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Leaf cuticular morphology of some angiosperm taxa from the Siwalik sediments (middle Miocene to lower Pleistocene) of Arunachal Pradesh, eastern Himalaya: Systematic and palaeoclimatic implications

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ABSTRACT

Seven fossil leaves with cuticle described here were collected from the lower, middle and upper strata of Siwalik (middle Miocene–lower Pleistocene) sediments of Arunachal Pradesh, India. A detailed comparison of the cuticular analysis of the fossils and their living relatives indicate that these fossil species belong to *Dysoxylum raptiensis*, *Macaranga* cf. *denticulata*, *Calophyllum suraikholensis*, *Combretum prechinense*, *Actinodaphne palaeoangustifolia*, *Shorea siwalika* and *Dipterocarpus koilabasensis*. Among these fossil species *C. prechinense* has been described as a new species. The present day distribution of the modern equivalent taxa of the fossils, structural features and the micro-morphological features of the fossil leaves together with epiphyllous fungal remains collectively indicate the prevalence of a warm humid tropical climate in this area during Siwalik sedimentation. The cuticular micro-morphological features help to confirm the identification of their leaf compressions to the species level and are clearly indicative of mesophytic ecological conditions that reflect a tropical climate with high precipitation. This is the first time Cenozoic fossil leaves of *Dysoxylum*, *Macaranga*, *Calophyllum*, *Combretum*, *Actinodaphne*, *Shorea* and *Dipterocarpus* are described using the micromorphology of their epidermis.

1. Introduction

Siwalik sediments are made up of rock materials eroded from the Himalayan Mountains deposited to the south on the flood plains of the foreland basins. The Siwalik sediments are characterised by the alternate presence of sandstone and mudstone facies, with the finer sediments very often containing abundant angiospermous fossils. During the last three decades several workers have recovered enormous number of leaf megafossils from the Siwalik foreland basins (Antal and Awasthi, 1993; Prasad, 1994a,b,c, 2006, 2008; Joshi and Mehrotra, 2007; Khan et al., 2011). By studying the plant fossils from Siwalik foreland basins it is possible to reconstruct Siwalik floristic evolution and to throw light on climatic changes that took place through Siwalik succession (middle Miocene–lower Pleistocene) along the length of the Himalayan foothills. The fossil leaf assemblages indicated that in the Himalayan foothills luxuriant, tropical forests, rich in a diversity of angiospermous taxa flourished during middle Miocene–lower Pleistocene times (Prasad, 2008; Khan et al., 2011).

Cuticular analysis is an important and proven tool for the identification of fossil leaves to lower (more precise) taxonomic levels (Johnson and Gilmore, 1921; Bandulska, 1923, 1926, 1931; Kräusel, 1938; Kvaček and Walther, 1981, 1984; Kovar, 1982; Kvaček, 1984; Liu, 1990; Vickulin, 1999; Zhuang et al., 2002; Wei et al., 2005; Hably and Kovar-Eder, 2006; Hu et al., 2007; Kovar-Eder and Sun, 2009; Li et al., 2009). However, until now cuticular studies of Cenozoic leaf remains from India have been rare. Cuticular analysis of angiosperm fossil leaves has been carried out previously from only two localities in India: late Holocene sediments of Himachal Pradesh (one taxon, Prasad et al., 2002) and upper Pliocene to lower Pleistocene sediments of Arunachal Pradesh (one taxon, Joshi et al., 2003). Cuticular anatomy of angiosperm leaf megafossils from Siwalik sediments is reported only from Arunachal Pradesh, India (Joshi et al., 2003) and Nepal (Prasad and Khare, 2004).

A reliable determination of the fossil leaves to the species level is not possible without cuticular analysis. So, leaf taxa reported from the different Siwalik strata based on macromorphology exclusively (Antal and Awasthi, 1993; Prasad, 1994a,b,c, 2006, 2008; Joshi and Mehrotra, 2007; Khan et al., 2011) need to be revised and until then should be considered as preliminary. For this reason the most comprehensive approach is to identify leaf taxa using both epidermal characters preserved in the fossil cuticle in conjunction with macromorphological

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characters of the leaf (Kovar-Eder et al., 1998). This approach is applied for the first time on the fossil leaves of *Dysoxylum*, *Macaranga*, *Calophyllum*, *Combretum*, *Actinodaphne*, *Shorea* and *Dipterocarpus* collected from the lower, middle and upper strata of the Siwalik (middle Miocene–lower Pleistocene) sediments of different localities of Arunachal Pradesh, India (Fig. 1). Previously we identified Siwalik leaf specimens on the basis of macromorphological criteria only (Khan et al., 2011). Here we present the first study dealing with cuticles that confirm our previous identifications and fossil leaves of *Combretum* have been described as a new species, *Combretum prechinense* Khan, Bera et Spicer TEV, sp. nov. The present investigation using fossil angiosperm leaves with cuticle from the Siwalik sediments of Arunachal foothill is not only for taxonomical purposes, but also for interpreting palaeoclimate and palaeoecology.

2. Geological background

Arunachal Pradesh is located towards the northeastern tip of India. The state is bound by the neighbouring countries of China (Tibet) to the north, Bhutan to the west and Myanmar to the east. Arunachal Pradesh is largely characterised by inaccessible rugged terrain with dense impenetrable forests, unpredictable climatic conditions and poor roads. Thus, it is, less well known geologically than other parts of India.

Arunachal Pradesh consists of four physiographic domains. These are a) the Himalayan range, b) the Trans-Himalayan range, c) the Naga–Patkoi range and d) the Brahmaputra plain. Each domain has a distinctive geological and tectonic history. Among the four sub-parallel linear zones from north to south of the Himalayan range, the Sub-Himalaya, or the Foothill Foredeep, is represented by the Siwalik hill range varying in width from 10 to 20 km. The upper Cenozoic (middle Miocene–lower Pleistocene) molasse sediments constituting the Siwalik Group occur as a linear belt along the foothills of Arunachal Pradesh extending from Bhutan to just east of Pasighat where they are covered by alluvium. However, Siwalik sediments reappear on the left bank of the Dibang River where they are tectonically overthrust by the rocks of the Bomdila Group along the Roing Fault, which according to Ranga Rao (1983), is the continuation of the Mishmi Thrust. The Siwalik Group is bounded to the north by the Main Boundary Fault along which the Pre-Palaeogene succession has been overthrust. Its southern limit with the alluvium of the Brahmaputra River is also marked in places by the Foothill Fault. Karunakaran and Ranga Rao (1979) divided the succession of Arunachal Pradesh foothills into the Dafla, Subansiri and Kimin formations broadly corresponding to the lower, middle and upper sub-divisions of the Siwalik Group of the northwestern Himalaya, and also considered these to be the northward extension of the Palaeogene and Neogene succession of Assam. However, Tripathi et al. (1981) were of the opinion that the sediments of the Siwalik Group occur as a nearly continuous stretch from Pakistan in the west to Arunachal Pradesh in the east. The lower, middle and the upper Siwalik are separated from each other by reverse faults and the three units are stacked in a reverse stratigraphic order (Table 1; Joshi and Chakraborty, 2001). Recently, on the basis of magnetostratigraphic data, Chirouze et al. (2012) proposed that the Siwalik Formation of Arunachal Pradesh was deposited between 13 and 2.5 Ma. The transition between the lower and middle Siwaliks is dated at about 10.5 Ma and the middle to upper Siwaliks transition is dated at 2.6 Ma.

A generalised description of the lower, middle and upper Siwaliks (Fig. 2) is as follows: The lower part of the Siwalik (middle to upper Miocene; Dafla Formation) consists of indurated, medium- to fine-grained, well sorted, bluish-grey sandstone and bluish-grey, greenish-grey, and nodular silty shale. Stringers and small lenses of lignitic coal aligned parallel to the bedding plane are frequent. Commonly observed bedforms in the lower Siwalik are laminated to massive, large trough, festoon, planar curved, and tabular cross beds together with ripple cross laminations (Joshi and Chakraborty, 2001). The sandstones and shales of the lower Siwalik are rich in plant fossils and have yielded leaf impressions and compressions, stems and seeds of dicotyledonous plants. The rocks are in general compacted, hard, indurated, sheared and slickenslided.

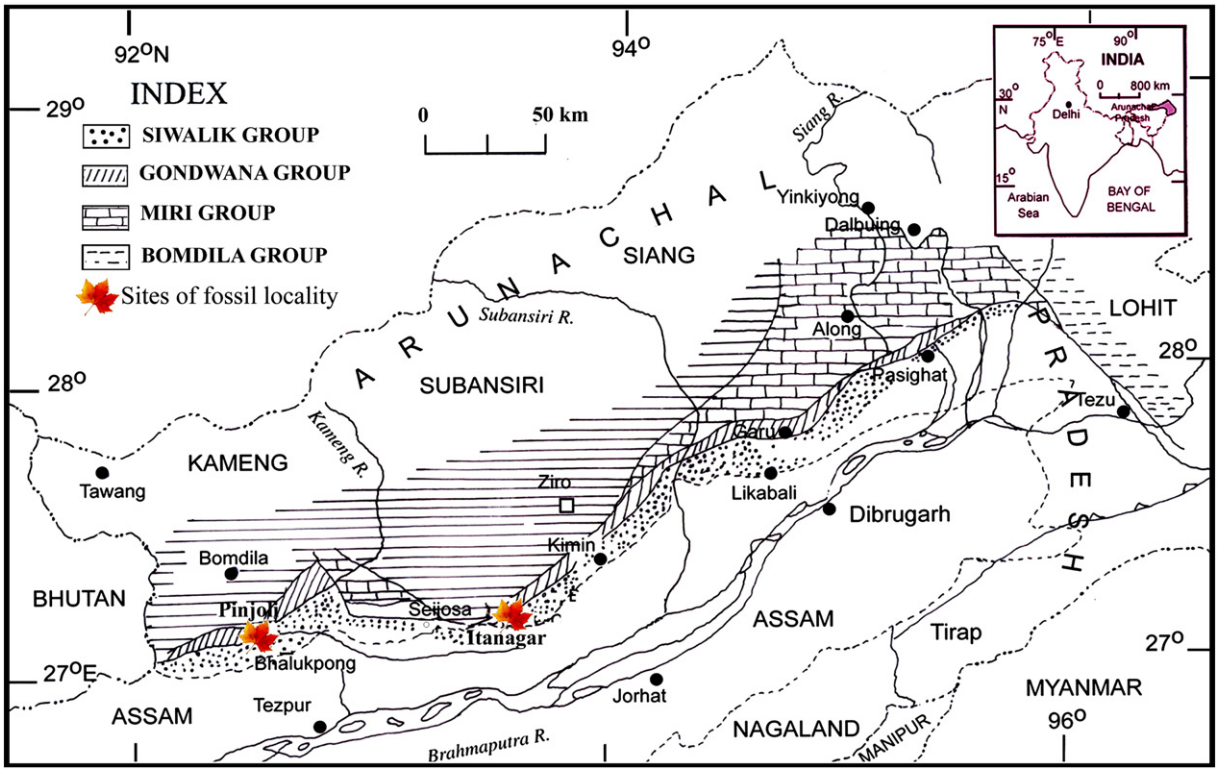

Fig. 1. Geological map of Arunachal foothill (modified after Singh and Tripathi, 1990), star indicates the fossil localities.