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Vegetation and climate from Late Quaternary Thimi Formation (Phaidhoka Section), Bhaktapur, Nepal

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ABSTRACT

The Thimi Formation is fluvio-deltaic deposit that constitutes the uppermost part of the sedimentary sequence in the Kathmandu Basin, and is featured by carbonaceous and diatomaceous clay, silty clay, silt, fine to medium grained sand beds, and thin to medium lignite beds. The Phaidhoka Section is located on the way to Nala from Chyamasingh, and is one of the major exposures of the Thimi Formation. Forty four samples were collected from 25 m thick surface exposure for palynological study. The study revealed the dominance of gymnosperm over the angiosperm and herbaceous members. The pollen diagram suggested *Pinus, Picea and Quercus* as the most dominant trees whereas *Poaceae* is other dominant among the grasses. Three major pollen assemblage zones were marked in the Thimi Formation. Zone P-I indicated warm temperate climate, whereas zone P-II and P-III indicated cold temperate climate. Molluscan operculum in the upper part indicated shallow water condition. The Bovid molars, limb and pelvic bones from the middle part of the section confirm the early findings of molar bones in this area.

Keywords: Late Quaternary, palynology, climate, Thimi Formation, Kathmandu Basin

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INTRODUCTION

The Kathmandu Basin is an intermontane basin filled with very thick sequence of lacustrine and fluvial deposits of Plio-Pleistocene age (Yoshida and Igarashi 1984, Moribayashi and Mauro 1980). The oldest formation is known as the Lukundol Formation exposed to the southern part of the basin. The primary basin was mainly confined to the southern part of the valley and was relatively small compared to the later. It started receiving sediments from the southern part and the Lukundol Formation and was formed in the process (Kizaki 1994). But, the uplifting of the Mahabharat Range in the southern part changed the course and the lake started shifting towards north. The tilting of the beds of the Lukundol Formation to the north is one of the major evidence. The new lake was much large and covered large area resulting in the deposition of younger sediments named as the Gokarna, Thimi and Patan formations (Fig. 1). The lake completely drained at the end of the last glacial epoch (Yoshida and Igarashi 1984). The Thimi Formation, a fluvio-lacustrine deposit, is distributed around Pashupatinath, Tribhuvan International Airport, Thimi, Bhaktapur and Patan comprises alternating layers of carbonaceous and diatomaceous clay, silty clay, silt and fine to coarse sand.

Yoshida and Igarashi (1984), Igarashi et al. (1988), and Yoshida and Gautam (1988) divided the basin sediments into the older-stage deposits (i.e. the Lukundol Formation), middle-stage deposits (i.e. the Boregaon, Chapagaon and Pyanggaon terrace deposits), and younger-stage deposits (i.e. the Gokarna, Thimi and Patan formations). A number of palynological investigations were also carried out by many researchers from the different sections of the Kathmandu Basin sediments (Vishnu- Mittre and Sharma 1984, Fuji and Sakai 2001, 2002, Paudayal and Ferguson 2004, Paudayal 2005, Paudayal 2006, Bhandari and Paudayal 2007, Paudayal 2011a, Paudayal 2011b).

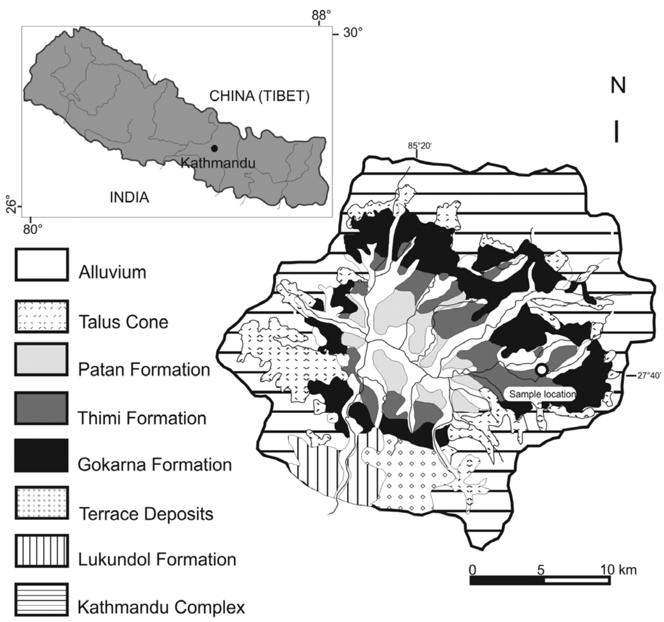

Fig 1: Geological map of the study area showing sampling location (black open cirlce) at Phaidhoka, Bhaktapur.

MATERIALS AND METHODS

Samples were taken from 25 m thick surface exposure at Phaidhoka, Bhaktapur belonging to the Thimi Formation (Fig. 2). The sediments of the Thimi Formation are relatively finer indicating the deposition might have occurred from suspension settling and only limited bedload transport via weak currents. The thin, parallel laminations of alternating silt and silty clay indicate widespread deposition from suspension over the sand beds. The sand and silt layer consists of cross bedded structure; wave ripple laminated structure and sometimes with the distortion of ripples in sand beds. The flow structure and distorted cross beds suggest the liquefaction or fludisation and hydro-plastic deformation. The deformation was considered to have been caused by paleo-earthquakes during sedimentation (Gajurel et al. 1998).

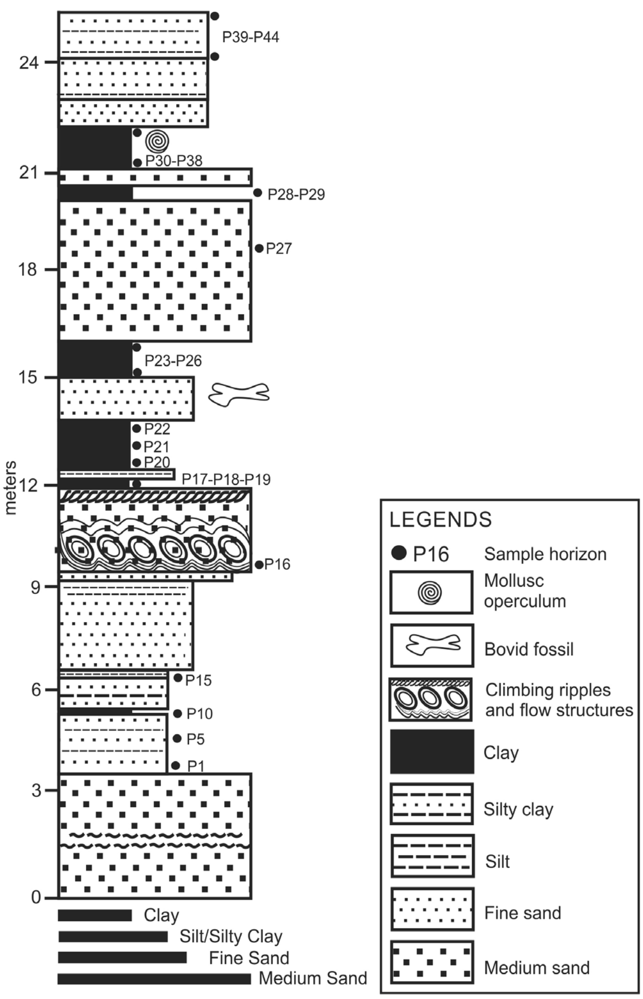

Fig. 2: Lithology of the Thimi Formation, Phaidhoka section, Bhaktapur.

The palynological samples were prepared at the Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, following the method described by Zetter (1989) and Ferguson et al. (2007). This includes series of chemical treatment of sediments such as concentrated HCl, HF, CH_3COOH, $KClO_3$, $(CH_3CO)_2O$, H_2SO_4. The organic content was separated using heavy liquid $ZnBr_2$ having specific gravity 2 gm/cm^3. The extracted organic material was then preserved in glycerin for microscopy. At least 300 pollen grains from each sample were point-counted under an OLYMPUS BX-43 light microscope. The palynomorphs were identified with the help of various pollen atlases and published literatures. The TILIA software was used for statistical analysis and preparing a pollen diagram.

RESULTS

a. **Invertebrate fossils**

In the upper part of the section a clay layer full of molluscan opercula are discovered. They are identified under family Bithyniidae belonging to the genus *Digoniostoma* and *Gabbia,* respectively.

b. Vertebrate fossils

Six large molars along with fragmented limb and pelvic bones belonging to family Bovidae (possibly *Bos* or *Bubalus*) are recorded from the middle part of the section. The molars and bones are still under investigation to their lower taxonomic level. The vertebrate fossils will be dealt in a separate paper.

c. Plant microfossils

Significant amount of plant microfossils (palynomorphs) helped us to understand the paleoclimatic evolution of the study area. Out of forty four samples collected from the Phaidhoka Section, twenty two samples were rich in palynomorphs. Altogether 94 species of plants belonging to 74 genera and 40 families were identified (Plates I-IX). The plant microfossils obtained from this section are identified and described below.

i. **Gymnosperms**

Family: Pinaceae

Cedrus **sp.** (Plate I, Fig. 1)

Shape: Bisaccate; Size: 70 µm, corpus 50 µm, sacci 20 µm; corpus perforate; Exine is thick, corpus attached with lower half of the sacci.

Picea sp. (Plate I, Fig. 2)

Shape: Bisaccate; Size: 70 µm, corpus 50 µm, sacci 20 µm; corpus perforate rugulate, alveolate, attached with majority width of corpus, weak angle between sacci and corpus.

Pinus roxburghii (Plate I, Figs. 3-4)

Shape: Bisaccate; Size: 80 µm, corpus 50 µm, sacci 35 µm; corpus rugulate, the attachment of corpus and sacci is featured by distinct angle, sacci attached with majority width of corpus, polar view shows the attachment of corpus exists at upper half.

Pinus wallichiana (Plate I, Figs. 5-6)

Shape: Bissacate; Size: 80 µm, corpus 50 µm, sacci 30 µm;

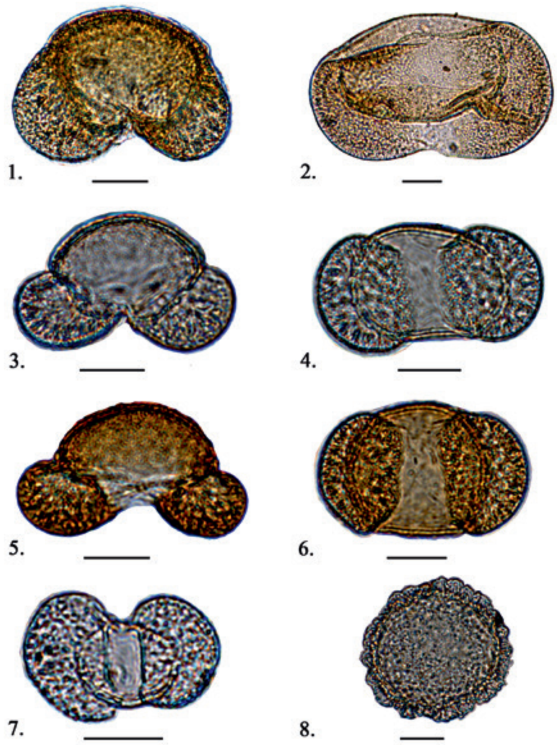

Plate-I: 1- *Cedrus* sp., 2- *Picea* sp., 3 and 4- *Pinus roxburghii* (equatorial and polar view), 5 and 6- *Pinus Wallichiana* (Equatorial and Polar view), 7- *Podocarpus* sp., 8- *Tsuga* sp. (scale bar = 20 µm).

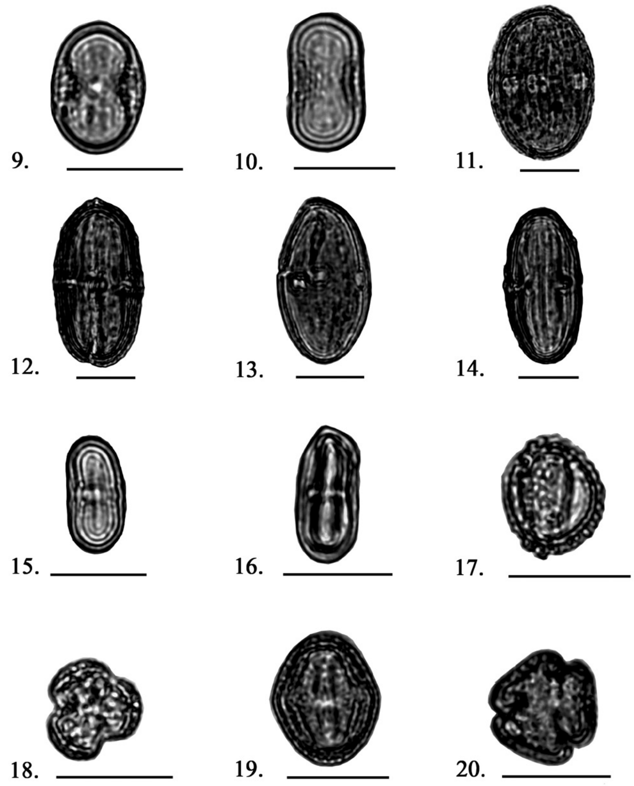

Plate-II: 9. *Justicia* sp. 1, 10. *Justicia* sp. 2, 11. *Strobilanthes* sp. 1, 12. *Strolbilanthes* sp. 2, 13. *Strobilanthes* sp. 3, 14. *Strobilanthes* sp. 4, 15. Apiaceae gen. indet.1, 16. Apiaceae gen. indet. 2, 17-18 *Ilex* sp., 19-20. Araliaceae gen. indet. (scale bar = 20 µm).

corpus is rugulate and rough, sacci finely alveolate, attached with majority width of corpus, polar view shows the attachment of corpus with sacci existing at upper half, corpus making distinct angle with sacci.

Tsuga sp. (Plate I, Fig. 8)

Shape: Monosaccate; Size: 70 µm, circular in polar view, corpus echinate and foveolate, verrucate to regulate, sacci echinate and foveolate.

Family: Podocarpaceae

Podocarpus sp. (Plate I, Fig. 7)

Shape: Bisaccate; Size: 50 µm, corpus 30 µm, saci 20 µm; corpus finely verrucate, sacci finely alveolate, attached with majority width of corpus, size of the corpus smaller than sacci.

ii. Angiosperms (Dicotyledons)

Family: Acanthaceae

Justicia sp. (1) (Plate II, Fig. 9)

Shape: Prolate; Size: polar axis 20 µm, equatorial axis 15 µm;. Aperture: colporate. Exine: 1.5 µm, sexine and nexine having equal thickness, sexine regulate and perforate around aperture.

Justicia sp. (2) (Plate II, Fig. 10)

Shape: Prolate; Size: polar axis 25 µm, equatorial axis 15 µm; Aperture: Colporate; Exine: 1.6 µm, sexine thicker than nexine, nexine alveolate and rough near aperture.

Strobilanthes sp. (1) (Plate II, Fig. 11)

Shape: Prolate; Size: Polar axis 60 µm, equatorial axis 40 µm; Aperture: Tri-colporate; Exine: 5 µm, sexine thicker than nexine, sexine coarsely reticulate.

Strobilanthes sp. (2) (Plate II, Fig. 12)

Shape: Prolate; Size: Polar axis 60 µm, equatorial axis 30 µm; Aperture: Tri-colporate, Exine: 5 µm, Sexine thicker than nexine, sexine divided into longitudinal strips and coarsely reticulate.

Strobilanthes sp. (3) (Plate II, Fig. 13)

Shape: Prolate; Size: Polar axis 50 µm, equatorial axis 25 µm; Aperture: Tri-colporate; Exine: 3.5 µm, sexine and nexine having equal thickness, sexine around aperture regulate and granulate.

Strobilanthes sp. (4) (Plate II, Fig. 14)

Shape: Prolate; Size: Polar axis 60 µm, equatorial axis 30 µm; Aperture: Tri-colporate, Exine: 5 µm, sexine thicker than nexine, sexine further subdivided into longitudinal strips, sexine near aperture foveolate.

Family: Apiaceae

Apiaceae gen. indet. (1) (Plate II, Fig. 15)

Shape: Prolate; Size: Polar axis 20-23 µm, equatorial axis 10-12 µm; Aperture: Tri-colporate, colpi extended almost upto poles; Exine: 1.3 µm, regulate and granulate.

Apiaceae gen. indet. (2) (Plate II, Fig. 16)

Shape: Prolate; Size: Polar axis 25 µm, equatorial axis 15 µm; Aperture: Tri-colporate; Exine: 2.3 µm, nexine thicker than sexine, sexine regulate and granulate.

Family: Araliceae

Araliaceae gen indet. (Plate II, Fig. 17-18)

Shape: Spheroidal and sub-prolate; Size: Equatorial view 25 µm, Polar view 20 µm; Aperture: Coloporate; Exine: 4.5 µm, reticulate, regulate and granular.

Family: Balsaminaceae

Impatiens sp. (Plate III, Fig. 21)

Shape: Oblate, rectangular; Size: Equatorial axis 32 µm; Aperture: Tetra-colporate; Exine: 1.8 µm, thickness of sexine and nexine similar, reticulate and granulate.

Family: Betulaceae

Alnus sp. (Plate III, Fig. 22)

Shape: Oblate, pentangular in polar view; Size: 18-20 µm; Aperture: Pentaporate, post vestibulum type; Exine: 1.5 µm, sexine thicker than nexine, tectum rugulate and micro-echinate.

Betula sp. (Plate III, Fig. 23)

Shape: Oblate, triangular in polar view; Size: 20 µm; Aperture: Tri-porate, circular pores, pores with chamber separates inner and outer walls; Exine 2.4 µm, sexine scrabate to regulate and thick at apex.

Corylus sp. (Plate III, Fig. 24)

Shape: Oblate, triangular in polar view; Size: 24 µm; Aperture: Tri-porate; Exine: 3.4 µm, exine has no arci and does not thicken in the aperture region. The sculpture of exine is slightly rugulate. Nexine thickness is not separated from the foot-layer of the aperture region.

Family: Bombacaceae

Bombax sp. (Plate III, Fig. 25)

Shape: Oblate, triangular in polar view; Size: 35 µm; Aperture: Tri-colporate, situated more or less at mid points; Exine: 3.3 µm, nexine thicker than sexine, clearly stratified, rugulate, alveolate, exine scrabate and reticulated.

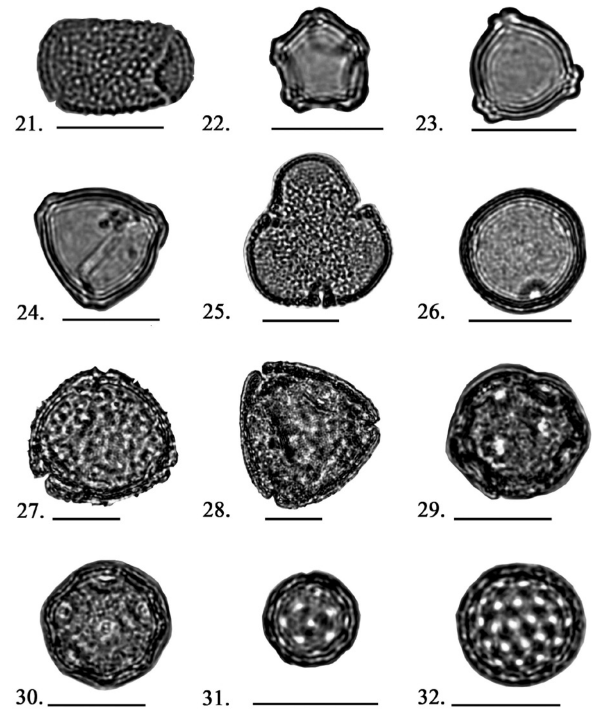

Plate-III: 21. *Impatiens* sp. 22. *Alnus* sp. 23. *Betula* sp. (Family Betulaceae), 24. *Corylus* sp. 25. *Bombax* sp. 26. Campanulaceae gen. indet. 27. *Lonicera* sp. (1), 28. *Lonicera* sp. (2), 29. Caryophyllaceae gen. indet. (1), 30. Caryophyllaceae gen. indet. (2), 31. Chenopodiaceae gen. indet. (1), 32. Chenopodiaceae gen. indet. (2) (scale bar = 20 µm).

Family: Campanulaceae

Campanulaceae gen. indet. (Plate III, Fig. 26)

Shape: Prolate, circular in polar view; Size: 25 µm; Aperture: Tri-porate, Exine 3.4 µm, sexine thicker than nexine, rugulate with low relief reticulum.

Family: Caprifoliaceae

Lonicera sp. (1) (Plate III, Fig. 27)

Shape: More or less spheroidal, oblate; Size: 40-44 µm; Aperture: Tri-colporate, colpi short; Exine: 4 µm, exine scabrous, echinate or micro-echinate, rugulate, foveolate.

Lonicera sp. (2) (Plate III, Fig. 28)

Shape: Oblate, triangular in polar view; Size: 45-47 µm; Aperture: Tri-colporate; Exine: 4 µm, sexine is thicker than nexine, rough and foveolate, echinate to microechinate.

Family: Caryophyllaceae

Caryophyllaceae gen. indet. (1) (Plate III, Fig. 29)

Shape: Spheroidal; Size: 28-30 µm; Aperture: Pantoporate; Exine: 2 µm, thickness between sexine and nexine similar, perforated rugulate and spinulated sexine.

Caryophyllaceae gen. indet. (2) (Plate III, Fig. 30)

Shape: Spheroidal or globular; Size: 22-25 µm; Aperture: Pantoporate; Exine: 4 µm, sexine thicker than nexine, sexine perforated, rugulate, unevenly reticulated.

Family: Chenopodiceae

Chenopodiaceae gen. indet. (1) (Plate III, Fig. 31)

Shape: Spheroidal or globular; Size: 12-14 µm; Aperture: Pantoporate, pore circular; Exine: 2 µm, Sexine thicker than nexine, sexine spinulated, perforate, pore membrane granulate, spinulate.

Chenopodiaceae gen. indet. (2) (Plate III, Fig. 32)

Shape: Spheroidal; Size: 25 µm; Aperture: Pantoporate; Exine: 3 µm, sexine thicker than nexine.

Family: Compositae

Artemisia sp. (1) (Plate IV, Fig. 33)

Shape: Prolate, lobate, circular in polar view; Size: Polar axis 25-27 µm; Aperture: Tricolporate; Exine: 3 µm, sexine is thicker than nexine, clearly stratified, sexine in meso-colpium thicker than in the colpi area.

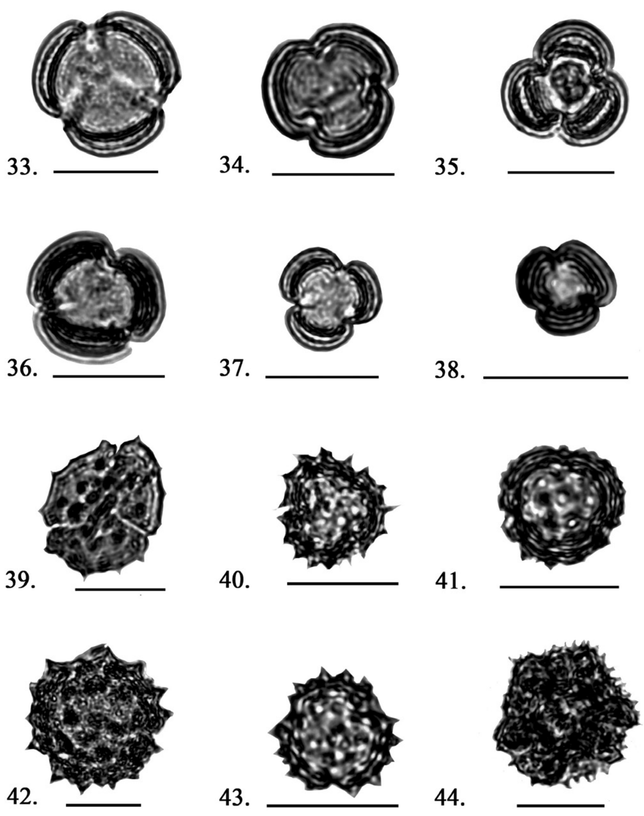

Plate-IV: 33. *Artemisia* sp. (1), 34. *Artemisia* sp. (2), 35. *Artemisia* sp. (3), 36. *Artemisia* sp. (4), 37. *Artemisia* sp. (5), 38. *Artemisia* sp. (6), 39. Compositae gen. indet. (1), 40. Compositae gen. indet. (2), 41. Compositae gen. indet. (3), 42. Compositae gen. indet. (4), 43. Compositae gen. indet. (5), 44. Compositae gen. indet. (6) (scale bar = 20 µm).

Artemisia sp. (2) (Plate IV, Fig. 34)

Shape: Prolate, lobate, circular in polar view; Size: Polar axis 22-25 µm; Aperture: Tricolporate, colpi as long as polar axis; Exine: 4 µm, sexine thicker than nexine, both distinctly stratified, varying sexine thickness.

Artemisia sp. (3) (Plate IV, Fig. 35)

Shape: Prolate, lobate, circular in polar view; Size: 20-22 µm; Aperture: Tricolporate, reduced colpi; Exine: 3 µm, sexine much thicker than nexine.

Artemisia sp. (4) (Plate IV, Fig. 36)

Shape: Prolate, lobate, circular in polar view; Size: 25 µm; Aperture: Tri-colporate, colpi wide at equator and narrow at poles, distinct with thick margins; Exine: 2 µm, sexine and nexine similar in thickness, micro-echinate and granulated.

Artemisia sp. (5) (Plate IV, Fig. 37)

Shape: Prolate, lobate, circular in polar view; Size: 15-17 µm; Aperture: Tri-colporate, colpi as wide as polar axis; Exine: 1 µm, sexine and nexine clearly stratified, micro-echinate, granulated

Artemisia sp. (6) (Plate IV, Fig. 38)

Shape: Prolate, lobate, semi-circular in polar view; Size: 10-12 µm; Aperture: Tri-colporate, reduced and contracted colpi; Exine: 2 µm, sexine thicker than nexine, distinctly stratified ornamentation.

Compositae gen. indet. (1) (Plate IV, Fig. 39)

Shape: Sub-prolate; Size: 32 µm; Aperture: Tri-colporate; Exine: 6 µm, sexine thicker than nexine, echinated and perforated, surface granulated, spines 2 µm in length.

Compositae gen. indet. (2) (Plate IV, Fig. 40)

Shape: Prolate; Size: 20 µm; Aperture: Tri-colporate; Exine: 4 µm, sexine is thicker than nexine, echinated, perforated, granulated.

Compositae gen. indet. (3) (Plate IV, Fig. 41)

Shape: Prolate, circular in polar view; Size: 22-25 µm; Aperture: Tri-colporate; Exine: 5 µm, exine straitified, exine is thick and coarsely granular, echinated, reduced spines.

Compositae gen. indet. (4) (Plate IV, Fig. 42)

Shape: Prolate, circular in polar view; Size: 40 µm; Aperture: Tri-colporate; Exine: 2 µm, sexine thicker, echinated, coarsely granular, spines 2 µm in length.

Compositae gen. indet. (5) (Plate IV, Fig. 43)

Shape: Prolate, circular in polar view; Size: 16 µm; Aperture: Tricolporate, colpuscovered with granular elements, narrow, smooth and sunken colpi; Exine: 4 µm, roughly granulated, echinated, thicker sexine.

Compositae gen. indet. (6) (Plate IV, Fig. 44)

Shape: Sub-prolate, hexagonal in polar view; Size: 33-35 µm; Aperture: Tri-coloporate.

Family: Dipsacaceae

Dipsacus sp. (1) (Plate V, Fig. 45)

Shape: Semi-oblate, spheroidal; Size: 65 µm; Aperture: Tri-colporate; Exine: 6 µm, very thicker sexine which is stratified into two layers, sexine echinate and microechinate, perforated and granulated, varying spine size, larger spines are stupa-shaped.

Dipsacus sp. (2) (Plate V, Fig. 46)

Shape: Oblate, spheroidal; Size: 55-60 µm; Aperture: Tri-colporate; Exine: 7 µm, sexine is thicker, extended and divided, granulated, sexine stratified into two layers, echinate and microechinate.

Family: Elaeagnaceae

Elaeagnus sp. (Plate V, Fig. 47)

Plate-V: 45. *Dipsacus* sp. (1), 46. *Dipsacus* sp. (2), 47. *Elaeagnus* sp., 48. *Rhododendron* sp. (1), 49. *Rhododendron* sp. (2), 50. *Rhododendron* sp. (3), 51. *Rhododendron* sp. (4), 52. Ericaceae gen. indet. (1), 53. Ericaceae gen. indet. (2), 54. Euphorbiaceae gen. indet. (1), 55-56. Euphorbiaceae gen. Indet. (2), Equatorial and Polar View (scale bar = 20 µm).

Shape: Oblate, triangular in polar view; Size: 25-27 µm; Aperture: Tri-colporate; Exine: 4 µm, sexine thinner than nexine, surface granulate and slightly undulating.

Family: Ericaceae

Rhododendron sp. (1) (Plate V, Fig 48)

Shape: Tetrahedral tetrad; Size: 40 µm; Aperture: Tri-colporate; Exine: 3 µm, sexine and nexine similar in thickness, probably psilate.

Rhododendron sp. (2) (Plate V, Fig. 49)

Shape: Tetrahedral tetrad; Size: 38 µm; Aperture: Tri-colporate; Exine 5 µm, sexine thicker than nexine.

Rhododendron sp. (3) (Plate V, Fig. 50)

Shape: Tetrahedral tetrad; Size: 40 µm; Aperture: Tri-colporate; Exine: 5 µm, sexine thicker than nexine.

Rhododendron sp. (4) (Plate V, Fig. 51)

Shape: Tetrahedral tetrad; Size: 35-38 µm; Aperture: Tri-colporate; Exine: 6 µm, thickness of exine not similar, undulating, sexine thicker than nexine.

Ericaceae gen. indet. (1) (Plate V, Fig. 52)

Shape: Tetrahedral tetrads; Size: 25-28 µm; Aperture: Tri-colporate; Exine: 3.5 µm, sexine and nexine similar in thickness.

Ericaceae gen. indet. (2) (Plate V, Fig. 53)

Shape: Tetrahedral tetrad; Size: 20-22 µm; Aperture: Tricolporate; Exine: 3.5 µm; sexine much thicker than nexine.

Family: Euphorbiaceae

Euphorbiaceae gen. indet. (1) (Plate V, Fig. 54)

Shape: Prolate, semicircular in polar view; Size: 17 µm; Exine: 3 µm, narrow, long colpus, marginal zone of colpus smooth, exine structure reticulate-rugulose.

Euphorbiaceae gen. indet. (2) (Plate V, Fig. 55-56)

Shape: Semi-circular in equatorial view, circular in polar view; Size: Equatorial axis 3 µm, Polar axis 32 µm; Exine: 6.5 µm, reticulated exine, sexine thicker than nexine, long narrow colpus.

Family: Fagaceae

Castanopsis sp. (Plate VI, Fig. 57)

Shape: Prolate and circular in equatorial view; Size: 14 µm; Aperture: Tri-colporate, colpi long and narrow; Exine: 2 µm, sexine and nexine similar in thickness, radially symmetrical, sculpture tangled-stringy-rugulose.

Quercus sp. (Plate VI, Fig. 58-59)

Shape: Prolate in equatorial view and lobate in polar view;

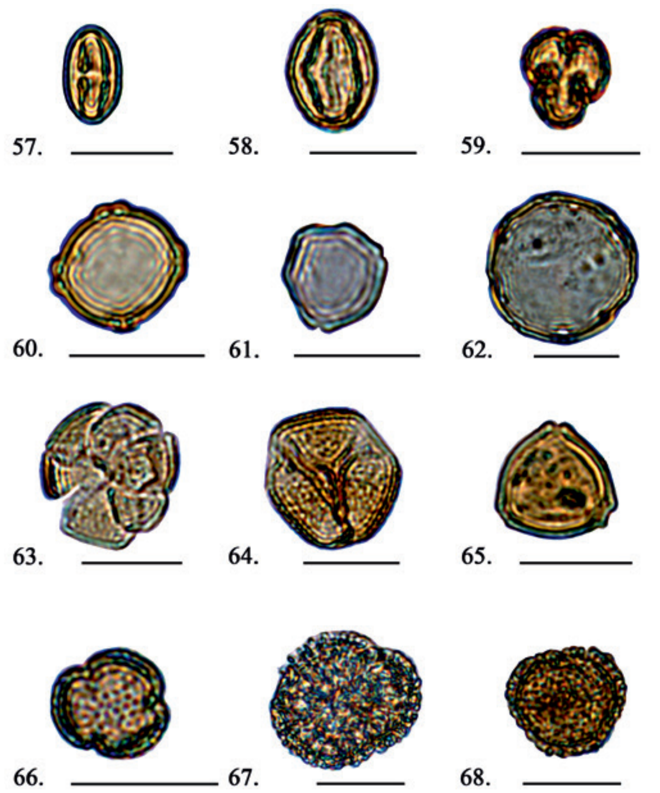

Plate-VI: 57. *Castanopsis* sp. (Family Fagaceae), 58-59. *Quercus* sp., Equatorial and Polar view, 60. *Myriophyllum* sp., 61. *Engelhardtia* sp. (Family Juglandaceae), 62. *Juglans* sp., 63. Family Labiatae gen. indet., 64. *Nymphoides* sp. 65. *Myrica* sp. 66. *Fraxinus* sp., 67. *Jasminum* sp., 68. *Ligustrum* sp. (scale bar = 20 µm).

Size: Equatorial axis 18 µm, polar axis 15 µm; Aperture: Tri-colporate, long narrow colpi; Exine: mesocolpium 2 µm relatively short, straight furrows, occasionally bent in the pore areas, surface verrucate to scabrate with elements of various sizes.

Family: Haloragaceae

Myriophyllum sp. (Plate VI, Fig. 60)

Shape: Oblate, semi-circular in equatorial view; Size: Equatorial axis 20 µm; Aperture: Pentaporate; Sexine slightly thicker than nexine, granulated.

Family: Juglandaceae

Engelhardtia sp. (Plate VI, Fig. 61)

Shape: Oblate, triangular in outline; Size: 16 µm; Aperture: Tri-porate; Exine: 3 µm, sexine thicker than nexine, granulated.

Juglans sp. (Plate VI, Fig. 62)

Shape: Oblate, spheroidal to sub-spheroidal, circular; Size: 38 µm; Aperture: Pantoporate; Exine: 2.5 µm, sexine thicker than nexine, tectum microechinate.

Family: Labiatae

Labiatae gen. indet. (Plate VI, Fig. 63)

Shape: Oblate to sub-spheroidal; Size: 28 µm; Aperture: Hexacolpate; Exine: 3 µm, sexine slightly thicker nexine, smoothly reticulated, furrows are generally straight and narrow.

Family: Menispermaceae

Nymphoides sp. (Plate VI, Fig. 64)

Shape: Triangular in polar view; Size: 28-30 µm; Aperture: Tri-colporate; Exine: 4 µm, sexine much thicker than nexine, granulated, alveolate.

Family: Myricaceae

Myrica sp. (Plate VI, Fig. 65)

Shape: Oblate, triangular in polar view; Size: 18-20 µm; Aperture: Tri-cilporate; Exine: 1 µm, sexine is thicker than nexine near and around pori, sexine microechinate.

Family: Oleaceae

Fraxinus sp. (Plate VI, Fig. 66)

Shape: Prolate, circular in polar view; Size: 15 µm; Aperture: Tri-colporate, colpi as long as polar axis; Exine: 1.5 µm, sexine thicker than nexine, granulated, alveolated.

Jasminum sp. (Plate VI, Fig. 67)

Shape: Spheroidal, circular in polar view; Size: 38 µm; Aperture: Tri-colporate; Exine: 3 µm, sexine thicker than nexine, surface of the exine is reticulated.

Ligustrum sp. (Plate VI, Fig. 68)

Shape: Spheroidal to sub-prolate, circular in polar view; Size: 22 µm; Aperture: Tri-colporate; Exine: 2.5 µm, sexine thicker than nexine, exine reticulated, foveolated.

Family: Onagraceae

Onagraceae gen. indet. (Plate VII, Fig. 69)

Shape: Tetrahedral tetrads; Size: 55-60 µm; Aperture: Tricolporate; Exine: 5 µm, sexine comparatively thicker than nexine, aspidated, exine distrinctly stratified, reticulated.

Family: Polygonaceae

Polygonum posumbo (Plate VII, Fig. 70)

Shape: Globular; Size: 10-15 µm; Aperture: Pantoporate; Exine: 1.5 µm, sexine thicker than nexine, exine stratified and reticulated.

Polygonum sp. (1) (Plate VII, Fig. 71)

Shape: Spheroidal; Size: 30-32 µm; Aperture: Pantoporate; Exine: 4 µm, sexine and nexine similar in size, reticulated, alveolated, columella long and closely packed, lumina with numerous rudimentary columellae.

Polygonum sp. (2) (Plate VII, Fig. 72)

Shape: Spheroidal; Size: 35 µm; Aperture: Pantoporate; Exine: 5 µm, sexine thicker than nexine, granulated, reticulated, micro

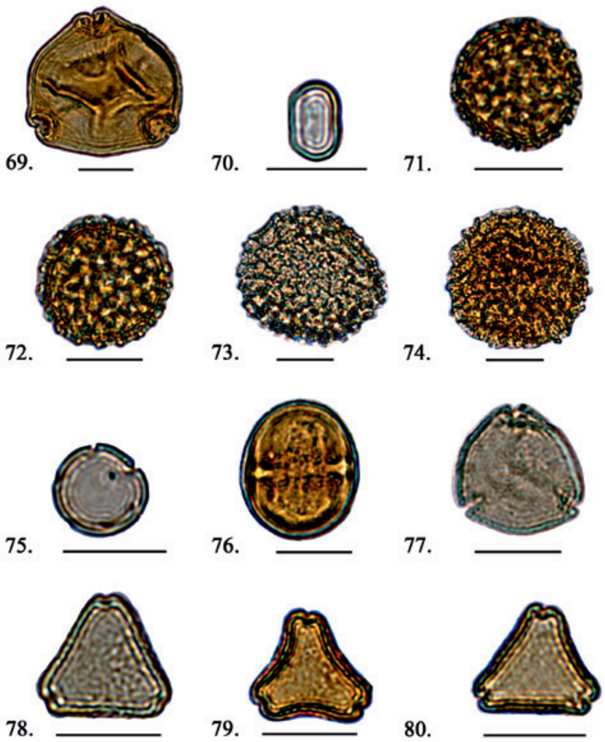

Plate-VII: 69. Family Onagraceae gen. Indet., 70. *Polygonum posumbu*, 71. *Polygonum* sp. (1), 72. *Polygonum* sp. (2), 73. *Polygonum* sp. (3), 74. *Polygonum* sp. (4), 75. Family Rubiaceae gen. indet., 76. Family Sapotaceae gen. indet., 77. *Symplocos* sp. (1), 78. *Symplocos* sp. (2), 79. *Symplocos* sp. (3), 80. *Symplocos* sp. (4) (scale bar = 20 µm).

spinules are seen on the edge, laminated.

Polygonum sp. (3) (Plate VII, Fig. 73)

Shape: Spheroidal; Size: 55-58 µm; Aperture: Pantoporate; Exine: 4 µm, sexine much thicker than nexine, reticulated, micro spinules, alveolated, columell along and closely packed.

Polygonum sp. (4) (Plate VII, Fig. 74)

Shape: Spheroidal; Size: 57-60 µm; Aperture: Pantoporate; Exine: 5 µm, sexine thicker than nexine, granulated, reticulated, micro spinules are seen on the edge, laminated.

Family: Rubiaceae

Rubiaceae gen. indet. (Plate VII, Fig. 75)

Shape: Spheroidal, circular in polar view; Size: 15-17 µm; Aperture: Pentaporate; Exine: 3 µm, sexine thicker than nexine, reticulated, perforated.

Family: Sapotaceae

Sapotaceae gen. indet. (Plate VII, Fig. 76)

Shape: Prolate, circular in polar view; Size: 28-39 µm; Aperture: Tetra-colporate; Exine: 4 µm, sexine thicker than nexine, perforated, alveolated.

Family: Symplocaceae

Symplocos sp. (1) (Plate VII, Fig. 77)

Shape: Triangular in polar view; Size: 30-32 µm; Aperture: Tri-colporate; Exine: 3 µm, sexine much thicker than nexine, roughly verrucate exine surface.

Symplocos sp. (2) (Plate VII, Fig. 78)

Shape: Triangular in polar view; Size: 20-22 µm; Aperture: Tri-colporate; Exine: 2 µm, sexine thicker than nexine, exine stratified, reticulated.

Symplocos sp. (3) (Plate VII, Fig. 79)

Shape: Triangular in polar view; Size: 22-25 µm; Aperture: Tricolporate; Exine: 4 µm, sexine and nexine similar in thickness, exine surface smoothly verrucated, reticulated.

Symplocos sp. (4) (Plate VII, Fig. 80)

Shape: Triangular in polar view; Size: 25-28 µm; Aperture: Tri-colporate; Exine: 3 µm, sexine slightly thicker than nexine, exine stratified.

Family: Ulmaceae

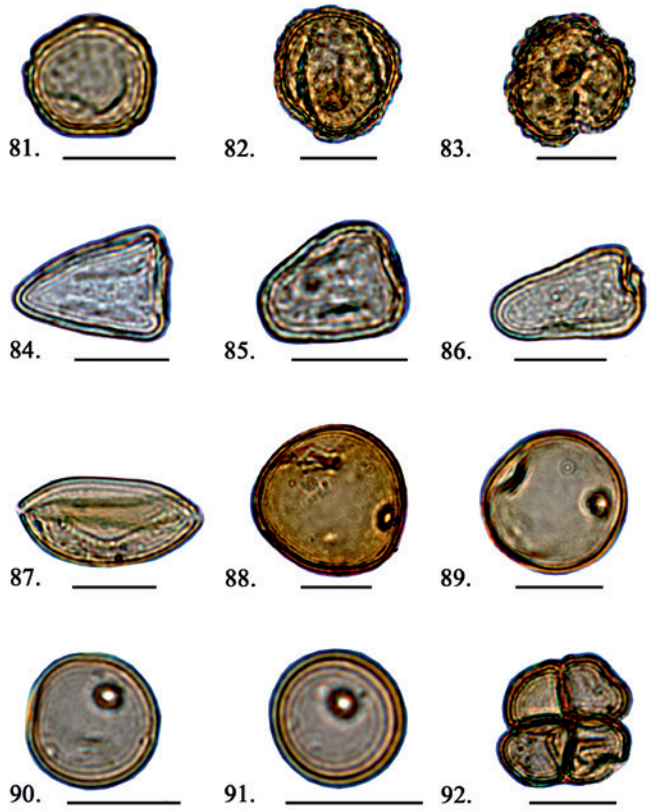

Plate-VIII: 81. *Ulmus* sp. 82-83. Family Valerianaceae gen. indet. (Equatorial and Polar View) 84. Cyperaceae gen. indet. (1), 85. Cyperaceae gen. Indet. (2), 86. Cyperaceae gen. Indet. (3), 87. Liliaceae gen. indet., 88-91. Poaceae gen. Indet., 92. *Typha* sp. (scale bar = 20 µm).

Ulmus sp. (Plate VIII, Fig. 81)

Shape: Oblate, pentagonal in polar view; Size: 22 µm; Aperture: Pentaporate; Exine: 1.5 µm, thicker sexine and regulated, walls are fragile and pores are typically less aspidate.

Family: Valerianaceae

Valerianaceae gen. indet. (Plate VIII, Figs. 82, 83)

Shape: Spherical in equatorial view, circular in polar view; Size: Equatorial axis 34 µm, Polar axis: 30 µm; Aperture: Tri-colporate; Exine: 5 µm, exine slightly thicker, columellae in mesocolpia simple, sparser, irregular in shape, branched above, ornamentation micro-echinate, verrucae absent.

iii. Angiosperms (Monocotyledons)

Family: Cyperaeae

Cyperaceae gen. indet. (1) (Plate VIII, Fig. 84)

Shape: Triangular; Size: 36 µm; Aperture: Monoporate; Exine 2.5 µm, sexine slightly thicker than nexine, smoothly covered exine, granulated, micro-echinated.

Cyperaceae gen. indet. (2) (Plate VIII Fig. 85)

Shape: Triangular; Size: 25 µm; Aperture: Monoporate; Exine: 2.8µm, Sexine much thicker than nexine, perforated, micro-echinated.

Cyperaceae gen. indet. (3) (Plate VIII, Fig. 86)

Shape: Triangular; Size: 30-35 µm; Aperture: Monoporate; Exine: 2.7 µm, sexine slightly thicker than nexine, perforated, reticulated.

Family: Liliaceae

Liliaceae gen. indet. (Plate VIII, Fig. 87)

Shape: Oblate, elliptic; Size: 40-44 µm; Aperture: Monosulcate; Exine: scabrated, reticulum irregular, very small lumina present.

Family: Poaceae

Poaceae gen. indet. (1) (Plate VIII, Fig. 88)

Shape: Spherical; Size: 40 µm; Aperture: Monoporate; Exine: 2 µm, sexine and nexine similar in thickness, micro-echinate, perforated.

Poaceae gen. indet. (2) (Plate VIII, Fig. 89)

Shape: Spherical; Size: 32-34 µm; Aperture: Monoporate; Exine: 1.5 µm, sexine and nexine similar in thickness, micro-echinate, perforated.

Poaceae gen. indet. (3) (Plate VIII, Fig. 90)

Shape: Spherical; Size: 25 µm; Aperture: Monoporate; Exine: 2 µm, stratified and smooth, both sexine and nexine similar.

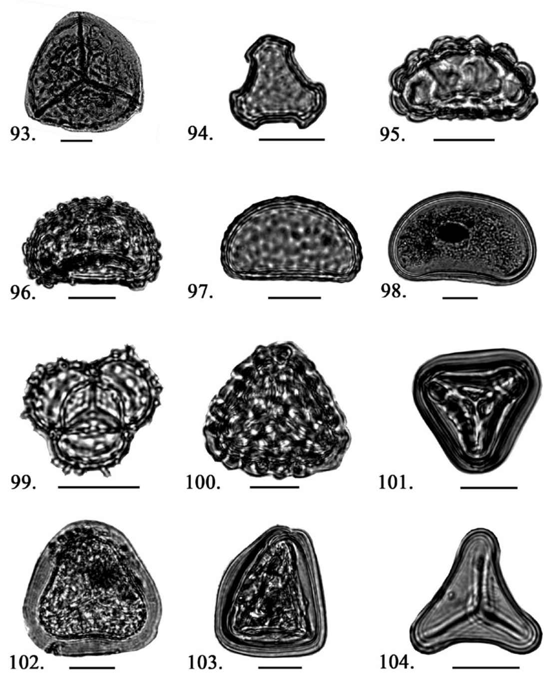

Plate-IX: 93. *Lycopodium* sp. (1), 94. *Lycopodium* sp. (2) 95. *Arthromeris* sp. 96. *Polypodium* sp. 97. *Davallia* sp. 98. *Polypodium* sp. 99. *Selaginella* sp. 100. *Pteris* sp. (1) 101. *Pteris* sp. (2), 102. *Pteris* sp. (3), 103. *Pteris* sp. (4), 104. *Cyathea* sp. (scale bar = 20 µm).

iv. Pteridophytes

Family: Lycopodiaceae

Lycopodium sp. (1) (Plate IX, Fig. 93)

Shape: Semi-circular in polar view; Size: 75-80 µm; Aperture: Trilete.

Lycopodium sp. (2) (Plate IX, Fig 94)

Shape: Triangular; Size: 25-30 µm; Aperture: Trilete.

Family: Polypodiaceae

Arthromeris sp. (Plate IX, Fig. 95)

Shape: Bilateral in polar view and kidney shaped in equatorial view; Size: 45 µm; Aperture: Monolete; Exospore: 5 µm, spinose and granulose, thickly undulated.

Polypodium sp. (Plate IX, Fig. 96)

Shape: Bilateral; Size: 90 µm; Aperture: Monolete; Exospore: 5 µm, spinose, roughly granulate.

Family: Selaginellaceae

Selaginella sp. (Plate IX, Fig. 99)

Shape: Circular, lobate; Size: 30-32 µm. Aperture: Trilete; Exospore: 3 µm, roughly echinated, slightly rugulated.

Family: Pteridaceae

Pteris sp. (1) (Plate IX, Fig. 100)

Shape: Triangular in polar view, straight to concave side and rounded corners; Size: 45-50 µm; Aperture: Trilete; Exospore is proximally verrucate and distally regulate.

Pteris sp. (2) (Plate IX, Fig. 101)

Shape: Triangular in polar view; Size: 40-45 µm; Aperture: Trilete; Verrucated exospores and distally regulate.

Pteris sp. (3) (Plate IX, Fig. 102)

Shape: Circular, Triangular in polar view; Size: 50-55 µm; Aperture: Trilete; Exospore with rounded corners, 5 µm, roughly granulose.

Pteris sp. (4) (Plate IX, Fig. 103)

Shape: Triangular in polar view; Size: 40-42 µm; Aperture: Trilete; Exospore slightly thicker than endospore, distally rugulated and proximally verrucate.

Family: Cyatheaceae

Cyathea sp. (Plate IX, Fig. 104)

Shape: Triangular, concave sides and rounded corners; Size: 35 µm; Aperture: Trilete. The exposure is 1.2-3 µm thick, psilate, perforate or verructae.

POLLEN ASSEMBLAGE ZONES

The pollen diagram prepared on the basis of palynomorphs shows three pollen assemblage zones; i.e. P-I, P-II and P-III in ascending order (Fig. 3).

Zone P - I

The ZONE P-I is the lowermost zone of this section and is featured by the dominance of *Pinus* (12.3-32.12%) followed by *Picea* (0.3-1.08%), *Tsuga* (0.43-1.71%) and very few *Podocarpus*. Similarly, angiosperm trees like and *Quercus* (8.59-22.46%) have the dominance in their group. Herbs like Poaceae (8.03-26.04%) are high and *Artemisia*, Compositae and Caryophyllaceae are smaller in percentages. Pteridophytes are represented by Polypodiaceae (1.56-23.91%), Triletes (1.28-8.85%) and other Monoletes (*1.2-4.81%)*. Wetland plants are represented by Polygonaceae, Cyperaceae and Liliaceae.

Zone P-II

This zone shows the significant decrease of pollen compared to previous zone. Gymnosperm such as *Pinus* (19.46-24.88%) has declined, whereas *Picea* (4-5.88%) and *Podocarpus* (0.67-2%) have retained their presence in similar way. The most distinguishing feature of this zone is the presence of *Cedrus*, which is completely absent in other zones. *Quercus* and Poaceaewhich were dominant in Zone P-I has declined in significant number. Angiosperms like *Alnus* and *Betula* shows weak presence whereas species like *Castanopsis, Juglan, Myrica, Fraxinus* are almost absent. *Artemisia* is most common among herbs. The wetland plants belonging to families Cyperaceae, Polygonaceae, and Liliaceae are dominant as in the previous pollen assemblage zone. Among Pteridophytes, Polypodiaceae (2.26-11.16%) and other Triletes (4.03-6%) are common.

Zone P-III

The Zone P-III is witnessed by the heavy increase of *Quercus* (12.14-24.06%). Similarly the percentage of gymnosperms such as *Picea* (3.26-10.5%), *Pinus* and *Tsuga* (3.27-7.34%) increased. *Alnus* and *Betula* also show their significant presence in this zone. *Artemisia* and other Compositae are evident. The percentage of Poaceae is fluctuating between 5-10% of the total pollen sum. Among the wetland plants *Polygonum* and Cyperaceae are still prominent while Liliaceae decreased. In Pteridophytes Polypodiaceae is dominant (3.84-21.79%) which is followed by Pteridaceae (0.75-3.98%) and other Triletes (0.66-14.68%). The percentage of Polypodiaceae has gradually increased towards the top.

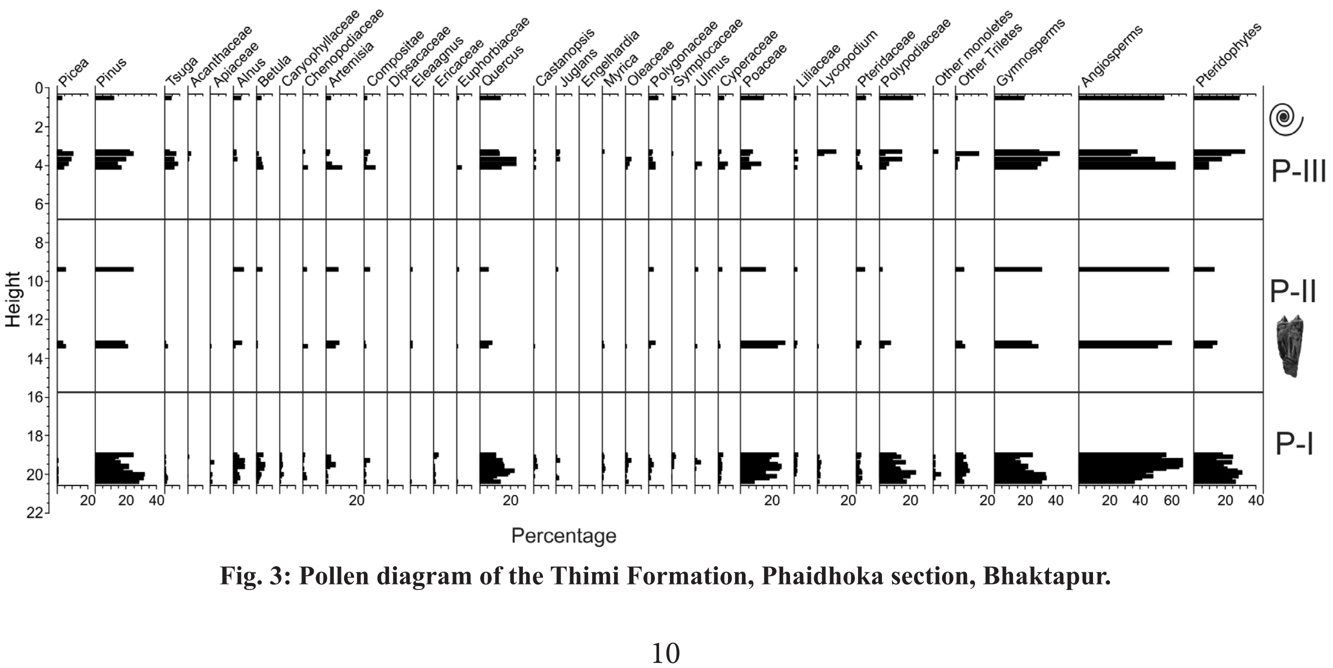

Fig. 3: Pollen diagram of the Thimi Formation, Phaidhoka section, Bhaktapur.

PALEOCLIMATE

The pollen analysis from the Phaidhoka Section of the Thimi Formation reveals three major pollen zones i.e. P-I, P-II and P-III. Every pollen assemblages were compared to present vegetation of central Nepal assuming that living plants had similar requirement of climate conditions compared to those of modern ones. Different plants carry their peculiar climatic signatures. Gymnosperms like *Pinus* represents sub-tropical to cool temperate climate whereas *Picea* represents cold and dry climate. Similarly, *Tsuga* represents moist cool temperate areas with high rainfall, cool summers and little or no water stress while major angiosperms such as *Quercus* represents sub-tropical to cold temperate climate. Similarly *Alnus* and *Betula* are found in temperate zones. *Artemisia* grows in temperate climates of both hemispheres, usually in dry or semiarid habitats. Compositae is most common in the arid and semiarid regions of subtropical and lowers temperate latitudes. Polypodiaceae and Pteridaceae are found in wet climates, most commonly in wet forest floor, representing humid climate. Polygonaceae, Cyperaceae, Typhaceae and Haloragaceae grow near water resources along the bank of river, pond and lakes.

In the pollen assemblage P-I, the dominant species among gymnosperm was *Pinus*, Other gymnosperms like *Picea* and *Tsuga* are present in minor numbers. The angiosperm tree *Quercus* is most dominant throughout the zone following by *Betula* indicating cold climate. *Alnus* indicate the wet condition in riverine and shadow areas. Grass pollen belonging to Poaceae are also dominant indication much dry condition. Pteridophytes fern like Polypodicaeae are found in wet regions. So the vegetation pattern of this assemblages if not uniform, but the majority of vegetation indicates the assemblage as warm temperate climate.

The pollen assemblage P-II marks as the significant decrease of pollen counts. Presence of frequent sandy layers made palynological sampling difficult in this part of the lithological section. Clastic nature of sediments may be responsible for yielding less pollen concentration. *Picea* has increased compared to previous pollen assemblage zone whereas *Pinus, Alnus, Betula, Quercus,* Poaceae and Polypodiaceae are thinly distributed. From the vegetation pattern, the climate can be concluded as colder than the previous pollen assemblage zone.

The pollen assemblage P-III marks the increment of *Pinus* which is dominant among Gymnosperms. *Picea* and *Tsuga* are dominant indicating much colder than zone P-II. Angiosperm tree *Quercus* and *Juglans* have increased indicating much colder in the upper part of this section. The gap in palynological record is evident in this zone because the sediments towards to are more clastic and followed by oxidation which subsequently unfavourable for the pollen preservation. The presence of lignite in upper part of this section indicates swampy and marshy depositional environment. The opercula are of Bithyniidae (*Digoniostoma* sp. or/and *Gabbia* sp.) are abundant in this lignite layer. Such kinds of freshwater molluscs live in shallow water on macrophytes and also on muddy substrate of temporary water bodies. The accumulation of empty shells and large number of opercula may be possible in limnic zone of lakes by water transportation and sedimentation over several meters. In every case this water body might be stagnant with large shallow regions. The large bovid molars recorded from the middle part of the section confirms the earlier findings by Paudayal et al. (2011) few hundred meters east of this section.

CONCLUSIONS

Palynological investigation from the Phaidhoka Section of the Thimi Formation revealed 94 species of plants belonging to 74 genera and 40 families. Palynological record suggests that the climate in the eastern Bhaktapur area was variable and not uniform in Late Quaternary Period. The gymnosperm like *Pinus, Picea* and *Tsuga* are most commonhaving higher frequency in middle and upper part of the section. Among the angiosperm trees *Quercus, Alnus, Betula, Myrica*, Oleaceae and Ericaceae are common. The climate during the deposition of uppermost and middle part of this section was comparatively colder than present day indicating cold temperate signature. However, the pollen assemblages indicate warm temperate climatic condition existed during the deposition of the lowermost part of this section.

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