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GEOLOGIE UND PALÄONTOLOGIE

A Pleistocene palynological assemblage from the Lukundol Formation (Kathmandu Basin, Nepal)

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(With 75 figures)

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Zusammenfassung

Das Ziel dieser Arbeit ist eine gründliche Dokumentation der Palynoflora eines kleinen Abschnitts der Lukundol-Formation des Kathmandu-Beckens in Nepal. Der Vergleich identer Objekte im Lichtmikroskop und dem Raster-Elektronen-Mikroskop soll ein besseres Verständnis der im späten Früh-Pleistozän vertretenen Taxa Nepals ermöglichen.

Insgesamt konnten 74 Taxa analysiert werden: 25 Sporen von Farnen und Moosen, 7 Gymnospermen, 41 Angiospermen und 1 Süßwasser-Zyste. Drei bis jetzt nicht dokumentierte *Quercus* Arten konnten aus der Formation nachgewiesen und abgebildet werden. Ebenso konnten 3 Poaceae und einige andere Taxa nun erstmals aus dem Pleistozän der Lukundol-Formation dokumentiert werden. Die Zusammensetzung der Vergesellschaftung lässt eine Beziehung zur „tropical evergreen upper montane forest“ Phase des Kathmandu-Beckens vermuten, die schon von anderen Autoren für das mittlere Pleistozän des Raumes diskutiert wurde.

Schlüsselwörter: Palynologie, Pleistozän, Himalaya, Nepal, Kathmandu Becken.

Abstract

The aim of the paper is to present a thorough documentation of the palynoflora of a small part of the Lukundol Formation from the Kathmandu Basin in Nepal. The comparison of light microscope pictures with the scanning electron microscope pictures of the identical specimens allows a better understanding of the taxa present in the latest Early or Middle Pleistocene of Nepal.

In total, 74 taxa were analysed, containing 25 spores from ferns and mosses, 7 different gymnosperms, 41 angiosperms and 1 freshwater cyst. Three until now never documented species of

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Quercus are recorded and illustrated from the formation; similarly 3 Poaceae and several other taxa are now documented for the first time from the Pleistocene of the Lukundol Formation. The overall composition of the assemblage suggests a relation to the "tropical evergreen upper montane forest" phase of the Kathmandu Basin, which was proposed for the middle Pleistocene of the area by other authors.

Keywords: Palynology, Pleistocene, Himalaya, Nepal, Kathmandu Basin.

Introduction

Nepal is mainly characterised by the high mountains of the Himalaya. These are the result of the collision between the Indian continent and the Eurasian plate during the early Cenozoic Era. The northward drift of India began during the Mesozoic causing the closure of the remaining Tethys Ocean in the north of India during the Paleogene and resulted in the uplift of the Himalaya during the Neogene (Najman et al. 2005; Zhu et al. 2005; Bera et al. 2008). The geological and paleontological investigations in the Himalaya were based mainly on India, whereas Nepal was left aside until the second part of the 20th century. At that time, the Kathmandu Basin in the middle of the Lesser Himalaya, came into the scope of scientific interests (e.g.: Hagen 1968; 1986; (Sharma 1973; West & Munthe 1981; Dongol 1985; West et al. 1988; Corvinus 1988, Sah et al. 1991). The Kathmandu Basin, located along the southern slopes of the Himalaya, is an intramontane basin. After the Kashmir Valley in India, it is the second biggest basin system in the whole Himalayan Mountains and the biggest in Nepal. With a diameter of 30 km in the east-west and of 25 km north-south direction it has a more or less circular outline covering an area of about 650 km². The average elevation today is around 1340 m. Its southern margin is formed by the Mahabharat Mountains with about 2000 to 2800 m altitude in the south and the Shivapuri Mountains in the north. The Shivapuri slope is mostly comprised of gneiss and granite, unlike the northwestern part, where Paleozoic rocks of the Phulchauki Group are outcropping, which nearly surround the rest of the basin (Stöcklin & Bhattarai 1981).

Geological setting

The Kathmandu Valley is filled by about 650 m Upper Pliocene to Quaternary clay, silt, sand and gravel (Moribayashi & Maruo 1980; Yoshida & Gautam 1988; Fort & Gupta 1981), overlaying the Precambrian Bhimphedi Group and the lower Paleozoic Phulchoki Group (Stöcklin & Bhattarai 1981). This basin-fill was formed by a lake and its associated alluvial-deltaic systems (Fig. 1), called Palaeo-Kathmandu Lake (Fujii & Sakai 2002). Today, the main drainage system of the area is the Bagmati River, which leaves to the gangetic delta in the south. The river drainage pattern and the associated sedimentation, however, were strongly modified by the uplift of the Mahabharat Range. Due to the rise of the Mahabharat Mountains, the usually southwards-oriented flow direction was deflected towards the east and west (Sakai et al. 2006). Consequently, the mountains

Fig. 1. Geological setting of the Kathmandu Basin, showing the sample location; modified after Fujii & Sakai (2001).

dammed the river water in the basin at their northern part, leading to the formation of the Palaeo-Lake Kathmandu.

The Lukundol Formation represents the oldest and major part of the basin fill of the Kathmandu Basin. This formation is exposed in the south of the Kathmandu Basin (Fig. 1), mostly along the Bagmati River, where also the type locality is described along the river Khahare Khola (Sakai et al. 2002). Within that succession, the basal Kalimati clay with intercalated lignites represents an open-lacustrine facies in the central part of the basin (Natori et al. 1980; Katel et al. 1996; Fujii & Sakai 2001). Clay and silt layers with elevated carbonate content are often rich in plant fossils. The base of the formation consists of coarse gravel, boulder and sand deposited by the braided river system of the Palaeo-Bagmati River (Sakai et al. 2002). At about 1 Ma, the deposition system changed, which led to the deposition of a four meter thick fossiliferous sandy unit in the otherwise monotonous mud-predominant sequence (Sakai et al. 2002). This change in the depositional environment does not only occur along the margin but can be found even in the centre of the Kathmandu Basin. Bivalves, gastropod-opercula and fish teeth occur in this sand bed which covers an area of 320 km². The large extent is interpreted as response to a lake level drop coinciding with a reversed current direction from south to north due to the rise of the Mahabharat Mountains. Consequently, fluvio-deltaic and back swamp environments became established.

This change appeared at about 1 Ma and is correlated with the Jaramillo Event at 0.99 Ma (Yoshida & Gautam 1988). Correspondingly, Goddu (2004) indicates an age of 0.9 Ma.

Above the sandy unit, silty mud was deposited representing a shallow lacustrine facies. The green algae *Pediastrum* is widespread in these deposits, pointing to shallow water conditions (Fujii & Sakai 2002; Yoshida & Igarashi 1984). The investigated samples derive from this part of the formation. Due to the still ongoing uplift of the mountains, the basin became quickly filled by sediments and the depocenters migrated further north. The Lukundol Formation is unconformably overlain by the Pleistocene lacustrine Gokarna Formation and the fluvio-deltaic Thimi and Patan Formations.

The Palaeo-Lake Kathmandu had its maximum extension at about 30.000 years BP, when it covered nearly the whole basin. A maximum lake depth of 1400 to 1440 m is calculated for that time (Fujii & Sakai 2002; Sakai et al. 2001; Saijo & Kimura 2007).

The Lukundol Formation is correlated with the Pliocene Karewa Formation in the Kashmir Basin and the Siwalik Group (Gupta 1975; Fort & Gupta 1981; West & Munthe 1981; Tuladhar 1982). Palaeomagnetic datings indicate a range from the Gauss Chron to the early Brunhes Chron (from late Pliocene to early Middle Pleistocene) (Yoshida & Gautam 1988; Fort & Gupta 1981). Amino-acid datings by Goddu (2004) document a distinctly younger age ranging between 1.8–0.75 Ma.

Due to the newer dating methods by Goddu and the correlation of the environmental changes within the Lukundol Formation with the Jaramillo Event by Yoshida & Gautam (1988), an age younger than 0.9 Ma is assumed.

Material and methods

The material was collected by Dr. David K. Ferguson and Dr. Khum N. Paudayal during a field-trip. The locality is known for leaf fossils near the place called Bungmati (N 27°37'53,62''N and E 85°18'28.29'', altitude 1336 m amsl) at the left and right bank of Nakkhu Khola, where a c. 11-m-thick part of the Lukundol Formation is exposed.

After the sample was crushed into small pieces and squelched in a mortar, some drops of HCl conc. were added to check, if the sample contained calcareous matter. Because no reaction was visible, directly the second step of the preparation was started to remove the silica with HF. The sediment was put into a copper pan above a Bunsen burner and was boiled between 10 and 15 minutes. After waiting about one hour for the sediment to settle down, the liquid was decanted and the sample was put into a glass vessel (600 ml). HCl conc. had to be added before it was again put above the Bunsen burner to boil the sample for another 10 to 15 minutes to avoid fluorspar/fluorite. Then another hour later the next decantation was done before the sample was filled into centrifuge tubes. To neutralise the acid, water was added and the tube was turned in the up to 3000 revolutions per minute. This step was repeated approximately 3 times. In the centrifuge tube, glacial acetic acid is the be added, before the same amount of saturated sodium chlorate was added till the tube was filled three-quarters and before 4 to 5 drops of concentrated hydrochloric acid werde added. Each tube was held in boiling water for approximately 5 minutes to promote oxidation. Afterwards the samples were washed with water and glacial acetic acid. In the next step the acetolysis liquid (ERDTMAN 1954) is added. Acetolysis is performed to colour the organic matter (sporopollenin part of all palynomorphs). After adding the acetolysis liquid, the sample was put into boiling water for another 5 to 10 minutes. The samples were then centrifuged and decanted.

For the work on the microscope the material, kept in glycerin, was put on a slide, but not covered with a cover glass. For light microscopy photography the pollen got transferred to a second slide, using a human short hair clued on a dissecting needle. The most interesting pollen and spore were moved outside the glycerin, where it sticks on the hair. As soon as the pollen grains touched a small drop of glycerin on the second slide, they departed the hair and a clear image could be taken. For the SEM the pollen grains were first collected in the same way with the hair on the needle outside the glycerin, before they were put on the stub in a drop of ethanol absolute, which removed the glycerin even from the pollen surface. No special fixing was done (ZETTER 1989; ZETTER & FERGUSON 2002).

For identification of the pollen mainly MOORE et al. (1995), BEUG (2004), FUJIKI et al. (2005) and GUPTA et al. (1986) were used. In addition, the palynological database from the University of Vienna (www.paldat.org) and the palynological homepage of the University of Arizona (http://www.geo.arizona.edu/palynology) were utilised.

Taxonomy

First palynological data from the Kathmandu Valley were presented by FRANZ & KRAL (1975) and KRAL & HAVINGA (1979). They focused on the Pleistocene sequences of the Palaeo-Lake Kathmandu. Based on the occurrence of temperate trees and herbaceous elements, they interpreted the climate to be more continental than at present. Later, a larger sample set was analysed by YOSHIDA & IGARASHI (1984), IGARASHI et al. (1988) and NAKAGAWA et al. (1996) resulting in the establishment of 5 pollen zones for the Lukundol Formation.

Additional palynonological studies have been performed by Fujii & Sakai (2002), Goddu (2004) and Paudayal (2002; 2004) which have been an important base for this study. The systematic arrangement follows Brands (1989-2005).

Abbreviations: LM – light-microscope, SEM- scanning electron microscope

Material: Natural History Museum Vienna, 2009B0001/0001 to 0020

Image annotion: A – Light microscop picture of the spore/pollen grain
B – Scanning electron microscope picture of the spore/pollen grain
C – Scanning electron microscope picture of the typical surface

Subphylum Euphyllophytina, Pryer et al., 2004

Class Polypodiopsida Cronquits, Takhtajan & Zimmermann, 1966

Order Polypodiales Link, 1833

Family Davalliaceae Mettenius ex Frank, 1877

Genus *Davallia* Smith, 1793

***Davallia* sp.**
Fig. 2

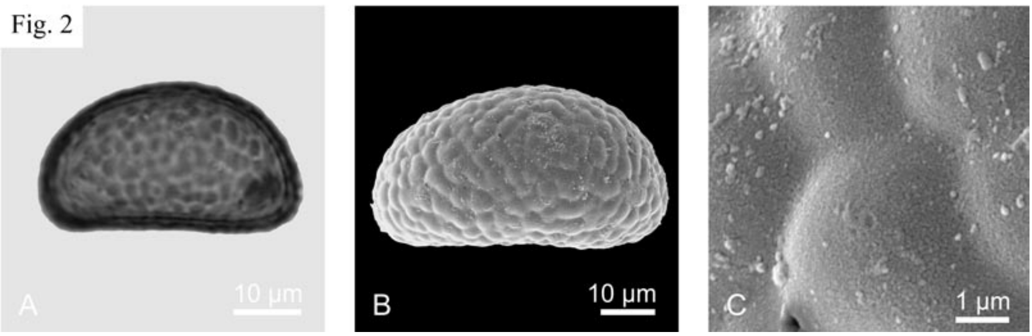
Size: medium (40–50 µm).

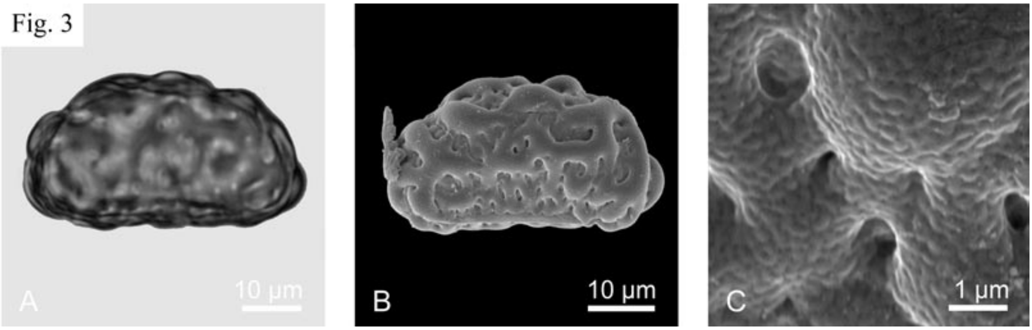
Shape: oblate; elliptic in equatorial view; elliptic in polar view.

Aperture type: monolet.

Exospore: LM: verrucate-like structure elements.
SEM: verrucate and additionally irregularly scattered granulae.

Fig. 2





Davalliaceae gen. indet.
Fig. 3

Size: medium (42–46 µm).

Shape: oblate; elliptic in equatorial view; elliptic in polar view.

Aperture type: monolet.

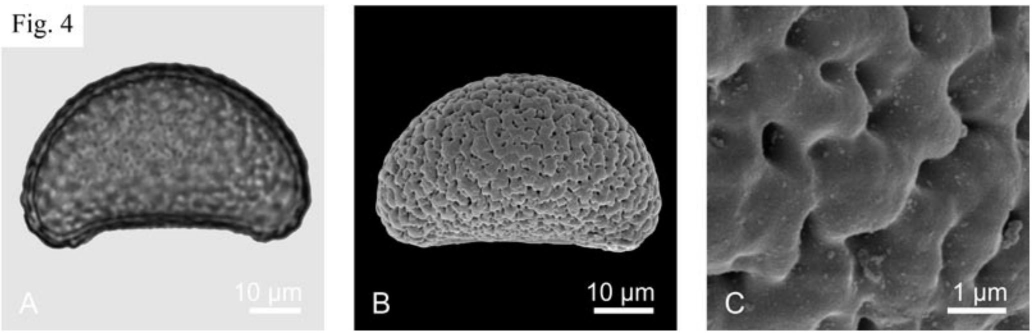
Exospore: LM: verrucate-like structure elements.

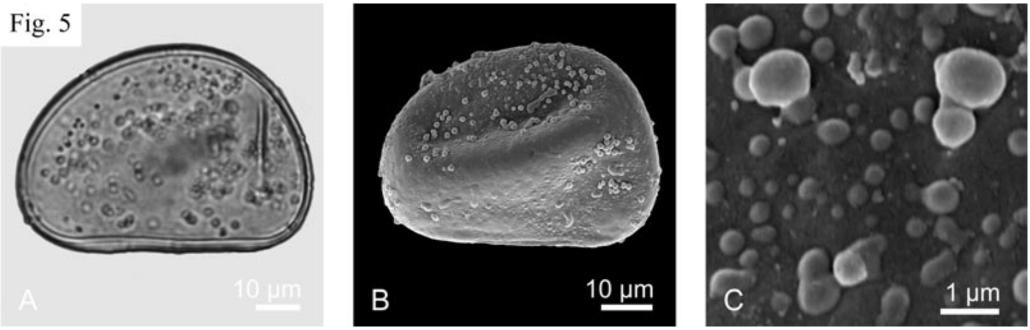
SEM: verrucate; the large verrucae form reticulum-like structure, the rugulae are larger at the distal pole, where around the aperture, they get smaller; the surface of the rugulae shows a mircoverrucate suprasculpture.

Family Polypodiaceae BERCHTOLD & PRESL, 1820

Genus *Lepisorus* (SMITH) CHING, 1933

***Lepisorus* sp.**
Fig. 4





Size: large (29–33 x 50–58 µm).

Shape: oblate; elliptic in the equatorial view; elliptic in polar view.

Aperture type: monolet.

Exospore: LM: verrucate-like structure elements.

SEM: foveolate to perforate; on the surface, granulae are irregularly distributed.

Genus *Pyrrosia* Mirbel, 1803

Pyrrosia sp.
Fig. 5

Size: large (60–70 µm).

Shape: oblate; elliptic in equatorial view; elliptic in polar view.

Aperture type: monolet.

Exospore: LM & SEM: psilate with irregular microverrucae

Polypodiaceae gen. indet. 1
Fig. 6

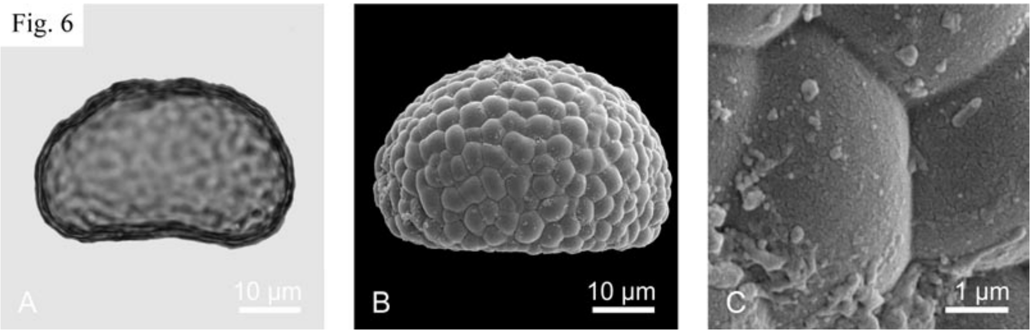
Size: medium (42–48 µm).

Shape: oblate; elliptic in equatorial view; elliptic in polar view.

Aperture type: monolet.

Exospore: LM: verrucate-like structure elements.

SEM: verrucate, additionally fossulate.



Polypodiaceae gen. indet. 2
Fig. 7

S i z e : medium to large (34–37 x 50–56 µm).

S h a p e : oblate; elliptic in equatorial view; elliptic in polar view.

A p e r t u r e t y p e : monolet.

E x o s p o r e : LM: verrucate-like structure elements.
SEM: verrucate with a fossulate and microverrucate surface.

R e m a r k s : This spore is distinguished from Polypodiaceae gen. indet. 1 by its larger size and the asymmetric verrucae.

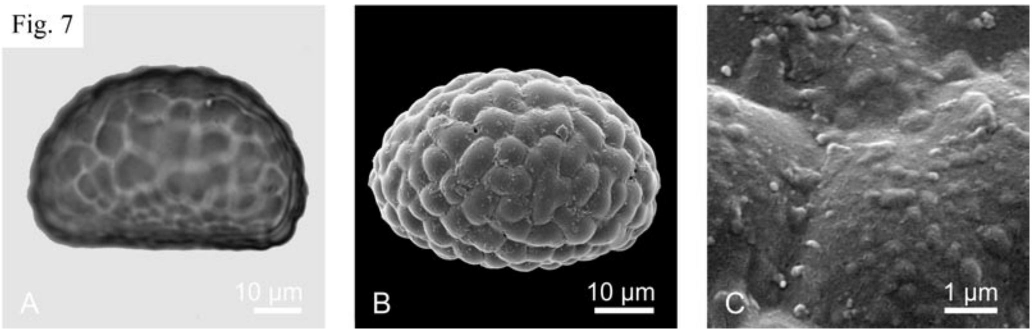
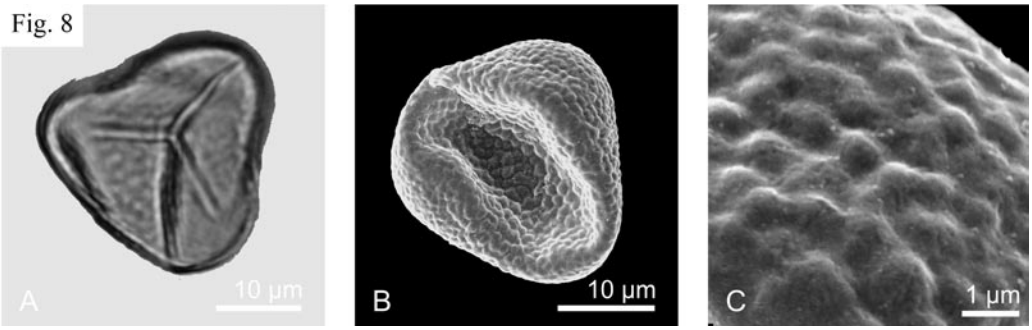


Fig. 8



Polypodiaceae gen. indet. 3
Fig. 8

Size: medium (24–26 µm).

Shape: oblate; straight obtuse triangular in polar view.

Aperture type: trilet.

Exospore: LM: scabrate to slightly verrucate.
SEM: verrucate in the SEM with irregularly scattered granulae.

Family Pteridaceae KIRCHNER, 1831

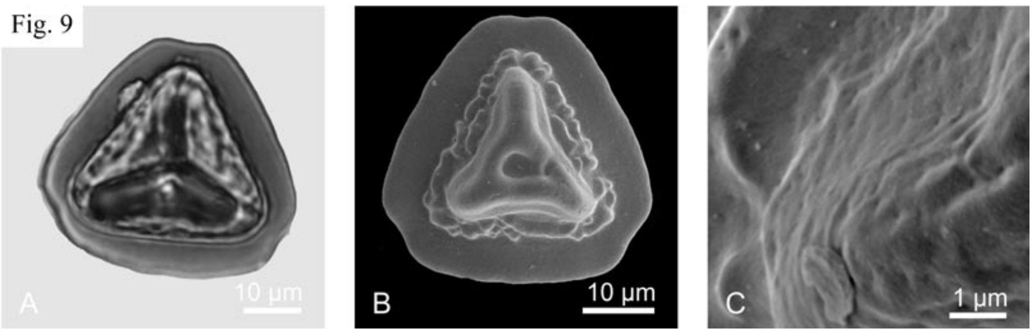
Pteridaceae gen. indet. 1
Fig. 9

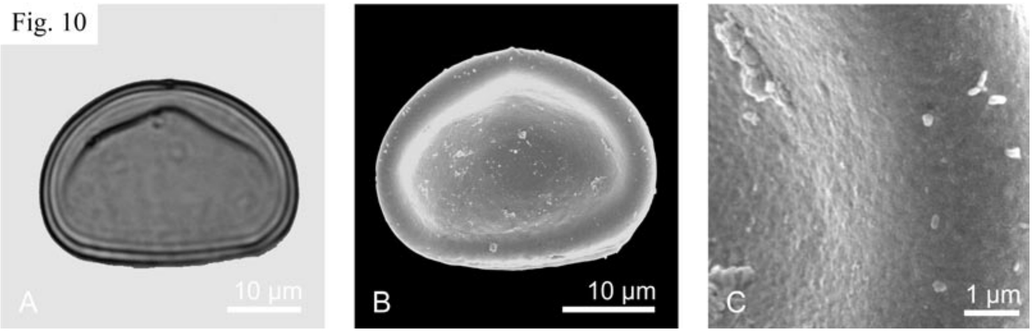
Size: medium (37–41 µm).

Shape: oblate; straight obtuse triangular in the polar view.

Aperture type: trilet.

Fig. 9





Exospore: LM & SEM: psilate in the central area, a random part of verrucae before a broad psilate cingulum.

Family Blechnaceae (PRESL) COPELAND, 1947

Genus *Woodwardia* SMITH, 1793

***Woodwardia* sp.**
Fig. 10

Size: medium (25 µm x 32–34 µm).

Shape: oblate, elliptic.

Aperture type: monolet.

Exospore: LM: psilate.
SEM: psilate to fossulate.

Subphylum Lycophytina KENRICK & CRANE, 1997

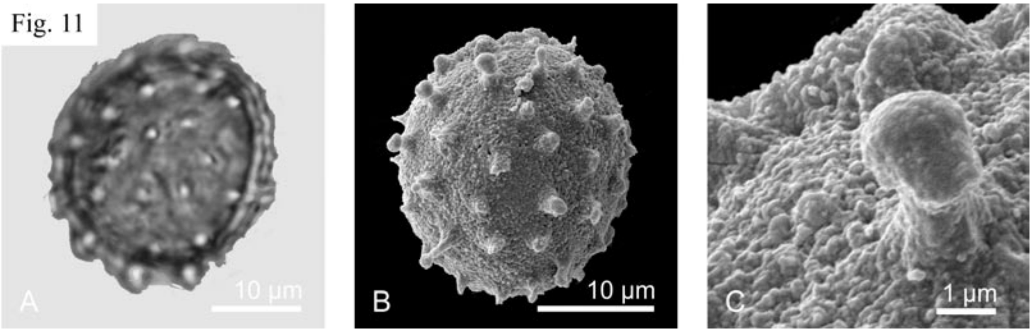
Class Lycopsida SCOTT, 1909

Lycopodiopsida BARTLING, 1830

Order Selaginellales PRANTL, 1874

Family Selaginellaceae WILLKOMM, 1854

Genus *Selaginella* PALISOT DE BEAUVOIS, 1805



Selaginella sp.
Fig. 11

Size: medium (23–28 µm).

Shape: oblate; spheroidal; circular in polar view.

Aperture type: trilet.

Exospore: LM: scabrate and pilate.

SEM: granulate and roughly fossulate with pilae (on the top granulate as well).

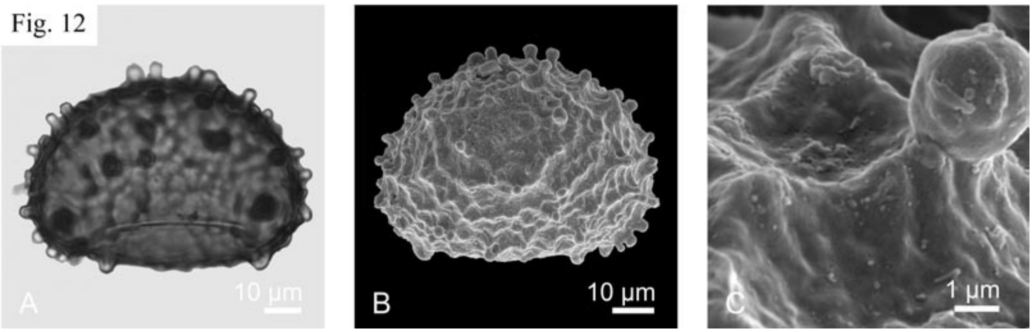
Remarks: Pilae occur only on the distal side of the spore where the ornamentation is also less distinctive.

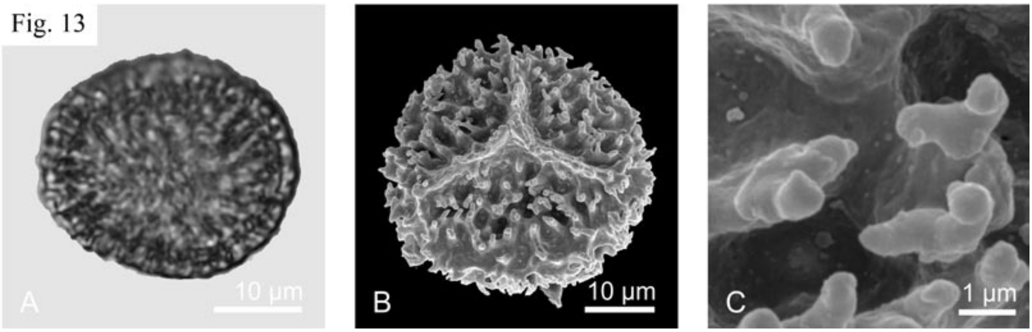
Spore gen. indet. 1
Fig. 12

Size: large (65–71 µm).

Shape: oblate; elliptic in the equatorial view; elliptic in the polar view.

Aperture type: monolet.





E x o s p o r e : LM: verrucate with baculae and rare clavae.

SEM: mircoverrucate and fossulate with baculae and rare clavae.

Spore gen. indet. 2
Fig. 13

S i z e : medium (27–33 µm).

S h a p e : oblate to spheroidal circular in the polar view.

A p e r t u r e t y p e : trilet.

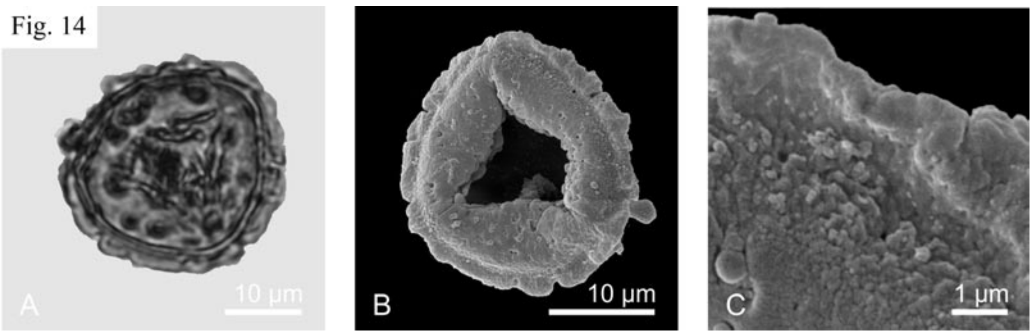
E x o s p o r e : LM: reticulate-like to gemmate.

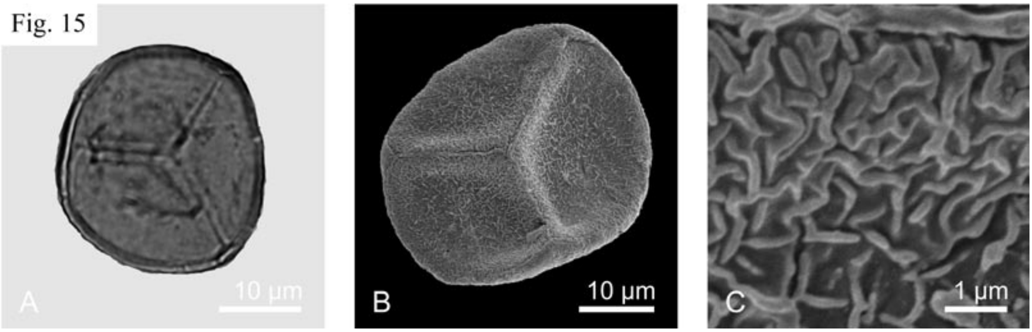
SEM: spinae-like forked sculpture elements are arranged to a reticulum-like sculpture.

Spore gen. indet. 3
Fig. 14

S i z e : medium (22–27 µm).

S h a p e : oblate; obtuse triangular.





A p e r t u r e t y p e : trilet.

E x o s p o r e : LM: verrucate.

SEM: perforate around the aperture; granulate close to the cingulum; few pilae on the distal side.

Spore gen. indet. 4

Fig. 15

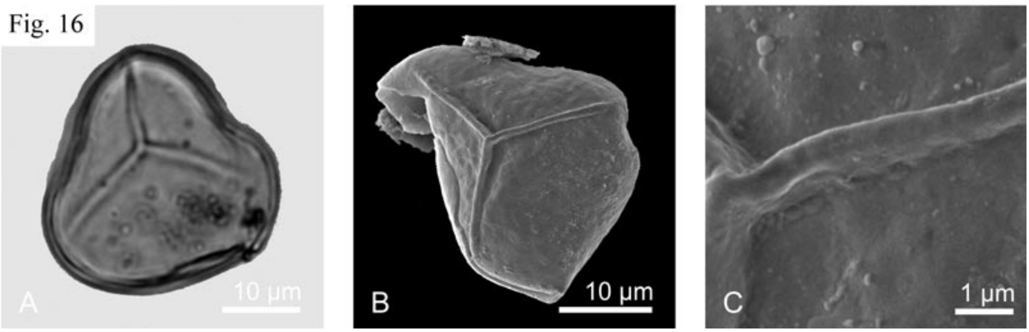
S i z e : medium (29–35 µm).

S h a p e : oblate; obtuse triangular to circular in polar view.

A p e r t u r e t y p e : trilet.

E x o s p o r e : LM: psilate to scabrate; a curva imperfecta can be seen.

SEM: psilate with microrugulae around the aperture.



Spore gen. indet. 5
Fig. 16

S i z e : small (20–23 µm).

S h a p e : oblate; obtuse triangular to circular.

A p e r t u r e t y p e : trilet.

E x o s p o r e : LM & SEM: psilate.

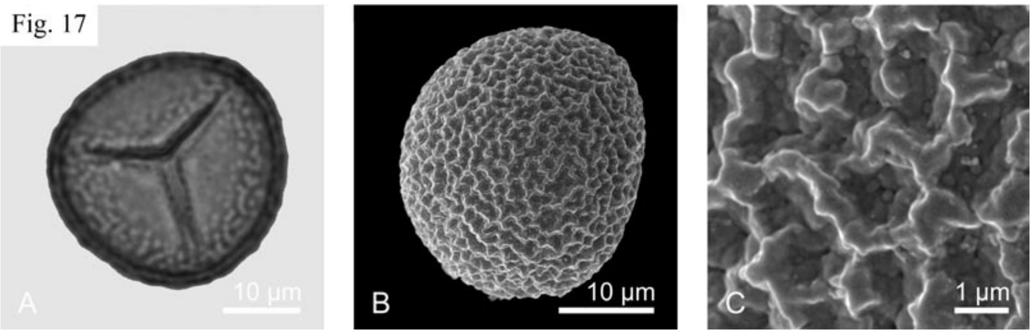
Spore gen. indet. 6
Fig. 17

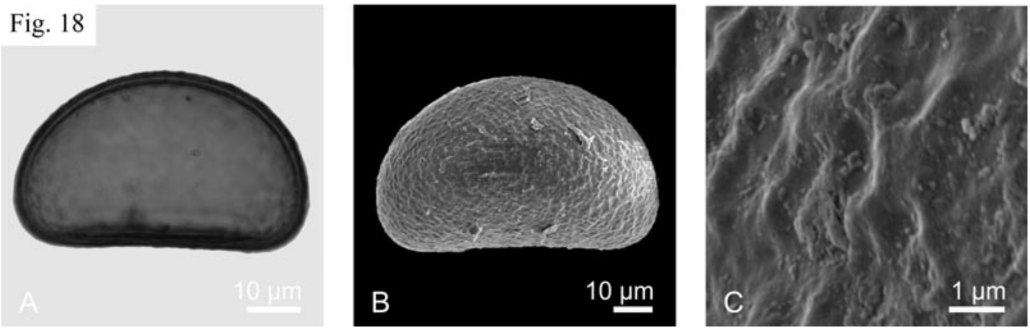
S i z e : medium (27–29 µm).

S h a p e : oblate; circular to obtuse triangular in polar view.

A p e r t u r e t y p e : trilet.

E x o s p o r e : LM: scabrate to rugulate.
SEM: shows a reticulate-like sculpture.





Spore gen. indet. 7
Fig. 18

Size: large (58–63 µm).

Shape: oblate; elliptic in the equatorial view; elliptic in the polar view.

Aperture type: monolet.

Exospore: LM: scabrate.
SEM: rugulate and fossulate.

Spore gen. indet. 8
Fig. 19

Size: medium (38–41 µm).

Shape: oblate; elliptic in the polar view.

Aperture type: monolet.

Exospore: LM: psilate.
SEM: fossulate to microrugulate and perforate.

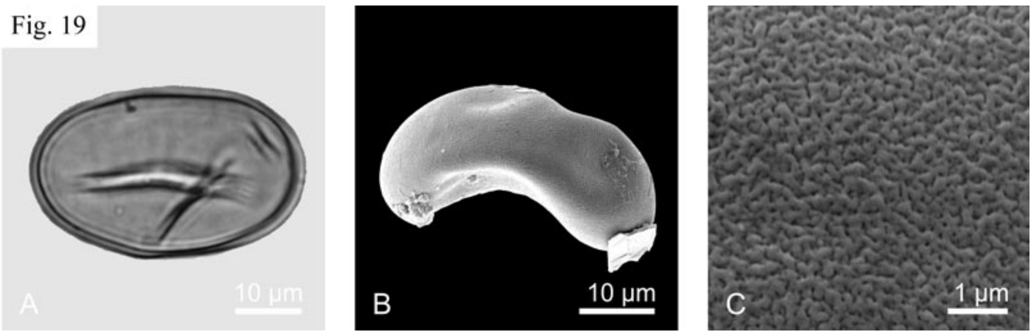
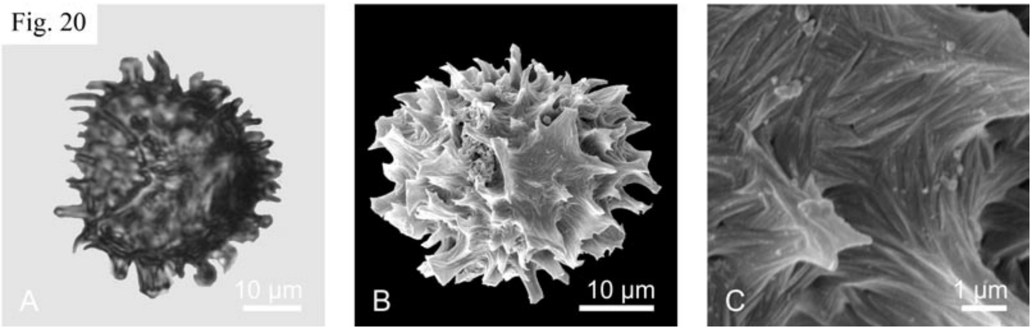


Fig. 20



Spore gen. indet. 9
Fig. 20

Size: medium (27–42 µm).

Shape: spheroidal to oblate; circular to obtuse triangular in polar view.

Aperture type: trilet.

Exospore: LM: echinate.

SEM: the echinae are covered leading to an angular scratched looking surface.

Spore gen. indet. 10
Fig. 21

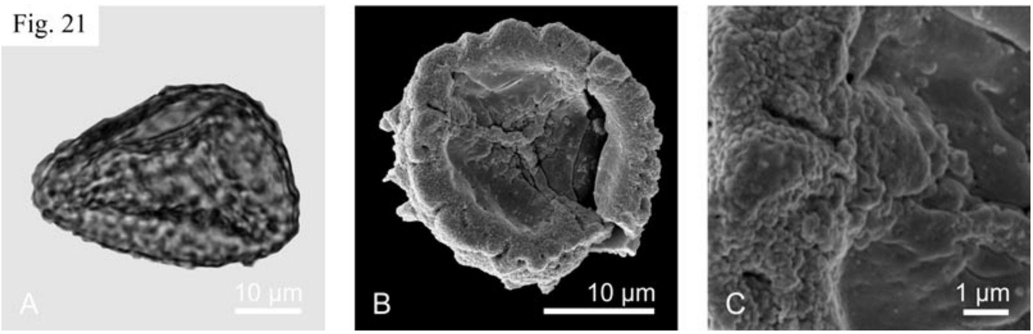
Size: medium (24–30 µm).

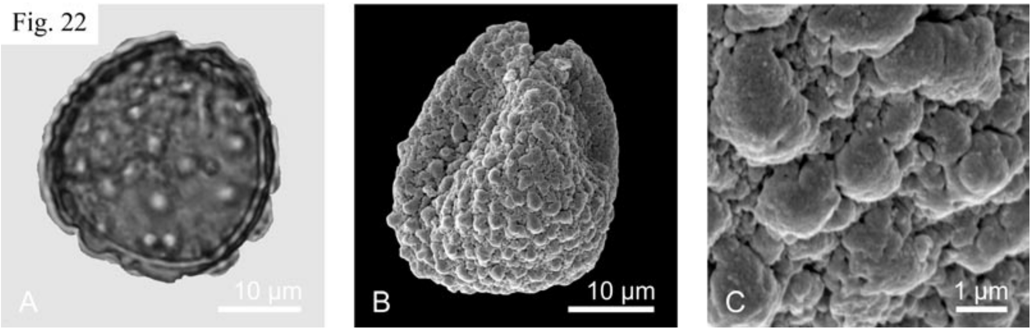
Shape: oblate; straight obtuse triangular.

Aperture type: trilet.

Exospore: LM: scabrate to verrucate.

Fig. 21





SEM: granulate to fossulate; psilate on the proximal side; around the trilet mark small verrucae appear; distal echinae-like sculpture elements are common.

Spore gen. indet. 11
Fig. 22

Size: medium (28–30 µm).

Shape: oblate; straight obtuse triangular.

Aperture type: trilet.

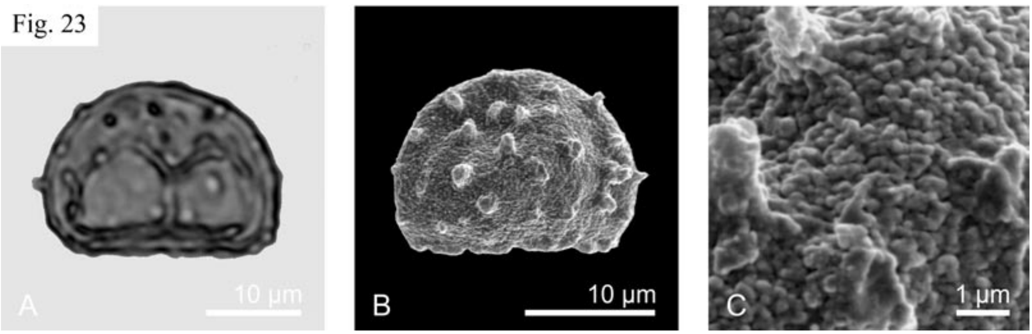
Exospore: LM: verrucate.

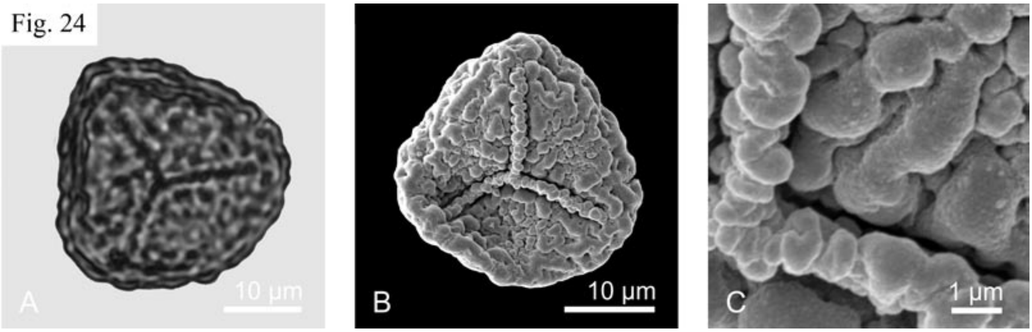
SEM: verrucate and fossulate.

Spore gen. indet. 12
Fig. 23

Size: small (19–24 µm).

Shape: oblate; elliptic in equatorial view.





A p e r t u r e t y p e: monolet.

E x o s p o r e: LM: psilate with few baculae.

SEM: granulate with roughly fossulate with baculae.

Spore gen. indet. 13

Fig. 24

S i z e: medium (26–29 µm).

S h a p e: oblate; straight obtuse triangular.

A p e r t u r e t y p e: trilet.

E x o s p o r e: LM: verrucate.

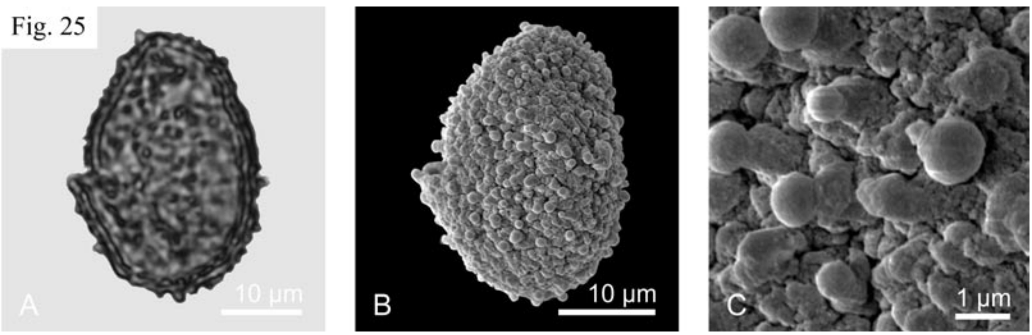
SEM: verrucate with a granulate to fossulate surface.

Spore gen. indet. 14

Fig. 25

S i z e: medium (17–20 x 28–32 µm).

S h a p e: oblate; elliptic.



Aperture type: monolet.

Exospore: LM: baculate to clavate.

SEM: sculpturing is characterized by gemmae or clavae.

Phylum Tracheophyta SINNOTT ex CAVALIER-SMITH, 1998

Subphylum Euphyllophytina PRYER et al., 2004

Class Gnetopsida THOMÉ, 1886

Order Gnetales FRIES, 1891

Family Ephedraceae DUMORTIER, 1829

Genus *Ephedra* LINNAEUS, 1753

***Ephedra* cf. *intermedia* SCHRENK & MEYER ex MEYER, 1846**

Fig. 26

Size: medium (39–44 x 14–17 µm).

Shape: oblate; inaperturate.

Aperture type: polyplicate.

Aperture number: 6.

Ornamentation: LM & SEM: psilate.

Class Pinopsida BURNETT, 1835

Order Pinales DUMORTIER, 1829

Family Pinaceae LINDLEY, 1836

Fig. 26

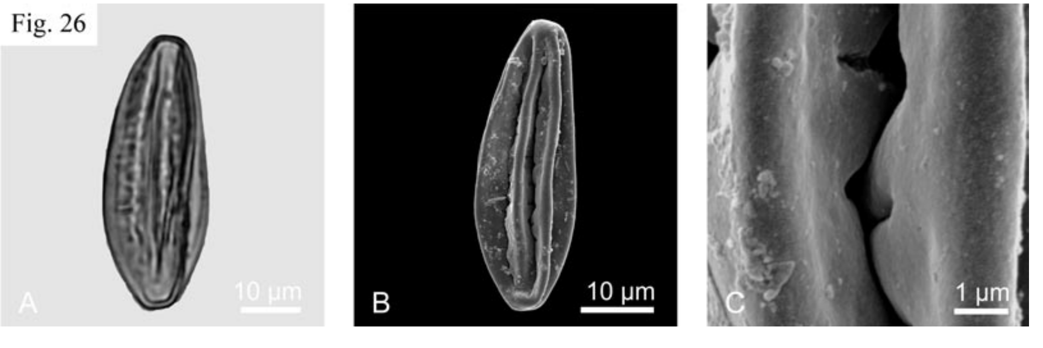
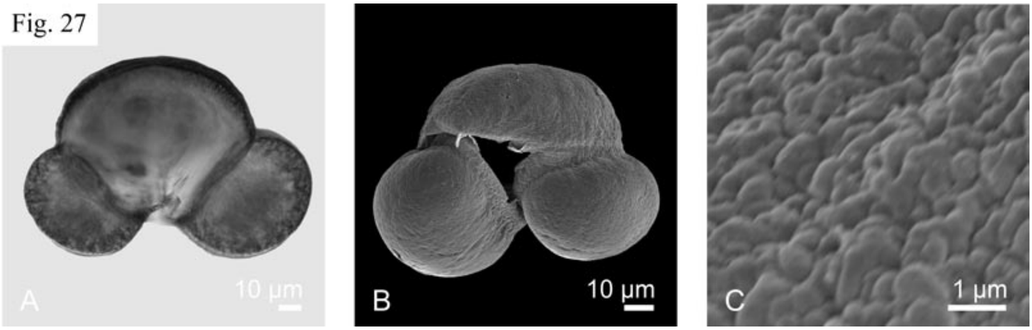


Fig. 27



Genus *Abies* MILLER, 1754

***Abies* sp.**
Fig. 27

Size: very large (110–115 µm).

Shape: bisaccate.

Aperture type: leptoma.

Aperture number: 1.

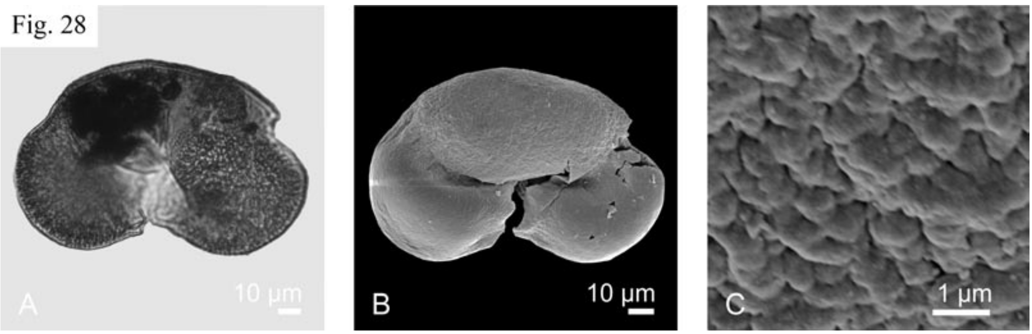
Ornamentation: LM: corpus is rugulate to verrucate; around the leptoma the ornamentation becomes coarser; the distinguishing feature to the other Pinaceae is the strongly thickened cappa.

SEM: corpus is rugulate to verrucate; around the leptoma the orna mentation becomes coarser; sacci are perforate.

Genus *Picea* DIETRICH, 1824

***Picea* sp.**
Fig. 28

Fig. 28



Size: very large (120–130 µm).

Shape: bisaccate.

Aperture type: leptoma.

Aperture number: 1.

Ornamentation: LM: scabrate; can easily be recognized among the Pinaceae be cause of the low angel between the corpus and the sacci;the sacci seem to touch each other around the leptoma.

SEM: surface of the corpus is rugulate and perforate; the ornamentation is coarser between the corpus and the sacci.

Genus *Pinus* LINNAEUS, 1754

Pinus roxburghii SARGENT in SILVA, 1897
Fig. 29

Size: large (50–60 µm).

Shape: bisaccate.

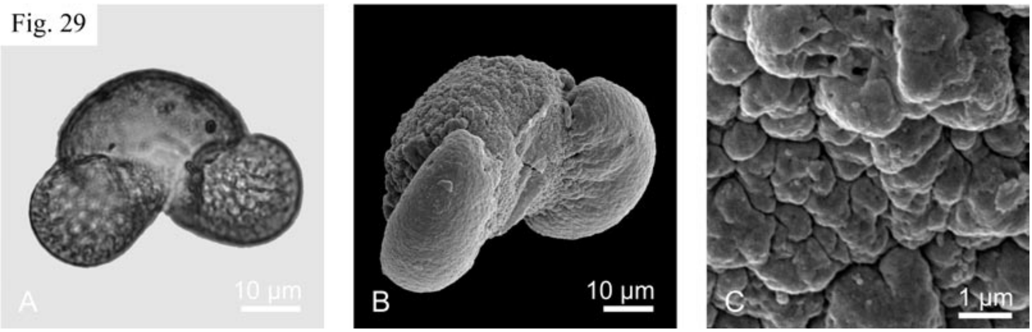
Aperture type: leptoma.

Aperture number: 1.

Ornamentation: LM: scabrate; the sacci display an acute angel to the corpus.

SEM: verrucate on the corpus, showing bigger verrucae around the sacci; the sacci are granulate and perforate.

Fig. 29



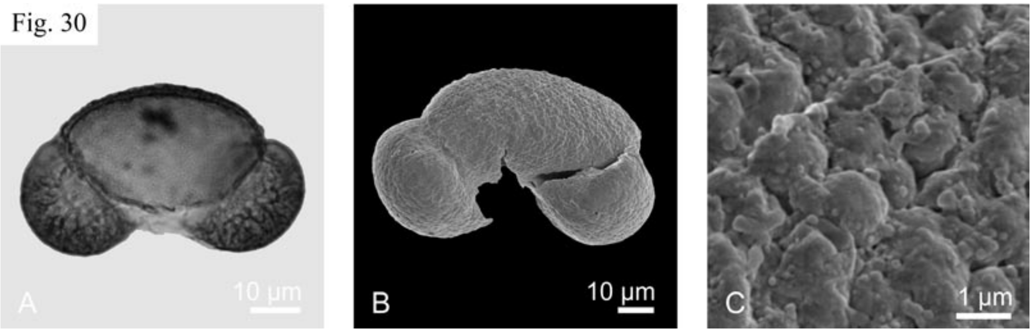


Fig. 30

Pinus wallichiana JACKSON, 1938
Fig. 30

Size: large (60–70 µm).

Shape: bisaccate.

Aperture type: leptoma.

Aperture number: 1.

Ornamentation: LM: scabrate; the sacci have blunt angels at the corpus.

SEM: verrucate on the corpus; the verrucae are next to the sacci; the sacci are granulate and perforate.

Genus *Tsuga* (ENDLICHER) CARRIÈRE, 1855

Tsuga cf. _dumosa_ (DON) EICHLER, 1887
Fig. 31

Size: large (66–68 µm).

Shape: monosaccate; circular in the polar view; bowl-shaped in the equatorial view.

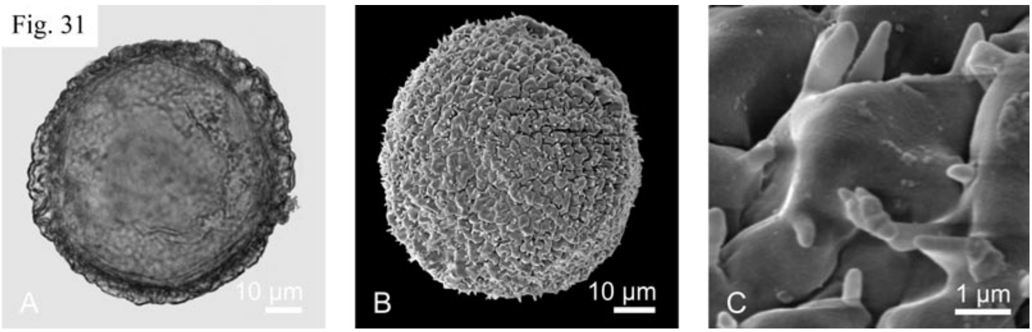


Fig. 31

Aperture type: leptoma.

Aperture number: 1.

Ornamentation: LM: scabrate and echinate.

SEM: verrucate or rugulate with irregularly scattered echinae of different size.

Order Podocarpales Pulle ex Reveal, 1992

Family Podocarpaceae Endlicher, 1847

Genus *Podocarpus* l'Héritier ex Persoon, 1807

***Podocarpus* sp.**
Fig. 32

Size: medium (32 µm).

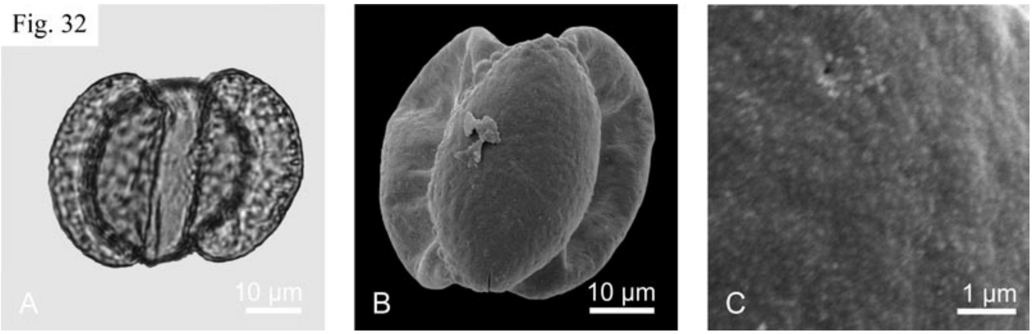
Shape: bisaccate.

Aperture type: leptoma.

Aperture number: 1.

Ornamentation: LM: scabrate.

SEM: microechinate; microechinae are densely scattered and very small; there is no difference between the ornamentation of the corpus and the sacci.



Class Magnoliopsida BRONGNIART, 1843

Subclass Caryophyllidae TAKHTAJAN, 1967

Superorder Caryophyllanae TAKHTAJAN, 1967

Order Caryophyllales PERLEB, 1826

Family Caryophyllaceae DURANDE, 1782

Caryophyllaceae gen. indet.
Fig. 33

Size: small (9–12 µm).

Shape: spheroidal.

Aperture type: porate.

Aperture number: panto.

Ornamentation: LM: scabrate; thick sexine is visible.

SEM: perforate and microechinate with microechinae; the echinae are more acute around the pores and cover also the pore membrane.

Family Chenopodiaceae VENTENAT, 1799

Chenopodiaceae gen. indet. 1
Fig. 34

Size: small (16–20 µm).

Shape: spheroidal.

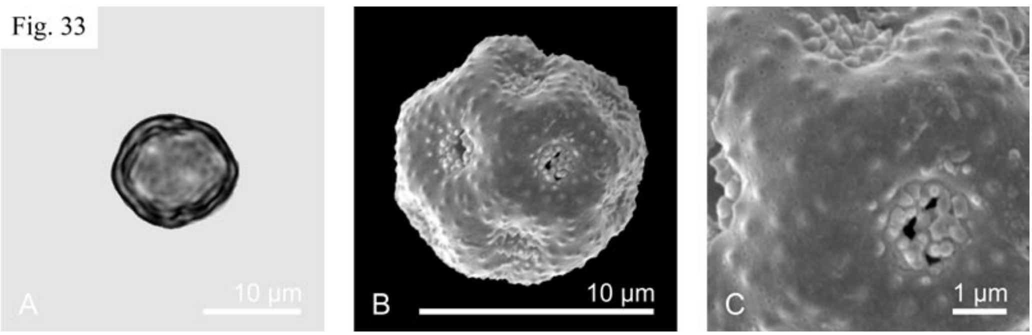
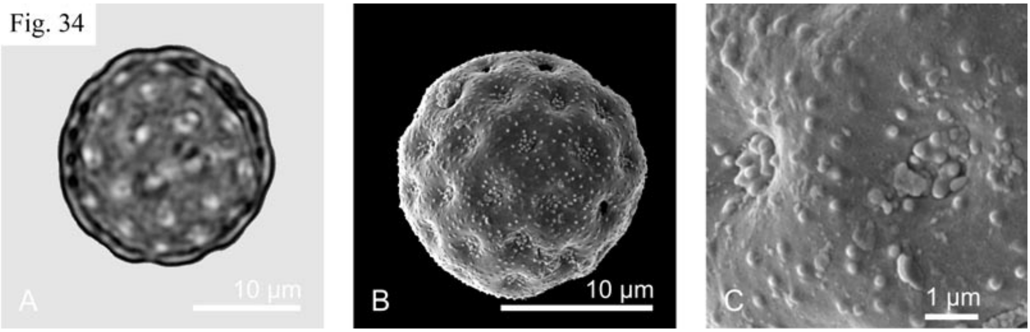


Fig. 33



Aperture type: porate.

Aperture number: panto.

Ornamentation: LM: scabrate.

SEM: perforate with microechinae; the microechinae are irregularly scatted, and densely cover the pore membrane.

Chenopodiaceae gen. indet. 2
Fig. 35

Size: small (21–23 µm).

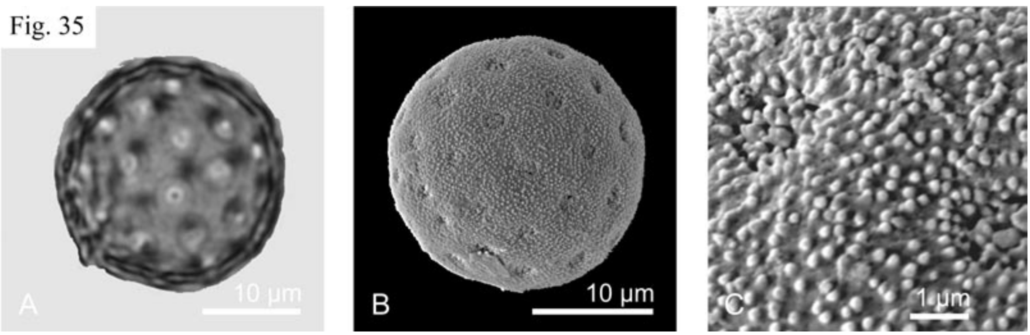
Shape: spheroidal.

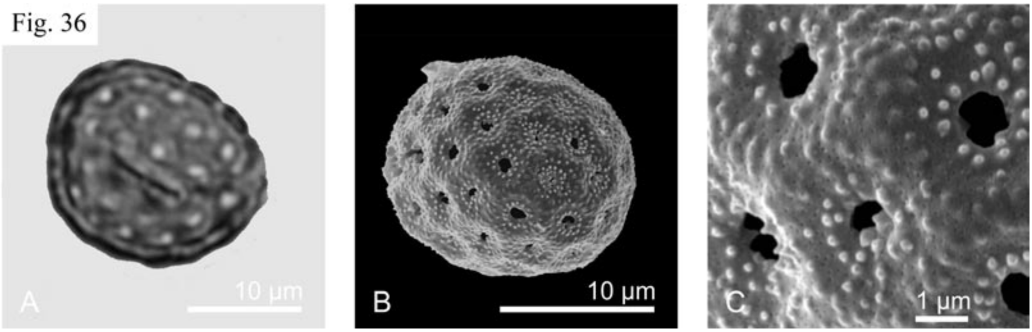
Aperture type: porate.

Aperture number: panto.

Ornamentation: LM: psilate.

SEM: perforate and microechinate; microechinae are densely scattered over the whole surface and the pore membrane.





R e m a r k s : It can be distinguished from the other Chenopodiaceae by its larger microechinae, which are more numerous than in Chenopodiaceae gen. indet. 1, but less than in Chenopodiaceae gen. indet. 3.

Chenopodiaceae gen. indet. 3
Fig. 36

S i z e : small (17–19 µm).

S h a p e : spheroidal.

A p e r t u r e t y p e : porate.

A p e r t u r e n u m b e r : panto.

O r n a m e n t a t i o n : LM: psilate to scabrate.
SEM: perforate with many microechinae.

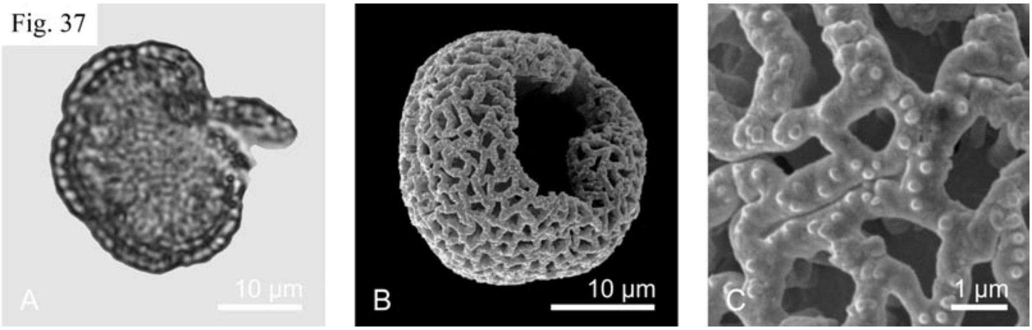
R e m a r k s : This species can be distinguished from Chenopodiaceae gen. indet. 1 and Chenopodiaceae gen. indet. 2 by it numerous echinae, which are regularly arranged. Moreover it differs in its less deep pores.

Class Magnoliopsida BRONGNIART, 1843

Subclass Lamiidae TAKHTAJAN ex REVEAL, 1992

Superorder Lamianae TAKHTAJAN, 1967

Order Lamiales BROMHEAD, 1838



Lamiaceae gen. indet.
Fig. 37

Size: medium (24–28 µm).

Shape: oblate; circular lobate in polar view.

Aperture type: colpate.

Aperture number: 6.

Ornamentation: LM: reticulate.

SEM: reticulate-heterobrochate; muri are regularly covered with mircoechinae.

Subclass Hamamelididae TAKHTAJAN, 1967

Superorder Faganae ENGLER, 1892

Order Fagales ENGLER, 1892

Family Fagaceae DUMORTIER, 1829

Genus *Quercus* LINNAEAUS, 1753

***Quercus semecarpifolia* SMITH, 1814**
Fig. 38

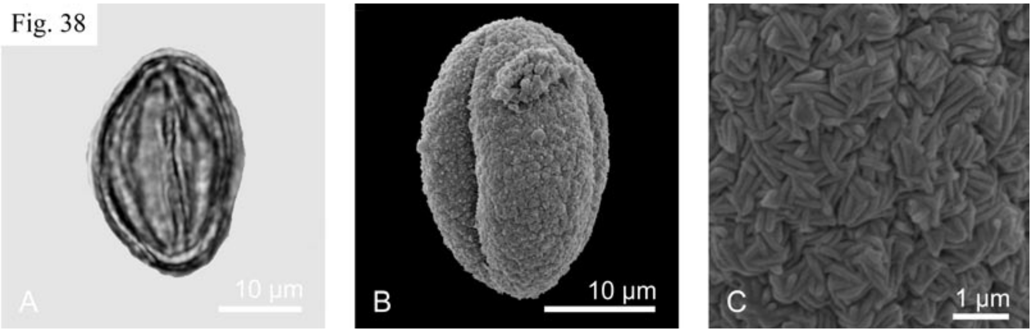
Size: small (17 x 25 µm).

Shape: prolate; elliptic in the equatorial view; circular to triangular in the polar view.

Aperture type: colpus.

Aperture number: 3.

Fig. 38



Ornamentation: LM: scabrate.

SEM: striate; the short striae do not have a reoccurring pattern; they often lie parallel to other and unite at a certain point.

Quercus glauca THUNBERG, 1784
Fig. 39

Size: small (15–18 x 19–22 µm).

Shape: prolate; elliptic in the equatorial view; circular to triangular in the polar view.

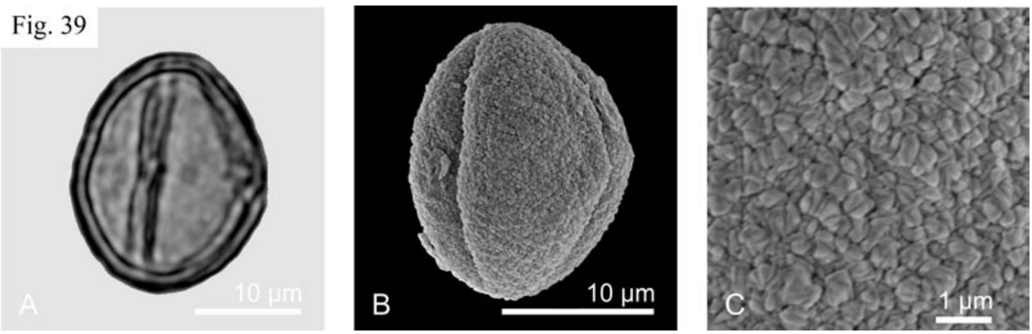
Aperture type: colporate.

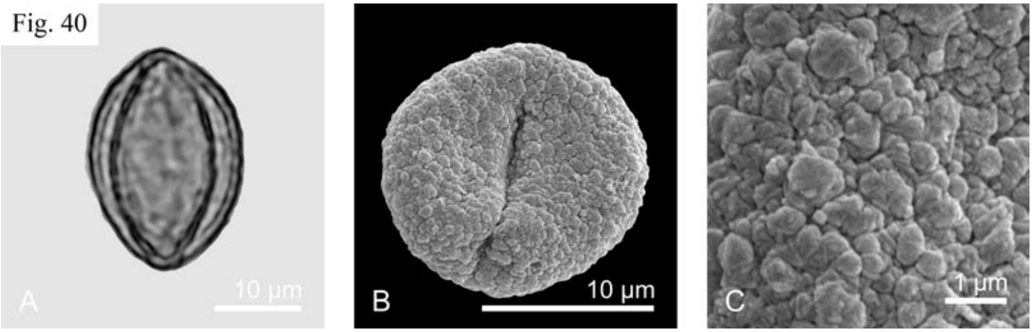
Aperture number: 3.

Ornamentation: LM: scabrate.

SEM: surface is characterised by mircoverrucae, which are often combined of several parts.

Fig. 39





Quercus sp. 1
Fig. 40

Size: small (15–18 x 18–24 µm).

Shape: prolate; elliptic to in the equatorial view; circular to triangular in the polar view.

Aperture type: colpus.

Aperture number: 3.

Ornamentation: LM: scabrate.

SEM: microverrucate; microverrucae show often a slightly striate suprasculpture.

Quercus sp. 2
Fig. 41

Size: small (15–17 x 17–22 µm).

Shape: prolate; elliptic in the equatorial view; circular to triangular in the polar view.

Aperture type: colpus.

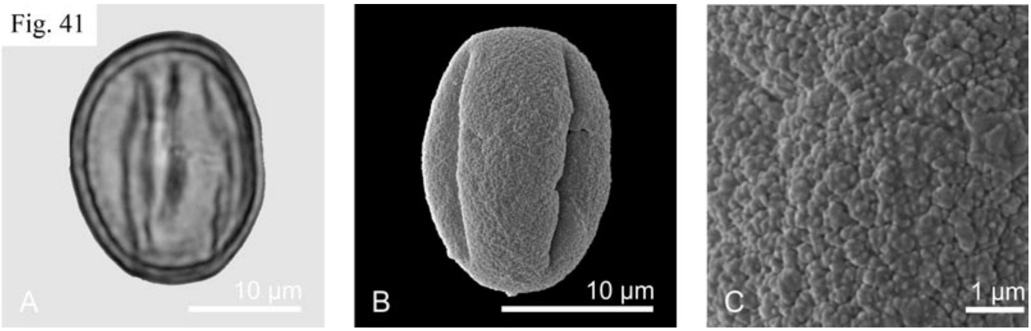
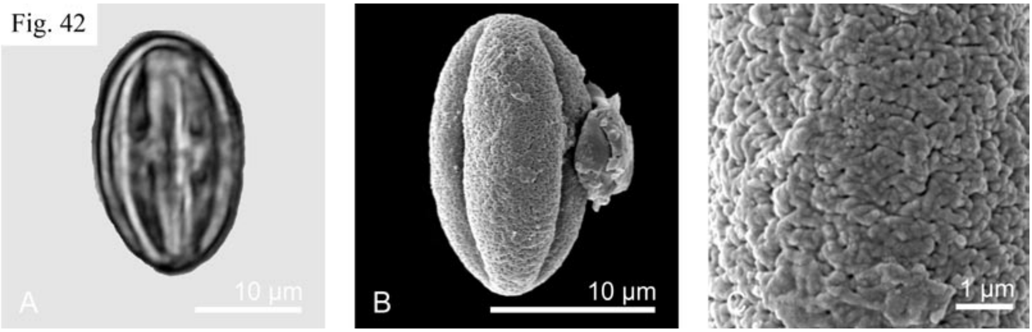


Fig. 42



Aperture number: 3.

Ornamentation: LM: scabrate.

SEM: microverrucate and fossulate; microverrucae show a micro-echinate suprasculpture.

Quercus sp. 3
Fig. 42

Size: small (12–14 x 19–22 µm).

Shape: prolate; elliptic in the equatorial view; triangular in the polar view.

Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: psilate to scabrate.

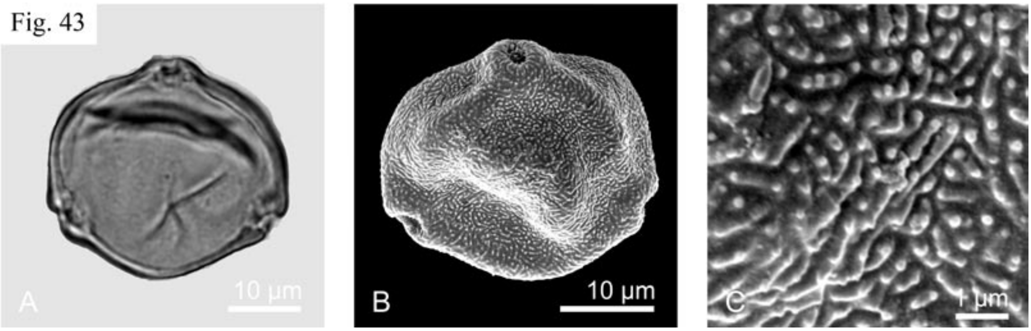
SEM: striate and perforate; short striae origin around perforations.

Order Corylales DUMORTIER, 1829

Family Betulaceae GRAY, 1821

Genus *Betula* LINNAEUS, 1753

Fig. 43



Betula sp.
Fig. 43

S i z e : medium (29–33 µm).

S h a p e : oblate; triangular obtuse convex in polar view; elliptic in equatorial view.

A p e r t u r e t y p e : porate.

A p e r t u r e n u m b e r : 3.

O r n a m e n t a t i o n : LM: psilate; sexine gets clearly thicker around the porus.
SEM: microrugulate with microechinae on the top of the microrugulae.

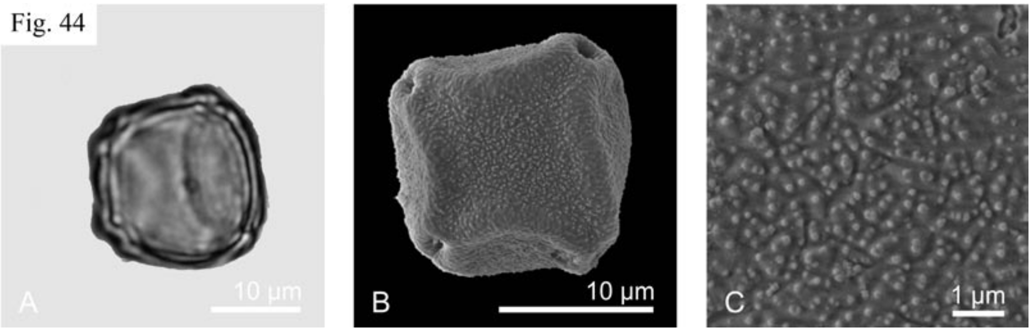
Genus *Alnus* Miller, 1754

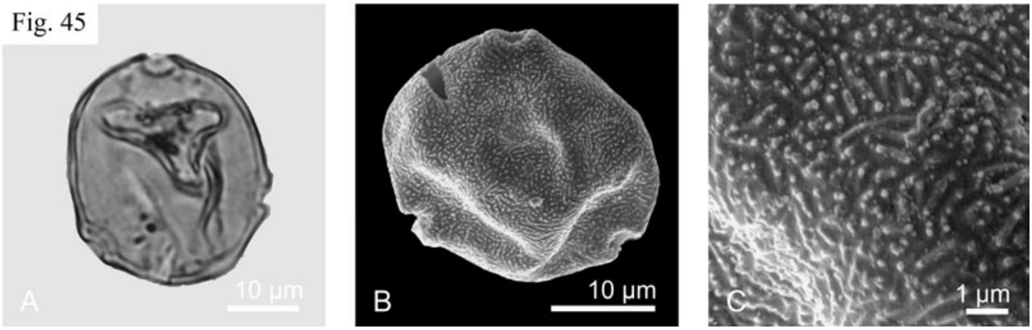
Alnus sp.
Fig. 44

S i z e : small (13–17 µm).

S h a p e : oblate; quinquangular obtuse concave.

Fig. 44





Aperture type: porate.

Aperture number: 4–6.

Ornamentation: LM: psilate; easy to recognize because of the thickened exine (arcus), that leads from one pore to the next.

SEM: microechinate to slightly microrugulate.

Family Corylaceae MIRBEL, 1815

Genus *Carpinus* LINNAEUS, 1753

***Carpinus* sp.**
Fig. 45

Size: medium (26–50 µm).

Shape: oblate; convex triangular in polar view.

Aperture type: porate.

Aperture number: 3.

Ornamentation: LM: psilate.

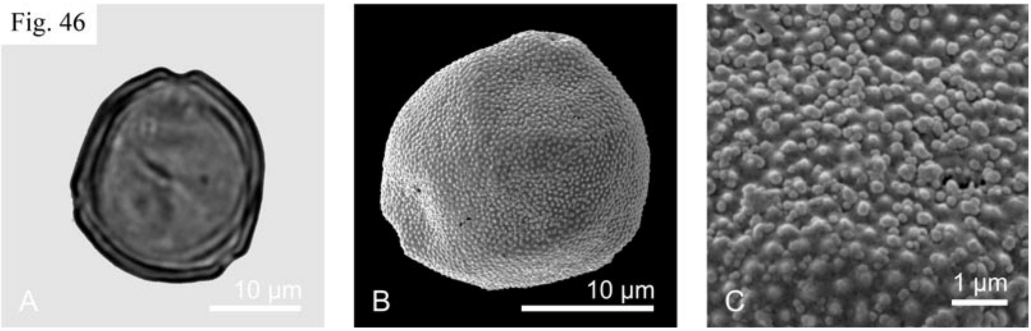
SEM: microrugulate and microechinate; microechinae are located on the top of the microrugulae.

Superorder Juglandanae TAKHTAJAN ex REVEAL, 1992

Order Juglandales DUMORTIER, 1829

Family Juglandaceae RICHARD ex KUNTH, 1824

Genus *Engelhardia* LESCHENAULT ex BLUME, 1825



***Engelhardia* sp.**
Fig. 46

Size: small (20–22 µm).

Shape: oblate; convex obtuse triangular in polar view.

Aperture type: porate.

Aperture number: 3.

Ornamentation: LM: psilate.

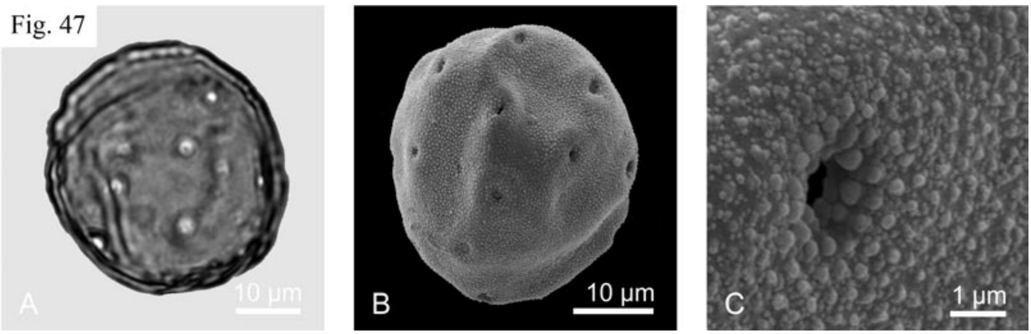
SEM: microechinate; microechinae are densely placed over the whole surface.

Genus *Juglans* LINNAEAUS, 1753

***Juglans* sp.**
Fig. 47

Size: medium (33–39 µm).

Shape: oblate.



Aperture type: porate.

Aperture number: more than 6; more or less regular arranged over the whole pollen grain.

Ornamentation: LM: psilate.

SEM: microechinate; the microechinae tend to get bigger around the porus.

Subclass Dilleniidae TAKHTAJAN, 1967

Superorder Primulanae DAHLGREN ex REVEAL, 1996

Order Styracales BURNETT, 1835

Family Symplocaceae DESFONTAINES, 1820

Genus *Symplocos* JACQUIN, 1760

***Symplocos* sp. 1**
Fig. 48

Size: small to medium (23–28 µm).

Shape: oblate; triangular obtuse concave in polar view.

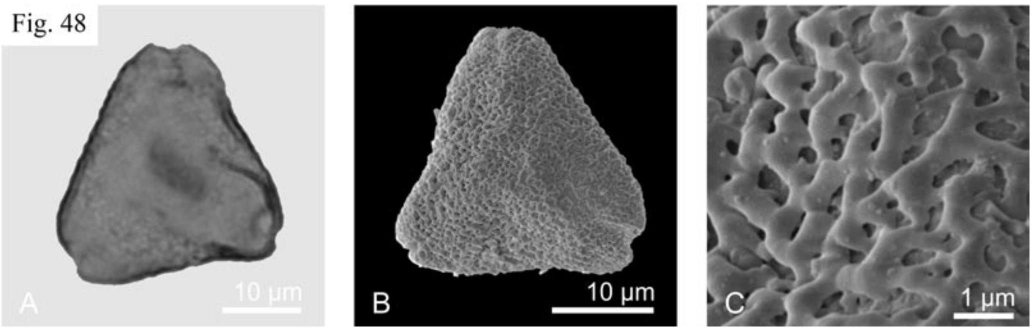
Aperture type: colporate.

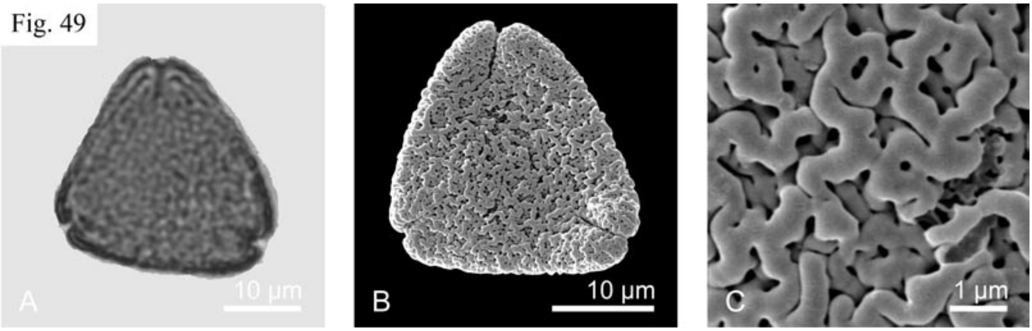
Aperture number: 3.

Ornamentation: LM: scabrate.

SEM: microreticulate-heterobrochate; the brochae of the reticulum are not always closed; vertexes are higher than the rest of the reticulum; thickness of the muri is varying; surface shows infrequent granulae.

Fig. 48





Symplocos sp. 2
Fig. 49

Size: small (23–24 µm).

Shape: oblate; triangular obtuse convex in the polar view; elliptic in the equatorial view.

Aperture type: (brevi-)colporate.

Aperture number: 3.

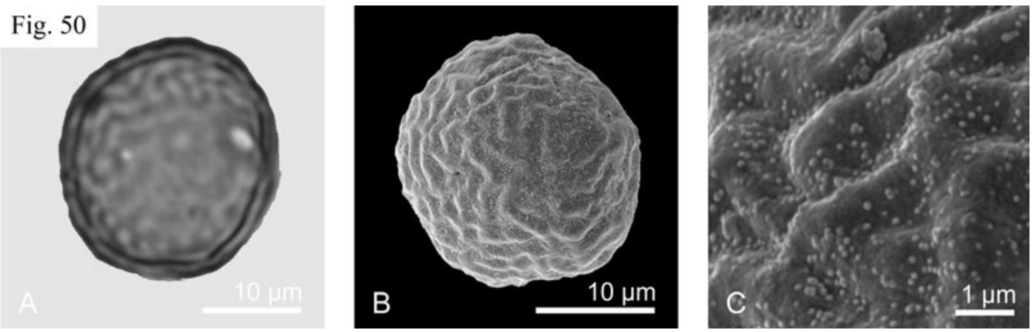
Ornamentation: LM: scabrate.
SEM: rugulate, perforate and fossulate.

Superorder Urticanae TAKHTAJAN ex REVEAL, 1992

Order Urticales DUMORTIER, 1829

Family Ulmaceae MIRBEL, 1815

Genus *Ulmus* LINNAEUS, 1753



Ulmus sp.
Fig. 50

Size: small (21–23 µm).

Shape: oblate; quinquangular obtuse in polar view; elliptic in equatorial view.

Aperture type: porate.

Aperture number: 4 to 6 (5).

Ornamentation: LM: rugulate.
SEM: rugulate with a granulate surface.

Genus *Zelkova* SPACH, 1841

Zelkova sp.
Fig. 51

Size: small (21–24 µm).

Shape: oblate; quadrangular convex in the polar view.

Aperture type: porate.

Aperture number: 4 to 5 (4).

Ornamentation: LM: rugulate.
SEM: rugulate with microechinate suprasculpture.

Remarks: *Zelkova* sp. has shorter stronger and often fused rugulae compared to *Ulmus* sp.

Fig. 51

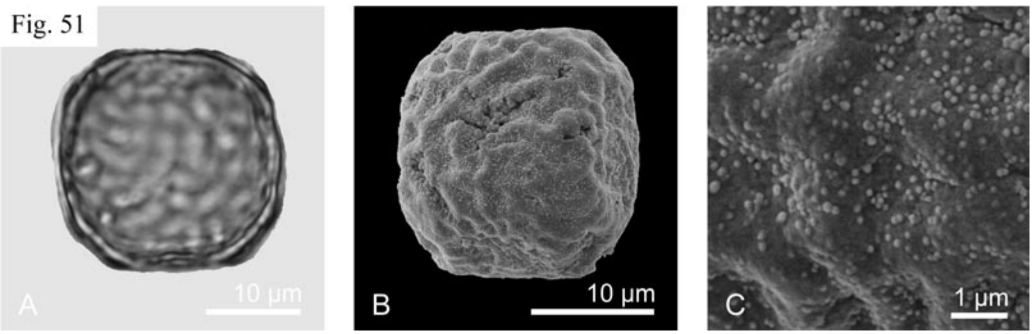
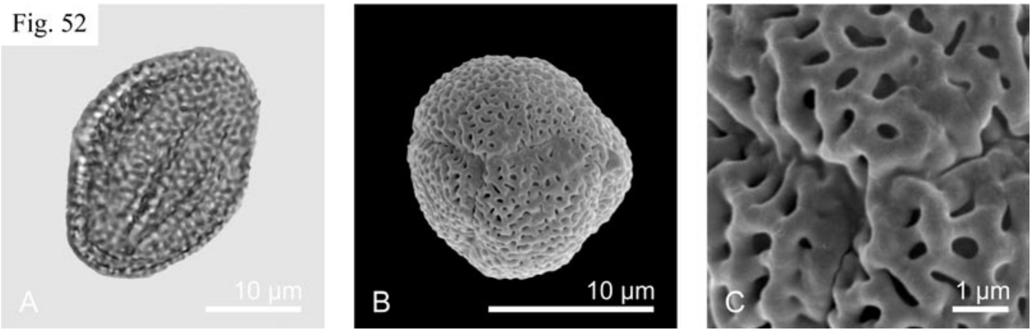


Fig. 52



Superorder Euphorbianae TAKHTAJAN ex REVEAL, 1992

Order Euphorbiales LINDLEY, 1833

Family Euphorbiaceae GMELIN, 1777

Genus *Phyllanthus* LINNAEUS, 1753

***Phyllanthus* sp. 1**
Fig. 52

Size: small (15–17 x 20 µm).

Shape: prolate; elliptic in equatorial view; almost circular in the polar view.

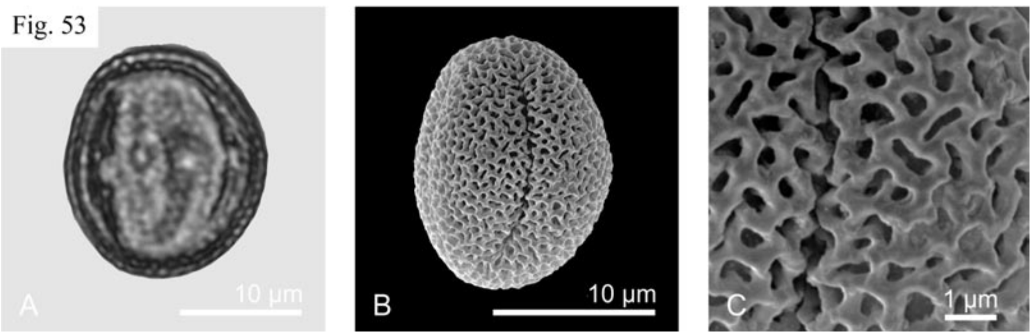
Aperture type: syncolpate.

Aperture number: 3.

Ornamentation: LM: microreticulate.

SEM: microreticulate-heterobrochate; no change in the ornamentation around the colpi.

Fig. 53



***Phyllanthus* sp. 2**
Fig. 53

S i z e : small (12–16 x 15–19 µm).

S h a p e : prolate; elliptic in equatorial view.

A p e r t u r e t y p e : colpate.

A p e r t u r e n u m b e r : 3.

O r n a m e n t a t i o n : LM: reticulate; the strongly thickened sexine is visible; also the colpi are clearly thickened.

SEM: reticulate-heterobrochate; the muri have a smooth surface.

Genus *Sapium* BROWNE, 1756

***Sapium* sp.**
Fig. 54

S i z e : small (15–17 x 19–22 µm).

S h a p e : prolate; elliptic in equatorial view; concave obtuse triangular in polar view.

A p e r t u r e t y p e : colporate.

A p e r t u r e n u m b e r : 3.

O r n a m e n t a t i o n : LM: psilate.

SEM: perforate with a slightly fossulate surface.

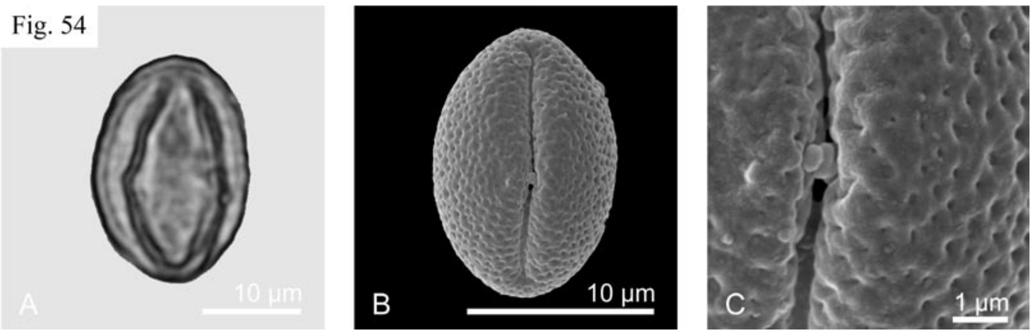
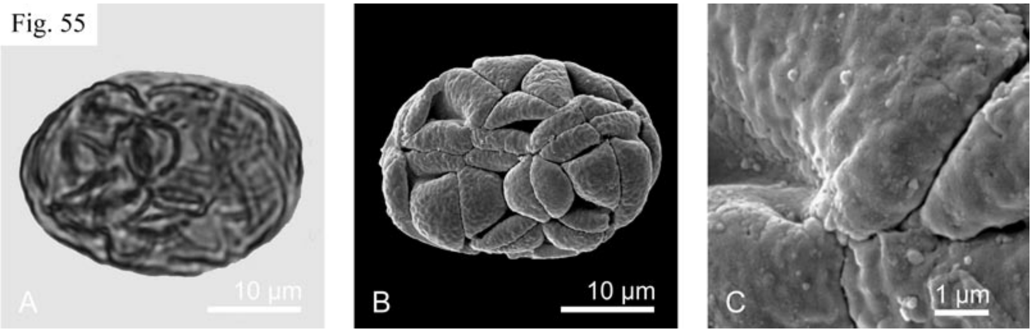


Fig. 55



Subclass Rosidae TAKHTAJAN, 1967

Superorder Fabanae DAHLGREN ex REVEAL, 1993

Order Fabales BROMHEAD, 1838

Family Fabaceae LINDLEY, 1836

Subfamily Mimosoideae BROWN, 1813

Mimosoideae gen. indet.
Fig. 55

Size: polyade, medium (30–35 µm).

Shape: elliptic.

Aperture type: unknown.

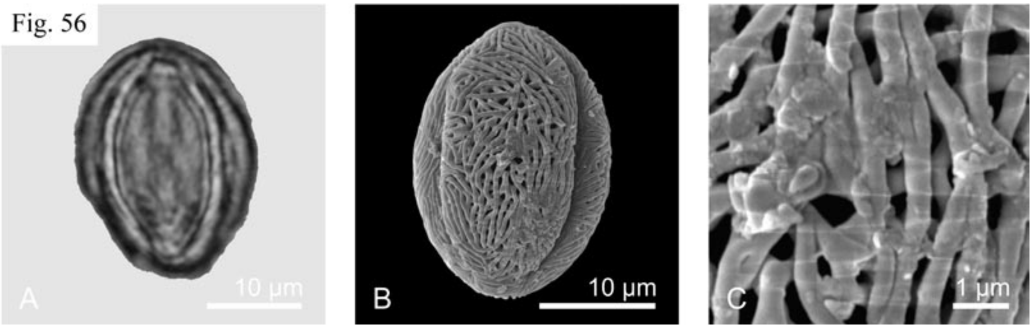
Aperture number: unknown.

Ornamentation: LM: psilate to scabrate; single grains are not always clearly visible.

SEM: microverrucate; perforate and fossulate.

Superorder Rutanae TAKHTAJAN, 1967

Order Rutales PERLEB, 1826



Family Rutaceae DURANDE, 1782

Genus *Zanthoxylum* LINNAEUS, 1753

***Zanthoxylum* sp.**
Fig. 56

Size: small (18 x 24 µm).

Shape: prolate; elliptic in equatorial view; circular to triangular in polar view.

Aperture type: colporate.

Aperture number: 3.

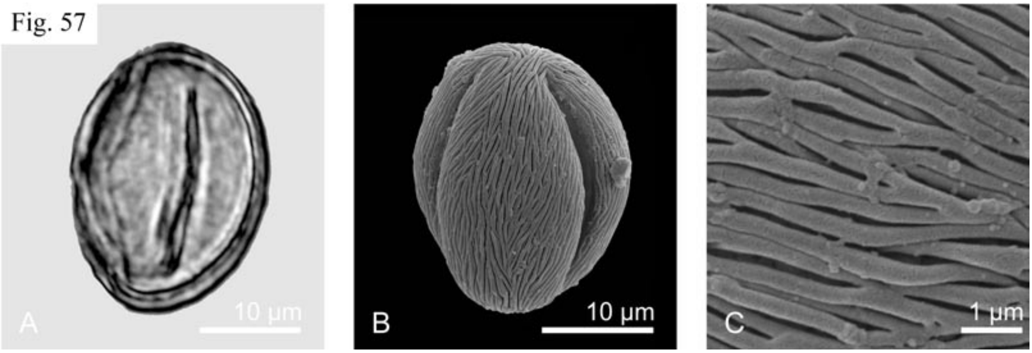
Ornamentation: LM: scabrate to slightly striate.

SEM: striato-reticulate; striae form a wide and irregular net over the mesocolpium, but get tighter at the poles and next to the colpi.

Order Sapindales DUMORTIER, 1829

Family Aceraceae DURANDE, 1782

Genus *Acer* LINNAEUS, 1753



Acer sp.
Fig. 57

Size: small (19 x 25 µm).

Shape: prolate; elliptic in equatorial view.

Aperture type: colpate.

Aperture number: 3.

Ornamentation: LM: scabrate to striate.

SEM: striate; striae are less than 0.5 µm wide and are irregularly branching.

Superorder Rhamnanae TAKHTAJAN ex REVEAL, 1992

Order Elaeagnales BROMHEAD, 1838

Family Elaeagnaceae ADANSON, 1763

Genus Elaeagnus LINNEAUS, 1753

Elaeagnus sp.
Fig. 58

Size: medium (30–33 µm).

Shape: oblate; triangular in polar view; obtuse elliptic in equatorial view.

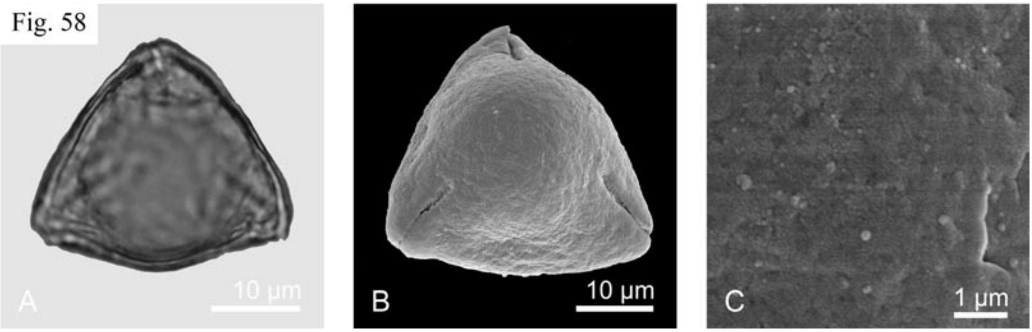
Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: scabrate.

SEM: psilate with irregularly scatted granulae.

Fig. 58



Subclass Cornidae FROHNE & JENSEN ex REVEAL, 1994

Order Araliales BURNETT, 1835

Family Apiaceae LINDLEY, 1836

Apiaceae gen. indet.
Fig. 59

Size: small to medium (10–12 x 24–27 µm).

Shape: prolate; elliptic in the equatorial view; triangular obtuse convex in the polar view.

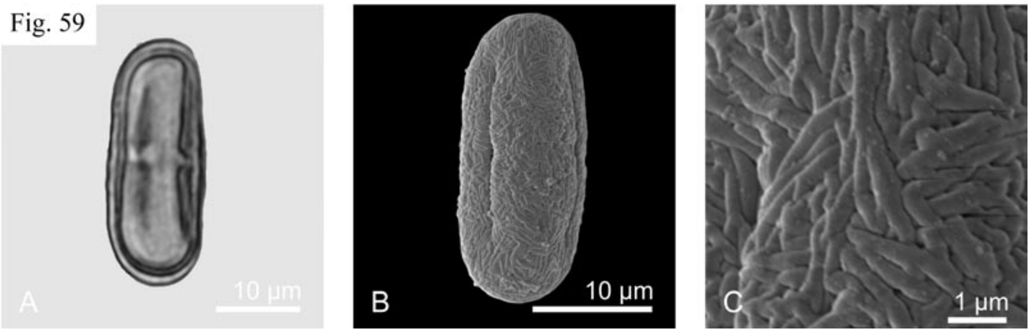
Aperture type: colpate.

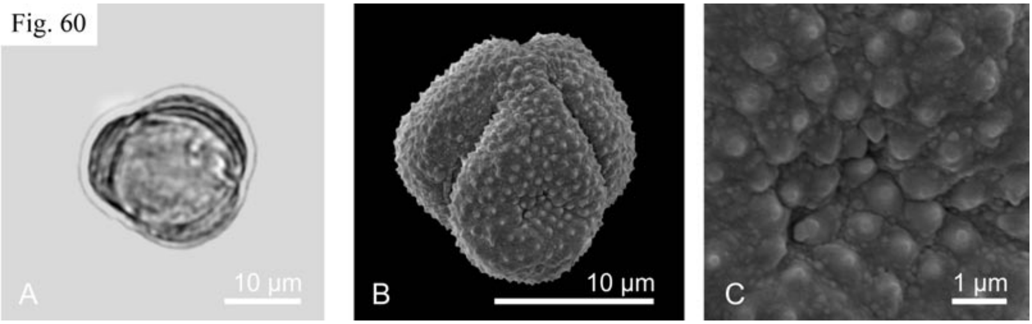
Aperture number: 3.

Ornamentation: LM: psilate; sexine seems to be thicked, especially around the poles.

SEM: striate; at the pole area, the striae show another pattern than in the mesocolpium area.

Fig. 59





Subclass Asteridae TAKHTAJAN, 1967

Order Asterales LINDLEY, 1833

Family Asteraceae BERCHTOLD & PRESL, 1820

Genus *Artemisia* LINNAEUS, 1753

***Artemisia* sp.**
Fig. 60

Size: small (15–20 µm).

Shape: subprolate; spheroidal in the equatorial view; triangular in the polar view.

Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: scabrate; sexine is clearly thickened.

SEM: microechinate and perforate; bigger echinae with a broad base are surrounded by numerous smaller ones.

Compositae liguliflorae gen. indet.
Fig. 61

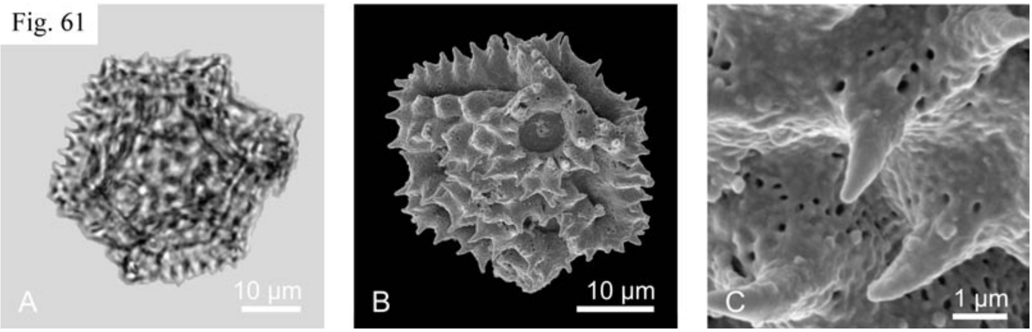
Size: medium (38–40 µm).

Shape: spheroidal.

Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: lophate to echinate.



SEM: echinate and perforate; the echinae cover the lophae, but form fenestrae, where the surface is visible; perforations are limited to the base of the echinae.

Compositae tubiflorae gen. indet. 1

Fig. 62

Size: medium (31–33 µm).

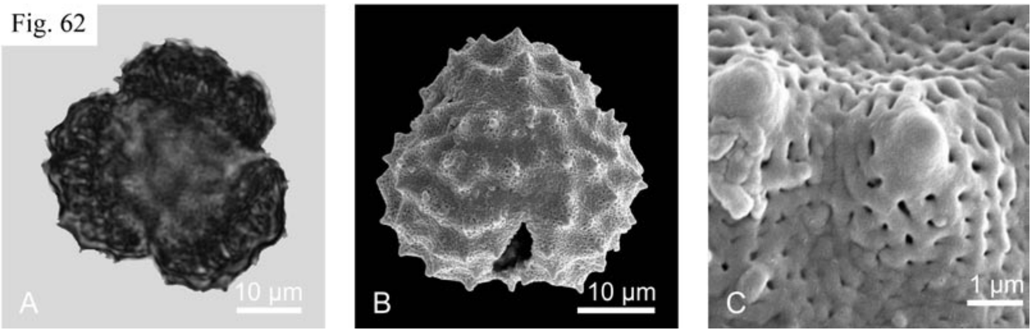
Shape: spheroidal to slightly oblate.

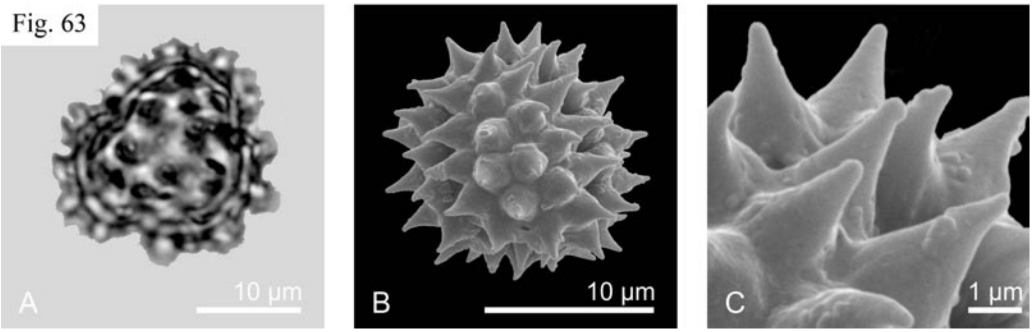
Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: echinate with thick wall.

SEM: echinate and perforate; the perforation is regularly distributed over the whole surface excluding the top of the echinae, and gets wider at the base of the echinae.





Compositae tubiflorae gen. indet. 2
Fig. 63

Size: small (15 x 16–20 µm).

Shape: spheroidal to slightly prolate.

Aperture type: colporate.

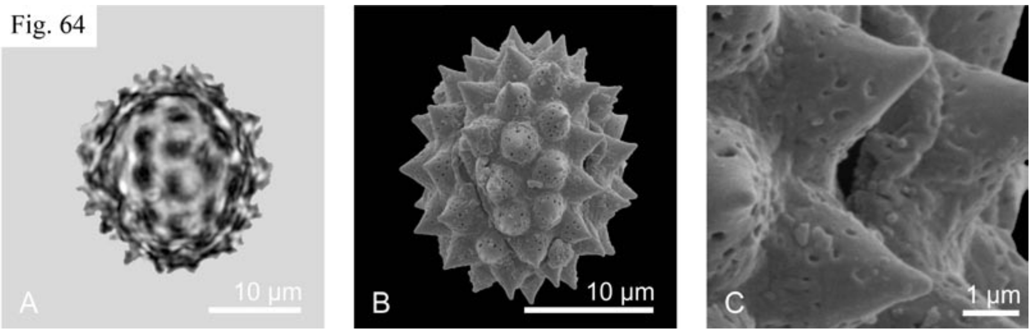
Aperture number: 3.

Ornamentation: LM: echinate.
SEM: echinate.

Compositae tubiflorae gen. indet. 3
Fig. 64

Size: small (18–20 x 20–21 µm).

Shape: spheroidal to subprolate.



Aperture type: colporate.

Aperture number: 3.

Ornamentation: LM: echinate.
SEM: echinate and mircoreticulate.

Compositae tubiflorae gen. indet. 4
Fig. 65

Size: small to medium (18–23 x 25–29 µm).

Shape: prolate.

Aperture type: colporate.

Aperture number: 3.

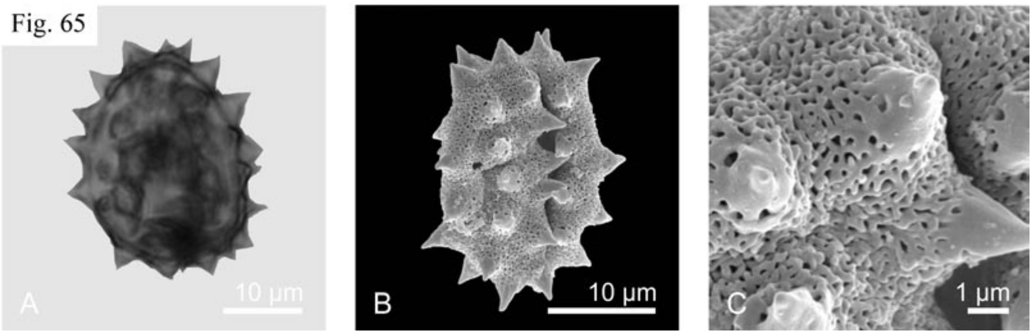
Ornamentation: LM: echinate.
SEM: echinate and microreticulate; the echinae have, except at the basis, a closed surface.

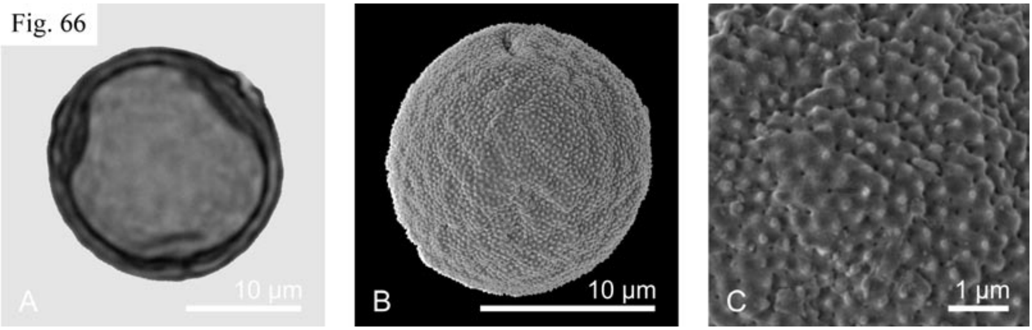
Subclass Lamiidae TAKHTAJAN ex REVEAL, 1992

Order Solanales DUMORTIER, 1829

Solanaceae ADANSON, 1763

Fig. 65





Solanaceae gen. indet.
Fig. 66

Size: small (15–19 µm).

Shape: oblate to spheroidal; obtuse triangular in the polar view.

Aperture type: (brevi-)colporate.

Aperture number: 3.

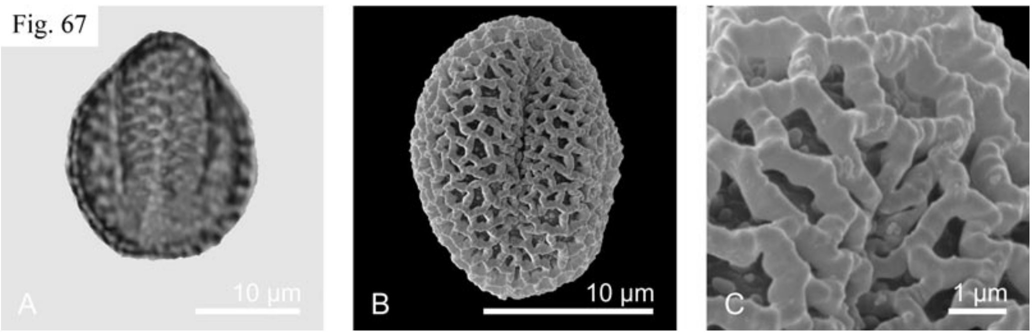
Ornamentation: LM: scabrate.
SEM: perforate and microechinate.

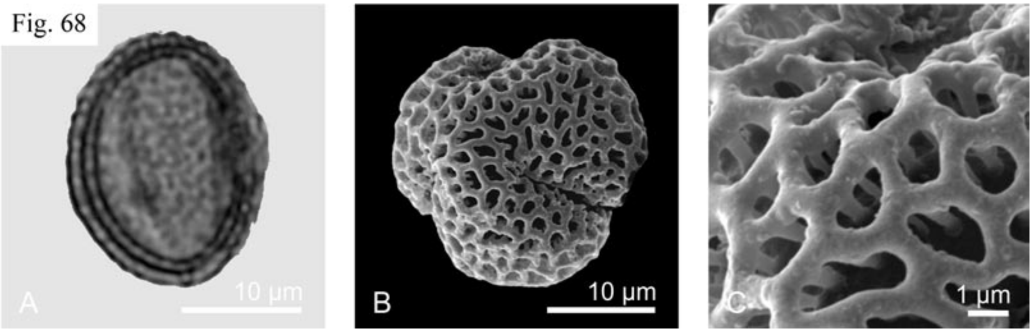
Order Oleales LINDLEY, 1833

Family Oleaceae HOFFMANNSEGG & LINK, 1813–1820

Genus *Fraxinus* LINNAEUS, 1753

***Fraxinus* sp.**
Fig. 67





S i z e : small (14–19 x 18–25 µm).

S h a p e : prolate; elliptic in equatorial view.

A p e r t u r e t y p e : colporate.

A p e r t u r e n u m b e r : 3.

O r n a m e n t a t i o n : LM: reticulate.

SEM: reticulate-heterobrochate; muri are coarse; free columella occur in the lumina.

Genus *Ligustrum* LINNAEUS, 1753

***Ligustrum* sp.**
Fig. 68

S i z e : small (18 x 22 µm).

S h a p e : prolate; elliptic in the equatorial view.

A p e r t u r e t y p e : colporate.

A p e r t u r e n u m b e r : 3.

O r n a m e n t a t i o n : LM: scabrate; nexine and sexine are clearly visible, while the sexine is slightly thicker.

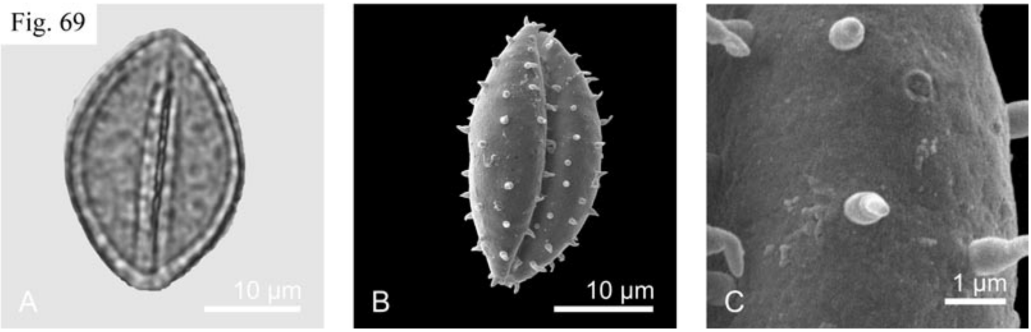
SEM: reticulate-heterobrochate; with smooth muri.

Class Liliopsida SCOPOLI, 1760

Subclass Arecidae TAKHTAJAN, 1967

Oder Arecales BROMHEAD, 1840

Fig. 69



Family Arecaceae SCHULTZ-SCHULTZENSTEIN, 1832

Arecaceae sp. 1
Fig. 69

Size: small to medium (15–19 x 27–28 µm).

Shape: oblate; elliptic in polar view.

Aperture type: sulcate.

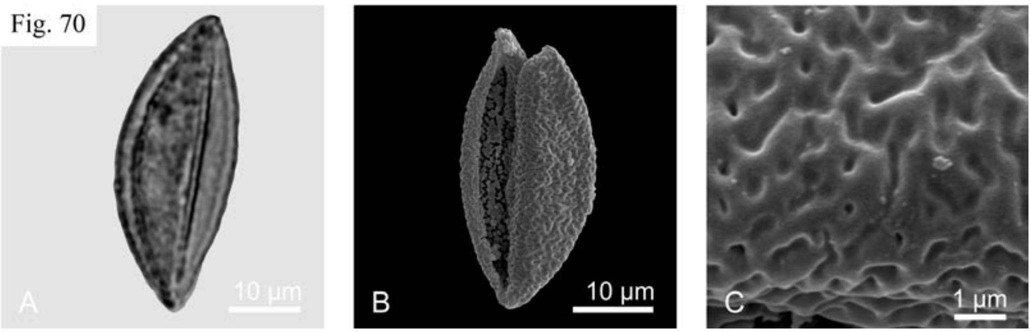
Aperture number: 1.

Ornamentation: LM: psilate to slightly coarse verrucate.

SEM: echinate and slightly foveolate; spines are infrequent and sometimes missing due to preservation, they lack a regular length or shape.

Arecaceae sp. 2
Fig. 70

Fig. 70



S i z e : medium (14–17 x 36–42 µm).

S h a p e : oblate; elliptic in polar view.

A p e r t u r e t y p e : sulcate.

A p e r t u r e n u m b e r : 1.

O r n a m e n t a t i o n : LM: scabrate.
SEM: perforate to foveolate with an irregular pattern.

Subclass Commelinidae TAKHTAJAN, 1967

Superorder Poanae SMALL, 1903

Order Poales SMALL, 1903

Family Poaceae (BROWN) BARNHART, 1895

Poaceae gen. indet. 1
Fig. 71

S i z e : medium (37–42 µm).

S h a p e : spheroidal.

A p e r t u r e t y p e : ulcerate.

A p e r t u r e n u m b e r : 1.

O r n a m e n t a t i o n : LM: psilate.
SEM: verrucate with a microechinate suprasculpture.

Fig. 71

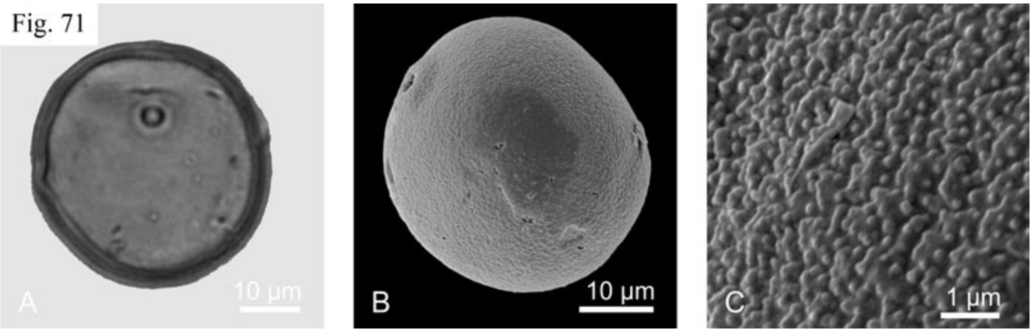
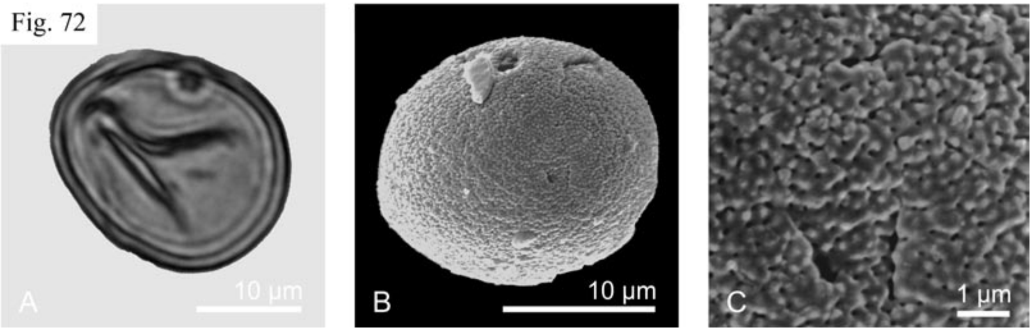


Fig. 72



Poaceae gen. indet. 2
Fig. 72

Size: small (19–20 µm).

Shape: spheroidal.

Aperture type: ulcerate.

Aperture number: 1.

Ornamentation: LM: psilate.
SEM: microechinate and perforate.

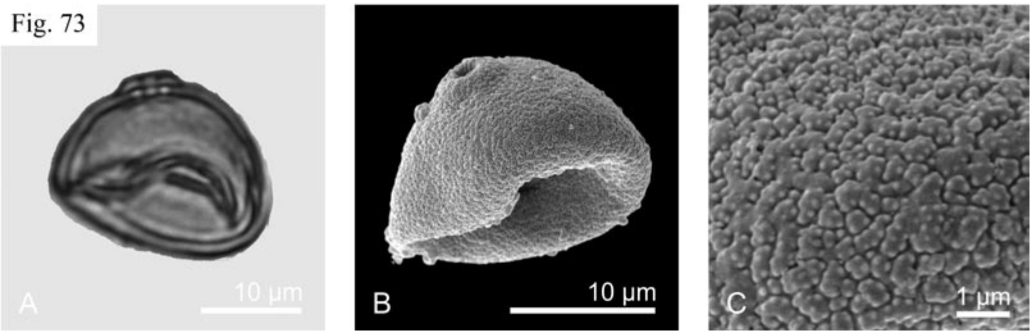
Poaceae gen. indet. 3
Fig. 73

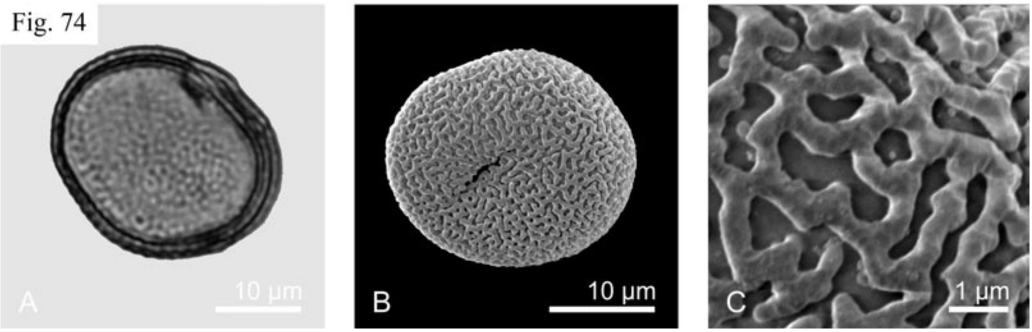
Size: medium (27–31 µm).

Shape: spheroidal.

Aperture type: ulcerate.

Fig. 73





Aperture number: 1.

Ornamentation: LM: psilate.

SEM: fossulate and microverrucate with a microechinate suprasculpture.

Subclass Aridae (BARTL, 1830) TAKHTAJAN, 1997

Superorder Typhanae (DUMORTIER, 1829) THORNE ex REVEAL, 1992

Order Typhales DUMORTIER, 1829

Family Typhaceae DURANDE, 1782

Genus *Typha* LINNAEUS, 1753

***Typha* sp.**
Fig. 74

Size: small to medium (22–26 µm).

Shape: spheroidal.

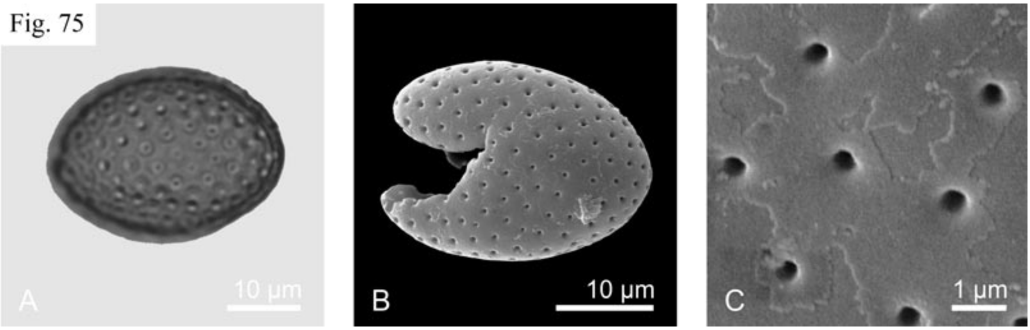
Aperture type: ulcerate.

Aperture number: 1.

Ornamentation: LM: reticulate; thick nexine and a very thick sexine.

SEM: reticulate-heterobrochate with rough muri.

Fig. 75



Freshwater cyst – gen. indet.
Fig. 75

Size: medium (20–24 x 29–32 µm).

Shape: ovoid.

Ornamentation: LM: perforate.
SEM: perforate.

Results and discussion

Mountain valleys, such as the Kathmandu Valley, are very suitable for paleoecological interpretations based on palynological samples. Such valleys are surrounded by high mountains and thus only a small amount of pollen can reach there from the hinterland except from the high areas of the Greater Himalaya, such as for example *Cedrus* sp. (Yoshida & Igarashi 1984). The herein documented assemblages from the Lukundol Formation are thus suggested to reflect largely the local flora.

Altogether 74 different taxa were found, including 25 spores from ferns and mosses, 7 gymnosperms, 41 angiosperms and 1 freshwater cyst. Of these, 37 were identified to genus level; only 4 could be determined to species level by comparison with recent taxa. Except 14 spores, all other taxa are assigned to a certain family. Polypodiaceae are most abundant within the spores. No algae, such as *Pediastrum*, were detected, despite their abundance in some parts of the formation (e.g. Fujii & Sakai 2002; Yoshida & Igarashi 1984). The assemblage yields well documented elements of this area, such as *Pinus* sp., *Quercus* sp. and Polypodiaceae, but also some rare elements, such as *Zanthoxylum* sp. Compared to Paudayal (2002), who published five different *Quercus* taxa, this investigation documents 3 additional taxa, suggesting a fairly high diversity of *Quercus*. Similarly, the Poaceae are now documented by 3 taxa, and seem to have been underrepresented so far by only one taxon (Paudayal 2002). In addition, *Acer* sp., *Ephedra* sp. and *Zanthoxylum* sp., which are also present in the modern vegetation of Nepal, are now documented from the Lukundol Formation for the first time. In contrast, the otherwise frequent *Castanopis* sp., *Polygonum* sp. and Sapotaceae are missing in this part of the Lukundol Formation. Additionally, aquatic plants do not appear at all whereas Paudayal (2002) reports *Trapa* sp., *Nymphoides* sp. and *Myriophyllum spicatum*. Moreover, otherwise abundant species of Compositae, Cayophyllacae, Symplocaceae and Apiaceae are only present in low numbers and Ericaceae are entirely missing.

The vegetation of the wetlands surrounding the shoreline is mainly represented by ferns, which commonly need a moister habitat. An element from the lake itself is *Typha* sp., which grew along the shore. The area around the lake was characterised by a succession of vegetation belts due to the difference in elevation. Trees such a *Zelkova* or *Fraxinus* were possibly living around the lake, whereas *Quercus* and *Pinus* were more common in adjacent zone and higher up in the closeby hills. *Picea* and *Abies* are also occurring, giving an example for the higher altitude vegetation. Concluding, the composition of the investigated samples with *Artemisia*, Chenopodiaceae, *Ephedra* and Poaceae suggests a rather open environment with low precipitation. The herein described and illustrated assemblage is thus an example for the vegetation of the comparatively drier late Early to Middle Pleistocene phase in the Kathmandu Basin. This phase is a result of the shift from moister and warmer climate with "tropical evergreen lower montane forest" to drier and cooler climate at c. 0.8 and 1 Ma and the establishment of a "tropical evergreen upper montane forest" (Yoshida & Igarashi 1984; Fujii & Sakai 2002; Paudayal 2002; Goddu 2004).

Concrete palaeoclimate interpretation was done by usage of the Coexistance Approach (Mosbrugger & Utescher 1997) to compare it with the recent climate of Nepal. The climatic condition in the Kathmandu area today is subtropical, influenced by the Asian Monsoon, which brings heavy rainfall during the summer, exceeding 300 mm within one month. The winter is dry and mostly frost-free; the average temperature is mild with mostly above 10°C.

The climatic reconstruction by using the Coexistence Approach showed very similar temperature and rainfall trends during the whole year. The only variance is the slightly warmer temperature data during the warmest month. No further climatic reconstruction have been done by other authors for this area or timespan.

Therefore it is obvious, that the climatic condition have been very similar in the Kathmandu Valley during the Pleistocene as today.

26 taxa were climatically investigated with the usage of the Coexistence Approach.

MAT	15.6 – 21.7 °C
CMT	5.0 – 13.6 °C
WMT	24.9 – 28.1 °C
MAP	823.0 – 1682.0 mm
MPwet	204 – 323.0 mm
MPdry	16.0 – 55.0 mm
MPwarm	111.0 – 172.0 mm

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