-boreal and arcto-alpine plants (*Lycopodium lagopus* (Laest.) Zinzerl.*, L. dubium* Zoega*, Selaginella selaginoides* (L.) Link) and *Botrychium boreale* J. Milde) spread, indicating a periglacial climate of this stadial (evidently the Older Dryas). The upper part of Unit 3 accumulated under a treeless steppe, judging from the very low percentages of pine and any other tree pollen (PZ 27). The steppe consisted of grasses and an impoverished assemblage of forbs. Sedges spread markedly, which indicates a high river level, probably connected with the final melting of the mountain glaciers in the Carpathian headwater tributaries of the Dniester. The climate was cold and continental.

In general, these reconstructions demonstrate that cold climate open landscapes prevailed during the formation of the studied deposits. Despite they have relatively high AP value, it is only because a large part of pine pollen is commonly wind-transported from distant trees. The deposits of the lower part of the sequence (PZ 2–13) accumulated under colder and wetter climate than those of its upper part, as indicated by the more extensive spread of cryophytes and moisture-loving plants. The alternation of periglacial tundra coenoses with cold mesophytic steppe and partly wooded steppe happened during this time. The typical tundra coenoses coincide with the tundra gleys (particularly PZ 3, 4 and 11). Boreal forest-steppe with rare occurrences of broad-leaved species (PZ 1) only existed before this cold period.

The upper part of the sequence (PZ 14–27) was formed under a drier and less cold climate, which is indicated by the larger extent of open landscapes with less frequent occurrence of tundra-steppe (and especially tundra) coenoses than earlier. Cold times with almost absolute predominance of open landscapes alternated with periods of medium-cold or boreal climate, marked by the wider spread and the larger diversity of arboreal vegetation. The warmer phases correspond to the horizons of pedogenic origin. Sporadic appearance of pollen of broad-leaved taxa in some of these horizons (PZ 15, 17, 18) enables the suggestion on the warmer climate of the corresponding interstadials. The driest spells, marked by the peaks in xeric herb occurrences, was during loess formation (PZ 21 and 19), and the coldest time occurred at the beginning of the last loess deposition (PZ 26).

5.3. Correlation on the basis of pollen data

Pollen sequences most appropriate for correlation with the Doroshivtsi III record are those located close downstream in the Dniester Valley: at Molodova I (Bolikhovskaya and Pashkevich, 1982), Molodova V (Pashkevich, 1987) and Korman IV (Pashkevich, 1977; Bolikhovskaya, 1986). The lithostratigraphy, geochronology and palaeoenvironments of these sites have been provided by Ivanova (1977,

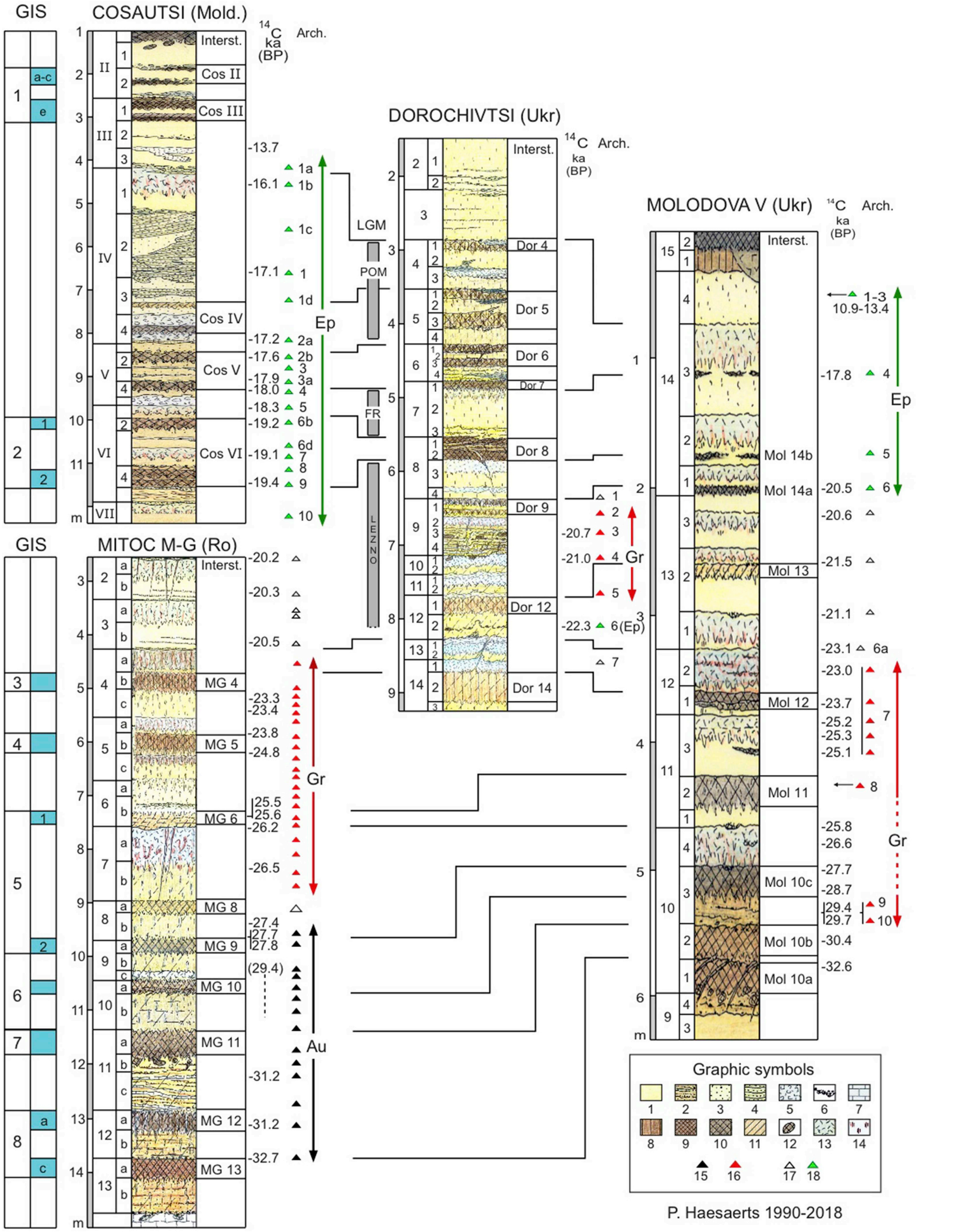

Fig. 8. East Carpathian Area (33–10 ka uncal BP). Correlation scheme linking Mitoc-Malu Galben, Cosautsi, Doroshivtsi III and Molodova V. For graphic symbols see Fig. 3 and 7. Abbreviations: GIS: Greenland Interstadials (Rasmussen et al., 2014). Interst.: interstadial events; Cos: Cosautsi; Dor: Doroshivtsi; Mitoc M–G: Mitoc-Malu Galben; Mol: Molodova V. Arch: Archaeology; Ep: Epigravettian; (Ep.): cultural layer with some Epigravettian component; Gr: Gravettian; Au: Aurignacian. LGM: Last Glacial Maximum; POM: Pomeranian; FR: Frankfurt.

1982, 1987), and the Molodova V site has been described, ^{14}C-dated in detail and correlated with other sites of the Pruth-Dniester Area by Haesaerts et al. (2003 and this paper). These, together with the positions of archaeological horizons, provide a basis for the correlation of the pollen results (Fig. 8).

The brown soil of subunit 14-2 at Doroshivtsi III is correlated with subunit 12-1 at Molodova V. In both units, the increase in AP (mainly conifers, but with a few broad-leaved taxa) indicate a relatively warm and wet interstadial. In both sites, the tundra gleys (unit 13 of Dor-III and subunit 12-2 of Mol-V) are marked by the appearance of abundant pollen of arcto-boreal species (especially at Dor-III). This vegetation reflects a very cold and humid stadial, termed by Grichuk (1989) as the 'cryohygrophytic stage' of the Late Pleniglacial. Unit 12 at Dor-III corresponds to the lower part of unit 13 at Mol-V. During this time, arcto-alpine plants became less abundant and then (during the weak interstadials Dor 12 and Mol 12) they disappeared, whereas dark conifers grew rather abundantly at both sites. The beds, dated between 21 and 20 ka BP, are related to units 11 to 9 at Dor-III and the upper part of unit 13 at Mol-V. This interval is marked at both sites by a drop in AP and an increase in the pollen of sedges and grasses. This indicates a cold climate, which is supported by the presence of pollen of arcto-alpine species at Dor-III. A further trend to aridification is seen in the strong predominance of NAP in the overlying beds at both sites, termed by Grichuk (1989) as the 'cryoxeric stage' of the Late Pleniglacial.

Pollen sample numbers in earlier studies of the Late Pleniglacial deposits of the region were small, as compared to those from the Dor III site: so all phases of vegetational dynamics revealed at Dor III cannot be completely reflected in pollen records elsewhere. In the Molodova I pollen data (Bolikhovskaya and Pashkevich, 1982; Bolikhovskaya, 1995), the Last Pleniglacial is represented by a drop in the AP and the appearance of pollen of arcto-alpine species in the interval between the Holocene and the palaeosol, related to Bryansk times (i.e. the upper Middle Pleniglacial). This time was characterized by periglacial forest-steppe vegetation including sparse birch-pine woods, shrubs (*Betula frutocosa* Willd., *B. nana* L. and *Alnaster fruticosus* Ledeb.) and open landscapes with *Artemisia,* Chenopodiaceae, grasses, sedges and cryophytes (*Botrychium boreale* J. Milde, *Arctous alpine* L., *Diphazium alpinum* (L.) Rothm., *Rubus chamaemorus* L., and *Selaginella selaginoides* (L.) Link). During a short warming in the middle of this period, alder and various bushes (*Corylus avellana* L., *Frangula alnus* Mill., *Lonicera* sp., and Caprifoliaceae), which are regarded as pioneer elements of broad-leaved forest, predominated. Only a few *Tilia cordata* Mill. and *Quercus robur* L. were present. At Dor-III, this phase might correspond to one of the short warm events, represented by humus horizons − either unit 8-1 or unit 7-1.

At Korman IV site (Kor IV) pollen record (Pashkevich, 1977; Bolikhovskaya, 1986), the coldest phase of the Late Pleniglacial is revealed in the 2 m-thick sequence of tundra gleys and sandy loams that overlie the Bryansk soil. Their base is ^{14}C-dated to 25.3 and 24.1 ka BP. The maximum pollen percentages of cryophytes (*Betula nana* L., *Betula humilis* Schrank. and *Selaginella selaginoides* (L.) Link.) enables the correlation of these beds with the 2 m-thick sequence (unit 13 to subunit 9-2) at Dor-III. The other feature in common in these beds between the two sections is the high percentage of spores. Further, the changes in AP percentages and the pollen sums of cryophytes in the described beds enable a higher precision correlation between them. The low AP (≤19%) and the highest percentages of cryophytes at the bottom of the Kor-IV gleyed beds fit well with what is recorded in PZ 2 and 3 at Dor-III. The increase in AP (52%) that follows at Kor-IV, accompanied by the disappearance of *Betula nana* L., allows a tentative correlation of this level with PZ 5 (humus horizon 12-1) at Dor-III. The intervening interval (30% of AP and a relatively low percentage of cryophytes) at Kor-IV might be a correlative of PZ 4 at Dor-III. Some decrease in the sums of cryophyte pollen and an increase in AP is seen in the upper part of the tundra gleys in both sites. The level with highest AP (65%) and the absence of cryophytes at Kor-IV might be tentatively compared with PZ 12 at Dor-III.

Pollen of cryophytes is practically absent in the middle part of the Kor-IV sequence, and that is also characteristic for the middle part of the Dor-III section (PZ 14–17 from units 8-2 – 7-1). Higher up in the Kor-IV section, there is an interval in which a few pollen of broad-leaved taxa occur together with small pollen percentages of arcto-alpine species. In the overlying loess bed, the sum of cryophytes increases and palynomorphs of broad-leaved plants disappear. Similar characteristics can be seen at Dor-III: 1) the co-occurrence of pollen from warm- and cold-loving species in the interval with alternating loess and humus-biological horizons (PZ 18–20 from units 6 – 5-3); 2) disappearance of pollen of broad-leaved taxa and the increase of cryophyte pollen in the overlying units 5-2 – 3 (PZ 21–27).

Thus, the Late Pleniglacial sequences studied for palynology in the Middle Dniester area demonstrate the predominance of open landscapes of periglacial and cold climate, which, nevertheless, alternated with short phases of less cold climate. During the warmer phases, the area was occupied by boreal woods, tree stands expanded, and the population of arcto-alpine plants became less, or disappeared. In all the pollen records of the area, the most humid and cold climate existed during the first half of the Late Pleniglacial. The second half was characterized by a more arid cold climate and a decrease in arboreal vegetation. During the short warm spells within this period, a few broad-leaved trees and bushes, preserved in well-protected refugia, were able to pollinate.

The pollen data from the Doroshivtsi III site differ from those from Molodova I, Molodova V and Korman IV sites in having higher pollen percentages of arcto-alpine species and lower pollen percentages of xerophytes. This obviously reflects the local environments of the sites, as the Doroshivtsi III vegetational succession developed on the surface of the lower terrace, with larger supplies of moisture than in the terrains where the other localities are located: and it can be noted that the majority of tundra plants thrive in humid localities. The proportions of pollen of xeric herbs also were not high in the Molodova V and Korman IV pollen records. Mesophytic herbal coenoses and sedges, together with arcto-boreal and boreal spore plants, dominated the open landscapes in the Dniester valley during the Late Pleniglacial.

5.4. Regional stratigraphic summary based on new data

The East Carpathian Area, with easy access to high quality flint, makes the link between the Baltic Plain and the Black Sea. It is known since the beginning of last century for its remarkable archaeological potential, mainly for what concerns Upper Palaeolithic sites (Morosan, 1938; Noiret, 2009). The best documented sites are Molodova I and V, Korman IV, and Cosautsi on the western bank of the Dniester, Ripiceni-Isvor and Mitoc-Malu Galben along the Romanian (western) bank of the Pruth (Fig. 1). All these sites are related to terrace systems preserved along the western valley slopes, which did act as sediment traps during complementary periods of the Upper Pleistocene regarding their elevation above the present-day alluvial plain (Haesaerts, 2007; Haesaerts et al., 2003, 2010). The cover deposits of most of these sites provided high-resolution pedosedimentary sequences with strong chronological frames based on long series of radiocarbon ages produced on charcoal mostly from Upper Palaeolithic cultural layers (Fig. 8).

At Mitoc, the first part of a unique 15 m sequence, consists of sandy loam deposits dated between 33 and 26 ka (units 13 to 7), with 6 palaeosols ranging from dark brown para-rendzina to incipient humic horizons, recording the interstadial events MG 13 to MG 8, whilst unit 7 wears a well-developed tundra gley dated between 26.5 and 26.0 ka (Fig. 9). The second part of the sequence consists of aeolian sandy silt dated up to 20.0 ka (units 6 to 2) with several tundra gleys (units 6a to 2a). It also records three pedogeneses related to interstadial events: the humic horizon 6b dated 25.5 ka (MG 6) and the two bioturbated brown horizons 5b and 4b respectively dated between 24.8 and 23.7 ka (MG 5) and just after 23.3 ka (MG 4); the latter horizon precedes the well-

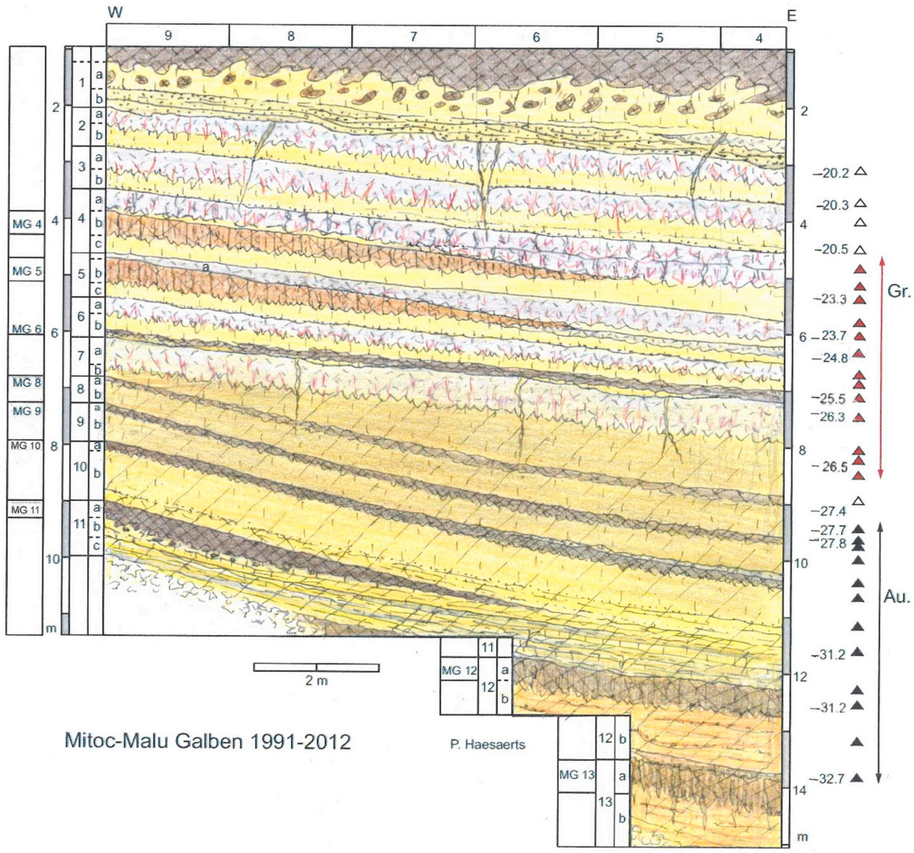

Fig. 9. Mitoc-Malu Galben (Romania): Stratigraphic units, radiocarbon dates and cultural layers (northern section, 2012). For graphic symbols and abbreviations see Figs. 3 and 8.

developed tundra gley 4a locally duplicated (Noiret et al., 2016, p. 39–45).

At Molodova V, related to a higher terrace system (Ivanova, 1987), the upper 6 m of the sequence encompassing units 10 to 14, is dated between 33 and 11 ka (Fig. 8). Only units 10 to 12 show close similarities with the Mitoc record, taking into account their pedostratigraphic signatures and their chronological frame up to 23 ka. In this way, most of the Molodova V interstadials events Mol 10 to Mol 12 have their equivalent at Mitoc. The same is true for the well-developed tundra gleys of subunits 10-4 and 12-2, respectively dated around 26 ka and 23.0 ka at Molodova, which fit with the tundra gleys 7a and 4a of the Mitoc sequence (Fig. 8).

At Molodova V, the overlying loess cover encompasses units 13 and 14 dated in between 23 and 11 ka. They complete the upper part of the Mitoc sequence and record the two short climatic episodes Mol 13 and Mol 14a marked by the humic horizons dated 21.5 and 20.5 ka.

At the opposite of these two sites, Cosautsi on the Moldavian bank of the Dniester is related to the lowest terrace system (Haesaerts, 2007, Fig. 13). Its 10 m thick sequence records the period between ca. 20 ka and the start of the Holocene, with an impressive succession of Epigravettian settlements well-dated between 19.4 and 13.7 ka. The first part of this sequence encompasses three doublets of humic horizons reported to the interstadial episodes Cos VI (19.4–19 ka), Cos V (18–17.6 ka) and Cos IV (17.2–17.0 ka), with in between cold snaps with sandy loam, chalky flows and a tundra gley. The upper part of the sequence points to the predominance of aeolian sedimentation (sandy loess) up to the Late Glacial, with evidence of two cold events between 17 and 16.1 ka: the pocket-like structure in subunit IV-2 and the tundra gley of subunit IV-1. At the top, two doublets of humic horizons record Bölling (Cos III) and Allerød (Cos II).

When we position the Doroshivtsi sequence within the East Carpathian system, together with Mitoc-Malu Galben, Cosautsi and Molodova V, a consistent correlation scheme may be proposed, based on their pedosedimentary signatures and their chronological frames documented by the consistent series of radiocarbon dates on charcoal (Fig. 8).

A first approach allows to position the Doroshivtsi sequence in the upper part of the Late Pleniglacial, with as corner-stone the pollen occurrence of *Dryas octopetala* L. in unit 3 at Doroshivtsi III (see Chapter 4.2). It may be ascribed to the start of the Late Glacial and could fit with the sandy loess III-3 at Cosautsi and with the loess of subunit 14-4 at Molodova V.

A second corner-stone at Doroshivtsi is marked by units 14 and 13, which record in succession the B horizon related to the interstadial event Dor14 capped by the well-developed tundra gleys of subunits 14-1 and 13-1, both prior to 22.3 ka (Figs. 7 and 8). A similar succession is encountered at Mitoc in the upper part of the section with the brown bioturbated horizon 4b (MG 4) also capped by a well-developed tundra gley (unit 4a) dated in between 23.3 and ca. 20.5 ka (Fig. 9). This is also the case at Molodova V where the humic horizon of subunit 12-1 (Mol 12) dated 23.7 ka is overlain by the strong tundra gley12-2 dated 23.1 ka on top (Fig. 8).

A third corner-stone is marked at Doroshivtsi by the doublet of dark brown humic horizons 8-1 and 8-2, the latter recording an interstadial event with large extension of wooded steppe in the valley (Dor 8-1, see Chapter 4.2). These humic horizons could be considered as being equivalent to the two humic horizons VI-4 and VI-2 at Cosautsi (Cos VI), dated between 19.4 and 19 ka. This assumption is reinforced by the high degree of resolution of units 12 to 8 at Doroshivtsi and by their radiocarbon ages. Indeed, in a first step, the second order interstadial Dor 12 dated in between 22.3 and 21 ka, can be put in parallel with Mol-13 dated to 21.5 ka at Molodova V, whilst in a second step the interstadial Dor 9 slightly posterior to 20.7, clearly fits with Mol-14a dated to 20.5 ka. With this correlation scheme being fixed, the second order interstadials events Dor 7 and Dor 6 most probably connect with Cos V dated between 18 and 17.6 ka, and Dor 5 with Cos IV dated between 17.2 and 17.1 ka.

Finally, the second order interstadial Dor 4, prior to the Late Glacial (Fig. 7), could fit the short climatic improvement recorded by palynology at Mezhyrich site in central Ukraine (Komar et al., 2003) related to the first Epigravettian occupation in this area, well dated 15.5 ka (Haesaerts et al., 2015).

6. Conclusions

The pedostratigraphic and pollen records of Doroshivtsi III combined with their radiocarbon chronological markers, represent a very complete record of the environmental oscillations of the main part of the Late Pleniglacial. It is related to the position of this site, acting as sediment and pollen trap, in the Dniester Valley. The Doroshivtsi sequence consists of fourteen units, each of hem dominated either by pedological or sedimentary features, all of them containing pollen. The Doroshivtsi III record appears as a unique opportunity to combine high-resolution pedosedimentary and palynology data that shows a remarkable concordance in their palaeoenvironmental interpretation. It provides a succession of 12 short-time interstadial events within the three distinct parts of the sequence (Fig. 7).

The lower part of the sequence encompasses units 14 to 9 (PZ 1 to 13, Fig. 6) and the cultural layers 7 to 1 with radiocarbon dates from 22.3 to 20.7 ka. It records the main part of the LGM (cf. Kozarski, 1980) which follows the major interstadial event Dor 14 (subunit 14-2, Figs. 7, 8 and 10) with a wooded steppe vegetation (PZ 1), and it includes 2 second order interstadial events: Dor 12 in subunit 12-1 (PZ 6) and Dor 9 in subunit 9-1 (PZ 13 and 12). The sandy loam deposits in between are characterized by the predominance of tundra, wooded tundra and tundra-steppe vegetation, typical for a very cold and rather humid climate. Judging from the percentages of arcto-alpine and arcto-boreal plants, the most humid cold episodes correspond to the tundra gleys of subunits 13-1, 11-1, 10-1 and 9-2, frequently distorted by cryogenic features.

The middle part of the sequence (units 8 to 4, PZ 14 to 25) records loess accumulation under mesophytic steppe alternating with episodes of humic pedogenesis, the latter coinciding with the spread of boreal trees in the Dniester Valley. Eight short-time interstadial events (Dor 8 to Dor 4) are marked by humic horizons ranging from para-rendzina (subunits 8-2, 8-1 and 7-1) to light brown horizons with humic biogalleries (subunits 6-3 to 4-1). The milder climate phases (with development of wooded steppe) evidently correspond to the interstadial events Dor-8 (subunit 8-2) and Dor 7 (subunit 7-1). The driest and coldest episodes occurred at the end of the phase with a sharp increase in the pollen of xerophytes and cryophytes in subunits 5-4 and 5-2.

The upper part of the sequence (units 3 and 2, PZ 26–27), recording the beginning of the Late Glacial (Fig. 7), is characterized by almost continuous loess accumulation in the treeless steppe under cold and dry climate.

The comparison of pollen *versus* charcoal at Doroshivtsi III demonstrates an over-representation of Pinus sylvestris L. pollen and under-representation of *Picea* (L.) Karst. palynomorphs, and this has been taken into account in the palaeoenvironmental reconstructions. Charcoal of temperate broad-leaved species is absent in the studied deposits that was also noticed in the Mitoc, Cosautsi and Molodova V sites of the East Carpathian Area, in which thousands of large charcoal samples were analysed for the period covering the Middle and Late Pleniglacial (cf. Fig. 8; Haesaerts et al., 2010). The sporadic occurrences of temperate tree pollen taxa (*Corylus avellana* L., *Acer campestre* L., *Prunus spinosa* L., *Ulmus* sp., *Tilia cordata* Mill.) are systematically linked to short-time interstadial events (Fig. 6) at the base and in the upper part of the Doroshivtsi sequence (Dor 14 prior to 23 ka BP, Dor 8 ca. 19.5 ka BP, Dor 7 and Dor 6 between 18 and 17.5 ka BP). The corresponding deposits also have higher pollen percentages of conifer and other boreal genera. On the contrary, pollen of broad-leaved trees are not found in the loess deposits, the observation which limits the impact of possible long distance pollen transport. Consequently, it is suggested that some broad-leaved trees have subsisted during cold episodes of the Late Pleniglacial to the south in protected areas of the Dniester and Pruth Basins close to the Carpathians. Our pedosedimentary and palynological data thus confirm the particular environmental character of the East Carpathian Area (Velichko and Iasaeva, 1992). Moreover, the possibility of the persistence of boreal and temperate trees refuges around 28.5 ka, at the end of the Middle Pleniglacial, has also been suggested for restricted areas of the western foothills of the Carpathians (Willis et al., 2000).

The Doroshivtsi III sequence, formed in between 23 ka and the Late Glacial, with its 12 short interstadial events, fits well into the regional East Carpathian sequence combining the Molodova V, Mitoc and Cosautsi sequences (Fig. 8). This high-resolution stratigraphic and palaeoenvironmental records, well radiocarbon dated from ca 33 ka BP up to the beginning of the Holocene (Figs. 9 and 10), evidently encompass interstadial events GIS 8 to GIS 1 of the Greenland Ice Sequence (Rasmussen et al., 2014). The Doroshivtsi III site demonstrates the occurrence of late Gravettian occupations up to 20.5 ka, almost simultaneously with the Epigravettian layer 6 at Molodova V (Fig. 8), but with an overlap of around 2 ka with the Epigravettian components of the Doroshivtsi cultural layer 6 dated to 22.3 ka (Kulakovska et al., 2015 and section 3.5 of this paper).

The Late Pleniglacial environmental signatures of the East Carpathian Area clearly differ from those of the Middle Danube Basin. In that region, humic horizons are rarely recorded in the Late Pleniglacial loess whereas tundra gleys occur as a predominant feature (Klima et al., 1962; Demek and Kukla. 1969; Haesaerts, 2007). At Dolní Věstonice (Klima, 1967, 1995; Haesaerts, 1990) and at Krakow-Spadzista (Van Vliet Lanoë, 1975; Kozlowski, 1986), the tundra gleys are associated with large ice-wedge pseudomorphs, indicative of continuous permafrost, dated around 23 ka (Washburn, 1973; French, 1976; Haesaerts and Van Vliet-Lanoë, 1981; Haesaerts, 1984). This confirms that tundra gleys record very cold and rather humid conditions (Figs. 7, 8 and 10; Haesaerts et al., 2016, 41) and raises questions about the attribution of tundra gleys at Nussloch (Germany) to interstadial events (Moine et al., 2018).

The pleniglacial pedosedimentary and pollen data from Doroshivtsi III and other sites of the Middle Dniester Area (Bolikhovskaya and Pashkevich, 1982; Bolikhovskaya, 1995) indicate that during the main part of the LGM, the regional climate was milder than in the adjacent regions. The Carpathians, the Pre-Carpathian and Podolian Uplands acted as protective barriers and their deeply dissected relief provided refugia for arboreal vegetation.

Ethical statement

The authors of this paper have read the rules on Ethical Principles. I certify that we did not bring any of the rules in our paper.

Declaration of competing interest

We – the First Author, Prof. Paul Haesaerts, and Corresponding Author, Prof. Natalia Gerasimenko – certify that there is no any conflicts of interest which could appear with publication of this paper, as there was only our team who work on lithopedostratigraphy, pollen, charcoal and archaeology of the Doroshivtsi III Upper Pleolithic site.

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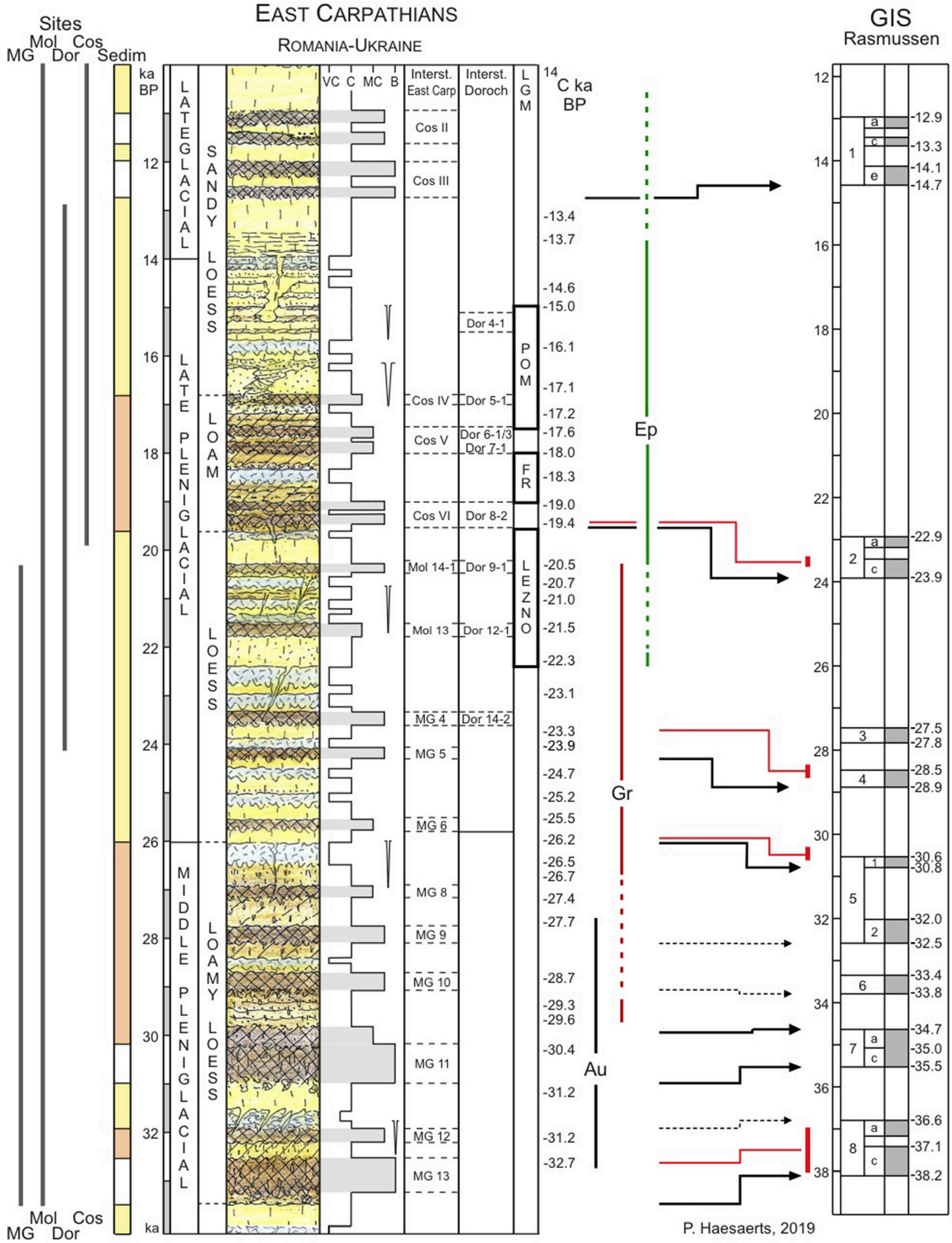

Fig. 10. The Doroshivtsi III data in context of the East Carpathian sequence (33-10 ka uncal BP) versus the GIS sequence (Haesaerts et al., 2009; Rasmussen et al., 2014). Graphic symbols and abbreviations: see Fig. 3 and 8. Sedim: sediment; pale yellow: loess; pale ochre: loam. Strong horizontal black lines: main links based on environmental signatures; strong horizontal red lines: set of calibrated radiocarbon dates BP (OxCal.4.2.3 software) positioned with regard to the Rasmussen ice chronology. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2019.12.018.

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