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Late Miocene Palaeoclimate and Ecosystem Dynamics in Southwestern Bulgaria – A Study Based on Pollen Data from the Gotse-Delchev Basin

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Abstract: A profile 63 m thick in the Late Miocene in the Gotse-Dechev Basin (SW Bulgaria) was sampled for pollen analysis in the Kanina opencast mine. The exposed sequence comprises a basal unit with brown coal-clay cycles and clayey/siliciclastic cover layers partly representing a lacustrine facies. A total of 60 pollen samples were analysed, but quantitative data are confined to 30 polleniferous samples.

The palynological analysis carried out provides data about the composition and structure of the fossil vegetation. The main vegetation type was a mixed mesophytic forest dominated by *Carya, Fagus, Betula, Quercus,* and *Ulmus.* Accessory elements included *Magnolia, Corylopsis, Liquidambar, Eucommia, Zelkova, Ulmus, Pterocarya, Juglans, Engelhardia, Platycarya, Symplocos*, Araliaceae, Vitaceae, *Hedera, Cornus,* and *Ilex.* Mid- and high-altitude vegetation elements *Tsuga, Abies, Keteleeria, Cathaya, Picea, Cedrus* are also present. Swamp vegetation with high proportion of *Alnus*, and minor percentages of Taxodiaceae, Cyrillaceae, *Myrica, Planera,* some Poaceae, Cyperaceae, and some ferns also existed.

Species of *Platanus, Alnus, Pterocarya, Salix, Staphylea,* and *Liquidambar* played important roles in the riparian vegetation. The aquatic vegetation consists of *Butomus, Potamogeton*, *Menyanthes*, *Sparganium, Typha* and Cyperaceae. Herbaceous palaeocoenoses had a limited distribution.

The climatic data reconstructed by the Coexistence Approach indicate mean annual temperatures of ca. 15.6–17.1°C. For mean annual precipitation intervals from 1096 to 1347 mm are most common. The narrowest coexistence intervals for the mean of the coldest month are 5 to 7.5°C. Summer temperatures were mainly between 24.7 and 26.4°C. The curve obtained for the means of summer temperatures illustrates some cyclic changes, partly also observed for other temperature parameters. The dynamics of the reconstructed data indicate that the climatic changes were probably cyclical. However, the presence of several unconformities in the sampled section does not allow an unambiguous interpretation of these data.

Key Words: Late Miocene, Bulgaria, Southeast Europe, palynology, vegetation, climate, Coexistence Approach

Güneybatı Bulgaristan Geç Miyosen Paleoiklimi ve Ekosistem Dinamikleri – Gotse-Delchev Havzasından Polen Verilerine Dayalı Bir Çalışma

Özet: Gotse-Dechev Havzası (GB Bulgaristan) Geç Miyosen'indeki 63 m kalınlığında bir profil, Kanina açık maden ocağından polen analizi için örneklenmiştir. Yüzeyleyen istif, kahverengi kömür-kil devirselliğiyle bir temel birimi ve gölsel fasiyesi kısmen temsil eden killi/silis kırıntılı örtü katmanlarını kapsamaktadır. Toplam 60 polen örneği analiz edilmiş, fakat sayısal veriler 30 polence zengin örneklerle sınırlı kalmıştır.

Gerçekleştirilen palinolojik analizler fosil bitki örtüsünün kompozisyon ve yapısı hakkında veriler sağlamaktadır. Temel bitki örtüsü tipi, başlıca *Carya, Fagus, Betula, Quercus* ve *Ulmus*'tan oluşan karışık bir ormandır. *Magnolia, Corylopsis, Liquidambar, Eucommia, Zelkova, Ulmus, Pterocarya, Juglans, Engelhardia, Platycarya, Symplocos*, Araliaceae, Vitaceae, *Hedera, Cornus* ve *Ilex* içeren ikincil elementler ile orta ve yüksek rakımlarda *Tsuga, Abies, Keteleeria, Cathaya, Picea, Cedrus* bitki örtüsü elementleri de bulunmaktadır. *Alnus*'un yüksek oranı ve Taxodiaceae, Cyrillaceae, *Myrica, Planera*'nın düşük yüzdeleri, birkaç Poaceae, Cyperaceae'li bataklık bitki örtüsü ve birkaç eğrelti de bulunmaktadır.

Platanus, Alnus, Pterocarya, Salix, Staphyle ve *Liquidambar* türleri ırmak kenarı bitki örtüsünde önemli rol oynadılar. Sucul bitki örtüsü *Butomus, Potamogeton*, *Menyanthes*, *Sparganium, Typha* ve Cyperaceae'den oluşmaktadır. Otsul fosil topluluğu sınırlı dağılıma sahipti.

Birarada Olma Yaklaşımı yöntemiyle yeniden değerlendirilen iklimsel veriler 15.6–17.1°C yıllık ortalama sıcaklığı belirtmektedir. Yıllık ortalama yağış aralığı için 1096–1347 mm en yaygın olanıdır. En soğuk ayın ortalaması için en dar Birarada Olma Yaklaşım aralığı 5–7.5°C dir. Yaz sıcaklıkları esas olarak 24.7 ve 26.4°C arasındadır. Yaz sıcaklıkları ortalamalarından elde edilmiş eğri, kısmen diğer sıcaklık parametrelerinde de gözlenmiş olan, birkaç devirsel değişikliği resimlemektedir. Yeniden düzenlenen verilerin dinamiği, olasılıkla devirsel karaktere sahip olan iklimsel değişimleri belirtmektedir. Ancak, örneklenen kesitte çok sayıda uyumsuzluğun varlığı, bu verilerin kesin bir yorumuna izin vermemektedir.

Anahtar Sözcükler: Geç Miyosen, Bulgaristan, Güneydoğu Avrupa, palinoloji, bitki örtüsü, iklim, Birarada Olma Yaklaşımı

Introduction

The Late Miocene represents a time-span of remarkable climatic and environmental changes on both global and regional scales. A warm phase in the middle Miocene (MMCO) was followed by a period with declining temperatures, as evident from the analysis of stable isotopes (e.g., Zachos *et al*. 2001). The opening of the Drake Passage, appearance of the circum polar current in the Southern Hemisphere, and intensified Antarctic glaciations, as well as the onset of Northern Hemisphere glaciations influenced the Late Miocene climate system, and led to a response of terrestrial ecosystems.

In the Balkan Peninsula the Late Miocene was characterized by large-scale palaeogeographic reorganizations that led to the appearance fresh water lakes. All these changes influenced the distribution of terrestrial vegetation, taxonomic composition of the flora, and appearance or disappearance of genera and species. The territory of Bulgaria, with its numerous Late Miocene freshwater basins, appears as a key region to understand the Neogene evolution of this link between Central and Eastern Europe and Asia Minor (Rögl 1998; Meulenkamp & Sissingh 2003), for it was the migration pathway and exchange route for many plant and animal species.

Recent palynological studies on the Neogene of Bulgaria elucidate the evolution of vegetation and climate (e.g., Ivanov 1995, 2003, 2010; Ivanov *et al.* 2002, 2007a, b, c; Hristova & Ivanov 2009; Utescher *et al*. 2009, etc).The present paper provides an analysis of Late Miocene vegetation/climate evolution based on the interpretation of palynological data using quantitative methods. The palynomorph assemblages studied originate from the Gotse-Delchev Basin in southwest Bulgaria.

Geological Settings

The Gotse-Delchev Basin is located in southwestern Bulgaria, in the valley of the Mesta River (Figure 1). The basin margins coincide with those of the Gotse-Delchev valley and are bounded by the Pirin Mountains to the northwest and west, the Rhodope Mountains to the east and northeast, and the mountains of Slavyanka and Falakro (Bald Mountain) to the south. The basin is about 22 km long, ca. 7 km wide, and has a total area of approximately 150 km^2. The Neogene basin fill rests on Proterozoic metamorphic rocks and a Palaeogene volcano-sedimentary succession.

Neogene sediments of the Gotse-Delchev Basin (Figure 1) have been previously studied (Bonchev 1923, 1960; Vankov 1923), but only in recent decades have lithological and biostratigraphic subdivisions based on detailed research been proposed (Vatsev 1980; Nenov *et al*. 1972; Pirumova & Vatsev 1979; Temniskova-Topalova & Ognianova 1979; Bozhkov *et al*. 1981; Temniskova-Topalova & Ognianova-Rumenova 1983; Choleev & Baltakov 1989; Popov 1994; Ognianova-Rumenova & Yaneva 2001; Yaneva *et al*. 2002). The first detailed description of the sediments from this basin were provided by Nenov *et al.* (1972), who differentiated two informal lithostratigraphic units – lower sandy-clayey formation and upper sandy-conglomerate formation. Vatsev (1980) introduced the now-accepted lithostratigraphic subdivision, with the Valevitsa

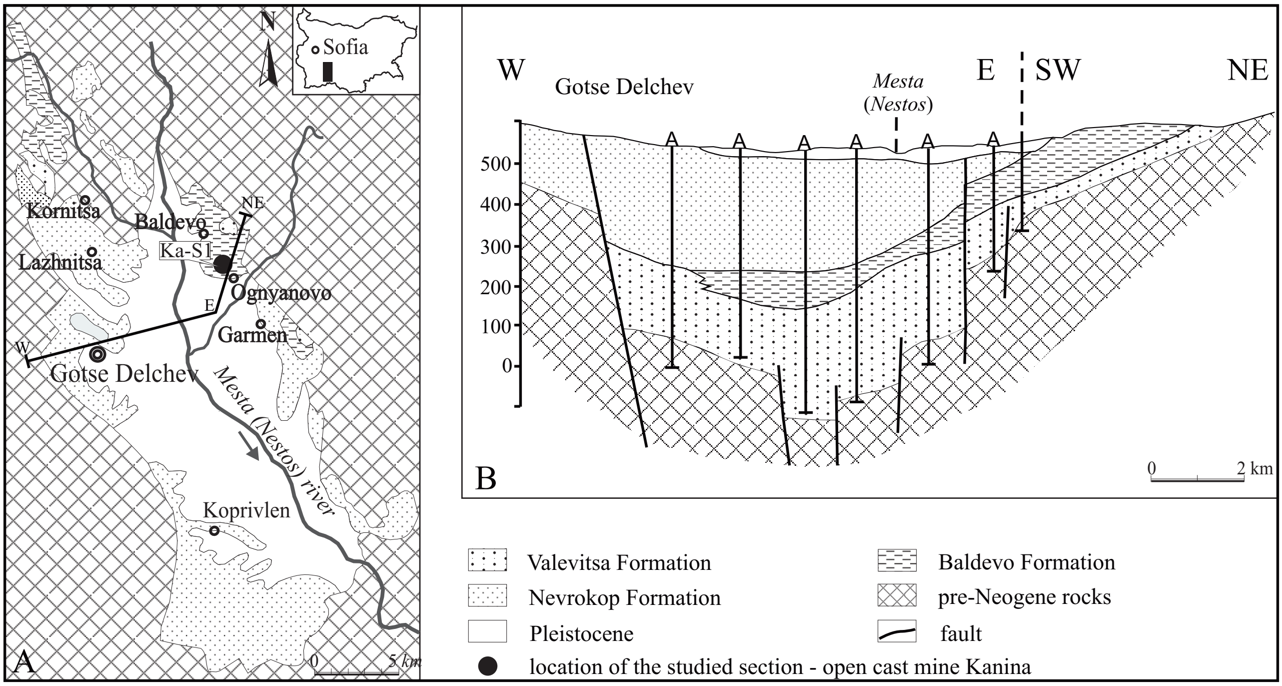

Figure 1. The Gotse-Delchev Basin. Schematic map **(A)** and section **(B)** (Redrawn after Vatsev 1980).

and Baldevo formations corresponding to the lower sand-clay formation, and the Nevrokop Formation corresponding to the upper sandy-conglomerate formation. Later Vatsev & Petkova (1996) introduced an additional lithostratigraphic unit, the Srednenska Formation. Thus, the sediments of the Gotse-Delchev Basin are subdivided into the following four official lithostratigraphic units (from bottom to top):

The Valevitsa Formation was defined by Vatsev (1980). It is characterized by alluvial and deltaic sediments represented by irregular conglomerates, sands, and sandstones up to 200 m thick.

The Baldevo Formation was introduced by Vatsev (1980). It consists of silts, silty clays, and silty sands exposed near the villages of Baldevo, Ognyanovo, and Garmen (Figures 1 & 2). At the bottom of the Formation is the main coal seam, ca. 5–6 m thick. The total thickness of the formation varies from 40–50 to 100–120 m (Popov 1994; Zagorchev 1995).

The Nevrokop Formation introduced by Vatsev (1980), is represented by polymictic sands, sandstones, and conglomerates, often cross-bedded, up to 500–600 m thick. The sediments occur in the western part of the basin.

The Srednenska Formation, defined by Vatsev & Petkova (1996), is represented by breccias, breccia-conglomerates, conglomerates, and sandstones, attaining a thickness of 30–100 m.

The results obtained by Bozkov *et al.* (1981) suggest that the Baldevo Formation thins out to the west and south, where the Nevrokop Formation directly rests upon the Valevitsa Formation and thus may be regarded as one single formation. Popov (1994) suggested that this formation should take the name of the Nevrokop Formation (Zagorchev 1995). The Valevitsa Formation should be considered as a member of the Nevrokop Formation. There is no palaeontological evidence for the age of the Valevitsa Member (Valevitsa Formation), but on the basis of its stratigraphic position a Maeotian age has been assigned (Vatsev 1980). Fossil mammals and floral remains indicate an Early to Middle Pontian age for the sediments of the Baldevo Formation (Vatsev & Petkova 1996). The analysis of diatoms suggested a Pontian to Pliocene age for diatomaceous clays and diatomites occurring in the upper part of the formation (Temniskova-Topalova & Ognjanova-Rumenova 1983, 1997; Temniskova-Topalova 1994).

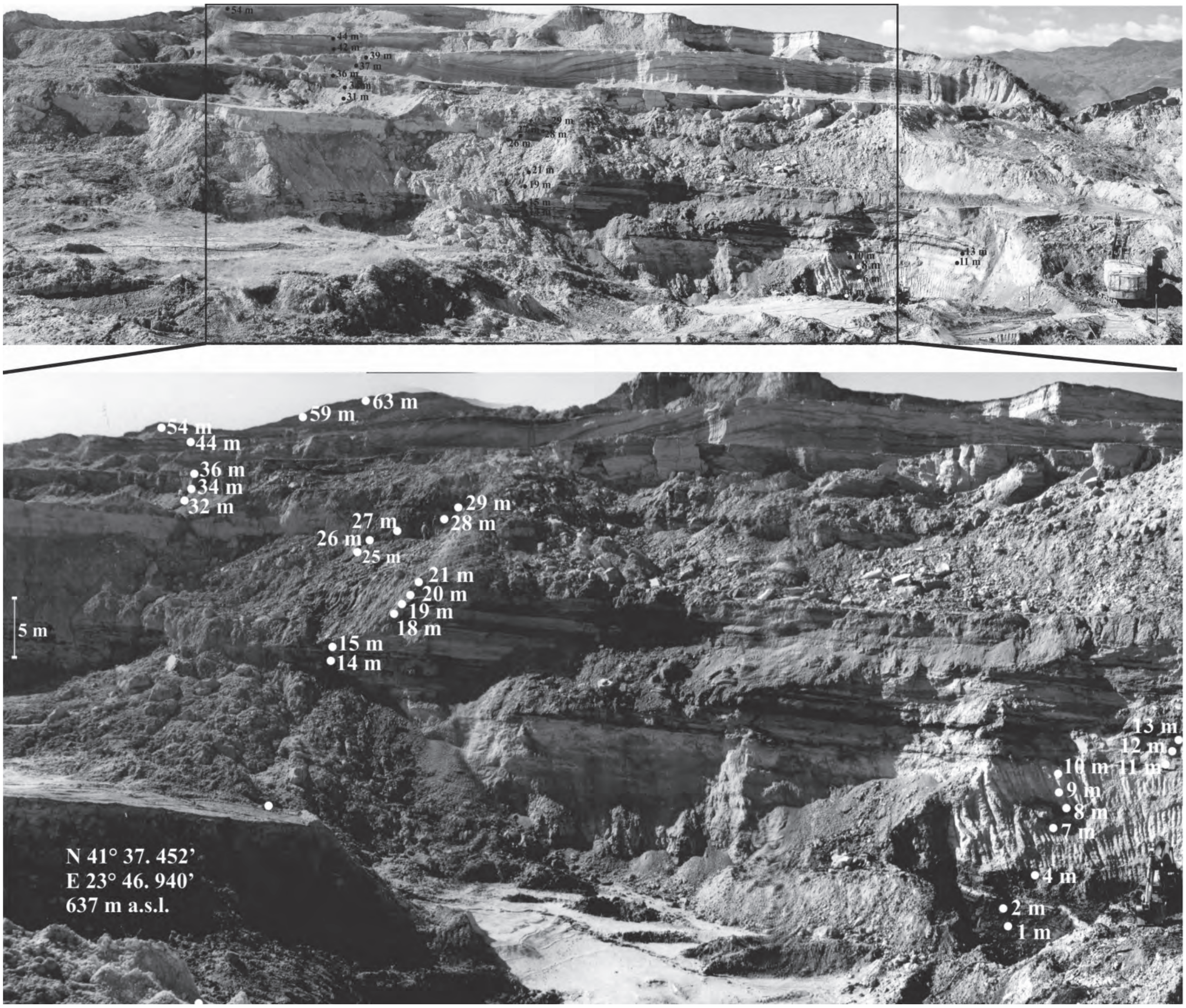

Figure 2. Gotse-Delchev Basin and open cast mine with the position of the studied profile indicated.

Detailed faunal studies carried out on the Hadjidimovo-1 locality during the last decade (Spassov & Ginsburg 1999; Spassov 2000, 2002; Geraads *et al*. 2001, 2003, 2005; Kostopoulos *et al*. 2001; Hristova *et al*. 2002; Merceron *et al*. 2006) provide new insight into the age of the sediments. The taxonomic composition of the faunal complex shows similarities with associations from several localities in the Balkan-Iranian region and Northern Paratethys yielding *Hipparion* fauna of the late Maeotian (middle Turrolian) age (Spassov & Geraads 2004). In particular, this complex corresponds to the boundary of the MN11/12 zone, or even the beginning of MN12 (Spassov 2002; Spassov & Geraads 2004). i.e., the accumulation of the Nevrokop Formation began in the Maeotian and continued during the Pontian. In view of the stratigraphic position of the Hadjidimovo locality and spatial relationships with the Baldevo Formation, the age of the latter may be defined as latest Maeotian to Pontian. For upper levels with diatomites a latest Pontian to early Pliocene age is probable. On the basis of the stratigraphic position of the Srednenska Formation Vatsev & Petkova (1996) suggested a Pliocene age.

The evolution of the Gotse-Delchev Basin began in the Maeotian with the deposition of coarse-grained alluvial sediments belonging to the first cycle of the Nevrokop Formation. In the late Maeotian fluviatile sediments of a braided river system were deposited (Spassov 2000; Yaneva *et al.* 2002; Tsankov *et al.* 2005). During this period the alluvial sediments of the Nevrokop Formation with its rich mammal fauna were deposited (MN 11-12 mammal zones: Spassov 2000; Tsankov *et al.* 2005). At the end of the Maeotian and the beginning of the Pontian the sedimentary facies changed. In the northeastern part of the basin large swamps developed and the brown coal deposits of the Baldevo Formation formed.

As a result of palaeogeographic changes and flooding, the swamp environment was replaced by a lake, and additional areas were flooded in the western part of the basin. During this period silty-clayey sediments of the Baldevo Formation were deposited, characterized by frequent facies changes. Around the villages of Baldevo, Garmen and Ognyanovo diatomaceous clays and diatomite was deposited. The accumulation of diatomite is probably related to changes in the hydrology and the temperature regime of the lake (Yaneva *et al.* 2002) and took place in the late Pontian to early Pliocene (Temniskova-Topalova & Ognianova-Rumenova 1983). The lake environment was later replaced by alluvial sedimentation (cross-bedded sands and sandstones). Sedimentation probably ended during the Pleistocene with the deposition of coarse-grained alluvial-fan deposits of the Srednenska Formation (Vatsev & Petkova 1996).

Materials and Methods

The present study is based on the analysis of 60 samples from the Kanina open-cast mine near the village of Ognjanovo, Gotse-Delchev District. A measured section (Ka-S1, 63.00 m thick) was sampled in detail in order to document sedimentary structures and facies. The section runs through the Baldevo Formation, exposed in the coal mine (Figure 2). The lithology of the section is shown in Figure 3. The section starts in the main brown coal seam, attaining a thickness of ca. 4.2 m. The lignites are partly massive or laminated and contain numerous cuticles. Thin siliciclastic layers are intercalated at regular intervals, getting coarser grained towards the top of the brown coal (Figures 2 & 3). These cycles of brown coal-clay and silty-clay 1–1.5 m in thickness are probably related to the dynamics of the hydrological regime of the basin, reflecting alternating paludal and lacustrine facies conditions.

The interval from 4.2 to 45.0 m consists of stacks of coarsening-upward cycles that can be interpreted as floodplain deposits of a meandering river system. The sequences are composed of laminated or bioturbated clays, partly with very high organic content and with plant cuticles, grading into silty clays, topped by cross-bedded sandy partly gravel channels, partly cross-bedded sands, and gravel containing drift wood.

At 45 m a lacustrine environment occurs. After the deposition of an organic clay containing plant cuticles, about 1 m thick, ca. 12 m of diatomites and diatomitic clays were deposited, with a sandy channel intercalated at 54.5 m. The section ends with stacked fluvial channel deposits. The geometry of these sandy channels is well exposed in the open cast, and the lack of fine-grained siliciclastic components points to a shift of the fluvial system into a braided-river type. The thickness of the diatomites is highly variable in the open cast. Locally the horizon has been completely removed by the palaeoriver. The diatomitic clays and diatomites contain a very rich, diverse leaf flora.

The samples analysed were collected from the section at various levels and processed to study the pollen content. For palynology samples were taken from every single layer, or at an average of ca. 50 cm after homogenizing the sediment. Each sample contained homogenized bulk material of a single layer or 50 cm of sediment where lithology is consistent, of ca. 10–20 cm where lithology changes rapidly, or at ca. 1.0 m in sands and sandy clays. The intervals from 21.0 to 23.5 m and 30.0 to 31.5 m were not sampled because these parts of the profile could not be accessed in the open cast mine.

The samples were processed according to the standard technique for disintegrating Cenozoic sediments, which includes successive treatment by hydrochloric acid (HCl), hydrofluoric acid (HF), potassium hydroxide (KOH), and heavy liquid separation ($ZnCl_2$) and were stored in glycerin.

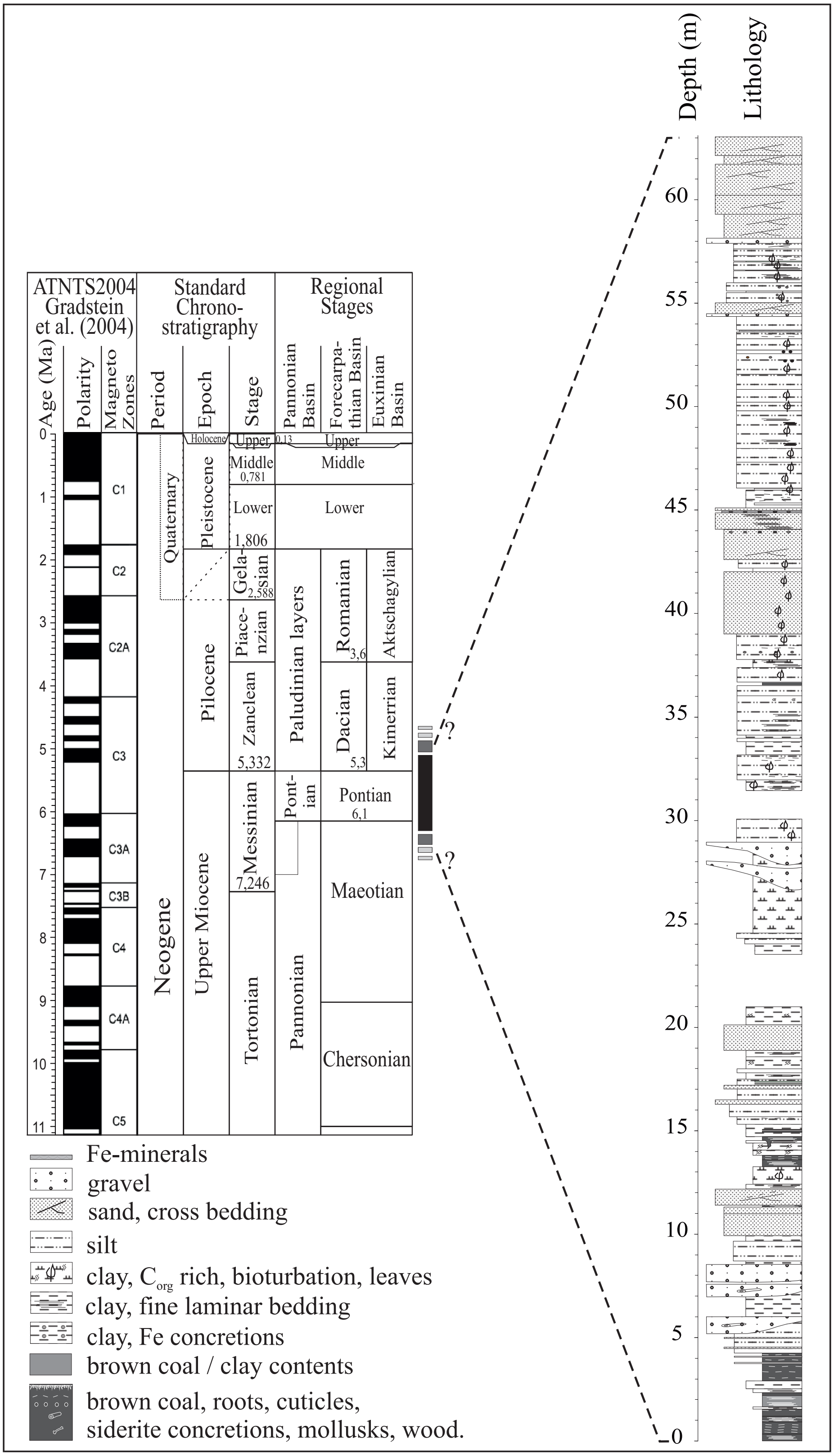

Figure 3. Lithological column of the studied section.

Unfortunately, 5 samples were entirely devoid of pollen, while 25 others contained pollen in low concentrations (with fewer than 100 grains counted). To minimize statistical errors and to avoid wrong interpretations, we omitted these 25 pollen spectra from our interpretation of the vegetation and palaeoclimate. The 30 remaining samples contained enough pollen/spore content to interpret vegetation and climate evolution. On the basis of pollen/spore counts of these 30 pollen spectra percentage pollen diagrams were plotted (Figures 4 & 5) showing the palynological record of the complete section. The percentage of each palynomorph taxon identified in the pollen spectra was calculated with respect to the total sum of arboreal (AP) and non-arboreal (NAP) pollen (AP+NAP= 100%). Local elements (L), such as spores and aquatic plants, were calculated on the basis of the sum AP+NAP+L= 100%. The total pollen sum for each sample is shown graphically in the pollen diagram (Figure 5). In addition, a synthetic pollen diagram was plotted (Suc 1984; Jiménez-Moreno *et al.* 2005; Figure 6), in which pollen taxa have been arranged in different groups on the basis of ecological criteria to clearly show temporal changes in vegetation.

Tracing the changes in the percentage values of the different pollen curves revealed the distinct pollen zones in the section studied. Differentiation of the pollen zones is based on sediments with a specified fossil content or specific palaeontological characters (characteristic pollen complexes, type and frequency of palynomorphs), which distinguish them from the neighbouring sediments (Gordon & Birks 1972). The pollen zones presented for each core were regarded as Local Pollen Zones (LPZ), indexed by letters and digits. Numerical zonation of the pollen diagrams was used as an auxiliary means for differentiation of LPZs (Birks 1974; Birks & Birks 2006), with the help of cluster analysis in grouping the palynological data obtained. The mathematical calculations and cluster analysis were carried out with the help of CONISS software (Grimm 1987).

To reconstruct quantitative palaeoclimatic data we applied the Coexistence Approach (CA) (Mosbrugger 1995; Mosbrugger & Utescher 1997), a method based on climatic requirements of all Nearest Living Relatives known for fossil flora. The CA provides quantitative data for various climatic variables, and has been successfully applied to the Neogene microfloral records (e.g., Ivanov *et al.* 2002, 2007a, b; Bruch *et al.* 2004; Syabryaj *et al.* 2007). The method was applied to a total of 30 samples, and 4 different variables were calculated: mean annual temperature (MAT), temperature of the coldest month (CMT), temperature of the warmest month (WMT), and mean annual precipitation (MAP). In addition to the coexistence intervals the curve connecting interval means is shown. When there is more than one coexistence interval per sample, the mean of all intervals has been calculated. Curves based on means do not represent the 'real' values but express the overall trends of climatic change. Pross *et al.* (2000) outlined the significance of the means of the CA intervals. Following these considerations, means were used to visualize climatic variability and evolution.

Palynological Subdivision

Local Pollen Zone GD-1 (Fagus-Carya-Betula): 1.55–15.10 m

This zone is characterized by the highest average content of *Fagus,* represented mainly by values from 8% to12%, with a maximum of 20.2% at 2.50 m, and *Carya,* represented mainly by values from 5% to 7%, occasionally higher (10.1%), or lower (2–3%). The pollen of *Betula* appears regularly with constant values (1 to 4%). *Pinus diploxylon* type is presented with values from 30 to 50%, while *Pinus haploxylon* type /*Cathaya* is less abundant (with a maximum of 20–22%), and tends to decrease in the upper part of the zone. The pollen of *Tsuga* is not represented in the lower part of the zone (main coal seam) but reaches up to 7–10% in the upper part. Local elements in that zone are represented by higher values, mainly due to the representatives of *Laevigatosporites* (Thelypteridaceae/Polypodiaceae) and *Osmunda* with maxima respectively of 54 and 70% (Figures 4 & 5).

Local Pollen Zone GD-2 (Cedrus-Pinus-Abies): 28.95–36.20 m

This zone is characterized by an increased average content of *Cedrus*, (6–11%, maximum of 17% at

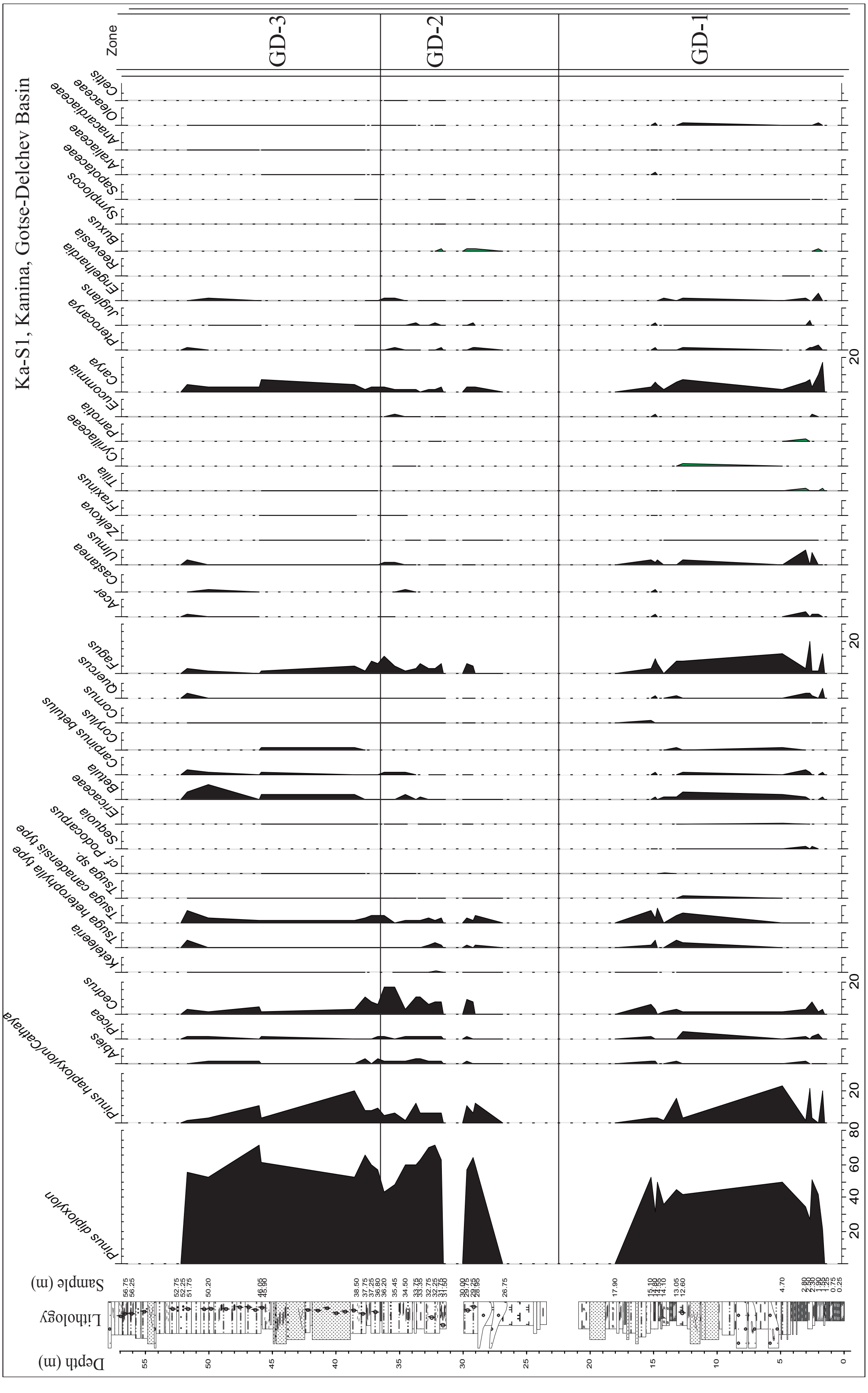

Figure 4. Percentage spores-pollen diagram of the studied section Ka-S1, Kanina, Gotse-Delchev Basin.

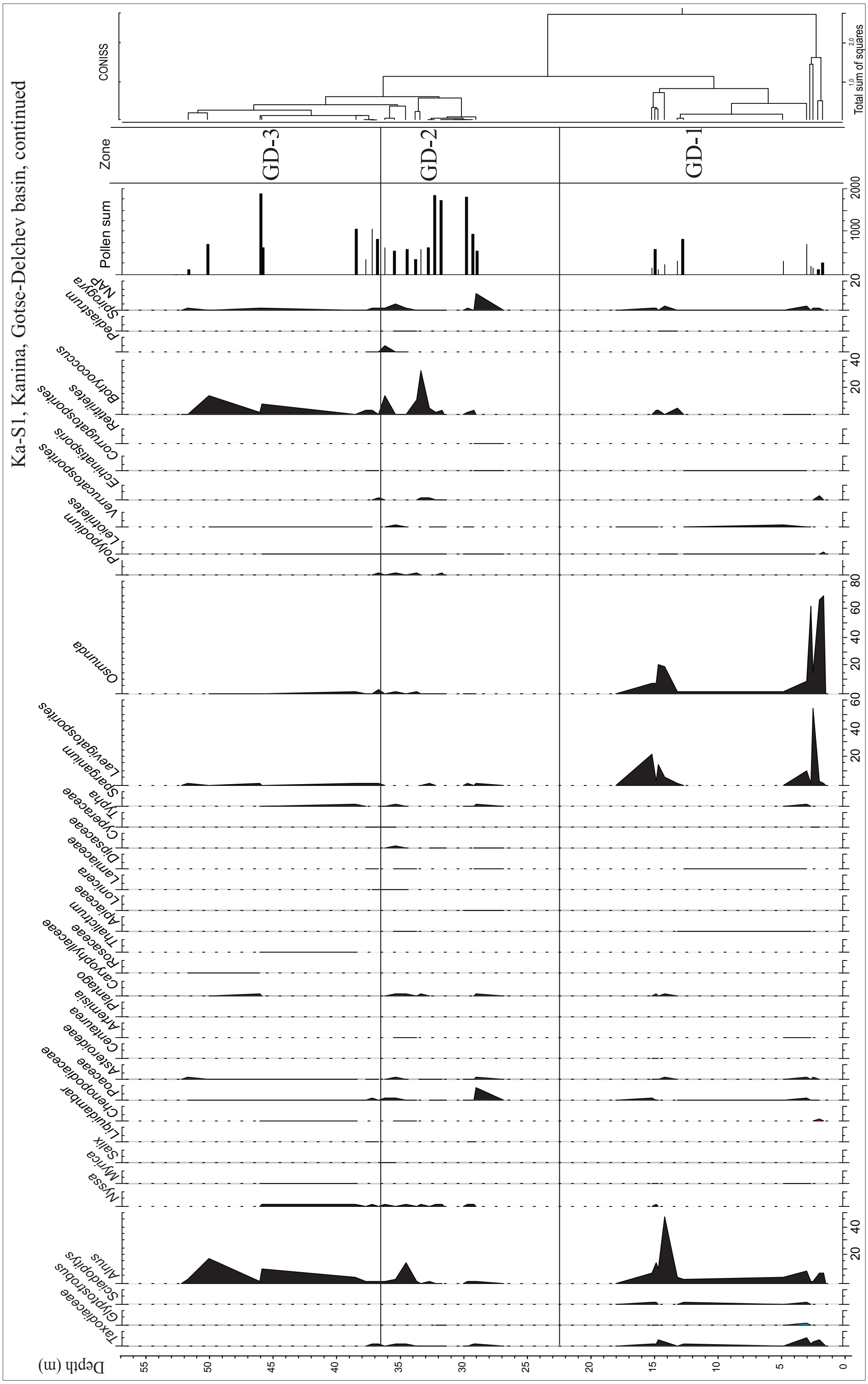

Figure 5. Percentage spores-pollen diagram of the studied section Ka-S1, Kanina, Gotse-Delchev Basin. Continuation.

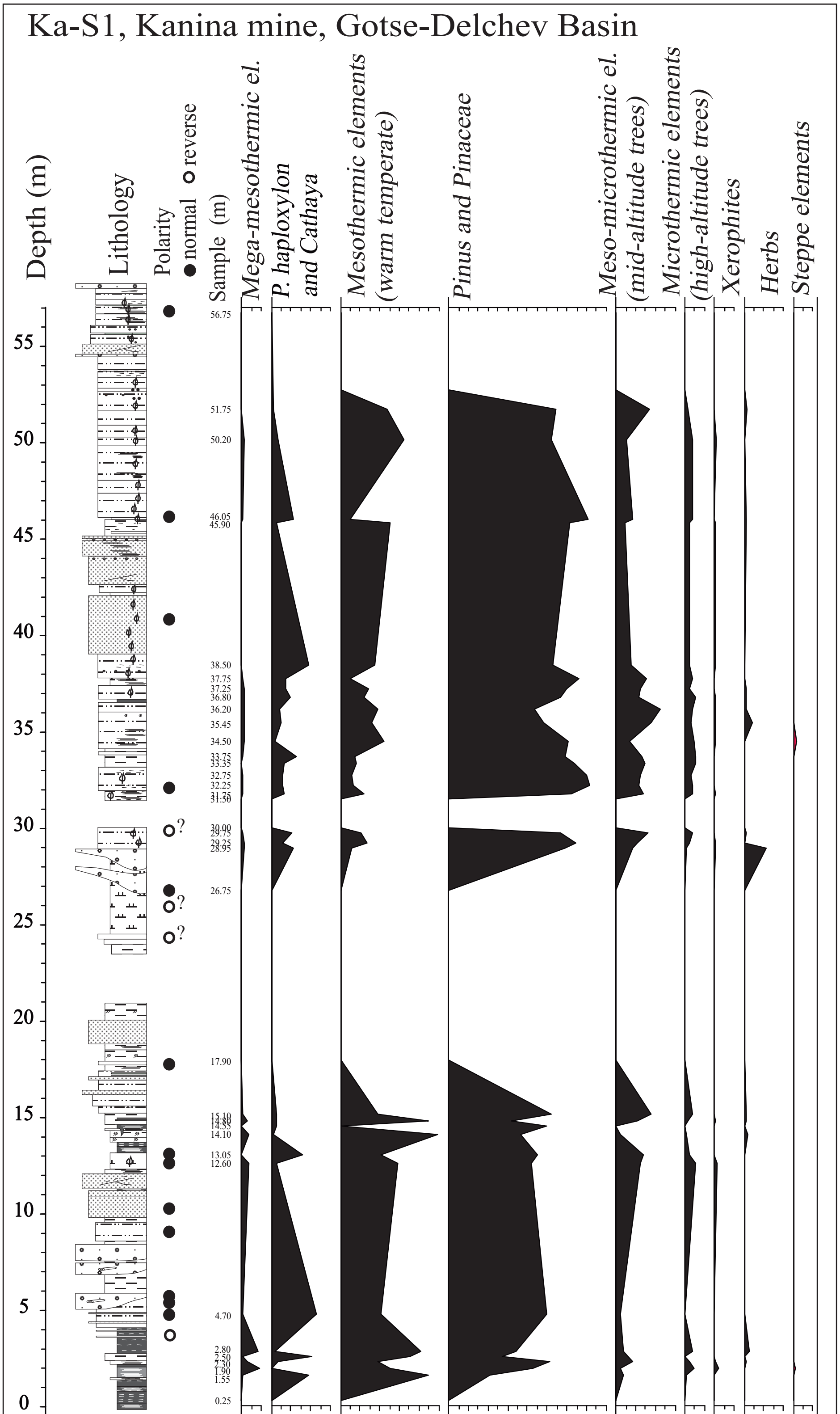
Ka-S1, Kanina mine, Gotse-Delchev Basin
Depth (m)
Lithology
Polarity
normal
reverse
Sample (m)
Mega-mesothermic el.
P. haploxylon and Cathaya
Mesothermic elements (warm temperate)
Pinus and Pinaceae
Meso-microthermic el. (mid-altitude trees)
Microthermic elements (high-altitude trees)
Xerophites
Herbs
Steppe elements

Figure 6.

35.45 and 36.20 m). Percentages of the *Pinus* pollen rise significantly, and the *P. diploxylon* type reaches up to 65–70%. Meanwhile, the *P. haploxylon* type / *Cathaya* shows a slight tendency to decrease, and values of 5–6% are most common, occasionally up to 10–11%. *Abies* increases slightly – up to 2–3%, in contrast to the rest of profile (1% or even single pollen grains). *Tsuga, Betula, Carya, Ulmus,* and *Alnus* have lower values. As a whole the mesothermic elements registered a slight decrease in their values in the pollen spectra of this zone (Figure 6). Spore plants are poorly presented with about 1% or less. Herbaceous plants (NAP) generally increased upwards and registered two maxima: 11.3% at 28.95 m and 4% at 35.45 m. An increased abundance of fresh water algae is characteristic for the upper part of the zone, mainly due to the increased proportion of *Botryococcus* (with a maximum of 32.3% at 33.35 m).

Local Pollen Zone GD-3 (Carya-Betula–Alnus): 36.80–51.75 m

In this zone *Pinus* dominated, and *P. diploxylon* type maintained a high average of about 55–65% (Figures 4 & 5). *P. haploxylon* type /*Cathaya* tends to increase in the lower part of the zone (up to 18.7%), followed by decrease towards the top. *Carya* pollen shows a percentage increase and ranges chiefly between 3 and 4 % with a peak of 7.2%. *Betula* generally increases upwards to 2–4% but has values of 7.9% at 50.20 m. Pollen of *Alnus* increases from 1% (bottom) up to 3–10% and a maximum of 17.8% at 50.20 m. A general decrease was observed in the quantities of *Cedrus, Abies, Picea, Carya,* and *Fagus*. Spore plants and herbs (NAP) are poorly represented. The green alga *Botryococcus* is represented by constant quantities of 3–8%.

Also present are deciduous broad-leaved trees such as *Ulmus, Betula*, and *Juglans* (Figures 4 & 5).

The dendrogram obtained from the cluster analysis confirmed in general the distinct differentiation of the different zones in the profile (Figure 5). At the top of LPZ GD-2, there is greater similarity in the group of three pollen spectra to the cluster of LPZ GD-3. At the beginning of LPZ GD-1 part of the pollen spectra from a coal-bearing layer is very clearly separated. This is due to the specificity of pollen complexes and high abundance of spore plants. The separation of this cluster can be considered as an indication of the subdivision of a separate pollen zone, but at this stage of our knowledge, such subdivision is not safe enough due to the small number of samples and the presence of barren samples or those with low pollen content.

Flora, Vegetation and Climate Analysis

Late Miocene Vegetation in the Gotse-Delchev Area

Material from the Gotse-Delchev Basin had already been the subject of palynological pilot studies by Ivanov (1995) and Ivanov & Slavomirova (2000). Based on the analysis of 11 samples from the Kanina open-cast coal mine and outcrops near the villages of Lazhnitsa and Kornitsa, the authors identified 88 palynomorph taxa. In this study 18 spore and pollen taxa have also been identified, so the total pollen

Figure 6. Synthetic pollen diagram. Pollen taxa have been arranged in different groups on the basis of ecological criteria to clearly manifest temporal changes in vegetation (acc. Suc 1984; Jiménez-Moreno *et al*. 2005).

- Mega-mesothermic elements: Taxodiaceae, *Taxodium, Symplocos, Engelhardia, Platycarya, Myrica*, Sapotaceae, *Distylium, Hamamelis, Corylopsis, Castanea-Castanopsis* type, Cyrillaceae-Clethraceae, *Reevesia*, Theaceae, *Alangium,* Chloranthaceae, *Parthenocissus,* Araliaceae, Arecaceae and others;
- *Pinus haploxylon* type and *Cathaya*;
- Mesothermic elements (warm temperate): *Quercus, Carya, Pterocarya, Carpinus betulus, Carpinus orientalis, Ostrya, Parrotia, Eucommia, Juglans, Zelkova, Ulmus, Tilia, Acer, Liquidambar, Alnus, Salix, Populus, Rhus, Celtis, Platanus, Nyssa, Ilex, Lonicera,* Caprifoliaceae, Vitaceae, *Fraxinus, Betula, Sequoia, Fagus, Hedera, Ilex, Tilia* and others;
- *Pinus* and Pinaceae indet.;
- Microthermic elements (high-altitude trees): *Tsuga, Cedrus, Sciadopitys; Abies, Picea, Keteleeria;*
- Xerophites: *Quercus ilex-coccifera* type; *Olea* type (Oleaceae), Caesalpiniaceae, *Pistacia*, *Rhus* and others;
- Herbs: Poaceae, Chenopodiaceae, Asteroideae, Cichorioideae, Centaurea, *Plantago,* Brassicaceae, Lamiaceae, Valerianaceae, Polygonaceae, *Knautia* (Dipsacaceae), Rosaceae, Malvaceae, Geraniaceae, *Erodium,* Caryophyllaceae and others;
- Steppe elements: (*Artemisia, Ephedra*).

record now includes 106 fossil palynomorphs (Plates 1–3).

The most variegated taxonomically are the angiosperm plants, represented in the fossil flora by 80 palynomorphs, of which the nearest living relatives belong to 48 extant plant families. The gymnosperms and ferns are less diverse, represented in the fossil flora by 19 and 7 taxa, respectively.

Most abundant among angiosperm pollen are Fagaceae (7 pollen types), Juglandaceae (6), Betulaceae (4), Asteraceae (4), Ulmaceae (3), and Hamamelidaceae (3). Notably, morphological characteristics of quercoid pollen are quite variable. There are at least four distinct morphological groups defined as four fossil species (Ivanov 1995; Palamarev & Ivanov 2003): *Quecoidites henrici* (Potonie) Pot., Th., Tierg. 1950 (*Quercus* sp. 1); *Quecoidites granulatus* (Nagy) Slodkowska 1994 (*Quercus* sp. 2); *Quecoidites asper* (Pfl. & Th.) Slodkowska 1994 (*Quercus* sp. 3) and *Quercopollis petrea* typus (*Quercus petrea* type) (Nagy 1985). The data from macrofloral studies also support high taxonomic diversity of *Quercus* species, as well as their importance for the structure of the Late Miocene vegetation (Palamarev & Ivanov 2003; Palamarev & Tsenov 2004).

With regard to the percentage proportion of taxa identified in the pollen spectra (Figure 4) it is evident that *Pinus* is predominant (*Pinus diploxylon* type prevails over *Pinus haploxylon* type/*Cathaya*). In some samples *Pinus*-pollen reaches up to 80%, which can be considered as over-representation. On one hand such over-representation can be due to the good possibility of long-distance air transport, on the other hand to a higher resistance of the exine, which favours preservation in more complicated environments during fossilization, e.g., oxygen-rich conditions or higher silt content. Such environmental conditions cause faster destruction and corrosion of the pollen with finer exine.

In addition, non-pollen palynomorphs were recorded. Most were zygospores of *Ovoidites* (*Spirogyra* type) and rare *Zygnema* (Zygnemataceae). They are more abundant at the bottom (lignites) and in layers with higher organic contents (Figure 5) (swamp conditions). The abundance of zygospores may be an indicator of environmental conditions (Chmura *et al*. 2006), e.g., water current, depth of basin, salinity, acidity, etc. The zygospores of *Zygnema* and *Spirogyra* are common in shallow freshwater basins (periphyton) and wet soils, attached to submerged aquatics and in pools with pH 7 (McCourt & Howshaw 2002). Zygnemataceae algae produce spores during sexual reproduction (conjugation). Conjugation is thought to be triggered by changes in the nutrients or water level. Higher frequency of *Spirogira*-spores usually corresponds to a higher water level in the mire. The exact influence of the hydroperiod on the distribution of zygospores is still under study, aiming to enhance the diagnostic value of these spores for palaeoenvironmental reconstruction (Chmura *et al*. 2006). The presence of other green algae (cenobia of *Pediastrum* and colonies of *Botryococcus*) indicates open water conditions. Their distribution is associated with diatomaceous and silty clays in the upper part of the profile (Figure 5).

In the section studied are recorded floral elements belonging to the following plant communities: euhydrophytic and hydrophytic herbaceous coenoses; hygrophytic (swamp) forest, riparian forest, mixed mesophytic forests, subxerophytic to xerophytic woody/shrub communities and herbaceous coenoses. The palaeoecological analysis of the fossil flora and the proportions of individual taxa indicate the dominance of forest palaeocoenoses. The proportion of herbaceous components in the pollen spectra is negligible (Figure 5).

Zonal vegetation was represented by mixed mesophytic forest. The role of dominants in these florally rich plant communities had representatives of *Carya, Fagus, Betula, Quercus,* and *Ulmus*. Minor are *Castanea, Carpinus*, and *Corylus*. Besides, representatives of various plant families played an important role in the structure of the plant communities: Magnoliaceae (*Magnolia*), Hamamelidaceae (*Corylopsis, Liquidambar*), Eucommiaceae (*Eucommia*), Ulmaceae (*Zelkova*), Fagaceae (*Castanea, Castanopsis*), Juglandaceae (*Pterocarya, Juglans, Engelhardia, Platycarya*), Symplocaceae (*Symplocos*), Araliaceae etc. The undergrowth was comprised of deciduous and evergreen shrubs, such as *Corylus, Cornus, Buxus, Ilex,* Ericaceae, Theaceae, ferns such as Pteridaceae, Osmundaceae, Polypodiaceae p.p. (*Verrucatosporites*), Dicksoniaceae, Selaginellaceae, and liana forms of Vitaceae (incl. *Parthenocissus*) and *Hedera*.

The palynological data obtained indicate that the vegetation was vertically differentiated. Mid- and/or high-altitude forests were spread on the slopes of the surrounding mountains. They constituted a mixed coniferous forest vegetation belt. The dominant species in these forests were species of genera *Picea, Tsuga, Abies, Keteleeria, Cathaya, Cedrus,* cf. *Podocarpus* and *Juniperus*. Some flowering plants, such as *Corylus, Betula, Fagus, Carpinus,* and *Pterocarya* were also part of the above-mentioned plant communities.

In the lower peripheral parts of the basin swamp forests (hydrophytic forest palaeocoenoses) developed in marshy areas flooded during all or most of the vegetative period. Dominant in these specific communities were species of *Alnus*, while Taxodiaceae (*Glyptostrobus*, *Taxodium*) had a limited distribution and were less important. Accompanying species were representatives of Cyrillaceae, *Myrica, Planera,* Poaceae, and Cyperaceae. The formation of this community type was strongly influenced by palaeogeographic changes and the development of swampy environments in periods with low water level in the basin. When swamp habitats were most widespread, hydrophytic forest palaeocoenoses were the main source of organic materials in forming peat.

The riparian forests, containing species of the genera *Platanus, Carya, Alnus, Ulmus, Ostrya, Pterocarya, Juglans, Salix, Staphylea,* and *Liquidambar,* formed communities in relatively restricted areas, mostly close to lakes and along the river systems. Their distribution depended on the dynamics of the river system in the study area (Choleev & Baltakov 1989). This type of plant community was closely linked to the swamp forests, as their components are mutually penetrated and mixed.

In open water areas of the palaeobasin, communities of aquatic plants were developed (euhydrophytic and hydrophytic herbaceous coenoses), which are represented in pollen spectra by *Butomus, Potamogeton, Menyanthes, Nuphar, Sparganium, Typha,* and Cyperaceae. Typical hydrophytes like *Brassenia, Euryale, Aldrovanda, Nuphar, Alisma.* and *Proserpinaca* and helophyte species of *Scirpus*, *Dulichium*, *Diclodocarya,* and *Decodon* identified as fruits/seeds found in the main coal seam have to be included here (Palamarev *et al.* 2002). In close interaction with the communities of the marsh and aquatic vegetation were representatives of the Polypodiaceae/Thelipteridaceae and *Osmunda*, as their distribution was related directly to changes in the basin water regime. The algal flora of the basin consists of *Botryococcus, Pediastrum, Spirogyra,* and *Zygnema,* recorded in the pollen spectra (see above).

Herbaceous plant communities had a very restricted distribution, obvious from their low percentages in the spectra (Figure5). They included representatives of the Apiaceae, Lamiaceae, Caryophyllaceae, *Plantago,* Dipsaceae, Poaceae, Asteroideae, Cichorioideae, *Artemisia, Centaurea*, and Chenopodiaceae. Semixerophytes/xerophytes (e.g, *Celtis, Pistacia,* Chenopodiaceae, *Artemisia*) were also present in the fossil flora. They indicate the existence of open sandy and/or rocky shore facies and slopes near the rivers and lake, which were suitable habitats for them. Palaeocarpological data also indicate the presence of drier habitats occupied by *Ostrya* and *Rubus* (Palamarev *et al.* 2002).

Vegetation Evolution in the Kanina Profile

Information about the vegetation during the formation of the main brown coal seam from our section is limited because only some of the samples contain enough spores and pollen (Figures 4 & 5). These brown coals have a characteristically high importance of spore plants. *Laevigatosporites* and *Osmunda* have the highest percentages (54 and 70%, respectively) during the whole period studied. Apparently they were also important in forming peat. A specific distribution pattern of these ferns is expressed by alternation of both types of spores with high percentages: trilete *Osmunda* spores corresponding to low quantities of monolete *Laevigatosporites*, and vice versa. This relationship was also observed in the interval from 14.10 to 15.10 m (Figure 5), when change of sedimentation took place and organic-rich clays, fine laminated clays, a thin coal layer (ca. 20 cm), and laminated clays were deposited, i.e. a change in environment from lacustrine to swamp and back. Both pterodophytes grow in wet and swampy places under different edaphic conditions and inundation regimes, and their different ecology is reflected by these changes. The changing proportions of these pteridophyte spores resemble the cyclic change in peat-bog vegetation described from the Pontian sediments of the Staniantsi Basin, W. Bulgaria (Utescher *et al*. 2009). The main components of the peat-bog vegetation were representatives of *Laevigatosporites* and *Osmunda,* showing similar alternation.

In the middle part of the section studied (LPZ GD-2) vegetation change was recorded, connected with decreasing percentages (of representatives) of the following genera: *Engelhardia, Carya, Fagus, Ulmus,* and *Betula*. The group of mega-mesothermic components is also less prominent (Figure 6); the group of micro-mesothermic components increases (altitudinal trees). Pollen of *Cedrus* and *Abies* are more abundant. A slight increase in the percentages of the non-arboreal pollen (NAP) was recorded in this part of the profile. These data indicate vegetation response to slight changes in environmental conditions, probably expressed by changes in precipitation.

In the upper part of the profile KaS1 (LPZ GD-3) an opposite trend was observed – a decreasing proportion of components of the altitudinal coniferous forests (*Cedrus* and *Abies*), and increased amounts of *Carya* and *Betula,* as *Fagus* tends to reduce its percentage in the pollen spectra. The mega-mesothermic floral elements remained scarce. An increase of warm temperate components occurred, with cool-temperate ones simultaneously decreasing.

Climate Reconstruction

The climatic data calculated for 30 palynomorph samples from section Ka-S1 are shown in Figure 7, where they are plotted together with the lithological profile. As shown by the analysis, microfloras provide well defined coexistence intervals in almost all samples for the temperature variables and mean annual precipitation. Less precise data and unspecific coexistence intervals were obtained for only a few pollen spectra with low taxonomic resolution (Figure 7).

The contemporary climate in the Gotse-Delchev valley (SW Bulgaria) is characterized by the following parameters: mean annual temperature (MAT) 11.4°C (11.0°C), temperature of the coldest month (CMT) –0.2°C (–0.2°C), temperature of the warmest month (WMT) 21.7°C (21.2°C), and mean annual precipitation (MAP) 695 mm, according to data from the meteorological station at Gotse Delchev, 511 m above sea level (Stringmeteo 2006–2009a, b).

Data obtained from the studied sections Ka-S1 (Figure 7) illustrate the dynamics of climatic conditions during sedimentation. Cases of non-specific coexistence intervals up to a range of about 8–9°C for temperature and over 1000 mm of precipitation are relatively rare, and only for some of the analyzed microfloras. One of the explanations for their occurrence is poor taxonomic composition of the flora and/or insufficient pollen content registered in these spectra. The wider CA-intervals occur mainly in coal-bearing sediments and probably are associated with the preservation potential of fossil palynomorphs. Thus climatic changes during the formation of the brown coal cannot be excluded as a reason for the floral changes observed.

CA-intervals for mean annual temperature most frequently range between 15.6 (15.7) and 17.1°C (Figure 7). These are both the highest and the most precise values obtained for this parameter, with the smallest width of coexistence range. Wider intervals obtained for mean annual temperatures range from 11.6–17.1°C to 18.4°C. Single cases provide lower temperatures (e.g., 13.6–15.8°C at 42.1 m) or non-specific intervals (e.g., 4.4–17.1°C at 13.05 m).

The calculated values for the mean temperature of the coldest month were mainly in a relatively narrow range of 5 to 7.5°C (Figure 7). The upper limit of this climatic parameter is constant and usually not more than 7.5°C, with the exception of coal samples and layers with coal-bearing sediments, where wider CA-intervals result. The lower limit of the winter temperatures (CMT) shows a greater variability than the upper. As mentioned above, in most cases the lower limits of the CA intervals are 5°C, but in some cases 3.8°C or 0.6–0.9°C are obtained. Exceptions, with a lower limit at –0.3°C, could be regarded as the most unusual (with the greatest width) coexistence intervals.

The most common coexistence intervals for the temperature of the warmest month range from 24.7 to 26.4°C and from 24.7 to 26.8°C, respectively (Figure 7). Wider CA-intervals were again obtained for

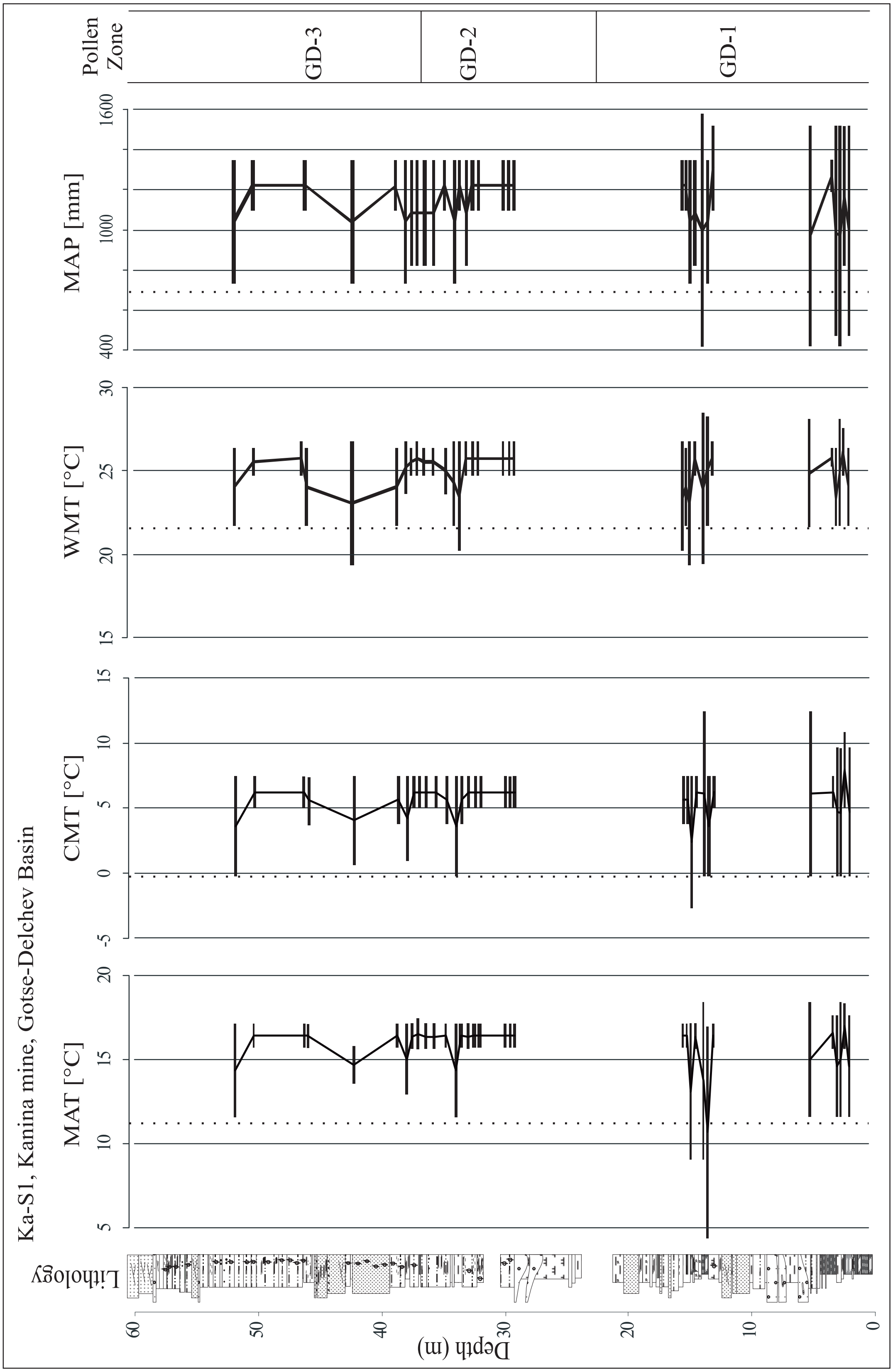

Figure 7. Dynamics of main climate parameters: mean annual temperature (MAT), temperature of the coldest month (CMT), temperature of the warmest month (WMT), mean annual precipitation (MAP). In addition to the coexistence intervals the curve linking their middle values is shown. Vertical dotted lines indicate recent values of climate parameters.

samples from the main coal seam and for the interval with organic-rich clays and brown coals (14.10–15.10 m). Quantitative data obtained for the values of summer temperatures may characteristically indicate that they show considerable variability, especially with respect to the estimated lower limit of the CA intervals. In addition to the above-mentioned values of the WMTs, intervals with lower limits at 19.3°C, 20.2°C, 21.7°C, or 23.6°C frequently occur. Such high variability of summer temperatures is rarely observed in palaeoclimatic reconstruction (e.g., Utescher *et al.* 2009). As usual, this climate parameter is one of the most constant. Probably palaeogeography and local environment was a prerequisite for specific climatic conditions in the Gotse-Delchev Basin and greater dynamics of the WMT. The curve connecting CA interval means of summer temperatures (WMT) displays cyclicity in the dynamics of temperature (Figure 7). These cycles were also observed in both the other temperature records (MAT and CMT), but are not so well expressed.

The results for mean annual precipitation recorded show significant variability. The narrowest CA-intervals for MAP range from 1096 to 1347 mm. Among wider intervals of 823–1347 mm they occur most frequently in the profile studied. Also non-specific coexistence intervals were obtained, with a width exceeding 1000 mm, for example 422–1520 mm and 471–1520 mm. These wide coexistence intervals occur in the brown coals (Figure 7).

The dynamics of the climate parameters in the profile studied show changes in climatic conditions in the region of the Gotse-Delchev Basin that are probably cyclical in nature, but they cannot be confirmed with certainty because of interruptions in the pollen record: e.g., the absence of pollen (or their scarcity) in part of the coal-bearing or sandy sediments is due to taphonomic reasons. However, the main trends in climate dynamics can be drawn with great confidence.

Data from the basal part of the profile (Figure 7: LPZ GD-1) point to the existence of a variable climate, with significant variations in temperature and precipitation. A climatic cycle is present at the depth interval from 1.55 to 2.8 m, where a change of the peat bog vegetation was observed: e.g., reconstructed climatic parameters indicate warm and humid climate conditions for depth level 1.9 m, slightly cooler and drier conditions between 2.3 and 2.5 m (decrease of the lower limits of CA intervals causing lower means of all climatic parameters studied), and a return to a warm and humid climatic phase at depth level 2.8 m. Such cyclic changes and alternations of warm and humid with cool and dry climatic phases was observed between 12.6 and 15.1 m in the section, where alternations of brown coal and clay occur. These cycles have a sediment thickness of around 1.0–1.3 m and probably were forced by precession, similar to the cycles described from a Pontian paludal to lacustrine sequence in the Staniantsi Basin, W Bulgaria (Utescher *et al.* 2009).

After these fluctuations and instability a period of warm and humid climatic conditions followed (Figure 7: LPZ GD-2), with only one deviation when the temperature decreased at 33.35–34.5 m followed by a warmer climate. Subsequent cooling of the climate, not connected to a significant decline in rainfall, was established at the beginning of LPZ GD-3 (Figure 7). The cooling is best expressed by the curve showing means of summer temperatures (WMT) and includes pollen flora in the range from 37.75 to 45.9 m. This colder period ended with the restoration of a warm and humid climate.

Conclusion

The palynological analysis carried out on brown coal and the sediments above the coal horizon exposed in the open-pit mine provides data about the composition and structure of the fossil vegetation. The ratios between main floral elements and the composition of the fossil flora are palaeoecologically analysed and discussed. The main plant palaeocommunities that existed during fossilization are characterized as follows: Mixed mesophytic forests dominated by *Carya, Fagus, Betula, Quercus,* and *Ulmus* formed the widespread zonal vegetation in the lowland and hilly areas surrounding the basin. A significant role in these forests was played species of *Magnolia, Corylopsis, Liquidambar, Eucommia, Zelkova, Ulmus, Castanopsis, Pterocarya, Juglans, Engelhardia, Platycarya, Symplocos*, Araliaceae, Vitaceae (incl. *Parthenocissus*), *Hedera, Cornus, Ilex,* Ericaceae, Theaceae, Pteridaceae, Osmundaceae, and Polypodiaceae. Vegetation components from the mid- and higher altitudes such as *Tsuga, Abies, Cathaya, Keteleeria, Picea, Cedrus,* cf. *Podocarpus* and *Juniperus* are also present. Palynological data provide evidence for the existence of a swamp vegetation with a high proportion of *Alnus* and minor percentages of Taxodiaceae (*Glyptostrobus*, *Taxodium*), Cyrillaceae, *Myrica, Planera,* Poaceae, Cyperaceae, and some ferns (*Osmunda* and Polypodiaceae/Thelipteridaceae).

Species of *Platanus, Carya, Alnus, Ulmus, Ostrya, Pterocarya, Juglans, Salix, Staphylea,* and *Liquidambar* played important roles in the riparian vegetation. The aquatic vegetation of the lake system consisted of *Butomus, Potamogeton*, *Menyanthes*, *Sparganium, Typha,* and Cyperaceae. Herbaceous palaeocoenoses had a limited distribution – herbaceous plants (Apiaceae, Lamiaceae, Poaceae, Asteroideae, Cichorioideae, Dipsaceae, *Artemisia*, and Chenopodiaceae) are well represented in all pollen spectra, but in comparatively low quantities.

The climatic data reconstructed by the Coexistence Approach indicate mean annual temperatures of ca. 15.6–17.1°C. Mean annual precipitation was commonly between 1096 and 1347 mm, but wider intervals of 823–1347 mm also occurred. The narrowest coexistence intervals for coldest month mean are 5 to 7.5°C, but in some cases the lower limit can go down to 3.8°C or even 0.6–0.9°C. Summer temperatures were between 24.7–26.4°C and 24.7–26.8°C, respectively. Especially, the curve obtained for the summer temperature means shows cyclic changes, partly also observed for other temperature parameters. The dynamics of the reconstructed data indicate that climatic changes in the late Miocene of SW Bulgaria were cyclical. However, the presence of several unconformities in the sampled section does not allow an unambiguous interpretation of these data.

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Plate 1

Fossil palynomorphs from the Gotse-Delchev Basin, Open cast mine Kanina

Figures 1–4. Polypodiaceae / Thelypteridaceae (*Laevigatosporites*)
Figures 5, 6. *Echinatisporis* sp.
Figures 7–10. *Osmunda* sp.
Figures 11–13. *Ginkgo* sp.
Figures 14, 15. *Cathaya* sp.
Figure 16. *Cedrus* sp.
Figure 17. *Pinus diploxylon* type
Figures 18, 19. *Tsuga canadensis* type
Figure 20. *Abies* sp.

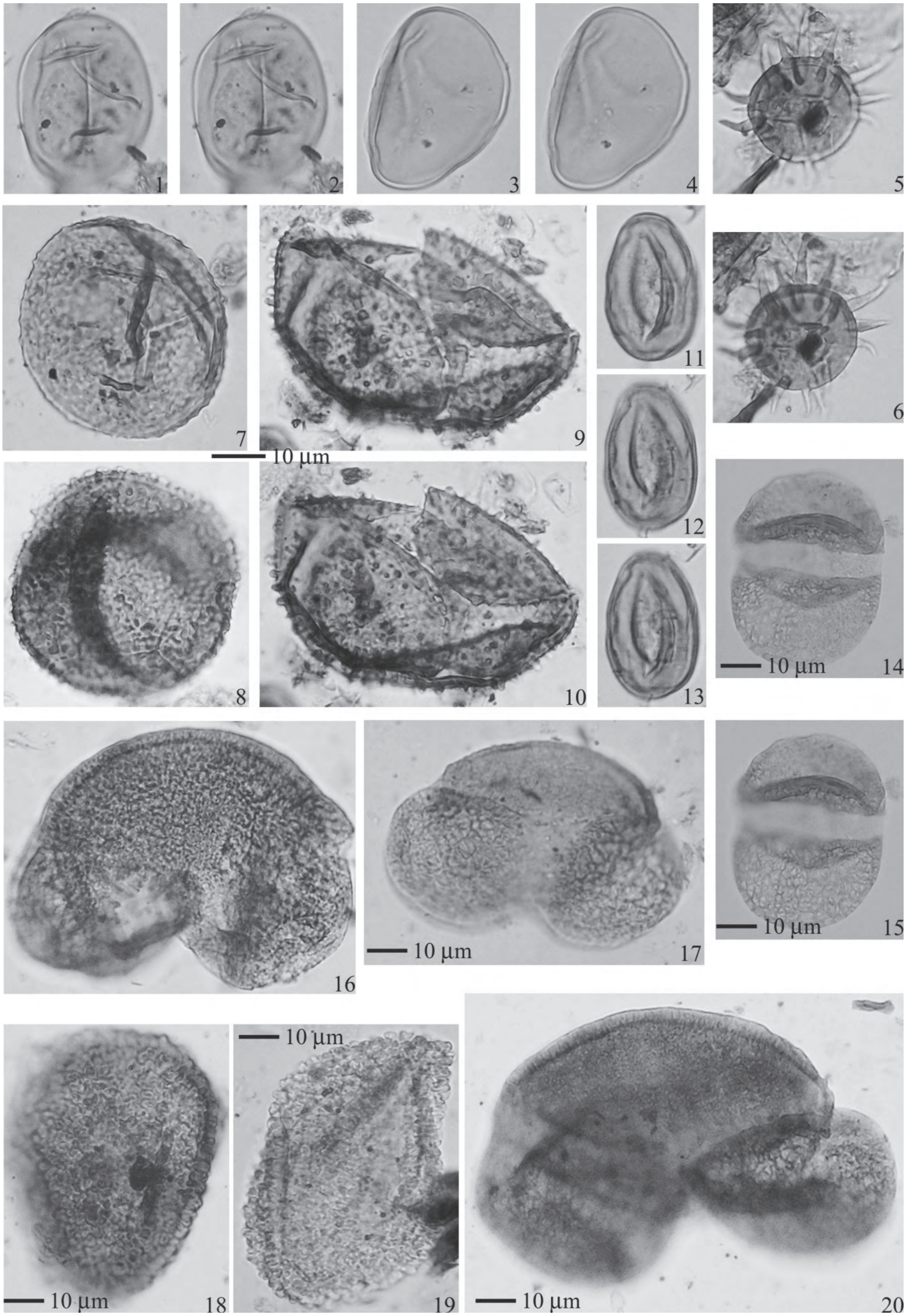
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Plate 2

Fossil palynomorphs from the Gotse-Delchev Basin, Open cast mine Kanina

Figures 1, 2. *Tsuga* cf. *heterophylla* type
Figures 3, 4. *Tsuga* sp.
Figures 5, 6. Taxodiaceae
Figures 7, 8. Taxodiaceae (*Glyptostrobus*)
Figures 9, 10. Taxodiaceae (*Taxodium*?)
Figures 11, 12. Taxodiaceae
Figures 13, 14. *Corylus* sp.
Figures 15, 16. *Carpinus betulus* type
Figures 17, 18. *Betula* sp.
Figures 19, 20. *Carpinus orientalis/Ostrya* type
Figures 21, 22. *Alnus* sp.
Figures 23, 24. *Ulmus* sp.
Figures 25, 26. *Castanea* sp. 1
Figures 27, 28. *Castanea* sp. 2
Figures 29–31. *Quercus* sp. 1
Figures 32–35. *Quercus* sp. 2
Figures 36–39. *Fagus* sp.

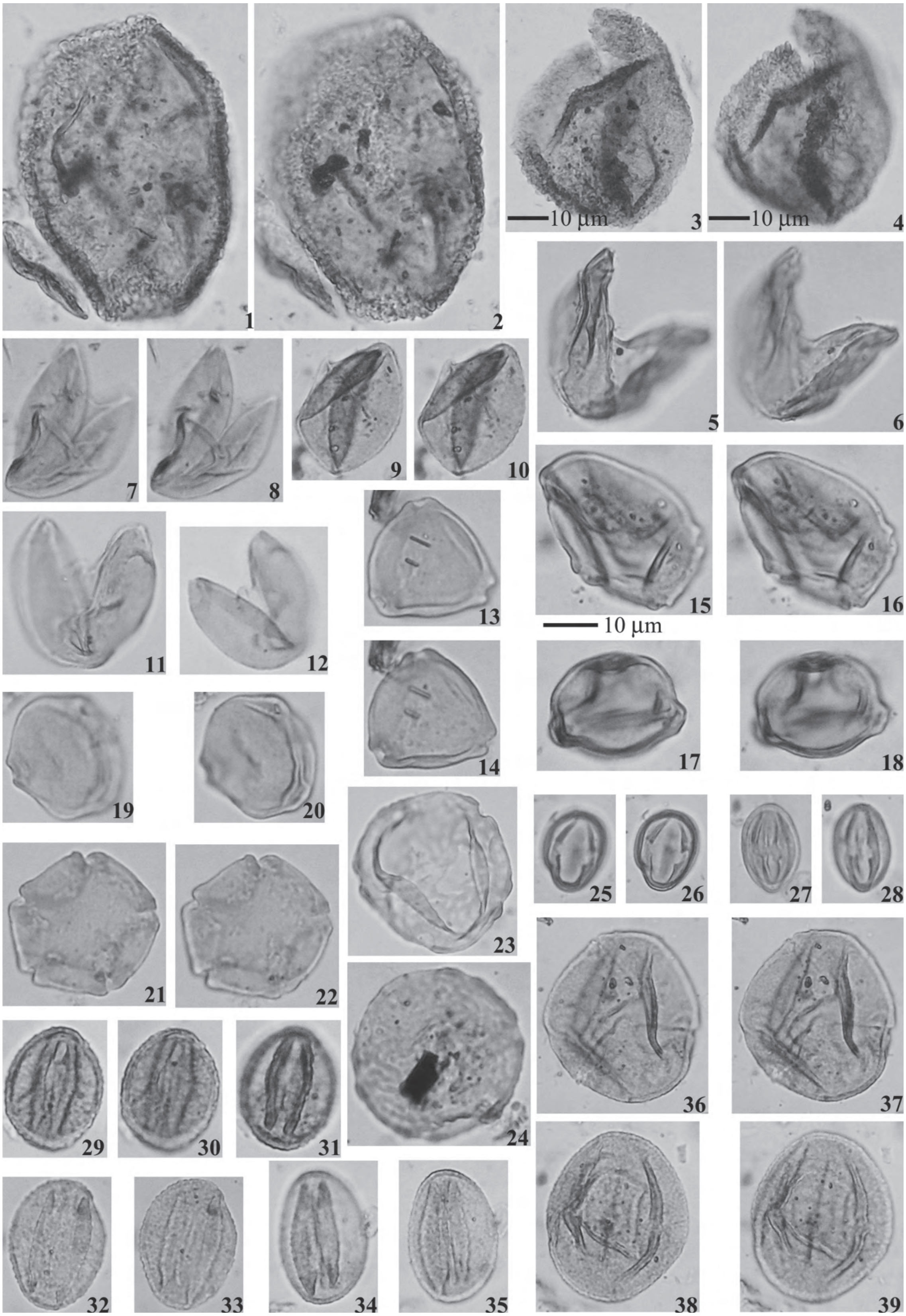
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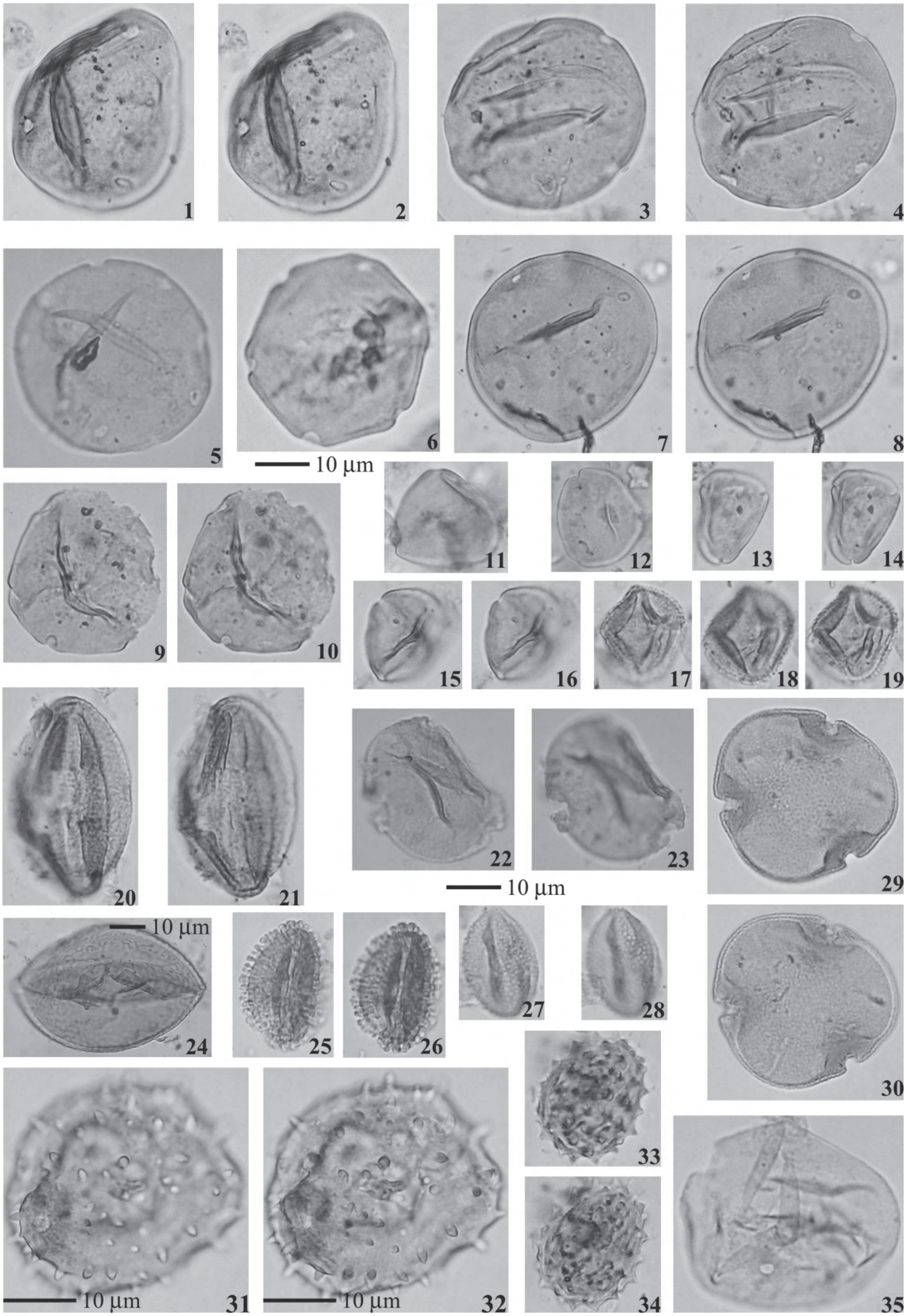
Plate 3

Fossil palynomorphs from the Gotse-Delchev Basin, Open cast mine Kanina

Figures 1–4, 7–8. *Carya* sp.
Figure 5. *Juglans* sp.
Figure 6. *Pterocarya* sp.
Figures 9, 10. *Pterocarya* sp. – corroded pollen grain
Figures 11–14. *Engelhardia* sp.
Figures 15, 16. cf. *Platycarya*
Figures 17–19. Caprifoliaceae
Figures 20, 21. *Staphylea* sp.
Figures 22, 23. *Symplocos* sp.
Figure 24. *Spirogira* sp.
Figures 25, 26. *Ilex* sp.
Figures 27, 28. *Salix* sp.
Figures 29, 30. *Tilia* sp.
Figures 31, 32. Nymphaeaceae (cf. *Nuphar*)
Figures 33, 34. Asteroideae
Figures 35. Poaceae (Bambusoideae).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