
Climatic significance of growth rings in the Mesozoic woods from India

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Many of the fossil woods described from the Mesozoic of India possess distinct growth rings which provide valuable proxy data to decipher multitude of environmental information of the concurrent periods. Detailed growth ring study of *Podocarpoxylon rajmahalense* (Jain) Bose & Maheshwari from Rajmahal Hills, Bihar was conducted to understand the growth environment of the fossil wood. Growth ring features of the fossil wood indicate that it could either be derived from a branch or young stem of a tree growing in the exterior of the forest. Large amount of early wood with only 1-3 rowed latewood cells indicates good soil moisture availability during the growing season. Absence of false rings further adds to the conclusion that the moisture would not have been the limiting factor during the growing season. Warm temperate type of climate would have existed during the life span of the present fossil wood.

Key-words—Growth rings, *Podocarpoxylon*, Palaeoclimate, Mesozoic, Rajmahal Hills (India).

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सारांश

भारत से मध्यजीवी युगीन काष्ठों में वृद्धिवलयों का जलवायवी महत्व

रामरतन यादव एवं आमलव भट्टाचार्य

भारत के मध्यजीवी कल्प से वर्णित बहुत सी अशिमत काष्ठों में वृद्धि वलय विद्यमान हैं जिनसे तत्कालीन समय की पर्यावरणीय जानकारी सुनिश्चित करने में महत्वपूर्ण आँकड़े मिलते हैं। बिहार में राजमहल पहाड़ियों से ज्ञात *पोडोकार्पाक्सिलॉन राजमहलेन्से* (जैन) बोस व माहेश्वरी के वृद्धि वलयों का विस्तृत अध्ययन किया गया। इस काष्ठ के वृद्धि वलयों के लक्षणों से प्रदर्शित होता है कि यह या तो किसी शाखा अथवा कम आयु के तने का भाग है जो वन के बाहरी ओर के क्षेत्र में विद्यमान था। आभासी वलयों की अनुपस्थिति से यह निष्कर्ष निकलता है कि वृद्धि के समय नमी की महत्वपूर्ण भूमिका रही है। इस अशिमत काष्ठ के जीवन काल में गर्म शीतोष्ण प्रकार की जलवायु विद्यमान रही है।

THE classical palaeobotanical studies for the palaeoenvironmental interpretations in India have so far largely depended on the identification of plant fossils in terms of known living taxa. Under this approach biological uniformitarian principle, which implies that there has been very little or no change in the climatic requirement of the nearest living relatives of the fossil plants, is used for palaeoenvironmental interpretations. The identification of fossil plants to their living counterparts is possible only for the Cenozoic fossils. In cases of the fossils from the early horizons prior to the Cenozoic, the potential for iden-

tifying them as living specimens greatly diminishes and they are therefore assigned to living groups or families. For such fossils, taxon independent approaches such as anatomical features of wood and leaf physiognomic features could be used as the reliable parameters to decipher palaeoenvironmental information.

Trees growing under the influence of seasonal climatic changes produce growth rings due to the rhythmicity of cambium activity. Their growth ring features such as ring widths, earlywood/latewood proportions, and anatomical and chemical features

are directly influenced by ambient environmental conditions of the concurrent growing period (Fritts, 1976; Schweingruber, 1988). Many of the growth ring features such as ring widths, cell diameter variations and earlywood/latewood proportions in growth rings are observable in fossil woods. The growth ring characters representing the observable parameter in fossil woods could be used as the important proxy source to derive the palaeoenvironmental information which would be independent of any recognition of identity or relationship of the fossil with modern taxa. However, for palaeoenvironmental interpretation of growth rings, there should be a clear understanding of the fossil wood from which plant part is derived because the woods of roots, stumps, trunk and branches all have certain individual characters. Although, most fragments of the fossil woods record only few rings, some specimens derived from trunk or boles are found to have long sequences of growth rings. Records of many years growth rings give a much more precise view of the variations in climate as well as the growth performance of the plants. Growth ring sequences of *in situ* fossil stumps or logs may provide environmental information of the palaeolatitude where the tree grew. Earlier studies on growth ring features of fossil woods from different geological horizons (Chaloner & Creber, 1973; Creber & Chaloner, 1984, 1985; Jefferson, 1982, 1983; Francis, 1984, 1986; Ash & Creber, 1992; Yadav & Bhat-tacharyya, 1994) have demonstrated their potential for palaeoenvironmental analysis.

Fossil woods of gymnosperms are very common during the Mesozoic in India. Many of these woods are in exquisite state of preservation keeping the finest details of cellular structures. The detailed record of growth rings from these well-preserved fossil woods may provide very precise information of climate as well as the productivity of forest trees. Growth ring features of *Podocarpoxyton rajmahalense* (Jain) Bose & Maheshwari (Holotype no. BSIP 17272) described from the Amarjola in Amrapara, Rajmahal Hills, Bihar (Jain, 1965) have been studied and presented in this paper.

GROWTH RINGS IN THE MESOZOIC CONIFER WOODS FROM INDIA

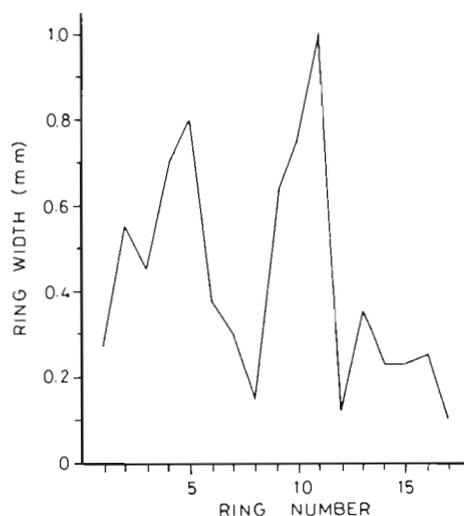
Conifer remains are chiefly found in the Upper Jurassic-Lower Cretaceous beds in India. Except few, majority of these fossil woods are referable to either

Araucariaceae or Podocarpaceae (Bose & Maheshwari, 1974). The anatomical features show the presence of growth ring in majority of these woods (Table 1).

GROWTH RING FEATURES OF *PODOCARPOXYTON RAJMAHALENSE* (JAIN) BOSE & MAHESHWARI

The petrified wood of *Podocarpoxyton rajmahalense* (Jain) Bose & Maheshwari from Rajmahal Hills, Bihar representing only half portion from the centre measures 2 cm in diameter. As the complete disc is not preserved, it is very difficult to assign whether it represents a branch or stem of a young tree. Ring widths of continuous sequences of 17 rings were measured from the cross section under binocular microscope. Ring size varies from 0.1 to 1.00 mm (Text-figure 1).

Cell radial diameter changes across the growth rings show that earlywood type cells constitute the major portion of the growth ring with only 1-3 row of latewood cells. No false ring were noted in any of the 17 rings. Cell radial diameters along the radial profile of a growth ring were measured under binocular microscope. According to the scheme proposed by Creber and Chaloner (1984) radial diameter changes of tracheidal cells across the growth ring show "D" type of growth curve (Text-figure 2).



Text-figure 1—Ring width variability in *Podocarpoxyton rajmahalense* (Jain) Bose & Maheshwari.

Table 1—Fossil conifer woods from the Mesozoic of India

Fossil wood	Growth rings	Horizon/Locality/Age	Author
<i>Araucarioxylon agathioides</i> (Krausel & Jain) Bose & Maheshwari	present	Rajmahal Stage Mandro, Rajmahal Hills, Bihar; Lower Cretaceous	Krausel & Jain, 1964
<i>A. amraparensis</i> (Sah & Jain) Bose & Maheshwari	present	Rajmahal Stage Mandro, Rajmahal Hills, Bihar; Lower Cretaceous	Sah & Jain, 1964
<i>A. hindrabunense</i> (Sah & Jain) Bose & Maheshwari	present	Gangapur Formation Adilabad, Andhra Pradesh; Lower Cretaceous	Manik & Srivastava, 1991
	indistinct	Rajmahal Stage Bindrabun Rajmahal Hills Bihar; Lower Cretaceous	Sah & Jain, 1964
<i>A. jurassicum</i> Bharadwaj	present	Rajmahal Stage Amarjola, Rajmahal Hills, Bihar; Lower Cretaceous	Bhardwaj, 1953
<i>A. mandroense</i> (Sah & Jain) Bose & Maheshwari	present	Rajmahal Stage Mandro, Rajmahal Hills, Bihar; Lower Cretaceous	Sah & Jain, 1964
<i>A. pranbitensis</i> Rajanikanth & Sukh-Dev	present	Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989
<i>A. rajmahalense</i> (Sahni) Bose & Maheshwari	present	Rajmahal Stage Rajmahal Hills Bihar; Lower Cretaceous	Sahni, 1931
	present	Kota Stage (Sripermatour Group) Vellum near Sripermatour, Tamil Nadu; Middle Jurassic	Suryanarayana, 1955
<i>A. santalense</i> (Sah & Jain) Bose & Maheshwari	indistinct	Rajmahal Stage Mandro, Rajmahal Hills, Bihar; Lower Cretaceous	Sah & Jain, 1964
	present	Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989
<i>Podocarpoxylon chandrapurensis</i> Rajanikanth & Sukh-Dev	present	Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989

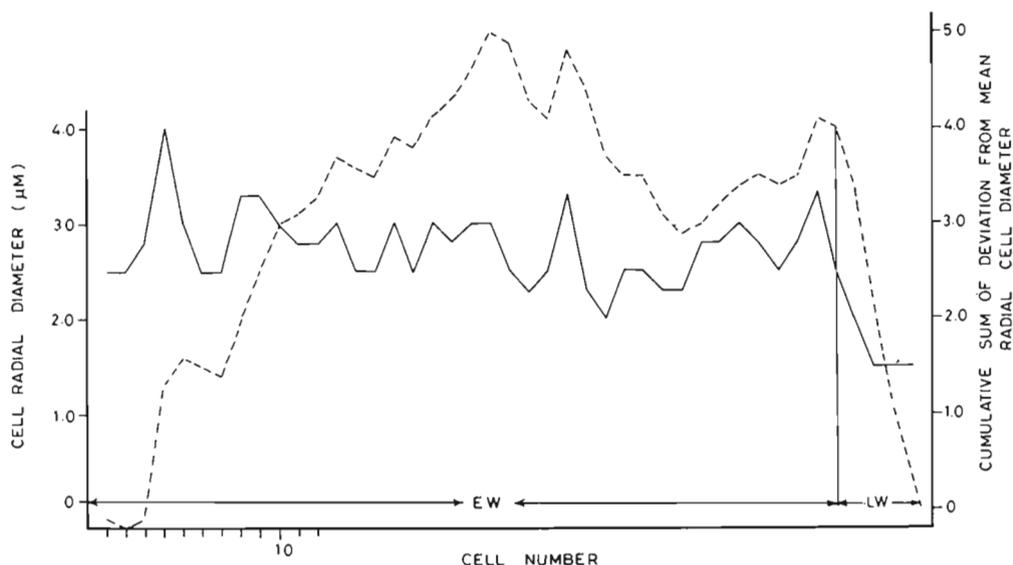
<i>P. godavarianum</i> (Sahni) Bose & Maheshwari	absent	Kota- Maleri Group, Bagapalmila in Godavari area; Upper Gondwana	Sahni, 1931
<i>P. indicum</i> (Bharadwaj) Bose & Maheshwari	present	Rajmahal Stage Rajmahal Hills Bihar; Lower Cretaceous	Bhardwaj, 1953
<i>P. krauseli</i> Rajanikanth & Sukh-Dev	present	Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989
<i>P. malerianum</i> (Sahni) Bose & Maheshwari	present	Maleri Stage Tiki, Rewah, M.P.; Upper Gondwana	Sahni, 1931
<i>P. parthasarthyi</i> (Sahni) Bose & Maheshwari	present	Sripermatour Group (Kota Stage) Vellum Sripermatour, Madras; Upper Gondwana	Sahni, 1931
	present	Gangapur Formation Adilabad, Andhra Pradesh; Lower Cretaceous	Rajanikanth & Sukh-Dev, 1989
<i>P. rajmahalense</i> (Jain) Bose & Maheshwari	present	Rajmahal Stage Amarjola, Rajmahal Hills, Bihar; Lower Cretaceous	Jain, 1965
	present	Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989
<i>P. sarmai</i> (Varma) Bose & Maheshwari	present	Trichinopoly Stage, Garudamangalam Trichinopoly Tamil Nadu; Cretaceous	Varma, 1954
<i>P. tirumangalense</i> (Suryanar- ayana) Bose & Maheshwari	present	Sripermatour Group, Sripermatour Tamil Nadu; Upper Gondwana	Suryanarayana, 1953
<i>P. trichinopoliense</i> (Varma) Bose & Maheshwari	present	Trichinopoly Stage, Garudamangalam Trichinopoly Tamil Nadu; Cretaceous	Varma, 1954
<i>Cupressinoxylon alternans</i> Sahni	present	Ragavapuram Godavari, Andhra Pradesh; Upper Gondwana	Sahni, 1931
<i>C. coromandelinum</i> Sahni	present	Sripermatour Group, Sripermatour Tamil Nadu;	Suryanarayana, 1953

<i>C. kotaense</i> Rajanikanth & Sukh-Dev	present	Upper Gondwana Kota Formation Maharashtra; Middle Jurassic	Rajanikanth & Sukh-Dev, 1989
<i>C. (Taxodioxylo) rajmahalense</i>	present	Rajmahal Stage Rajmahal Hills, Bihar; Lower Cretaceous	Bhardwaj, 1953
<i>Circoporoxylon amarjolense</i> Krausel & Jain	present	Rajmahal Stage Amarjola, Amrapara Rajmahal Hills, Bihar; Lower Cretaceous	Krausel & Jain, 1964
<i>Taxoxylon rajmahalense</i> Bhardwaj	present	Rajmahal Stage Amrapara Rajmahal Hills, Bihar; Lower Cretaceous	Bhardwaj, 1952

INTERPRETATION OF GROWTH RING FEATURES

Presence of well marked growth rings in the fossil wood indicates that the growth environment of concurrent growing period of the fossil wood was characterized by well defined seasons. The small size of the wood block with the central preserved portion indicates that it could either be derived from a branch or young stem. It is possible to recognize the woods of twigs and branches due to the presence of asymmetrical rings and reaction wood produced in response to the gravity pulling. But due to the absence of complete cross section, asymmetric nature of growth rings could not be ascertained in the

present fossil wood. Therefore it could not be possible to identify if the present fossil wood was derived from a twig or branch. Growth rings in young trees growing in interior of the forests under thick canopy cover are suppressed for several years mainly due to the limited availability of sunlight (Fritts, 1976). Trees resume the normal growth only after they reach an appropriate height where sufficient light is available to carry out the normal photosynthetic activity. The presence of unsuppressed growth rings in the fossil indicates that the specimen is not derived from the young tree growing in the interior of the forest. It could either be derived from the leading branch or young tree growing in the exterior of the forest where



Text-figure 2—Cell radial diameter changes across a ring in *P. rajmahalense* (Jain) Bose & Maheshwari. Point from where the cumulative sum of deviations turns sharply towards zero indicates the early wood/late wood boundary. **EW**—early wood, **LW**—late wood.

there was no competition from the neighbouring trees. Fluctuation in growth ring sizes of the fossil wood (Text-figure 1) denotes variability in year to year climate. The widths of growth rings are related with the number of tracheidal cells in growth rings. The narrowest ring has 5 row of tracheids whereas the widest 45. The number of cells across a growth ring gives a measure of cambial activity and, therefore, whether the tree is growing well or not. Few number of tracheidal cells in some rings show very short growing season, however, large number of cells in others indicate the rapidly dividing cambium and thus very favourable climate for tree growth. Small cell numbers (less than 10) in a ring of twig indicate a stressed cambium where cell divisions are few either due to water stress or unsuitable conditions (Chapman, 1994).

Wood anatomical features of a branch or young stem are important to study the microclimatic conditions. As the branches or young stems are very close to the crown, they are more responsive to crown activity. The cambium activity first appears in branches or young stems and also remains active in the late growing season. Therefore, in temperate climate they are most likely to be damaged by spring or autumn frosts than in trunks or stumps. The thinness of branches or young stems makes them cool rapidly and thus the cambium is more likely to be damaged in twigs, branches or young stems (Bannan, 1954). The absence of any cellular damage in any of the 17 growth ring sequences indicates that the climate in early as well as late growing season would have been frost free.

Changes in cell radial diameter across the growth ring show that large diameter earlywood cells constitute the major portion of ring with very little amount of latewood ranging from 1-3 cells. Such type of growth curves are classified as "D" type according to the scheme of Creber and Chaloner (1984) and indicate growing seasons that are relatively uniform but with a terminal event representing the cessation or retardation of cambial activity. Large amount of earlywood type cells indicates continuous shoot growth. As the shoot extension slows down and gradually ceases, narrow lumened latewood type cells are formed. Environmental conditions that favour bud break, rapid shoot growth and continued leaf development result in high level of auxin production and large diameter cells of earlywood type (Lar-

son, 1964). Radially elongated thin-walled earlywood cells are conductively more efficient and indicate good moisture supply throughout the growing season. Studies with *Pinus radiata* grown in Victoria show positive correlation of tracheid diameter with soil water supply during the growing season (McKinnell & Shepherd, 1971). Similarly, Barnes *et al.* (1977) observed that earlywood formation in *Pinus caribea* in five sites in Zimbabwe, is dependent on continuous water supply. Latewood formation depends on the onset in the shortage of water availability. Harris (1955) showed that an abrupt change from earlywood to latewood in *Pinus sylvestris* growing in East Anglia could be caused by water shortage at that time. Similarly, Kraus and Spurr (1961) also found that there is a close agreement between the dates of the onset of soil water shortage and the timing of earlywood/latewood transition in *Pinus resinosa* trees growing in southern Michigan. Water supply is one of the strongest factor controlling tree growth. As much as 90 per cent of annual variation in xylem increment may be attributed to water availability in arid regions and up to 80 per cent in mesic sites (Zahner, 1963). Large amount of earlywood type cells with only 1-3 rowed latewood cells in the growth rings of the fossil wood indicates almost continuous shoot growth. Rapid cell elongation resulting in the formation of earlywood type cells is associated with needle growth. As the activity of apical bud and elongating needles declines, and the amount of soil moisture diminishes, the size of mature differentiated tracheids declines. Climatic conditions that favour bud break, rapid shoot growth and continued leaf development result in high level of auxin production and consequently large diameter earlywood type cells (Larson, 1964).

Except for the minor fluctuations, sharp decrease in tracheidal size resulting in the formation of false rings was not seen in growth rings. Branches and young trees are very prone to produce false rings as multiple flushes of leaves caused due to climatic changes during the growing season usually result in concurrent burst of large cell production (Fritts, 1976). Many trees growing in extreme climatic areas such as at the edges of the arid zone have been found to have many false rings (Glock & Agerter, 1963). Replenishment of soil moisture or the reduction of water stress result in the resurgence of shoot and radial growth causing the unaligning tracheids to

expand to the larger early wood size. Such resumption in growth are usually common in young branches or in the upper portion of stem near the crown. The absence of false rings in the present fossil wood indicates that the tree grew in mesic climate where there was no shortage of moisture supply during the growing season. Earlier study of the growth ring features of *Sabnioxylon* (Yadav & Bhattacharyya, 1994) showed "A" type of growth rings where there is a sharp transition at earlywood/latewood boundaries. These type of rings occur when a water shortage abruptly sets in during the growing season. The growth features of the present fossil wood indicate that it could be derived from different ecological provenance where water supply was not the limiting factor for tree growth.

Growth ring features of *P. rajmahalense* (Jain) Bose & Maheshwari such as "D" type of growth curve, absence of false rings as well as any indication of frost damage indicate the prevalence of favourable climate with uniform growing conditions. Warm temperate type of climate would have prevailed during the concurrent growing period of the fossil wood. Other palaeofloral evidences from Rajmahal Formation in Rajmahal Hills have indicated sub-tropical to tropical type of climate (Sukh-Dev, 1987) when its palaeolatitude was around 40° South. In India, large number of fossil woods with distinct growth rings have been reported to be very common in different geological horizons. The growth ring studies of *in situ* specimens would provide valuable climatic informations at respective palaeolatitudinal positions.

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