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FUNGAL REMAINS FROM LATE HOLOCENE LAKE DEPOSIT OF DEMAGIRI, MIZORAM, INDIA AND THEIR PALAEOCLIMATIC IMPLICATIONS

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ABSTRACT

The present communication is an attempt to portray the fungal remains retrieved from a 2m deep sediment profile analysed from Demagiri, southern Mizoram. Several types of fungal forms/spores encountered in the lake sediments comprise *Alternaria*, *Helminthosporium*, *Tetraploa*, *Curvularia Cookeina*, *Nigrospora*, *Multicellaesporites*, *Ornasporonites*, *Dyadosporonites*, *Actinopelte*, *Kutchiathyrites*, *Clasterosporium*, *Helicoma*, *Entophlyctis*, etc. encompassing a time bracket of last 850 yr BP. In fact, the organic-rich sediments drifted from the nearby tropical humid forest cover provided an ideal habitat/substratum for the growth of fungi. The preponderance of fungal remains in the investigated lake bed sediments could be attributed to in situ proliferation of the fungi as well as their transportation from the adjoining forest belt, from higher riches by wind and water and by upthermic winds from the lower elevations to the depositional site. In all, the recovery of fungal remains in great diversity and numbers suggests that the region enjoyed a humid climatic condition during the course of sediment accumulation the lake basin.

Keywords: Late Holocene, Fungal remains, Palaeoclimate, Demagiri, Mizoram

INTRODUCTION

The role of fungal remains in stratigraphy was dealt by Graham (1962) and Elsik (1974). However, their relevance in palynostratigraphical studies of the sedimentary deposits is rather uncertain, as they have a wider range of distribution in term of geological time scale, i.e. Precambrian to Recent times and do not demonstrate any marked variability in their gross morphological characters and forms over such a long span of time. The record of Microthyriales from the Cretaceous Period to the Recent is a well-known example of such case (Elsik, 1978). Despite all this, their presence in the sedimentary deposits provides a very reliable information in order to unravel the depositional environment of the sediments, nature of substrata and the host plants upon which the fungi flourished prior to getting buried in the sedimentary deposits as well as their habits and local habitats during the past. So far, considerable work has been carried out on the Tertiary fossil fungal remains from the various regions of the country such as Himachal Pradesh (Saxena, Sarkar and Singh, 1984; Sarkar and Singh, 1988), Gujarat (Kar and Saxena, 1976, 1981; Kar, 1979,1985; Rawat, Mukherjee and Venkatachala 1977), Rajasthan (Sah and Kar, 1974), Kerala (Rao and Ramanujum, 1975, 1976; Patil and Ramanujum, 1988), Tamil Nadu (Venkatachala and Rawat, 1972) and northeastern India (Kar, Singh and Sah, 1972; Salujha, Kindra and Rehman, 1972; Hait and Banerjee, 1994; Kar, Mandaokar and Ratan, 2005, 2006).

However, there are only a few sketchy publications on the fungal remains from the Quaternary deposits of the country such as West Bengal (Gupta, 1970), Tripura (Prasad and Ramesh, 1983; Prasad, 1986), Tamil Nadu (Rao and Menon, 1970), Gujarat (Sharma, 1976) and Arabian Sea (Ratan and Chandra, 1982). Hence, in this pursuit, it was intended to extend such studies on Quaternary fungal remains in Mizoram, where there are a good number of potential organic-rich lacustrine deposits available, owing to presence of diversified forest floristic of this part of northeast India. During the course of pollen analytical investigation of 2 m deep sediment profile from Demagiri, southern Mizoram (Chauhan and Mandaokar, 2006), encompassing a time span of last one millennium, we have come across a large number of fungal spores in the sediments. The database gathered on this aspect has enabled us to get acquainted with the fungal diversity and palaeoenvironmental conditions prevailing in the region during the period of sediment accumulation in the lake basin as well as to strengthen and to substantiate the pollen-based palaeoclimatic inferences drawn from southeastern Mizoram (Chauhan and Mandaokar, 2006).

The site of the present investigation, i.e. Demagiri lies between 22°52' E latitude and 92°28'N longitudes approximately 120 km west of Lunglei hills in southern Mizoram (Fig.1). Topographically, the area is mountainous comprising medium-sized hills with gentle slopes and attaining an average altitude of 900m. The lake basin is encircled with mountain range all around. The lake is perennial and measures 30m in diameter. It is bordered with a 1-2m wide swampy margin.

GEOLOGY

Geologically, the Mizoram-Tripura miogeosynclinal basin is a part of larger Assam-Arakan region. The early geological investigation in Mizo hills was carried out by La Touche (1891), Hayman (1937) and Franklin (1948). Das Gupta (1948) reviewed the geology and petroleum prospects of the Lushai hills and concluded that in general the area was unattractive. The beds generally trend N–S, dipping at 20° to 50° either eastward or westward and comprise sandstones, siltstones, shale, mudstones with a few pockets of shales, limestones, calcareous sandstones and intraformational conglomerates (Karunakaran, 1974; Ganju, 1975; Ganguli, 1983).

CLIMATE

The region is characterized by the prevalence of a humid climate which is influenced by southwest monsoon. The mean minimum and maximum winter temperatures are 11°C and 21°C, whereas the mean minimum and maximum summer temperatures are 20°C and 30°C respectively. The months of April and May are marked by stormy winds. The monsoon rainfall takes place

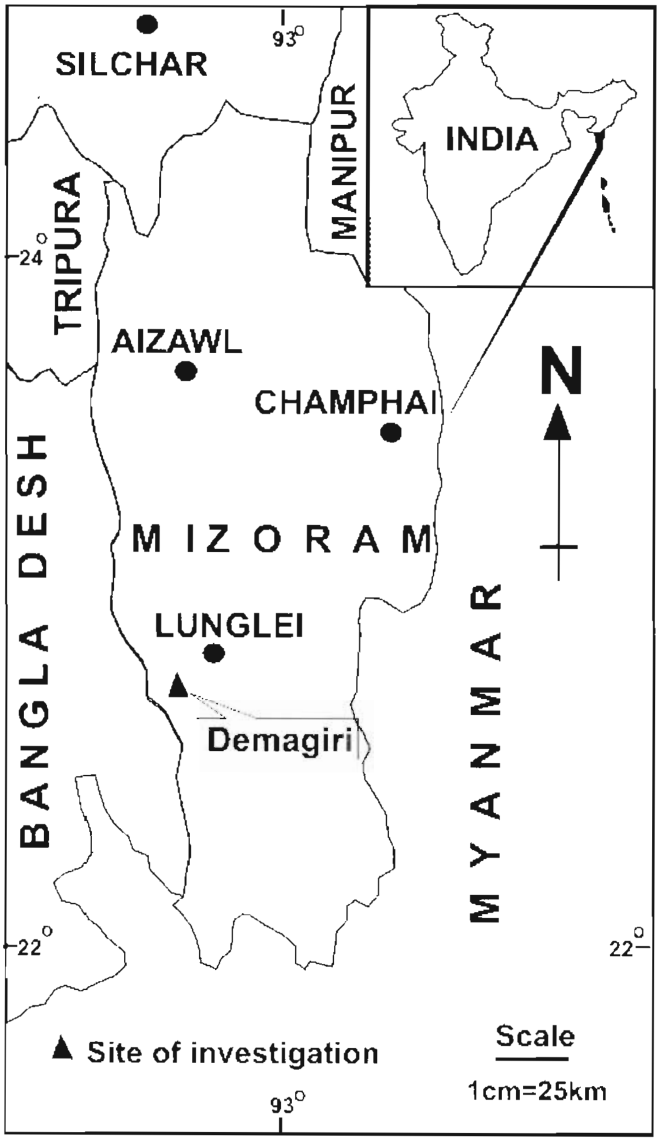


Fig. 1. Map showing the study area at Demagiri, Mizoram.

from the mid of May to September. However, the torrential rains occur between the months of June and August. The average annual rain fall recorded for the region is *ca.* 2100mm.

VEGETATION

In general, the region abounds with dense and diversified tropical evergreen forests. *Artocarpus chaplasha*, *A. heterophylla*, *Hopea odorata*, *Mimusops elengi*, *Manilkara hexandra*, *Madhuca indica*, *Terminalia* sp., *Cedrela toona*, *Lagerstroemia speciosa*, *Syzygium cymosum*, *S. cumini*, etc. are the major ingredients of these forest. The ground vegetation is dominated by grasses, whereas *Ageratum conyzoides*, *Mazus japonicus*, *Stellaria media*, *Justica* simplex, *Solanum xanthocarpum*, etc. also occur very frequently. *Typha latifolia*, *Nymphaea* sp., *Potamogeton* sp., *Lemna* sp., etc. are the common aquatic plants of lakes and ponds. Ferns grow abundantly in damp and shady situations.

MATERIAL AND METHOD

A 2 m deep trench was dug out on the dried margin of the lake and in total 10 samples were picked up from it for the fungal studies. Two bulk samples were also collected from this trench at wider intervals for radiocarbon dating. Beyond the depth of 2 m further collection of the samples was abandoned as water started oozing.

The sediment composition of the trench profile does not exhibit much conspicuous change and it is mainly constituted of silt, clay and sand in variable fractions at different depths. The depth-wise lithological details of the trench are as below (Fig. 2):

Depth	lithology
0-80 cm	Brownish silty clay
80-100 cm	Brownish clay
100-180 cm	Brownish sandy clay
180-200 cm	Brownish clayey sand

Two radiocarbon dates, i.e. 150±140 yr BP (BS-2463) at 20-100 cm depth and 740± 120 yr BP (BS-2452) at 1.60-2.00 cm depth have been determined for this trench profile. However, the sediment accumulation rate of 1cm/4.2 yr calibrated for this profile has been used for extrapolating the age of 850 yr BP for the beginning of the sedimentary deposit.

For the segregation of fungal remains from the sediments the conventional technique of maceration was employed, using various chemicals. The samples were treated with 10% aqueous KOH solution to deflocculate the fungal spores/remains from the sediments followed by 40% HF treatment for 3-4 days in order to remove the silica content. Thereafter, the samples were treated with HCL for 5 minutes to dissolve the carbonates and to oxidize the organic content by treating them with HNO3 for one day. This was followed by washing of material with water 3 times to remove the acid content. Finally, the samples were prepared in 50% glycerin solution for microscopic examinations.

DESCRIPTION OF FUNGAL REMAINS

During the course of investigation, we have come across a large number of fungal remains in the sediments belonging to well known 19 extant genera and 5 form-genera comparable to their modern counter parts. In addition, 4 fungal fruiting bodies and spores of unknown affinities have also been recovered in the sediments. The identification of the fungal remains has been executed by comparing them with the photographs and illustrations available in the published literature (Elsik, 1968; Prasad, 1986; Pirozynski, *et al.*, 1988; Chauhan and Sharma, 1991) as well as in the reference books (Alexopoulos *et al.*, 1966; Subramanium, 1971; Ainsworth *et al.*, 1973). The frequency diagram has been prepared in order to depict the fluctuating trends of the prominent fungal remains throughout the sequence (Fig.3). The detailed morphological diagnoses along with concise accounts on the habits and habitats of the fungal remains and their earlier records from the other Tertiary and Quaternary beds are given below.

1. ***Tetraploa*** (Pl. I, figs.1-2): Dark brown spore provided with 4-multicellular long appendages; spore measures 40x20μm in dimension excluding appendages with length up to 30μm. *Comments*: *Tetraploa* has been reported from the Quaternary of Malvan (Surat), Gujarat (Sharma, 1976), Miocene of Kerala-Quilon beds (Rao and Ramanujam, 1975) and Palaeocene-Eocene of Cauvery Basin, Tamil Nadu (Venkatachala and Rawat, 1972).
2. ***Multicellaesporites elsikii*** (Pl.I, figs. 3-4): Fungal spore 9-celled, spindle-shaped measuring 58-60 x 11-15 μm in size;

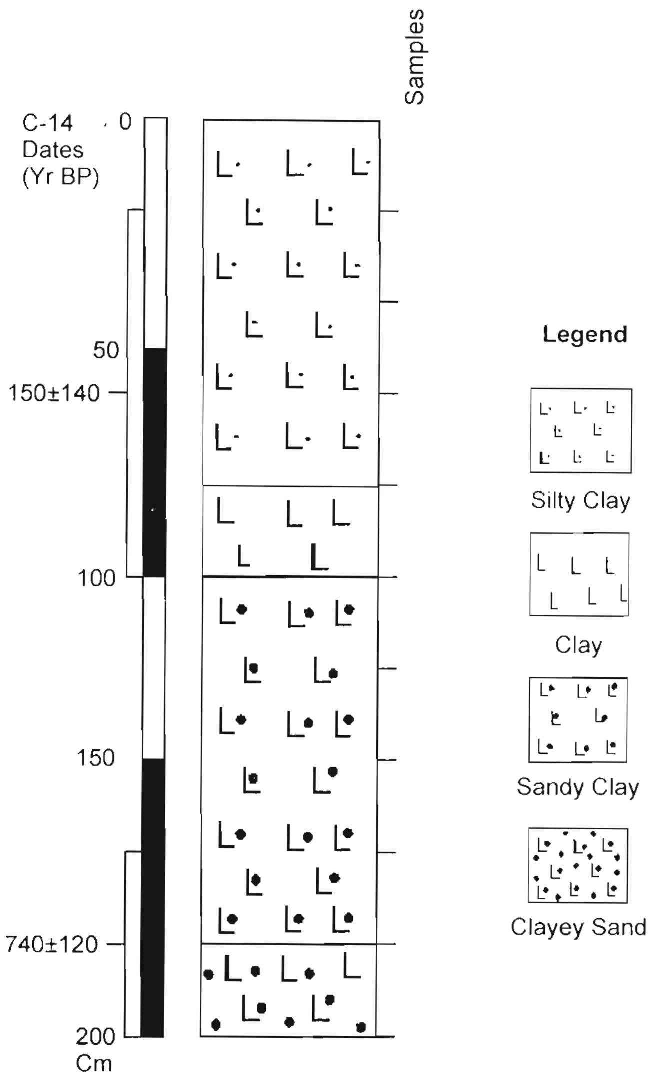


Fig.2. Lithology and radiocarbon dates of the profile.

generally pentacellate, inaperturate; septa thick; middle cells broad and bulging, whereas the terminal cells smaller and tapering; fungal body covered with undulating transparent layer; spore surface with granulate pattern.
Commentts: It resembles with the *Multicellaesporites elsikii* described by Kar and Saxena (1976) from Paleocene of Kutch, Gujarat.

3. ***Ornasporonites*** (Pl. I, figs. 5-6): Ascospore 5-celled, elongated in shape and 40x18μm in dimension; septa between cells are very thick; cells are constricted.
Comments: This kind of spores has been reported in the Miocene of Cannanore lignite, south India (Ramanujum and Rao, 1978) and the Holocene deposits of Tripura (Prasad, 1986).
4. ***Dyadosporonites*** (Pl.I, figs.7-8): Spore 4-celled with distinct constriction at the septa, measuring 75-94μm x12-16μm in dimension; middle cells large, broad and gradually tapering, whereas the terminal cells are small and narrow with blunt ends; surface provided with hyphal growth.
Comment: This type of spores has also been described by Elsik (1968) from the Tertiary deposits of Texas. From India, such spores have been reported by Ramanujum and Rao (1978) from the Cannanore lignite.
5. ***Foveoletisporonites*** (Pl.I, figs. 9-10): Fungal spores multiseriate, 70μm long and 12μm broad, transverse septa about 10 in number. Spore wall distinctly foveolate arranged in horizontal rows in between the septa of spores.
Comments: Such type of fungal spores was also recorded from Warkalli and Quilon Neogene beds of Kerala (Ramanujam and Rao, 1978).
6. ***Herpotrichiella***: (Pl. I, figs. 11-18): Fungal spore fusiform, 50-60μm long and 15-20μm broad; 4-celled, middle cells broad and dark, terminal cells are light in colour and thin-walled; spore 3 septate, septa dark and broad.
Comments: This type of fungal body has also been described from the Holocene deposits of Tripura, India (Prasad, 1986).
7. **Ascospore** (Pl. I, figs. 12-13): Ascospores unicellular, oval-shaped, elongated and measures 45μm long and 22μm at their widest; they appear darker in the broader part and get hyaline towards polar regions.
8. ***Cookeina*** (Pl. I, figs. 14-19): Spore 2-celled, golden yellow in colour; measuring 30-35μm in length and 5-20μm in width; fusiform; surface provided with longitudinal striations; septum lanceolate and distinct.
Comments: Spore exhibits affinities with the modern *Cookeina*. This fungus has been described from Tanganyika lake sediments (Wolf and Cavaliere, 1966), the Neogene sediments of Quilon and Warkalli, Kerala (Ramanujum and Rao, 1978) and the Holocene deposits of Tripura (Prasad, 1986). Some species of this saprophytic fungus occur in mycorrhizal association with higher plants.
9. **Fungal spore Type I** (Pl. I, figs. 15-20): Fungal spore large dark colour, fan-shaped (25x12μm).
Comments: This type of spore has been recorded rarely. It could not be assigned to any modern taxa due vague morphological features.
10. ***Kutchiathyrites*** (Pl. I, figs. 16-17): Microthyraceous fungi, eccentrically developed, 64-110x41-73 μm, ostiole absent, radiating hyphae dark and well developed than the transverse ones, hyphae interconnecting and forming squarish, non-porate paranchymatous cells.
Comments: The fungal remain exhibits very close similarities with those reported from the Oligocene of Kutch Gujarat (Kar, 1979). It resembles with the extant members of Microthyriales.
11 ***Actinopelte*** ((Pl. I, figs. 21-22): Fungal fruiting body sub-circular, measuring about 76x70μm in dimension, ostiole indistinct, fruiting body composed of radiating files of elongated cells. The peripheral cells are in the form of projecting spines.
Comments: Based on the presence of peripheral spinose cells the fruiting body is comparable to *Actinopelte*.
12. **Fruiting body of Ascomycetes** (Pl. I, fig. 23): Fruiting body large, dark in colour and measures about 60μm in length and 45μm at its widest. It is flat and concave on poles.
Comments: similar fruiting bodies of Ascomycetes have been encountered in the recent sediment from Kumaon Himalaya (Chauhan and Sharma, 1991).
13. ***Clasterosporium*** (Pl. I, figs. 24-25): Fungal spore multicellular, uniseriate, measuring 70μm in length and 12μm in width, dark brown in colour with thick transverse septa between cells; individual cells varies from 6-16μm x 4-8μm in size.
Comments: This type of spores has been reported from the Holocene deposits of Tripura (Prasad, 1986) and the east

African lake sediments (Wolf, 1966). The fungus grows commonly on the leaves of swampy vegetation.

14. ***Leptosphaeria*** (Pl. II, figs. 1-2): Fungal spore 5-celled measuring about 40 x 18µm in dimension; middle cells rectangular, whereas the terminal cells with rounded ends; septa between cells are thick and distinct.
Comments: It is a common parasite on some crops and wild plants.

15. ***Helicoma*** (Pl. II, figs. 3-4): Triradiating hyphae multicellular covered with a undulating transparent layer, septa very thick, one of the branch of hyphae coils and measuring 40x20µm in size, middle cell at the junction of the hyphae triangular and broader than the rest of the cells.
Comments: It occurs commonly as saprophytic on wood and barks.

16. ***Entophlyctis*** (Pl. II, fig. 5): Sporangia show cranulate and lobed margin, dark brown irregular-shaped fungal body with length 40µm and width 30µm.
Comments: Van Geel (1978) has recorded this type of fungal body from the Holocene sediments of Netherlands. This chytridialean, aquatic saprophytic fungus has been noticed in the Holocene deposits of Tripura (Prasad, 1986).

17. ***Stemphylium*** (Pl. II, figs. 6, 29-30): Conidia large globose 65-80µm long and 40-60µm broad, dictyospores flattened on the poles, cell wall very thick (Subramanium, 1971).
Comments: It is a member of Hypohmycetes. The multicellular conidia are generally airborne and their number varies according to rains.

18. **Teliospore of *Prospodium*** (Pl. II, figs. 7-8): Spore bicelled (32x17µm), light brown, transparent, constricted at the middle. Septum broad and prominent, spore surface covered a distinctly reticulate wall.
Comments: It is common pathogens of wheat in India. It shows close resemblance with the teliospore of other members of Pucciniaceae.

19. **Uredospore of *Puccinia*** (Pl. II, figs. 9 -10): Uredospore bicelled measuring 70 x 30 m in dimension, dark with broad septum, cells of the spore constricted at the middle and provided with apertures on each end.
Comments: It is common pathogens of wheat in India.

20. ***Nigrospora*** (Pl. II, figs., 11-12): Spore unicellular, black and globose, measuring 30-36 µm in diameter; a hyaline germinating papillate type wart present on the surface.
Comments: This common pathogen of grasses has been recovered abundantly in lake sediments.

21. ***Curvularia*** (Pl. II, figs. 13-14): Conidia 3-celled, dark brown in colour, 40µm long and 10 µm broad, thick walled, somewhat fusiform slightly curved or bent with central enlarged dark-coloured cells, whereas the terminal cells are much smaller and lighter in appearance.
Comments: It is common pathogen of grasses and has been recorded abundantly in the investigated site. It has been reported in the Quaternary deposits from Malvan (Surat), Gujarat (Sharma, 1976) and Pykara, Ootacamund, Tamil Nadu (Rao and Menon, 1970).

22. ***Periconia*** (Pl. II, figs. 15-16): Spore spheroidal, dark brown, 20µm in diameter, surface provided with densely packed spinules with thick wall.
Comments: It occurs commonly as parasitic or saprophytic in nature.

23. ***Spegazzinia*** (Pl. II, figs. 17-18): spores bicelled (30x20µm); brownish-yellow; spetum thick; surface prominently echinate, spine about 1.5µm long and sharply pointed.
Comments: This type of spores has been recorded from the Neogene strata of Kerala. (Ramanulum and Rao, 1978).

24. **Fungal spore Type II** (Pl. II, figs. 19-26): Fungal spore large dark colour, bi-celled measuring about 60x30µm in size with broad constriction at the middle; the extreme polar areas provided with prominent notches.
Comments: This type of spore has been scantily recorded in the sediment; however, its affinities could not be ascertained to any extant taxa.

25. ***Cladosporium*** (Pl. II, figs. 20, 24-25): Spores 1-celled, yellowish-brownish, sessile, broadly ellipsoid (20x10µm in size) with distinct helium; spore surface densely echinulate.
Comments: This parasitic/saprophytic fungus (Subramanian, 1971) has been recorded frequently in the sediments.

26. ***Synchytrium*** (Pl. II, figs. 21-22): The colonial fungi with 32-30 diameter contain loosely packed roundish hyaline cells of 12µm diam. each.

27. ***Cunninghamella*** (Pl. II, fig. 23): Vesicle dark brown, spherical in shape measuring 45µm in diameter, surface provided with spine like denticles.
Comments: It is found commonly as parasitic on human as well as saprophytic on dung and soil.
Comments: This parasitic fungus is found in moist situations and has been encountered sporadically in the sediments.

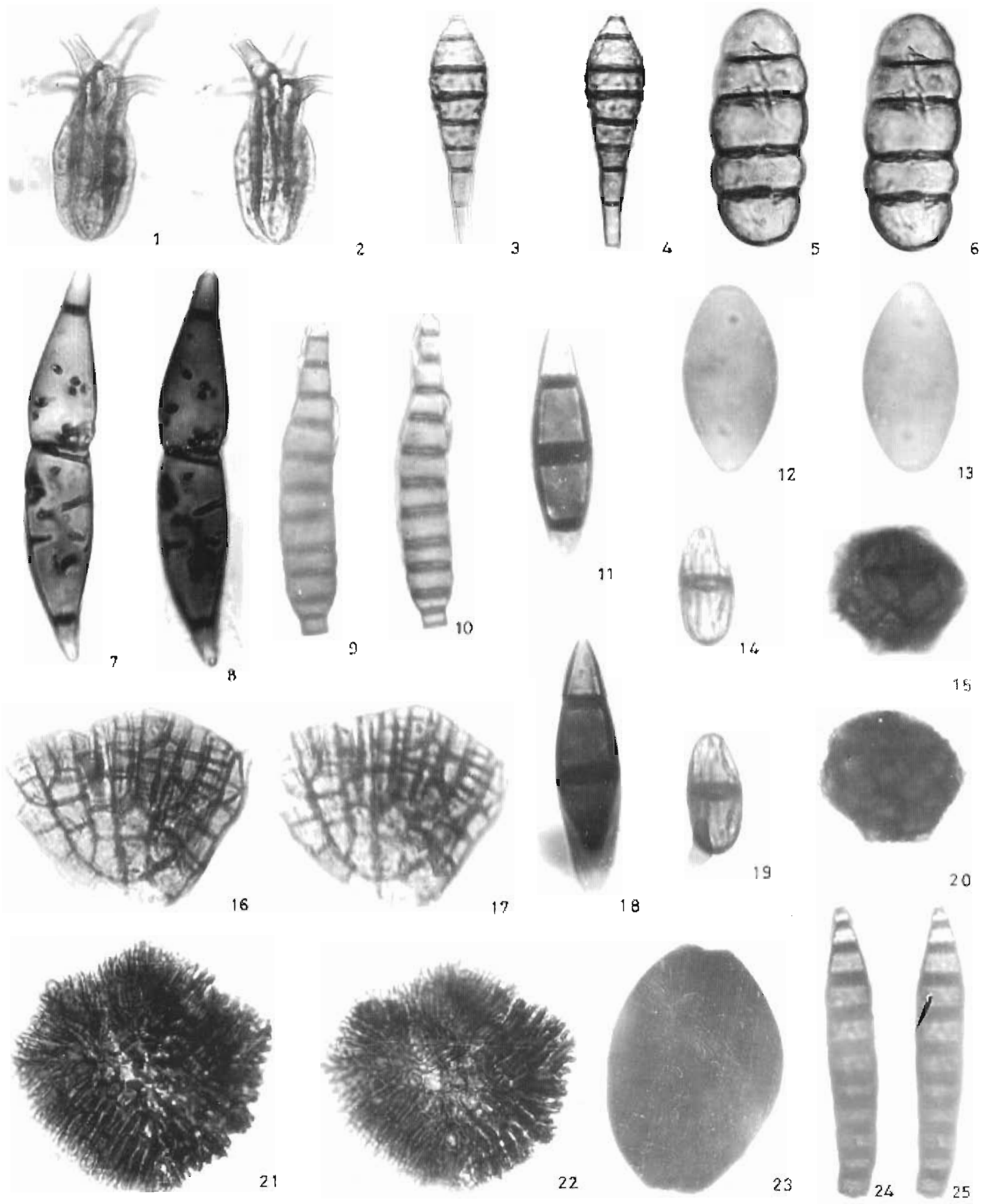
28. ***Dictyoarthrinium*** Type (Pl. II, figs. 27-28): Conidia dark brown, composed of 4 flattened and compressed and squarish cells in outline and constricted at the septa, 11-13µm in diameter.
Comments: This member of Hyphomycetes occurs

EXPLANATION OF PLATE I

(Magnification x 500)

1-2.	*Tetraploa*
3-4.	*Multicellaesporites elsikii*
5-6.	*Ornasporonites*
5-6.	*Dyadosporonites*
9-10.	*Foveoletisporonites*
11-18.	*Herpotrichiella*
12-13.	**Ascospore**
14-19.	*Cookeina*
15-20.	**Fungal spore Type I**
16-17.	*Kutchiathyrites*
21-22.	*Actinopelte*
23.	**Fruiting body of Ascomycetes**
24-25.	*Clasterosporium*

Plate I



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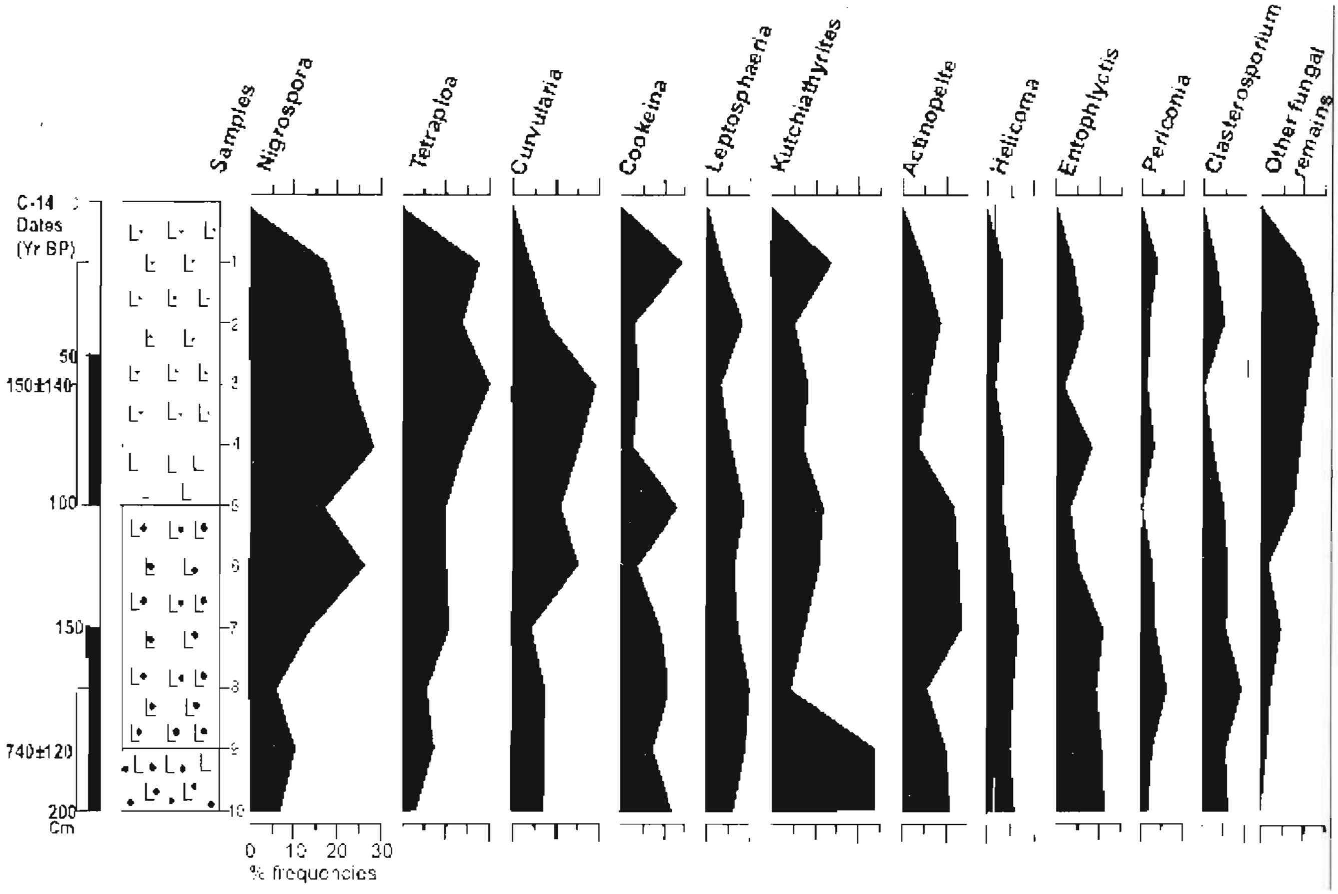

Fig. 3. Frequency diagram showing major fungal remains from Demagiri, Mizoram.

commonly on dead leaves of *Borassus aethiopium* (Subramanium, 1971).

PALAEOCLIMATIC INFERENCES

The retrieval of diversified fungal assemblage in the sediments provides very valuable insights into the palaeoenvironmental conditions prevailed in the investigation area during the past. Such studies also facilitate to understand to what extent the inferences drawn from this approach are complementary with that generated using other proxy signals. The record of fungal remains in the 2m deep sediment profile from Demagiri has brought out significant database to work out the palaeoclimate and depositional environment of the sediments in the southern Mizoram during the last millennium. The fungal taxa recovered in this lacustrine deposit have demonstrated very close affinities with their modern counterparts. Hence, with the availability of the database regarding their identity and the various physical requirements for their proper growth and dissemination, it become much feasible to infer the past climatic conditions and depositional environment of the sediments in a much precise manner, for which no empirical records are known. The investigation has unraveled a much diversified fungal assemblage comprising 19 well-established modern taxa comprising extant genera viz., *Nigrospora, Cookeina, Tetraploa, Curvularia, Helicoma, Periconia, Leptosphaeria, Prospodium, Herpotrichiella, Entophlyctis, Puccinia, Cladosporium, Actinopelte, Dictyoarthrinium, Clasterosporium, Spegazzinia, Cunninghamella, Stemphylium, Synchytrium* and 5 form-genera such as *Foveoletisporonites, Ornasporonites, Multicellaesporites, Kutchiathyrites* and *Dyadosporonites* as well as 4 types of fungal fruiting bodies and spores of unknown

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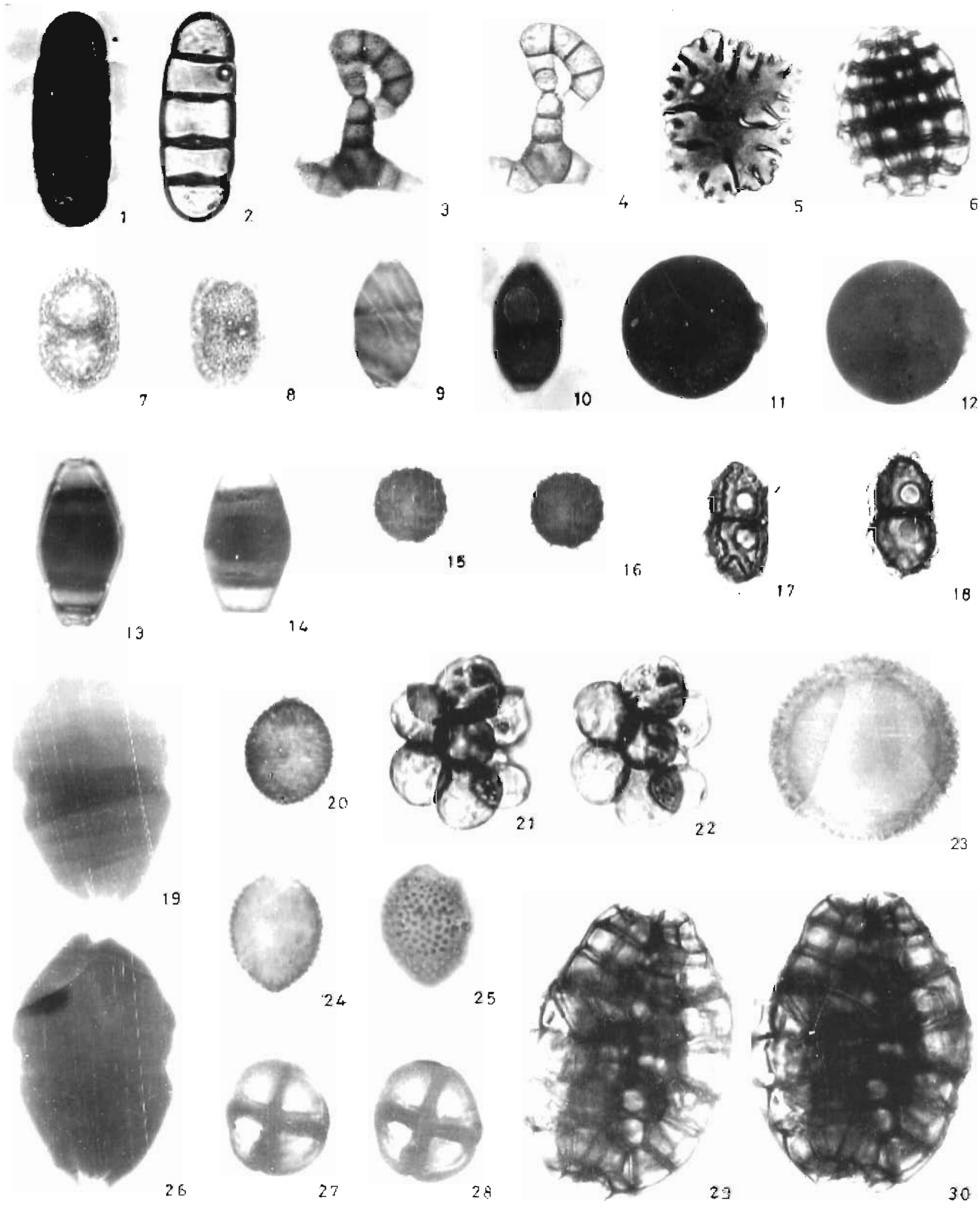
EXPLANATION OF PLATE II

(Magnification x 500)

1-2.	***Leptosphaeria***	13-14.	***Curvularia***
3-4.	***Helicoma***	15-16.	***Periconia***
5.	***Entophlyctis***	17-18.	***Spegazzinia***
6,29-30.	***Stemphylium***	19-26.	**Fungal spore Type II**
7-8.	**Teliospore of *Prospodium***	20,24-25.	***Cladosporium***
9-10.	**Uredospore of *Puccinia***	21-22.	***Synchytrium***
11-12.	***Nigrospora***	23.	***Cunninghamella***
		27-28.	***Dictyoarthrinium***

Plate II



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affinities. The frequent record of woody saprophytic fungi such as *Cookeina, Helicoma, Herpotrichiella, Entophlyctis* and *Periconia*, in the lower half of the sequence covering a time span of 850 to 400 yr BP suggests the presence of abundance of organic matter in the form of decaying logs and litter on the ground floor, which provided very a suitable substratum for their proliferation (Fig.3). The region supported diversified and dense tropical forests during the course of sediment accumulation as indicated by the considerable encounter of fruiting bodies of epiphyllous fungi such as *Actinopelte* and *Kutchiathyrites* belonging to Microthyriales, in appreciable numbers, which grow presently on the tropical trees. Hence, their presence strongly advocates the prevalence of a very humid climate with high temperature and rainfall as they require such type of optimal climatic conditions for their maximum propagation. The climatic inferences deduced from the present investigation have also been substantiated by the pollen proxy, demonstrating thereby the presence of diversified tropical evergreen forest in the region (Chauhan & Mandaokar, 2006) as well as documentation of similar fungal forms in the Holocene deposits from Tripura (Prasad, 1986) by this time. On the other hand the recovery of the common parasitic fungi of grasses and other herbaceous plants such as *Tetraploa, Curvularia, Leptosphaeria, Puccinia, Nigrospora*, etc., implies the occurrence of good herbaceous vegetation on the forest floor on account of prevailing favourable climatic conditions around the site of investigation. Furthermore, the sediment accumulation took placed in the ponding environment as evidently deciphered by the presence of aquatic-saprophytic fungi such as *Clasterosporium* and members of chytridialean group viz., *Entophlyctis* and *Synchytrium* right from the beginning of the sequence. However, since 400 yr BP onwards the considerable depletion in the epiphyllous microthyrious fungi viz., *Actinopelte* and *Kutchiathyrites* and a contemporary increase in *Tetraploa, Curvularia, Leptosphaeria, Puccinia, Nigrospora*, etc., which thrive commonly on grasses and other herbaceous elements, imply that the climate got relatively less humid in contrast to that prevailed earlier. The climatic implications derived for this time bracket are agreement with the pollen results inferred from this lake bed (Chauhan and Mandaokar, 2006), reflecting thereby the existence of less varied and sparse forests in the region in response to onset of a adverse climatic conditions.

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