

Significant Palynomorphs from the Thanetian Kroisbach-Member in Salzburg (Eastern Alps, Austria)

ILSE DRAXLER^{*)}

2 Text-Figure, 1 Table, 5 Plates

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Wichtige Palynomorphe aus dem Kroisbach-Member (Thanetium) in Salzburg (Ostalpen, Österreich)

Zusammenfassung

Im Areal des paläogenen Haunsberg-Helvetikums (Salzburg) wurden im lithostratigrafischen Typusprofil des Kroisbachgrabens in den glaukonitischen Sanden der Kroisbach-Subformation (Thanetium, kalkige Nannoplanktonzone NP8) marine und terrestrische Palynomorphe lichtmikroskopisch und rasterelektronenmikroskopisch untersucht. Die Mikroflora, die im marinen Milieu abgelagert wurde, enthält vor allem Moos- und Farnsporen, Koniferen- und Angiospermenpollen und Dinoflagellaten. 57 Arten von Pollen und Sporen wurden bisher nachgewiesen, 38 konnten botanisch bestimmt werden. Soweit Pollen und Sporen modernen Pflanzenfamilien und Gattungen zuordenbar waren (Taxodiaceae, Anacardiaceae, Fagaceae, Sterculiaceae, Bombacaceae, Icacinaceae, Sapotaceae, Caesalpiniaceae, Schizeaceae) kann auf ein warmes subtropisches/tropisches Klima mit entsprechender Vegetation verschiedener Standorte geschlossen werden.

Abstract

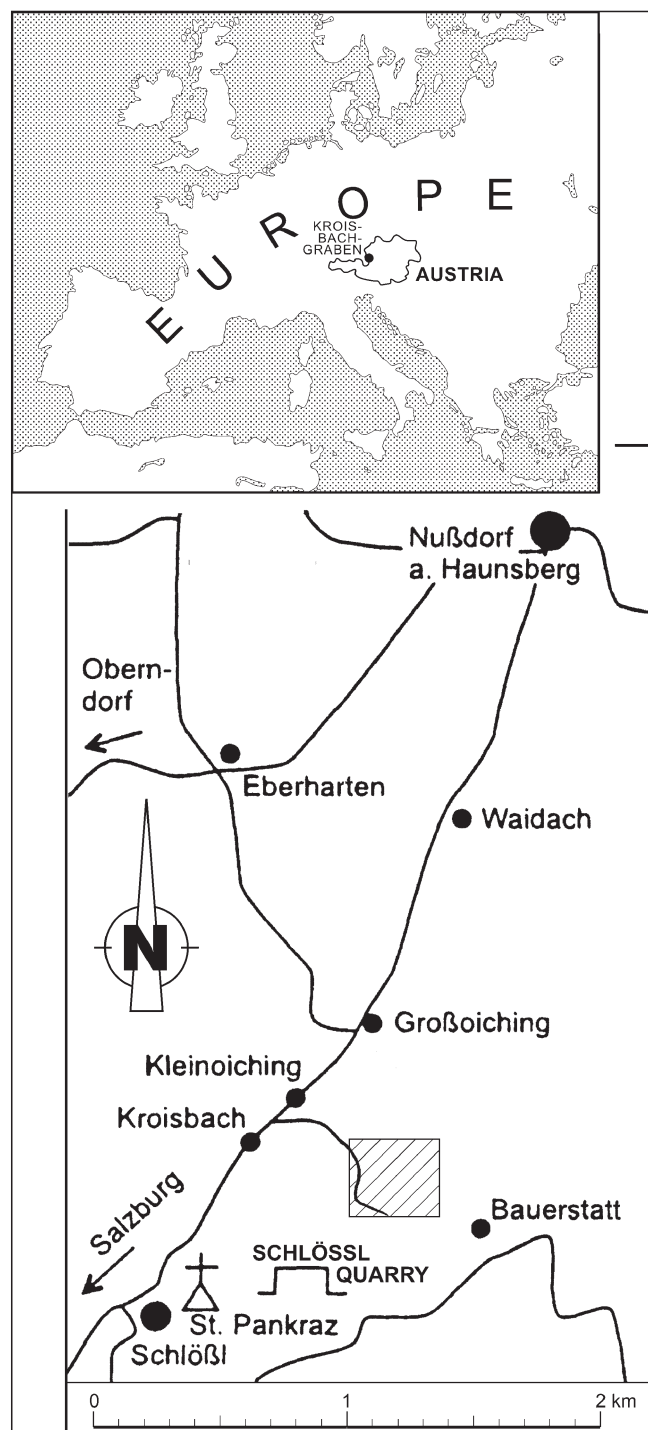
Marine and terrestrial palynomorphs have been studied with light microscope and scanning electronic microscope from the type-locality of the glauconitic Kroisbach Member (Thanetian calcareous nannoplankton Zone NP8) in the area of the paleogene Haunsberg-Helvetic zone (Salzburg). The microfloral assemblage in the marine sediments consists of mosses, ferns, conifers, angiosperms and dinoflagellates. The pollen assemblage is dominated by angiosperms, juglandaceous/myricaceous triporates, tricolporates and normapollen. 57 species of pollen and spores were found up to now in the samples and 38 could be assigned to modern taxa. As far as the pollen and spores could be affiliated to modern plant families (Taxodiaceae, Juglandaceae, Anacardiaceae, Aquifoliaceae, Fagaceae, Sterculiaceae/-Bombacaceae, Icacinaceae, Sapotaceae, Caesalpiniaceae, Schizeaceae) the assemblage indicates warm-subtropical to tropical climate with the corresponding vegetation from different biohabitats.

^{*)} Dr. ILSE DRAXLER, Geologische Bundesanstalt, Neulinggasse 38, 1030 Wien.
ilse.draxler@geologie.ac.at

1. Introduction

Detailed sedimentological and paleontological investigations of the Southern Helvetic Zone have been carried out previously by TRAUB since 1938 (TRAUB, 1990 – historical review), GOHRBANDT (1963), VOGELTANZ (1970, 1972), TICHY (1980), KUHN & WEIDICH (1987), MOOSLEITNER (1988), MERBELLER (1988), KUHN (1992) and SCHULTZ (1998).

The shallow marine deposits of the Kroisbachgraben-section close to Salzburg (Text-Figs. 1 and 2) were deposited on the southern shelf of the European plate at a paleolatitude of about 35° N (SMITH et al., 1994). The depo-



Text-Fig. 1. Sketches of the geographical position of the sampling locality Kroisbachgraben N of the town of Salzburg, Austria. Modified after RASSER & PILLER (1999).

sitional environment was part of the littoral zone (KUHN 1992). The lithostratigraphic subdivision of the sampled section has now been well defined by RASSER & PILLER (1999, 2001).

The section consists of 66 m of silty marls and claystones (Oiching Formation) and the carbonate dominated Kressenberg Formation. At the base of this formation two meters of glauconitic sandstone occur (Kroisbach Member), which contain abundant oyster shells ("Grypheenbank"). Calcareous nannoplankton of this member (STRADNER in GOHRBANDT, 1963) indicate a Thanetian age (*Heliolithus riedelii* zone – NP8 in the classification of MARTINI, 1971). In this paper a diverse microflora from the Kroisbach Member is described and its paleoclimatic significance is discussed.

The first description of the spore-pollen composition of Lower Thanetian sediments in Kleinoiching (Salzburg) was given by KEDVES 1970, 1980.

2. Material and Method

The lithostratigraphic type section Kroisbachgraben was described in detail by RASSER & PILLER (1999, 2001). 16 Samples were taken in the outcrop of Kroisbachgraben (Text-Fig. 1) from the base upward in the clayey marl and the greenish glauconitic sand (Fig. 2). The samples were treated by a standard method with HCl and HF, subsequent acetolyses and by sieving with a 7µm nylon gauze to retain the palynomorphs. The species were studied by light microscope and scanning electron microscope according to the combined method of ZETTER (1989). The grains were picked out with a hair on a needle under the LM, identified, photographed and transferred to a stub for further investigation with the SEM. This technique is necessary for a more detailed study of the morphological features and the mainly botanically based identification for the paleoclimatic interpretation. The most characteristic pollen and spores are illustrated and described.

The palynofacies of the clayey marl is dominated by brown and black wood and kerogen particles and a moderate abundance and diversity of pollen, spores and dinoflagellates. The glauconitic sandy sediments of the Kroisbach Member are richer in three dimensional pollen and spores. They are partly well preserved and could be studied in detail. Three samples of the „Kroisbach Member“ were used for this investigation (Text-Fig. 2). The reason for pollen preservation in the rather coarse sediment is perhaps the low oxygen environment existing during glauconitisation (RASSER & PILLER, 2001).

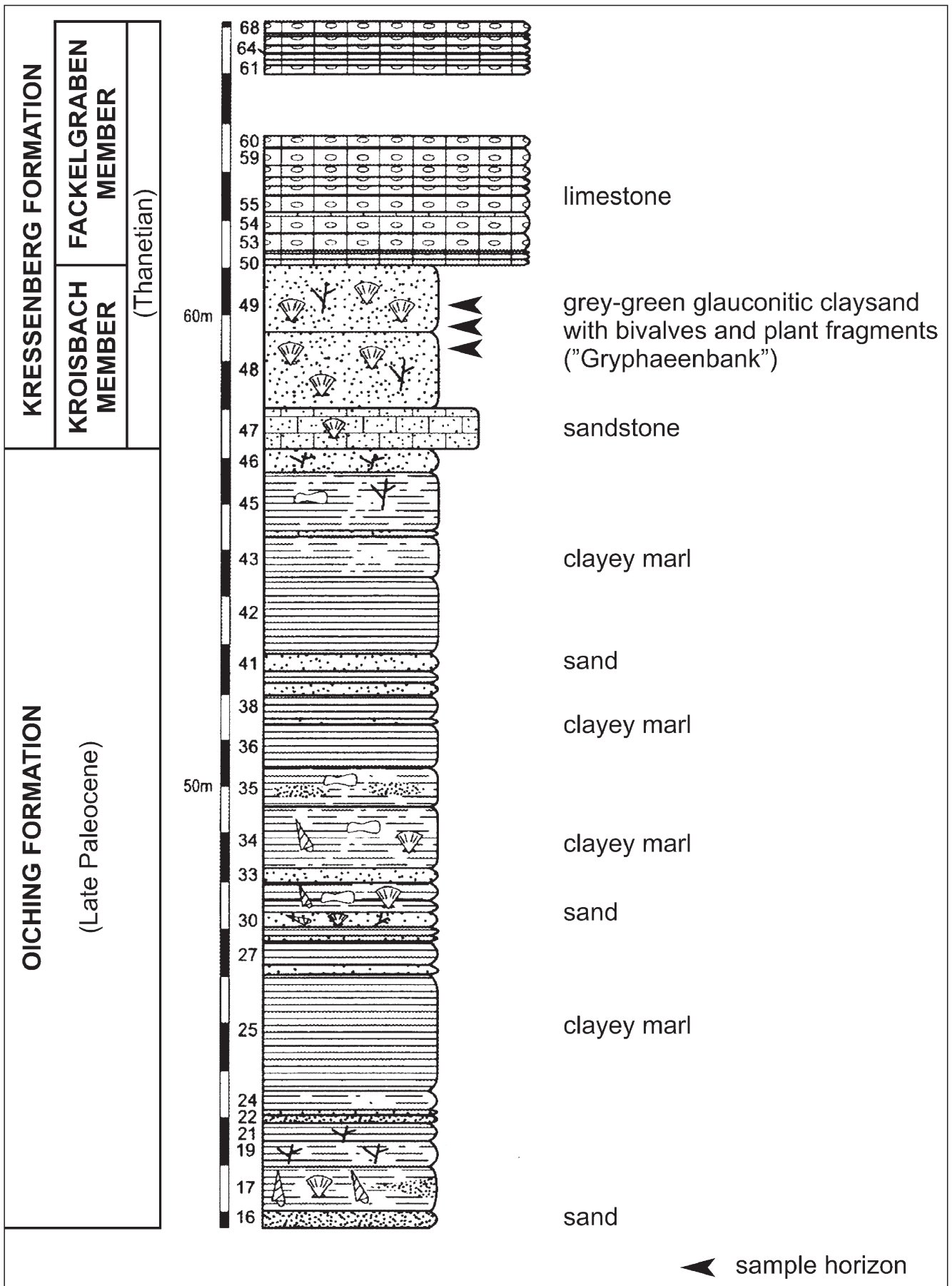
3. Results

3.1. Organic Facies

The organic facies is composed of a variety of organic particle types including fine-grained organic matter, cell fragments, strongly fractioned wood fragments (semi-opaque material), humic bodies, a few fungal remains and dinoflagellates.

3.2. List of Palynomorphs

The taxa of the present study are listed below alphabetically in a natural and partly morphological system. The information about the climatic regime of the taxa was obtained from MABBERLEY (1997) and HEYWOOD (1993).



Text-Fig. 2.
 Upper part of the Kroisbachgraben profile with sample horizons.
 Modified after RASSER & PILLER (1999).

Table 1.
List of taxa represented by palynomorphs occurring in the „Kroisbach Member“.

Family/Group	Genus	Form-genus	Preferred climatic conditions	Abundance
BRYOPHYTA				
Sphagnaceae		<i>Stereisporites</i> sp.	none, humid	x
PTERIDOPHYTA				
Lycopodiaceae	<i>Lycopodium</i> (3)	<i>Camarozonosporites</i>	temperate to tropical	x
Adiantaceae	<i>Pteris</i> (2)	<i>Polypodiaceoisporites</i>	temperate to tropical	x
Polypodiaceae	indet	<i>Laevigatosporites</i>	warm to tropical	x
Schizeaceae	<i>Lygodium</i> (2)	<i>Leiotriletes</i> sp.	warm to tropical	x
		<i>Trilites multivallatus</i>		x
	<i>Anemia</i>	<i>Cicatricosisporites paradorogensis</i>	warm to tropical	x
GYMNOSPERMAE				
Pinaceae	<i>Pinus</i>	<i>Pityosporites labdacus</i>	temperate to warm	xxx
	<i>Cathaya</i>	<i>Pityosporites microalatus</i>	warm	x
Taxodiaceae	indet	<i>Inaperturopollenites</i>	warm to tropical	xx
ANGIOSPERMAE				
Anacardiaceae	indet	<i>Tricolporopollenites striatopunctatus</i> .	warm to tropical	x
Aquifoliaceae	<i>Ilex</i> (2)	<i>Ilexpollenites</i> sp.	temperate to tropical	x
Arecaceae	indet (2)	<i>Monocolpopollenites</i>	tropical	x
Betulaceae	<i>Alnus</i>	<i>Alnipollenites</i> sp.	temperate to warm	x
Bombacaceae	indet		tropical	x
Caesalpiniaceae	indet	<i>Margocolporites</i> sp.	tropical	x
Ericaceae	indet		temperate to warm	x
Fagaceae	<i>Eotrigonobalanus</i> sp.	<i>Tricolporopollenites cingulum</i>	warm to tropical	xxx
	indet.	<i>Tricolporopollenites</i> sp.	warm to tropical	xxx
	indet.	<i>Tricolporopollenites</i> sp.		xx
Hamamelidaceae	indet (2)		warm	xx
Icacinaceae	indet	<i>Compositoipollenites</i> sp.	tropical	x
Juglandaceae	<i>Platycarya</i>	<i>Platycaryapollenites</i> sp.	temperate to warm	x
Mastixiaceae	indet	<i>Tricolporopollenites edmundi</i>	temperate to tropical	x
Moraceae	indet		temperate to tropical	x
Myricaceae	<i>Myrica</i>	<i>Triatriopollenites rurensis</i>	temperate to warm	xx
Nyssaceae	<i>Nyssa</i>	<i>Nyssapollenites</i> sp.	temperate to warm	x
Platanaceae	<i>Platanus</i>	<i>Platanipollis</i>	temperate to warm	x
Sapotaceae	indet (2)	<i>Tetracolporopollenites</i> sp.	warm to tropical	xx
Sparganiaceae	<i>Sparganium</i>		temperate to warm	x
Tiliaceae	<i>Craigia</i> sp.		tropical	x
FOSSIL MORPHOTYPES				
		Normapolles:		
		<i>Pompeckjoideaepollenites subhercynicus</i> (Middle Turonian to Upper Eocene)		xx
		<i>Trudopollis</i> (Middle Turonian-Lower Eocene)		xx
		<i>Nudopollis thiergartii</i> (Maastrichtian-Middle-Eocene)		xx
		<i>Plicapollis</i> (Middle-Senonian-Middle Eocene)		x
		<i>Stephanoporopollenites hexaradiatus</i> ssp. <i>semitribinae/tribinae</i> (Thanetian)		x
		<i>Basopollis vancampoe.</i> (Thanetian)		x

Table 1.
Continued.

		<i>Vacuopollis</i> (3) (Maastrichtian-Lower Eocene)		x
		<i>Interpollis</i> (Paleocene-Middle Eocene)		x
		<i>Postnormapolles</i> :		
		cf. <i>Labraferoidaepollenites</i>		x
		<i>Rugulitriporites</i> (3)		xx
		<i>Subtriporopollenites constans</i>		xx
		<i>Subtriporopollenites</i> sp.		xx
		Normapolles redeposited:		
		<i>Triatriopollenites</i>		x
		<i>Oculopollis</i> (Santonian-Campanian)		x
DINOFLAGELLATES				
		<i>Apectodinium homomorphum</i>		
		<i>Apectodinium</i> sp.		
		<i>Deflandrea oebisfeldensis</i> Pl.1, Fig. 1-3		
		<i>Deflandrea denticulata</i>		
		<i>Cordosphaeridium</i> sp.		
		<i>Spiniferites</i> sp.		

x = sporadically (<1 %); xx = 1–5 %; xxx = 5–15%.

3.3. Systematic Descriptions:

Some of the typical and stratigraphically significant pollen and spores are described and illustrated on Plates 1–5.

Pteridophyta

Schizeaceae

Cicatricosisporites paradorogensis KRUTZSCH 1959

Pl. 1, Figs. 7–9

Shape: Triangular obtuse.

Size: 60 µm.

Aperture: Trilete.

Exospore: Irregular ridges, 2–3 µm, interrupted by foveolae.

Stratigraphical range: Upper Paleocene / Lower Eocene–Upper Oligocene (THIELE-PFEIFFER, 1988).

Fam. indet.

Trilites multivallatus (PFLUG 1953) KRUTZSCH 1959

Pl. 1, Figs. 10–12

Shape: Triangular obtuse to semi-circular

Size: 56 µm.

Aperture: Trilete

Exospore: High corrugate, fossulate

Stratigraphical range: Paleogene (Ypresian) of Loksbergen, KRUTZSCH & VANHOORNE, 1977).

Angiosperms

Normapolles

In the described locality 10% of the pollen assemblage belong to the extinct Normapolles group which could not be affiliated to extant taxa. They were most likely produced by

amentiferous trees and shrubs and have a botanical affinity to Myricales/Juglandales (FRIES, 1983). The brevaxone pollen grains have a complex structure of the aperture and a structured wall with a characteristic microsculpture (GOCZAN et al., 1967; STANLEY & KEDVES, 1975; ZETTER et al. 2002).

Pompeckjoidaepollenites subhercynicus (KRUTZSCH 1954) KRUTZSCH 1967

Pl. 2, Figs. 1–3

Shape: Oblate, triangular-subcircular outline.

Size: 23–26 µm.

Aperture: Tricolpate, enlarging of the sexine round the aperture (endanulus).

Wall thickness: 1.5 µm, nexine thinner than sexine. Exine tectate, characteristic for this form species is that the nexine is separated in three areas, nexine is absent between these areas.

Sculpture: Fine coni, regularly distributed.

Stratigraphical range: Middle Turonian–Upper Eocene, main occurrence: Maastrichtian–Middle Eocene.

Stephanoporopollenites hexaradiatus tribinae KRUTZSCH 1961

Pl. 2, Figs. 7–13

Shape: Oblate, lobate, hexangular, triple symmetry.

Size: 22–26 µm.

Aperture: Zonocolporate, brevicolpate-porelike, slightly protruding, endoapertures delineated by atria, without depressions between the two and two arranged apertures.

Exine: 1 µm, sexine slightly thicker than nexine.

Sculpture: The first SEM photography was published by KEDVES (1977) from *Stephanoporopollenites hexaradiatus* ssp. *semtribinae* from the Thanetian (zone II) assemblage des-

cribed as "rugulate in most cases", the sculpture in the example from the "Gryphaeenbank" in Kroisbachgraben is rough "hummocky", with verrucae and irregular channels between the "hummocks" and is characteristic for an extinct Normapolles pollen type in a narrower sense and does not belong to the Juglandaceae/Myricaceae pollen types.

Stratigraphical range: *St. hexaradiatus* ssp. *semitribinae* is a keyform and stratigraphically significant for the Thanetian.

The described *Stephanoporopollenites hexaradiatus* ssp. *tribinae* form is going higher up to the uppermost Paleocene (KEDVES & RUSSEL, 1968) and lowest Eocene (KRUTZSCH & VANHOORNE, 1977).

Remark: In the "Gryphaeenbank" samples more forms resemble the subfsp. *tribinae*, few *semitribinae*, and also transitional forms. Only one example of *Stephanoporopollenites hexaradiatus* ssp. *hexaradiatus* was found.

Nudopollis thiergartii
(THOMSON & PLUG 1953) PLUG 1953

Pl. 3, Figs. 1–3

Shape: Oblate, concave.

Size: 25 μm .

Aperture: Tricolpate, three strongly protruding apertures from convex-sided amb, long pore canal with pronounced annuli, aperture without intrapunctuated atrium.

Exine: Sexine thicker than nexine.

Sculpture: Smooth in LM images, in SEM small coni regularly distributed.

Stratigraphical range: Maastrichtian–Middle Eocene, frequent in Thanetian sediments of Menat (KEDVES & RUSSEL, 1982) and Lower Thanetian of Kleinoiching (KEDVES, 1980).

Basopollis vancampoae
KEDVES, HEGEDUS & BOHONY 1971

Pl. 4, Figs. 1–3

Shape: Triangular, concave.

Size: 25 μm .

Aperture: Tricolpate, strongly protruding, ectocolpus sometimes gaping split like, shorter on the distal side, with tiny praevestibules described from the holotype by LM images (KEDVES et al., 1971).

Exine: Tectate, sexine thickened in the aperture region, nexine thinner than sexine.

Sculpture: Rough, rugulate, short rugae with verrucae.

Stratigraphical range: Thanetian.

***Vacuopollis* sp.**

Pl. 4, Figs. 4–6

Shape: Triangular, slightly convex.

Size: 26 μm .

Aperture: Tricolporate, short colpi, protruding, without oculi endolamellae in the aperture region, shallow atria.

Exine: Wall thickness 1 μm , in the aperture areas 2 μm .

Sculpture: Scabrate.

Stratigraphical range: Maastrichtian – Lower Eocene.

Postnormapolles (PLUG 1953)

cf. *Labraferoidaepollenites*

Pl. 2, Figs. 4–6

Shape: Triangular with convex sides.

Size: 22 μm .

Aperture: Exoaperture short slit, 3 μm long, nozzle-like labra, vestibulum 5 μm wide.

Exine: 1.5 μm .

Sculpture: Tiny cones regularly and densely distributed.

Remark: Myricoid type of pollen grain.

***Subtriporopollenites constans* PFLUG 1953**

Pl. 3, Figs. 4–6

Shape: Spheroidal in polar view.

Size: 22 μm .

Aperture: Triporate to brevicollate, one aperture sub-equatorial.

Exine: 1–1.5 μm , sexine thicker than nexine.

Sculpture: Regularly distributed tiny cones (0.2 μm).

Stratigraphical range: Paleocene–Lower Eocene.

Remark: Probably ancient Juglandaceous pollen-type.

***Subtriporopollenites* sp.**

Pl. 3, Figs. 7–9

Shape: Oblate-triangular, convex sides.

Size: 30 μm .

Aperture: Triporate, subequatorial.

Exine: 1.5 μm thick, sexine thicker than nexine.

Sculpture: Sculpture pattern in SEM with densely regularly distributed conate elements (0.3 μm –0.5 μm) seem a little different in diameter.

Rugulitriporites balinkaense
(KEDVES 1974) KEDVES 1982

Pl. 3, Figs. 10–12

Shape: Triangular, convex sides, slightly deformed.

Size: 26–30 μm .

Aperture: Triporate, pore diameter 1 μm , with annulus.

Exine: 1–1.5 μm , sexine thicker than nexine.

Sculpture: Rugulate-verrucate, rugae 1.5 μm –3 μm .

Stratigraphical range: Thanetian (KEDVES & RUSSEL, 1982) – Middle Eocene (KEDVES, 1974).

Tiliaceae

***Craigia* sp.**

Pl. 4, Figs. 7–9

Shape: Triangular-obtuse, slightly deformed

Size: 35 μm .

Aperture: Tricolporate thickenings of the porus in the form of a horse shoe.

Exine: 1.5 μm .

Sculpture: Reticulate, with some extracolumellae, smooth muri, width of lumina 0.3–0.5 μm .

Remark: The smaller lumina size and the micromorphology separate this specimen from Sterculiaceae/Bombacaceae. Species of the genus are extant in SW China.

Caesalpiaceae

Margocolporites sp.

Pl. 4, Figs. 10–12

Shape: Spheroidal, circular in polar view.

Size: 32 μm .

Aperture: Tricolporate, broad colpi, membrane finely verrucate.

Exine: Semitectat.

Sculpture: Microreticulate-undulating tectum, surface with microverrucae on the muri.

Remark: LM and SEM images of another taxon of this family in ZETTER et. al., (1999).

Fagaceae

Eotrigonobalanus sp.

(*Tricolporopollenites cingulum*)

Pl. 5, Figs. 1–3

Shape: Prolate, in equatorial view elliptic.

Size: C-axis 26 μm , b-axis 18 μm .

Aperture: Tricolporate, colpi are 20 μm long, slightly protruding of the sexine in the endoaperture.

Exine: Nexine equal to sexine.

Sculpture: Rugulate, rugae growing together and covered with irregularly interwoven rods.

Remarks: This pollen-type can be compared with that one described as the fossil Fagaceae *Eotrigonobalanus* WALTHER & KVACEK from the paleogene of Central Europe by ZETTER in WALTHER & ZETTER (1993) The LM image resembles the formspecies *Tricolporopollenites cingulum* (R. POTONIE) THOMSON & PLUG 1953.

It is one of the most frequent pollentypes in the Kroisbach Member samples.

Fagaceae gen. indet. fsp. 1

Pl. 5, Figs. 4–6

Shape: Prolate, in equatorial view elliptic.

Size: C-axis 25 μm , b-axis 18 μm .

Aperture: Tricolporate, colpi narrow, do not reach the polarea, endoaperture slightly protruding.

Exine: Sexine is thicker than nexine and obviously thickened in the pol areas (2 μm), Tectum perforate.

Sculpture: Short rods and verrucae irregularly joined around the perforations.

Remarks: The LM images resembles *Perforonuxpollenites menatensis* KEDVES & RUSSEL, 1982, Menat, Paleocene, Thanetian. Frequent.

Fagaceae gen. indet. fsp. 2

Pl. 5, Figs. 7–9

Shape: Prolate, in equatorial view elliptic

Size: C-axis 23 μm , b-axis 15 μm .

Aperture: Tricolporate, colpi narrow of 12 μm length endoaperture slightly protruding.

Exine: Nexine equal to sexine, not thickened at the poles.

Sculpture: Verrucate with nannoverrucae.

Sapotaceae gen. indet fsp.1

Pl. 5, Figs. 10–12

Shape: Prolate, elliptic in equatorial view.

Size: C-axis 42 μm , b-axis 21 μm .

Aperture: Tetracolporate, ectoapertures narrow colpi, colpi length 32 μm , endoaperture protruding, alongate, rectangular.

Exine: Nexine thicker than sexine.

Sculpture: Undulated surface, tectum perforated and with foveae and nannoverrucae, reduced around ectoaperture.

4. Discussion

The palynoflora of the near shore marine sediments of the "Kroisbach Member" contains 94% pollen and spores and six percent dinoflagellates. From the pollen and spore flora calculated as 100% angiosperms are 93%, gymnosperms 4% and 3% are spores. All the taxa are listed above in Table 1. To affiliate the taxa to modern families and genera and to get more botanical data for comparison with modern environments it is necessary to use the combined method of light microscope and scanning electron microscope investigation described by ZETTER (1989). The pollen surface seen with the scanning electronic microscope is one of the most valuable distinguishing features for specific diagnosis of dispersed material (ZETTER et al. 2002).

The most characteristic and dominant pollen in the Thanetian samples from the "Kroisbach Member" are from wind-pollinated plants, extinct Normapolles, ancient Juglandaceae and Myricaceae and the tricolporate Fagaceae. Only a small part of the pollen came from entomophilous plants (Icacaceae, Aquifoliaceae, Mastixiaceae, Sapotaceae, Caesalpiaceae). One of the factors to be considered is that the pollen and spore assemblage deposited in the marine environment is only a part of the original taxa diversity in the paleocommunities which produced these pollen and spores. The low rate of larger fernspores may be due to the distance from the shore (BRUCH, 1998). The composition of the pollen assemblage is probably strongly influenced by the transport of the pollen from the land to the sea. Another factor which affects the composition of the pollen assemblage is the oxygenation in part of the floral remains. Therefore, the taxa yield of the palynoflora is not fully representative. These factors have to be considered before discussing the stratigraphy, paleoecology and paleoclimatology.

4.1. Stratigraphy

The outcrop in the Kroisbachgraben provides an Upper Paleocene section: The Oiching Formation, the Kroisbach Member and the basal part of the Fackelgraben Member (Text-Fig. 2).

The glauconitic sandstone is equivalent to the standard nannoplankton zone NP8 due to the occurrence of the marker fossil *Heliolithus riedelii* (STRADNER in GOHRBANDT 1963, p. 51).

Therefore, the age of the co-occurring microflora in the "Kroisbach Member" may be recognised from the nannoflo-

ra. The sediments of the Kroisbach Member are overlain by massive Thanetian algal limestones, the basal part of the Fackelgraben Member according to the lithostratigraphic subdivision of RASSER & PILLER 1999. The algal limestone of the Fackelgraben Member („Unterer Lithothamnienkalk“) was previously assigned to the Upper Paleocene by HAGN (1981). KUHN (1992) presented data of planktonic foraminifera for an Early Eocene age. But recent results by J. EGGER (unpublished data) date the Fackelgraben Member by calcareous nannoplankton from the marly interlayers to NP 9 (RASSER & PILLER, 2001). So the Fackelgraben Member is assigned to a Late Paleocene (Thanetian) age.

In the palynomorph assemblage of the Kroisbach Member the elements of the angiosperms of the group of Normapolles (from the Normapolles floristic province in the Northern Hemisphere from middle latitudes) are considered biostratigraphically useful. Typical examples are: *Vacuopollis* sp., *Trudopollis* sp., *Subtriporopollenites* sp., *Plicapollis pseudoexcelsus*, *Nudopollis thiergartii*, *Interpollis* sp., *Basopollis vancampoe*, *Pompeckjoidaepollenites subhercynicus*. The most important marker species for the Thanetian is the rather small *Stephanoporopollenites hexaradiatus* sbfsp. *semitribinae* and *Stephanoporopollenites hexaradiatus* sbfsp. *tribinae* (Pl. 2, Figs. 7–13) which commonly occur in the pollen assemblage of the Kroisbach Member samples. It is characterized by having extremely short stratigraphic ranges and wide geographic distribution ranges (ZAKLINKAJA, 1981). The high proportion of triporate pollen with a myricaceous surface (PLANDEROVA, 1974) and *Engelhardia*-like pollen belonging to the Postnormapolles not allied to the Normapolles sensu stricto is significant for assignment to Upper Paleocene.

The taxonomy of Normapolles and Postnormapolles has become very complicate and therefore needs systematical revision with LM, SEM and TEM on well preserved pollen assemblages (ZETTER, 2002).

The glauconitic sandstone of the “Kroisbach Member” is also characterized by the occurrence of dinoflagellates. *Apectodinium* sp. is one of the stratigraphically most significant dinocyst taxon in the assemblage. Different species of *Apectodinium* occur infrequently (Pl. 1, Figs. 4–6), also with horns but not the species *Apectodinium augustum* with the typical long lateral horns and the well developed antapical horns (HARLAND, 1979). The well known global *Apectodinium* event starts later in the upper NP 9 in the northern and southern hemisphere (HEILMAN-CLAUSEN & EGGER, 2000; CROUCH et al., 2001) and is characterized by a *Apectodinium*-dominated assemblage (>60%) and the regular occurrence of *Apectodinium augustum* (EGGER et al., 2000). *Apectodinium* species occur commonly during significantly transgressive phases (JOLLEY, 1998).

4.2. Comparison with Microfloras from other Localities

The pollen assemblage of the “Kroisbach Member” is comparable with other European localities. A striking similarity exists to the terrestrial microflora deposited in the Thanetian layers of the sequence in the basin of Menat, Auvergne, France (KEDVES & RUSSEL, 1982), dated as 56 Ma. by Ka/Ar and therefore within the global warming period of the late Paleocene and early Eocene interval. Of course, this comparison is strictly limited to the LM investigations. The palynoflora of marine Ypresian layers from Gelinden Overbroek (Belgium) described by SCHUMACKER-LAMBRY (1978) is comparable in the taxa composition with high diversity in the Normapolles group with the marker *Stephanoporopollenites hexaradiatus semitribinae* and *tribinae*. A very rich microflora with more than 230 (morphologically) described species from two lignitic deposits of Ypresian (Lowermost Eocene) in Belgium was published by KRUTZSCH & VANHOORNE (1977). These assemblages very

rich in taxa described as morphotypes are comparable only in part.

A pollen assemblage with plant elements indicating a subtropical/tropical climate and high amounts of dinoflagellates could be identified from offshore sediments (NP9) of the Anthering flysch section near Salzburg (DAXLER, 2000)

The excellent preserved and very diverse Paleocene/Eocene Krappfeld palynoflora (Carinthia, Austria) was affiliated to modern genera and families and is characterized by different Arecaceae (palms) types (HOFMANN & ZETTER, 2001; ZETTER & HOFMANN, 2001). Arecaceae – Nypoidae (*Spinozonocolpites*), and *Nypa* mangrove palm were not found in the “Kroisbach Member” samples. The *Nypa* palm dominated mangrove is characteristic for Eocene floras around the Eocene thermal maximum (COLLINSON, 2000). The probably younger microflora from the Krappfeld area yielded a much higher biodiversity than the Kroisbach Member samples, with 120 species which were affiliated to modern genera by HOFMANN & ZETTER (2001). Many of them belong to megathermal genera with a tropical life form, and 80% have an entomophilous dispersal mechanism.

4.3. Vegetation and Paleoclimatic Implications

The depositional environment of the Kroisbach Member sediment was the littoral zone of the southern European shelf.

56 species have been found in the samples. Most of the specimens could be affiliated to modern taxa at least to the family level (93% Angiospermae, 4% Gymnospermae nearly 3%, Pteridophyta and <1% Bryophyta).

In the “Kroisbach Member” samples pollen of wind pollinated plants (Normapolles, Fagaceae) are more common than the animal dispersed diaspores. The pollen deposition of entomophilous plants is low.

Even the precise reconstruction of the plant communities is not possible because of delimiting factors for species identification mentioned before, however, different plant communities are indicated and some paleo-habitats could be recognised.

The inferred paleoecological conditions of some families reflect the importance of swamp or riparian vegetation. Taxodiaceae (*Inaperturopollenites* sp. mostly preserved as “hiatus“, which means that the pollen exine is split open in a particular way) was most probably from a lower lying swampy land. The dominance of pine in the coniferous pollen indicate perhaps a pine forest on the sandy soil of the coastal plain. The predominance of tricolporate grains of the Fagaceae family suggest a lowland forested swampy area as well (ANDERSON & MULLER, 1975), but these evergreen Fagaceae also occur on better drained soils along river banks (*Eotrigonobalanus* sp.; WALTHER & ZETTER, 1993). Icacinaceae, Anacardiaceae, Juglandaceae, Sapotaceae could have grown in the swamp forest or in the riparian fringe vegetation. Myricaceae (*Myrica*), *Ilex* and Ericaceae grow in the shrub layer. The ferns (Polypodiaceae, Schizaeaceae) are the herbaceous plants on the ground. Mesophytic broad-leaved semi-evergreen forests with Fagaceae, Juglandaceae, Mastixiaceae, Tiliaceae, Sapotaceae, Hamamelidaceae were situated on elevated areas. There are some indications of lianas with Icacinaceae and *Lygodium* sp.

The tropical entomophilous types like Arecaceae, Icacinaceae, Sapotaceae, Mastixiaceae are less common. The majority of the pollen producing plants are anemophil or ambophil. For the wind dispersal mechanism seasonal dryer climatic conditions are needed (ZETTER & HOFMANN, 2001). For the interpretation of the vegetation and climatic conditions the microflora has to be compared with recent representatives. The potential climatic zone distribution of

nearest living relatives can be given for the following plant elements (after HEYWOOD, 1993): Juglandaceae are a family of deciduous trees and mostly north-temperate to subtropical in range. The Palmae (Arecaceae) are mainly tropical with a few subtropical and temperate outliers. Sapotaceae occur pantropically mainly in lowland and lower mountain rain forests. Icacinaceae: This family comprises trees, shrubs and lianas, almost all of which inhabit tropical rain forests. Aquifoliaceae: This family is widely distributed in both temperate and tropical regions. Caesalpiniaceae comprise mainly tropical and subtropical trees and shrubs. Mastixiaceae: In the Indo-malaysian region there are some 25 species of *Mastixia* medium to tall evergreen trees. Anacardiaceae are mainly subtropical and tropical in their present distribution with trees, shrubs and lianas. These accessory plant elements detected in the Kroisbach Member are strongly indicative of paratropical to subtropical climate conditions. The lack of *Nypa* palm, that are common today in tropical areas of South East Asia, may suggest a some-

what cooler climate before the two distinct peaks near the Paleocene-Eocene boundary (55.5 Ma) and in the middle to late early Eocene during the long period of global warming characterizing late Paleocene to early Eocene time (AUBRY et al., 1998; WING, 2000). The Thanetian microflora of the Helvetic Zone support a rather subtropical, bordering on tropical climate perhaps with seasonal variation not within a peak of warming with the corresponding plant-communities in wet and better drained habitats.

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Plate 1

Deflandraceae

Figs. 1–3: *Deflandrea oebisfeldensis* ALBERTI 1959

Peridiniaceae

Figs. 4–6: *Apectodinium* sp.

Figs. 7–9: *Cicatricosisporites paradorogensis* KRUTZSCH 1959.

Figs. 10–12: *Trilites multivallatus* (PFLUG 1953) KRUTZSCH 1959.

Light microscope (LM) images bar = 10 μ .

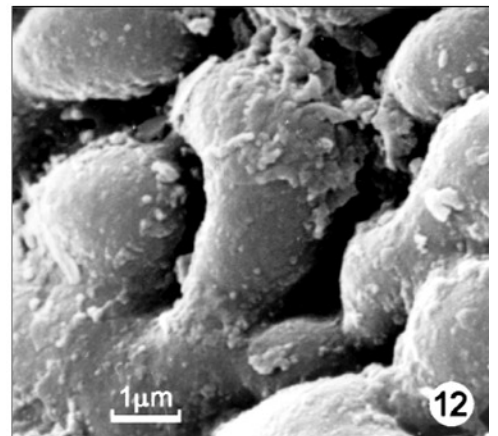
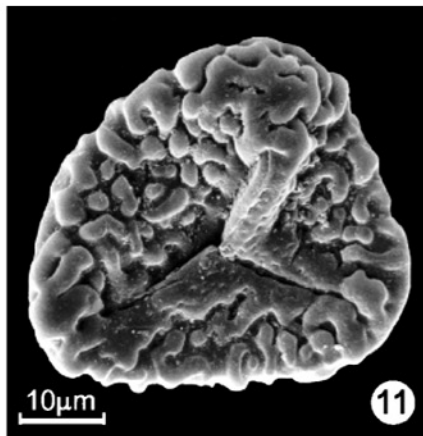
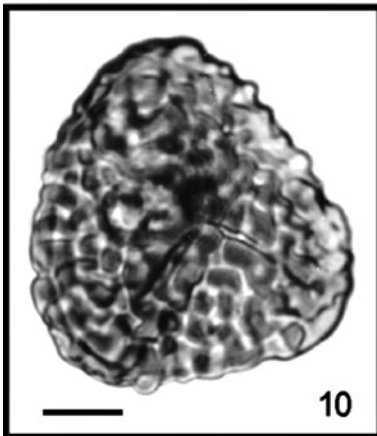
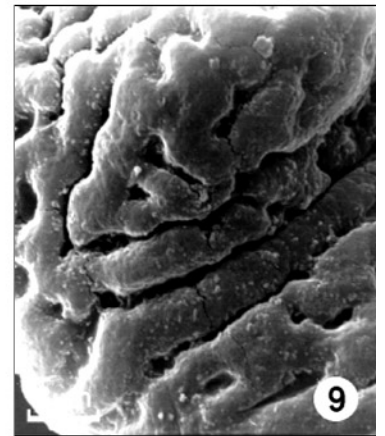
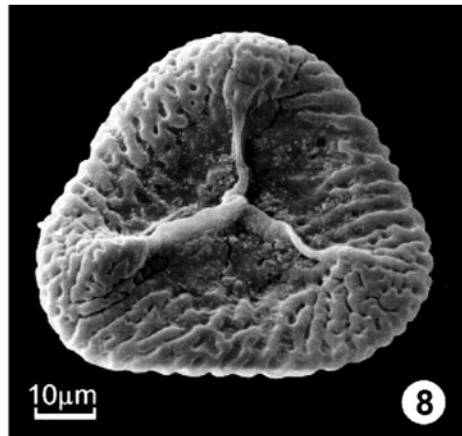
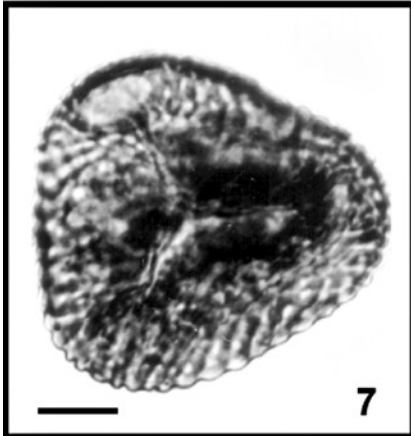
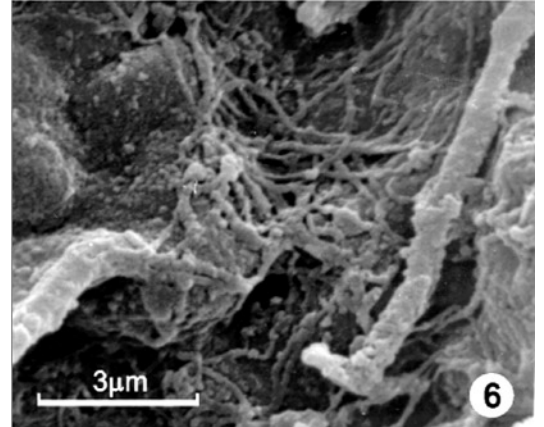
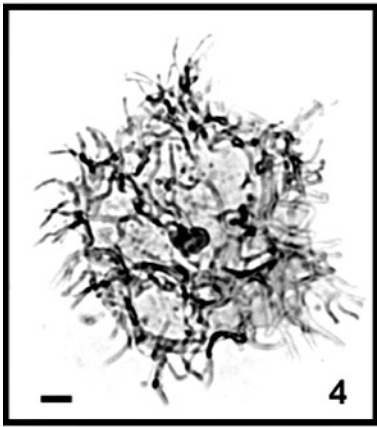
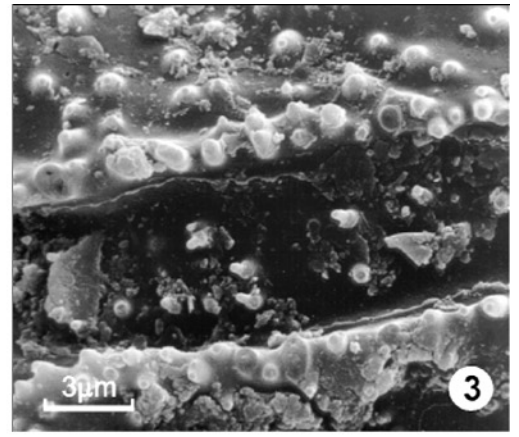
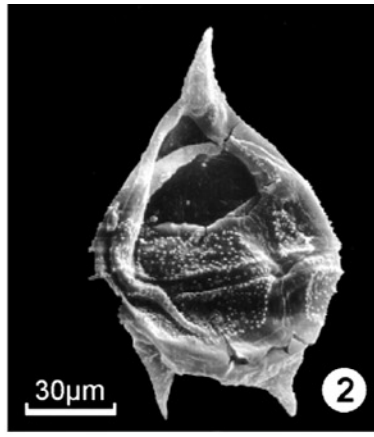
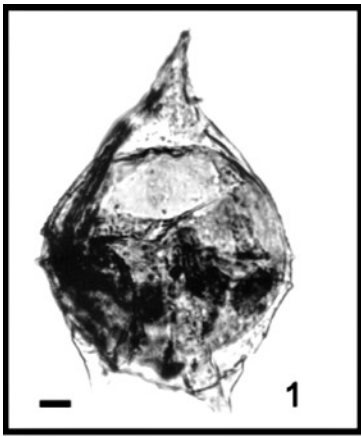


Plate 2

Figs. 1–3: *Pompeckjoidaepollenites subhercynicus* (KRUTZSCH 1954) KRUTZSCH 1959.

Fig. 1: Polar view.

Fig. 2: Polar view.

Fig. 3: Detail of the tectum.

Figs. 4–6: cf. *Labraferoidaepollenites*

Fig. 4: Polar view.

Fig. 5: Polar view.

Fig. 6: Detail of the tectum, apertural area.

Fig. 7–13: *Stephanoporopollenites hexaradiatus tribinae* KRUTZSCH 1961.

Fig. 7: Polar view.

Fig. 8: Oblique view.

Fig. 9: Detail of the aperture areas.

Fig. 10: Detail of the tectum.

Fig. 11: Polar view.

Fig. 12: Polar view.

Fig. 13: Detail of the tectum.

Light microscope (LM) images bar = 10 μ .

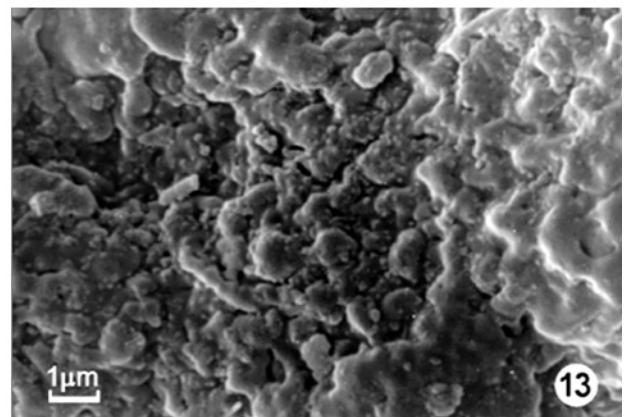
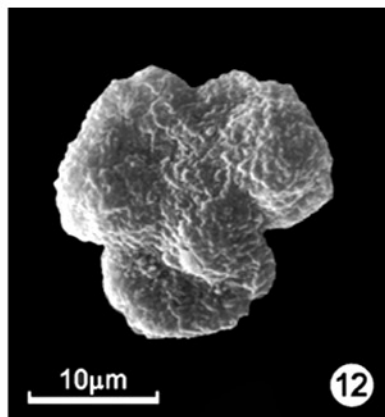
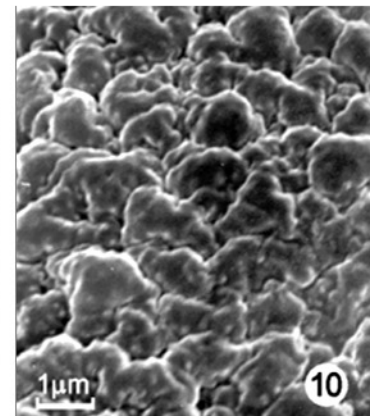
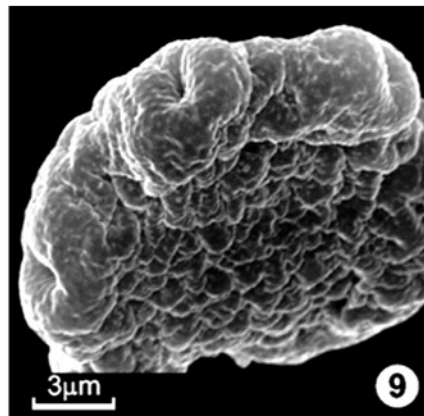
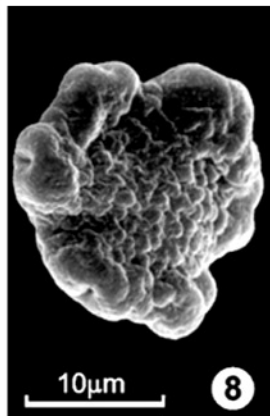
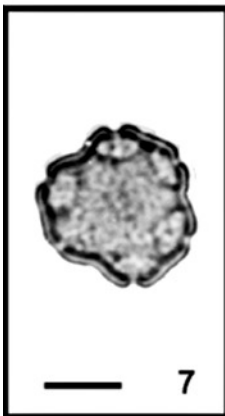
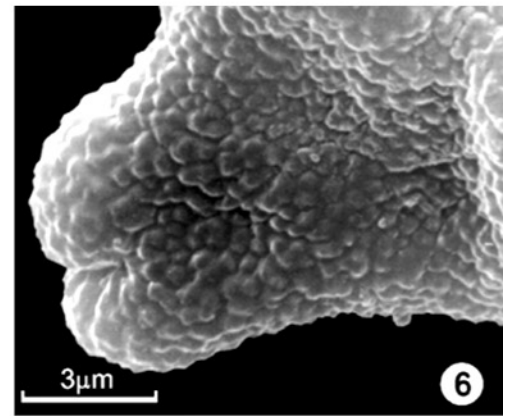
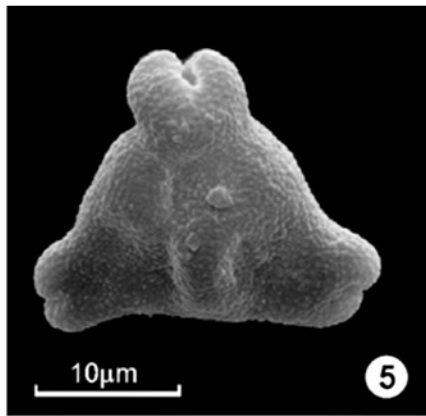
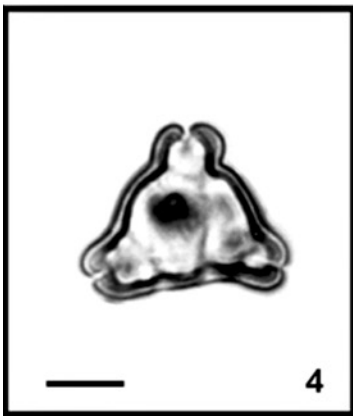
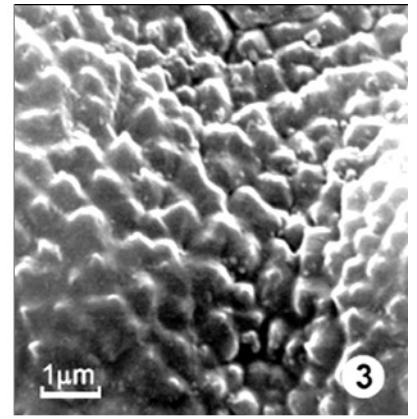
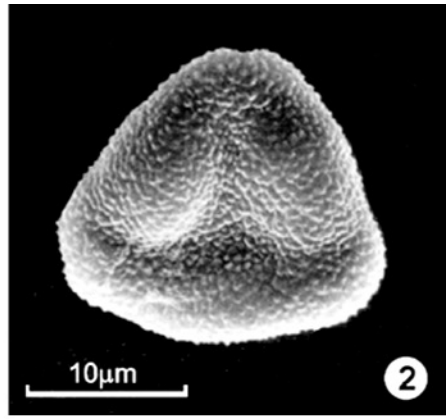


Plate 3

Figs. 1–3: *Nudopollis thiergartii* (THOMSON & PFLUG 1953) PFLUG 1953.

Fig. 1: Oblique view.

Fig. 2: Oblique view.

Fig. 3: Detail of the tectum, apertural area.

Figs. 4–6: *Subtriporopollenites constans* PFLUG 1953.

Fig. 4: Polar view.

Fig. 5: Polar view.

Fig. 6: Detail of the tectum

Figs. 7–9: *Subtriporopollenites* sp.

Fig. 7: Polar view.

Fig. 8: Polar view.

Fig. 9: Detail of the tectum

Fig. 10–12: *Rugulitriporites halinkaense* (KEDVES 1974) KEDVES 1982.

Fig. 10: Polar view.

Fig. 11: Polar view.

Fig. 12: Detail of the tectum.

Light microscope (LM) images bar = 10 μ .

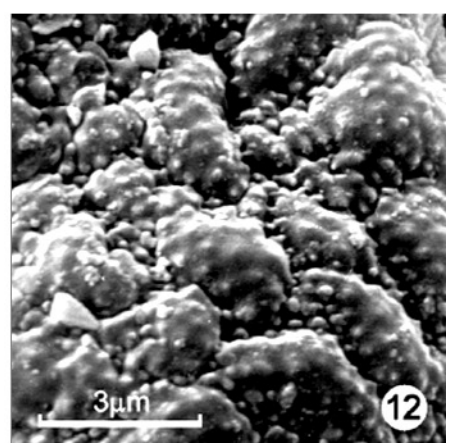
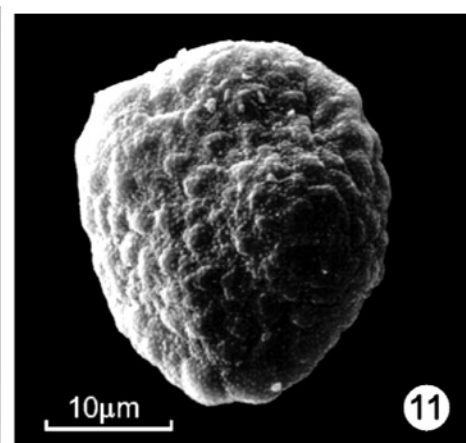
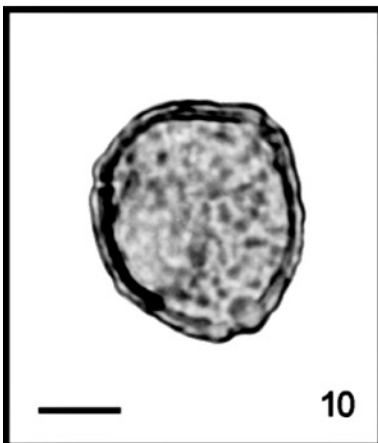
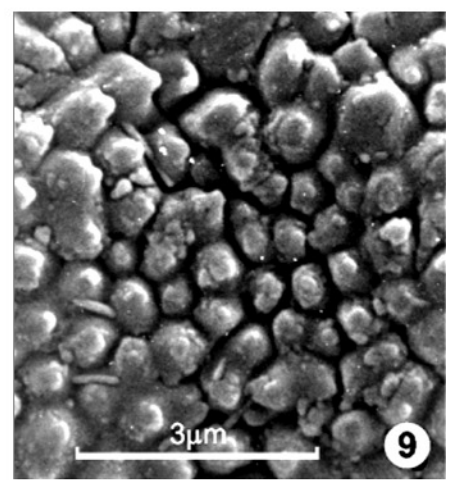
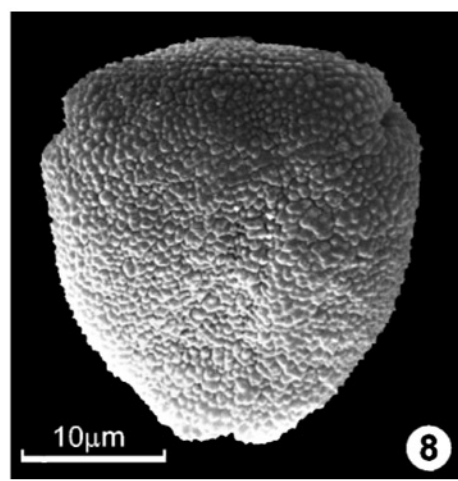
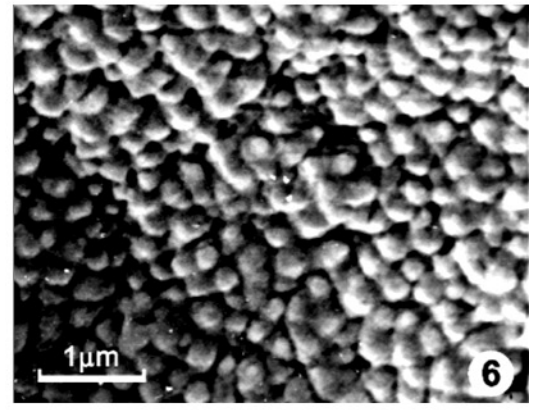
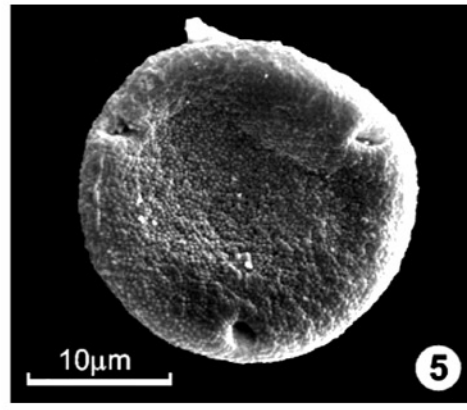
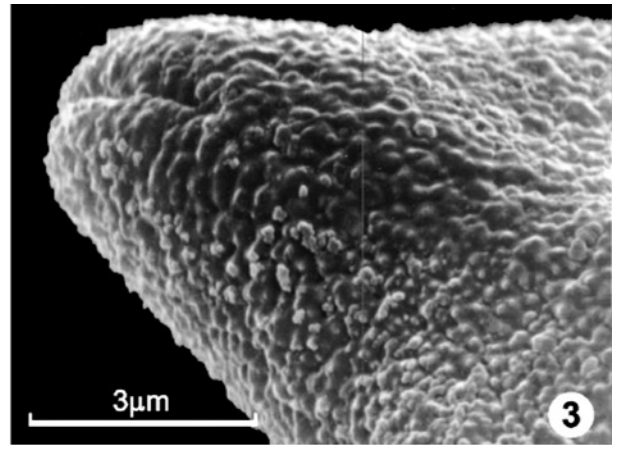
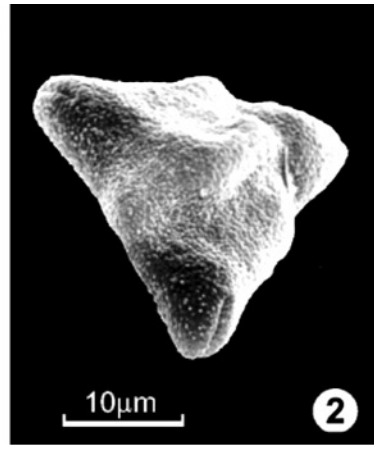
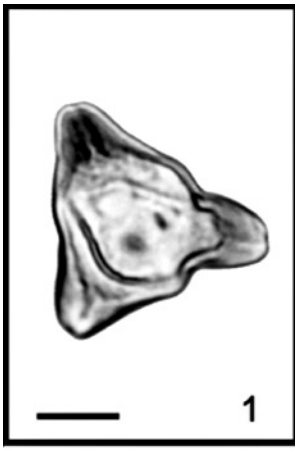


Plate 4

Figs. 1–3: *Basopollis vancampoe* KEDVES, HEGEDUS & BOHONY 1971.

Fig. 1: Polar view.

Fig. 2: Polar view.

Fig. 3: Detail of the tectum.

Figs. 4–6: *Vacuopollis* sp.

Fig. 4: Oblique view.

Fig. 5: Oblique view.

Fig. 6: Detail of the tectum

Tiliaceae

Figs. 7–9: *Craigia* sp.

Fig. 7: Polar view.

Fig. 8: Polar view.

Fig. 9: Detail of the tectum

Caesalpiniaceae

Fig. 10–12: gen. indet.

Fig. 10: Polar view.

Fig. 11: Polar view.

Fig. 12: Detail of the tectum.

Light microscope (LM) images bar = 10 μ .

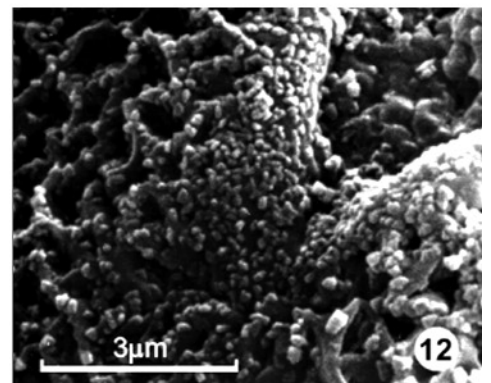
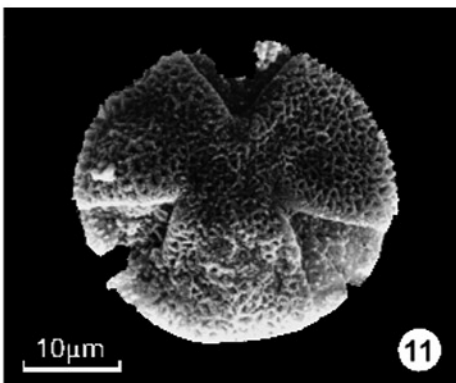
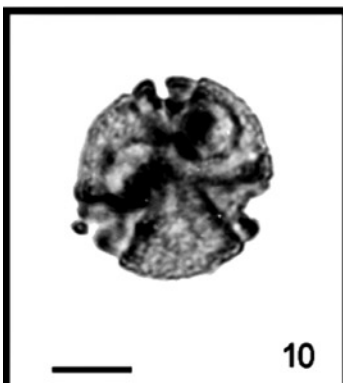
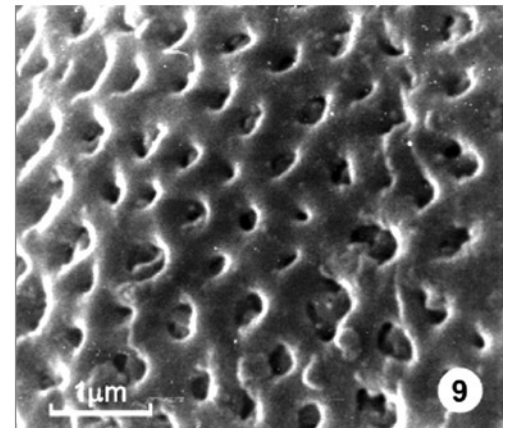
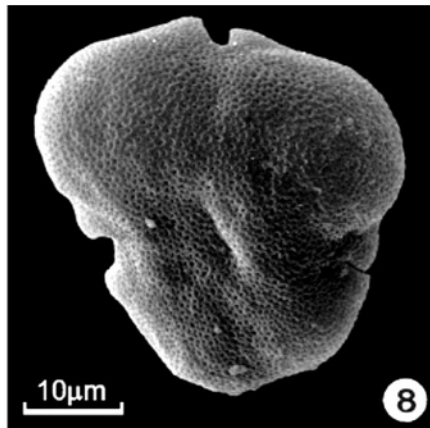
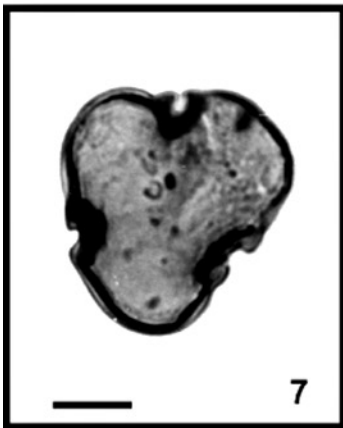
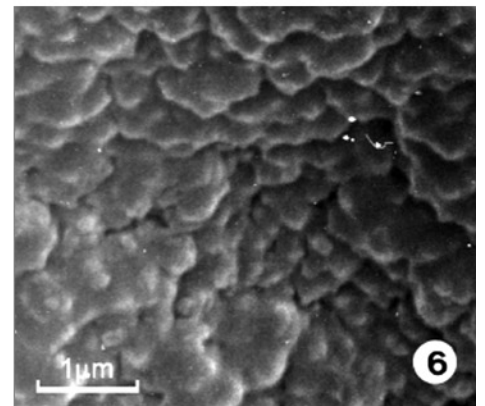
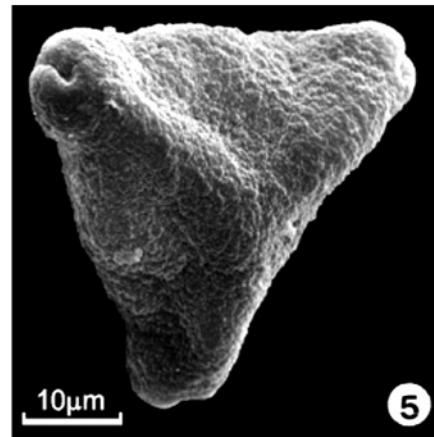
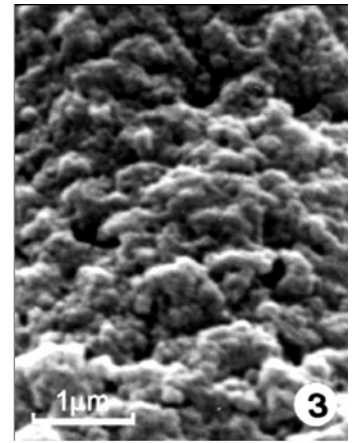
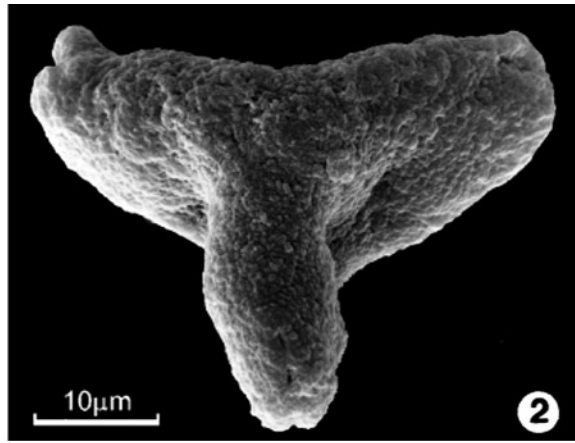
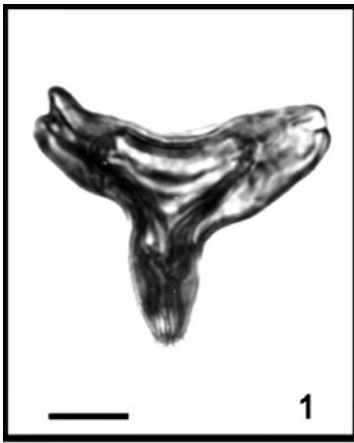


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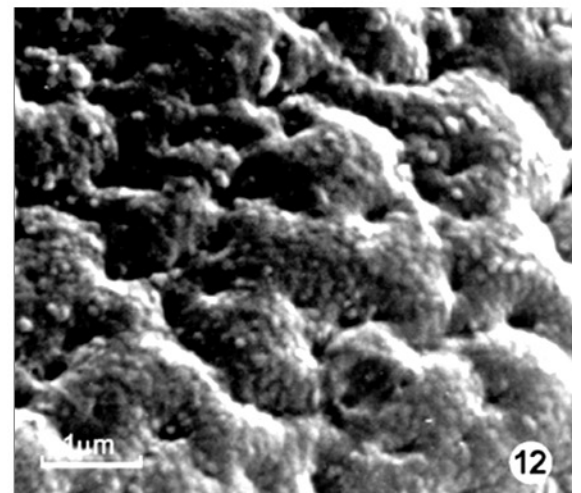
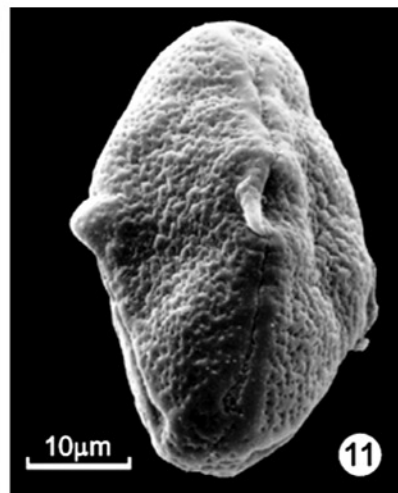
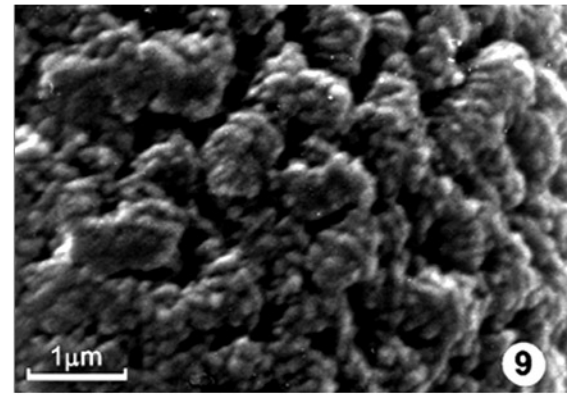
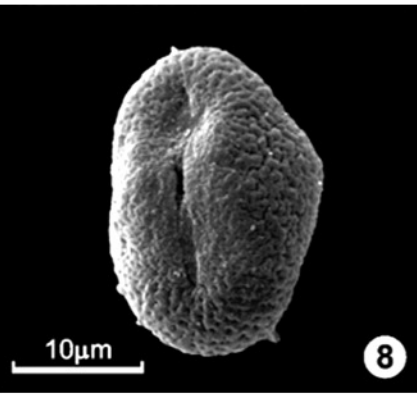
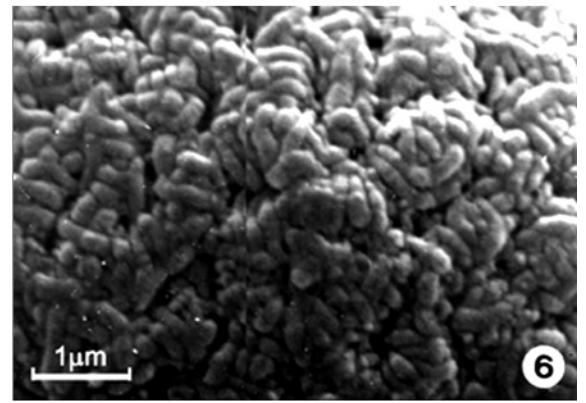
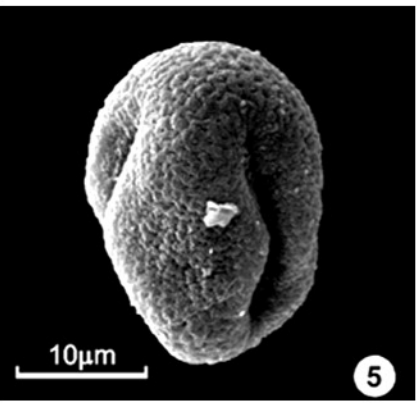
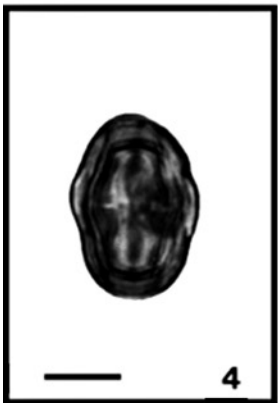
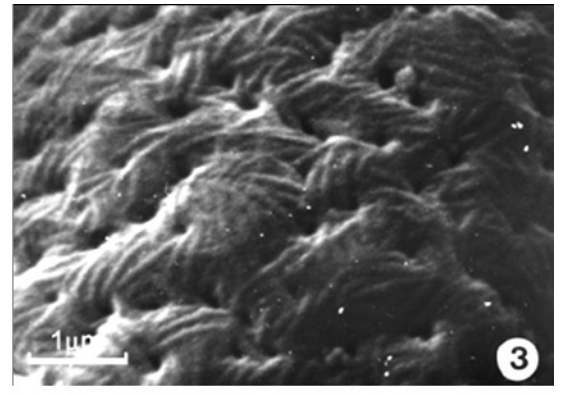
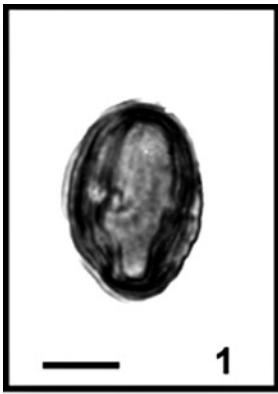
Fagaceae

- Figs. 1–3: *Eotrigonobalanus* sp.
Fig. 1: Equatorial view.
Fig. 2: Equatorial view.
Fig. 3: Detail of the tectum.
- Figs. 4–6: gen. indet., fsp.1.
Fig. 4: Equatorial view.
Fig. 5: Equatorial view.
Fig. 6: Detail of the tectum
- Figs. 7–9: gen. indet., fsp.2.
Fig. 4: Equatoria view.
Fig. 5: Equatoria view.
Fig. 6: Detail of the tectum

Sapotaceae

- Fig. 10–12: gen. indet.
Fig. 10: Equatorial view.
Fig. 11: Equatorial view.
Fig. 12: Detail of the tectum.

Light microscope (LM) images bar = 10 μ .



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