First megafossil evidence of Cyatheaceous tree fern from the Indian Cenozoic

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A part of the compressed tree fern axis with leaf and adventitious root scars in unusual arrangement from Plio–Pleistocene sediments of Arunachal Pradesh, India is described as *Cyathea siwalika* sp. nov. This record suggests that *Cyathea* was an important component of tropical evergreen forest in the area during the Plio–Pleistocene and this group subsequently declined in importance within the local vegetation.

1. Introduction

Miocene to Pleistocene strata deposited as a piedmont along the southern flank of the Himalayas are rich in fossil plants but pteridophytes are rare and poorly preserved. Although dispersed spores of various fern groups have been recorded regularly, a few macroscopic fern remains have been reported. They were recorded from Uttarakhand, Assam and Arunachal Pradesh belonging to the Thelypteridaceae (Prasad 1991; Guleria and Srivastava 2000; Joshi and Mehrotra 2003; Prasad *et al.* 2004; Khan *et al.* 2007; Mehrotra *et al.* 2011). The entire Siwalik sedimentary succession has been assigned into three units such as lower part of the Siwalik (middle–upper Miocene), middle part of the Siwalik (Pliocene) and upper part of the Siwalik (upper Pliocene–lower Pleistocene) (Kumar 1997). Recently, on the basis of magnetostratigraphic data, Chirouze *et al.* (2012) proposed that the Siwalik Group in 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. The generalized Neogene–Quaternary stratigraphy of Arunachal Pradesh is given in table 1.

Here we describe the first evidence of Cyatheaceae based on a part of the compressed stem with leaf and adventitious root scars from the upper Siwalik of Papumpare district of Arunachal Pradesh, India (figure 1). This also appears to be the first macroscopic record of a cyatheaceous fern from the Indian Cenozoic.

2. Material and methods

The single available specimen is a carbonized (compressed) stem fragment with the scar of a petiole base surrounded by adventitious root scars. It was collected from the Kimin Formation (equivalent to the upper Siwalik: upper Pliocene–lower Pleistocene) of Papumpare district, Arunachal Pradesh (situated between 26°27'52" and 29°29'54"N and 91°29'50" and 97°24'56"E), eastern Himalaya

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Table 1. Neogene–Quaternary stratigraphy of Arunachal Pradesh (Kumar 1997).

Period	Epoch		Sub-Himalaya	Naga–Patkoi ranges	Brahmaputra plains
Quaternary	Holocene		Newer Alluvium	Newer Alluvium	Newer Alluvium
		U			
	Pleistocene	M	Older Alluvium (Hapoli Fm.)	Older Alluvium	Older Alluvium
		L	Kimin Fm. (Upper Siwalik)	Dihing Fm.	Dhekiajuli Fm.
Neogene	Pliocene	U			
		L	Subansiri Fm. (Middle Siwalik)	Namsang Fm.	Namsang Fm./ Dupi Tila Fm.
		U	Dafla Fm. (Lower Siwalik)	Girujan Fm.	Girujan Fm.
	Miocene	M	Kimi Fm.	Tipam Fm.	Tipam Fm.
		L	Tourmaline granite	Surma Group?	Surma Group

Figure 1. Geological map of Arunachal foothill (modified after Singh and Tripathi 1990), red square indicates the fossil locality.

(figure 1). This formation is characterized by alternation of loosely packed, very coarse-to-fine grained, friable, grey sandstones, silt, clay and gravelly-boulder beds (Kumar 1997). External morphology of the fossil remains was studied with a hand lens and incident light microscopy. Photographs showing structural details of the fossil

specimen were taken using an incident light compound microscope (Stemi SV 11, Zeiss). The format of the descriptions and author citation of a new plant fossil species is mainly after Punt (1994). Holotype specimen is housed in the Herbarium and Museum of the Department of Botany, University of Calcutta (CUH), Kolkata.

Figure 2. *Cyathea siwalika* Bera, Gupta et Mukhopadhyay sp. nov. CUH/PPL/IB7/TF/1. (a) Cyatheoid arrangement of vascular bundles within the leaf scar. Scale bar = 1 cm. (b) Stem surface showing the marks of root traces within root (marked by red arrow). Scale bar = 0.5 cm.

3. Systematic description

Order: Cyatheales

Family: Cyatheaceae Kaulfuss

Genus: *Cyathea* Smith

Species: *Cyathea siwalika* Bera, Gupta et Mukhopadhyay, sp. nov. (figures 2 and 3)

Diagnosis: Stem fragment associated with an obovate leaf scar, ca. 8 cm long, 4.5 cm wide; surface with scars of adventitious roots. Leaf traces in *Cyathea*-type arrangement; three meristeles of median pair remain free. Adaxial arc consists of nine pairs of bundles; the superior series of lateral folds of 6–8 pairs of bundles, the inferior one of three pairs, and the abaxial arc 26. Vascular formula (Nishida 1981b) is – (8x4.5): 3i-9-6(8)-3-26.

Description: The specimen consists of a stem fragment associated with a single well-preserved leaf scar that consists of a surface ornamented by numerous adventitious root scars (figure 2a). The

leaf scar is obovate, ca. 8 cm long, 4.5 cm wide, and is enclosed by strongly developed fundamental tissue of the leaf cushion. The vascular system supplying the leaf comprises numerous meristeles arranged in ‘*Cyathea* type’ (Ogura 1972), two ‘7’-shaped as the adaxial or upper strand and one arc shaped as the abaxial or lower strand with more or less incurved margins. Individual meristeles are small, ‘V’-shaped and 1–1.5 mm in diameter. Three meristeles that are comparable with the median pair bundles (Nishida 1981b) remain isolated in the middle part of the petiole base. The adaxial arc consists of 9 pairs of bundles. The superior series of lateral fold is composed of 6–8 pairs of bundles, the inferior one of three pairs. The lower or abaxial arc is composed of 26 bundles (figure 2a). Both medullary and cortical meristeles, are evident on the inner (axial) side of the specimen (figure 3b). Vascular formula is (8x4.5): 3i-9-6(8)-3-26 (letter ‘i’ meaning isolated, after the total number of the median pair traces). The narrow basal portion of preserved stem surface is clothed with adventitious root scars (figure 2b) that are 2–4 mm in diameter.

Holotype: Specimen no. CUH/PPL/IB7/TF/1.

Horizon: Kimin Formation.

Locality: Road cuts along the Itanagar–Bandardewa road in Papumpare District.

Age: Late Pliocene to Early Pleistocene.

Material: One well-preserved specimen.

Etymology: Species named after Siwalik Group.

Affinities: The vascular traces arranged in a cyathean pattern of Ogura’s leaf base suggest that the specimen shows closest affinity with the family Cyatheaceae, especially with the genus *Cyathea* Smith (*sensu* Kramer 1990). The family Cyatheaceae was composed of the genera *Lophosoria*, *Metaxya*, *Thyrsopteris*, *Dicksonia*, *Cystodium*, *Cibotium*, *Culcita*, *Cyathea* and *Cnemidaria* (Mettenius 1856). Bower (1926) however, gave much importance to the soral positions and created two families, Cyatheaceae and Dicksoniaceae, widely separated from each other. He included *Dennstaedtia* and other related genera in the Dicksoniaceae. Holttum and Sen (1961) considered that such wide separation between the Cyatheaceae and Dicksoniaceae was unwarranted since the early developmental stages of their sori were closely similar. They admitted that a degree of relationship exists between the dennstaedtioids and cyatheoids but preferred to exclude the dennstaedtioids from the Cyatheaceae. However, this idea did not gain much acceptance (Kramer 1990). Existing molecular evidence indicate a close relationship among the families Cyatheaceae, Thyrsopteridaceae, Loxomataceae, Culcitaceae, Plagiogyriaceae, Cibotiaceae, Dicksoniaceae and Metaxyaceae (Hasebe

Figure 3. (a) An extant species of *Cyathea* Smith showing oval-leaf scars with more or less similar vascular arrangement (marked by yellow arrows). (b) An interior view of the leaf scar (from the cortical side) of the fossil leaf scar of *C. siwalika* Bera, Gupta et Mukhopadhyay sp. nov., showing medullary meristele (marked by yellow arrow) and cortical meristeles (marked by red arrow). Scale bar = 1 cm.

et al. 1995; Wolf et al. 1999; Pryer et al. 2004; Smith et al. 2006). There are some anatomical studies on tree-fern stipes and stems (Thomae 1886; Ogura 1972; Nishida 1984). We are unable to trace its affinity with any known extant species of *Cyathea* on the basis of only vascular traces (figure 3a). Although the present specimen is morphologically only partly preserved showing a part of stem with vascular traces of leaf and adventitious roots, no fossil cyatheaceous fern is recorded so far with these combinations of characters and therefore a new species, *Cyathea siwalika*, is proposed for the fossil fern specimen.

4. Discussion

Cyathea Smith (Cyatheaceae sensu Kramer 1990) represents tree ferns ranging in age from the Jurassic to present (Taylor et al. 2009). Several structurally preserved stems of Cyatheaceae are found as fossil records. Ogura (1927) described a Cretaceous fern *Cyathocaulis nakdongensis* from Korea and Japan having resemblance with the stem anatomy of extant *Cyathea*. Later, Ogura (1941a, b) described a number of taxa, viz., *Cyathocaulis tateiwai*, *C. yabei* from the early Cretaceous of Korea and Philippines, and *Cibotium iwatanse* from the late Cretaceous of Japan. Other Cretaceous genera with cyatheaceous affinity are *Caulopteris brownii* from England (Renault 1883), *Yezopteris polycycloides*, *Cyathocaulis yezopteroides*, *Cibotocaulis* from Japan, Saghalien, and Korea (Nishida 1981a, 1989), *Oguracaulis*

banksii from Tasmania (Tidwell et al. 1989), *Conantiopteris schuchmanii* from California (Lantz et al. 1999) and *Rickwoodopteris hirsuta* from western North America (Stockey and Rothwell 2004).

Cyathorachis is a Cretaceous genus used for rachides comparable with extant Cyatheaceous members (Nishida 1981b). There are a few reports of Cyatheaceous pinnules with sori (Collinson 2001; Skog 2001). Smith et al. (2003) described *Cyathea cranhamii*, an anatomically preserved tree fern sori from the early Cretaceous of Vancouver Island, British Columbia. Recently, Vera (2013) described a new cyathealean tree fern, *Yavanna chimaerica* from the early Cretaceous of Livingston Island, Antarctica.

Cenozoic records of Cyatheaceous members are *Dendropteridium cyatheoides* from the late Tertiary of Kenya (Bancroft 1932), *Cyathodendron texanum* from the late Eocene of Texas (Arnold 1945), *Alsophilocaulis calveoli* from the Tertiary of Argentina (Menendez 1961), *Cibotium tasmanense* from the Tertiary of Tasmania (Gould 1972), *Cibotium oregonense* from the late Eocene of Oregon, western North America (Barrington and Davis 1983) and *Nishidacaulis burgii* from Eocene–Oligocene of Nebraska, South Dakota, USA (Tidwell and Nishida 1993).

In the Indian Cenozoic, Cyatheaceae are known only on the basis of dispersed spores (viz., various representatives of *Cyathidites*: see Saxena and Trivedi 2006), macroscopic remains have not been recovered to date. Both *Cyathidites major* Kar

et al. (1994) and *C. minor* Couper. Kar (1990) have been recovered from the sediments hosting *Cyathea siwalika* (Khan *et al.* 2006; Paruya 2012).

The extant species of *Cyathea* (*sensu* Kramer 1990) grow in habitats ranging from tropical rain forests to temperate woodlands in pantropical to southern temperate regions of the world (Kramer 1990; Braggins and Large 2004). They are prevalent from lowland to montane as well as sub-alpine vegetation. Some species occur in the understorey of moist forests and in ravines, others prefer more open habitats, even swamps, while some grow preferentially in disturbed sites as an important constituent of pioneer vegetation (Kramer 1990). *Cyathea* is a significant component of tropical forests of southern, central, northern and eastern India (Dixit 1984). Among the 11 species of *Cyathea* in India, *Cyathea spinulosa* Wall. and *Cyathea contaminans* (Hook) Copel. are widely distributed through the mountainous regions. In Arunachal Himalaya, the genus is restricted to the tropical evergreen forest zone (up to 1000 m), whereas the study area lies within the tropical semi-evergreen forest zone (up to 600 m) where *Cyathea* is rare (Hazra *et al.* 1996).

Earlier recorded mega plant fossil (Joshi *et al.* 2003a, b; Bera *et al.* 2004; Joshi and Mehrotra 2007; Bera and Khan 2009; Khan *et al.* 2011, 2014 and Khan and Bera 2014a, b) and palynofossil (Khan *et al.* 2006) data clearly suggests that tropical evergreen forest cover was prevailing in the study area under a tropical warm humid climate during the Siwalik sedimentation period (late Pliocene to early Pleistocene). Therefore, present record suggests that *Cyathea* was an important component of tropical evergreen forest cover in the area during the Plio-Pleistocene. Later, the forest was slightly changed to tropical semi-evergreen type due to eco-climatic changes owing to the possible upheaval of the Himalayas and perhaps this is the reason for the rare occurrence of modern *Cyathea* in the tropical semi-evergreen forest zone of Arunachal Pradesh.

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