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Lateglacial and early Holocene vegetation development in the Gutaiului Mountains, northwestern Romania

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Abstract

Pollen analyses and AMS ^{14}C measurements were performed on lacustrine sediments and peat sequences from two former crater lakes (Preluca Tiganului, Steregoiu) situated in the Gutaiului Mountains in northwestern Romania, in order to reconstruct the vegetation development during the Lateglacial and Early Holocene.

Before c. 14,700 cal. years BP (GS-2) open vegetation with shrubs (*Salix*, *Juniperus*), grasses and herbs (e.g. *Artemisia* and Chenopodiaceae) prevailed in the area. Around c. 14,700 cal. years BP and coinciding with the beginning of GI-1e, *Pinus* expanded, and patchy vegetation with scattered *Pinus* stands developed. The last 100 years of GI-1e (14,150–14,050 cal. years BP) were characterised by an increase in *Pinus* and *Betula* and an expansion of open forest communities. This development was shortly interrupted between 14,050 and 13,800 cal. years BP (likely corresponding to the cold phase GI-1d), when the tree cover became reduced and open vegetation with scattered *Pinus* individuals became frequent. The period with a significant expansion of *Betula* and *Picea* and the formation of an open forest (including *Pinus* and *Ulmus*), which took place between 13,800 and c. 12,950 cal. years BP, is tentatively correlated with GI-1c-a. A renewed reduction in tree cover (decrease of *Picea* and *Betula*, disappearance of *Ulmus*) started at ~12,950 cal. years BP and at 12,600 cal. years BP forest stands were rapidly replaced by open vegetation communities with low shrubs (*Salix*, *Juniperus*), grasses and herbs (e.g. *Artemisia* and Chenopodiaceae). The period between 12,900 and 11,500 is correlated with the cold phase GS-1.

At 11,500 cal. years BP, most likely as a response to the warmer climatic conditions at the beginning of the Holocene, an expansion of *Betula* and *Alnus* and, slightly later, also of *Ulmus* can be observed. Between 11,500 and 11,250 cal. years BP, open forests with *Betula*, *Pinus* and *Ulmus* were widespread in the area. At 11,250 cal. years BP dense forests dominated by *Ulmus* replaced the open forest type. Around 10,700 cal. years BP *Quercus*, *Tilia* and *Fraxinus* expanded strongly, and *Acer* and *Corylus* became established. Mixed deciduous forest with *Picea* dominated the upland vegetation between 10,700 and 10,150 cal. years BP. At 10,150 cal. years BP *Corylus* increased significantly and between 10,150 and 8500 cal. years BP, dense mixed deciduous forests with *Picea* and *Corylus* were abundant in the area.

Climatic fluctuations seem to have been the driving force behind vegetation changes during the Lateglacial period, while the forest development during the Early Holocene was mainly driven by migrational and successional processes.

1. Introduction

Within palaeoecology, much attention has been devoted to tree migration, particularly to the migration from glacial refugia as a response to the climatic amelioration at the transition to the Holocene (e.g. Iversen, 1960; van der Hammen et al., 1971; Huntley and Birks, 1983; Huntley, 1988; Huntley and Webb, 1989). Palaeoecologists have also realised that knowledge of the dynamics and extinction of species in glacial refugia is important in order to understand the contemporary composition of the vegetation. The old assumption that the tree vegetation retreated towards the south at the end of an interglacial (e.g. Reid, 1935) has been shown to be an oversimplification (Bennett et al., 1991; Huntley, 1993). Instead, the survival of trees in southern Europe throughout warm stages may be equally as important for the long-term Quaternary

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vegetation development, as a survival during cold stages (Bennett et al., 1991).

However, neither the location of these glacial refugia is known in detail (Huntley and Birks, 1983; Willis, 1994), nor the areas where different tree species survived. Mid-altitude sites in, for instance Italy and the Balkans, where climatic conditions might have been favourable to support tree vegetation during cold stages, have been suggested as most likely refuge areas (e.g. Huntley and Birks, 1983; Bennett et al., 1991; Willis, 1992b, 1994).

The majority of the pollen records available today from southern Europe have been obtained from regional-scale sites which have a large pollen source area (Huntley and Birks, 1983; Willis, 1994). Therefore, they mainly show the regional, but not exactly the local vegetation development (Jacobson and Bradshaw, 1981; Sugita, 1993, 1994). Furthermore, many of these records have very low time resolution and are often restricted to the Holocene only. It is thus, difficult to locate exactly areas which could have acted as refugia and to reconstruct the local forest vegetation. Many trees show low pollen frequencies during the Lateglacial (Willis, 1994) and such low values are in general, difficult to evaluate without complementary data. A further problem is that many trees may have occurred in these refugia at very low densities. Conventional pollen analysis based on sediments from large sites does not allow detection of these low-density occurrences (Bennett, 1986; Kullman, 1995), but should be combined with plant macrofossil studies. However, such studies are yet rare from southern central Europe and the Balkans (Willis, 1992a–c; Willis et al., 2000; Wohlfarth et al., in press).

Another intriguing feature in Holocene palaeoecology is the remarkably rapid rate at which many tree species appear to have migrated from their glacial refugia (Huntley and Birks, 1983; Huntley, 1988). Such rapid migration rates are also shown, e.g. for *Quercus* and *Fagus*, which have a dispersal biology that would suggest a much slower migration. There is thus a possibility that some of these trees, which have been supposed to occur only in glacial refugia in southernmost Europe (e.g. Greece), also occurred further to the north. If this was the case, it would be easier to explain the seemingly rapid tree migration during the Early Holocene. Unfortunately, there is still not much evidence available to support this hypothesis, mainly because of a lack of detailed high-resolution studies (Willis, 1994).

An area, which can be regarded as potentially important for the study of glacial refugia, and the local presence of tree species during the Lateglacial, is Romania. Large mid-altitude areas—particularly in the Carpathian Mountains and adjacent areas in northwestern Romania—may have had a suitable climate during the Lateglacial. Romania is also strategically situated in the middle of the migration routes from Greece and Bulgaria towards the north. Most tree species occurring today in northern Europe may have migrated through Romania (or from refugia in Romania) during the Early Holocene. If this was the case, it should be possible to detect early Holocene migration patterns in Romanian pollen records.

Unfortunately, Romania is nearly a "white spot" on the palaeoecological map of Europe (Willis, 1994; Berglund et al., 1996). Although pollen stratigraphic work has a long tradition in Romania (e.g. Pop, 1960), and a relatively large number of sites have been studied, the results are almost entirely published in national journals and therefore largely unknown outside Romania (e.g. Coldea, 1971; Diaconeasa and Stefureac, 1971; Pop, 1971; Diaconeasa and Farcas, 1996; Farcas, 1996). Most of these studies comprise only the Holocene, and all studies are characterised by low sampling resolution and a complete lack of radiocarbon dates. Age estimates have mainly been derived by comparing the vegetation development to the Lateglacial and Holocene vegetation zonation established for central Europe (Firbas, 1949, 1952). This makes it very difficult to compare the timing of the vegetational development with the well-dated sequences from e.g. northern and western Europe (Berglund et al., 1996). Recently, however, Farcas et al. (1999) published a reconstruction of the regional Lateglacial and Holocene vegetation development, based upon pollen stratigraphy and AMS ^{14}C dates from two sites in northeastern and southwestern Romania. Soon, AMS dates and pollen and macrofossil data will also be published from a site in northwestern Romania (Wohlfarth et al., in press), but the studied profile only covers the earliest part of the Lateglacial, c. 14,700–13,600 calibrated years BP.

It is clear that additional palaeoecological investigations are urgently needed in Romania. New high-resolution pollen studies, combined with AMS ^{14}C dating, will enable problems relating to glacial refugia and early Holocene tree migration to be addressed. Moreover, a network of sites at different altitudes should reveal local and regional differences in the composition of the Lateglacial and early Holocene vegetation. The chance of detecting refugia would, through such an approach, be far better than in a study performed on a single site only.

The aim of this investigation is to present a spatially and temporally detailed reconstruction of the Lateglacial and Early Holocene vegetation development in the Gutaiului Mountains in northwestern Romania. The study is based on high-resolution pollen analyses and AMS ^{14}C measurements performed on cores from two relatively small and closely situated mid-altitude sites. In due course, plant macrofossil data also will be available, as well as pollen data covering middle and late Holocene vegetation changes.

2. Study area

The area with the two investigated former crater lakes (Preluca Tiganului and Steregoiu) is situated southeast of the small town of Negresti-Oas, on the western flank of the Gutaiului Mountains at an altitude of c. 700–900 m a.s.l. (Fig. 1). This massif is part of the Eastern Carpathian mountain chain, which stretches in a NNW–SSE direction and has peaks rising up to c. 1200–1400 m a.s.l.

The first site, Preluca Tiganului (47°48′83″N; 23°31′91″E), is situated at an altitude of c. 730 m a.s.l., has an almost circular surface area of c. 1 ha and is drained by a small stream. Gently rising slopes surround the site to the east and south. South of the site, the Tigan Mountain attains an altitude of 843 m, and towards the north, fairly steep slopes lead down to the Talna valley, which is situated at c. 400 m a.s.l. The surrounding forest vegetation consists of relatively young *Fagus* stands and recently (less than 20 years) planted *Picea* trees. In earlier investigations by Lupsa (1980) the site is described as an eutrophic to mesotrophic mire with a field layer dominated by grasses, sedges and herbs.

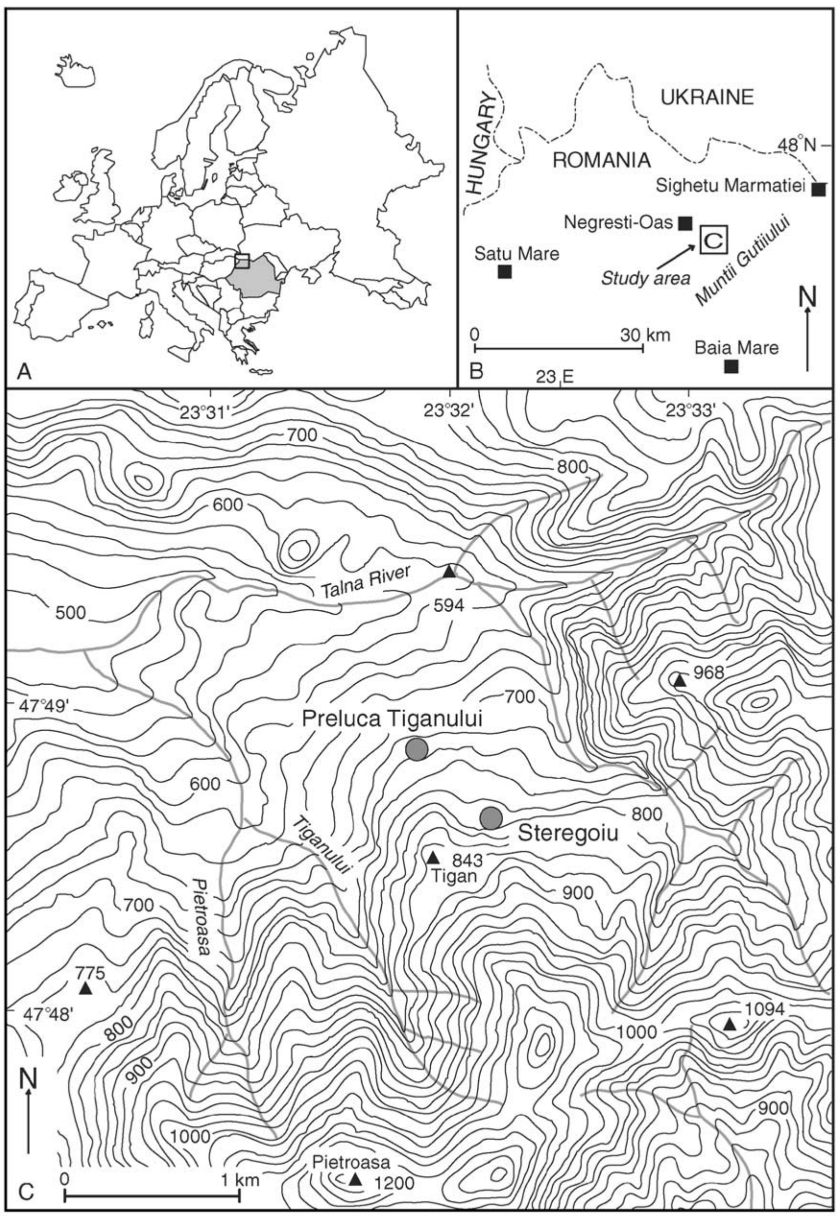

Fig. 1. Location of the investigation area in northwestern Romania and a detailed map of the study area showing the position of the investigated sites, Preluca Tiganului and Steregoiu.

The second site, Steregoiu (47°48′48″N; 23°32′41″E), is situated at a somewhat higher altitude than Preluca Tiganului, at c. 790 m a.s.l. It has a roughly elongated surface (c. 50 × 100 m) of c. 0.5 ha. The site is drained by a small stream towards the east. It is surrounded by fairly steep slopes to the south and west, where a small stream enters the basin. Towards the northeast fairly steep slopes lead down to the Talna valley. The surrounding vegetation is dominated by young *Fagus* (approximately 30–50 years) and *Picea* stands. The site can be described as a eutrophic to mesotrophic mire with a field layer dominated by grasses, sedges and herbs.

There are no climate records directly available for the study area, but records from weather stations in Satu Mare and Baia Mare (Fig. 1), and from the eastern (Ocna Sugutag) and northern (Sighetu Marmatiei) part of the Gutaiului Mountains, may be used as a good approximation. Highest mean annual air temperatures of 9.5°C are recorded at Satu Mare and Baia Mare, while temperatures range slightly lower at 7.8°C and 8.5°C east and north of the mountain chain. Mean annual precipitation is lowest in Satu Mare (c. 600 mm). It rises towards the east to c. 850 mm around Baia Mare and then decreases slightly to c. 700 and 750 mm towards the east and the north.

From a geological point of view, the area represents the northwestern termination of a volcanic arc, situated in the inner part of the Eastern Carpathians. The volcanic activity in this region took place during the Late Pliocene, generating a large range of intermediary and acidic rocks, in particular dacites, andesites and rhyolites (Borcos et al., 1979). The main bedrock type in the study area is andesite. There is no published information about Quaternary deposits in the area, but our own field observations in, for instance road cuts, indicate that most of the soil cover is derived from slope processes. It is also assumed that alpine glaciers did not reach below 1800 m a.s.l. in the Carpathians during the Last Glacial Maximum (LGM) (Balteanu et al., 1998). The low elevation of the Gutaiului Mountains makes it unlikely that the area was glaciated during the Weichselian, but is however, likely that the area has been subjected to periglacial conditions during the LGM.

3. Methods

Sediment cores were taken in the centre of each basin in May 1999, where the organogenic deposits were thickest (Table 1). Coring was performed with a strengthened Russian corer (diameter: 5 cm, length: 1 m), and each core was taken with an overlap of 50 cm, in order to obtain enough material for analyses.

Table 1
Simplified lithostratigraphic descriptions of the analysed profiles from Preluca Tiganului and Steregoiu

Depth (m)	Description
(*A*) *Preluca Tiganului. The pollen analysed levels extend between 9.89 and* 4.01 *m*	
0–6.13	Fen peat
6.13–8.70	Carr peat
8.70–8.78	Peaty gyttja
8.78–8.89	Gyttja peat
8.89–9.10	Peat
9.10–9.14	Gyttja peat
9.14–9.33	Clay gyttja
9.33–9.49	Peaty gyttja
9.49–9.59	Clay gyttja
9.59–9.68	Fine detritus gyttja
9.68–9.84	Coarse detritus gyttja
9.84–9.90	Fine detritus gyttja
(*B*) *Steregoiu. The pollen analysed levels extend between* 5.92 *and* 2.83 *m*	
0–1.25	Fen peat
1.25–2.80	Carr peat
2.80–4.28	Coarse detritus gyttja
4.28–4.57	Gyttja
4.57–5.26	Clayey gyttja
5.26–5.44	Gyttja clay
5.44–5.70	Silty clay (partly laminated)
5.70–5.84	Sandy silt
5.84–5.92	Silty clay

The cores were described in the field, and thereafter wrapped in plastic film and placed in half PVC tubes. Subsequently they were transported to the Department of Quaternary Geology in Lund, Sweden, where they were stored at 4°C. Prior to sub-sampling all cores were carefully cleaned, described again and visually correlated with each other.

The profiles were continuously sub-sampled at c. 2.5 cm intervals for pollen analysis. The preparation of the samples (1 cm^3) follows standard methods (Berglund and Ralska-Jasiewiczowa, 1986; Moore et al., 1991). To enable the calculation of pollen concentration, tablets with a known content of *Lycopodium* spores were added to each subsample (Stockmarr, 1971). Microscope slides were prepared from the residue and scored for pollen. At least 450–500 grains were counted in each subsample, except when pollen concentration was low, a minimum of 300 grains was accepted. Pollen counts were made at 400 × magnification, but 1000 × was used for some critical determinations. Pollen keys and illustrations in Moore et al. (1991) and Reille (1992) were used for pollen identification. Pollen slides in the reference collection at the Department of Quaternary Geology, Lund University, were also used to check some pollen types. Pollen nomenclature follows Moore et al. (1991).

Table 2
AMS ^{14}C dates from Preluca Tiganului and Steregoiu. Calibrated ages at $\pm 2\sigma$ as derived by the OxCal 3.5 computer program are also given (Bronk Ramsey, 1995). The date used to construct a chronology for the pollen diagrams (Figs. 2 and 3) is either, a mid-point of the calibrated interval (at $\pm 2\sigma$), or an adjusted date, which takes into account the calibration curve and the most probable interval (at both $\pm 1\sigma$ and $\pm 2\sigma$), and the stratigraphic position of the sample (assuming a roughly uniform sedimentation rate, see chronology chapter)

^{14}C Lab. number	Depth (m)	Dated material	^{14}C age BP	Calibrated years BP	Date used to construct a chronology (cal. years BP)
(*A*) *Preluca Tiganului*					
Ua-16341	5.25–5.205	Charcoal, wood, bark	8565±90	9900–9400	9650 at 5.23 m
Ua-16340	6.07–6.03	Wood	9185±100	10,640–10,610 (1.4%), 10,590–10,180 (94%)	10,450 at 6.05 m
Ua-16339	6.34–6.29	Wood	9680±90	11,250–10,700	10,900 at 6.315 m
Ua-16338	6.43–6.385	Wood	9685±95	11,250–10,700	11,150 at 6.41 m
Ua-16337	6.725–6.68	Peat (washed)	10,240±90	12,750–11,350	11,400 at 6.70 m
Ua-16336	7.09–7.045	Wood	10,265±115	12,850–11,350	11,675 at 7.07 m
Ua-16335	7.36–7.315	Peat (washed)	10,190±110	12,750–11,250	11,750 at 7.34 m
Ua-16334	8.285–8.24	*Picea* needles, bark, wood	11,515±115	13,850–13,150	13,450 at 8.26 m
Ua-16333	8.73–8.70	Twigs	11,950±125	14,350–13,550	13,950 at 8.715 m
Ua-16332	9.19–9.14	*Picea* needles, cone	12,065±115	…–14,626 (45.7%), 14,350–13,800 (47.5%), 13,750–13,650 (2.2%)	14,100 at 9.165 m
Ua-16331	9.45–9.40	*Picea* needles	12,230±105	15,450–14,550 (62.5%), 14,450–14,050 (29.7%), 13,950–13,750 (3.2%)	14,200 at 9.425 m
Ua-16330	9.905–9.85	Wood	12,250±105	15,450–14,550 (63.9%), 14,450–14,050 (29.1%), 13,950–13,850 (2.4%)	14,400 at 9.88 m
(*B*) *Steregoiu*					
Ua-16329	3.28–3.23	*Picea* needles	8300±85	9490–9030	9260 at 3.255 m
Ua-16328	4.05–4.004	*Picea* needles, twigs, leaf fragments	9130±95	10,600–9900	10,250 at 4.03 m
Ua-16327	4.36–4.32	*Picea* needles	9530±85	11,200–10,550	10,700 at 4.34 m
Ua-16326	4.544–4.50	Wood fragments	9665±110	11,250–10,600	11,100 at 4.52 m
Ua-16325	4.694–4.64	Charcoal, leaves, wood	10,325±150	12,850–11,350	11,400 at 4.67 m
Ua-16324	5.164–5.12	Wood fragments	10,910±105	13,200–12,800 (80.6%), 12,750–12,600 (14.8%)	12,150 at 5.14 m
Ua-16323	5.324–5.274	Leaves, *Picea* needle, wood	12,365±115	15,450–14,050	14,000 at 5.30 m

AMS ^{14}C measurements were carried out on terrestrial plant macrofossils (Table 2). The samples were treated with 1% HCl (6 h below boiling point) and 0.5% NaOH (1 h at 60°C), then dried at 100°C overnight in small glass bottles and sent to the AMS facility in Uppsala, Sweden. From the first site, Preluca Tiganului, 12 samples were dated, and from the second, Steregoiu, seven samples were dated.

4. Results and interpretations

4.1. Lithostratigraphy

Simplified stratigraphies for the analysed profiles from Preluca Tiganului (0–9.90 m) and Steregoiu (0–5.92 m) are presented in Table 1 (see also lithology columns in the pollen diagrams, Figs. 4 and 5).

The stratigraphy for Preluca Tiganului indicates that the crater lake became overgrown relatively early (at 8.70 m), when carr peat started to accumulate (Fig. 4). From this level on the site has been a mire, initially with carr vegetation, but from 6.13 m and upwards, it has been a more or less open fen. Since the bottom sediment in the cored profile is fine detritus gyttja, this may imply that the corer did not penetrate into the oldest sediments in the basin, which may be more or less minerogenic (cf. stratigraphy for Steregoiu) (Wohlfarth et al., in press). Between 9.90 and 8.70 m different types of lake sediment were deposited (Table 1), varying from fine and coarse detritus gyttja, to clay gyttja and gyttja peat. These sediments imply that the site underwent significant water level changes.

The stratigraphy for Steregoiu shows that this basin was a lake until it became overgrown at 2.80 m and carr peat started to accumulate (Fig. 5). From this level on, the site has been a mire. At 1.25 m, a fen peat started to develop, implying that the site had become an open fen. The first slightly organogenic sediments (gyttja clay) start to be deposited at 5.44 m, and show that the site had become a lake. The bottom part of the profile, below 5.44 m, comprises minerogenic material, which was probably deposited by slope processes, or in-washed by streams originating from higher altitudes. A clayey gyttja is deposited between 5.26 and 4.57 m. This layer has an erosive contact with the underlying gyttja clay, which points to a hiatus.

4.2. Chronology

The AMS ^{14}C measurements from the two sites give reasonably concordant ages in respect to depth and sediment types (Table 2). However, many of the dates fall within a complicated part of the radiocarbon calibration curve (Stuiver et al., 1998), where for instance, the long plateau at c. 12,600 ^{14}C years BP, but also several other smaller plateaus, make it difficult to obtain good calibrated dates. Consequently, calibration of these dates will result in large standard errors, which do not allow a reliable chronology to be established for the vegetation development during the Lateglacial and Early Holocene.

To avoid the problem with large standard errors, age–depth curves were constructed (Figs. 2 and 3). However, the use of such curves assumes that the sedimentation rate is fairly uniform, which is not always the case (hiatii may be a problem, and at least one hiatus is present in the profile from Steregoiu at 5.26 m, see above). An independent test for this assumption are, however, the curves for total pollen concentration (Figs. 4 and 5). The curves for Preluca Tiganului and Steregoiu are reasonably smooth and do not indicate any larger deviations from an overall uniform accumulation rate.

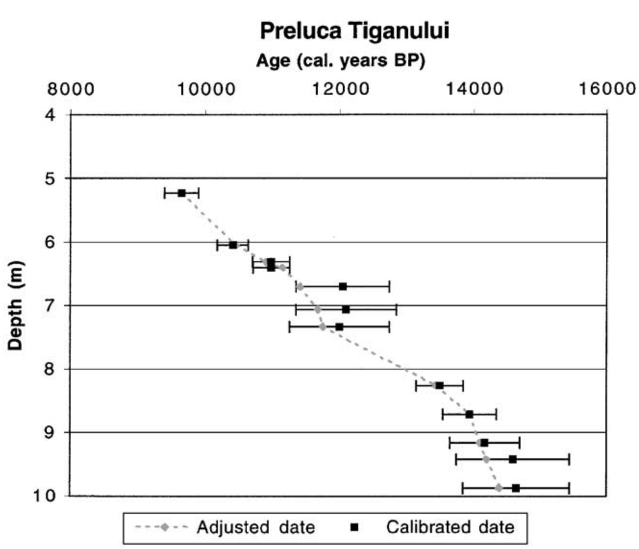

Fig. 2. Calibrated dates and an age–depth curve for the site Preluca Tiganului (Table 2A).

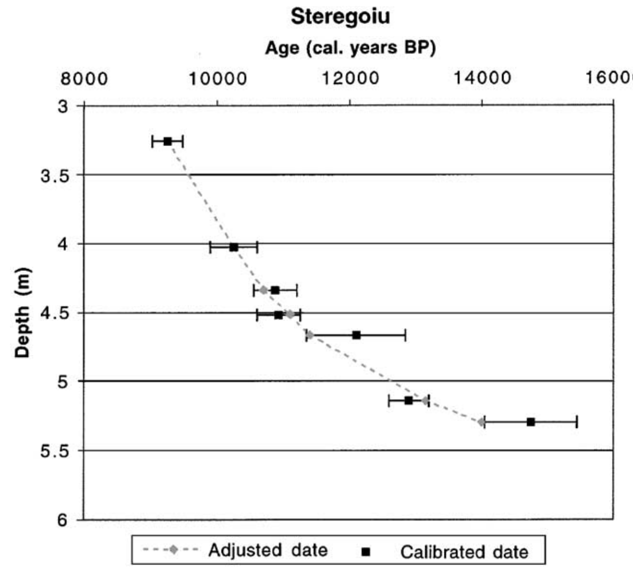

Fig. 3. Calibrated dates and an age–depth curve for the site Steregoiu (Table 2B).

Age–depth curves were established on dates which fall within uncomplicated parts of the calibration curve, and on dates which have relatively small standard errors (Table 2). From these dates it is possible to calculate a sediment accumulation rate for Preluca Tiganului of c. 12.4 years/cm for the peat sequence between 8.70 and 4.00 m, and c. 3.8 years/cm for the bottom sediments between 9.90 and 8.70 m. Accordingly, an accumulation rate for Steregoiu could be calculated of c. 15.2 years/cm for the gyttja sequence between 4.67 and 2.80 m, and c. 41.3 years/cm for the bottom sediments between 5.44 and 4.67 m. The accumulation rate for the bottom-most part with minerogenic deposits is, however, unknown as it was not possible to find plant macrofossils in this material. The second step has been to plot the "complicated" dates on these curves, and then assign ages that better fit the age–depth curve than the earlier obtained calibrated ages (Figs. 2 and 3; Table 2). That this procedure makes sense is reflected by the fact that the two profiles give highly consistent dates for the reconstructed vegetation development (Figs. 4 and 5; see also the synthesis of the pollen data and chronology below). The method used in this study thus allows calibrated years BP to be assigned to all the individual AMS ^{14}C measurements and to all zone boundaries (see Section 4.3).

4.3. Pollen stratigraphy and vegetation development

The pollen data are presented in percentage diagrams with all terrestrial pollen types included in the calculation sum (Figs. 4 and 5). To facilitate the description and interpretation of these pollen diagrams in terms of vegetation changes 12 local pollen assemblages zones were established for Preluca Tiganului (LPAZ P1–P12; Table 3, Fig. 4), and eleven zones for Steregoiu (LPAZ S1–S11; Table 4, Fig. 5). These zones have been established visually, and each zone boundary denotes significant changes in pollen deposition, and hence represents major changes in vegetation cover. The validity of these zones has also been confirmed by using an independent multivariate method (CONISS). As the pollen data set is very large, we focus in this paper on upland woodland development only (the pollen diagrams show all identified tree pollen types, but only selected herb and shrub pollen types). The on-site vegetation and site development will be discussed in detail elsewhere.

4.4. Lateglacial and early Holocene vegetation development in the Gutaiului Mountains, a synthesis

We present here a synthesis of the Lateglacial and Early Holocene woodland development in the study area as reconstructed from the pollen data and AMS ^{14}C measurements (Figs. 4 and 5; Tables 3 and 4). For the period >14,700 cal. years BP, the synthesis is based on LPAZ S1 only, and for the period 14,700–13,800 cal. years BP, LPAZ S2 and LPAZ P2–P4 have been used. Between 13,800 and c. 8500 cal. years BP, the inferred vegetation development is based on local pollen assemblages zones from both sites.

Before 14,700 cal. years BP, the area was dominated by open vegetation, which was most likely composed of a patchy mosaic with low shrubs, such as *Salix* and *Juniperus* (possibly also *Betula*), and grasses, sedges and herbs, such as *Artemisia* and Chenopodiaceae. However, patches with un-vegetated ground also occurred. *Pinus* may have grown in valleys, where favourable microclimatic conditions prevailed, or could have formed open forests in lowland areas.

4.4.1. 14,700–14,150 cal. years BP

The reconstructed vegetation consisted of a mosaic of scattered *Pinus* trees, low shrubs, such as *Salix* and *Juniperus*, and grasses, sedges and herbs, such as *Artemisia* and Chenopodiaceae. Areas with un-vegetated ground may have existed. The occurrence of scattered pollen grains of *Picea* might suggest that it was present on favourable sites in valleys at lower altitudes.

4.4.2. 14,150–14,050 cal. years BP

During this time period, the upland vegetation changed into open forests, in which *Pinus* and *Betula* were common. There is evidence for a local expansion of carr forest at Preluca Tiganului (mainly *Betula*) and Steregoiu (mainly *Alnus*). Patches of open vegetation probably also occurred in the region, but these were most likely restricted to higher altitudes.

4.4.3. 14,050–13,800 cal. years BP

The return to open vegetation with scattered *Pinus* individuals characterises this time slice. The vegetation may have comprised mosaic patches with low shrubs and scattered trees, such as *Salix*, *Juniperus* and *Pinus*, and patches with grasses, sedges and herbs, such as *Artemisia* and Chenopodiaceae. The low pollen values for *Picea* might suggest that it was present regionally, probably on favourable sites in valleys. Macrofossils of several *Pinus* species (*P. sylvestris*, *P. mugo* and *P. cembra*) as well as remains of *Populus* and *Larix* have been identified in sediments corresponding to this period by Wohlfarth et al. (in press). However, pollen grains of *Populus* and *Larix* have not been found in the present study.

4.4.4. 13,800–12,950 cal. years BP

From 13,800 cal. years BP onwards, open forests with *Betula*, *Picea* and *Pinus* occurred in the area. During the middle part of the period, *Ulmus* shows remarkably high values, which may imply that it was locally abundant. The seemingly rapid expansion, initially of *Picea*, and later of *Ulmus*, indicates that they had been present already earlier in the region, however, in very low numbers. Areas with open vegetation were likely to have been restricted to higher altitudes. Macroscopic charcoal gives additional information when interpreting pollen data, as it is believed that such charcoal represents local fires (Patterson et al., 1987; Clark, 1988). In the study by Wohlfarth et al. (in press), macroscopic charcoal was found in sediments from Preluca Tiganului at levels that correlate to this period. *Picea* is fire sensitive and shows highly variable values in LPAZ P5 (Fig. 4). It is therefore tempting to attribute the decrease of *Picea* at c. 8.40 and 8.20 m to local forest fires.

4.4.5. 12,950–12,600 cal. years BP

This time period is characterised by open *Betula*, *Pinus* and *Picea* forests. *Ulmus* had probably diminished already during the beginning of the period. *Betula*, *Pinus* and *Picea* appear to have decreased rapidly, at the same time as *Artemisia* and Chenopodiaceae in particular expanded strongly. At around 12,600 cal. years BP, the forest vegetation became severely reduced, and probably only open woodland of *Betula* and *Picea* existed locally.

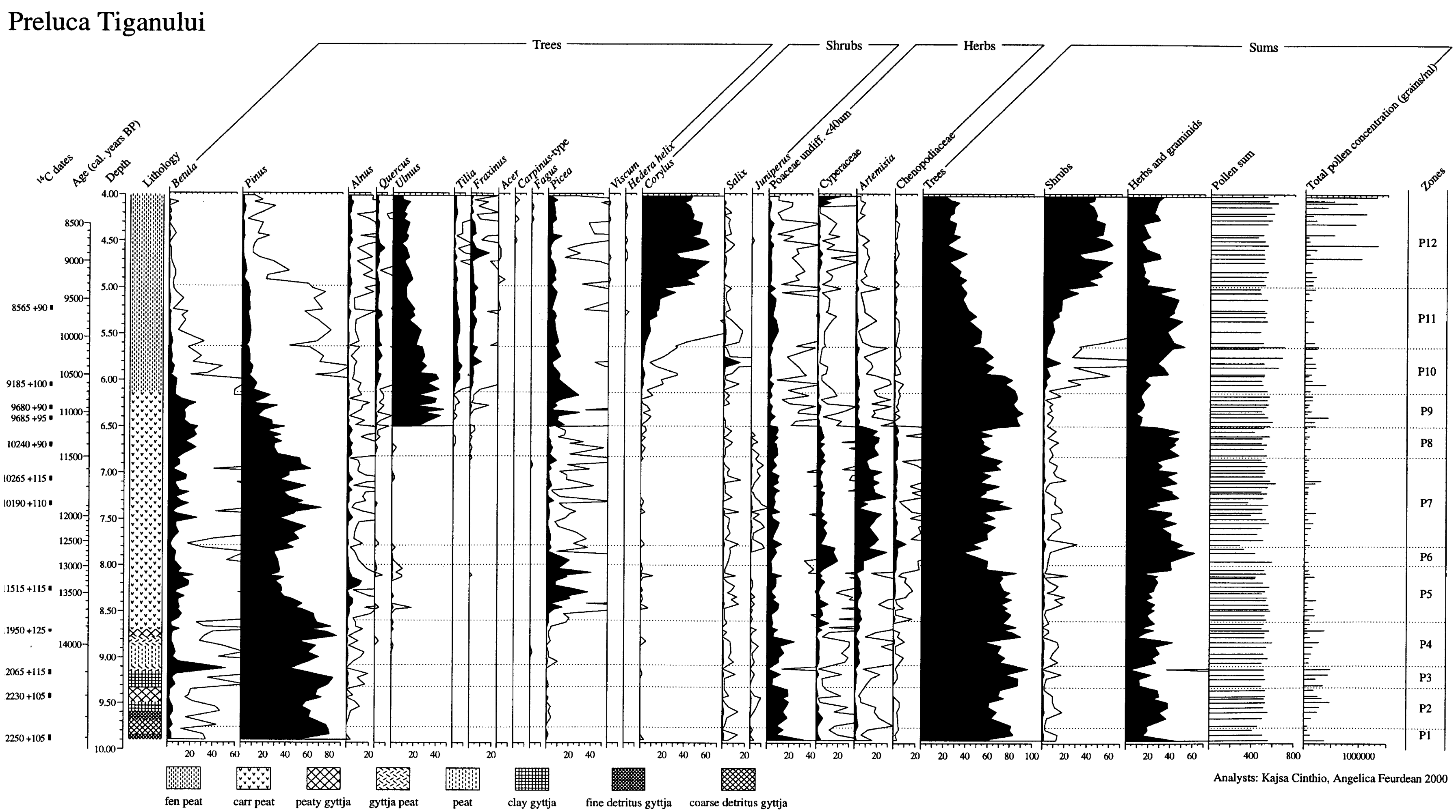

Fig. 4. Percentage pollen diagram from the site Preluca Tiganului with selected pollen taxa presented on a linear depth scale (covering the profile between 4.01 and 9.89 m). Radiocarbon dates and a non-linear time scale in calibrated years BP are shown to the left of the diagram, as well as a simplified stratigraphy. The pollen diagram covers roughly the time interval between c. 14,400 and 8100 cal. years BP.

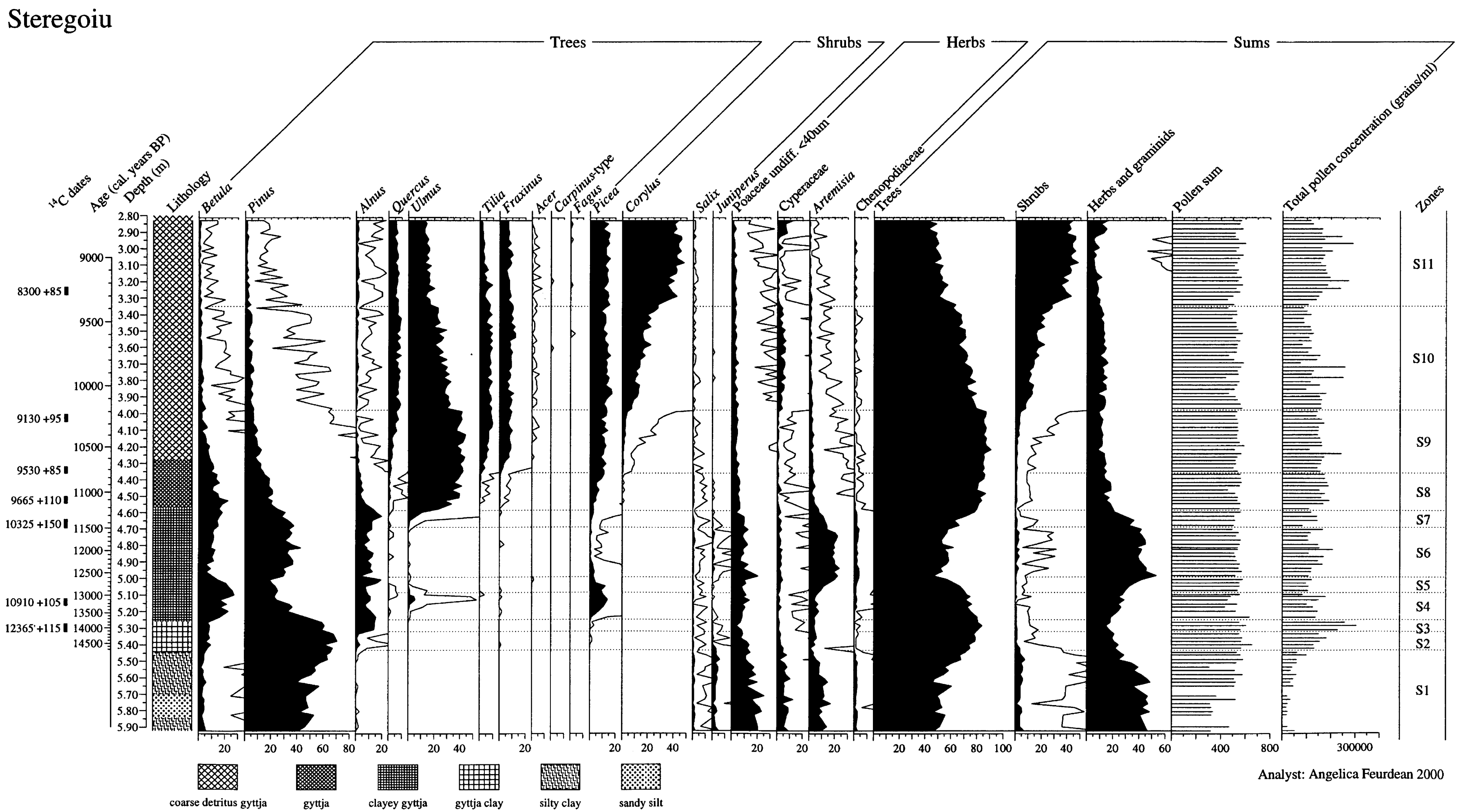

Fig. 5. Percentage pollen diagram from the site Steregoiu with selected pollen taxa presented on a linear depth scale (covering the profile between 2.83 and 5.92 m). Radiocarbon dates and a non-linear time scale in calibrated years BP are shown to the left of the diagram, as well as a simplified stratigraphy. The pollen diagram covers roughly the time interval between c. 15,500 and 8700 cal. years BP.

Table 3
Summary of the pollen stratigraphy, chronology and vegetation history for Preluca Tiganului (see Fig. 4 for pollen diagram). A correlation with the pollen zonation for Steregoiu is also given

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Steregoiu
P1, *Pinus*–Poaceae LPAZ	9.89–9.75	c. 14,400–14,350	Very high pollen percentages for *Pinus* (55–80%), high percentages for Poaceae undiff. <40 μm (15–35%), and low, but significant values for *Betula* (2–3%) and Cyperaceae (1.5–3%). *Salix* and Chenopodiaceae have significant occurrences. Presence of scattered pollen grains of *Juniperus*	Open vegetation with a dominance of grasses. Scattered *Pinus* individuals	Middle part of S2?
P2, *Pinus*–Poaceae–Cyperaceae LPAZ	9.75–9.32	14,350–14,150	Very high pollen percentages for *Pinus* (60–75%), high percentages for Poaceae undiff. <40 μm (15–20%), and low, but significant values for *Betula*, Cyperaceae and *Artemisia*. *Alnus*, *Salix*, *Juniperus* and Chenopodiaceae have significant occurrences. Presence of scattered pollen grains of *Picea*. Compared to the preceding zone, *Artemisia*, Cyperaceae and *Juniperus* have increased	Open vegetation, most likely a mosaic with low shrubs, grass, sedges and herbs. Scattered *Pinus* individuals	Late phase of S2?
P3, *Pinus*–*Betula* LPAZ	9.32–9.08	14,150–14,050	Very high pollen percentages for *Pinus* and *Betula* (above 50% in the topmost sample), fairly high percentages for Poaceae undiff. <40 μm, and low, but significant values for *Artemisia*. *Alnus* and Cyperaceae have significant occurrences. *Salix* and Chenopodiaceae have a continuous presence with low values. Compared to the preceding zone, *Betula* has increased, while *Juniperus*, Poaceae undiff. <40 μm, Cyperaceae and *Artemisia* have decreased	Open forest dominated by *Pinus* and some *Betula* individuals. Expansion of *Betula* in local carr forest	Earliest phase of S3?
P4, *Pinus*–Poaceae–*Artemisia* LPAZ	9.08–8.60	14,050–13,800	Very high pollen percentages for *Pinus* (50–80%), high and fairly high percentages for Poaceae undiff. <40 μm and *Betula* (only in the bottom-most sample), and low, but significant values for Cyperaceae and *Artemisia*. *Alnus*, *Salix*, *Juniperus* and Chenopodiaceae have significant occurrences. Presence of scattered pollen grains of *Picea*. Compared to the preceding zone, Poaceae undiff. <40 μm, Cyperaceae, *Artemisia* and Chenopodiaceae have increased, while *Betula* has decreased	Open vegetation, most likely a mosaic with low shrubs, grass, sedges and herbs. Scattered *Pinus* individuals	S3?
P5, *Pinus*–*Picea*–*Betula* LPAZ	8.60–8.00	13,800–12,950	High to very high pollen percentages for *Pinus* (35–70%) and *Picea* (5–40%), fairly high percentages for *Betula*, *Alnus*,	Open forest, initially dominated by *Betula* and *Picea*. *Pinus* was probably also common. Local	S4

Table 3 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Steregoiu
			Poaceae undiff. <40 μm, Cyperaceae and *Artemisia*, and low, but significant values for *Salix* and Chenopodiaceae. *Ulmus* has significant values only in the middle and the topmost part of the zone. Presence of single or scattered pollen grains of *Quercus*, *Fraxinus*, *Corylus* and *Juniperus*. Compared to the preceding zone, *Betula*, *Alnus*, *Picea*, Cyperaceae, *Artemisia* and Chenopodiaceae have increased, while *Pinus* has decreased	establishment and expansion of *Picea*. At the middle of the zone, *Ulmus* probably also was established	
P6, *Pinus*–*Artemisia*–Cyperaceae LPAZ	8.00–7.79	12,950–12,600	High pollen percentages for *Pinus*, *Artemisia* (10–25%) and Cyperaceae (10–20%), fairly high percentages for *Betula* and *Picea*, and low, but significant values for Poaceae undiff. <40 μm and Chenopodiaceae. *Alnus* and *Salix* have significant occurrences. Presence of single or scattered pollen grains of *Quercus* and *Ulmus*. Compared to the preceding zone, Cyperaceae, *Artemisia* and Chenopodiaceae have increased, while *Betula*, *Pinus*, *Alnus*, *Picea* and Poaceae undiff. <40 μm have decreased	Open forest dominated by *Picea*, *Betula* and *Pinus*. *Ulmus* diminished already at the beginning of the zone. At the end of the zone expansion of open vegetation, particularly by *Artemisia* and Chenopodiaceae	S5
P7, *Pinus*–*Artemisia* LPAZ	7.79–6.82	12,600–11,500	Very high or high pollen percentages for *Pinus* (40–75%) and *Artemisia* (10–25%), fairly high percentages for *Betula*, Poaceae undiff. <40 μm and Cyperaceae, and low, but significant values for *Alnus*, *Picea* and Chenopodiaceae. *Salix* and *Juniperus* have significant occurrences. Compared to the preceding zone, *Betula*, *Pinus*, *Juniperus* and Poaceae undiff. <40 μm have increased, while *Picea* and Cyperaceae have decreased	Open vegetation, most likely a mosaic with low shrubs (mainly *Salix* and *Juniperus*), grass, sedges and herbs. Scattered *Betula* individuals	S6
P8, *Pinus*–*Betula*–*Artemisia* LPAZ	6.82–6.49	11,500–11,200	High pollen percentages for *Pinus* (25–35%), *Betula* and *Artemisia*, fairly high percentages for Poaceae undiff. <40 μm and Cyperaceae, and low, but significant values for *Alnus*, *Picea* and Chenopodiaceae. Presence of single or scattered pollen grains of *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Corylus* and *Juniperus*. Compared to the preceding zone, *Betula*, *Alnus* and Chenopodiaceae have increased, while *Pinus* and *Juniperus* have decreased	Open forest dominated by *Betula* and *Pinus*	S7

Table 3 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Steregoiu
P9, *Ulmus–Picea–Pinus* LPAZ	6.49–6.13	11,200–10,700	High pollen percentages for *Ulmus* (25–45%), *Betula*, *Pinus* and *Picea*, and low, but significant percentages for Poaceae undiff. <40 μm, Cyperaceae and *Artemisia*. *Alnus*, *Quercus*, *Corylus* and Chenopodiaceae have significant occurrences. Presence of single or scattered pollen grains of *Tilia* and *Fraxinus*. Compared to the preceding zone, *Ulmus* and *Picea* have increased, while *Betula*, *Pinus*, Poaceae undiff. <40 μm, Cyperaceae, *Artemisia* and Chenopodiaceae have decreased. *Quercus*, *Tilia*, *Fraxinus* and *Corylus* also have increased, although their percentages are still low. *Ulmus* and *Picea* have high values already at the bottom of the zone, without an expansion in the preceding zone. This strongly suggests that the initial expansion phase for these taxa are not represented and that a hiatus, probably of short duration, is present	Dense forest dominated by *Ulmus* and *Picea*, but *Betula* and *Pinus* were probably also common. Establishment of *Quercus*, *Tilia* and *Fraxinus*	S8
P10, *Ulmus–Picea* LPAZ	6.13–5.64	10,700–10,100	High pollen percentages for *Ulmus* (25–40%), fairly high percentages for *Pinus* and *Picea*, and low, but significant values for *Betula*, *Quercus*, *Tilia*, *Fraxinus*, *Corylus* and Poaceae undiff. <40 μm. *Alnus*, *Salix*, Cyperaceae and *Artemisia* have significant occurrences. Compared to the preceding zone, *Quercus*, *Tilia*, *Fraxinus* and *Corylus* have increased, while *Betula*, *Pinus*, *Ulmus*, *Picea*, Poaceae undiff. <40 μm and *Artemisia* have decreased	Dense forest dominated by *Ulmus*, but *Picea*, *Quercus*, *Tilia* and *Fraxinus* were also common. Establishment of *Corylus*	S9
P11, *Corylus–Ulmus–Picea* LPAZ	5.64–4.98	10,100–9300	High pollen percentages for *Ulmus* (15–25%) and *Corylus* (10–40%), fairly high percentages for Poaceae undiff. <40 μm, and low, but significant values for *Pinus*, *Quercus*, *Tilia*, *Fraxinus* and *Picea*. *Betula*, *Alnus*, *Salix*, Cyperaceae and *Artemisia* have significant occurrences. Presence of single or scattered pollen grains of *Acer* and *Hedera helix*. Compared to the preceding zone, *Corylus* and Poaceae undiff. <40 μm have increased, while *Betula*, *Pinus*, *Ulmus*, *Picea* and *Artemisia* have decreased. *Corylus* shows an increasing trend throughout the zone	Dense forest dominated by *Ulmus* and *Corylus*, but *Picea*, *Quercus*, *Tilia* and *Fraxinus* were also common	S10

Table 3 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Steregoiu
P12, *Corylus*–*Ulmus* LPAZ	4.98–4.01	9300–c. 8100	Very high pollen percentages for *Corylus* (40–65%), fairly high percentages for *Ulmus* (10–15%), *Fraxinus* (has a peak value above 15%), *Picea* and Cyperaceae (only in the topmost samples), and low, but significant values for *Alnus*, *Quercus*, *Tilia* and Poaceae undiff. <40 μm. *Pinus* and *Artemisia* have significant occurrences. Presence of single or scattered pollen grains of *Betula*, *Acer*, *Carpinus*-type, *Fagus*, *Viscum*, *Hedera helix* and *Salix*. Compared to the preceding zone, *Corylus* has increased, while *Betula*, *Pinus*, *Ulmus*, *Tilia* and Poaceae undiff. <40 μm have decreased	Dense forest dominated by *Corylus* and *Ulmus*, but *Picea*, *Quercus*, *Tilia* and *Fraxinus* were also common. Local presence of *Acer*, *Hedera helix* and *Viscum*	S11

Table 4
Summary of the pollen stratigraphy, chronology and vegetation history for Steregoiu (see Fig. 5 for pollen diagram). A correlation with the pollen zonation for Preluca Tiganului is also given

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Preluca Tiganului
S1, *Pinus*–Poaceae–*Artemisia* LPAZ	5.92–5.43	>14,700	High pollen percentages for *Pinus* (40–55%), fairly high percentages for Poaceae undiff. <40 μm (10–20%), *Artemisia* (5–15%) and Cyperaceae (5–10%), and low, but significant values for *Betula* (c. 5%), *Juniperus* (3–5%) and Chenopodiaceae (c. 3%). *Salix* has a significant occurrence. Low total pollen concentration (above 50,000 grains/cm^3 only in a few samples)	Open vegetation, most likely a mosaic with low shrubs, grass, sedges and herbs	?
S2, *Pinus*–Poaceae–*Betula* LPAZ	5.43–5.32	c. 14,700–14,150	Very high pollen percentages for *Pinus* (60–70%), fairly high percentages for *Betula* and Poaceae undiff. <40 μm, and low, but significant values for Cyperaceae and *Artemisia*. *Alnus*, *Salix* and *Juniperus* have significant occurrences. Compared to the preceding zone, *Betula*, *Pinus* and *Alnus* have increased, while *Salix*, *Juniperus*, Poaceae undiff. <40 μm, Cyperaceae, *Artemisia* and Chenopodiaceae have decreased. The total pollen concentration has increased to values above 100,000 grains/cm^3	Open vegetation with scattered *Pinus* and *Betula* individuals	P1–P3?

Table 4 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Preluca Tiganului
S3, *Pinus–Alnus–Betula* LPAZ	5.32–5.25	14,150–c. 13,750	Very high pollen percentages for *Pinus*, fairly high percentages for *Betula* and *Alnus*, and low, but significant values for Poaceae undiff. <40 μm and Cyperaceae. *Salix* and *Juniperus* have significant occurrences. Presence of single or scattered pollen grains of *Picea* and Chenopodiaceae. Compared to the preceding zone, *Alnus* has increased, while *Pinus*, Poaceae undiff. <40 μm and Cyperaceae have decreased	Open forest dominated by *Pinus* and *Betula*	P4?
S4, *Betula–Pinus–Picea* LPAZ	5.25–5.09	13,750–12,950	High pollen percentages for *Betula* (15–25%) and *Pinus*, fairly high percentages for *Picea* (5–15%), *Alnus*, Poaceae undiff. <40 μm and *Artemisia*, and low, but significant values for *Ulmus* (has a top value at 5.3% in the middle of the zone), Cyperaceae and Chenopodiaceae. Presence of single, or scattered pollen grains of several tree pollen types, such as *Fraxinus*, *Quercus* (around 1% in the topmost samples) and *Tilia*. Compared to the preceding zone, *Betula*, *Ulmus* and *Picea* have increased, while *Pinus*, *Alnus* and *Juniperus* have decreased	Open forest dominated by *Betula* and *Picea*. *Pinus* was probably also common. Establishment and expansion of *Ulmus* (and *Quercus*?)	P5
S5, *Betula–Pinus–Alnus* LPAZ	5.09–4.99	12,950–12,600	High pollen percentages for *Betula* (15–25%) and *Pinus*, fairly high percentages for *Alnus* (has a peak around 20% at the top of the zone), *Picea*, Poaceae undiff. <40 μm and *Artemisia* (increases strongly, from c. 10% at the bottom to c. 20% at the top), and low, but significant values for Cyperaceae and Chenopodiaceae. *Quercus* and *Ulmus* have a significant occurrence in the bottom sample. Compared to the preceding zone, *Betula*, *Alnus* and *Artemisia* have increased, while *Pinus*, *Picea* and *Ulmus* have decreased	Open forest dominated by *Betula*, *Pinus* and *Picea*. *Ulmus* diminished at the beginning of the zone. Expansion of open vegetation, particularly by *Artemisia* and Chenopodiaceae	P6
S6, *Pinus–Artemisia*–Poaceae LPAZ	4.99–4.69	12,600–11,500	High pollen percentages for *Pinus* (30–40%), fairly high percentages for *Artemisia* (c. 20%), *Alnus*, *Betula* and Poaceae undiff. <40 μm, and low, but significant values for Cyperaceae and Chenopodiaceae. *Picea*, *Salix* and *Juniperus* have significant occurrences. Presence of scattered pollen grains of *Quercus* and	Open vegetation, most likely a mosaic with low shrubs, grass, sedges and herbs. Scattered *Betula* individuals	P7

Table 4 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Preluca Tiganului
			Ulmus. Compared to the preceding zone, *Pinus*, *Juniperus*, Poaceae undiff. <40 μm, *Artemisia,* Chenopodiaceae and Cyperaceae have increased, while *Betula* and *Picea* and have decreased		
S7, *Pinus–Betula–Alnus* LPAZ	4.69–4.59	11,500–11,250	High pollen percentages for *Pinus* (35–40%), fairly high percentages for *Betula* (c. 15%), *Alnus* (10–20%), Poaceae undiff. <40 μm and *Artemisia*, and low, but significant values for *Ulmus*, Cyperaceae and Chenopodiaceae. *Picea* and *Salix* have significant occurrences. Presence of scattered pollen grains of *Quercus* and *Juniperus*. Compared to the preceding zone, *Betula*, *Alnus* and *Ulmus* have increased, while *Pinus*, *Juniperus*, *Artemisia* and Chenopodiaceae have decreased. *Ulmus* shows increasing values throughout the zone (it starts with very low values and ends with c. 10%)	Open forest dominated by *Betula* and *Pinus*. Establishment and expansion of *Ulmus*	P8
S8, *Ulmus–Pinus–Betula* LPAZ	4.59–4.36	11,250–10,750	Very high pollen percentages for *Ulmus* (20–45%), fairly high percentages for *Pinus*, *Betula* and *Picea*, and low, but significant values for *Alnus*, Poaceae undiff. <40 μm and *Artemisia*. *Fraxinus*, *Quercus*, *Tilia*, *Salix* and Cyperaceae have significant occurrences. Presence of scattered pollen grains of *Corylus* and *Juniperus*. Compared to the preceding zone, *Ulmus*, *Fraxinus*, *Picea*, *Quercus* and *Tilia* have increased, while *Alnus*, *Pinus*, *Juniperus* and *Artemisia* have decreased. *Fraxinus*, *Picea*, *Quercus* and *Tilia* are showing increasing values throughout the zone	Dense forest dominated by *Ulmus*, but *Picea*, *Betula* and *Pinus* were also common. Establishment of *Quercus*, *Tilia* and *Fraxinus*	P9
S9, *Ulmus–Picea–Fraxinus* LPAZ	4.36–3.98	10,750–10,200	Very high pollen percentages for *Ulmus* (40–45%), fairly high percentages for *Picea*, *Pinus*, *Betula*, *Fraxinus*, *Tilia* and *Quercus*, and low, but significant values for *Alnus*, *Corylus*, Poaceae undiff. <40 μm and *Artemisia*. *Salix*, Cyperaceae and Chenopodiaceae have significant occurrences. Presence of scattered pollen grains of *Acer*. Compared to the preceding zone, *Fraxinus*, *Tilia* and *Quercus* have increased, while	Dense forest dominated by *Ulmus*, but *Picea*, *Quercus*, *Tilia* and *Fraxinus* were also common. Establishment of *Corylus* and *Acer*	P10

Table 4 (*continued*)

Zone	Depth (m)	Age (cal. years BP)	Description	Inferred local upland vegetation	Correlation with Preluca Tiganului
			Pinus and *Betula* have decreased. At the bottom of the zone *Corylus* shows an increasing trend throughout the zone (from 0.2 at the bottom to about 4% at the top)		
S10, *Ulmus–Corylus–Picea* LPAZ	3.98–3.35	10,200–9400	High pollen percentages for *Ulmus* (25–30%) and *Corylus* (10–25%), fairly high percentages for *Picea*, *Fraxinus*, *Tilia* and *Quercus*, and low, but significant values for *Pinus*, Cyperaceae and Poaceae undiff. <40 μm. *Betula*, *Artemisia* and *Alnus* have significant occurrences. Regular presence of pollen grains of *Acer* and Chenopodiaceae. Compared to the preceding zone, *Corylus* has increased, while *Ulmus*, *Pinus*, *Betula* and *Alnus* have decreased. *Corylus* is showing gradually increasing values throughout the zone, while *Ulmus* is showing gradually decreasing values	Dense forest dominated by *Ulmus*, *Corylus* and *Picea*, but *Quercus*, *Tilia*, *Fraxinus* and *Acer* were also common. Expansion of *Corylus*	P11
S11, *Corylus–Ulmus–Picea* LPAZ	3.35–2.83	9400–c. 8700	Very high pollen percentages for *Corylus* (ca 40%), fairly high percentages for *Ulmus*, *Fraxinus*, *Picea*, *Quercus*, *Tilia* and Cyperaceae (only in the topmost samples, with values around 10%), and low, but significant values for *Alnus*, *Pinus* and Poaceae undiff. <40 μm. *Acer* and *Artemisia* occur regularly with very low values. Compared to the preceding zone, *Corylus* has increased, while *Ulmus*, *Tilia* and *Artemisia* have decreased	Dense forest dominated by *Corylus* and *Ulmus*, but *Picea*, *Quercus*, *Tilia* and *Acer* were also common	P12

The strong expansion of *Artemisia* and Chenopodiaceae implies that open vegetation had started to spread regionally.

4.4.6. 12,600–11,500 cal. years BP

During the whole time period open vegetation prevailed in the area, and consisted probably of a mosaic with patches dominated by low shrubs, such as *Salix*, *Juniperus* and *Betula*, and patches dominated by grasses and herbs, such as *Artemisia* and Chenopodiaceae. More or less un-vegetated and unstable ground also occurred, particularly at higher elevations. The percentages for *Betula* and *Pinus* are comparably high, suggesting that these trees were present regionally, but that they did not form a tree cover near the sites. Instead, they may have existed as more or less dense stands in valleys, where a favourable microclimate allowed tree growth. *Picea* has low, but significant values, which may imply that it occurred regionally on favourable sites.

4.4.7. 11,500–11,250 cal. years BP

From 11,500 cal. years BP onwards, open forests became re-established and were dominated by *Betula* and *Pinus*. *Ulmus* was probably not present in the local forest stands at the beginning of the period, but seems to have been as common as *Betula* at around 11,250 cal. years BP. *Ulmus*, which became established rather early, expanded quickly, and constituted the dominant tree at the end of the time period. At Preluca Tiganului, the rise of *Ulmus* percentages is remarkably sharp, increasing from 0% to 25% in successive levels. Although there is no obvious change in the sediment stratigraphy at this point, the sharp increase for *Ulmus* suggests a hiatus, which most likely was of short duration. The forest probably had initially a rather open structure, which diminished rapidly, when *Ulmus* started to expand. The occurrence of *Juniperus* pollen, and the high values for Poaceae undiff. <40 μm and *Artemisia*, particularly at the beginning of the period, probably indicate that areas with open vegetation occurred in the region, however, most likely at higher altitudes.

4.4.8. 11,250–10,700 cal. years BP

Dense forests, in which *Ulmus*, *Picea*, *Betula* and *Pinus* were common, dominate this period. Broad-leaved trees, such as *Quercus*, *Tilia* and *Fraxinus* were most likely to have been present in the forests, but in low densities. *Ulmus* and *Picea* seem to have expanded significantly. The significant values for Poaceae undiff. <40 μm and *Artemisia* probably indicate that some patches with open vegetation occurred, most likely at higher altitudes.

4.4.9. 10,700–10,150 cal. years BP

From 10,700 cal. years BP onwards, dense forests in which *Ulmus* was most frequent occurred in the area. *Picea*, *Quercus*, *Tilia* and *Fraxinus* were probably also important forest components. *Acer* probably occurred in the forests, while *Betula* and *Pinus* had become rather rare. A slight presence of *Corylus* suggests that it had started to expand regionally and *Quercus*, *Tilia* and *Fraxinus* seem to have expanded significantly. The low, but significant values for Poaceae undiff. <40 μm and *Artemisia* indicate that some patches with open vegetation occurred in the region, but most likely rather far from the cored sites.

4.4.10. 10,150–9350 cal. years BP

Ulmus, *Corylus* and *Picea* dominated the dense forests during this period, but *Quercus*, *Tilia*, *Fraxinus* and *Acer* were also common. An important change in the vegetation is indicated by the significant expansion of *Corylus* at the expense of *Ulmus*. The low values for Poaceae undiff. <40 μm and *Artemisia* indicate that some areas with open vegetation occurred in the region, but again these were most likely to have been situated far from the cored sites.

4.4.11. 9350–c. 8500 cal. years BP

Dense forests composed of mainly *Corylus* and *Ulmus* and to a lesser extent of *Picea*, *Quercus*, *Tilia*, *Fraxinus* and *Acer* prevailed in the area. Few areas with open vegetation may have existed in the region.

5. Regional comparisons

Farcas et al. (1999) published a reconstruction of the regional Lateglacial and Holocene vegetation development at two high-altitude sites in the northeast (Iezerul Calimani, 1650 m a.s.l.) and southwest (Taul Zanogutii, 1840 m a.s.l.) of the Romanian Carpathians, based upon pollen analyses and AMS ^{14}C measurements. The low temporal resolution of the Lateglacial part in these pollen diagrams make comparisons with the diagrams from the present study difficult. However, the Early Holocene development is better expressed and comparatively well dated, which is due to the higher temporal resolution in the profiles. At the site closest to the study area (Iezerul Calimani, c. 155 km to the SE), the beginning of the Holocene is marked by an expansion of *Betula*, *Alnus* (*A. viridis*) and *Ulmus* (probably at lower altitudes). Slightly later, *Picea* also expands. At the site farthest from the study area (Taul Zanogutii, c. 300 km to the SSW), the transition to the Holocene is marked by a strong expansion of *Betula*, which is followed by slight expansions of *Ulmus*, *Alnus* (*A. viridis*) and *Picea*. Later, at c. 10,800 cal. years BP, *Quercus* became established, and *Ulmus* and *Picea* expanded further. At c. 10,100 cal. years BP, *Corylus* started to expand. As these sites are located at higher altitudes than the mid-altitude sites investigated here, they are not strictly comparable, because vegetation types may differ strongly. However, the general vegetation changes seen in these diagrams have striking similarities with the development seen in our sites, where the beginning of the Holocene is marked by an increase of *Betula* and *Alnus*, and slightly later, also of *Ulmus*. At 10,700 cal. years BP, broad-leaved trees expanded, and at 10,150 cal. years BP *Corylus* increased. In time, the Early Holocene vegetation changes seen in our area seem to correlate well with the development at Iezerul Calimani and Taul Zanogutii.

From the Polish Carpathians, Ralska-Jasiewiczowa and Latalowa (1996) presented pollen data for a mid-altitude site (Tarnawa Wyzna, 670 m a.s.l.; 160 km to the NNW). At this site, the vegetation development during the Lateglacial and Early Holocene seems to be well expressed, but the chronology is somewhat uncertain, because it is based on comparatively few conventional radiocarbon dates only. The overall Lateglacial vegetation development seems to agree largely with the changes seen in our area, with a dominance of *Pinus*, *Artemisia*, *Juniperus* and some *Picea* (also *Larix*, *Pinus cembra* and *P. sylvestris* were present). Around 12,900 cal. years BP *Picea* expanded significantly, and this phase probably correlates to the period 13,800–12,600 cal. years BP in the Gutaiului area, where *Picea* formed an open forest. At Tarnawa Wyzna, the beginning of the Holocene is marked by a reduction of *Juniperus* and *Artemisia*, and an expansion of *Pinus*

Table 5
Comparison of establishment and expansion dates for selected tree species in the study area and the Polish Carpathians (Tarnawa Wyzna). All dates are expressed in calibrated years BP

		Gutaiului Mts.	Polish Carpathians
	Expansion	10,150	9550
Corylus	Establishment	10,700	10,400
	Expansion	10,700	9700
Tilia, *Quercus*	Establishment	11,250	10,400
	Expansion	11,300–11,200	10,400–11,300
Ulmus	Establishment	11,400–11,300	11,250

cembra. Slightly later, at c. 11,100 cal. years BP, *Picea*, *Pinus sylvestris* and *Betula* expanded and *Ulmus* became established. Around 10,700 cal. years BP *Betula* and *Pinus* became reduced, while *Picea* and *Ulmus* increased significantly and *Corylus* became regionally established. Around 9500 cal. years BP *Corylus*, *Tilia*, *Quercus* and *Alnus* expanded strongly. In general, this vegetation development seems to be very similar to the development in our area, although the timing of comparable events appears to differ. The establishment and expansion of the different tree species seems to have occurred hundred, to several hundred years earlier in the Gutaiului Mountains than in the Polish Carpathians (Table 5). The establishment and expansion of, for instance, *Ulmus*, occurred between 11,500 and 11,250 cal. years BP. At Tarnawa Wyzna, however, *Ulmus* became only established at c. 11,250 cal. years BP and did not expand until c. 900 years later. The later dates for the Early Holocene establishment and expansion of trees in the Polish Carpathians may imply that these trees had to migrate into the area from distant refugia, otherwise they should have become established at around the same time as in the Gutaiului Mountains.

Recent investigations by Willis et al. (1995, 2000) in Hungary, particularly at the site Bátorliget marsh (c. 130 m a.s.l.) in northwestern Hungary (c. 95 km to the west), revealed that forests with *Betula*, *Pinus* and *Picea* dominated the area during the Lateglacial. The transition to the Holocene resulted in a rapid shift to deciduous woodland, where broad-leaved trees and shrubs, such as *Quercus*, *Tilia*, *Ulmus*, *Carpinus* and *Corylus* increased. Later *Quercus* became the dominant constituent of the forests. This vegetation development differs considerably from the development seen in the Gutaiului Mountains, particularly for the last part of the Lateglacial, where open vegetation dominated the study area. The rapid expansion at Bátorliget of, in particular, *Tilia*, *Quercus* and *Corylus*, which started almost at 11,500 cal. years BP, must imply that these species were already present in the area (probably in nearby refugia). The contrasting vegetational development between the Gutaiului Mountains and Bátorliget must, at least in part, be attributed to a large difference in altitude and regional climate.

6. Tree refugia in northwestern Romania

Willis et al. (2000) found firm evidence based on macroscopic charcoal, for at least eight different species of trees and shrubs (*Pinus cembra*, *P. sylvestris*, *Picea*, *Larix*, *Betula*, *Carpinus*, *Juniperus* and *Salix*) occurring on the Hungarian plain between 32,500 and 16,500 ^{14}C years BP. Pollen diagrams from several sites in Hungary also indicate that these species must have formed more or less dense forests during the Fullglacial period. The occurrence of low numbers of broad-leaved tree pollen types, such as *Ulmus*, *Quercus*, *Carpinus* and *Corylus* in the pollen diagrams, may indicate that these trees also occurred in Hungary during the Fullglacial period, but only in micro-environmentally favourable sites. However, the presence of Fullglacial refugia in northwestern Romania cannot be established on present evidence, as the profiles in the study area do not fully cover this period. The bottom zone (LPAZ S1) in Steregoiu may reach back into the Fullglacial, since the sediments are older then c. 14,700 cal. years BP. The pollen assemblage for this zone does not indicate the presence of local forests, but the high percentages for *Pinus* imply that it occurred regionally, most likely at lower altitudes, and that *Betula*, *Salix* and *Juniperus* were present in the area.

During the later part of the Lateglacial, the pollen data clearly show that *Alnus*, *Ulmus* and *Picea* also occurred in the region. The strong expansion of *Alnus* at 14,150 cal. years BP, and of *Ulmus* and *Picea* at c. 13,800–13,500 cal. years BP, may indicate that these species immigrated from nearby refugia, most likely located in northwestern Romania. Between 12,600 and 11,500 cal. years BP *Ulmus* and *Picea* may have survived regionally in sheltered places.

The late expansion of *Quercus*, *Tilia*, *Fraxinus*, *Acer* and *Corylus* between 10,700 and 10,200 cal. years BP may indicate that these trees did not occur in local refugia in the study area during the Lateglacial. Instead, they had to migrate into the area from refugia further away. However, these refugia cannot have been situated very far from the investigated area, otherwise the expansion of these tree species would have occurred much later (as they did for instance, in the Polish Carpathians, see above). It seems most likely, that these refugia were located further to the south in Romania, or in lowland areas further to the west (e.g. the Hungarian plain).

7. Correlation with North Atlantic climatic events

The beginning of the organogenic sedimentation and the first occurrence of scattered *Pinus* individuals at around 14,700 cal. years BP correlates in time to the start of the first deglacial warming phase (GI-1e) of the GRIP ice core event stratigraphy (Björck et al., 1998; Walker et al., 1999). The lowermost minerogenic sediments in Steregoiu, which were deposited before c. 14,700 cal. years BP, could then correspond to the end of the last distinctly cold period of the Last Glacial Maximum (GS-2). Prevailing cold climatic conditions are indicated by the open vegetation, which consisted of a patchy mosaic with low shrubs, grass, sedges and herbs and patches of un-vegetated ground. Successively warmer climatic conditions between c. 14,700 and 14,050 cal. years BP (corresponding to GI-1e) can be inferred from the transition from open vegetation with scattered *Pinus* individuals to open forest with *Pinus* and *Betula*. The marked reduction in tree cover and the renewed spread of open vegetation with low shrubs, grass, sedges and herbs and only few scattered *Pinus* individuals between 14,050 and 13,800 cal. years BP, indicates a return to colder climatic conditions and corresponds approximately in time to the short GI-1d event, seen in the GRIP event stratigraphy between 14,050 and 13,900 cal. years BP (Björck et al., 1998; Walker et al., 1999). Open forest with mainly *Betula* and *Picea*, but also *Pinus*, and from c. 13,400 cal. years BP onwards *Ulmus*, became re-established at around 13,800 cal. years BP. This development and the shift of the open vegetation belt to higher elevations, points to markedly warmer climatic conditions between 13,800 and 12,950 cal. years BP, a time period that corresponds approximately to GI-1c–GI-1a in the GRIP event stratigraphy.

Due to the different estimates for the length of the Younger Dryas or GS-1 (c. 1300 years in the Cariaco basin, on which the radiocarbon calibration curve is based, Stuiver et al. (1998) and Hughen et al. (2000), c. 1150 years in the GRIP ice core, Björck et al. (1998) and Walker et al. (1999)), the age of the Alleröd/Younger Dryas or GI-1/GS-1 transition is either set to c. 12,950 cal. years BP or to 12,650 ice core years BP. Consequently, calibrated radiocarbon dates for this transition will range around 12,950 cal. years BP, although they correspond in time to the GRIP GI-1/GS-1 boundary. Therefore, the changes seen in our records starting at around 12,950 cal. years BP should be broadly time-parallel with the beginning of GS-1. Initially, i.e. between 12,950 and 12,600 cal. years BP, open *Betula*, *Pinus* and *Picea* forests dominated, but around 12,600 cal. years BP the forest vegetation became severely reduced and herb and grass communities started to expand around the study sites, reflecting cold climatic conditions. While open vegetation consisting of patches with low shrubs, grass and herbs dominated at middle altitudes and patches with un-vegetated and unstable ground existed at higher elevations, *Betula* and *Pinus* may have retreated into sheltered valleys. These trees did not become re-established close to the sites until c. 11,500 cal. years BP, coincident with the beginning of the Holocene.

Although several short-term cooling episodes occurred during the early Holocene in the North Atlantic region (e.g. Björck et al., 1997), these seem not to have had any impact on the forest development between 11,500 and 8500 cal. years BP. The re-establishment of open *Pinus*, *Betula* and *Ulmus* forests (11,500–12,250 cal. years BP) was followed by a succession of dense *Ulmus*, *Picea*, *Betula* and *Pinus* forests with some *Quercus*, *Tilia* and *Fraxinus* (11,250–10,700 cal. years BP). Later they were followed by dense *Ulmus*, *Corylus* and *Picea* forests and eventually by dense *Corylus* and *Ulmus* forests with some *Picea*, *Quercus*, *Tilia*, *Fraxinus* and *Acer*.

The forest development reconstructed for Preluca Tiganului and Steregoiu therefore shows that the distinct Lateglacial cooling events G1-1d and GS-1 had a major impact on the forest composition around mid-altitude sites in northwestern Romania. During both periods, the gradually expanding open forests became greatly reduced and were replaced by open vegetation communities. While the response of the vegetation to the earlier, GI-1d cooling seems to have been instantaneous, the response to the GS-1 cooling, which is clearly expressed around the North Atlantic region, was very likely delayed by a few hundred years. It could be argued that this delay is an artefact due to chronological problems. However, it is also possible that the forest communities had at that time (13,800–12,600 cal. years BP) already reached a certain stability, which was not as easy to disturb, as compared to GI-1d, when forests had only just started to develop. The prolonged cold temperatures of GS-1, however, may have eventually caused a severe disturbance and fragmentation of the forest communities, which then in turn led to the re-establishment of shrub and herb assemblages. The rapid reforestation by open *Betula* and *Pinus* forests at 11,500 cal. years BP shows that the dramatic rise in temperatures, which characterises the start of the Holocene in numerous North Atlantic records, also had an immediate impact on the environment surrounding the study sites. While climatic fluctuations seem to have been the driving force behind forest composition changes during the Lateglacial period, the Early Holocene forest development was mainly driven by migrational and successional processes.

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