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BADENIAN (LANGHIAN – EARLY SERRAVALLIAN) PALYNOFLORA FROM THE CARPATHIAN FOREDEEP AND VIENNA BASIN (CZECH AND SLOVAK REPUBLICS)

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Abstract. The Badenian (Langhian - Early Serravallian) marine sediments from the adjacent areas within the Central Paratethys and NE part of the Vienna Basin, were studied from a palynological perspective. The pollen data document a subtropical climate during the Miocene Climatic Optimum with dominant representation of zonal vegetation being evergreen broadleaved forests. Higher differentiation of oak type pollen, increasing number of *Platanus* pollen and different types of herb were observed.
Some thermophilous elements (especially Sapotaceae, Palmae, Mastixiaceae and Lygodiaceae) decreased and there was an increase of the warm to cold temperate zone taxa which were first registered during the Late Badenian. These findings together with a higher proportion of extrazonal vegetation (*Tsuga*, *Picea* and *Abies*) in the Late Badenian pollen spectra document changes due to the uplift of the Carpathian Mountain chain.

■ Palynology, Badenian, Langhian, Early Serravallian, Carpathian Foredeep, Vienna Basin

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Introduction

The adjacent areas within the Central Paratethys in the Czech and Slovak republics, the Carpathian Foredeep and Vienna Basin, were studied from a palynological perspective. The Lower Badenian (early Langhian) transgressions from the Mediterranean toward the Central Paratethys realm flooded the Pannonian Basin and continued along straits in the Carpathian Chain into the Carpathian Foredeep. During the Lower Badenian, in addition to the shallow partial basins, depressions of unstratified calcareaous clay developed which were more than a hundred metres deep – "tegels" (Brzobohatý 1982, 1997; Chlupáč et al. 2002). The isolation of eastern parts of the Central Paratethys at the end of this period (Late Langhian) resulted in the "Middle Badenian" salinity crisis. Thick evaporite sediments were deposited in the Carpathian Foredeep. During the Upper Badenian (Early Serravallian), the most recent total marine flooding covered the whole back-arc basin and a great part of the foredeep (Kováč et al. 2007). The globally observed Middle Miocene Climatic Optimum is, according to Böhme (2003) and Utescher et al. (2000), clearly reflected in the studied Badenian material. Mountain chain uplift and strong relief development is documented by the origin of river drainage feeding into the huge deltaic systems of the back arc basin (Kováč 2000; Konečný et al. 2002).

The lowermost Badenian strata, which can be recognized almost everywhere in the Central Paratethys realm, contain planktonic foraminiferal assemblages in which the genus *Praeorbulina* is associated with the genus *Orbulina* in the calcareous nannoplankton Sphenolithus heteromorphus Zone NN5 (Berggren et al. 1995; Fornaciari, Rio 1996). The time span of the Late Badenian is approximately coeval to the upper part of the MN7 Globorotalia peripheroacuta Lineage Zone of Berggren et al. (1995) and the lower part of the Discoaster exilis Zone NN6 (Martini 1971).

Material and methods

In total 64 Lower Badenian and 39 Upper Badenian samples of marine clays were studied palynologically.

The Lower Badenian samples came from the boreholes Ivaň, Rebešovice, Chrlice, Opatovice, Otmarov, Přemyslovice and outcrops Brno-Královo Pole, Moravské Knínice and Sivice, situated in the southern part of the Carpathian Foredeep and from the three regional stratotype localities Oslavany (OV-1), Židlochovice (Ž–1) and (Ž–2). The Late Badenian sediments came from the boreholes Gajary 23, Sekule 1, Jakubov 54, Zohor 1, Lozorno and outcrop at the faciostratotype locality Devínska Nová Ves situated in the Vienna Basin.

Standard maceration with HCl (20%), HF, KOH and HCl (10%) was carried out. Due to the increasing number of palynomorphs, heavy liquid ($ZnCl_2$) with a density of $2g/cm^3$ was utilised. Pure glycerine or glycerine gelatine were most frequently used as the observation media.

The percentage of the individual taxa were calculated from the total sum of a minimum 150 determined pollen grains and spores.

The palaeotropical and arctotertiary elements are classified based on the Neogene pollen flora of Central Europe (Stuchlik et al.1994). The vegetation units terminology was used according to Kvaček et al. (2006) and Kovar-Eder et al. (2008).

To resolve the situation with problematic taxa identification, *Quercus*, *Platanus,* selected herbs, *Castanea* x *Castanopsis,* a recent *Castanea* pollen material has been studied under SEM. These observations and photos were done using Scanning Electron Microscope JEOL JSM – 649 OLV at the Institute of Geological Sciences, Masaryk University in Brno.

Vegetation

The Lower Badenian palynospectra were rich in Dinoflagellata and foraminiferal linings (Pl. 1, figs 1-3). Sporadic occurrences of *Botryococcus* (Pl. 1, fig. 4) and pollen of aquatic coastal plants *Sparganium*, *Potamogeton* and *Utricularia* (Pl. 2, fig. 25) indicated a fresh water influence on some facies.

The proportion of zonal vegetation with evergreen broadleaved forests (Sapotaceae, *Engelhardia*, *Platycarya*, evergreen Fagaceae – *Castanopsis, Trigonobalanopsis*, morphotypes *Tricolporopollenites henrici*, *T. microhenrici*, *T. liblarensis*, *Reevesia*, *Cornus-Mastixia*, Rutaceae and Araliaceae and Pteridaceae) represents up to 30% of the pollen spectra (Pl. 2). In the Miocene time interval, the thermophilous morphotaxa *Gothanipollenites gothani* and *Clerodendrumpollenites microechinatus* were first found in Lower Badenian sediments of the studied area.

The broad-leaved deciduous elements of warm – temperate mixed mesophytic forests such as *Quercus*, *Castanea*, *Carya*, *Celtis*, *Juglans, Tilia*, *Zelkova*, *Ostrya*, *Carpinus, Betula* and *Cercidiphyllum* generally did not exceed 10%. A higher diversity of "oak type" pollen grains, e.g. *Quercus robur-pubecscens,* were recorded in the pollen spectra (Pl. 2, figs 6-10, Pl. 4, figs 7-12). *Cercidiphyllum* and *Castanea/Castanopsis* were identified from the Lower Badenian pollen spectra (Pl. 2, fig. 15; Pl. 3, figs 1-15).

The azonal vegetation was represented by riparian forests with *Ulmus*, *Alnus*, *Fraxinus, Liquidambar*, *Salix* and Lythraceae and the coastal swamps by *Nyssa, Sciadopitys,* Taxodiaceae, Cyrillaceae and Myricaceae. Pollen grains of *Platanus ipelensis* sensu Pacltová (1984) were abundantly present for the first time in the Lower Badenian taphocenoses (Pl. 2, figs 11-14, Pl. 4, figs 10-12). In the pollen spectra herbs and heliophilous elements Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae, Ericaceae and *Ephedra* were regularly present, less frequent were *Urtica, Plantago, Salvinia* and *Lavandula* (Pl. 2). There were noticeable polyporate pollen grains with microechinate perforate sculptures visible under SEM, they were determined as Caryophyllaceae cf. *Saponaria* (Pl. 4, figs 1-3), or without perforations – *Thalictrum* type (Pl. 4, figs 4-6).

An extremely high proportion (more than 60%) of Pinaceae pollen was present in some samples (Pl. 1). From the borehole Oslavany and the uppermost parts of boreholes Židlochovice 1, practically only Pinaceae and dinoflagellates were found. This could be due to taphonomical and ecological reasons (long air-transport range and therefore accumulation in marine sediments distant from the seashore).

In comparison with the Lower Miocene spectra, portion of the thermophilous elements P1 sensu Stuchlik et al. (1994), *Symplocos*, Sapotaceae, Palmae, Mastixiaceae and Lygodiaceae started to decrease since the Badenian (Doláková, Slamková 2003; Doláková et al. 1999). An increased proportion of the arctotertiary taxa (*Quercus, Ulmus* and *Carya*) were noted in the Upper Badenian palynospectra from the Vienna Basin. Thermophilous elements (*Platycarya, Engelhardia, Myrica, Distylium* and thermophilous Fagaceae) were still present, but Sapotaceae had disappeared. Herbs were represented predominantly by the halophytic taxa – mainly Chenopodiaceae. The higher proportions (up to 30%) of extrazonal (mountain) vegetation in the pollen spectra (*Picea, Abies, Tsuga, Cedrus*) were first recorded from the Upper Badenian. The main reason of this phenomenon is the uplift of the Carpathian Mountain chain and subsidence of adjacent lowlands.

Discussion

Lower Badenian macrofloristic remains from the Carpathian Foredeep are rare. Only in the Lower Badenian marine sandstones at Smolín near Pohořelice, Knobloch (1963, 1968) and Knobloch et al. (1975), described poorly preserved Lauraceae leaves *Daphnogene bilinica*, and Betulaceae leaves. The macrofloristic taphocenoses from the vicinity of Česká Třebová were described by Knobloch (1968); Knobloch et al. (1975) as an association totally dominated by arctotertiary elements (prevailing being *Myrica lignitum*, *Alnus* cf. *feroniae*, *Pinus, Salix, Populus, Fagus, Pterocarya, Parrotia, Ulmus* and *Fraxinus*).

Equally previously published palynological results from the Lower Badenian sediments of the Carpathian Foredeep (Basistová, 2009; Bruch et al. 2004; Hladilová et al. 1999, 2001) our results indicate a more thermophilous – subtropical character of the climate.

Macrofloristic findings from the Upper Badenian were described at the localities Opava – Kateřinky, and borehole Smolkov near Opava (Knobloch 1968). An absence of laurophylous leaves was observed and a generally warm – temperate character of the paleoclimate equaly to sediments with Lower Badenian floras.

In the Upper Badenian pollen spectra from boreholes OS-1 Kravaře and OS-2 Hať in the vicinity of Opava, the arctotertiary elements (with a high proportion of Pinaceae, partly mountain vegetation) dominated and thermophilous taxa were represented only by *Engelhardia* and Lygodiaceae (Cicha et al. 1985).

Planderová and Gabrielová (1975) noticed a decrease in the most thermophilous elements (Sapotaceae, *Symplocos*, Palmae, Mastixiaceae and Lygodiaceae) in the Lower Badenian pollen spectra in comparison with Early Miocene spectra. Based on this data they interpreted a subtropical climate with humidity oscillations during the Badenian time interval. Based on the Upper Badenian pollen spectra Planderová (1990) interpreted a drier and colder climate in comparison with the Lower Badenian time span. In comparison with the Karpatian pollen spectra, the proportion of herbs and heliophillous elements in Badenian material is higher (Doláková and Slamková 2003).

Holcová et al. (1996) observed up to 30% thermophilous taxa in the Lower Badenian pollen spectra from the borehole N-95 in Strháry-Trenč graben from the South Slovakia basin.

Based on many palynological studies, Oszast and Stuchlik (1977), Łancucka-Srodoniowa (1966) and Dyjor and Sadowska (1984) observed some differences between Badenian floras from the Lowlands in Southern Poland (more subtropical and warm – temperate) and from the mountain regions (2-3 altitudinal zones with warm-temperate mixed forests and with coniferous forests in the upper parts).

Planderová et al. (1993a,b) noted a lack of paleotropical elements of the P1 group in the Lower Badenian in the northern part of the Paratethys area. In the Upper Badenian they observed these elements only in the southern Paratethys area (Hungary and former Yugoslavia). Based on the flora of Parschlung (Karpatian/Early Badenian) Kovar-Eder et al. (2004) indicated a drier warm-temperate climate with relatively rare subtropical humid elements, while subhumid sclerophyllous woody taxa were well represented.

Kováč et al. (2008) and Kvaček et al. (2006) previously published palynological studies of Badenian sediments. In comparison with these data it is evident that even though the Badenian climate was generally subtropical, the proportion of key termophilous taxa rapidly decreased in the Upper Badenian.

Conclusions

Pollen flora from the Lower Badenian sediments indicated the presence of evergreen broadleaved forests, constituting up to 30% of the pollen spectra. In comparison with the Lower Miocene time span the proportion of thermophilous elements, Sapotaceae, *Symplocos*, Palmae, Mastixiaceae and Lygodiaceae, decreased in the Badenian pollen spectra. A greater differentiation of "oak type" pollen and a higher amount of *Platanus* pollen were recorded in the studied samples which corresponds with the results of Knobloch and Kvaček (1996).

Herbs and heliophilous vegetation started to be more frequent than in Lower Miocene floras.

In comparison with macrofloristic findings, the pollen grains indicate that the Lower Badenian floras had a more thermophilous character. Due to the need for more detailed analyses and correlation, this study will continue on a larger scale and Badenian sediments from Hungary, Slovenia, and Austria will be analysed in the future.

Initiation of altitudinal zonation (Kováč et al. 1998, Kováčová et al. in press) is documented by an increase of mountain elements and arctotertiary taxa (*Quercus, Ulmus* and *Carya*), a decrease of thermophilous elements (*Platycarya, Engelhardia, Myrica, Distylium* and thermophilous Fagaceae), and the disappearance of Sapotaceae in the palynospectra during the Upper Badenian.

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Explanation of the plates

PLATE 1

1. Foraminiferal tapetum, Židlochovice 1 (2.3 m).
2. Marine dinoflagellates, Židlochovice 2 (8.9 m).
3. Marine dinoflagellates: a – LM, b – SEM, Židlochovice 1 (11.1 m).
4. *Botryococcus* sp., Židlochovice 1 (7 m).
5. *Cathayapollis potoniei* (Sivak) Ziembińska-Tworzydło, Židlochovice 1 (7 m).
6. *Cedripites miocaenicus* Krutzsch, Židlochovice 1 (8,5 m).
7. *Cathayapollis* sp., SEM, a – whole pollen grain, b – detail, Židlochovice 1 (11.1 m).

PLATE 2

1. Sapotaceae: *Sapotaceoipollenites sapotoides* (Pflug et Thomson) Potonié; Moravské Knínice.
2. Mastixioideae: *Cornaceaepollis satzvayensis* (Pflug) Ziembińska-Tworzydło, Židlochovice 1 (10.9 m).
3. *Quercoidites henrici* (Potonié) Potonié, Thomson et Thiergart, Ivaň (43.75 m).
4. *Platycaryapollenites miocaenicus* Nagy, Židlochovice 1 (10.9 m).
5. *Hedera* type: *Araliaceoipollenites reticuloides* Thiele-Pfeifer; Židlochovice 1 (9.7 m).

6.–10. *Quercus robur-pubescens* type: *Quercoidites granulatus* (Nagy) Slodkowska; 6,7 – Židlochovice (excavation); 8 – Židlochovice 1 (10.3 m); 9,10 – Moravské Knínice.

11.–14. *Platanus* sp.: *Platanipollis ipelensis* (Pacltová) Grabowska; 11,12 – Židlochovice 1 (10.3 m); 13 – Židlochovice 1 (11.1 m).

15. *Cercidiphyllum* sp.: *Cercidiphyllites minimireticulatus* (Trevisan) Ziembińska-Tworzydło, Židlochovice 1 (10.9 m).
16. *Urtica* sp.: *Triporopollenites urticoides* Nagy, Židlochovice 2 (16 m).
17. *Plantago* sp.: *Plantaginacearumpollenites miocaenicus* Nagy, Židlochovice 1 (10.3 m).
18. *Lavandula* sp.: a,b, Židlochovice 1 (0.9 m).
19. *Salvia verticillata* type; Židlochovice 1 (9.7 m).

20.–23. Caryophyllaceae gen. indet.: *Caryophyllidites microreticulatus* Nagy, 20 – Židlochovice 1 (10.9 m); 21, 22 – Židlochovice 1 (7 m); 23 – Židlochovice 1 (10.3 m).

24. *Galium* type, Židlochovice 1 (9.7 m).
25. *Utricularia* sp.; Židlochovice 1 (9.7 m).
26. Asteraceae: *Tubulifloridites macroechinatus* (Trevisan) Nagy, Ivaň (16.2 m).
27. Asteraceae: *Cichoreacidites gracilis* Nagy, Ivaň 43.7 m).

PLATE 3

1.–9. *Castanea* sp. – recent pollen, 1–6 LM; 7–9 SEM.

10.–12. *Castanea* sp.: *Tricolporopollenites cingulum* (Potonié) *oviformis* Thomson et Pflug – form A, Židlochovice1 (11.1 m), 10 – LM; 11–12 – SEM.

13.–15. *Castanopsis* sp.: *Tricolporopollenites cingulum* (Potonié) *oviformis* Thomson et Pflug – form B, Židlochovice 1 (11.1 m), 13 LM; 14–15 SEM.

16.–18. ?Fagaceae: *Tricolporopollenites liblarensis* (Thomson) Grabowska, Židlochovice 1 (11.1 m), 16 – LM; 17–18 – SEM.

PLATE 4

1.–3. Caryophyllaceae: cf. *Saponaria* sp., Židlochovice 1 (11.1 m), 1 – LM; 2–3 – SEM.

4. –6. cf. *Thalictrum* sp., Židlochovice 1 (11.1 m), 4 – LM; 5–6 SEM.

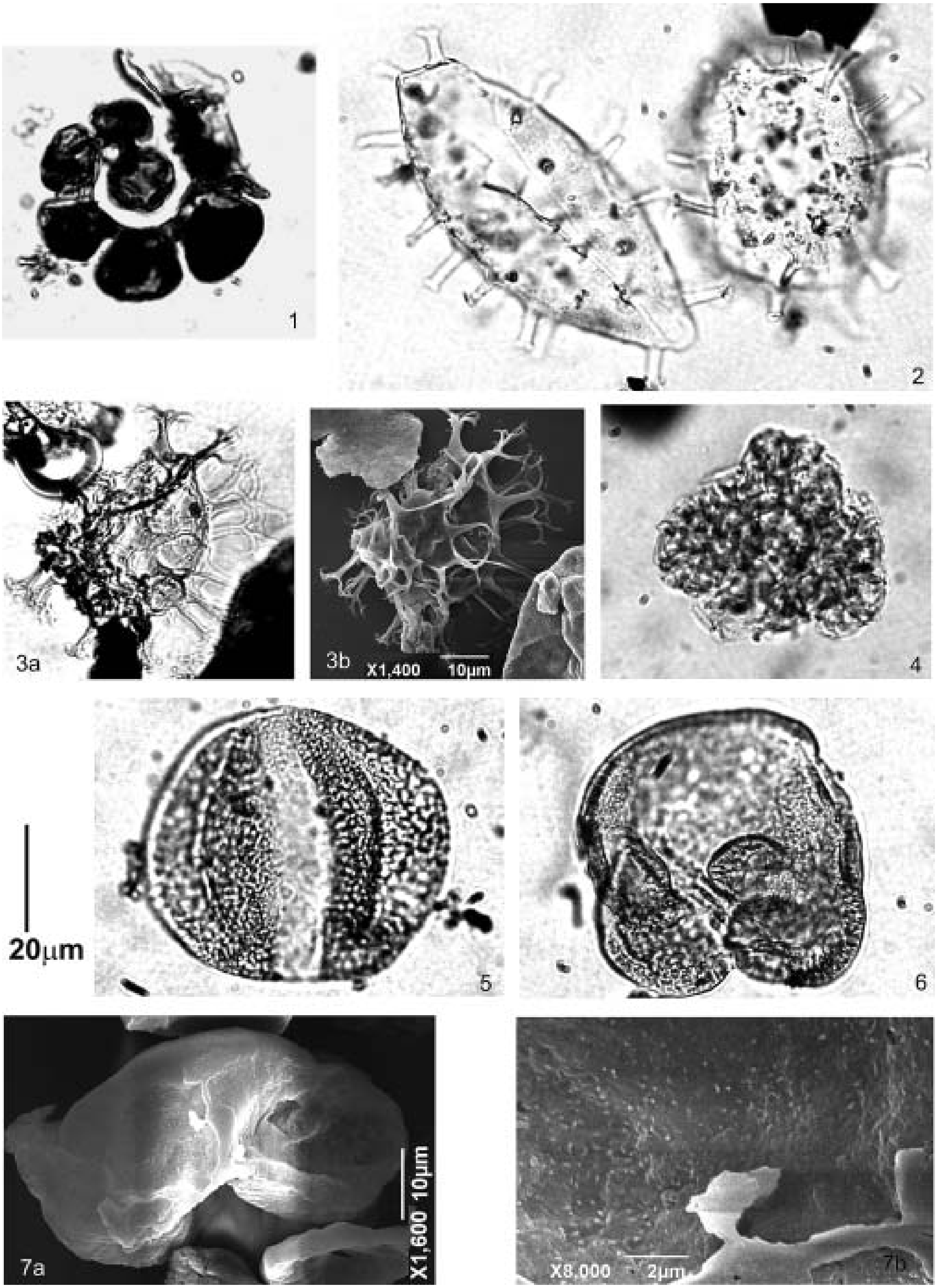
7. –9. *Quercus* sp., Židlochovice 1 (11.1 m), 7 – LM; 8–9 SEM.

10.–12. *Quercus* sp., Židlochovice 1 (11.1 m), 10 – LM; 11–12 SEM.

13.–15. *Platanus* sp.: *Platanipollis ipelensis* (Pacltová) Grabowska, Židlochovice (11.1 m), 13 – LM; 14–15 – SEM.

LM – light microscope
SEM – scanning electron microscope
Magnification of all photographs is indicated directly in figures.

PLATE 1



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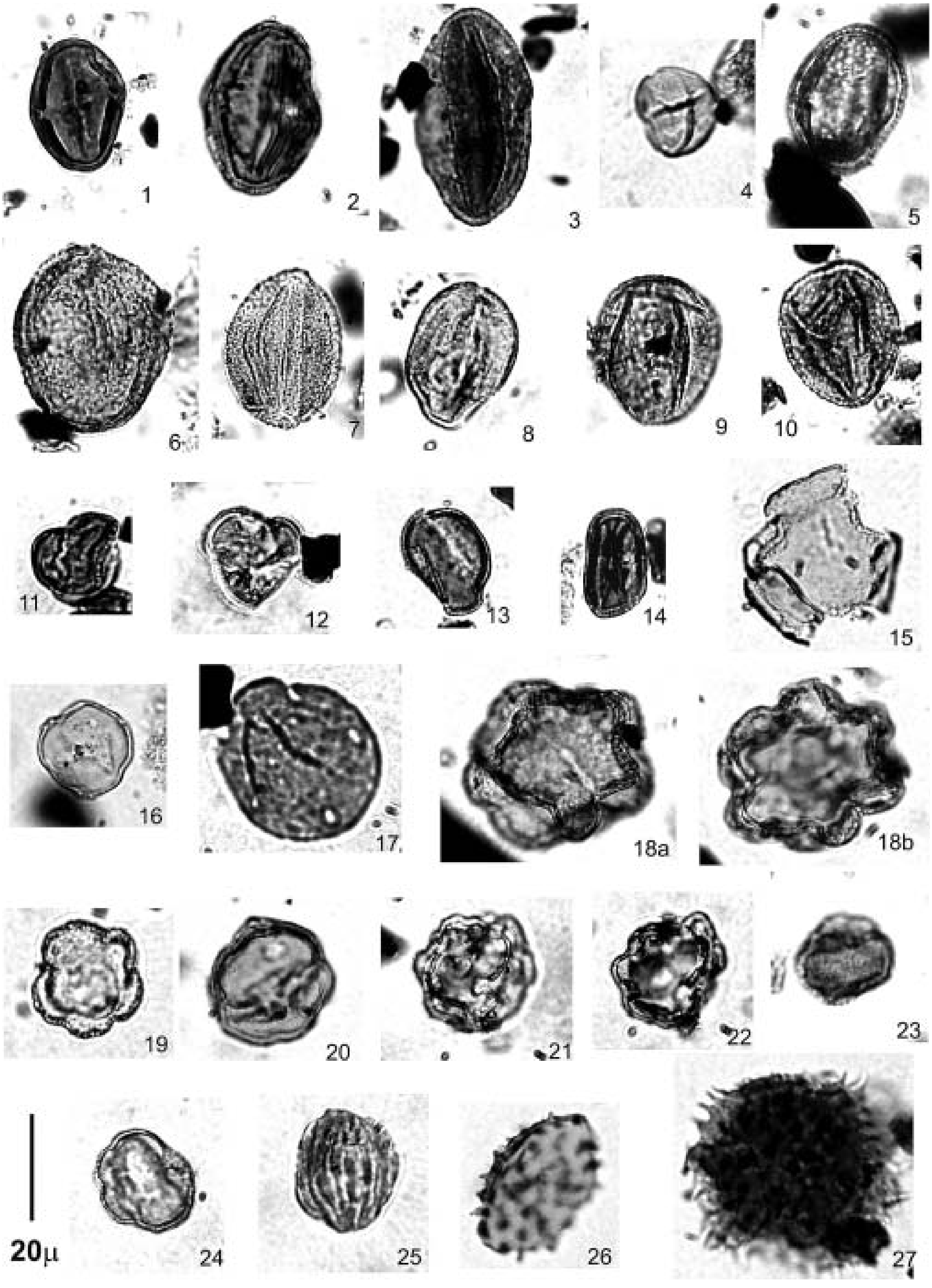
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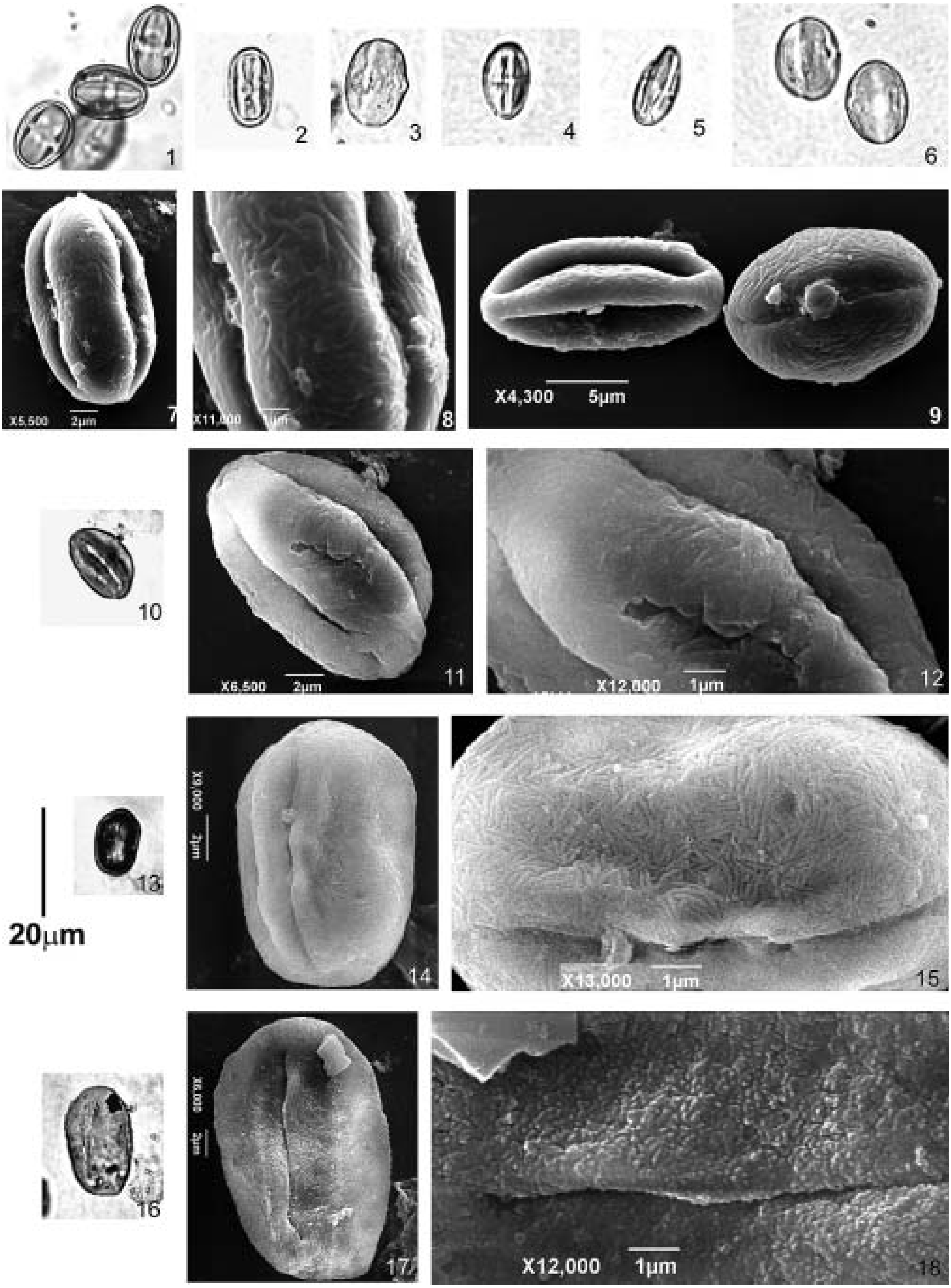
PLATE 3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5
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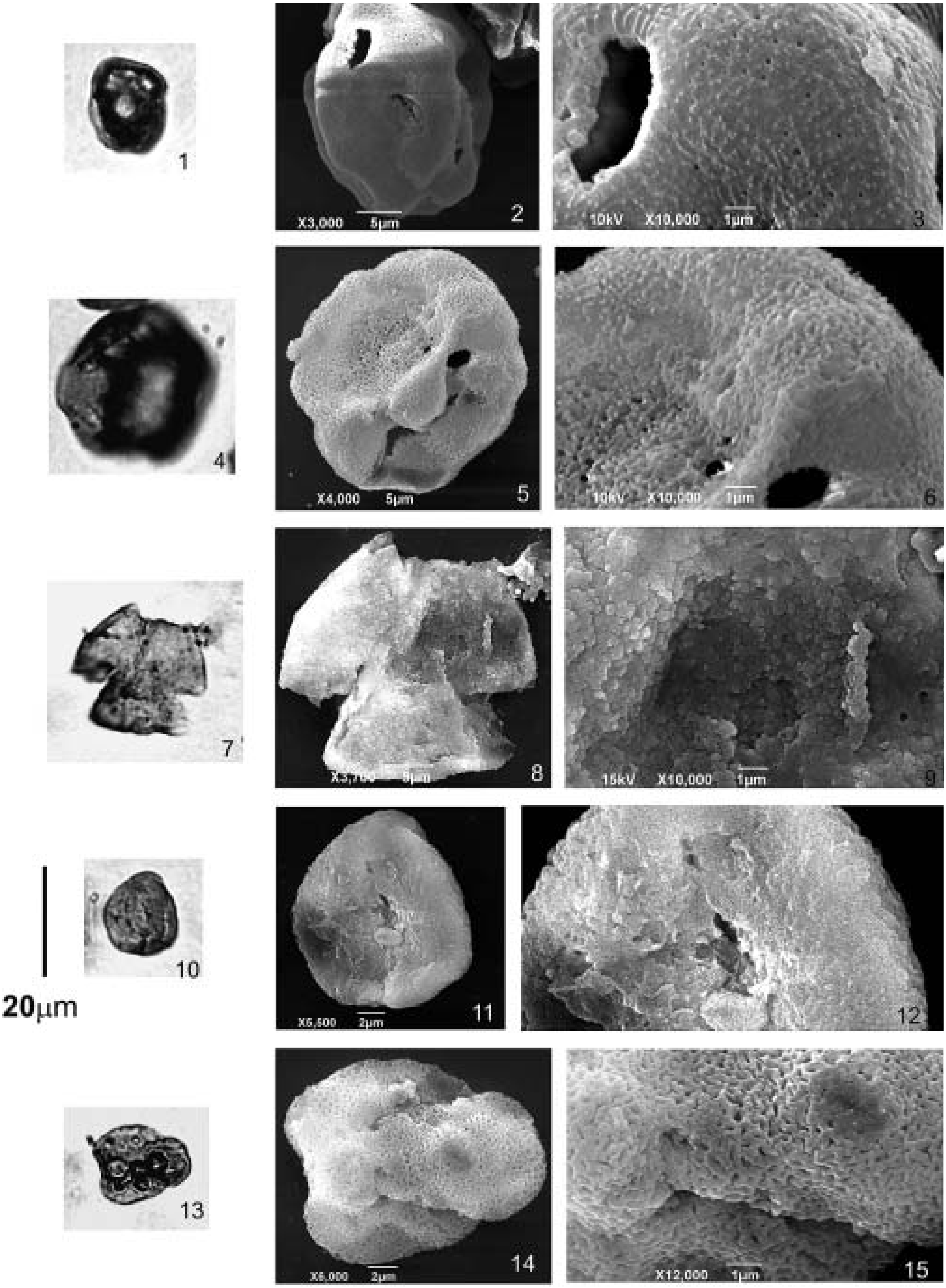
X5,500 2μm 7
X11,000 1μm 8
X4,300 5μm 9
10
X6,500 2μm 11
X12,000 1μm 12
13
20μm
X9,000 3μm 14
X13,000 1μm 15
16
X8,000 3μm 17
X12,000 1μm 18

PLATE 4



1
X3,000 5µm
2
10kV X10,000 1µm
3
4
X4,000 5µm
5
10kV X10,000 1µm
6
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8
15kV X10,000 1µm
9
10
20µm
X5,500 2µm
11
12
13
X6,000 2µm
14
X12,000 1µm
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