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Chronological framework for the Lateglacial pollen and macrofossil sequence in the Pirin Mountains, Bulgaria: Lake Besbog and Lake Kremensko-5

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Abstract: The sediments of numerous cirque lakes in the Pirin Mountains have yielded several generalized pollen diagrams, but low stratigraphic and temporal resolution has hampered detailed reconstruction of the vegetational history, especially for the Lateglacial. New pollen and macrofossil analyses of high stratigraphic resolution combined with well-controlled time–depth curves for Lake Besbog and Lake Kremensko-5 now permit the firm identification of the Lateglacial interstadial interval (Bølling–Allerød), dated at 13.8–12.6 ka cal. BP at Besbog and 14.1–12.8 ka cal. BP at Kremensko-5 and correlated with the Greenland Interstadial GI-1 (14.5–12.6 ka cal. BP). Macrofossil analyses indicate that during the Bølling–Allerød period *Betula* and *Juniperus* occurred around the lakes (at 2124–2250 m a.s.l). Following the Younger Dryas a *Betula* woodland covered the mountains between 1900 and 2250 m in the early Holocene. Because of higher summer insolation at this time, the temperate deciduous forest reached up to 1900 m, or 800 m above their present limit, producing a regional pollen rain that dominated pollen deposition in the cirque lakes. After about 7000 cal. yr BP conifer forests replaced the birch woodland at middle and high elevations.

Key words: Vegetation history, Lateglacial chronology, Holocene, macrofossils, Pirin Mountains, Bulgaria.

Introduction

The Pirin and Rila mountains are in the heart of the Balkan Peninsula, the mostly mountainous land between the Adriatic Sea on the west and the Black Sea on the east (Figure 1). In southwestern Bulgaria these mountains are high enough to have been occupied by numerous small glaciers during the late Pleistocene, and the combination of cirque lakes and the long-time palynological research in Bulgarian institutes has resulted in numerous publications about the vegetation history. However, the early pollen studies in the Pirin and Rila mountains were based on cores taken from dry lakes, peat or the margins of extant lakes (Bozilova, 1975, 1977; Bozilova and Smit, 1979; Stefanova and Bozilova, 1992, 1995; Stefanova and Oeggl, 1993; Panovska *et al.*, 1995; Stefanova, 1997). For the Lateglacial very few radiocarbon dates had been obtained (Bozilova *et al.*, 1990; Huttunen *et al.*, 1992), and interpretations of the Lateglacial pollen profiles were based only on rough biostratigraphical correlations with the sequence in western Europe. Many of the studies pre-date the era of radiocarbon dating of terrestrial macrofossils by Accelerator Mass Spectrometry (AMS), as well as the conversion of dates to the calendar timescale according to the dendrochronological standard. The lack of an accurate chronology and of high-resolution pollen and macrofossil analysis has hindered reliable reconstructions of a regional vegetational and climatic history for comparison with the well-documented history in adjacent areas, eg, the eastern Alps and central Europe.

In 1994, on the initiative of Brigitta Ammann of the University of Bern, a project was organized by Elissaveta

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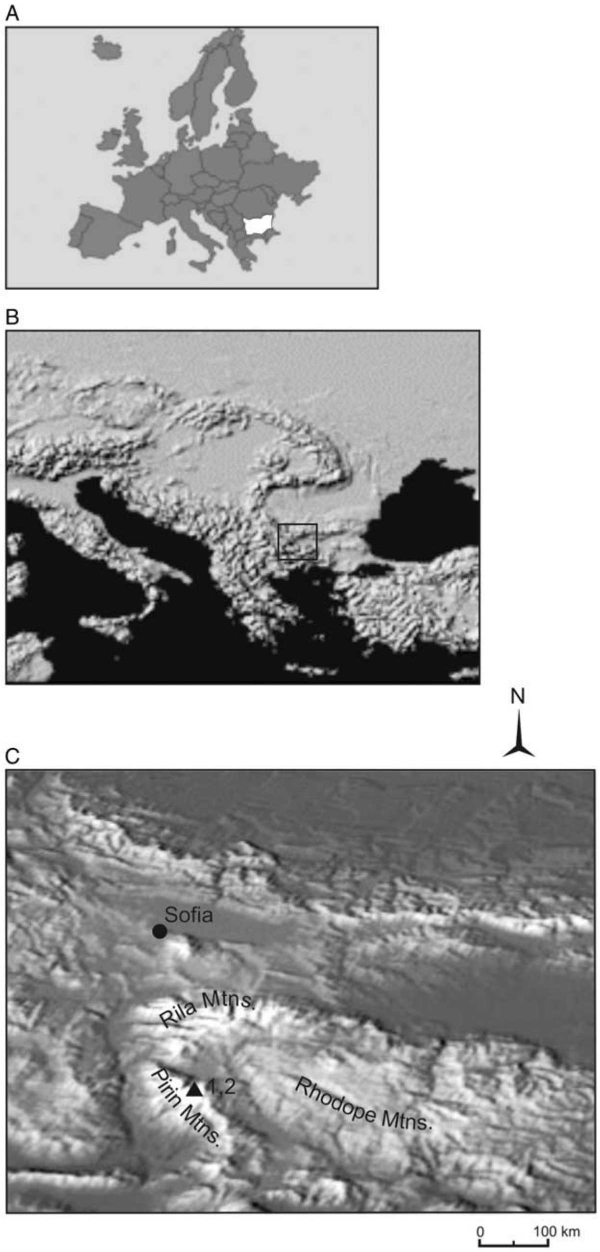


Figure 1 (A) Map of Europe, with Bulgaria shown as white. (B) Map of southeastern Europe showing area of (C)

Bozilova of the University of Sofia to obtain cores from the centres of cirque lakes near the upper forest limit in the Rila and Pirin mountains. Six lakes were cored, and pollen diagrams for several have since been published (Table 1), so that more pollen diagrams are available for the Rila and Pirin mountains than for any other area of comparable size in the Balkan Peninsula; a tribute not only to the abundance of cirque lakes but to the endeavours of the Bulgarian palynologists. Some attempts have been made to identify a consistent regional pollen sequence for the Lateglacial (eg, Tonkov *et al.*, 2006). However, the low stratigraphic resolution and the lack of macrofossil analysis, especially for the Lateglacial, have continued to be a problem, and the few radiocarbon dates do not all support the biostratigraphic correlations.

The present paper attempts to improve the reconstructions by providing a close chronology for the detailed pollen and macrofossil stratigraphies of two additional sites in the northern Pirin Mountains (Table 1). A pair of sites was chosen to provide a replication of results. Lake Besbog had been the subject of an earlier study on cores from the lake margin, for which the dominance of non-arboreal pollen was interpreted as an indication of early-Holocene treeless vegetation (Stefanova and Bozilova, 1995). A new core was taken from the centre of the lake with the hope that a Lateglacial record would be recovered. Lake Kremensko-5 also had a previous study, which showed that the Lateglacial interval was well covered but that in the pollen stratigraphy the critical early-Holocene record was missing (Atanassova and Stefanova, 2003), so a new core was also obtained there.

Regional climate and vegetation

The climate of the mountains below an altitude of 1000 m a.s.l. is transitional continental/submediterranean, and above this altitude it is typical montane. The annual precipitation above 2000 m a.s.l. is 1100–1200 mm, with a maximum in November–December and a minimum in August (Velev, 1997).

The nature of the vegetation in the Pirin Mountains is determined by the elevation and by the distance from the Mediterranean area. According to Veltshev (1997), several vegetation belts are represented.

(1) The lowest belt, up to 500 m a.s.l., is locally represented only in the southern part of the mountains and consists of communities with Mediterranean elements such as *Quercus coccifera*, *Juniperus excelsa* and *Phillyrea latifolia*.
(2) The belt of xerothermic oak forest (about 500–700 m a.s.l.) is formed by *Quercus cerris*, *Q. pubescens*, *Q. frainetto* and *Carpinus orientalis.*
(3) In the mesophilous and xeromesophilous *Quercus–Carpinus* belt (up to 800–900 m a.s.l. or locally 1000 m a.s.l.) communities *of Quercus dalechampii* and *Carpinus betulus* are typical, but *Pinus nigra*, *Ostrya carpinifolia* and *Corylus avellana* also occur.
(4) The belt of *Fagus* forest (from 900–1000 to 1500–1600 m a.s.l.) has *Fagus sylvatica* as dominant, but it is represented in the northern Pirin Mountains only by fragments. Communities of *Abies alba*, *Pinus nigra*, *Pinus peuce* and *Picea abies* occur locally.
(5) In the coniferous belt (between 1500–1600 m and 2000–2200 m a.s.l.) communities of *Pinus sylvestris* and *Picea abies* are most abundant. The Balkan endemic species *Pinus peuce* and the relict subendemic species *Pinus heldreichii* are also present.
(6) The vegetation in the subalpine belt (about 2000–2500 m a.s.l.) is dominated by *Pinus mugo*, *Juniperus sibirica* and *Vaccinium myrtillus.*
(7) In the alpine belt (above 2500 m a.s.l.) communities of *Sesleria comosa*, *Festuca airoides*, *Agrostis rupestris* and *Carex curvula* are common on silicate terrane and *Sesleria coerulea*, *S. corabensis* and *Carex kitaibeliana* on marble terrane.

The nomenclature for the vascular plants follows the *Flora of the Republic of Bulgaria* (Jordanov *et al.*, 1963–1995).

Study area and sites of investigations

The Pirin Mountains are composed largely of Precambrian crystalline rocks (Boyagjev, 1959). Numerous glacial cirques are marked by multiple lakes (Vlaskov, 1998) (Figure 2). The

Table 1 Recent pollen diagrams from the Pirin and Rila mountains, showing stratigraphic resolution of pollen data for phases of the Lateglacial, as well as the number of radiocarbon dates for the Lateglacial and for the Holocene

Mountains	Site (m a.s.l.)	Reference	Number of pollen spectra			Number of ^{14}C dates	
			Younger Dryas	Bølling–Allerød	Oldest Dryas	Lateglacial	Holocene
Pirin[a]	Banderishko, 2190	Tonkov *et al.* (2002)	2	2	4		6
Pirin[a]	Dalgoto, 2310	Stefanova and Ammann (2003)	4				9
Pirin	Kremensko-5, 2124	Atanassova and Stefanova (2003)	5	6	9	2	
Pirin[b]	Kremensko-5, 2124	Stefanova *et al.* (this paper)	15	12	5	4	8
Pirin[b]	Besbog, 2250	Stefanova *et al.* (this paper)	8	16	12	4	4
Pirin	Mozgovitsa, 1800	Tonkov (2003)					2
Pirin[a]	Muratovo, 2230	Bozilova *et al.* (2004)					7
Pirin	Breznishko, 1963 Okadensko, 2475	Atanassova and Stefanova (2005)					4
Rila[a]	Sedmo Rilsko, 2095	Bozilova and Tonkov (2000)	4	14	5	1	2
Rila[b]	Ostrezki, 2320	Tonkov and Marinova (2005)					5
Rila[a]	Lake Trilistnika, 2216	Tonkov *et al.* (2006)	6	8	9	4	

[a] Based on 1994 mid-lake core.
[b] Major macrofossil counts.

northern part of the mountains, where the two sites of investigation are located, extends up to 2914 m a.s.l.

Lake Besbog (2250 m, 41°44′ N 23°32′ E) is a cirque lake located at the end of an aerial tram and beside a hut that serves as the base for hiking and other recreation (Figure 3A). The lake is 125 m long and 75 m wide and has a maximal depth of 7 m. Its surface area is about 1.9 ha, and the hydrological catchment is about 77 ha (Ivanov *et al.*, 1964).

In another cirque about 3 km from Lake Besbog is Lake Kremensko-5 (2124 m, 23°32′ E), which is the lowest in a string of five lakes (Ivanov *et al.*, 1964). Today Lake Kremensko-5, with a surface smaller than that of Lake Besbog, is almost

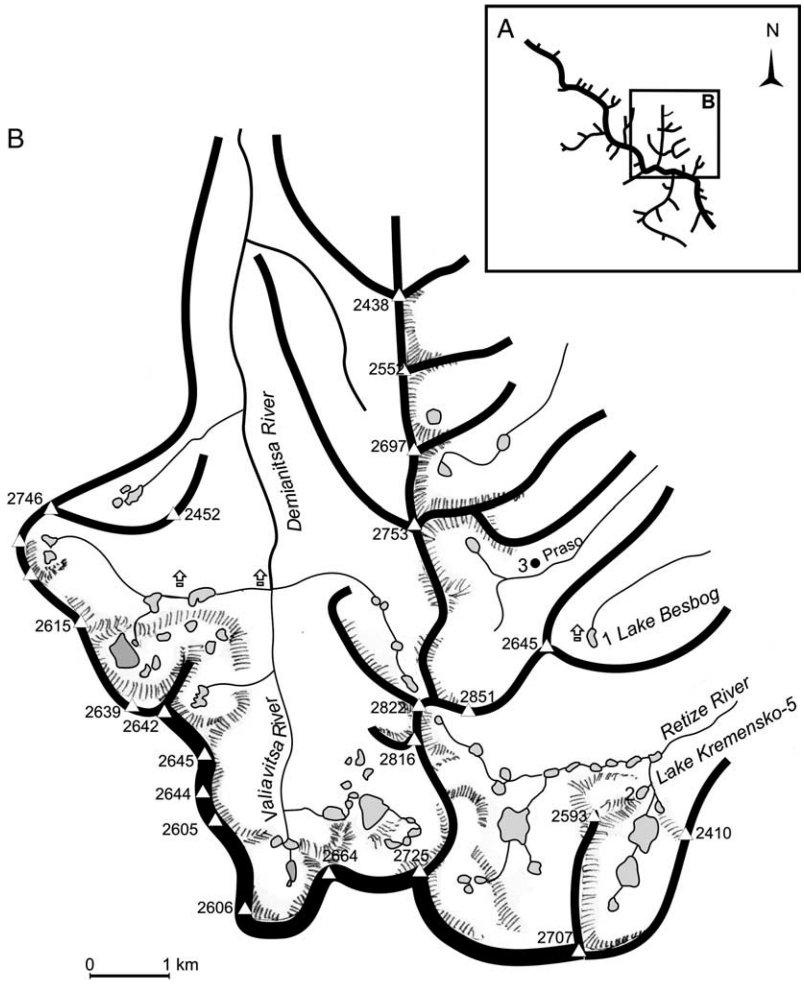


Figure 2 (A) Main crest and tributary ridges in the Pirin Mountains. (B) Cirques and cirque lakes in the area outlined in (A) Elevations (m) of peaks on the ridge crests are shown, as well as locations of 1, Lake Besbog; 2, Lake Kremensko-5; and 3, Mire Praso. The other sites mentioned in the text are in different part of Pirin Mountains. Modified from Popov (1979)

Figure 3 (A) Lake Besbog in middle distance. The area is dominated by *Pinus mugo*, with isolated *Pinus peuce* trees in the distance. (B) Lake Kremensko-5, now largely a mire. *Pinus peuce* trees are visible on the nearby slop

filled with peat (Figure 3B), as is Lake Kremensko-4, situated above it.

The aquatic vegetation in the lakes is represented by *Ranunculus aquatilis* and *Sparganium angustifolium*, as well as *Isoetes lacustris* in Lake Besbog. The vegetation surrounding the sites is formed by *Drepanocladus exannulatus*, *Aulacomnium palustre*, *Dryopteris filix-mas*, *Athyrium filix-femina*, *Carex acuta*, *Carex ovalis*, *Eleocharis palustris*, *Juncus trifidus*, *J. conglomeratus*, *J. filiformis*, *Luzula luzuloides*, *Dianthus microlepis*, *Silene vulgaris*, *Silene pusilla*, *Scleranthus neglectus*, *Cerastium fontanum*, *Arenaria biflora*, *Campanula persicifolia*, *Campanula alpina*, *Cirsium appendiculatum*, *Achillea clusiana*, *Taraxacum appenninum*, *Senecio rupestris*, *Centaurea rhenana*, *Carduus kerneri*, *Polystichum lonchitis*, *Peucedanum oligophyllum*, *Cardamine rivularis*, *Scabiosa triniifolia*, *Hypericum perforatum*, *Trifolium pratense*, *Plantago gentianoides*, *Rumex acetosa*, *Rumex acetosella*, *Saxifraga stellaris*, *Potentilla erecta*, *Geum coccineum*, *Gentiana pyrenaica*, *Gentianella bulgarica*, *Nardus stricta*, *Poa media* and many others. The trees and shrubs are represented by *Vaccinium myrtillus*, *Juniperus sibirica*, *Pinus mugo* and *Pinus peuce*.

Methods

Coring

At Lake Besbog a core 565 cm long was taken from mid-lake in water about 200 cm deep with the use of a square-rod piston corer 5 cm in diameter (Wright, 1991). At Lake Kremensko-5 the top 6 cm of peat was excavated by hand, and the underlying 374 cm of lake sediment were taken with the same piston corer. Cores were extruded in the field and transported in PVC tubes cut lengthwise. Core drives were 1 m long, but recovery was incomplete in a few cases.. The major gaps at Besbog (580–595 cm) and at Kremensko-5 (45–92 cm) are shown by shaded bands on the pollen diagrams.

Sampling

Samples for pollen analysis and for loss-on-ignition (Heiri *et al*., 2001) were taken at intervals of 1–2 cm across the transition from Lateglacial to Holocene and at broader intervals elsewhere. For macrofossil analyses samples were taken as contiguous 4 cm sections (volume *c*. 15 cm^3).

Pollen and macrofossil analysis

All samples for pollen analyses were prepared by the acetolysis method (Faegri and Iversen, 1989). At each level at least 500 terrestrial pollen grains were identified to the lowest possible taxonomic level by keys (Punt, 1976; Punt and Clarke, 1980, 1981, 1984; Punt *et al.*, 1988, 1995; Moore *et al.*, 1989; Punt and Blackmore, 1991; Reille, 1992, 1995; Beug, 2004) and the pollen reference collections at the pollen laboratories in Sofia University and the University of Minnesota. *Pinus* diploxylon-type may include *P. sylvestria*, *P. mugo*, *P. nigra* and *P. heldreichii*, but *Pinus* haploxylon-type must represent *P. peuce*, the only five-needle pine in the Bulgarian mountains. Stomata and charcoal particles were counted on pollen slides (Hansen, 1995; Sweeney, 2004; Tinner and Hu, 2003). Pollen diagrams were prepared with Tilia and Tilia TGView 2.02 programs (Grimm, 2004).

Macrofossil samples were washed through sieves of 0.5 and 0.25 mm mesh. For the identification of the plant macroremains the reference collection of the Limnological Research Center (University of Minnesota) and literature sources (Katz *et al.*, 1965; Tomlinson, 1985) were used. The results are presented on the pollen diagram as numbers of macrofossils per unit volume.

Radiocarbon dating

Terrestrial macrofossils and, in a few cases, fine organic sediment were used for dating by accelerator mass spectrometry (AMS) (Table 2). Dates were calibrated with the program Calib 5.0.1 (Stuiver and Reimer, 1993), using the IntCal04 data set (Reimer e*t al.*, 2004). Age–depth models were made with a weighted mixed-effects regression procedure within the framework of generalized additive models (Heegard *et al.*, 2005) and supplemented by Heegard's (2003) R function Cagedepth. In this procedure the central points of the calibrated age are used in the modelling, and the one standard deviations of the calibrated age are used as weights. Calibrated dates with a low standard deviation have a greater weight in the regression.

Numerical analysis

The zonation of the percentage pollen diagrams was made separately by the method of optimal partitioning (Birks and Gordon, 1985). The number of statistically significant zones at each site was determined with the broken-stick model (Bennett, 1996). The two pollen-percentage data sets were combined by taxon and run in a principal component analysis (PCA) in order to identify the main components of variance and to compare the two pollen records. The analyses were carried out on the covariance matrix after square-root transformation (Giesecke, 2005).

Results

Chronology

Depth–age models based on calibrated ages are shown in Figure 4. One outlying date on the depth–age curve for Besbog was excluded from the model, and four for Kremensko-5. Uncalibrated radiocarbon dates are shown on the pollen diagrams (Figures 5 and 6), and the calibrated age scale is indicated in 1000-yr intervals. The calibrated ages for specific levels mentioned in the text are taken from the table of spectra based on the age model, not by interpolation between 1000-yr marks. The independently developed models are used to plot the paired pollen stratigraphies of the two sites on the NGRIP timescale (North Greenland Ice Core Project Members, 2004) (Figure 7). The slight mismatches of the two stratigraphies can be attributed to the slight differences in the two depth–age curves.

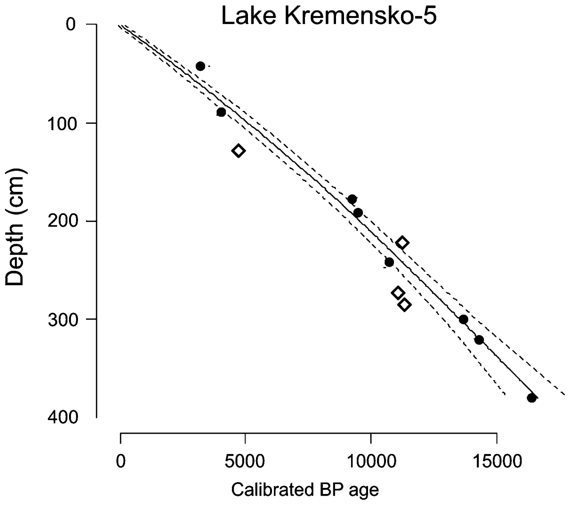
Pollen stratigraphy

For the Kremensko-5 core 108 pollen and spore taxa and algal types were identified in a total of 78 spectra, and for Besbog

Table 2 Results of radiocarbon measurements of samples from studied sites

Locality	Lab. no.	Depth (cm)	Material dated	^{14}C dates (uncal. BP)	Age (cal. BP, 1σ range)
Lake Besbog	Poz-6612	256–260	*Pinus mugo* needle, wood	2185±35[a]	2234–2305
	Poz-7033	308–312	*Pinus mugo* needles,	2195±30	2234–2305
	Poz-7037	408–412	*Carex* fruit, *Pinus* bud-scales, charcoal, wood	3960±35	4406–4447
	Poz-7036	480–484	*P. peuce* needle, *Pinus* bud-scales, charcoal, wood	4890±40	5594–5647
	Poz-7035	574–578	*P. peuce* needle, *Carex* fruit, *Pinus* bud-scale	9300±50	10 477–10 575
	AA55664	610	Silt, 10% organic	10 211±54	11 823–11 938
	Poz-7034	632	Silt, 10% organic	11 900±70	13 689–13 834
	AA55665	656	Silt, 3% organic	12 184±69	13 960–14 129
	AA55666	680	Silt, 4% organic	12 841±67	15 018–15 280
Lake Kremensko-5	AA55070	42–46	Wood	3274±36	3519–3557
	AA55071	92–96	Wood	3593±36	3847–3927
	AA55072	124–128	*Pinus* seed, wood	4398±37[a]	4876–4944
	AA55073	176–180	Wood	8334±47	9301–9428
	Poz-6664	190–194	*Carex* fruits, *Rubus* seeds, bud-scales	8520±50	9491–9536
	AA55074	205–208	Juniperus needle fragment + wood	7623±77[a]	8370–8481
	Poz-7039	248	Silty gyttja, 25% organic matter	9330±50	10 490–10 591
	AA55075	235–240	*Pinus* needle fragment	9630±52[a]	11 068–11 166
	AA55076	262–266	*Carex* fruit, wood	9194±61[a]	10 253–10 416
	AA55077	278–282	Juniperus needle fragment + wood	9206±68[a]	10 262–10 427
	Poz-7038	300	Silty gyttja, 10% organic matter	11 810±60	13 611–13 759
	AA55078	320–322	Clay, 3–4% organic	12 331±77	14 078–14 456
	AA55079	380–383	Clay, 3% organic	13 526±77	15 872–16 285

[a] Radiocarbon dates omitted from the depth–age model.
Laboratory codes: AA, Arizona; Poz, Poznan



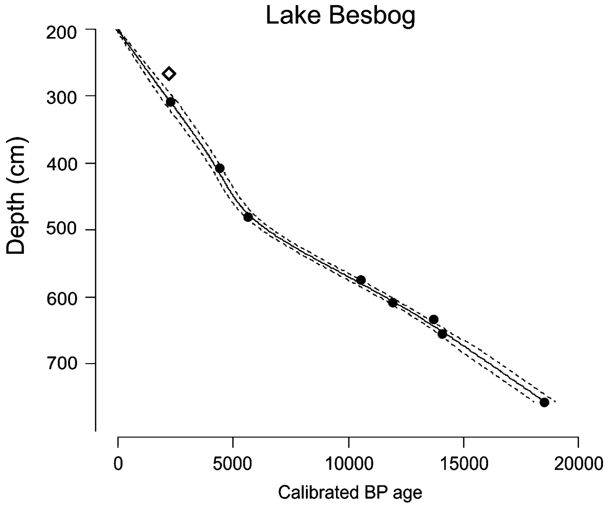


Figure 4 Depth–age models. Dates of open squares are omitted from the model (see Table 2)

143 taxa for 68 spectra. The main pollen diagrams (Figures 5 and 6) contain most of the taxa identified, and Table 3 indicates by percentage values the dominant pollen taxa for each of the four pollen-assemblage zones. The table also indicates for each site those taxa that show continuous occurrence throughout one or another zone, and it also indicates the number of additional taxa with only occasional occurrence.

Zones 1–3 represent the Lateglacial. All three zones are dominated by non-arboreal taxa (*Artemisia*, Chenopodiaceae, Poaceae) as well as *Ephedra*, but the middle one also features a major maximum of *Pinus* diploxylon-type as well as minor occurrences of *Betula*, *Quercus*, *Alnus*, *Ulmus* and *Corylus*, and also macrofossils of *Pinus peuce*, *Juniperus* and *Betula*. The Holocene is covered by zones 4–6. Zone 4 is dominated by pollen of *Betula*, *Quercus*, *Tilia*, *Ulmus* and *Corylus*, zone 5 by maxima of *Pinus* diploxylon-type, *Pinus peuce* (with macrofossils) and *Abies*, and zone 6 by *Pinus peuce*, *Picea* and *Fagus*, as well as *Pinus* diploxylon-type.

Principal component analysis

The PCA of the entire data set separates the samples into three clusters (Figure 8). The first cluster contains the samples of Lateglacial age (zones PK-1–3 and PB-1–3), which are characterized by dominance of herb taxa (*Artemisia*, Chenopodiaceae, *Achillea*, *Aster* and Poaceae). A good correspondence is evident between the next two clusters and the statistically significant pollen assemblage zones. In one cluster (zones PK-4 and PB-4) are all samples with early-Holocene dominants such as *Juniperus*, *Betula*, *Pinus* diploxylon-type and also *Quercus*, *Ulmus*, *Tilia* and *Corylus.* The last group is represented by samples dominated by conifers (*Pinus peuce*, *Abies*, *Picea*), as well as *Fagus* and *Carpinus betulus* (zones PK-5–6, PB-5–6).

The PCA of the full data set illustrates in a different way from the pollen diagrams the main stages in the vegetation development around the two lakes.

Sediment accumulation

The basal sediments at both sites consist of slightly organic silt as estimated from loss-on-ignition at 550°C (Figures 5 and 6). In the Lateglacial sediments the organic content averages about 10%, and at the Holocene boundary it increases to about 20%. Small gaps in the core occur between the 1-m core sections because of incomplete recovery.

Discussion

The pollen zones are correlated with the European biostratigraphic subdivisions of the Lateglacial on the basis of the calibrated ages, which in turn are correlated with the Greenland NGRIP isotope stratigraphy (see below).

Oldest Dryas (PB-1, PK-1)

Artemisia, Chenopodiaceae and Poaceae dominate at both sites, and *Ephedra* is continuously present. The 10–15% pollen of *Pinus* diploxylon-type pollen and the scattering of other arboreal pollen types is attributed to distant transport, even though curves for several arboreal taxa (*Pinus peuce*, *Betula*, *Quercus*, *Alnus*) are continuous or nearly so, and a needle of *P. peuce* was found at Kremensko. In addition to the herb taxa showing continuous occurrence in this zone (Table 3), the lowest sample for Besbog includes *Betula*, *Achillea*, *Aster*-type, *Centaurea jacea*-type, *Dianthus*, *Ranuncuculus acris*-type, *Taraxacum* and Cyperaceae. The herbs listed suggest the composition of the ground cover immediately after ice retreat. For Kremensko-5, the comparable list of basal pollen taxa includes *Abies*, *Alnus*, *Ulmus*, *Quercus*, Apiaceae, *Aster*-type, *Taraxacum*, *Cirsium*, *Plantago major/media*, *Ranunculus acris*-type, *Scleranthus*, *Trifolium* and Monolete fern spores. The earlier publication for Kremensko-5 (Atanassova and Stefanova, 2003) mentioned corroded pollen grains in the basal samples, implying redeposition, but in the new core no such grains were found.

Bølling–Allerød (PB-2, PK-2)

In western Europe the Bølling–Allerød interstadial marks incipient afforestation. At Besbog this horizon is marked by a broad but sharp peak with up to 40% *Pinus* diploxylon-type and macrofossils of *Pinus peuce* and *Juniperus* (PB-2, 620–640 cm, dated 13.8–12.6 ka cal. BP). It also has slightly more pollen of *Quercus*, *Alnus*, and *Ulmus* than the Oldest Dryas, all derived by distant transport from lower elevation, but implying that these trees were in fact more abundant there than previously. *Artemisia* is reduced to only 15% and Chenopodiaceae to 5%, but values of Poaceae are higher (20%), as in PB-3 above. At Kremensko-5 the equivalent zone (PK-2, 310–280 cm) in silty sediments has a *Pinus* diploxylon-type maximum that is less distinct than at Besbog, perhaps because *P. mugo* was less well developed around the site than at

Besbog, as is the case today. More important are the macrofossils of *Betula*, *Juniperus* and *Pinus peuce*. Noteworthy are the lower values of *Artemisia* and Chenopodiaceae compared with Poaceae. At both Kremensko-5 and Besbog the *Pinus* maximum coincides with the first rise of organic matter and also of *Pediastrum*. These two features suggest an increase in aquatic productivity, which, along with the higher arboreal pollen percentages and (in the NAP) the higher Poaceae compared with *Artemisia* and Chenopodiaceae, indicate conditions more mesic than in the Oldest Dryas. The dates for the Bølling–Allerød at Besbog (13.8–12.6 ka cal. BP) and Kremensko-5 (14.1–12.8 ka cal. BP) permit a reasonable correlation with Interstadial 1 (GI-1) in the Greenland ice core (NGRIP, 14.5–12.6 ka cal. BP), which is the Bølling–Allerød equivalent (Figure 7) (Bjørck *et al.*, 1998).

Younger Dryas (PB-3, PK-3)

In the Kremensko-5 diagram the Younger Dryas is recognized by a clear maximum of *Artemisia* (40%) and Chenopodiaceae (15%) covering 30 cm (280–250 cm) of silty sediment with dates of 12.6–11.6 ka cal. BP (PK-3). At Besbog, this herb maximum is equally strong (PB-3). It has the same composition as at Kremensko-5 and is in silty sediments at least 20 cm thick (600–620 cm–the top cannot be determined because of the gap in the core caused by incomplete recovery. The date for the base at Besbog is 12.6 ka cal. BP and for the top a little younger than 11.8 ka cal. BP. A few macrofossils of *Betula*, *Juniperus* and *Pinus peuce* were found in this zone at both sites.

Early Holocene (PB-4, PK-4)

The Holocene at Kremensko-5 starts with a change from silt to gyttja, an abrupt decrease in *Artemisia* and Chenopodiaceae, and a sharp increase in *Pinus* diploxylon-type and *Betula* (PK-4), along with increases in *Quercus*, *Juniperus* and *Alnus*, which had been present sporadically in the Lateglacial. *Tilia*, *Ulmus*, *Fraxinus*, *Carpinus* and later *Corylus* also increased and prevailed until about 6.5 ka cal. BP. At Besbog the sharpness of the change is not apparent because of the small gap (580–598 cm) in the core. Along with the pollen assemblage of deciduous-tree types, in which *Quercus* reaches 30% and *Tilia* and *Ulmus* 7% each, are many macrofossils of *Betula* and *Juniperus* at both sites, and occasional *Pinus peuce* needles (PB-4). The *Betula* and *Juniperus* macrofossils could represent the upper forest limit, but in the absence of macrofossils of the temperate deciduous trees listed it is not possible to assert that these trees also occurred as high as 2100–2200 m, for today they are not found above 1100 m.

A similar early-Holocene pollen assemblage of deciduous-tree types occurs at Lake Dalgoto, another cirque lake in the northern Pirin Mountains (Stefanova and Ammann, 2003). Here it was interpreted not as the record of local vegetation but rather as the result of distant transport of pollen from deciduous forests, which, because of higher summer insolation, occurred at a higher elevation than today, close enough to Dalgoto to contribute abundant pollen by distant transport–even *Tilia*, which is insect pollinated. The same explanation can be offered for Besbog and Kremensko-5. Possibly the mire of Praso at 1900 m (No. 3 on Figure 2) represents the upper limit of the postulated mid-elevation deciduous forest, for numerous *Betula* macrofossils and a *Quercus* fragment are reported from this site (Stefanova and Oeggl, 1993). Because *Betula* and *Juniperus* macrofossils were found at Besbog and Kremensko-5 as well as at Praso, it is probable that a *Betula* forest prevailed over the 350 m elevation difference between Praso and the cirque lakes, and that it also marked the upper forest limit in the early Holocene. Macrofossils of *Pinus peuce* indicate that this tree was also present at the forest limit. The continuation of low values of *Artemisia* and Chenopodiaceae and of at least 20% Poaceae, as well as the presence of *Rumex* and other NAP in the early Holocene at Kremensko-5 and Besbog, imply that if a forest existed at these elevations it was open or patchy, whatever its composition, so that pollen of distant transport could reach the sites from below. In fact, the diversity of herb types seen in the Lateglacial continues in the early Holocene, suggesting that the groundcover did not have a continuous overstorey of trees even then. Relatively dry conditions are implied, perhaps a result of higher summer insolation, which may also have been the cause for the inferred elevational increase in temperate deciduous trees near Praso–an increase large enough to provide the source for the early-Holocene transport of their pollen to the high-elevation sites. In any case, if the sites were nearly treeless in the early Holocene, and if the upward expansion of mixed oak forest to at least 1900 m was the result of climatic warming, then the absence of trees at higher elevations must have been the result of the persistence of the dry conditions that had prevailed during the Lateglacial–a condition inferred not only in the Balkan Peninsula but also to the east in Turkey, Iran, and southwestern Siberia (Wright *et al.*, 2003). This climatic conclusion for the Pirin Mountains is supported by the finding that at the same time in the early Holocene a now-forested area at 1400 m in the Rhodope Mountains, which adjoin the Pirin Mountains on the east, was not forested at all but was characterized by steppe until 8.8 ka cal. BP (Stefanova *et al.*, 2006).

Mid-Holocene (PB-5, PK-5)

About 7.5 k cal. BP *Pinus* diploxylon-type pollen increased along with *P. peuce* and *Abies*, while pollen of the temperate deciduous trees decreased, as well as that of Poaceae and other non-arboreal types. Macrofossils of *Pinus mugo*, *P. peuce* and *Betula* were found at Kremensko-5. Apparently conifers took over the high elevations, to which they are well adapted, and forced *Betula* and the deciduous trees of the Praso area to lower elevations. *Picea* was a minor component, and both species of *Carpinus* increased at this time. Herbaceous types decreased to modern values.

Late Holocene (PB-6, PK-5 upper part)

At about 4 ka cal. BP *Abies* and *Pinus peuce* in the pollen sequence were joined or largely replaced as dominants by *Picea* and *Fagus*, which continue to modern time. The change in dominant conifers is a common feature of diagrams in the Pirin Mountains (eg, Atanassova and Stefanova, 2005). Distant transport to these sites must still be important, for *Carpinus*, *Fagus* and other deciduous types do not occur today at the elevation of the cirque lakes.

Climatic inferences

The Lateglacial in the Pirin Mountains may have been too cold and dry for trees at all elevations, although some conifers (especially *Pinus sylvestris*, *P. mugo* or *P. peuce*) may have been present in some habitats at lower elevations. If the early Holocene was warmer because of high insolation (Kutzbach *et al.*, 1993) and allowed the *Quercus*-mixed forest to expand up to mid-elevations and deliver abundant pollen to a thin *Betula* woodland at 2200 m, it was also dry enough to maintain vegetation of *Artemisia*, Chenopodiaceae and Poaceae at high elevations. Then, with a change to cooler and moister

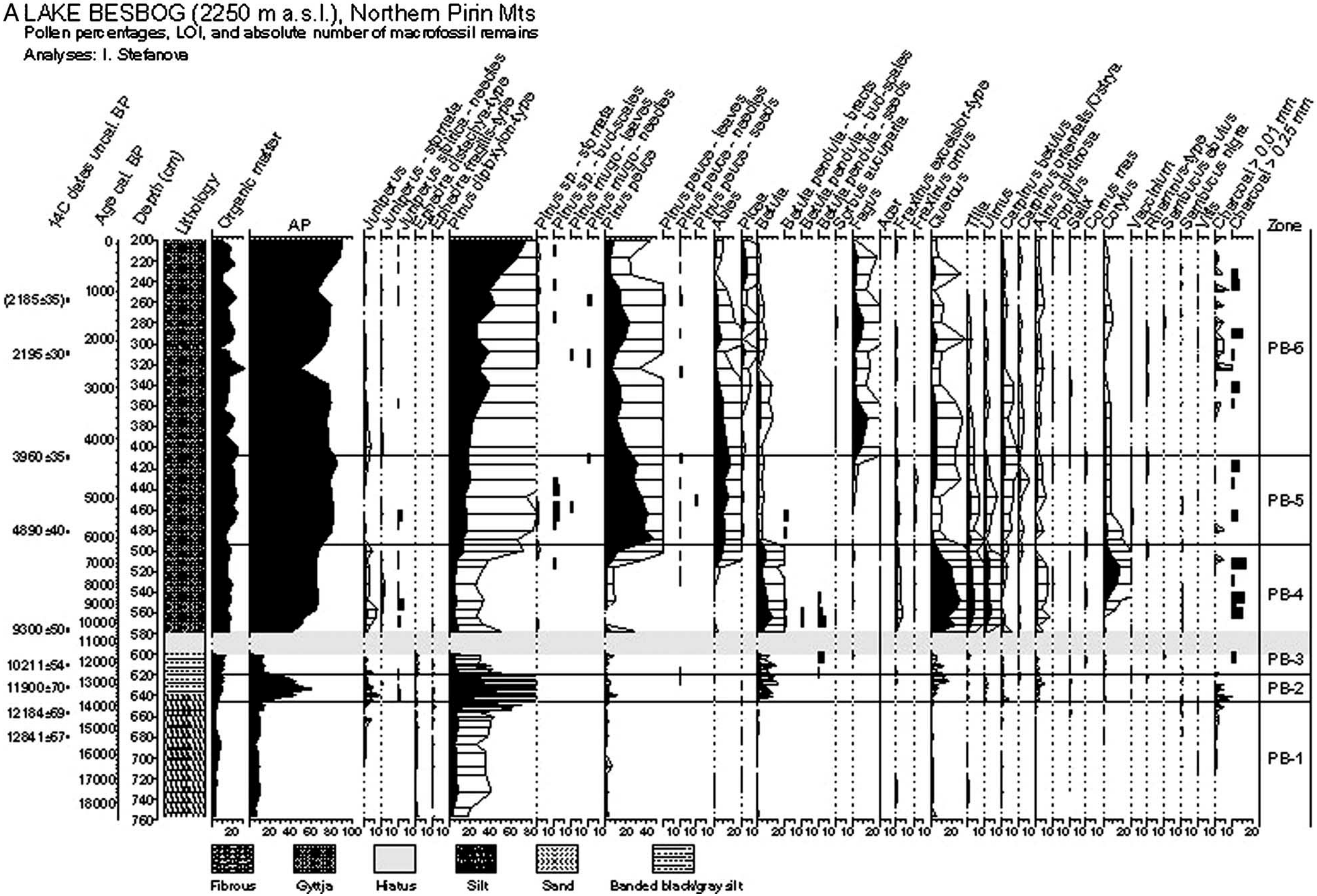

A LAKE BESBOG (2250 m a.s.l.), Northern Pirin Mts
Pollen percentages, LOI, and absolute number of macrofossil remains
Analyses: I. Stefanova
14C dates uncal. BP
Age cal. BP
Depth (cm)
Lithology
Organic matter
AP
Juniperus
Juniperus - stomata
Juniperus sibirica - needles
Ephedra distachya-type
Ephedra fragilis-type
Pinus diploxylon-type
Pinus sp. - stomata
Pinus sp. - bud-scales
Pinus mugo - leaves
Pinus mugo - needles
Pinus peuce
Pinus peuce - leaves
Pinus peuce - needles
Pinus peuce - seeds
Abies
Picea
Betula
Betula pendula - bracts
Betula pendula - bud-scales
Betula pendula - seeds
Sorbus aucuparia
Fagus
Acer
Fraxinus excelsior-type
Fraxinus ornus
Quercus
Tilia
Ulmus
Carpinus betulus
Carpinus orientalis/Ostrya
Alnus glutinosa
Populus
Salix
Cornus mas
Corylus
Vaccinium
Rhamnus-type
Sambucus ebulus
Sambucus nigra
Vitis
Charcoal > 0.01 mm
Charcoal > 0.25 mm
Zone
(2185±35)
2195±30
3960±35
4890±40
9300±50
10211±54
11900±70
12184±69
12841±57
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
PB-6
PB-5
PB-4
PB-3
PB-2
PB-1
20
20 40 60 80 100
10 10 10 10 10
20 40 60 80
10 10 10 10
20 40
10 10 10
20 10
20 10 10 10 10
20 10 10 10
20
10 10 10 10 10 10 10 10
20 10 10 10 10 10 10 10 20
Fibrous
Gyttja
Hiatus
Silt
Sand
Banded black/gray silt

Figure 5

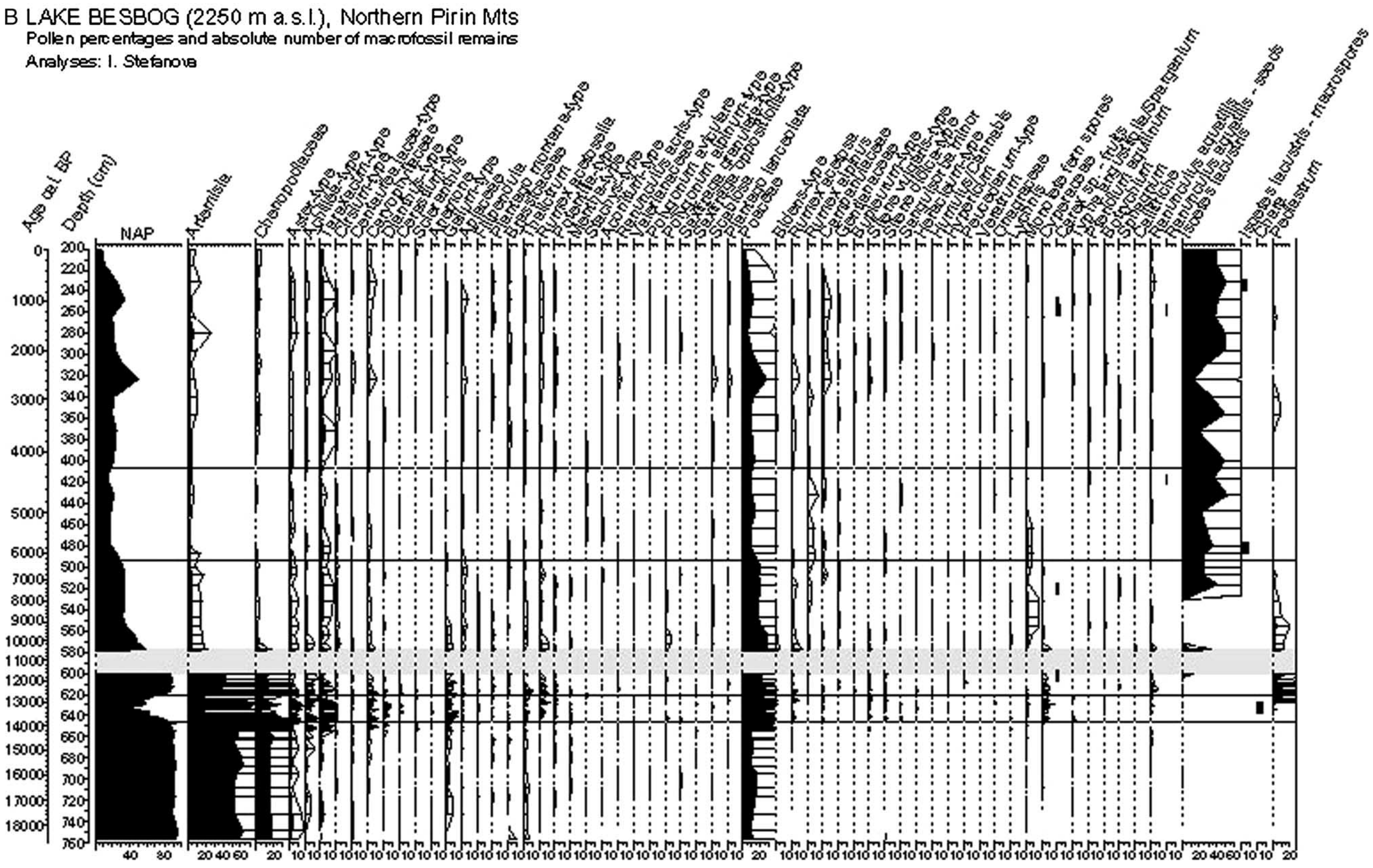


Figure 5 Pollen diagram for Lake Besbog. Shaded band indicates gap in core. (A) Arboreal pollen; (B) non-arboreal pollen

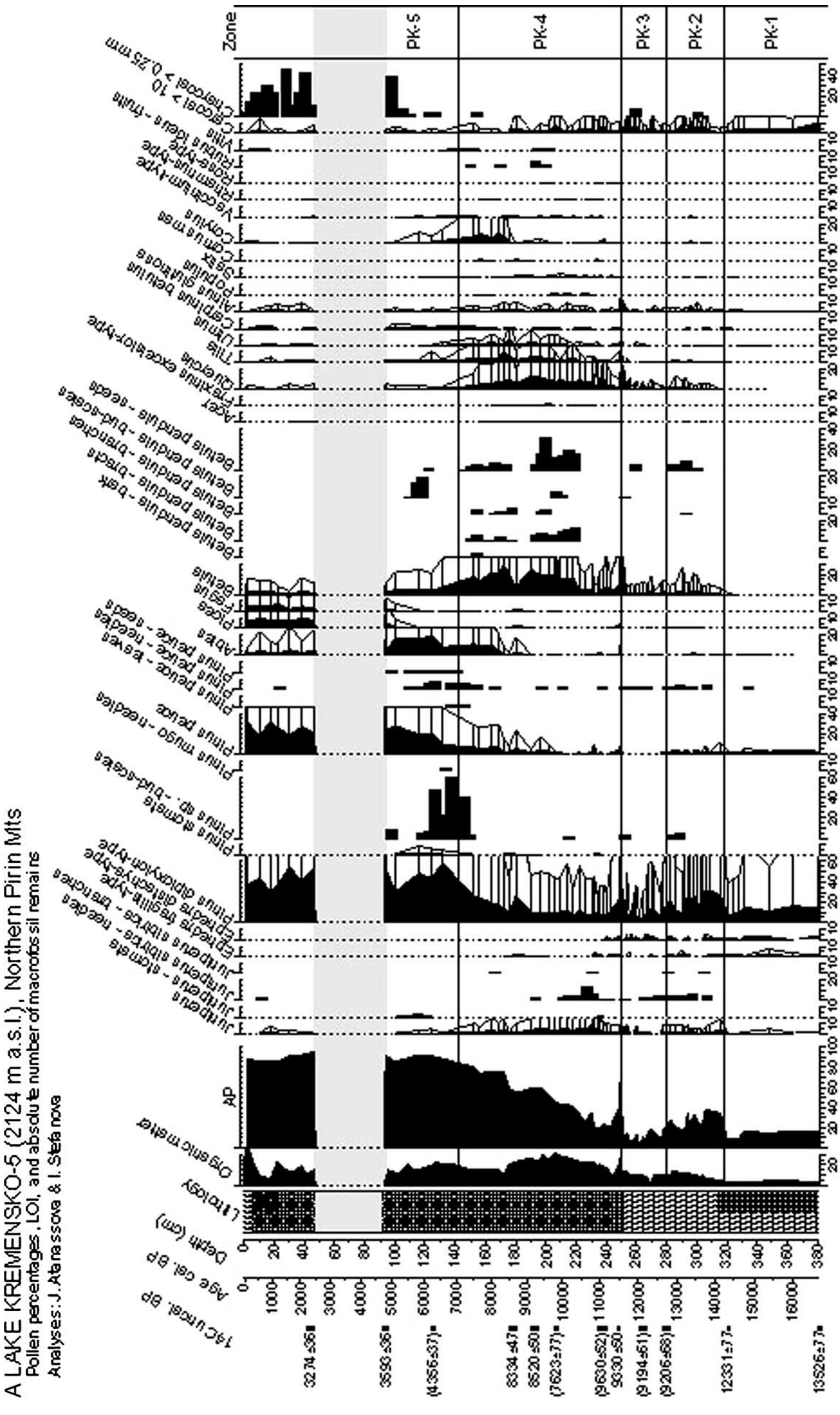

A LAKE KREMENSKO-5 (2124 m a.s.l.), Northern Pirin Mts
Pollen percentages, LOI, and absolute number of macrofossil remains
Analyses: J. Atanassova & I. Stefanova
14C uncal. BP
Age cal. BP
Depth (cm)
Lithology
Organic matter
AP
Juniperus
Juniperus - stomata
Juniperus sibirica - needles
Juniperus sibirica - branches
Ephedra fragilis-type
Ephedra distachya-type
Pinus diploxylon-type
Pinus stomata
Pinus sp. - bud-scales
Pinus mugo - needles
Pinus peuce
Pinus peuce - leaves
Pinus peuce - needles
Pinus peuce - seeds
Abies
Picea
Fagus
Betula
Betula pendula - bark
Betula pendula - bracts
Betula pendula - branches
Betula pendula - bud-scales
Betula pendula - seeds
Acer
Fraxinus excelsior-type
Quercus
Tilia
Ulmus
Carpinus betulus
Alnus glutinosa
Populus
Salix
Cornus mas
Corylus
Vaccinium-type
Rhamnus-type
Rosa-type
Rubus idaeus - fruits
Vitis
C.coal > 10
Charcoal > 0.25 mm
Zone
PK-5
PK-4
PK-3
PK-2
PK-1
3274±36
3593±36
(4356±37)
8334±47
8520±50
(7623±77)
(9630±52)
9330±50
(9194±61)
(9206±68)
12331±77
13526±77
Peat
Gyttja
Sand
Hiatus
Silt

Figure 6

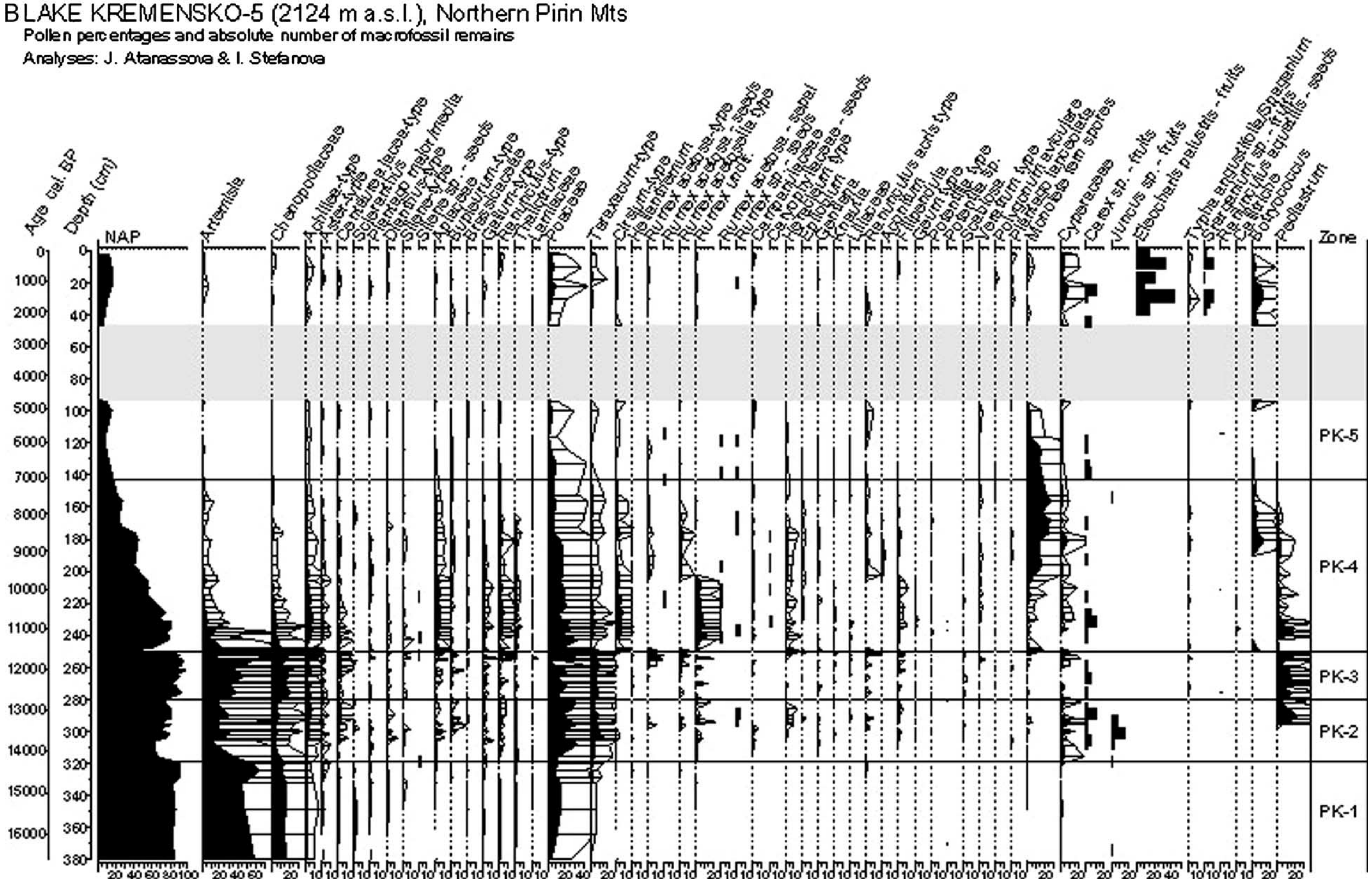


Figure 6 Pollen diagram for Lake Kremensko-5. Shaded band indicates gap in core. (A) Arboreal pollen; (B) non-arboreal pollen

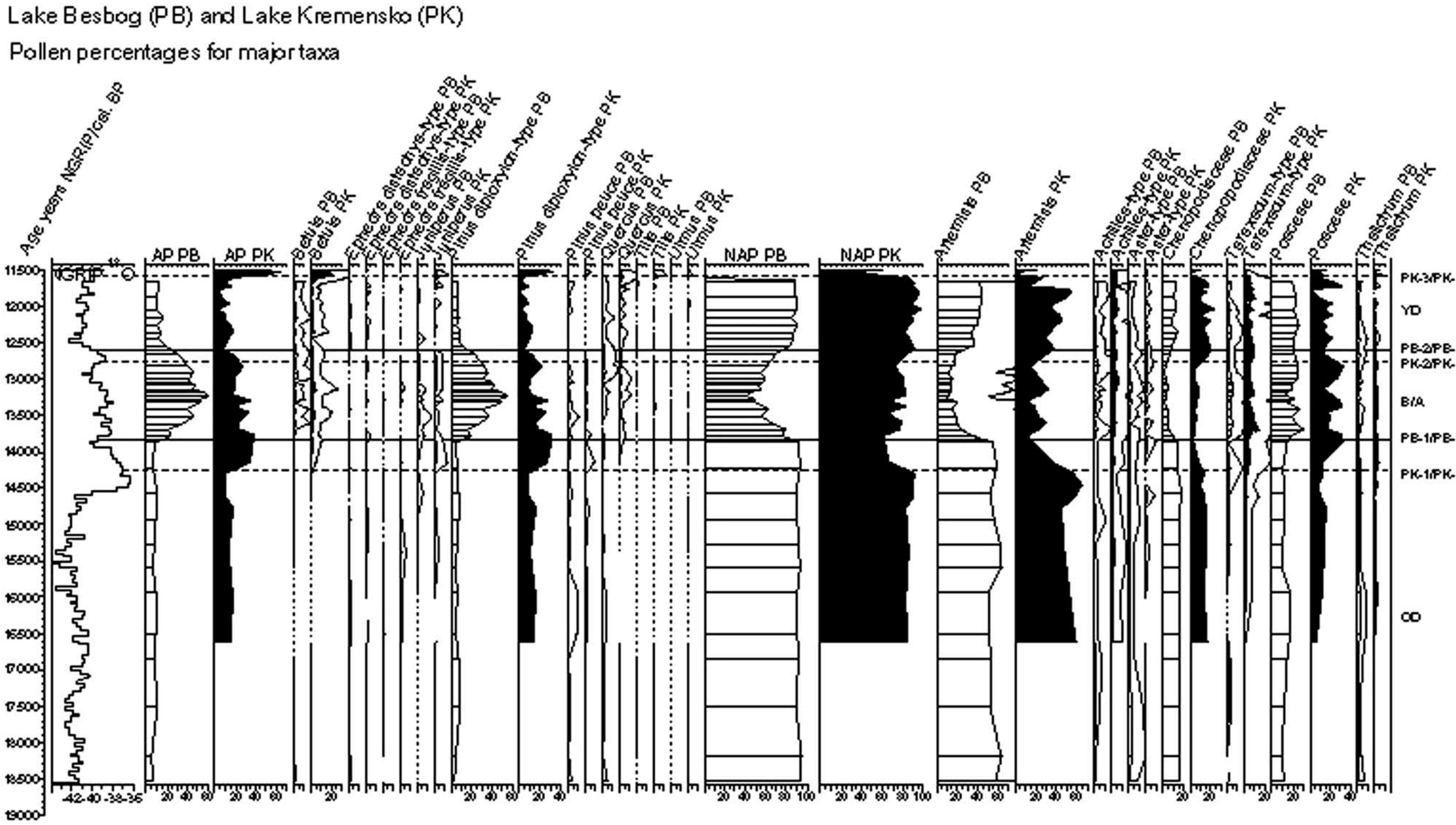


Figure 7 Major pollen profiles plotted as pairs for Besbog and Kremensko-5 to show similarity of the stratigraphies. The independent calibrated chronologies of the two sites allow them to be plotted on the Greenland NGRIP timescale

Table 3 Summary of pollen stratigraphy. Dominant taxa in each zone are indicated by % values. Taxa with continuous curves for each pollen zone are indicated for Besbog (B) and Kremensko-5 (K). Numbers of taxa with only occasional occurrence in each zone are also shown

	Oldest Dryas	Bølling–Allerød	Younger Dryas	Early Holocene
AP continuous				
Pinus diploxylon-type	BK	B40%, K25%	BK	B, K10%
Pinus peuce	BK	BK	B	BK
Juniperus	K	BK	B	BK
Betula		BK	BK	B10%, K20%
Acer	B	B	B	K
Carpinus		B	B	B
Quercus	B	BK	BK	B25%, K
Tilia		K		BK
Ulmus		B		BK
Fraxinus				B
Alnus	K	BK	BK	BK
Corylus		B	B	B25%, K
Salix		B	B	K
Ephedra	BK		BK	
Vaccinium				K
Occasional	9B, 4K	10B, K9	10B, 5K	
NAP continuous				
Achillea-type	BK	BK	BK	BK
Allium-type				K
Apiaceae		BK	B	BK
Artemisia	B50%, K50%	B15%, K20%	B40%, K50%	BK
Aster-type	B	B	BK	BK
Brassicaceae			B	K
Bupleurum-type		B		K
Campanulaceae		B		K
Caryophyllaceae		B	B	B
Centaurea jacea-type	K	BK	K	BK
Cerastium		B	B	
Chenopodiaceae	B15%, K15%	BK	B15%, K15%	BK
Cichoriaceae	K	K	K	K
Cyperaceae	BK	BK	B	BK
Cirsiu-type		B		BK
Dianthus-type		BK	BK	K
Epilobium				K
Filipendula		B	B	K
Galium-type	BK	BK	BK	K
Gentianaceae				B
Heracleum				K
Plantago major/media	K		B	
Plantago montana			B	
Polygonum alpinum				B
Monolete fern spores	K	K	BK	K
Poaceae	B10%, K10%	B K20%	B20%, K10%	B30%, K20%
Potentilla-type		B	B	
Ranuncuis acris-type			B	
Ranunculus aquatilis			B	
Ranunculus-type	K	K	K	K
Rumex		K	K	
Rumex acetosa		B	B	B
Rumex acetosella		B	B	B
Rumex alpinum				B
Scabiosa				B
Scleranthus		B	B	
Silene dioica-type		B	B	
Silene vulgaris-type		B	B	
Taraxacum-type		B	B	B
Thalictrum	BK	BK	BK	BK
Veratrum-type				K
Occasional	B25, 14K	B38, 44K	B33, K40	B29, K36

conditions about 7.5 ka cal. BP as summer insolation waned, the conifers took over elevations above 2000 m, and the mixed *Quercus* forests at mid-elevations were depressed to their present range. *Abies* dominated in the uppermost forest in the mid-Holocene along with *Pinus peuce*, but with the continued cooling in the late Holocene *Picea* came to dominate, along with *Pinus* diploxylon-type (probably *P. mugo*).

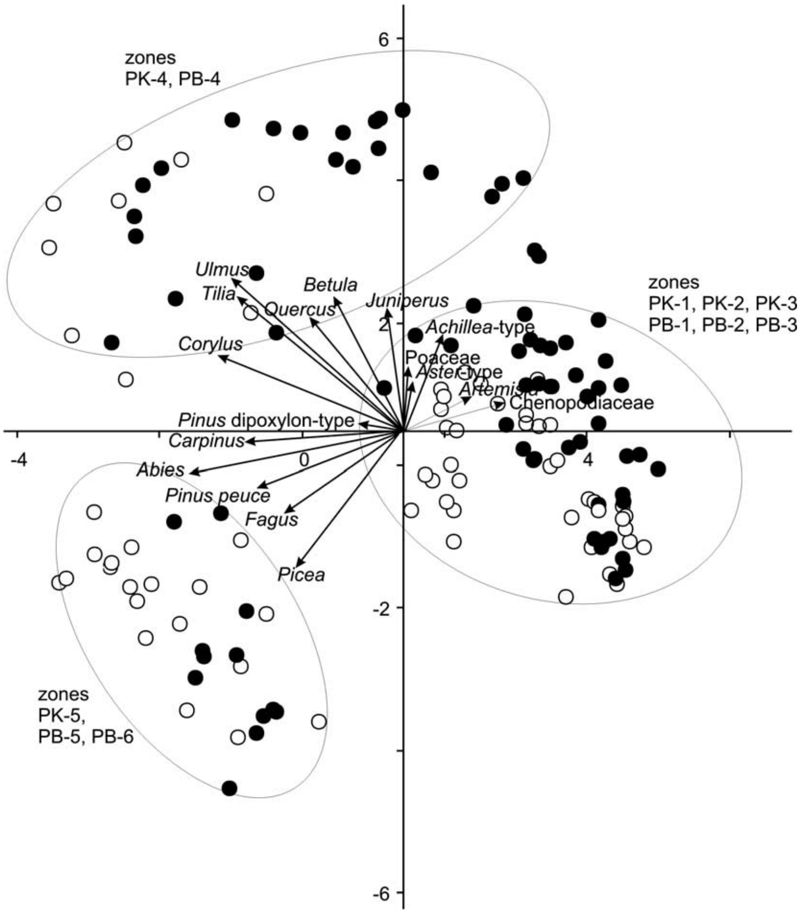


Figure 8 Principal components analysis of the taxon combined pollen percentage data from Lake Besbog (open circles) and Lake Kremensko-5 (solid circles). The first two axes are significant and explain 30% and 21% of the variance, respectively

Regional relations

The low stratigraphic and temporal resolution for most of the earlier pollen diagrams from the Rila and Pirin mountains and the lack of macrofossil data left uncertainties in the reconstruction of the vegetational history, but the detailed pollen and macrofossil stratigraphies combined with the well-controlled chronology for Besbog and Kremensko-5 in the Pirin Mountains can now serve as a framework for interpreting the Lateglacial and Holocene pollen records of the other sites. As a whole, a coherence in the vegetational history for the entire area is apparent. Comparisons with records from adjacent areas to the east, north and south, however, point to broader regional differences for the Lateglacial and Holocene vegetational and climatic history.

In the Rhodope Mountains, a lower mountain system adjoining to the Pirin Mountains on the east, the early Holocene was marked by the persistence of treeless vegetation for at least 2000 years while deciduous forest was expanding at mid-elevation in the Pirin Mountains (Stefanova *et al*., 2006), but both developments are consistent with high summer temperatures related to high summer insolation.

In Romania, in the southwestern Carpathian Mountains about 400 km north of the Rila/Pirin mountain complex, the well-dated site of Taul Zanagutil of glacial origin at 1840 m is near the upper forest limit and thus comparable in setting with the lakes in the Pirin Mountains (Farcas *et al*., 1999). Differences in the pollen sequence include the development of *Picea* and *Alnus viridis* in the Bølling–Allerød interstadial of the Lateglacial, instead of mostly *Pinus*, as in the Pirin. *Picea* and *Alnus* are also prominent in the early Holocene, where *Ulmus* and *Tilia* precede rather than accompany *Quercus* as the most conspicuous temperate deciduous tree types. *Picea* is even better developed in the mid-Holocene, when it is joined by *Carpinus* and then in the late Holocene by *Fagus* and *Abies*. The Lateglacial prominence of *Picea* supports the identification of the Carpathians as a more important glacial refuge for this conifer than the Bulgarian mountains.

In northern Greece in the Pindus Mountains the site of Rezina Marsh (1800 m), about 250 km southwest of the Pirin Mountains, has only 8 cm of Lateglacial sediment, and it cannot be subdivided into pollen zones (Willis, 1994). It is dominated by herbaceous pollen and has 10% *Pinus* and 5% *Quercus*, which could be attributed to distant transport, but the small amounts of *Abies* and temperate deciduous trees of low pollen dispersal characteristics are believed to represent nearby localized stands refugial from earlier temperate times. In the early Holocene *Quercus* abruptly increased to 30%, and *Abies* and the temperate deciduous types also increased, resulting in a temperate woodland of mixed composition. Macrofossil analysis yielded no remains of trees, so local presence could not be demonstrated. Such a reconstruction differs from that for the Pirin Mountains, where *Betula* macrofossils at both Besbog and Kremensko-5 (2250 and 2124 m) and at Praso (1900 m) suggest a broad elevational belt of *Betula* forest in the early Holocene, with the pollen of temperate deciduous trees reaching high elevations as the regional pollen rain coming from the temperate forest at lower elevation, eg, 1800 m. This happens to be the same elevation as Rezima Marsh in Greece, where such a forest is postulated. *Betula* has not been a factor in Greek vegetation history, nor has *Picea*.

Conclusions

Radiocarbon dating of the pollen and macrofossil stratigraphy for Lake Besbog and Lake Kremensko-5, two cirque-lake sites at 2250 and 2140 m in the northern Pirin Mountains of Bulgaria, indicates that the Lateglacial sequence can be correlated with the Lateglacial calendar chronology of the Greenland ice core. The Bølling–Allerød horizon is represented by a temporary increase in arboreal pollen. Following the temporary expansion of NAP in the Younger Dryas, in the early Holocene macrofossils of *Betula* both here and at the site of Praso at 1900 m indicate a broad elevational belt of birch woodland, but the high pollen percentages of *Quercus*, *Tilia*, *Ulmus* and other deciduous trees are believed to represent the regional pollen rain derived from lower-elevation mixed oak forests that had expanded upward as a result of increased summer temperatures related to higher summer insolation. In the mid-Holocene with reduced summer insolation conifers took over the high elevations, and the dominant types shifted in the late Holocene from *Abies* and *Pinus peuce* to *Picea*. The subalpine *Pinus mugo* covers much of the area near the sites today.

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