Diverse palynoflora from amber and associated sediments of Tarkeshwar lignite mine, Surat district, Gujarat, India

Amber, a complex compound of terpenoids and phenolic derivates[1] is a fossilized resin produced from the trunk and the roots of some trees. It acts as a good preserving agent for micobiota and yielding insect remains from Permian onwards[2,3]. In India, pioneering work on the insect remains from amber was started by Shukla and co-workers[4]. They recorded well-preserved, fossilized remains of insects from amber pieces of Tertiary age from Mahudanra valley, Palamu, Bihar. Since the last decade several insect remains have been reported from amber, especially from the Cambay basin of western India[5–11]. However, little information is known about other organic fossil remains in amber. Here we report exceptionally well-preserved palynomorphs and non-pollen palynomorphs (NPP) from the macerated amber pieces of Tarkeshwar lignite mine, Surat district, Gujarat. The present study also records some thin-walled microfossils such as algae, testate amoeba and egg cases of insects from amber. Such thin-walled fossil remains are rarely recovered from the conventional palynological preparation as they get easily destroyed by the harsh chemical treatment given to the sediments to recover microfossils. The study of amber along with sediments gives a complete picture of microbiota that existed at the time of deposition of the sediments. On the basis of marker palynotaxa from the amber and associated lignite sediments, age and depositional environment of the Tarkeshwar lignite deposits are assessed.

The Tarkeshwar lignite mine occurs near the village Valia (lat. 21°22′35″–21°26′35″N and long. 73°04′00″–73°07′35″E) in Surat district of Gujarat (Figures 1 and 2 *a*). It has 7–8 m amber-bearing lignite seam, which is overlain by variegated clays, nummulitic limestone and clays (Figure 2 *b*). Literature survey on microbiota from amber shows that most of the studies on fossil biota from amber are carried out mainly by observing polished pieces of amber. Such studies obscure most of the diagnostic characters of palynomorphs. In the present study a special technique is used to dissolve amber pieces to recover microbiota. For palynological study, amber pieces are dissolved in toluene and stirred intermittently for 2–3 h till all the amber is completely dissolved. The dissolved mixture is sieved using 500-mesh sieve, washed with distilled water and dehydrated with glacial acetic acid and centrifuged. Then the residue is acetolysed using acetolysing mixture of acetic anhydride and concentrated sulphuric acid in the ratio of 9 : 1 over a sand bath for 5 min or till the water starts boiling. Next this mixture is centrifuged to remove the supernatant acetolysed mixture and the residue is sieved and washed with distilled water. The slides are prepared by smearing the residue mixed with polyvinyl alcohol solution on the cover slips. The dried coverslips are mounted on a glass slide using Canada balsam.

The slides prepared are observed under Olympus BX 51 microscope. All the studied palynological slides are housed in the Museum of PG Department of Geology, RTM Nagpur University, Nagpur.

Highly diverse and well-preserved palynoassemblage is recorded from the macerated residue of amber. The assemblage comprises of palynotaxa such as *Acanthotricolpites* spp., *Ctenolophonidites costatus* (Figure 3 *m*), *Cryptopolyporites cryptus*, *Dipterocarpuspollenites retipilatus* (Figure 3 *e* and *k*), *Dipterocarpuspollenites* sp., *Incrotonipollis neyvelii* (Figure 3 *f*), *Intrareticulites brevis*, *Lakiapollis ovatus*, *Liliacidites* sp., *Margocolporites* sp., *Neocouperipollis kutchensis*, *Palmaepollenites kutchensis* (Figure 3 *c*), *P. neyvelii*, *Paravuripollis mulleri* (Figure 3 *j*), *Polagalacidites clarus*, *Polycolpites* spp., *Proxapertites cursus*, *Pseudonothofagidites gujaratensis*

Figure 1. ***a***, Tarkeshwar lignite mine. ***b***, Amber piece from the lignite.

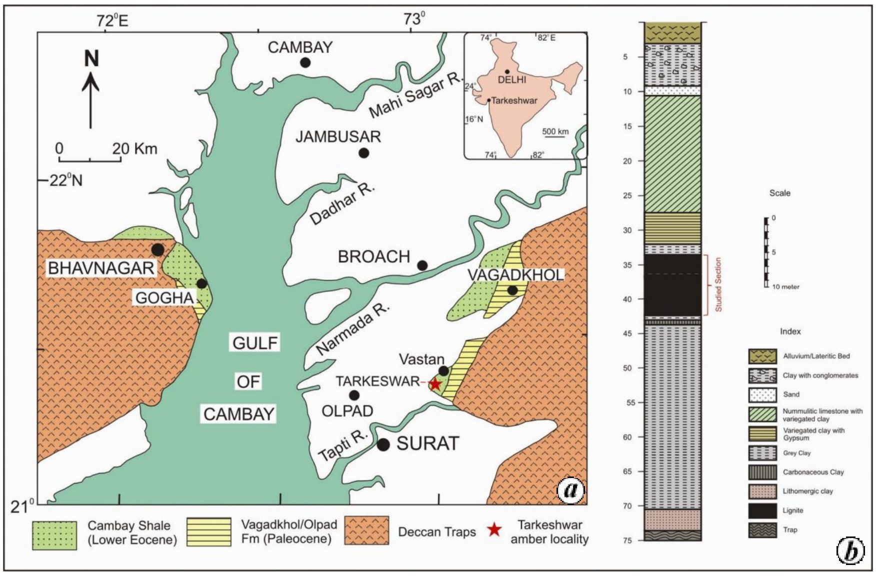

Figure 2. ***a***, Location of the study area. ***b***, Litholog of Tarkeshwar lignite mine.

(Figure 3 *i*), *Triorites* sp. and *Verrutricolporites* sp. The recovered assemblage might have been transported by air or insects and embedded in the resin. Significantly, the palynoassemblage recorded from the amber has good frequency of pollen of the family Dipterocarpaceae (*Dipterocarpuspollenites retipilatus*, *D.* sp.). The dipterocarp plant is an important source of amber and occurs mostly in the tropical to subtropical climate. The record of good concentration of Dipterocarpaceae pollen from the amber suggests that they were probably the main source of these amber pieces. In India, the most prolific fossil records of Dipterocarpaceae are found in sequences younger than Miocene[12–14]. Recently, Dutta *et al.*[15] recorded some pollen of Dipterocarpaceae from Early Eocene[16–18] Vastan lignite deposits of Surat district, Gujarat. The presence of a good number of Dipterocarpaceae pollen (*D. retipilatus*) in the amber of Tarkeshwar and Vastan lignite strongly suggests that the family Dipterocarpaceae was a significant member of the plant canopy since Early Eocene. Apart from pollen grains, diverse assemblage of NPP like monocellate, dicellate and multicellate fungal spores and hyphae, fungal fruit bodies of Microthyriaceae (Figure 3 *a*), algal sporocarps, leaf cuticles, trachids, woody remains, immature anther (Figure 3 *p*) and soil and litter microorganisms like testate amoeba (*Prorodon*-like, *Nebela*-like, Figure 3 *d* and *o*), egg cases (Figure 3 *g*), insects wings (Figure 3 *l*) and insect legs (Figure 3 *h*), have also been recorded from the amber. These forms are present with all their details. The presence of testate amoeba in the amber suggests that some of the amber pieces might have been solidified in the soil.

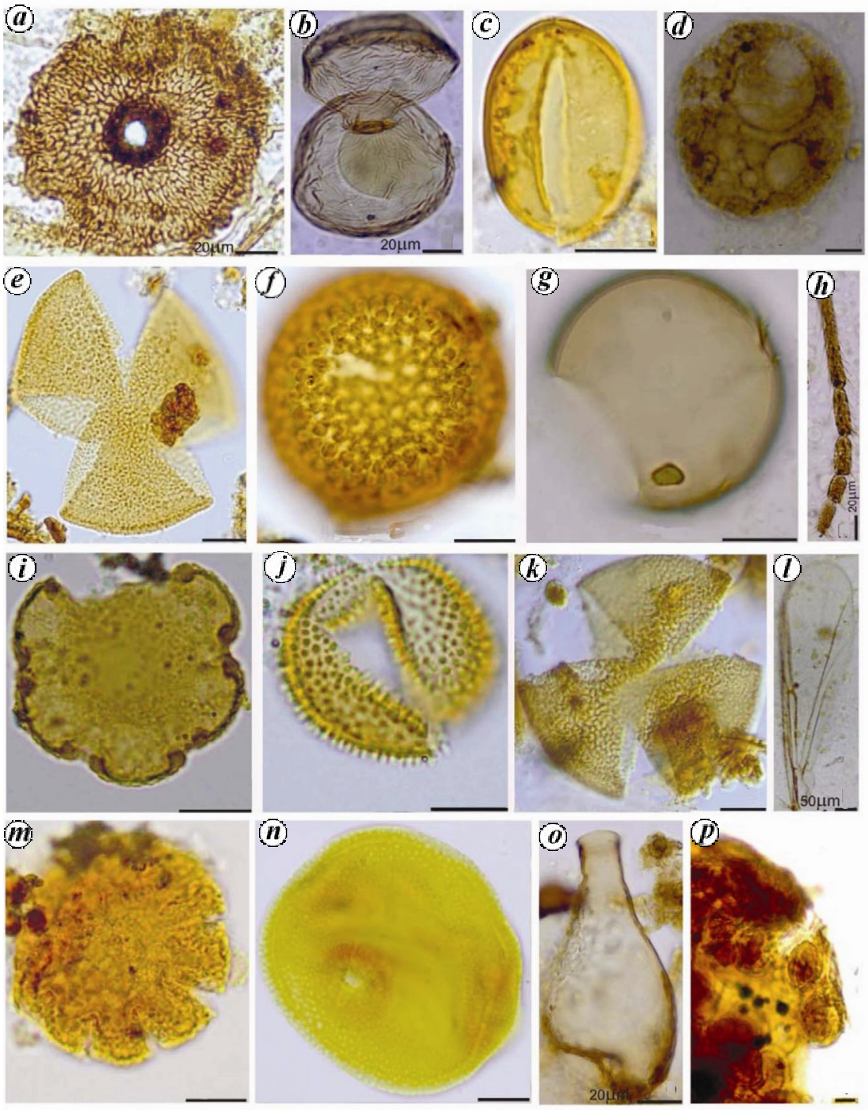

Figure 3. ***a***, Epiphyllous fungi Microthyriaceae, slide no. A-2, 2; ***b***, Air sacs, slide no. T-1, 2; ***c***, *Palmaepollenites kutchensis*, slide no. A-2, 1; ***d***, Testate amoeba, slide no. T-21, 1; ***e***, ***k***, *Dipterocarpuspollenites retipilatus*, slide nos A-2, 1 and A-2, 5; ***f***, *Incrotonipollis neyvelii*, slide no.A-8, 1; ***g***, Egg case of insect, slide no. T-2b, 1; ***h***, Insect part, slide no. T-1, 2; ***i***, *Pseudonothofagidites gujaratensis*, slide no. A-2, 4; ***j***, *Paravuripollis mulleri*, slide no. A-2, 1; ***l***, insect wing, slide no. T-9; ***m***, *Ctenolophonidites costatus*, slide no. A-2, 4; ***n***, *Tricolporopollis matanomadhensis*, slide no. Ta 38, 2; ***o***, Testate amoeba, slide no. T-2, 1 and ***p***, Part of anther with cluster of pollen grains, slide no. T-4b, 1. (Scale bars represent 10 µm or as otherwise mentioned.)

To know the age of the lignite deposits, palynological study of the associated lignite sediments of Tarkeshwar lignite was also carried out. The study shows presence of age-marker palynotaxa such as *Acanthotricolpites bulbospinosus*, *Angulocolporites microreticulatus*, *Cryptopolyporites cryptus*, *Ctenolophonidites costatus*, *Incrotonipollis neyvelii*, *Intrareticulites brevis*, *Iugopollis tetraporites*, *Lakiapollis ovatus*, *Longapertites vaneendenburgii*, *Neocouperipollis rarispinosus*, *Palmaepollenites kutchensis*, *P. nadhamunii*, *P. ovatus*, *Polycolpites* spp., *Polagalacidites clarus*, *Proxapertites cursus*, *Pseudonothofagidites gujaratensis*, *Retistephanocolpites williamsii* and *Tricolporopollis matanomadhensis*, which collectively suggest Early Eocene age for the Tarkeshwar lignite. However, due to the presence of some distinct Palaeocene–Eocene forms such as *Matanomadhiasulcites maximus*, *Tricolporopollis matanomadhensis* (Figure 3 *n*), *Racemonocolpites maximus*, *Tricolpites reticulatus* and *Incrotonipollis neyvelii*, the lower age limit can be extended up to Late Palaeocene. The overall palynoassemblage of this lignite deposit shows similarity with the nearby Vastan lignite mine, which is considered to be Early Eocene on the basis of palynomorphs and dinoflagellates[17–20]. However, Palaeocene–Eocene marker taxa such as *Tricolporopollis matanomadhensis*, *Racemonocolpites maximus*, *Tricolpites reticulatus* and *Incrotonipollis neyvelii* were exclusively recorded from the Tarkeshwar lignite.

The recovered assemblage is also indicative of depositional environment and climate. The presence of pollen grains showing affinity with *Gunnera* (*Intrareticulites brevis*) of Gunneraceae, *Durio*

(*Lakiapollis ovatus*) of Bombacaceae, *Ctenolophona* (*Ctenolophonidites costatus*) of Ctenolophonaceae, *Cryptopolyporites cryptus*, *Polycolpites* spp. and *Polygalacidites* indicates freshwater swampy conditions at the time of deposition. The absence of marine microfossils like dinoflagellate and foraminiferal linings in the lignite indicates deposition in distinctly terrestrial setting. The prevalence of humid tropical climatic conditions and heavy rainfall[21–23] is indicated by the record of high frequency of fungal remains, especially epiphyllous fungi Microthyriaceae from the sediments as well as amber.

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Age of Himalayan cedar outside its natural home in the Himalayas

The Himalayan cedar popularly known as deodar (*Cedrus deodara* (Roxb.) G. Don) is endemic to Hindu Kush, Karakoram and western Himalaya. Natural distribution of this species in the western Himalaya is restricted to areas receiving winter snow and summer monsoon rainfall. With the decreasing amount of winter snowfall from northwest to eastern part of the Himalaya, the deodar gradually disappears in natural forests. In scientific studies, Garhwal is taken as the natural eastern limit of Himalayan cedar in the western Himalaya[1]. But, exceptions to this also exist in the literature as indigenous forests of Himalayan cedar were reported in 1924 in Karnali Valley, West Nepal[2]. However, Bhattacharyya *et al.*[3] while studying tree core samples of Himalayan cedar from Giri Gaon (29°45′N and 82°10′E), Nepal, could establish only 265 years (AD 1714–1978) chronology. Atkinson[4] mentioned that there is no natural grove of Himalayan cedar in Kumaon, and these could have been first planted in temple complexes. According to his estimates[4], numerous plantations of Himalayan cedar around temples in Kumaon aggregate ~800 acres. Though Himalayan cedar is known to grow over thousand years in the western Himalayan region[5], the age of plantation trees in sacred groves around temples in Kumaon is not known. In Hindu mythology Himalayan cedar for its grandeur appearance is treated as sacred and the most preferred tree to be planted in temple complexes. Whether the age of Himalayan cedar plantations is contemporaneous with the construction of temples is not precisely known. Popular belief indicates that Himalayan cedar was first introduced in Jageshwar temple area in Kumaon, where it has almost naturalized with good regeneration. Though these sacred groves of Himalayan cedar in Kumaon region are still patchy, they play a crucial role in maintaining good floral and faunal diversity.

The Jageshwar temple, dedicated to Lord Shiva, was built ~9–13th century AD and plantation of Himalayan cedar trees could have commenced after that. To ascertain the date of plantation of Himalayan cedar around temple complexes, we surveyed and collected increment core samples from old-looking