On the occurrence of carbonised woods resembling *Terminalia* and *Sonneratia* in Palaeogene deposits of Gujarat, western India

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The carbonised woods resembling modern woods of the genus *Terminalia* Linn. and *Sonneratia* Linn. belonging to family Combretaceae and Sonneratiaceae, respectively are described from the Rajpardi lignite mine situated in Bharuch District of South Gujarat. The fossils indicate the existence of tropical palaeoclimat and presence of sea in the vicinity of Rajpardi during Eocene. These form the first record of carbonised woods from Gujarat and from the Palaeogene sediments of India too.

**Key-words**—Carbonised woods, *Terminalia*, *Sonneratia*, Palaeoenvironment, Palaeogene (India).


The carbonised woods have been reported from the Lower Karewa of Kashmir (Awasthi & Guleria, 1982; Lone et al., 1985), the Neogene sediments of Neyyeli in Tamil Nadu (Ambwani, 1982; Awasthi 1984; Awasthi & Agarwal, 1987; Agarwal, 1989) and from Varkala in Kerala (Awasthi & Ahuja, 1982; Awasthi & Panjwani, 1984; Awasthi & Srivastava, 1990a, b). It is evident from the above records that all the carbonised woods have so far been recorded only from the Upper Tertiary sediments of India. In the present paper carbonised woods are being described for the first time from the Palaeogene sediments of India.

The Rajpardi lignite mine from where the present fossils are described belongs to Palaeogene. There has been difference of opinion about the precise age of the Rajpardi lignite. Kathiara (1969) proposed Oligocene to Upper Eocene age, whereas Gadekar (1980) opined it to be Oligocene. Sudhakar and Basu (1973), based on outcrops and subsurface geology, established the Palaeogene stratigraphy of the southern Cambay Basin and inferred Middle Eocene to Upper Eocene age for the Rajpardi lignite. Recently, palynological investigations of the lignite have been carried out by Bhattacharya (1987) and Kar and Bhattacharya (in Press), and they have assigned Lower Eocene age to the lignite. Phadrare and Thakur (1990) on the other hand consider the age of Rajpardi lignite as Early to Middle Eocene. The lignite mine is situated about 35 km north-east of Bharuch on Ankleshwar-Rajpipla road (at about 21°43'55" Lat. : 73°13'30" Long. : Map 1). The area in general is characterised by undulating and flat topography with a number of small rivers and water channels which ultimately join river Narmada in the north. The carbonised woods were recovered...
from lignite bands and lenses alternating with carbonaceous clay from block number 13 of the mine in the form of big and small logs. Preservation apparently seems good but on closer microscopic examination most of the samples were found completely oxidised. Due to compression and overcharring, it is difficult to make out the anatomical details satisfactorily, thus making the task of identification difficult. A large number of samples were sectioned and studied and two of them with workable preservation are being described in the present paper.

It is important to mention here that Panandhro lignite mine in district Kutch is the only other lignite mine in Gujarat. Lignite of this mine has also been dated as Lower Eocene (Kar, 1978). In contrast to Rajpardi lignite, the Panandhro lignite is almost devoid of carbonised woods although a number of leaf impressions have been reported from this mine (Lakhanpal & Guleria, 1981; Guleria & Lakhanpal, 1984).

**SYSTEMATIC DESCRIPTION**

**Family—Combretaceae**

**Genus—** *Terminalioxylon* Schönfeld 1947

*Terminalioxylon palaeocalamansanai* sp. nov.

Pl. 1, figs 1-3, 5, 9

The present species is based on a small piece of carbonised wood measuring about 20 cm long and 6 cm in diameter.

**Description**—Wood diffuse porous (Pl. 1, figs 1, 2). Growth rings inconspicuous, delimited by smaller vessels and broader bands of fibrous tissue in the outer portion of the ring and narrow closer concentric bands of zonate parenchyma. Vessels small to large (mostly medium), solitary or in multiples of 2–4, rarely more or in double row, round to oval, almost evenly distributed. 3–8 per sq mm; t.d. 62–210 μm, r.d. 62–160 μm; vessel members 270–620 μm long with truncated or tailed ends; perforations simple nearly horizontal or oblique, tyloses not seen, gummy infiltration present (Pl. 1, figs 1, 2), intervessel pits bordered, alternate, oval, elliptic to angular, sometimes coalescent, 4–6 μm in diameter, vestured. Parenchyma abundant, paratracheal forming narrow sheath around the vessels, rarely aliform with short lateral extensions; zonate parenchyma forming sometimes broken mostly concentric wavy bands partially or completely enclosing the vessels, 1–6 cells wide (Pl. 1, figs 1, 2), parenchyma bands separated by somewhat wider bands of fibrous tissues; apotracheal parenchyma sparse, scattered in fibrous tissue; parenchyma cells round, oval to slightly elliptic in cross section, up to 28 μm in diameter, thin-walled, sometimes filled

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**PLATE 1**

*Sonnerratioxylon prepetalum* Awasthi

1. Cross section showing nature and distribution of vessels and parenchyma, × 60; Slide no. BSIP 36563-I.
2. Cross section magnified to show details of vessels and parenchyma, × 100; Slide no. BSIP 36563-I.
3. Intervascular pitting, × 550; Slide no. BSIP 36563-II.
4. Cross section showing nature and distribution of vessels and xylem rays, × 90; Slide no. BSIP 36554-II.
5. Tangential longitudinal section showing xylem rays, × 100; Slide no. BSIP 36563-II.
6. Tangential longitudinal section showing uniseriate xylem rays, × 120; Slide no. BSIP 36564-III.
7. Cross section showing growth rings, × 90; Slide no. BSIP 36564-I.
8. Radial longitudinal section showing xylem rays, × 180; Slide no. BSIP 36564-IV.
with gummy deposit or granular infiltration, crystals present. Xylem rays fine, closely spaced, uniseriate or rarely biseriate due to pairing of cells (Pl. 1, fig. 5); 6-24 μm wide, 3-29 cells or 44-775 μm high, 13-20 rays per mm; homocellular to weakly heterocellular, consisting of wholly procumbent cells or with single marginal rows of upright or squarish cell at one or both ends (Pl. 1, figs 5, 9), gummy infiltration abundant in ray cells, crystals not seen. Fibres more or less aligned in radial rows, forming concentric and somewhat wavy bands alternating with narrower bands of parenchyma, angular to polygonal in cross section, 8-20 μm in diameter, 3-6 μm thick, occasionally septate, inter fibre pits rarely seen, very small, simple.

The above mentioned characters collectively indicate affinity of the fossil wood to the genus *Terminalia* Linn. Among a large number of the Indian species of *Terminalia*, woods of only three species, namely *T. bellerica* Roxb., *T. bialata* Steud and *T. calamansanai* (Blanco) Rolfe (syn. *T. pyrifolia* Kurz) possessed banded parenchyma (Pearson & Brown, 1932; Ramesh Rao & Purkayastha, 1972) and are thus comparable with the present fossil. However, *T. bialata* can easily be differentiated from the present fossil in the absence of typical concentric bands. The common pattern of parenchyma in this species is usually aliform to confluent (Pearson & Brown, 1932, p. 534; Ramesh Rao & Purkayastha, 1972, p. 184; Purkayastha et al., 1976, p. 36) though sometimes forming bands. *Terminalia bellerica* like *T. calamansanai* shows very close similarity with fossil in the nature of parenchyma. However, absence of septate fibres in *T. bellerica* differentiates it from *T. calamansanai* as well as from the present fossil. Thus the fossil shows closest resemblance with the wood of *Terminalia calamansanai*.

The genus *Terminalia* was established by Schönfeld (1947) for the fossil wood of *Terminalia*. Mädel-Angeliewa and Müller-Stoll (1973) emended the diagnosis of the genus *Terminalia* Schönfeld and merged *Anogeissus* Navale 1964 and *Anogeissus* Louvet 1964 in it. However, Prakash (1979, p. 54) disagreed with the contention of Mädel-Angeliewa and Müller-Stoll and again separated the genus *Anogeissus* Navale 1964 for the fossil woods of *Anogeissus* and *Terminalia* Schönfeld for the fossil woods of all species of *Terminalia*. The genus *Terminalia* is used here in its original sense as proposed by Schönfeld.

A large number of fossil woods have been described under the genus *Terminalia* from India and many other countries. The author is aware of 37 species of the genus. A list of 25 species has been given by Mädel-Angeliewa and Müller-Stoll (1973) out of which *T. geinitzii* (Schenk) Mädel-Angeliewa & Müller-Stoll has been merged with *Luminitzeroxylon* by Kramer (1974b, pp. 20, 22). However, Prakash (1979, p. 55) while re-establishing the genus *Anogeissus* Navale 1964 has opined that both *T. geinitzii* and *T. intermedium* (Kräusel) Mädel-Angeliewa & Müller-Stoll belong to *Anogeissus*. The remaining species are listed below:

<table>
<thead>
<tr>
<th>Name</th>
<th>Locality</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Terminalia</em></td>
<td></td>
<td></td>
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<tr>
<td><em>kratiense</em> Serra 1966</td>
<td>Cambodia</td>
<td>Tertiary</td>
</tr>
<tr>
<td><em>tunesense</em> Fessler-Vrolant &amp; Duperson-Laudoueneix 1986, Tunisia Desneux, 1981</td>
<td>Egypt</td>
<td>Oligocene &amp; Miocene</td>
</tr>
<tr>
<td><em>Terminalia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>densiporosum</em> Kramer, 1974b</td>
<td>Sumatra</td>
<td>Mi-Pliocene</td>
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<tr>
<td><em>Terminalia</em></td>
<td></td>
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</tr>
<tr>
<td><em>sp.</em> Kramer, 1974b</td>
<td>Java and</td>
<td>Mi-Pliocene</td>
</tr>
<tr>
<td><em>Terminalia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>sp.</em> Lemoigne et al., 1974</td>
<td>Ethiopia</td>
<td>Miocene</td>
</tr>
<tr>
<td><em>T. pachitanensis</em> Sukieman, 1977</td>
<td>Java</td>
<td>Miocene</td>
</tr>
<tr>
<td><em>T. doubingeri</em> Lemoigne, 1978</td>
<td>Ethiopia</td>
<td>Miocene</td>
</tr>
<tr>
<td><em>Terminalia</em></td>
<td></td>
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</tr>
<tr>
<td><em>sp.</em> Lemoigne 1978</td>
<td>Ethiopia</td>
<td>Plio</td>
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<tr>
<td><em>T. palaemanii</em> Prakash, 1981</td>
<td>India</td>
<td>Pleistocene</td>
</tr>
<tr>
<td><em>T. varkalaensis</em> Awasthi &amp; Ahuja, 1982</td>
<td>India</td>
<td>Mid-Miocene</td>
</tr>
<tr>
<td><em>T. ghosbii</em> Satyanarayan &amp; Mahabale, 1984</td>
<td>India</td>
<td>Oligo-Miocene</td>
</tr>
<tr>
<td><em>T. swalicus</em> Prasad, 1989</td>
<td>India</td>
<td>Mid-Miocene</td>
</tr>
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</table>

*Terminalia* wood from India listed by Awasthi and Ahuja (1982) and Prasad (1989) has already been merged under *Brachystegia* Lakhani & Prakash 1970 by Lemoigne (1978).

In addition, Bande et al. (1987) described a fossil wood of *Terminalia* as *Terminalia proglascescens* from the Tertiary of Zaire. Among all the known fossil species, *Terminaliatoxylon corysaceum* (Prakash & Awasthi, 1971; Vozenin-Serra & Prive-Gill, 1989) shows some resemblance with the present fossil in possessing infrequent parenchyma bands along with aliform parenchyma. However, none of the fossil species possess regular
parenchyma bands, hence the present fossil differs from all of them. Since the present fossil shows close similarity with the wood of *Terminalia calamansanai* and is different from all the known species of *Terminalioxylon*, a new specific name *Terminalioxylon palaeocalamansanai* is assigned to it.

The genus *Terminalia* consists of about 250 species of large trees, widely distributed in the tropical region of both the hemispheres (Willis, 1973, p. 1136). *Terminalia calamansanai*, with which the present fossil shows the closest affinities, is a large tree measuring up to 30 m and found in the plain forests of Lower Myanmar, common in Prome, Pyinmana, Meiktila districts and extends to neighbouring countries in South-East Asia. It is also found as a small tree about 1 to 1.5 m in girth in Tavoy, near the sea-coasts (Pearson & Brown, 1932; Ramesh Rao & Purkayastha, 1972).

**Specific Diagnosis**

*Terminalioxylon palaeocalamansanai* sp. nov.

*Wood diffuse porous. Growth rings inconspicuous, marked by smaller vessels and broader bands of fibrous tissue in the outer portion of the ring and narrow closer concentric bands of zonate parenchyma. Vessels small to large, mostly medium, t.d. 62-210 μm, r.d. 62-160 μm; solitary or in multiples of 2-4 or more, 3-8 per sq mm; vessel members 270-620 μm long with truncated or tailed ends; perforations simple; intervessel pits alternate, bordered, vented, 4-6 μm in diameter. Parenchyma abundant paratracheal forming narrow sheath around the vessels, rarely aliform, mostly forming concentric wavy bands, 1-6 cells wide, parenchyma bands separated by somewhat wider bands of fibrous tissue; apotracheal parenchyma sparse, scattered in fibrous tissue. Xylem rays fine, closely spaced, uniseriate or rarely biseriate due to pairing of cells, 6-24 μm wide, 3-29 cells or 44 to 775 μm high, 15-20 per mm, homocellular to weakly heterocellular. Fibres forming concentric and somewhat wavy bands alternating with the narrower bands of parenchyma, cells 8-20 μm in diameter, wall 3-6 μm thick, occasionally septate, interfibre pits rarely seen, simple.

*Holotype*—Specimen no. BSIP 36563.

*Locality*—Rajpardi lignite mine, block no. 13.

*Family—Sonneratiaceae*

*Genus—Sonneratioxylon* Hofmann 1952

*Sonneratioxylon preapetalum* Awasthi 1969

Pl. 1, figs 4, 6-8

The description is based on a single specimen of wood measuring 15 cm in length and 4 cm in diameter. The specimen is slightly compressed due to which tissues are flattened.

**Description**—Wood diffuse porous. Growth rings present, delimited by somewhat denser fibrous tissue (Pl. 1, figs 4, 7) in the outer portion of the ring. Vessels very small to small, usually solitary or in multiples of 2-3 or more; almost evenly distributed, 16-30 per sq mm, round to oval, flattened and flattened due to compression, open and sometimes plugged with gummy contents or tyloses, t.d. 32-96 μm (mostly 49-80 μm), r.d. 36-104 μm, vessel members 240-640 μm in length with truncate or slightly oblique ends, perforations simple, intervessel pits occasionally seen, probably due to crushing of the vessels as a result of compression, alternate, bordered, vented, 3-6 μm in diameter. Parenchyma absent. Xylem rays fine, mostly uniseriate (Pl. 1, fig. 6), occasionally biseriate due to pairing of cells; rarely biseriate 8-16 μm wide, 3-26 cells or 64-400 μm in height; closely spaced, 18-30 per mm; ray tissue heterogeneous, rays homocellular to heterocellular, consisting of procumbent cells with upright or squarish cells (Pl. 1, fig. 8), upright cells 28-44 μm in tangential height, procumbent cells 12-24 μm in tangential height; cells usually filled with gummy material, solitary crystals occasionally seen in the upright cells. Fibres aligned in radial rows, more or less oval, angular, polygonal to flattened in shape, 8-24 μm in diameter, lumen 4-12 μm, wall 3-6 μm thick, non-libriform, septate, septa rarely seen, interfibre pits could not be seen.

*Specimen*—Specimen no. BSIP 36564.

*Locality*—Rajpardi lignite mine, Block no. 13.

It is clear from the above mentioned characters that the fossil shows close similarity with the modern woods of Sonneratioxylon (Metcalfe & Chalk, 1950; Pearson & Brown, 1932; Purkayastha, 1982) of Sonneratiaceae. It has been found to show the closest similarities with the woods of three species of Sonneratioxylon, viz., *S. preapetalum* Buch-Ham., *S. caseolaris* Linn. Engler (syn. *S. acida* Linn.) and *S. alba* Smith which are xylotomically very similar (Purkayastha, 1982, p. 41).

In 1952, Hofmann instituted the genus *Sonneratioxylon* to accommodate the fossil woods of Sonneratioxylon. Until recently, eight species of *Sonneratioxylon* were known, viz., *S. prambacchense* Hofmann 1952 from the Oligocene of Austria; *S. dakshinense* Ramanujam 1957 from the Tertiary of south India; *S. dudukurense* Krishna Rao & Ramanujam 1966 from the Deccan Intertropical Series, Andhra Pradesh; *S. preapetalum* Awasthi 1969 from the Cuddalore Series of south India; *S.
aubrevillesi: Louvet 1970 from the Eocene of Libya; *S. intertrappeum* Biradar & Mahabale 1975; *S. caseolarioides* Shete & Kulkarni 1982 and *S. nawargaoensis* Bande & Prakash 1984; the last three species are from the Deccan Intertrappean sediments of Madhya Pradesh and Maharashtra. In addition fossil woods referable to *Sonneratia* have also been reported by Verma (1950) and Shallom (1963). The affinities of some of these woods with *Sonneratia* have been considered to be doubtful by Awasthi (1969, p. 255). Biradar and Mahabale (1975, p. 217) merged the woods described by Verma (1950) and Shallom (1963) into *Sonneratia oxylon intertrappeum*. Further, Chitaley (1969) described the fossil roots comparable to *Sonneratia apetalas* as *Sonneratia rhizosratioides*. Out of all the known species of *Sonneratia oxylon*, the present fossil shows closest resemblance with *S. preapetalum* reported from south India, Kachchh and South-East Asia (Awasthi, 1969; Lakanpal et al., 1984; Kramer, 1974a; Vozenin-Serra et al., 1989). Recently Mehrrota (1989) while describing the above species from the Intertrappean sediments of Mandla District of Madhya Pradesh merged *Sonneratia oxylon intertrappeum, S. caseolarioides* and *S. nawargaoensis* into *S. preapetalum*. Awasthi (1969, on the basis that all these species are anatomically very similar but differ only in minor and variable characters and thus accordingly revised the diagnosis of *S. preapetalum*. In his revised diagnosis of *S. preapetalum*, Mehrrota (1989, p. 132) has stated “growth rings absent” though they have already been mentioned to be present in *S. preapetalum* and *S. intertrappeum* (Biradar & Mahabale, 1975, pp. 211, 215, 216; Lakanpal et al., 1984, p. 259; Vozenin-Serra et al., 1989, p. 347) and same is the case in modern woods of comparable species of *S. preapetalum* (Pearson & Brown, 1932; Purkayastha, 1992, p. 41) though at time the growth rings may be inconspicuous and may not be visible.

The genus *Sonneratia* consists of five species (Willis, 1973, p. 1078) growing in the mangrove swamps along the sea coasts of East Africa, North Madagascar, Seychelles, South-East Asia and warmer regions of Australia. The three comparable species, viz., *S. alba*, *S. apetala* and *S. caseolars* are found in tidal creek and littoral forests of Sundarbans, coastal forests of Orissa, Andhra Pradesh, Karnataka, Maharashtra and Andamans extending westwards to the Indus delta.

Occurrence of fossils of *Sonneratia* and *Terminalia calamansanai* (syn. *T. pyrifolia*) suggests the existence of tropical conditions and the presence of sea in the vicinity of Rajpardi during Eocene. Evidently the sea has receded since then from the area. It seems that *Sonneratia* must have been growing near the site of deposition and *Terminalia* either near the site of deposition or further inland.

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