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EVIDENCE OF *ARAUCARIA* (MONKEY-PUZZLE) FROM LAMETA FORMATION (UPPER CRETACEOUS), PISDURA, MAHARASHTRA, INDIA

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ABSTRACT
Araucaria (Monkey-Puzzle) comprising woods, leaves, fertile organs (cones and pollen grains) are known from the Mesozoic sediments of northern and southern hemispheres. Records of fossil *Araucaria* from Indian Upper Cretaceous age are known from the Deccan Intertrappean beds of Central India and Pondicherry Formation, Tamil Nadu. So far seven araucaroid fossil wood species viz. *Araucarioxylon deccanii* (Shukla, 1938), *A. resinosum* (Shukla, 1944), *A. chhindwarensis* (Billimoria, 1948), *A. eocenum* (Chitaley, 1949), *A. shuklai* (Singhai, 1958), *A. mohgaoensis* (Lakhanpal *et al.,* 1977) and *A. keriense (*Trivedi and Srivastava, 1989) are recorded from the Upper Cretaceous sediments of Indian subcontinent. The present fossil araucaroid wood has been recovered for the first time from the sediments of well-known dinosaurian locality at Pisdura, Maharashtra State India. This locality contains a huge assemblage of dinosaur skeletal remains and their coprolites (referable to herbivorous titanosaurid sauropods). Some coprolites also contained the vegetative and fertile parts showing *Araucarian affinity*. Remains of angiosperm plant mega-fossils specially (seeds) belonging to the family Arecaceae and Capparidaceae are also known (DebiDuttaandAmbwani, 2007). In addition some pteridophyte and gymnosperm leaves, axes and cones are also reported from these sediments (Ambwani *et al.*, 2003). Algal remains (*Aulacoseira*) recovered from the dinosaur coprolites, are presume to have been ingested by the animals through water. The frequency of the plant mega fossils as compared to the skeletal remains and the coprolites is too low in this locality. Efforts are needed to achieve more data of plant megafossils to reconstruct the vegetation scenario of this area.

Keywords: *Araucaria, (Monkey-Puzzle), Coprolites, Dinosaur, LametaFormation (Upper Cretaceous), Pisdura, Maharashtra, India*

INTRODUCTION
The Late Cretaceous (Maastrichtian) sediments exposed at Pisdura near Temurda village in Nand-Dongaron, Chandrapur District (79º 05': 20º 10'), Maharashtra state, India, yield majority of dinosaurian skeletons and coprolites. However, recovery of plant mega and microfossils from time to time has also been made by Mohabey (1996), Ambwani *et al., (*2003), Mohabey and Samant (2003), Ghosh *et al.*, *(*2003), Kar *et al., (*2004), Ambwani and Debi Dutta (2005), Prasad *et al., (*2005) and Debi Dutta and Ambwani (2007). The plant megafossils representing pteridophytes, gymnosperms and angiosperms are noteworthy from the palaeoecological view point as the herbivore titanosaurid sauropods consumed for their survival. Occurrence of algal remains (*Aulacoseira*) (recovered by maceration of the coprolites) is presumed to have been ingested by the animals through water while presence of fungal spores is supposed a post-void phenomenon (Thulborn, 1991; Ambwani, *et al.*, 2003; Ghosh, *et al.*, 2003; Mohabey and Samant, 2003; Kar *et al.,* 2004; Ambwani and Dutta, 2005; Dutta and Ambwani, 2007).
The present investigation highlights the recovery of a gymnosperm fossil wood referable to the extant *Araucaria*. This fossil was found associated with the dinosaurian skeletal and coprolite remains in the sediments. In addition a few auracaroid leaf fragments and megasporophylls were also found embedded within the coprolites (Figure 4j-l). Presence of these elements further confirms that the herbivore dinosaurs were the consumers. Fossil records of Araucariaceae are widely known from different horizons of India and abroad. In India this family is known from Upper Gondwana sediments showing maximum development up to Early Cretaceous. As postulated by Croizat (1958) it diminishes in Upper Cretaceous

time and nearly faced extinction in terminal Cretaceous. Petrified Forest National Park in Arizona contains hundreds of acres of perfectly preserved logs of ancient *Araucaria* that grew in nearby highlands of North America during the Late Triassic period (over 200 million years ago) that co-exited with dinosaurs. Many of the petrified logs belong to the genus *Araucarioxylon* related to present day species of *Araucaria*. A petrified ovulate cone of *Araucaria mirabilis* dates back to the Jurassic Period (135-180 million years ago), recorded from Patagonia, Argentina (Stockey, *et al.*, 1992 and Pollock, 1995). Its near extinction in Maastrichtian is also important from the viewpoint of change in the environment for its survival in Indian subcontinent as well as other continents. Shortfall of the plants probably also acted as one of the causal factors for the extinction of dinosaurs. As it is well understood that the dinosaurs were the dominant members in the Mesozoic Era where in the Lameta Formation around Nand-Donergaon, Maharashtra is rich in dinosaurian evidences and possibly the sauropods were represented by *Titanosaurus indicus, T. blanfordii, Laplatosaurus madaascarensis, Antarctosaurus septentrionnalis* and the sauropod nestingssites while their coprolites ares. The coprolites are generally associated with the reptilian remains of bones and non-marine mollusks represent the fresh water environment. The main plant representatives in this formation includeseveral species of charophytes (eg. *Platycharapeltata*, *P. compressus, Steplanochara, Pachichara, Azolla* alongwith angiosperms (represented by seeds of Arecaceae and Capparidaceae). Some specific pollen and spores referable to *Ariadinaesporites, Gabonisporites, Palmaepollenites, Spinizonocolpites* mainly occurs in these sediments. Occurrence of some fossil woods though known but not worked out at large. A detailed account of palaeontology of this area has been discussed by Khosla *et al.*, (in press).

Geological Setting

The Lameta Formation (Late Cretaceous) at Pisdura is overlain by the Deccan volcanic rocks, comprised of basal red and green silty non-laminated clays, which rest over the Precambrian granites and schists with a pronounced unconformity over the Kamthi Formation. Here the clays generally attain up to 6 m thickness associated with less frequently occurring sandstones of vertical and lateral accretion types. Sometimes pockets of grey and yellow marls are also present in the clays. These clays are overlain and overlapped by yellow and cream laminated clays and shales interbedded with thin limestones and marlites (Figure 1, 2). The Formation conventionally has been considered as fluvio-lacustrine deposit (Hislop, 1869; Medlicott and Blanford, 1994; Von-Huene and Matley, 1933). Based on the detailed lithofacies analysis of this area, later views on their possible marine origin also emerged (Jain and Sahni, 1985; Sahni, 1984; Mohabey *et al.*, 1993; Mohabey, 1996, 2001) favored the deposition as in alluvial-limnic environments under semi arid climate having seasonal fluctuations (Mohabey and Udhoji, 1990; Hensen *et al.*, 1996; Mohabey, 1996, 2001). Although freshwater environment around the area can not be ruled out (Ambwani and Dutta, 2005; Dutta and Ambwani, 2007)

The Lameta sediments of Nand-Dongargaon at Pisdura have been known for their rich assemblage of fragmentary dinosaurs bones (Hislop, 1869) represented by *Titanosaurus indicus, T. blanfordi, Laplatosaurus medagascarensis, Antarctosaurus septentrionalis* (Lydleker, 1979; Matley, 1921, 1939; Von-Huene and Matley, 1933; Berman and Jain, 1982). As regards the age of the Lameta beds of Pisdura inland basin, (Mohabey, 1984, 1990; Mohabey and Mathur, 1989; Sahni, 1984; Vianey-Liaud *et al.*, 1987; Prasad *et al.*, 1988; Prasad and Khajuria, 1995) assessed as the Late Cretaceous.

MATERIALS AND METHODS

The fossil wood and coprolites under the present study were collected from the sediments exposed at Pisdura, (79º 05´ and 20º 10´) in Warora District, Maharashtra state (Figure 1). The fragmentary wood specimens are found scattered in the exposed sediments along with the coprolites and dinosaurian bones. Only one gymnosperm wood piece showing affinities with the present day *Araucaria* has been found in the present collection. The fossil woods are rare to the extant of 1-2% as compared to the skeletal remains and the excrements of the dinosaurs. The silicified fossil wood measures about 10 cm long and 2. 5 cm in thickness (Figure 4 a), is dark brown to grey in color. It is fine grained compact and nonporous in nature; the central part shows presence of pith region. The preservation of the specimen is satisfactory to reveal

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Research Article

all the anatomical details. For the detailed study and identification, the wood was cut in to transverse (TS), tangential longitudinal (TLS) and radial longitudinal (RLS), after grinding and polishing these sections permanent slides were prepared by usual methods.

Description

The gymnospermous fossil wood is compact and nonporous in nature, distinctly demarcated in to early and late wood. It shows inconspicuous growth rings, which are separated by thick wall zone of Late wood. These zones are smaller and generally comprise 10-20 cells thick (Figure 4 b, c). About 7-8 growth rings can be seen in the total width (2. 5cm) of the specimen. Thin medullary rays about 5-6 tracheid cells apart, can be observed radiating from the centre towards the periphery (Figure 4 c, d). The tracheid cells are polygonal in shape as seen in cross section (Figure 4 d, e). The frequency of the rays is 8-10 per mm. They are generally 1-2 cells wide and may extend up to 6 cells high as seen (Figure 4g). Sometimes translucent dark substance (probably resin) may be seen filled in these cells (Figure 4 e). The wood parenchyma is absent. The tracheids show typical araucaroid pits on their walls, in alternate rows (Figure 4 h). The pits are usually simple in nature and measure about 4 µm sizes; generally one cross-field pit on the radial wall of the cells is present. The central part (pith) is degraded to reveal detailed cellular structure. Silica crystals (phytoliths) are present in the ray cells of the wood (Figure 4i).

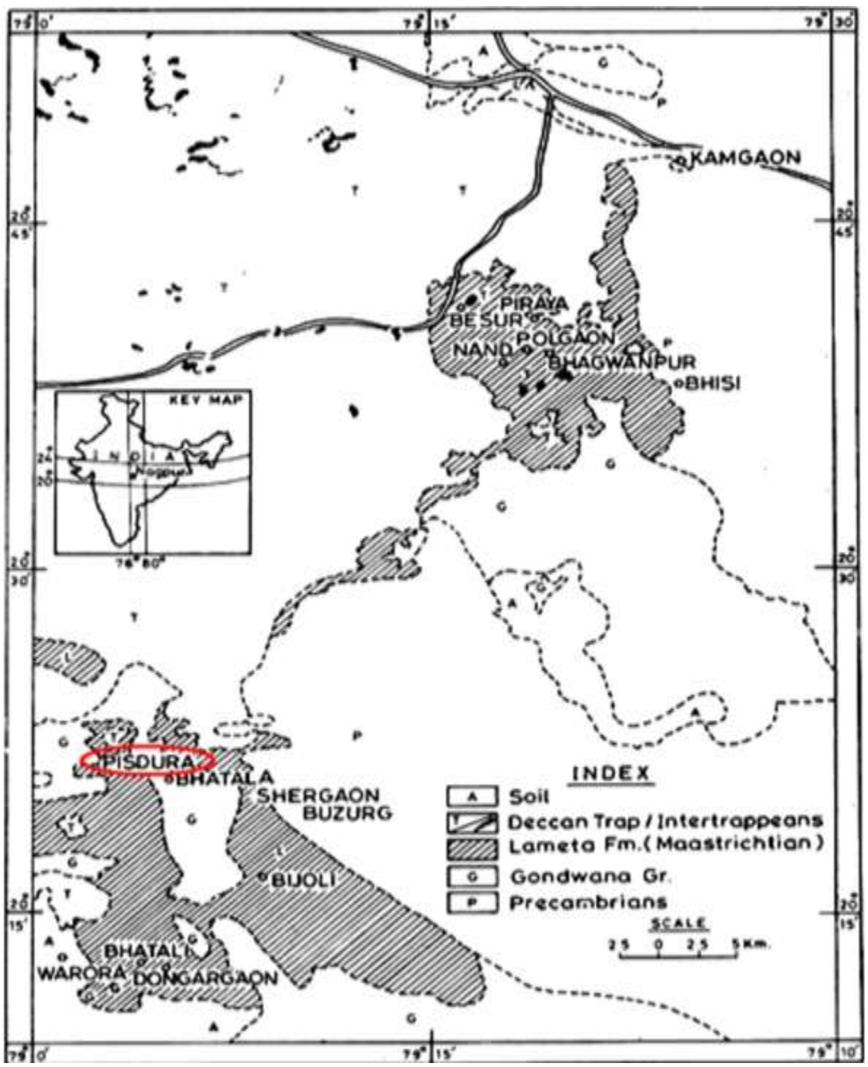

Figure 1: Map showing the fossil locality (Pisdura) from was the samples for investigation were collected (after Mohabey, 1996)

Research Article

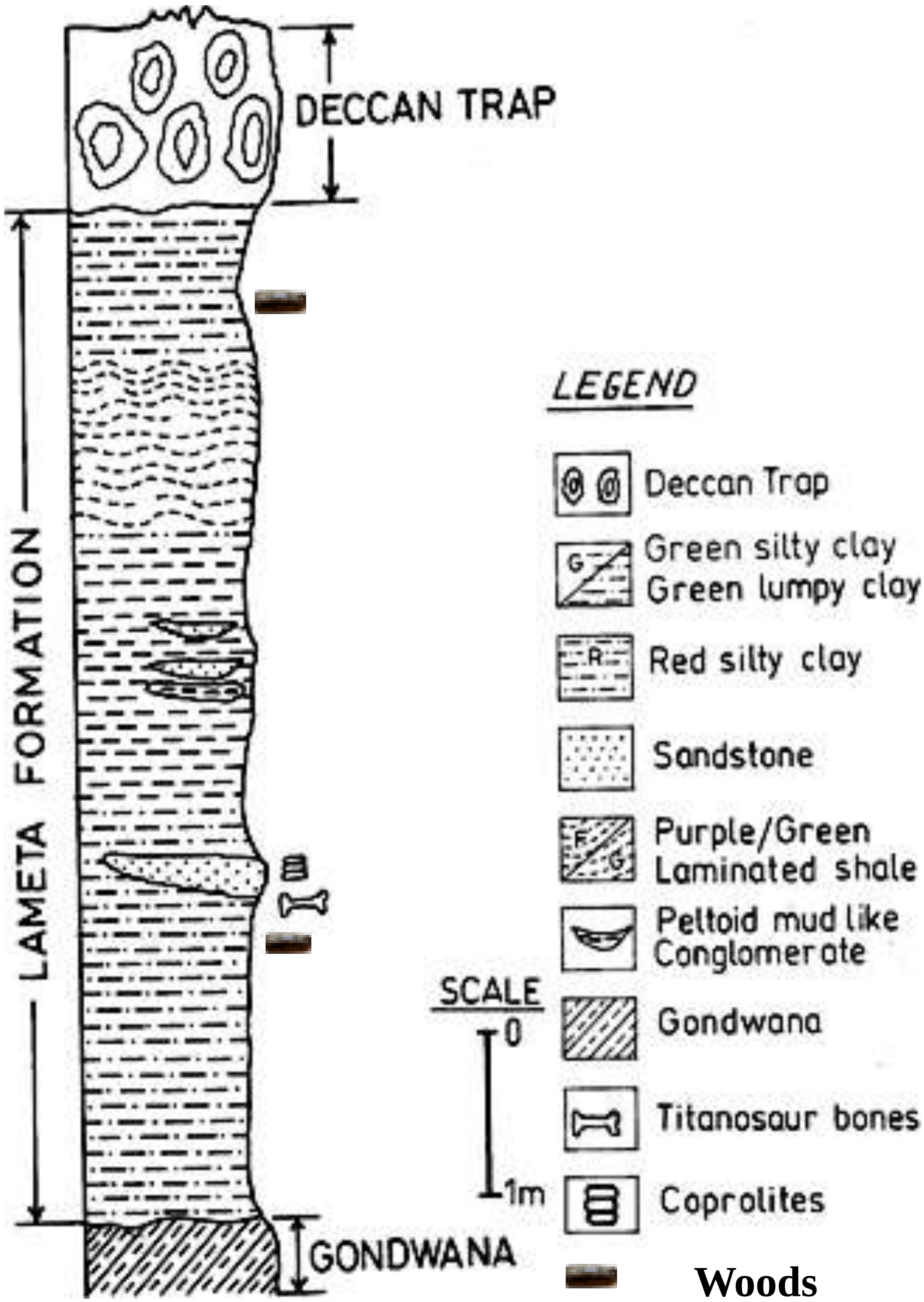

Figure 2: Litholog of the area to show the arrangement of different sediments

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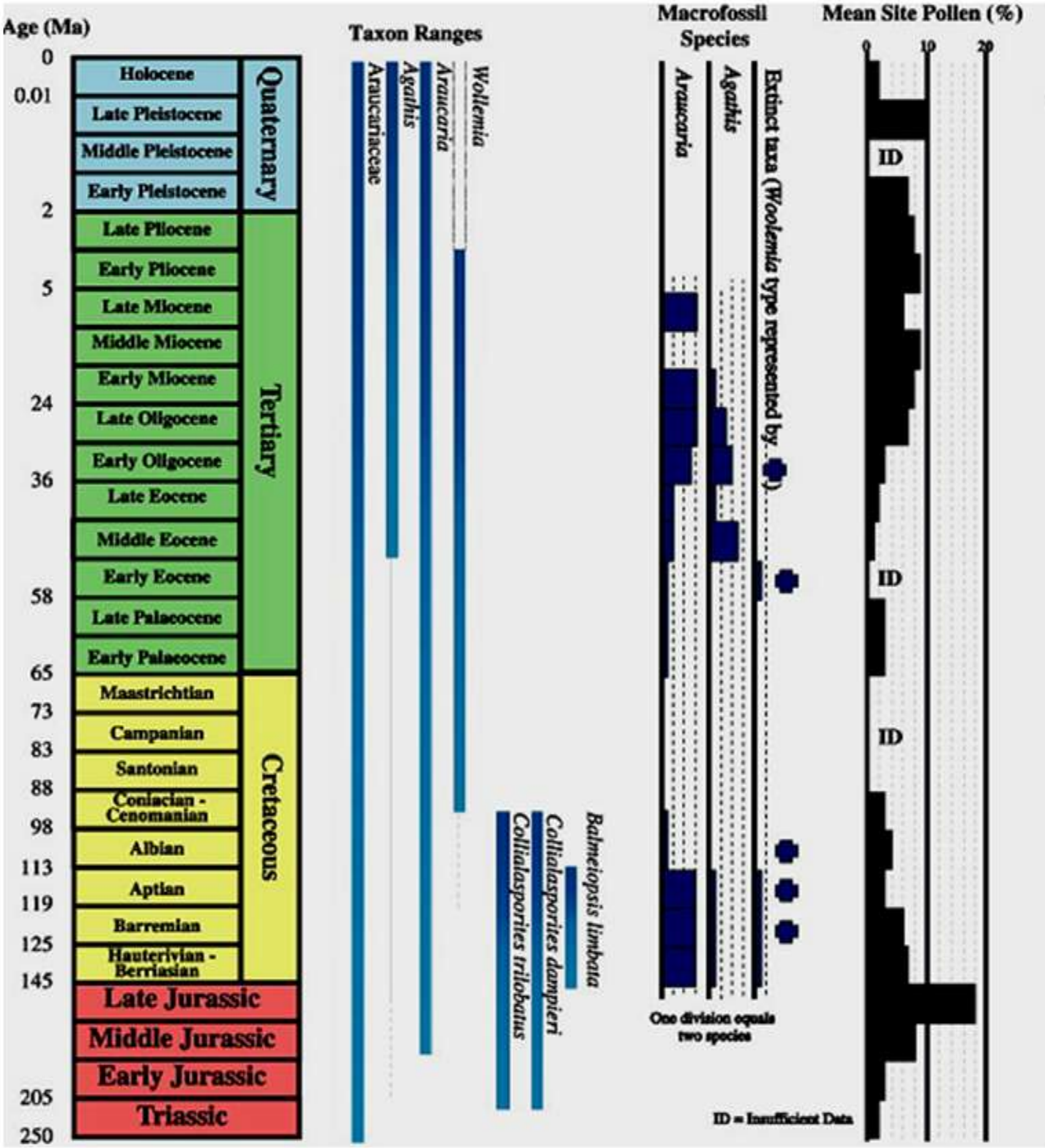

Figure 3. The diagram indicates the records of Australian Araucariaceae including taxon stratigraphic ranges, representation of predominantly southeastern Australian Macrofossil species (Data from Hill and Brodribb, 1999) and average Araucariaceae percentage from pollen records and relation to major environmental changes and events, land temperature estimates from southern Australia, E-from leaf size index of Greenwood (1994). M- from overlapping bioclimatic ranges of pollen and macrofossil taxa from the brown coal of laerove valley (Kershaw, 1997) P- from last glacial maximum pollen data Kershaw (1998) H- from bioclimatic profile of an early Holocene. Occurrence of the aquatic *Brasenia* Lloyd and Kershaw, 1997 (data online).

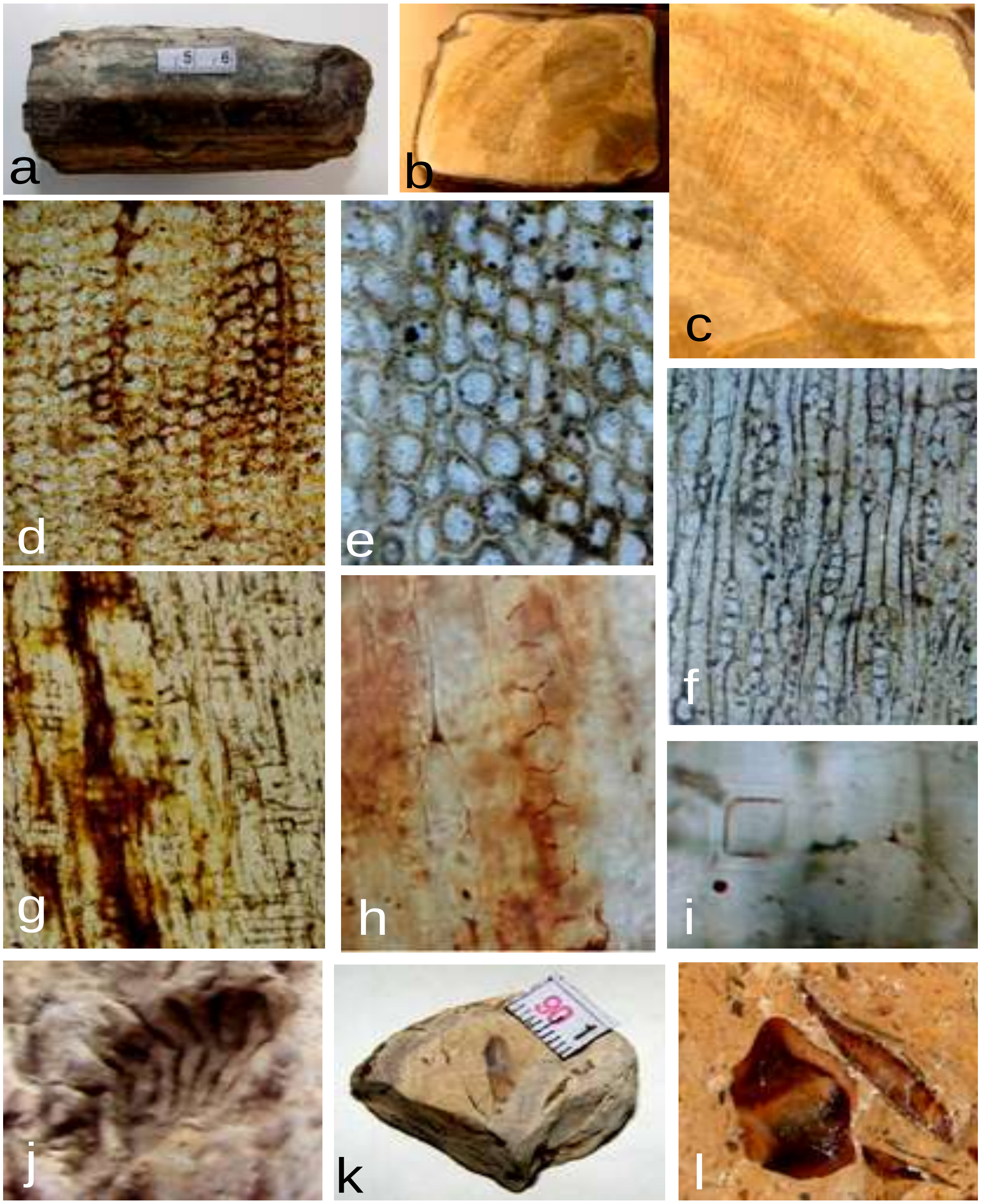

Figure 4: (a) Fossil wood of *Araucaria*, *(*b-c) cross section of wood showing growth rings of early and late wood with wood rays, (d) cross section of the wood showing the details of cellular structure and presence of uniseriate medullary rays x 30, (e) tracheid cells with angular shape containing resin material on their walls x75 (f), tangential longitudinal section (TLS) showing nature of medullary rays x 100, (g) RLS of the wood showing arrangement of wood rays (medullary rays) and crystals x 100, (h) tangential longitudinal section showing araucaroid pits on the trachied wall x 100, (i) magnified view of ray cell with crystal x 200, (j) a part of coprolite with auraucaroid cone impression x 10, (k) part of coprolite showing embedded scale leaf of *Araucaria*. (l) A part of another coprolite showing araucaroid megasporophyll and a part of scale leaf.

DISCUSSION

On the basis of detailed anatomical characters the present fossil wood indicates its affinities with the extant wood of *Araucaria*. Both show imperceptible growth rings, late wood tracheids with slightly narrower lumina as compared to early wood. Tracheids in cross section are generally angular in shape with absence of wood parenchyma. Both fossil and living specimens rays are generally 1-2 cell wide, their height extends up to 30-40 µm and 10-20 µm wide. The longitudinal walls of the tracheids are seldom with bordered pits, when present they are linear in orientation. Two rows of bordered pits (typically araucaroid type), are present on the on the tracheid walls, characteristically alternate in orientation; pit apertures are minute and smooth; a single pit on the radial walls of the tracheids can be seen. Presence of dark resinous matter in the cells of fossil and the modern woods is noticed.

The family Araucariaceae includes the taxa *Araucaria* and *Agathis;* whereas *Araucaria* at present is restricted to New Guinea, eastern Australia, Chilean Argentina, Cordillera and Brazil (Willis, 1973; Billimoria, 1948). Based on their anatomical features hardly can be differentiated from each other. The wood of *Agathis* though possesses typical araucaroid bordered pits on the tracheid walls but has comparatively very narrow diameter (Greguss, 1955) and the radial diameter extends only up to 20µm. The rays are generally 2-5 tracheid cells apart and 8-10 cells in height. The tracheids in cross section are generally square in shape with very thin walls. *Agathis* possesses uniseriate rays and cupressoid field pits. As a matter of fact some modern conifers such as *Cedrus* (Cedar) also have two rows of bordered pits on the tracheid walls, which sometimes show alternate pattern, however, in the present specimen these pits necessarily are circular in shape.

The fossil records of Araucariaceae are widely known from different horizons of India ranging from the Upper Gondwana to the Upper Cretaceous sediments. The initiation of the continental rifting towards the end of the Jurassic created exclusion of India and Africa, which resulted a subsequent change in Gondwana vegetation to a major phase of flora modernization. The beginning of the Cretaceous perhaps initiated the appearance of *Wollemia* related taxa and a large number of *Araucaria* species. It may be related as Indian plate moved from south to northward, could not provided suitable climate for their survival (Croizat, 1958; Dietz and Holden, 1970; Schuster, 1972; Rosen, 1978; Stockey, 1982; Dettmamm, 1994; Zatawniak, 1994; Pollock, 1995; Kar *et al.*, 1998). It is also evident that the Late Cretaceous Gymnosperm family was well established and the genus *pinus* host was already highly diversified and wide spread (Miller, 1987). The volcanic activity during the Upper Cretaceous was responsible for their gradual disappearance and gave ground for the development of angiosperms (Croizat, 1958; Muller, 1970; Doyle, 1978; Doyle and Hotton, 1991; Stokey, 1982; Vasanthy *et al.*, 2004). According to these workers during the Late Triassic period (over 200 My ago) the trees of extinct forest related to present day Araucariaceae including *Araucaria heterophylla, A. araucariana* and *A. biwildii* coexisted with dinosaurs. At the close of Cretaceous period these taxa probably entered in a transitional phase. This also stands true in the context of the Indian subcontinent that from Lameta Formation to Intertrappeans, (the Deccan volcanism) through a series of environmental stresses had adversely affected the biota leading to gradual or even step wise extinction of the genus *Araucaria*. A change from semi-arid to sub-humid to humid climatic conditions is envisaged with the advent of Deccan volcanic eruptions. However, there were extinctions within the family Aurcariaceae that would have also played a role to reduce the pollen percentage in the sediments. Taking this as an account, the decline of Araucariaceae resulted the disadvantage to many araucarian species by middle Cretaceous peak temperature and humidity (Figure 3). During the Upper Cretaceous (65my ago) about the time when dinosaurs became extinct; it is obvious to presume that araucariaceae had been a major source of food material to these animals as revealed by the co-existence of dinosaurs skeletons, fossil woods and other plant parts in their coprolites of Lameta Formation at Pisdura.

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