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Reconstruction of climatic and environmental changes in NW Romania during the early part of the last deglaciation (~15,000–13,600 cal yr BP)

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Abstract

High resolution pollen, plant macrofossil, charcoal, mineral magnetic and sedimentary analyses, combined with AMS ^{14}C measurements, were performed on multiple sediment sequences along a transect through the former crater lake Preluca Tiganului in northwestern Romania in order to reconstruct the climatic and environmental changes during the early part of the Last Termination. Lake sediments started to accumulate at ~14,700 cal yr BP. Initially the upland vegetation consisted of an open forest with mainly *Betula* and *Salix* and few *Pinus* sp., but from 14,500 cal yr BP onwards, *Pinus mugo*, *P. sylvestris* and *Populus* and later on also *Larix* became established around the lake. Between 14,150 and 13,950 cal yr BP, *Pinus cembra* seems to have replaced *P. mugo* and *P. sylvestris*. At ~13,950 cal yr BP the tree cover increased and *Picea* appeared for the first time, together with *Pinus cembra*, *P. mugo* and *Larix*. From ~13,750 cal yr BP onwards, a *Picea* forest developed around the site. Based on the combined proxy data the following climatic development may be inferred: 14,700–14,500 cal yr BP, cooler and wet/humid; 14,500–14,400 cal yr BP: gradually warmer temperatures, wet/humid with dry summers; 14,400–14,320 cal yr BP: warm and dry; 14,320–14,150 cal yr BP: cooler and wet/humid; 14,150–14,100 cal yr BP: warm and dry; 14,100–13,850 cal yr BP: warmer and wet/humid; <13,850 cal yr BP: warm and dry. The tentative correlation of this development with the North Atlantic region assumes that the period >14,700 cal yr could correspond to GS-2a, the time span between 14,700 and 14,320 to GI-1e, the phase between 14,320 and 14,150 cal yr BP to GI-1d and the time frame between 14,150 and 13,600 cal yr BP to the lower part of GI-1c.

1. Introduction

Paleoclimatic and paleoenvironmental research has been most intense in areas around the North Atlantic region, where distinct Lateglacial and early Holocene climatic fluctuations are widely recognized (Bond et al., 1997; Björck et al., 1998; von Grafenstein et al., 1999). Continental areas, such as eastern and southeastern Europe, are represented by fewer records, often with poor chronological control (Willis, 1994). This makes it difficult to compare their paleoclimatic development with the North Atlantic region. The scarcity of good paleoenvironmental data sets for eastern Europe (Willis, 1994; Berglund et al., 1996) and particularly for Romania (Farcas et al., 1999) is surprising, since this region has been repeatedly pointed out as an important glacial refuge area, from which trees started to migrate at the beginning of the Holocene (e.g. Huntley and Birks, 1983; Bennett et al., 1991; Huntley, 1993; Willis, 1994). If trees were able to survive in this region, the climatic conditions in some environmentally favourable localities, e.g. in deep incised mountain valleys, during the Last Glacial Maximum (LGM) and during the early part of the last deglaciation could not have been as severe as in northern and central Europe.

The biogeographic reconstructions by Huntley and Birks (1983), Bennett et al. (1991), Huntley (1993) and Willis (1994) had to rely on previously published pollen stratigraphic work with low temporal resolution and inadequate dating control. Furthermore, these older

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pollen stratigraphic studies had often been carried out on regional-scale sites, which are less suitable for a reconstruction of the local vegetation. Plant macrofossil records, which could give clear indications for the local presence of plant species (e.g. Birks, 1980, 1993), were not available. Altogether, this made it (i) difficult to locate exactly supposed refuge areas and (ii) to address directly the paleoclimatic conditions that might have prevailed during this critical time span. Only recently could it be shown, based on macroscopic charcoal analysis, that coniferous trees (*Pinus*, *Picea*, *Larix*, *Juniperus*) did exist during the LGM in Hungary, where they probably survived in specific micro-environmental habitats, such as, e.g. sheltered mountain valleys or south-facing slopes (Willis et al., 2000).

Pollen stratigraphic work has a long tradition in Romania (e.g. Pop, 1929, 1932, 1960) and although many peatbog sequences have been investigated during the last century, none of them has been radiocarbon dated. Age assignments have mainly been derived by comparing the vegetation development to the Lateglacial and Holocene vegetation zonation established for central Europe (Firbas, 1949, 1952). Several of the localities of Pop and others are now under re-investigation with respect to pollen stratigraphy (S. Farcas, pers. comm. 1999), but almost all of these cover the Holocene period only (J.-L. de Beaulieu, pers. comm., 2000). Recently, Farcas et al. (1999) published a reconstruction of the regional Lateglacial and Holocene vegetation development, based upon low-resolution pollen stratigraphy and AMS ^{14}C dates from two peatbog sequences in northeastern and southern Romania. However, the stratigraphic resolution of the analysed pollen samples was low and only two AMS ^{14}C dates could be obtained for the Lateglacial part. In neighbouring Hungary, new multi-disciplinary studies are emerging, but these deal mainly with the LGM (Willis et al., 2000) and the Holocene (Willis et al., 1995) and do not have sufficient time control for the deglacial period.

The focus of this investigation is on a detailed reconstruction of the paleoclimatic and paleoenvironmental changes that occurred during the early part of the last deglaciation (GI-1e, GI-1d and GI-1c (Björck et al., 1998; Walker et al., 1999)) in northwestern Romania, based on a multidisciplinary study of a lake sediment sequence. This restricted time period was chosen because it (1) covers the beginning of the first distinct warming seen in Northern Hemisphere terrestrial, marine and ice core records (Lowe and INTIMATE Members, 1995; Walker, 1995) and (2) includes transitions between colder and warmer phases (Björck et al., 1998; Walker et al., 1999), which due to the lack of a high-resolution analysis are not always evident in terrestrial records. Detailed pollen stratigraphic studies covering the whole Lateglacial and the early Holocene will be presented elsewhere (Björkman et al., in prep.).

The record is derived from the former crater lake, Preluca Tiganului (Fig. 1), where high-resolution pollen, plant macrofossil, charcoal and sedimentary analyses have been carried out, combined with mineral magnetic properties and AMS ^{14}C measurements. Multiple cores along a transect through the basin have been used in an attempt to reconstruct possible paleohydrological changes following the method of Digerfeldt (1988, 1997a, b). The combination of pollen and plant macrofossil analyses on the same cores gives more detailed information than either method alone about the nature of the changing upland vegetation; it also provides a means of distinguishing local presence of certain taxa from populations growing at some distance from the site (Birks, 1993), separating species within families, which have differing environmental preferences but morphologically homogeneous pollen (e.g. Birks and Mathewes, 1978; Watts, 1978; Hannon, 1999) and over- or under-representation of certain taxa in the pollen and macrofossil record.

2. Study area

The former crater lake Preluca Tiganului (N 47°48′83″; E 23°31′91″) is situated southeast of the small town of Negresti-Oas, on the western flank of the Gutaiului Mountains at an altitude of 730 m a.s.l. (Fig. 2). This massif is part of the Eastern Carpathian mountain chain and stretches in a NNW–SSE direction with peaks rising up to 1200–1400 a.s.l. (Fig. 1). The former crater lake, which is overgrown, has an almost circular surface area of ca. 1 ha and is drained by a small stream. Gently rising slopes surround the site to the east and west. South of the bog, the Tigan Mountain attains an altitude of 843 m, and towards the north, fairly steep slopes lead down to the Talna River valley, which is situated at ca. 400 m a.s.l. (Fig. 2). The surrounding forest vegetation consists of a fairly young *Fagus* forest and recently planted *Picea* trees. Earlier investigations by Lupsa (1980) have described Preluca Tiganului as an eutrophic to mesotrophic mire with a vegetation consisting of *Nardus stricta*, *Festuca rubra*, *Anthoxanthum odoratum*, *Deschampsia caespitosa*, *Juncus conglomeratus*, *Carex stellulata*, *C. flava*, *C. canescens*, *C. rostata*, *Eriophorum latifolium*, *Potentilla erecta*, *Galium palustre*, *Lysmachia vulgaris* and *Caltha palustris/laeta*.

Climate records for the area are available from weather stations in Satu Mare and Baia Mare and from the eastern (Ocna Sugutag) and northern (Sighetul Marmatiei) part of the Gutaiului Mountains (Fig. 1). 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 (592 mm). It rises to 862 mm

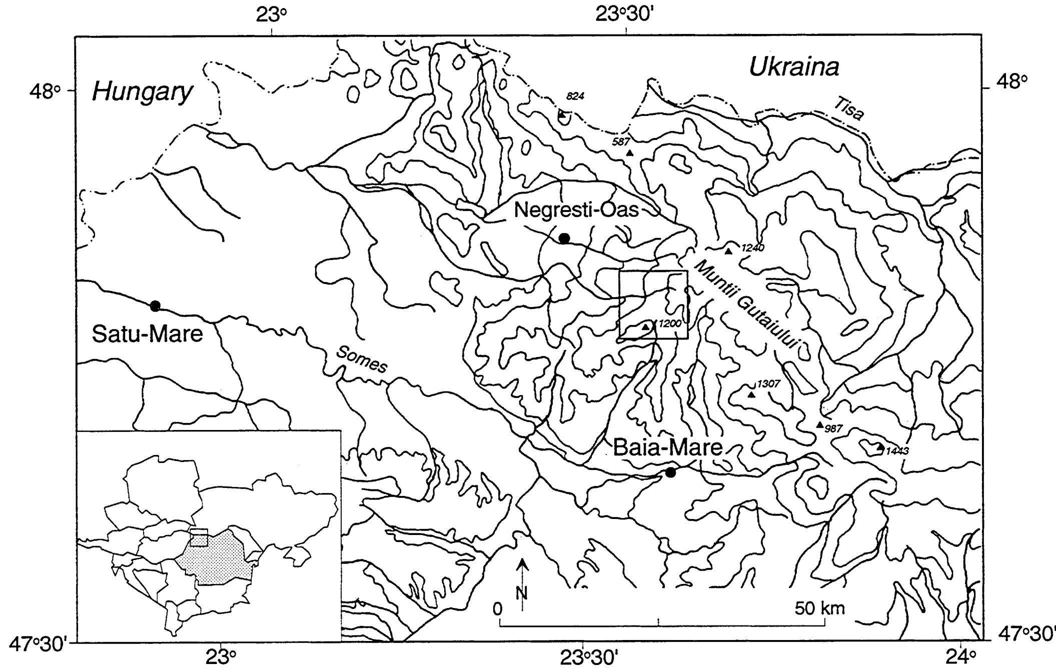

Fig. 1. Northwestern Romania and location of the study area in the Gutaiului Mountains, southeast of Negresti Oas. The location of the investigated site, which is shown in detail in Fig. 2, is indicated by a square.

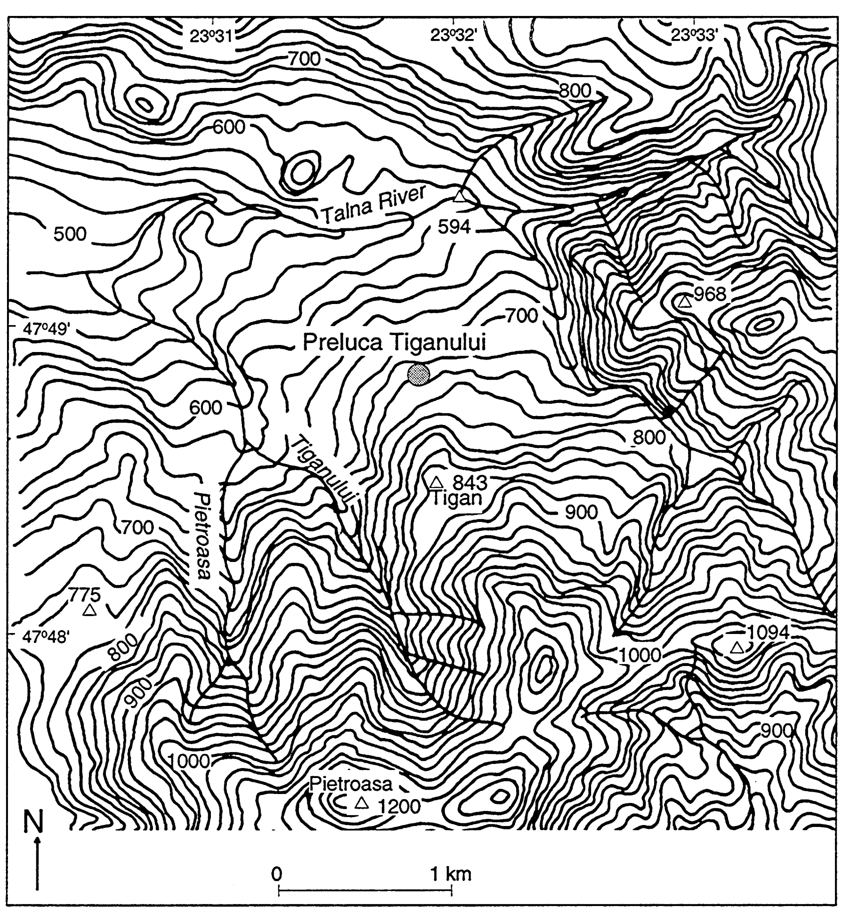

Fig. 2. Topographic map showing the location of the small, former crater lake Preluca Tiganului (filled circle).

around Baia Mare and decreases slightly to 718 and 742 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 acid rocks (dacites, andesites, and rhyolites) (Borcos et al., 1979). The main bedrock types consist of andesites, with pyroxenes as the main component, and andesites rich in quartz. Published information about Quaternary deposits is not available for the area, but observations in road cuts indicate that most of the sediments are derived from slope processes. It is also generally assumed that alpine glaciers did not reach below 1600 m in the Carpathians during the LGM (Woldstedt, 1958). The low elevation of the Gutaiului Mountains makes it therefore unlikely that the area was glaciated.

3. Methods

Sediment cores were taken in June 1997 at four coring points (CP) along an E–W transect with a strengthened Russian corer (diameter: 5 cm, length: 1 m) (Fig. 3a). The cores were described in the field and the basal sediments from CP 1 to 4 were selected for further analysis (Fig. 3b). These cores were wrapped in plastic film, placed in half PVC tubes, and transported to the Department of Quaternary Geology in Lund, Sweden, where they were stored at 4°C. Prior to sampling, all cores were carefully cleaned, described again and visually correlated with each other.

Saturation isothermal remnant magnetization (SIRM) analysis was performed to aid the visual correlation of the individual cores and as a proxy for in-wash of minerogenic material. Contiguous samples were taken in plastic boxes ($2 \times 2 \times 2\,cm^3$) along the entire cores (CP 2a–c, 4a, b), making sure to avoid lithological boundaries. SIRM was induced in a maximum magnetic field of 1 T ($\mu_0 H = 1\,T$) with a Redcliff puls magnetizer, and the remnant magnetization was measured with a Molspin 'Minispin' magnetometer. The samples were dried at 40°C after measurement to calculate mass specific units ($mA\,m^2\,kg^{-1}$). The same samples were then used to measure weight loss on ignition (LOI) at 550°C and at 925°C according to the method of Bengtsson and Enell (1986). The content of organic material (OM) was calculated based on LOI at 550°C, and is expressed as % of the dried sample weight (at 105°C). LOI values of $<0.2\%$ between 550°C and 925°C showed that carbonates were not present.

Petrographic analysis (on selected samples), clay mineralogy and grain size measurements were carried out on CP 2b and c to obtain information about the provenance of the minerogenic material, to recognize phases with increased minerogenic in-wash and as a proxy for humidity changes. Clay mineralogical analyses were carried out by transmission electron microscopy, X-ray diffraction of powder and oriented samples (natural or treated with ethylene glycol). The same samples were used for grain size analysis, which was done by planimetry and the following fractions were distinguished: 0.15–0.06 mm (sand), 0.006–0.004 mm (silt), <0.004 mm (clay).

CP 2a–c were analysed both for pollen and plant macrofossils in order to study upland vegetation changes, while CP 4a–b were only analysed for plant macrofossils, mainly for the purpose of reconstructing possible lake-level changes. To enable the calculation of pollen concentrations, tablets with a known content of *Lycopodium* spores were added to each sample. The preparation of the pollen samples ($1\,cm^3$) followed Berglund and Ralska-Jasiewiczowa (1986). For plant macrofossil analysis (Wasylikowa, 1986), contiguous sub-samples were taken, soaked in 5% NaOH and sieved through 0.25 mm meshes under running water. The residue was kept in distilled water at 4°C. Plant macrofossils were identified as closely as possible using published plant atlases, floras and keys available (Bertsch, 1941; Farjon, 1984; Tomlinson, 1985; Tutin et al., 1964–1980; Vidakovic, 1991). All fossil remains were matched with specimens from the reference collection at the Department of Quaternary Geology, Lund and/or from the reference collection of Gina Hannon, to ensure reliable identifications. Plant remains identifiable to taxa or species were systematically counted and presented as concentration per 30 ml sediment. *Larix* needles and *Populus* bracts are shown in terms of their presence or absence, instead of absolute counts. Absolute counts of macro-charcoal were made, defined here as black crystalline material, which crumbles easily (Axelsson, 1995). The sieve remains from CP 2b were further used to estimate the amount of mosses as compared to rootlets, in order to aid in the interpretation of water level changes. The pollen and plant macrofossil diagrams were visually sub-divided into three phases, primarily to facilitate the description of the major paleoecological changes through the record.

AMS ^{14}C measurements were carried out on bulk sediment samples and on plant macrofossils (mainly wood) (Table 2a). The samples were dried at 70°C overnight in small glass bottles and sent to the AMS facility in Uppsala. Sample preparation for bulk sediment samples included removal of visible organic material, treatment with 1% HCl (6–8 h below boiling point) and 1% NaOH (6–8 h below boiling point). The soluble part, which was precipitated with concentrated HCl, was cleaned, dried and then used for the

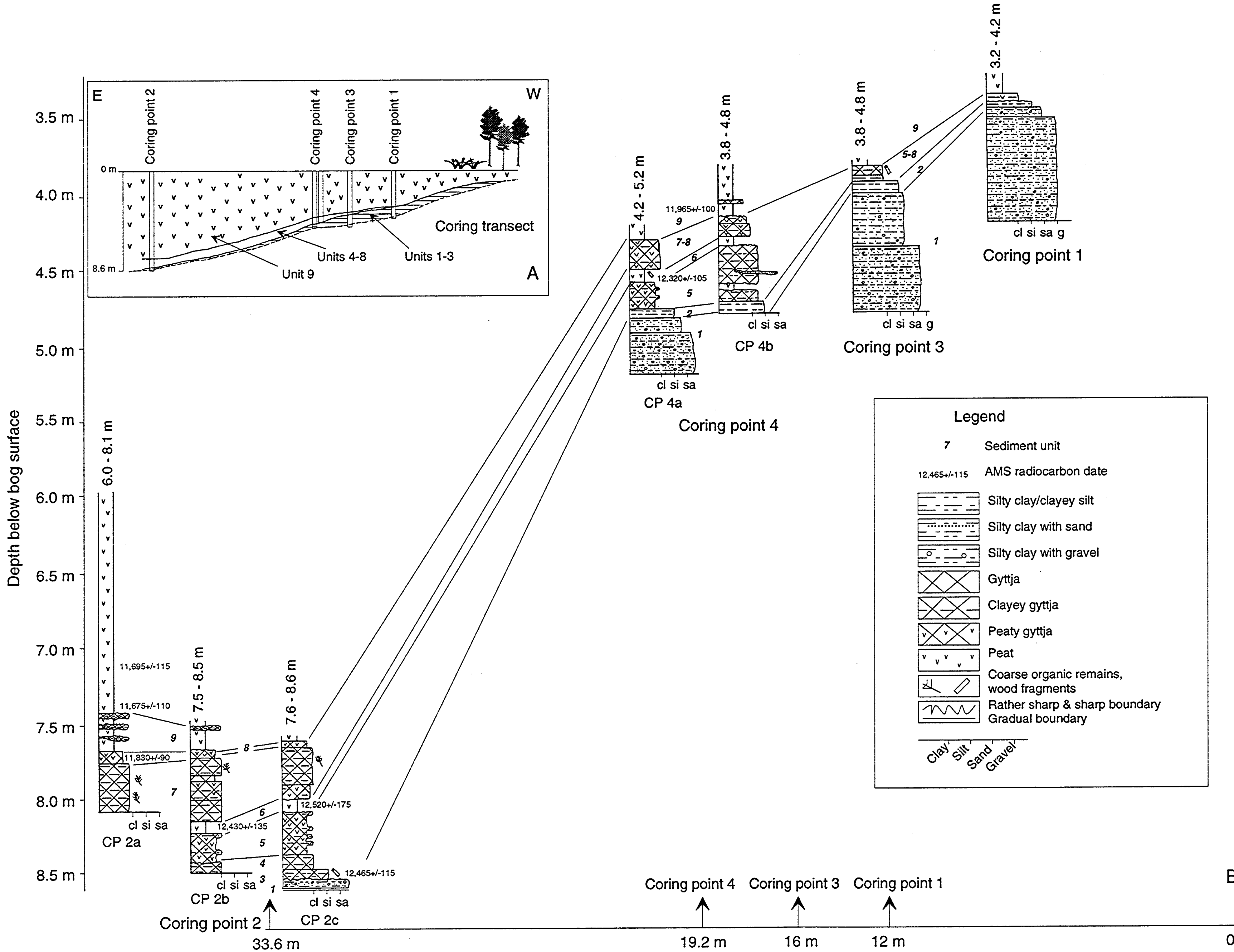

Fig. 3. (A) Sketch showing the position of the different coring points (CP) along the transect through the former crater lake. (B) Lithostratigraphy of the different cores at each CP and stratigraphic correlation between the cores and CPs. See Tables 1a–g for a detailed lithostratigraphic description.

measurements. Plant macrofossil samples for AMS dating were treated with 1% HCl (6 h below boiling point) and 0.5% NaOH (1 h at 60°C). For the AMS measurements, the insoluble fraction (INS) was used.

4. Results

4.1. Lithostratigraphy, mineral magnetics, content of organic matter and clay mineralogy

Based on the lithostratigraphical description of each core and on the correlation between the different cores along the transect, nine sedimentary units were assigned to the sequences (Fig. 3b; Tables 1a–g). The three central cores (CP 2a–c) are well correlated with each other in respect to both SIRM and OM and results are, therefore, presented for the combined sequence (Fig. 4).

The stiff bottom sediments in unit 1 show a dominance of andesite and porphyritic gabbro clasts in the gravel fraction, while the clay fraction contains, among others, magmatic and metamorphic quartz, pyroxene, olivine, zircon, titanite, garnet, epidote, tourmaline and apatite. OM reaches 8% and SIRM values fluctuate between 2.0 and 5.5 $mA\,m^2\,kg^{-1}$. In the overlying unit 2 (CP 4, 3, 1), SIRM ranges at 1.4–3.0 $mA\,m^2\,kg^{-1}$ and OM attains 8–10%. In units 3 and 4 (CP 2) SIRM values are low and OM increases to between 14 and 35%. Clay dominates the grain size and silt is present with 20%. Halloysite and kaolinite make

Table 1

Depth (m) below surface	Sediment unit	Sediment description
(a) *Lithostratigraphic description of the sediment sequence at CP 1; g = gradual, LB = lower boundary*		
3.20–3.34	9	Dark brown peat, gLB
3.34–3.41	?5–8	Dark brown clayey peat with lenses of the underlying clay, eroded lower boundary
3.41–3.445	2	Light brown to reddish, stiff silty clay with organic material, gLB
3.445–3.50	1	Light brown to reddish stiff silty clay with gravel and sand, some organic material, gLB
3.50–4.20		Light brown to reddish stiff silty clay with gravel and sand
(b) *Lithostratigraphic description of the sediment sequence at CP 3; g = gradual, LB = lower boundary*		
3.80–3.825	9	Dark brown peat with some clay lenses, gLB
3.825–3.875		Dark brown clayey gyttja with wood pieces, gLB
3.875–3.92	5–8	Mixture of reddish-brown clay, brown organic clay and dark brown gyttja, gLB
3.92–4.00	2	Brown slightly organic silty clay, gLB
4.00–4.355	1	Light brown to reddish silty clay, some gravel and sand, gLB
4.355–4.80		Light brown to reddish silty clay with gravel and sand
(c) *Lithostratigraphic description of the sediment sequence at CP 4b; g = gradual, rs = rather sharp, s = sharp, LB = lower boundary*		
3.80–4.04		Dark brown to black peat, rsLB
4.04–4.065	9	Dark brown peaty gyttja, gLB
4.065–4.145		Dark brown peat, rsLB
4.145–4.20	7–8	Dark brown slightly clayey, peaty gyttja, gLB
4.20–4.28		Brown clayey, peaty gyttja, gLB
4.28–4.345	6	Dark brown to black peat with wood pieces, rsLB
4.345–4.595		Light brown silty clayey gyttja with organic-rich horizons and coarse plant fragments, rsLB; beige sandy lens with sLB between 4.525 and 4.53 m
4.595–4.645	5	Dark brown to black peat, rsLB; light brown clayey gyttja layer between 6.635 and 4.64 m
4.645–4.71		Brown clayey silty gyttja/silty gyttja clay with fairly coarse plant fragments, gLB
4.71–4.80	2	Brown-reddish, slightly organic silty clay
(d) *Lithostratigraphic description of the sediment sequence at CP 4a; g = gradual, LB = lower boundary*		
4.20–4.295	9	Dark brown to black peat, gLB
4.295–4.495	7–8	Layers of dark brown slightly clayey, peaty gyttja and brown clayey peaty gyttja, gLB
4.495–4.58	6	Dark brown to black peat with wood pieces, gLB
4.58–4.76	5	Layers of dark brown to black peaty gyttja and brown clayey peaty gyttja, gLB
4.76–4.82	2	Brown-reddish, slightly organic silty clay, gLB
4.82–4.925		Brown silty clay, with some gravel and sand, gLB
4.925–5.20	1	Brown-yellowish silty clay with gravel and sand
(e) *Lithostratigraphic description of the sediment sequence between 6.0 and 8.1 m at CP 2a; g = gradual, rs = rather sharp, s = sharp, LB = lower boundary*		
6.00–7.45		Dark brown to black peat, rsLB
7.45–7.485		Greyish brown clay gyttja, slightly peaty, rsLB
7.485–7.53		Dark brown to black peat, sLB
7.53–7.555	9	Greyish brown clayey gyttja, slightly peaty, sLB
7.555–7.605		Dark brown to black peat, sLB
7.605–7.63		Lens of greyish brown clayey peaty gyttja, sLB
7.63–7.70		Dark brown to black peat, gLB

Table 1 (*continued*)

Depth (m) below surface	Sediment unit	Sediment description
7.70–7.77	8	Dark brown to black peaty gyttja, gLB
7.77–8.10	7	Brown clayey gyttja with coarse organic material
(f) *Lithostratigraphic description of the sediment sequence between 7.5 and 8.5 m at CP 2b; g = gradual, rs = rather sharp, s = sharp, LB = lower boundary*		
7.50–7.55		Dark brown to black peat, sLB
7.55–7.56	9	Greyish brown clayey gyttja, slightly peaty, sLB
7.56–7.70		Dark brown to black peat, sLB
7.70–7.75	8	Dark brown to black peaty gyttja, gLB
7.75–7.86		Brown clayey gyttja with coarse organic material, gLB
7.86–7.90		Dark brown gyttja, gLB
7.90–8.025	7	Brown slightly clayey, peaty gyttja, gLB
8.025–8.165		Brown clayey gyttja, gLB
8.165–8.235	6	Dark brown peat, gLB
8.235–8.435	5	Dark brown peaty gyttja with brown to light grey, clayey gyttja layers between 8.235–8.255 m, 8.365–8.37 m and 8.385–8.41 m, rsLB
8.435–8.50	4	Brown slightly clayey gyttja
(g) *Lithostratigraphic description of the sediment sequence between 7.6-8.6 m at CP 2c; g = gradual, rs = rather sharp, s = sharp, LB = lower boundary*		
7.60–7.635	9	Dark brown to black peat, gLB
7.635–7.69	8	Dark brown to black peaty gyttja, rsLB
7.69–7.92	7	Brown clayey gyttja with coarse organic material (peat), gLB
7.92–8.01		Brown to dark brown slightly clayey peaty gyttja, rsLB
8.01–8.105	6	Dark brown peat, rsLB
8.105–8.39	5	Dark brown peaty gyttja with brown greyish slightly clayey peaty gyttja layers between 8.105–8.125 m, 8.20–8.225 m, 8.255–8.27 m, 8.295–8.305 m; wood remains between 8.38 and 8.39 m, gLB
8.39–8.47	4	Brown, slightly clayey gyttja, gLB
8.47–8.555	3	Brown silty clay gyttja with wood fragments, sLB
8.555–8.60	1	Light brown yellowish stiff silty clay with gravel

up 55% of the clay mineral fraction. Unit 5 (CP 2, 4) is missing in the cores closer to the shore (CP 1, 3) or may be part of the sediments, grouped together under 'units 5–8'(see below). SIRM is generally low, OM attains up to 40% and a slight rise in the silt fraction occurs in the middle part of the unit. Unit 6 (CP 2, 4) shows low SIRM values, OM percentages of 36–59%, a slight increase in illite and smectite and a decrease in kaolinite and halloysite. In unit 7 (CP 2), SIRM attains again slightly higher values, which are paralleled by a distinct increase in the silt and sand fraction and by a decrease in OM percentages. Illite/smectite initially dominate the clay minerals, but at ca. 8.00 m, kaolinite/halloysite increase again and goethite occurs at 7.93 m. Petrographic analyses indicate the presence of soft, partly broken clay particles between 8.025 and 7.90 m. Unit 8 (CP 2) is characterized by low SIRM and high OM values.

Equivalent layers to units 7 and 8 at CP 4 are most likely composed of clayey, peaty gyttja and brown clayey gyttja layers (Fig. 3b). SIRM values are low and OM fluctuates between 10 and 30%. At CP 3 and 1, units 3–8 are missing (Fig. 3b) and the corresponding sediments are made up of clay, organic clay or brown gyttja, which are overlain by clayey gyttja with wood pieces (CP 3), or clayey peat with lenses of clay (CP 1).

The peat in unit 9 can be traced along the whole transect. SIRM is generally low and OM values attain up to 90%. From 7.625 m upwards kaolinite dominates and halloysite has a distinct decrease.

4.2. Plant macrofossil and pollen stratigraphy

The combined pollen (selected taxa) and plant macrofossil analyses are shown in Fig. 5 for CP 2 and the plant macrofossil diagram for CP 4b is presented in Fig. 6. The plant macrofossil assemblages were visually divided into the three main phases: PT-1, *open forest/wetland*; PT-2, *increase in tree cover;* and PT-3, *Picea* forest.

4.2.1. Open forest/wetland (PT-1)

PT-1*a*: The pollen assemblage of woody plants shows high *Pinus* values and low values for *Betula* and *Salix*, while the herbaceous taxa are dominated by Poaceae and Cyperaceae. The scarce plant macrofossil remains include Poaceae, *Carex* spp., abundant mosses, few *Pinus* spp. and, macro-charcoal (Fig. 6).

PT-1*b*: *Pinus* pollen values initially increase, but decline again in sediment unit 6, and the first *Picea* pollen appear. Plant macrofossils include *Pinus sylvestris*, *P. mugo*, *Salix* sp., tree *Betula* sp. and *Populus*,

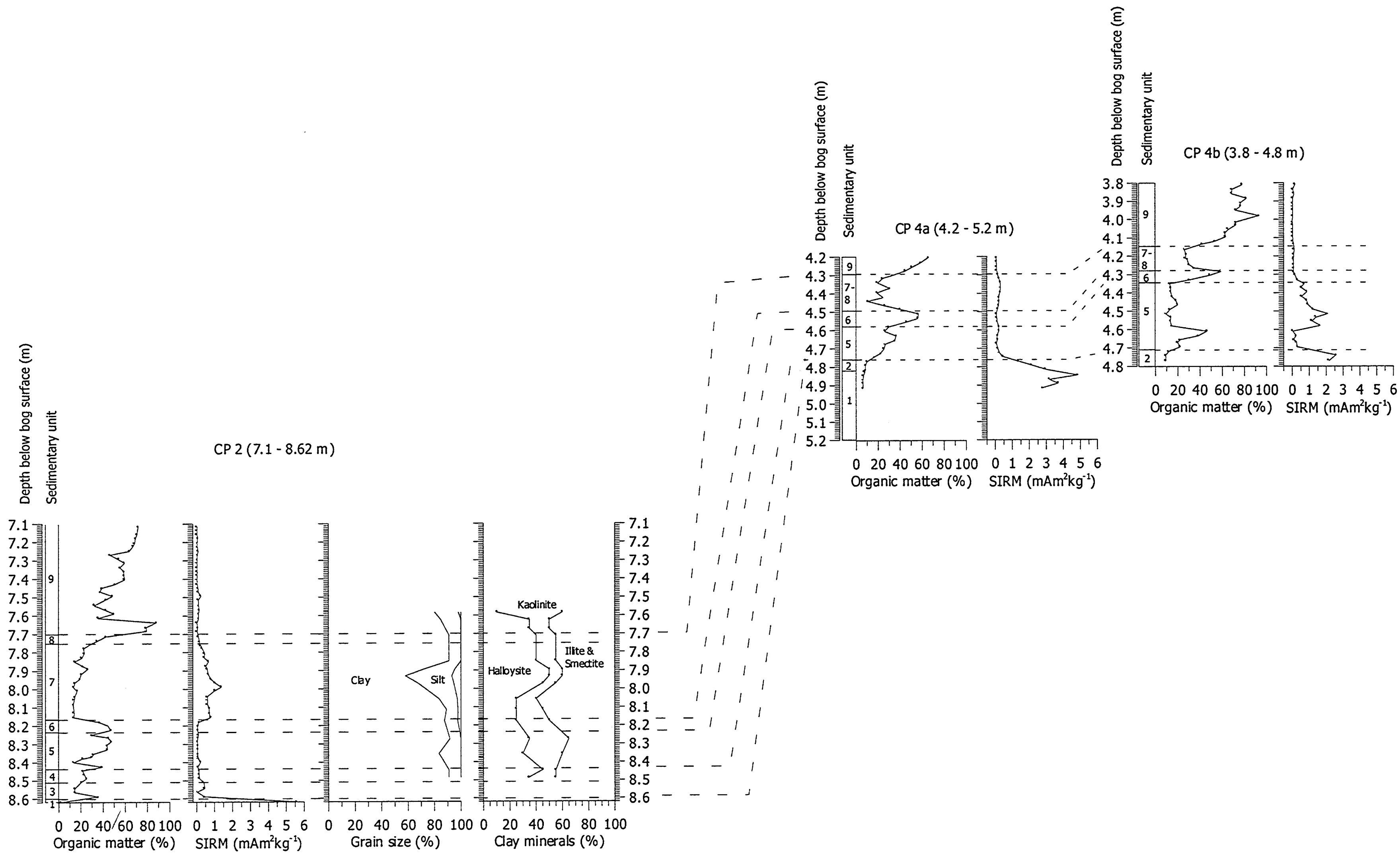

Fig. 4. Organic matter, SIRM, grain size and clay mineralogy at CP 2 and organic matter and SIRM at CP 4a and 4b. See Tables 1c–g for a detailed lithostratigraphic description of the sequences and Fig. 3 for the location of the cores.

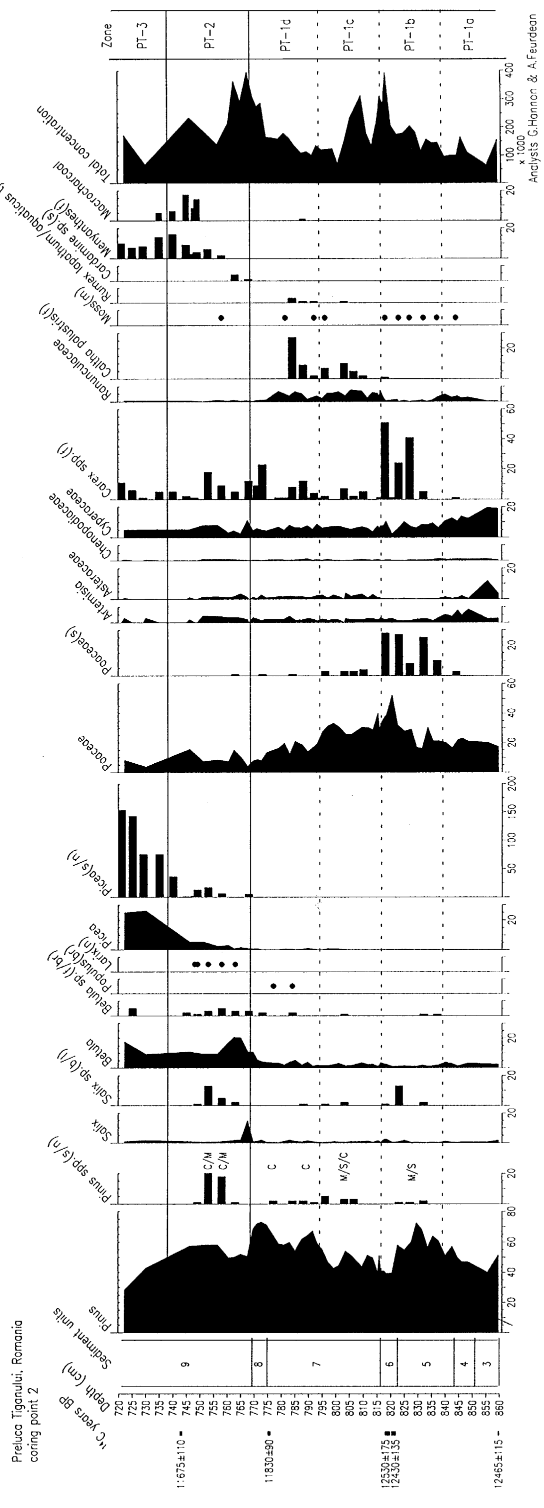

Fig. 5. Combined pollen and plant macrofossil diagram for CP 2. See Tables 1d–g for details on the lithostratigraphy and Fig. 3 for the location of the core. s = seeds, n = needles, nt = nuts, b = bracts, l = leaves, f = fruits, C = *Pinus cembra*, S = *Pinus sylvestris*, M = *Pinus mugo*.

scattered *Caltha palustris*, mosses, Caryophyllaceae (cf. *Stellaria* sp.), *Urtica dioica*, *Rumex lapathum/aquaticus* and *Viola* (Figs. 5 and 6). The decrease in *Pinus* pollen and macrofossil percentages in sediment unit 6 coincides with a maximum abundance of Poaceae pollen and macro remains.

PT-1c: *Pinus* has high values and *Salix*, *Betula* and *Picea* pollen are present in low percentages (Fig. 5). Macrofossils include *Pinus sylvestris, P. mugo, P. cembra*, *Salix* sp. and tree *Betula* sp. remains. The high pollen percentages for Poaceae, Cyperaceae and Ranunculaceae are mirrored by the presence of Poaceae, *Carex* spp. and *Caltha palustris* macro remains.

PT-1d: *Pinus* pollen values are high, while *Salix*, *Betula* and *Picea* remain low and Poaceae and Ranunculaceae percentages decline upwards. Macrofossils include few *Pinus cembra, Salix* sp., *Betula* sp., *Populus*, rare Poaceae, abundant *Carex* spp. and *Caltha palustris* and some *Rumex lapathum/aquaticus*. Single finds of macro-charcoal occur. PT 1c/d at CP 4b (Fig. 6) comprises *Pinus cembra*, *Picea, Larix*, *Salix* sp., *Betula* sp., *Carex* spp., and scattered finds of *Caltha palustris* and *Rumex lapathum/aquaticus*.

4.2.2. Increase in tree cover (PT-2)

This phase shows high *Pinus* and *Betula* pollen percentages and gradually rising values for *Picea* (Fig. 5). A distinct peak in *Salix* pollen percentages occurs at the very beginning of the zone and is followed by a peak in *Betula*. Poaceae, *Artemisia*, Asteraceae, Cyperaceae and Ranunculaceae have low values. Macrofossils include *Pinus cembra*, *P. mugo*, *Picea* and *Larix*, *Betula* sp. and *Salix* sp. and frequent *Carex* spp. (Figs. 5 and 6). *Menyanthes trifoliata* appears for the first time and scattered finds of *Cardamine* sp., *Rumex lapathum/aquaticus* and *Caltha palustris* occur at CP 4b. Charcoal fragments are present in fairly large quantities in the upper part of the phase.

4.2.3. Picea forest (PT-3)

Pinus pollen values decline gradually, *Picea* increases distinctly and *Betula* has significant values. Only scattered macrofossils of *Pinus* sp., *Salix* sp. and *Betula* sp. occur, while *Picea* needles become abundant. Herb pollen values decrease and macrofossil finds include *Carex* spp., *Menyanthes trifoliata* and some *Caltha palustris*. Charcoal fragments are recorded until 7.35 m at CP 2, but a very pronounced charcoal layer occurs in CP 4b (Fig. 6).

4.3. Sieve remains

The presence of mosses as compared to rootlets was estimated in the sieve remains at CP 2b. The lowermost sample (sediment unit 4; 8.435–8.45 m) showed a dominance of mosses. In sediment unit 5 mosses and

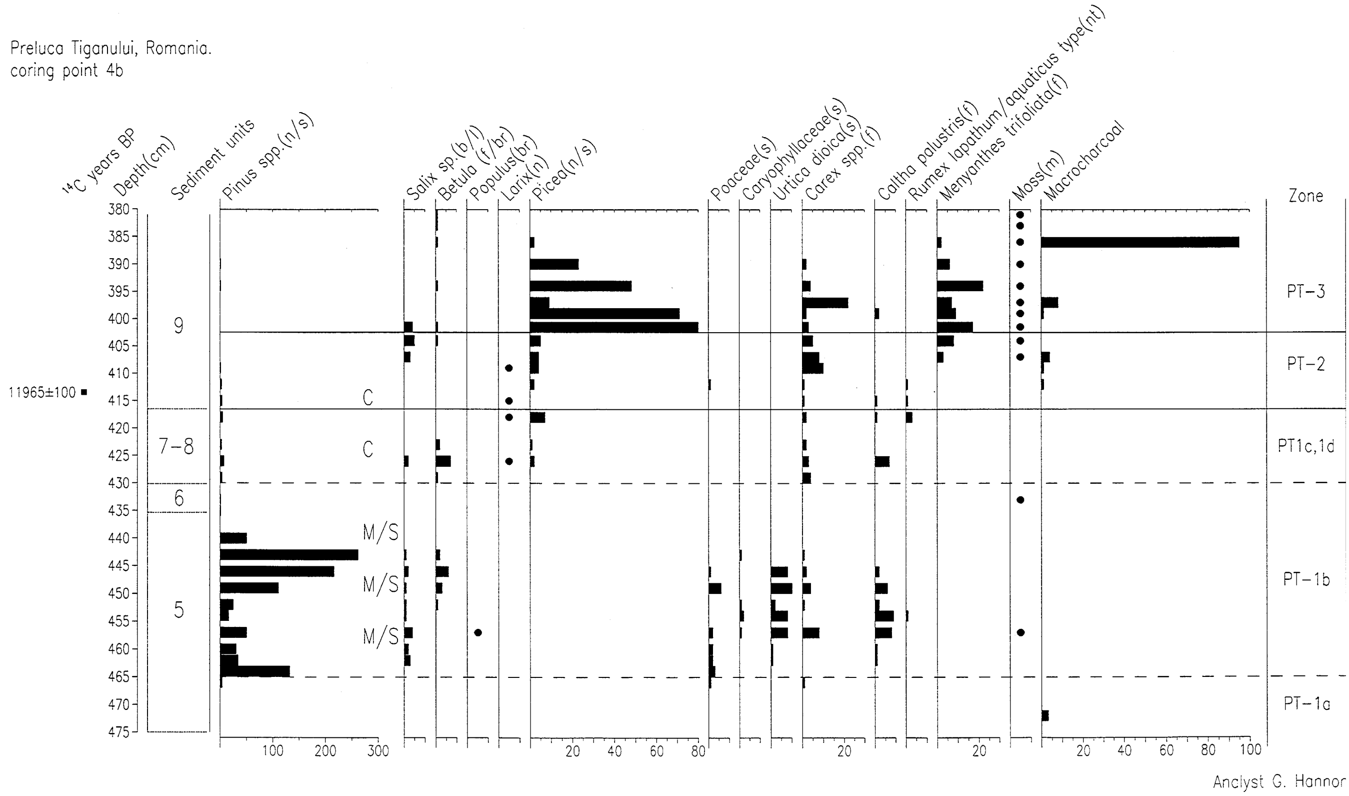

Fig. 6. Plant macrofossil diagram for CP 4b. See Table 1c for details on the lithostratigraphy and Fig. 3 for the location of the core. s = seeds, n = needles, nt = nuts, b = bracts, l = leaves, f = fruits, C = *Pinus cembra*, S = *Pinus sylvestris*, M = *Pinus mugo*.

rootlets initially occur together (8.45–8.36 m), but from 8.36 m upwards, rootlets become dominant. In unit 7, coarse detrital plant material is present between 8.12 and 8.05 m, but rootlets increase gradually from 8.05 m upwards and dominate between 7.94 and 7.70 m (upper part of unit 7, unit 8).

4.4. Chronology and age model

The eight AMS ^{14}C measurements from CP 2 and CP 4 display fairly consistent ages with respect to depth and sediment unit (Table 2a, Fig. 3b). However, most of the dates fall within a complicated part of the radiocarbon calibration curve (Stuiver et al., 1998), where the long plateau at ca. 12,600 ^{14}C yr BP and several other smaller plateaus make it difficult to obtain good calibrated dates.

To deal with this problem, the radiocarbon measurements were projected onto the combined sequence at CP 2, following the lithostratigraphic correlation between the different coring points and an adjusted depth level was calculated for each AMS ^{14}C sample (Table 2a). In a first approach this adjusted depth–age curve was used to find the best match to the radiocarbon calibration curve (Stuiver et al., 1998). A best fit was obtained by assuming a sedimentation rate of 14 cm/100 yr between 8.6 and 7.75 m (units 1–7) and of 13 cm/100 yr between 7.75 and 7.1 m (units 8 and 9) (Fig. 7). However, since the radiocarbon dates are unevenly distributed between the sediment units, the age model does not allow detecting abrupt changes in sedimentation rate or possible hiatuses, nor does it give proper sedimentation rates for each single sediment unit. The validity of the obtained cal yr estimates were, therefore, tested by (a) performing a standard calibration with the Oxcal Program v3.5 and (b) applying the sequence function in the model option of the program to the radiocarbon measurements (Bronk Ramsay, 2000). This latter approach allows the information that one measurement precedes another to be incorporated into the resultant probability distribution (Bronk Ramsay, 2000), but does not take sedimentation rates or sedimentation rate changes into consideration. As shown in Table 2b, all cal yr estimates obtained by the three approaches fall within the calculated probability ranges, except for the lowermost radiocarbon date (Ua-12782), where the age calculations resulted in differences of up to 600 years. This part of the calibration curve belongs also to one of the more uncertain time periods with respect to radiocarbon calibration, due to the long 12,600 ^{14}C plateau and a valid age attribution is, given one single date only, not possible.

Since all three calibration approaches result in approximately the same age estimates, but because the Oxcal v3.5 calibrations under- or overestimate sedimentation rates within the same units (e.g., units 6 and 9) (see Table 2b), we favour here the use of the visual age model (Fig. 7). Based on this tentative model, cal yr BP were assigned to the boundaries of the sediment units and to the different vegetation phases.

5. Climatic and environmental reconstruction

5.1. > ~14,700 cal yr BP

A stiff partly sandy silty clay with gravel-sized volcanic rock particles (unit 1) is the oldest sediment recovered along the transect and probably forms the bottom of the former lake basin. It is devoid of visible plant material and organic matter values of 2–8% could, therefore, be explained by water bound in the clay fraction. The fairly strong SIRM signal indicates presence of magnetic minerals (Figs. 3 and 4). These sediments may originate from slope processes, through which weathered volcanic material was transported from the surrounding slopes into the former crater. The strong compaction/over-consolidation of the sediments could relate to post-depositional dry conditions over a longer time period or, to overburden by e.g. a glacier. However, glacier overburden can be ruled out, since alpine glaciers, if at all present in this area, did not reach below 1600 m a.s.l. during the LGM (Woldstedt, 1958). If, on the other hand, a small cirque glacier had developed in the crater, traces of glacially derived sediments, such as sand, silt and clay should have been deposited. It may, therefore, be possible that a period of extremely dry conditions lead to an over-consolidation of the sediments after their deposition (Fig. 8).

The brown-reddish, slightly organic silty clay in unit 2 is only present in the cores closer to the shore. It displays a slightly higher organic content than the sediments in unit 1, but SIRM values are considerably lower (Figs. 3 and 4). Stratigraphically, this unit could correspond to unit 3 in CP 2, which has similar OM values. However, the fact that the lower boundary of unit 2 at CP 4a is gradual, whereas the lower boundary of unit 3 at CP 2 is sharp, and the clear difference in colour between the two units may argue against a time-synchronous deposition. Unit 2 could, therefore, similar as unit 1, originate from

Table 2

(a) *AMS ^{14}C dates from the different cores along the transsect in Preluca Tiganului, related to core, core depth and sedimentary unit. The adjusted depth has been obtained by projecting the dated levels in cores* 3.8–4.8, 4.2–5.2, 7.1–8.1 *and* 7.6–8.6 m *on the corresponding layers in core* 7.5–8.5 m

Lab. no.	Sample ID	Core	Depth (m)	Adjusted depth (m)	Sed. unit	Dated material	^{14}C age BP ($\pm 1\sigma$)	$\delta^{13}C$ (‰PDB)
Ua-12782	T-1	7.6–8.6	8.555–8.55	8.60–8.595	3	Bulk; clay gyttja	12,465 ± 115	−30.25
Ua-14017	T-24	7.6–8.6	8.06–8.04	8.20–8.18	6	Bulk; peat	12,520 ± 175	−28.61
Ua-13417	T-20	7.5–8.5	8.22–8.20	8.22–8.20	6	wood; leaves	12,430 ± 135	−27.87
Ua-14018	T-26	7.1–8.1	7.76–7.75	7.76–7.75	8	Bulk; peaty gyttja	11,830 ± 90	−28.22
Ua-14019	T-27	7.1–8.1	7.435–7.425	7.435–7.425	9	Bulk; peat	11,675 ± 110	−29.32
Ua-15264	T-54	7.1–8.1	7.15–7.10	7.15–7.10	9	Wood	11,695 ± 115	−23.8
Ua-14020	T-28	4.2–5.2	4.55–4.54	8.20–8.21	6	Wood	12,320 ± 105	−25.74
Ua-14021	T-29	3.8–4.8	4.14–4.13	7.69–7.68	9	Bulk; peat	11,965 ± 100	−27.96

(b) *Comparison of cal year estimates obtained from the visual match shown in Fig. 7 to those obtained from simple calibration with the Oxcal v*3.5 *program and to those obtained by applying the* '*sequence*' *function in Oxcal v*3.5 (Bronk Ramsey, 2000). *If not otherwise stated the probability of the calibration results is* 95.4%

Lab. no.	Sed. unit	^{14}C age BP ($\pm 1\sigma$)	Calibrated dates BP	'Sequence' function cal years BP	Visual matching cal years BP
Ua-12782	3	12,465 ± 115	14,400 (+1150/−350)	15,250 (+500/−800)	14,650
Ua-14017	6	12,520 ± 175	14,400 (+1250/−350)	14,500 (+850/−450)	14,350
Ua-13417	6	12,430 ± 135	14,400 (+1150/−350)	14,450 (+900/−400)	14,350
Ua-14018	8	11,830 ± 90	14,000 (+350/−550) (86.9%)	14,005 (+345/−255)	14,000
Ua-14019	9	11,675 ± 110	13,600 (+550/−450) (93%)	13,695 (+225/−225)	13,775
Ua-15264	9	11,695 ± 115	13,600 (+550/−450) (92.1%)	13,545 (+305/−245) (94.1%)	13,550
Ua-14020	6	12,320 ± 105	14,200 (+1250/−150)	14,275 (+975/−225)	14,350
Ua-14021	9	11,965 ± 100	14,100 (+250/−550) (78%)	13,910 (+160/−280)	13,950

slope processes or could, as outlined below, have been formed during the subsequent lake level rise.

5.2. ~14,700–14,550 cal yr BP

The silty clay gyttja and the overlying slightly clayey gyttja (units 3 and 4) are the first sediments to record a lake phase at CP 2. The sharp lower boundary of unit 3 suggests a hiatus of unknown length between the deposition of units 1 and 3. Sediments corresponding to units 3 and 4 are not found at CP 4, 3 and 1, where unit 2 is intercalated between units 1 and 5 (Figs. 3 and 4). Since sediments, which give indications for a first lake phase, are only observed at CP 2, the lake level must have reached just below CP 4a. Wave action could have led to an erosion of the surface sediments of unit 1 at CP 4, 3 and 1, which in turn could have resulted in the deposition of unit 2. If this scenario is correct, a rise in lake level of ~3.5 m could be inferred. The dominance of mosses in the sieve remains corroborates the rise in lake level, which is inferred from the sediments (Fig. 8).

The gradual decrease of minerogenic in put, indicated by low SIRM values and the increased organic production in the lake, shown by slightly higher OM values and by the transformation of kaolinite into halloysite, point to decreased erosion from the surrounding slopes. The pollen and plant macrofossil data indicate generally open vegetation, dominated by Poacaeae, *Artemisia* and Cyperaceae (Figs. 5 and 6). However, the high values of *Pinus* pollen and the occurrence of *Betula* and *Salix* pollen can be interpreted as local presence of these taxa, since the first *Pinus* needles appear at CP 4b and abundant plant macro remains of these three taxa are recorded from 14,500 cal yr BP onwards.

Taken together, the proxy data indicate a gradual stabilization of the soils in the open forest catchment, the development of a small lake and wetlands and the beginning of an organic production in the lake during a period of possibly cool-temperate and wet climatic conditions and low evaporation (Fig. 8).

5.3. 14,550–14,300 cal yr BP

The sediments during this time period (units 5 and 6) are composed of peaty gyttja with clayey gyttja layers (CP 2, 4a) or silty clayey gyttja with coarse plant fragments and intercalated peat and sand layers (CP 4b) and are overlain by peat (Fig. 3). These two units cannot be distinguished at CP 3 and 1, where a mixture of sediments, probably belonging to lithological units 5–8 was recognized. The deposition of lake sediments (unit 5) up to CP 4b indicates a further rise in the lake level (Fig. 8), but the peat and sand horizons in CP 4b show that the lake shore was most probably situated close to CP 4b. The lack of corresponding sediments at CP 3 and CP 1, the fluctuating SIRM and OM values at CP 4b (Fig. 4) and the composition of the plant macrofossil assemblage (see below) could be taken as further support for a shoreline position close to CP 4b-3. If the lake level was situated close to CP 4b-3, wave action could have caused erosion and reworking of the sediment material in CP 3 and 1, which is expressed in the sediment mixtures encountered at these coring points. The increasing dominance of rootlets in the sieve remains from ~14,500 cal yr BP onwards shows the initiation of a lake level lowering (Fig. 8). The gradually increasing organic content of the sediments, together with low SIRM values and decreasing grain size, indicate that in-wash of minerogenic material decreased considerably upwards. Halloysite/kaolinite dominate over illite/smectite in the clay mineral assemblage, which could point to slightly warmer and wet/humid conditions in the catchment (Figs. 4 and 8).

The deposition of peat in unit 6 (14,400–~14,320 cal yr BP) marks the end of this first lake stage and implies that large parts of the basin became dry. The peat is only present in CP 2 and 4, which may indicate that the area around CP 3 and 1 became too dry for peat formation. The increase in illite/smectite as compared to kaolinite/halloysite in unit 6 could be interpreted in terms of warmer and drier climatic conditions in the catchment.

In the lowermost part of unit 5, the vegetation was very similar to the previous time period. However, from ca. 14,500 cal yr BP onwards, abundant macrofossils of *Pinus sylvestris/mugo*, together with *Salix, Populus* and *Betula* confirm their presence around the lake, while herbaceous plant communities were still a dominant component of the vegetation (Fig. 5). At CP 4b, the macrofossil assemblage of herbaceous plants was more diverse and species-rich and included Poaceae, Caryophyllaceae, *Urtica dioica*, *Carex* spp., *Caltha palustris* and *Rumex lapathum/aquaticus* (Fig. 6), which could suggest a lower water level at this CP as compared to CP 2. Single occurrences of macro-charcoal at ~14,500 cal yr BP at CP 4b could be indicative of forest fires possibly during summers. Between 14,400 and 14,320 cal yr BP, i.e. coincident with the development of peat in the lake basin, Poaceae and *Carex* macro remains become frequent together with *Caltha palustris* in the central part of the basin. The scarce woody plants recorded during this time period are remains of *Salix* at CP 2b and *Pinus* needles at CP 4b.

The combined proxy data (Fig. 8), which show a further rise in lake level, may indicate more and more stable catchment soils and an increasing organic production in the lake. Although herbaceous plant communities still dominated the local vegetation, *Pinus*, *Betula*, *Salix* and *Populus* must have been growing closer to the basin. The overall development could be interpreted in terms of warmer and wet/humid climatic

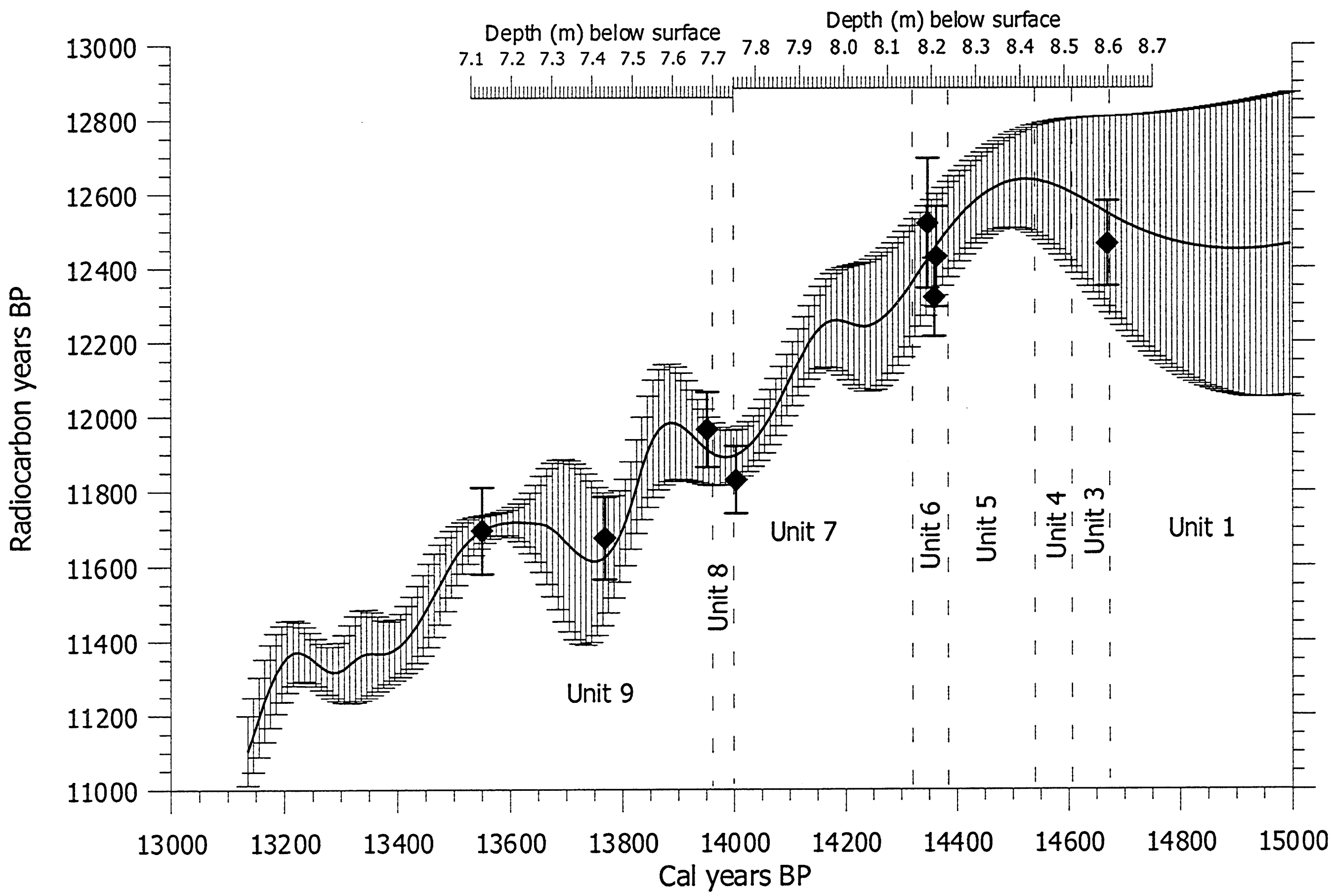

Fig. 7. Tentative age model for the investigated sediment sequence at Preluca Tiganului. This model is based (a) on a projection of all AMS ^{14}C dates on the section CP 2, (b) on a calculated, adjusted depth level for each radiocarbon date (see Table 2a) and on a comparison of the radiocarbon dates with the INTCAL98 calibration curve (Stuiver et al., 1998). See text for discussion.

conditions and low evaporation and occasionally dry summers. The gradual lake level lowering started at ~14,500 cal yr BP and led at ca. 14,400 cal yr BP to the formation of a peat layer in the whole basin. The spread of mire plants into the central part of the basin indicates, together with the distinct change in the clay mineral assemblage, a distinctly drier, but still warm phase and possibly increased evaporation between 14,400 and 14,320 cal yr BP (Fig. 8).

5.4. ~14,300–13,950 cal yr BP

The preceding low lake level phase was again followed by a rise in lake level and a subsequent shallowing up (Fig. 8). This is clearly documented by the sediment succession at CP 2 (clayey gyttja, clayey peaty gyttja, clayey gyttja with coarse organic material in unit 7 and peaty gyttja in unit 8) (Figs. 3 and 4) and by a renewed increase in rootlets at ~14,150 cal yr BP. Additional support comes from the plant macrofossil record, where the increase/decrease in *Caltha palustris* fruits coincides with the presumed lake-level changes at CP 2 (Fig. 5). Layers corresponding to units 7 and 8 are missing in the cores closer to the shore, where a clayey peaty gyttja (CP 4) and a mixture of clay and gyttja or clayey peat (CP 3, 1) were deposited. It is likely that the lake level was again initially situated close to CP 4a and that wave action around the shore could have led to erosion of the underlying layer, which in turn could explain the sediment mixtures encountered at CP 1, 3 and 4.

The organic content decreased considerably during unit 7 and increased in-wash of minerogenic material is indicated by slightly higher SIRM values (Fig. 4). This is especially pronounced between ~14,200 and 14,150 cal yr BP, where SIRM shows a distinct peak, both the silt and sand fraction increase markedly and reworked clay particles occur. Illite/smectite dominate the clay mineral assemblage between 14,320 and 14,200 cal yr BP, but decrease in favour of kaolinite/halloysite at ~14,200 cal yr BP (Fig. 8). Higher values of illite/smectite could indicate drier conditions in the catchment. However, since the increase in illite/smectite coincides with the rise

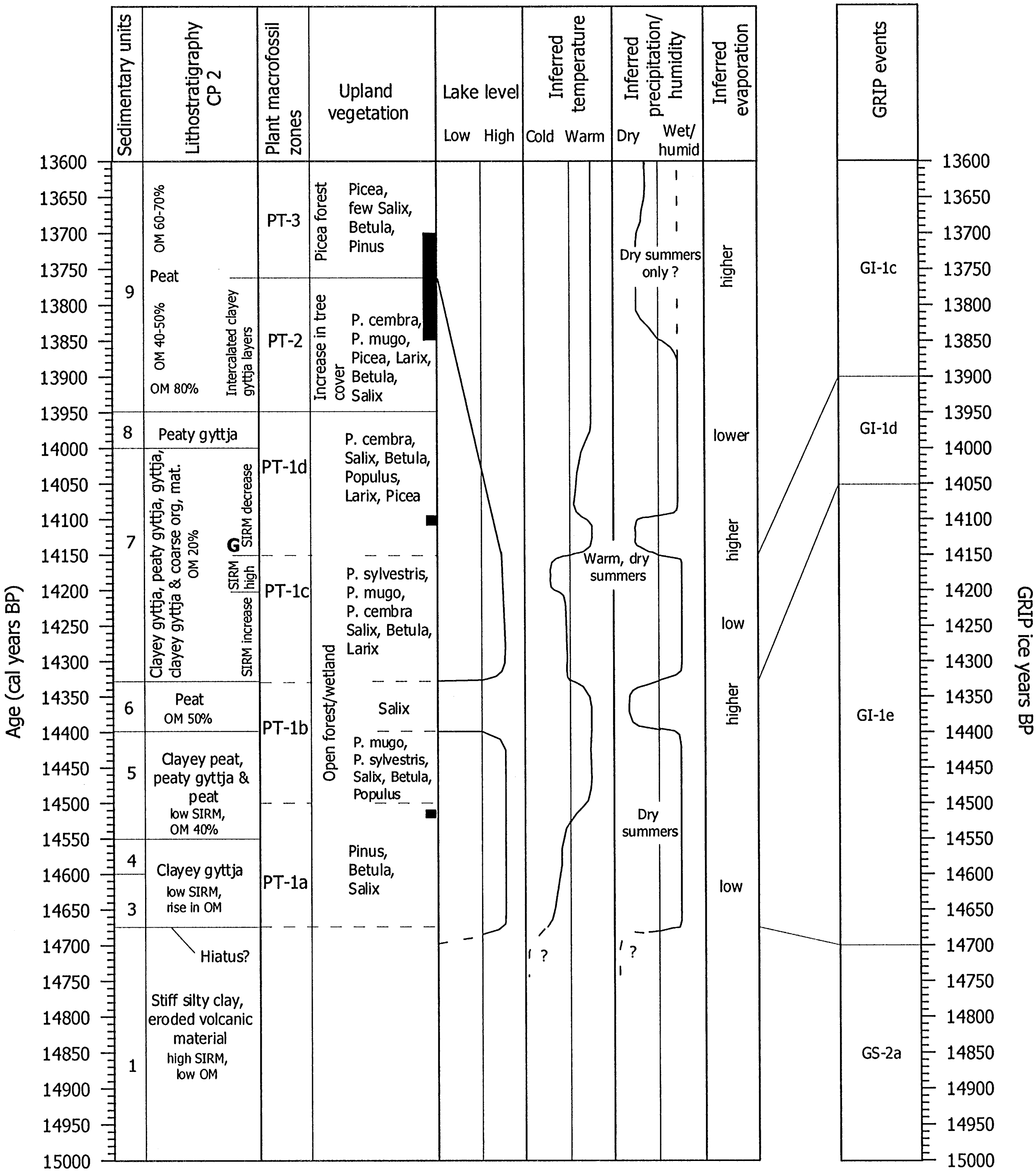

Fig. 8. Summary chart of the climatic and environmental development at Preluca Tiganului during the early part of the last deglaciation based upon lake level changes, sediment parameters, clay mineralogy, pollen and plant macrofossil data and calibrated radiocarbon dates. A tentative correlation of the different phases to the North Atlantic region/GRIP ice core record (Björck et al., 1998; Walker et al., 1999) is shown to the far right. G = occurrence of Goethite, black squares = occurrence of macro-charcoal.

in lake level and occurred before the phase of increased minerogenic in-wash mentioned above, it is likely that these clay minerals had been formed during the previous dry phase and that they were washed into the lake during the lake-level rise. The generally wet/humid conditions implied by the dominance of kaolinite/

halloysite for the middle and upper parts of unit 7, were, however, interrupted by a short, dry phase at ~14,150 cal yr BP, which can be inferred from the presence of goethite at 7.93 m in CP 2. During unit 8, i.e. from 14,000 cal yr BP onwards, the increasing organic content and the decreasing SIRM values, indicate a return to calmer conditions, with less catchment erosion.

The open forest community around the lake consisted initially of *Pinus sylvestris/mugo* and *Pinus cembra* with some *Salix* and *Betula*, but from ~14,100 cal yr BP onwards, *Larix* and *Populus* macro remains indicate that these tree species were also present (Fig. 5). Also around or just before this time period, *Pinus sylvestris/mugo* seem to have gradually been replaced by *Pinus cembra*. *Picea* pollen appear in low numbers throughout unit 7 at CP 2 and macro remains at CP 4 confirm its closeness to the lake (Fig. 6). Macro-charcoal remains appear in very low numbers at ~14,100 cal yr BP and could indicate forest fires, which would give support for drier summers at this time.

The different proxy data (Fig. 8) show a fairly complicated climatic development during this time period. The rise in lake level, which started at ~14,320 cal yr BP, was accompanied by in-wash of minerogenic material from the surrounding slopes and by a decrease in the organic content of the sediments, which could indicate cooler and wet/humid climatic conditions with low evaporation. The distinct phase of increased minerogenic input, which is seen between ~14,200 and 14,150 cal yr BP, could be interpreted as recording slightly more severe climatic conditions in the catchment. The gradual lake level lowering started at ~14,150 cal yr BP and coincides with the occurrence of goethite and macro-charcoal between ~14,150 and 14,100 cal yr BP. All three proxies could be taken as indicative for warmer and drier conditions and higher evaporation, at least during summers. During the gradual drop in lake level, the clay mineral assemblage suggests warmer and wetter/more humid conditions in the catchment. This is in turn corroborated by the replacement of *Pinus sylvestris/mugo* by *Pinus cembra* at ~14,150 cal yr BP, because the latter plant requires plenty of moisture in the air and the soils (Vidakovic, 1991).

5.5. 13,950–13,600 cal yr BP

The gradual infilling of the basin and the final overgrowing started at ~13,950 cal yr BP and was completed at ~13,750 cal yr BP. Low SIRM values reflect a calm environment with no or little in put of minerogenic material and the fluctuating organic content (Fig. 4) is likely related to different grades of humification and not to varying input of mineral material. Open water areas may have initially persisted along the shore and in the basin, which can be inferred from the presence of *Menyanthes trifoliata*. Wet/humid conditions during the initial phase of peat formation may be indicated by the small peak in *Salix* pollen values at ~13,950–13,900 cal yr BP, and by the presence of *Pinus cembra*. The forest community around the lake was initially composed of *Pinus cembra*, *Larix*, *Salix* and *Betula* and, to a minor extent of *Picea*, but was at ~13,750 cal yr BP replaced by a *Picea* forest. Forest fires, indicated by a distinct peak in macro-charcoal between 13,850–13,700 cal yr BP at CP 2 and again at a later time at CP 4b give support to the interpretation of warm and dry climatic conditions, especially during summer. The distinct reduction in *Picea* macrofossils during both charcoal events shows that the forest fires affected the *Picea* stands (Figs. 5 and 6). The gradual shift of *Menyanthes* further towards the centre of the basin and the high frequency of *Picea* macrofossils in the central core, indicate that open water surfaces were strongly reduced and that the conditions along the shore must have become drier.

The general climatic conditions may have initially been warm and wet/humid with higher evaporation (Fig. 8), as indicated by the clay mineral assemblage, the appearance of *Menyanthes trifoliata*, the presence of *Pinus cembra* and by the continued formation of peat. However, the occurrence of macro-charcoal from ~13,850 cal yr BP onwards, shows frequent forest fires, probably due to dry summers, which affected the *Picea* forest during at least two events. Based on the disappearance of *Pinus cembra* it could also be argued that the climatic conditions in generally became slightly drier.

6. Regional comparisons

The disadvantage with such a high-resolution multi-proxy study is, that comparisons to other records in the region can be very difficult, because most of these are based on low sampling resolution, poor dating control and often, only on one environmental parameter, such as pollen-based vegetation reconstructions.

From a vegetation point of view, the early establishment of forest taxa, such as the different *Pinus* species, *Picea*, *Larix* and deciduous *Betula*, *Salix* and *Populus*, encountered at Preluca Tiganului during the early part of the last deglaciation, is not surprising because several of these species (*Pinus*, *Picea*, *Larix*, *Betula*, *Salix)* were present in northeastern Hungary during the LGM (Willis et al., 2000). Their early and fairly rapid establishment at Preluca Tiganului makes it, however, also very likely that they could have existed in nearby sheltered areas during phases of maximum cold.

However, comparisons between the vegetation development seen at Preluca Tiganului and at other investigated sites in Hungary, Romania and Poland are more difficult to attempt. In Farcas et al.'s (1999) recently published pollen diagrams from northeastern and southern Romania, a dominance of *Pinus*, Poaceae and *Artemisia* characterize the Lateglacial part of the diagrams. An increase in *Picea* pollen values can e.g. only be observed at around 11,140 ± 75 ^{14}C yr BP in the diagram from the site Taul Zanogutii in southern Romania, which would correspond to 13,060 ± 190 cal yr BP and is thus considerably younger than the *Picea* increase seen at Preluca Tiganului at ~13,950 cal yr BP. At Bátorliget in northeastern Hungary (Willis et al., 1995), which is a low-land site (130 m a.s.l.) and situated less than 100 km to the west of Preluca Tiganului, the Lateglacial pollen spectra are interpreted as reflecting initially steppic and forest elements and later a denser, boreal forest. However, based on the pollen diagram alone and because of the lack of radiocarbon dates this development cannot be compared to our vegetation reconstruction. At the site Kis-Mohos Tó, situated in northern Hungary and approximately 500 km to the west of our site (Willis et al., 2000), the pollen diagram could be interpreted in terms of decreasing *Pinus* pollen values and increasing *Picea* values at ~14,000 cal yr BP. However, this development occurs during a phase with high *Artemisia* pollen values, which is not consistent with the local development at Preluca Tiganului. From the eastern part of the Polish Carpathians, pollen and plant macrofossil evidence indicates that Allerød forests below 700 m a.s.l. were composed of *Pinus sylvestris*, *P. cembra*, *P. mugo*, *Larix* and to some extent of *Picea*, while *Betula* seems to have been less important (Ralska-Jasiewiczowa and Latalowa, 1996). Although these latter records do not extend further back in time, they show that similar tree species as those recognized earlier at our site must have gradually colonized areas further to the northwest.

The first distinct change from cold and dry to cool-temperate and wet climatic conditions, which occurred at Preluca Tiganului at ~14,700–14,650 cal yr BP (Fig. 8), corresponds in time to the beginning of the first deglacial warming (GI-1e) seen in the GRIP ice core record at 14,700 GRIP ice yr BP (Björck et al., 1998; Walker et al., 1999). The synchroneity of this transition shows that the warming signal seen in the North Atlantic region was rapidly transmitted into areas situated further to the east. The time period between ~14,300 and 14,150 cal yr BP, which is characterized by increased minerogenic input and low organic production, could be interpreted in terms of slightly cooler, wet/humid climatic conditions. It includes a distinct phase with higher silt/sand content and increased SIRM values between ~14,200 and 14,150 cal yr BP. The INTCAL98 radiocarbon calibration curve (Stuiver et al., 1998) shows that radiocarbon ages for the lower and upper boundary of the Older Dryas/GI-1d would result in calibrated ages of ~14,200 and ~14,100–13,900 cal yr BP, respectively. In the GRIP ice core the corresponding time period has an age of 14,050–13,900 yr BP (Björck et al., 1998; Walker et al., 1999). Although highly speculative, the period between ~14,320 and 14,150 cal yr BP or parts of it, might correspond to the GI-1d cold period seen in the GRIP ice core (Fig. 8). Provided that this correlation is correct, it would imply that even shorter cooling events, which are seen in records from around the North Atlantic region, had an impact on areas situated further to the east. Between ~14,150 and 13,850 cal yr BP, warmer and wet/humid climatic conditions prevailed around Preluca Tiganului. However, from 13,850 cal yr BP onwards, it might have become considerably drier, at least during summers, which could point to increased continentality. Tentatively the time period from 14,150 cal yr BP onwards might be compared with the lower part of GI-1c.

7. Conclusions

(1) The oldest sediments, which were deposited before ~14,700 cal yr BP might indicate dry and cold conditions in the catchment. Their age is highly uncertain, but they could belong to the earliest part of the Last Termination, i.e. to GI-2a (Walker et al., 1999).

(2) Between ~14,700 and 14,320 cal yr BP, a vegetation consisting of woody plants (*Betula*, *Salix*, *Pinus mugo, P. sylvestris, Populus*) and herbs became established around the lake. Initially the climatic conditions may have been cool and wet/humid, possibly with few warm and dry summers, but from ~14,500 cal yr BP onwards, warmer temperatures may have prevailed. The distinct lake level lowering between 14,400 and 14,320 cal yr BP is interpreted as reflecting a short phase with warm and drier climatic conditions. Tentatively the time span between 14,700 and 14,320 cal yr BP could be correlated with GI-1e of the GRIP ice core event stratigraphy.

(3) Between 14,320 and 14,150 cal yr BP, the open forest vegetation consisted of *Pinus sylvestris*, *P. mugo*, *P. cembra*, *Salix*, *Betula* and *Larix*. Based on a renewed rise in lake level and increased minerogenic input, slightly cooler and wet/humid climatic conditions, which may have been most pronounced between 14,200 and 14,150 cal yr BP, are inferred. Although highly speculative, either the whole time period between 14,320 and 14,150 cal yr BP or parts of it may be time equivalent with the GI-1d cold phase seen in the GRIP ice core record.

(4) At around 14,150 cal yr BP, the lake level started to decrease gradually. This lake level lowering may have coincided with warm and dry summers or, possibly even with a short, warm/dry phase, which was followed by generally warm and wet/humid climatic conditions. Between 14,150 and 13,950 cal yr BP, *Pinus cembra*

seems to have replaced *P. sylvestris* and *P. mugo* and occurred together with *Salix*, *Betula*, *Populus*, *Larix* and the first *Picea* trees. From ~13,950 cal yr BP onwards, the tree cover increased and the forests around the site, which were initially composed of *Pinus cembra*, *Pinus mugo*, *Picea*, *Larix*, *Betula* and *Salix,* developed at ~13,750 cal yr BP into a *Picea* forest with few stands of *Salix*, *Betula* and *Pinus*. The final overgrowing of the lake also occurred at around this time period. The warm and possibly wet/humid climatic conditions, which are inferred between 13,950 and 13,850 cal yr BP, may have been succeeded by a dry period from 13,850 cal yr BP onwards. However, it may also be likely that these dry climatic conditions prevailed during summers only. Tentatively the time period from ~14,150 cal yr BP onwards is correlated with GI-1c in the GRIP ice core event stratigraphy.

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