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PALAEOBOTANICAL STUDIES IN INDIA, HISTORY AND PROGRESS - A REVIEW

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History of palaeobotanical investigations in India began by the publications of Oldham and Morris, and Feistmantel on the Mesozoic exposures of plant fossils at the Rajmahal Hills, Cutch, Jabalpur, Madras outliers and South Rewa basin. Arber's work at the British museum London, on *Glossopteris* like leaves added much about the Palaeozoic Strata of India. Seward and Sahni published a revision of already known fossil plants of the Gondwana land of the country. Sahni and his students studied fossil plants of Palaeozoic, Mesozoic and Tertiary exposures and identified fossils of all the groups of plant i.e. algae to angiosperms. Teachers and scientists of various institutions, universities, and colleges at Calcutta, Allahabad, Lucknow, Poona, Nagpur, Rewa, Ajmer and Jodhpur added much to the palaeobotanical studies in the country. In addition to morphology and anatomy of fossil plants investigations on extinct spores and pollen grains also began at the BSIP Lucknow, ONGC Dehradun, Calcutta university, and Allahabad university. At Jodhpur a new pattern of study on extinct plants began, i.e., chemistry of fossil plants (Petrifactions and Lignite) and could achieve success in separation and identification of as many as nineteen amino-acids by chromatography technique. Further investigations on this aspect are required using better tools and techniques.

Key words: Amino-acids, Chemistry, Extinct plants, Investigations, Lower Devonian Rhynie chert

History

Europeans came to India, established business and carried coal blocks and other kinds of rocks from India to their countries and studied. Brongniart (France) (1828-1837) identified a number of new species of *Glossopteris* Brong. e.g. *G. angustifolia, G. browniana* etc. McClelland (1850) also created new species of this taxon e.g. *G. aculis, G. frondosa* etc. Schimper (1869) established *G. Indica.* Morris (1840) studied Mesozoic plants of Cutch and identified two new species of the genus *Ptilohyllum* Morr. i.e. *P. acutifolium* and *P. cutchense.* The geological survey of India took initiation by, publication of fossil flora of Rajmahal Hills, Bihar (now Jharkhand) by Oldham and Morris (1863). Feistmantel followed them and studied several fossiliferous sites of Mesozoic and Palaeozoic Horizons e.g. Cutch (1876), Rajmahal Hill (1877), Golapilli (1877a), Jabalpur (1877b), Madras outliers (1879), Lower Gondwana (1879a) etc. Zeiller (1902) published an account of the taxon *Vertebraria* from coal deposits of India. Seward (1900) and Bancraft (1913) studied the anatomy of Indian material of Bucklandias (Bennettitalean stems) and considered these peculiar and different from other known species of this taxon. In 1905 Arber published a catalogue of the material of *Glossopteris* present at British museum of natural history, London. Seward (1917) in his book 'Fossil Plants' III included the descriptions of fossil plants from India like *Nilssonia princeps* (O & M) Sew. *Bucklandia indica* Seward, *Williamsonia indica* Seward etc. Seward and Sahni (1920) published a revision of Indian Gondwana plants and suggested changes in nomenclature of some of the fossil plants e.g. species of *Cycadites,* into *Nilssonia* species, *Pterophyllum* species (O & M) 1863 and Feistmantel (1877) into *Nilssonia* Brong. species etc. Sahni (1828, 1831) published revision of Indian fossil Conifers in two volumes i.e. incrustation and petrifaction. Sahni (1932) described the anatomy of a petrified wood *Homoxylon rajmahalense* and correlated to the anatomy of vessel-less angiosperms. For observation of his opinion, he gave a problem to his first registered research scholar K. M. Gupta towards doctorate thesis on the anatomy of four extant taxa of vessel-less angiosperms i.e. *Trochodendron, Tetracentron, Drimys and Zygogonium*. Gupta (1934) suggested relationship of *Homoxylon* closer to Cycadeoidales than vessel-less angiosperms.

This opinion was also favored by later workers Hsu & Bose (1952), Bose & Sah (1954). In 1932 Sahni established a new species of *Williamsonia, W. sewardiana* from the Rajmahal Hills, also suggested its reconstruction and association with *Bucklandia* stem and *Ptilophyllum* leaves. In 1936 Sahni reported the occurrence of *Matonidium* and *Weichiella* (ferns) from Himmatnagar (Gujrat) rocks. Sahni and Rao (1933, 1934) published papers on fossils (impressions) from Mirzachowki and Onthea areas of Rajmahal Hills and established new taxa like *Dictyzamites hallei* n. sp. and *Rajmahalia paradoxa* gen et sp nov. etc.

Sahni (1936-1947) also paid attention on Tertiary fossil floras of Madhya Pradesh etc. like Mohgaon Kala (Chhindwara), Sausar etc. and described new taxa e.g. *Azolla intertrappea* (1941) *Enigmocarpon parijai* (1943), *Rhodeites* sp. (1943a), *Viracarpon elongatum* (1944), *V. hexaspermum, Palmoxylon sundram* (fruit Cocos like 1947), *Chara sausarei* (Sahni & Rao SRN 1943) etc. In 1948 Sahni established a new group of Jurassic gymnosperms 'The Pentoxyleae' from the Rajmahal Hills. A monograph on fossil monocotyledons was also published in the name of Sahni (1964) completed by Dr. Uttam Prakash of BSIP Lucknow. Prof. Sahni expired in 1949.

Prof. Sahni and students had gone in 1932 on a collection to the Rajmahal Hills for finding out the exact location of the site from where G B Hobson of GSI had collected the chert piece and given to Prof. Sahni, This chert had the marking of petrified *Taeniopteris* like cycadean leaves etc. Fortunately, H S Rao and K M Gupta reached the exact location Nipania situated near the village Amarapara where they had stayed. Next day the entire party went to Nipania and made collection of the pieces of cherts. Prof. Sahni gave material for investigation to B P Srivastava and A R Rao. Rao studied the morphology and anatomy of the leaves of *Taeniopteris spatulata* (Rao1943), later on Sahni (1948) described the leaf as *Nipaniophyllum raoi* Sahni. Srivastava studied other fragments of the fossil plants and established the new taxa like *Lycoxylon* and other pteridophytes and gymnosperms e.g. *Pentoxylon sahnii, Nipanioxylon guptai, Carnoconites compactum* and *C. laxum.* Unfortunately, B P Srivastava expired prior submission of doctorate thesis to Lucknow university. Prof. Sahni published Srivastava's incomplete work in the form of a full paper with an obituary note (Srivastava 1946). Rao described new genera of fossil conifers like *Nipaniostrobus* (1943a) and *Nipanioruha* (1947).

Gupta (1943) described a new species of *Williamsonia, W. sahnii* which was collected from Khairbani (Mirzachowki) area, Rajmahal Hills. He believed it a bisexual fructification but doubtful. Ganju (1946, 1947, 1947a) described a number of new genera and species of pteridophytes and gymnosperms from the Rajmahal Hills e.g. *Ontheanthus polyandra* gen. et sp. nov. Sitholey and Bose (1970) changed the name to *Weltrichia polyandra* (bennettitalean male fructification), *Ontheostrobus sessilis* (cycadean seed cone) etc. Bhardwaj (1952, 1953) described the anatomy of extinct conifers from the Rajmahal Hills. He was primarily a bryologist, Bhardwaj modified himself and worked on extinct spores and pollen grains. Hsu and Bose (1952) restudied the material of *Homoxylon rajmahalense* Sahni and favored the opinion of Gupta (1934). Bose and Sah (1954) changed the name to *Sahnioxylon rajmahalense* (Sahni) and also established a new species *S. andrewsii* from the Rajmahal Hills. Bose remained incharge of the Mesozoic Section in the Institute (BSIP) for a long time.

Bose and his associates like S K Roy (Cutch fossil flora), Sukhdev (Jabalpur Athgarh etc.), K P Jain (Rajmahal Hills), S C Srivastava (Triassic), M L Kasat Jabalpur, Rajmahal Hills), J Banerji (Cutch, Rajmahal Hills), B N Jana (Kathiawar) etc. All did good work on Mesozoic exposures. Bose *et al.* (1984) suggested change in name of *Carnoconites laxum* Sriv. to *C. rajmahalense* (Wieland). This is not justified and needs reconsideration

(Sharma 2001). Sitholey and Bose (1953) described a new male fructification of *Willamsonia, W. santalensis* which was later on 1970, they changed to *Weltrichia santalensis*. In this paper they criticized Sharma (1969) who had studied a large number of nicely preserved specimens of this fructification from Sakrigalighat and had suggested different reconstructions of young, unopened and mature forms. Bose and Kasat (1972) published a review on the leaf taxon *Ptilophyllum* Morris. Bose and Banerji (1984) published a detailed account on the fossil flora of Cutch. Bose et al (1985) described the fossil plant 'Pentoxylon' in detail. Srivastava and Banerji (2000) also published an account of the Pentoxylon plant. Sharma (2001) published misinterpretation of the above noted two papers and some papers of foreign authors who knew very little about the Pentoxyleae and also made reconstruction without proper studies of specimens and slides of the Pentoxyleae.

Dr. K R Surange remained director of BSIP Lucknow for long time and supervised the research work of many scientist on the *Glossopteris* flora of India like H K Maheshwari, P K Maithy, K M Lele, S Kulkarni (S. Chandra) etc. During the tenure as director of the institute he organized an international symposium (1964) on Gondwana land. Surange also published a CSIR New Delhi monograph (1966) on 'Indian fossil Pteridophytes' Surange *et al.* (1974) also published an edited book on Palaeobotany and palynological activities of the institute and other Indian workers. K M Lele did enough work on Middle Gondwana flora and established the geological position of South Rewa Gondwana basin. D C Bhardwaj enhanced the palynological studies in BSIP Lucknow. He was associated by a number of dedicated and hardworking scientists like Suresh c. Srivastava, R S Tiwari, R K Kar etc. Dr. Lakhanpal looked after the Tertiary Horizon and led a team of enthusiastic workers like N Awasthi, R Dayal, J S Guleria, R C Mehrotra, Rashmi Srivastava etc. Lakhanpal *et al.* (1976) edited a book 'A catalogue of Indian fossil plants' published by BSIP Lucknow. Dr. Uttam Prakash studied anatomy of a large number of taxa of fossil woods of the Tertiary Horizon and created a number of new taxa belonging to both monocot and dicot fossil plants. He was assisted by a number of scientists like R Dayal, G K B Narale etc. Dr. Vishnu Mittre (1953, 1955, 1956, 1957, 1959) did enough work on the Mesozoic flora of the Rajmahal Hills e.g. the Male fructification *Sahnia nipaniensis* of the Pentoxyleae, *Araucarites bindrabunensis, Osmundites sahnii, Nipaniostrobus* sp. *Nipanioruha* sp. *Mehtaia* sp. *Sitholeya* sp. etc. He described an angiospermous pollen grain *Sporojuglandites* jurassica and showed also the preservation of dividing chromosome in fossil spores (Vishnu Mittre 1969). Then he sifted to palynology and archaeology of Pleistocene and supervised the research work of H P Gupta, C Sharma, B D Sharma (BSI) etc. Dr. Venkatachala enhanced researches on extinct spores and pollen grains of all the Horizon specially, of Cutch area. He was associated with a hard-working scientist R K Kar. During his tenure as director, an International symposium was organized by the institute on 'Concepts, limits and extension of Gondwana System'. Venkatachala and Maheshwari (1987) did not accept the age of Gondwana System from Upper Carboniferous to Lower Cretaceous that is there are no Lower, Middle and Upper Gondwanas in India. Gondwana limited to only Permian Period. This concept needs reconsideration. Dr. Sinha (Ex. Director of BSIP) was a well-known geologist who worked on North-West Himalaya. Mukund Sharma and many other scientists were associated with him. The institute publishes two research Journals, 'The Palaeobotanist' of the BSIP while second is 'Geophytology' of the Palaeobotanical Society. The name of institute is now changed to Birbal Sahni Institute of Palaeosciences. The term Palaeo- is associated with life and certainly not with Physics, Inorganic and Physical Chemistry, Biotechnology and Tissue culture. Palaeogeology and Palaeogeography use and need examples of plant fossils and animal

fossils. The attachment of the term Palaeoscience for Palaeobotany needs reconsideration.

In past, researches on fossil plants were done in various Universities, Colleges and institutions. At Calcutta university J Sen and Manju Banerji did enough work on Palaeozoic fossil plants and Palynology. For detail, kindly read J. Sen comm. Vol. (Santapau *et al.* 1969). At Allahabad university Dr. D D Pant and D D Nautiyal studied Palaaeozoic fossil plants specially the *Glossopteris* flora of coal fields for detail kindly reed Comm. Vol. of D D Pant (1982) and D D Nautiyal (2000). At Poona University Dr. T S Mahabale and his students Deshpande, Paradharkar and Brader studied the anatomy of a number of angiospermous woods collected from Decan Intertrappean rocks. Mahabale (1950) had discovered a specimen of *Salvinia* from the Tertiary cherts. Dr. (Mrs.) S D Chitaley established a centre of Palaeobotanical studies at the Institute of science, Nagpur. She also started a research journal 'Botanica'. Her students G V Patil, M T Sheikh etc. did enough work on fossil plants of Intertappean rocks of Nagpur and Mohgaonkala (Chhindwara, MP). Dr. S D Saxena made collections of fossil plants from South Rewa Basin and did good work on *Phyllotheca,* an Equisetalean plant. At Lucknow University Dr. A R Rao and Dr. B S Trivedi continued palaeobotanical researches in the botany department. Dr. Rao did work on Mesozoic plants whereas Dr. Trivedi studied Tertiary angiosperms. Dr. Rao and V K Menon studied different types of fossil plants. Rao and Vimal studied palynology of Palana (Bikaner) Lignite. Dr. K P Rhode studied many angiosperms of the Tertiary rocks during his stay at Udaipur. Dr. K M Gupta started investigations of fossil plants at Govt. college Ajmer and gave a research problem on 'Indian fossil cycads with special reference to the genus *Williamsonia* Carr.' to B D Sharma. They continued their researches on the Mesozoic flora of Rajmahal Hills. Gupta (1969) described a new species of cycadean frond *Nilssonia, N. sahnii;* An Osmundaceous rhizome *Osmundites rajmahalensis* (1970) and a cycadean stem *Sewardeoxylon sahnii* Gupta (1971). Sharma joined Jodhpur university (1967) and continued researches on the fossil flora of the Rajmahal Hills. D R Bohra worked on a new assemblage of fossil plants of Sonajori exposure, Rajmahal Hills and identified many new taxa of petrified fossil ferns and gymnosperms (Sharma & Bohra 1976, 1978, Bohra & Sharma 1979, 1979a,1980, 1980a). A new petrified megastrobilus *Araucarites mitterii* Bohra & Sharma (1980) was also collected from Sonajori locality. O P Suthar and Sharma (1986) studied fructifications of gymnosperms of the Rajmahal Hills and (in 1988) gave a new interpretation to the structure of male fructification *Sahnia rajmahalense* Vishnu Mittre (Suthar et al 1988). Suthar and Sharma (1986) described petrified fructification of conifers while Suthar *et al.* (1988) described petrified isolated seeds of conifers from the Rajmahal Hills. Sharma and Suthar (1989) noted algal symbiotic in araucarian roots from the Mesozoic rocks of Rajmahal Hills identical to the coralloid roots of *Cycas.* Harsh & Sharma (1988) described *Araucarioxylon bikaneriense* sp. nov. from newly discovered site of fossils at Bikaner (Harsh & Sharma 1990) and studied the anatomy of petrified angiospermous woods collected from the Eocene strata of Bikaner and identified six new species of *Lagerstroemioxylon,* one new species of *Baringtonioxylon,* one new species of *Caryoxylon,* three new species of *Terminalioxylon* and two new species of *Anogaissusoxylon* and four species of *Dryoxylon* (Harsh & Sharma 1995, Harsh *et al* 1992, Harsh & Shekhawat 2014). Harsh also studied chemistry of a wood from lignite (Harsh & Sharma 1992). He had also separated amino-acids from some petrified woods of the Rajmahal Hills (Sharma & Harsh 1987). Tripathi *et al.* (1998) studied plant microfossils from the lignite of Rajasthan.

Sharma studied the bennettitalean plants in detail e.g. Leaves- The *Ptilophyllum* Morris, *Anomozamites* Schimper, *Dictyozamites*

Oldham etc. Stem- *Bucklandia guptai,* n. sp. *B. dichotomin*. n. sp. The anatomy of the latter is more or less similar to that of *Homoxylon rajmahalense* Sahni. Fructifications of seed bearing *Williamsonia, W. guptai* n. sp., *W. amarjolense* n. sp., male fructification- *Weltrichia (Williamsonia*) *santalensis* Sith & Bose, *W. campanulatiformis* n. sp. etc. Sharma studied all details of the *Williamsonia* fructification i.e. morphology, anatomy including epidermal structures of bracts, ontogeny of ovule, structure of micropyle, formation of pollen chamber, megaspore mother cell and it's linear division, origin and structure of archegonia, development of dicot embryo, structure of seed in longisection, and formation of a fruit like body (Sharma 1970,1970a, 1970b, 1970c, 1974, 1976, 1979). He also published many review articles on *Williamsonia* (Sharma1977, 1992 etc.).

Sharma and associate also did enough and good work on fossil ferns of Marattiaceae, Gleicheniaceae, Schizaeaceae, Matoniaceae, Dicksoniaceae, Cyatheaceae, Dryopteridaceae, Dipteridaceae etc. (Sharma 1969, 1971b, 1975, 2004, 2017 etc.). Many permineralized specimens of pteridophytes have also been studied and described the anatomy of petioles, rhizomes, roots and sori with sporangia and spores (Sharma1973, 1973a, 1973b, 1989, Bohra and Sharma 1979, Sharma *et al.* 1979). Review articles published on fossil pteridophytes from the Rajmahal Hills (Sharma 2004, Sharma *et al.* 2013, 2015). Sharma and associates also prepared slides and studied a piece of Rhynie chert (Lower Devonian) donated by Prof. Lemoigne of France and published several papers. Sharma and Bohra (1984) the structure of sporangium of *Horneophyton* (Rhyniopsida). Sharma and Tripathi (1999) reported the presence of *Sclerocystis* type fossil fungal sporocarp in Early Devonian Rhynie chert. Bohra *et al.* (2018) studied behavior of sporangia and spores in Lower Devonian Rhynie chert plants etc.

Sharma and students have also published a review article on Indian Mesozoic conifers-Mega fossils in BSI Journal Nelumbo (Harsh *et al.* 2018). Sharma and associates have collected fossils of all the groups of plants i.e. algae, fungi, lichens, bryophytes, gymnosperms and angiosperms and published papers on them. These are-

Algae - *Eudorina, Vaucheria, Chara, Polysiphonia, Red algae* (Sharma & Tripathi 1997, Sharma & Harsh 1994, Sharma 2014, 2014a, Harsh & Shekhawat 2019).
Fungi - Saprophytic fossil fungi (Sharma et al 2017)
Lichens – (Sharma et al 2001, 2015)
Bryophytes – leafy Jungermanniales, Metzgeriales and Marchantiales (Sharma 2017, 2017a)
Pteridophytes - given above- many
Gymnosperms – given above- many
Early angiosperms – *Lesquaria* like fructification (Sharma 1997)
Angiosperms - given above- many
Further investigations are needed on fossil plants of all the groups of Botany.

Syllabi get revised with new policies. However, knowledge of Botany can not be compromised for interested learners of Botany which has to included classical Botany to form the basis of understanding of plants i.e. Algae, Funfi, Lichens, Pteridophytes, Gymnosperms, Early angiosperms, Morphology, anatomy, taxonomy, reproduction biology, embryology etc.

Progress

In majority the earlier workers studied fossil plants based on impressions of leaves and rarely on petrifactions of stems and fructifications viz. Oldham and Morris (1863), Feistmantel (1876, 1877 etc.) Epidermal characters also remained uninvestigated even in incrustations. Seward (1900) and Bancraft (1913) studied anatomy of Indian Bucklandias and found different from European species. Sahni (1931) published first paper on petrified conifer of India and identified several new types viz. *Mesomebrioxylon codaverianum, M.*

parathasarathyi, M. malarianum, Cupresinoxylon coromandelinum, C. alternum, Dadoxylon (*Araucarioxylon*) *rajmahalense,* and fructifications like *Indostrobus bifidolepis* and *Takliostrobus aletus.* In 1932 Sahni described the anatomy of a petrified stem *Homoxylon rajmahalense* in which tracheids had pittings similar to those of vessel-less angiosperms and cycadeoideas (Gupta 1934). In 1932a Sahni described a petrified fructfication *Williamsonia sewardiana* and also suggested its reconstruction i.e. association with the stem of *Bucklandia* and leaves of *Ptilophyllum* (Fig. 6). Rao (1943), Bose, (1953), Jacob and Jacob (1954), Sharma (1967) etc. used epidermal characters in identification of new taxa. Sharma and Harsh (1987) believed that the study of chemistry of petrifactions by using modern tools and techniques, might prove helpful in taxonomy of extinct plants. Systematically the investigations of Indian fossil plants are given below-

Algae- Stromatolites (algal cherts) are known from Cambrian and older rocks. Valdia (1967, 1969) reported from Lower Himalayan carbonate formation and Himachal Pradesh. Verma (1954) identified *Neomarci* and *Acicularia* from Trichinapaly and *Calypenia* (Desicaldaceae) from the Cretaceous of South India. There are many isolated publications on algal fossils. During recent years many papers were published on petrified material. Sharma and Suthar (1986) described a fossil bryophyte *Sporangeoceros nipanica* which was later on Sharma *et al.* (2002) reinterpreted and transformed to *Characiosiphonites nipanica* (Chlorophyceae). Sharma and Harsh (1994) described a Polysiphonous type red alga from non-marine deposits of Rajmahal Hills. It resembles red alga *Polysiphonia* in structure. Sharma *et al.* (2015) published additional studies on this alga. Sharma (2014) described a red alga with distinct fertile structures from the locality Chilgujri of the Rajmahal Hills. Sharma (2014a) could see in a slide prepared of the Nipania chert, algal filaments with fertile structure similar to extant *Vaucheria* like siphonous alga. These investigations suggest relationship of marine algae of present to non-marine type of red alga of past (Early Cretaceous).

Fungi – Rao (1958) reported the fungi deposits in Tertiary rocks. Rao and Menon the fungal remains in the cuticle of Quaternary deposits of South India. Sharma *et al.* (2017) have described the occurrence of septate and non-septate mycelia and unicellular spores in the ovules (seeds) of *Carnoconites* (Pentoxyleae) and *Araucarites* collected from the Rajmahal Hills.

Lichens - Sharma *et al.* (2001) reported for the first-time occurrence of a fossil lichen in the Nipania chert of Rajmahal Hills. It is a cross section of an oval shaped body with many scattered, circular, blackish algal bodies, in matrix made up of fungal mycelium. It was identified as lichen type A. Sharma *et al.* (2015) reported two new types of lichens i.e. B and C. Lichen B has united cup shaped body containing blackish, globular algal bodies in the basal portions of the cups. Cups are made of fungal mycelia. It is a pyrenocarpus type lichen. Lichen type C is an apothecium consisting of hair like paraphysis and intermingled fungal asci. In the lower portion of apothecium there are many small granular dark coloured algal bodies. The fourth type of lichen D was described by Sharma (2017) from Nipania chert and called it a cyanolichen consisted of central circular bodies of cyanobacteria (blue green alga) enclosed in circular or angular fungal covers. It resembles *Winfrenatia reticulata* type cyanolichen (Taylor *et al.* 1997, 2009).

Bryophytes – Bose and Pal (1982) described an impression of a bifurcated narrow thallus and called *Hepaticites pantie* sp. nov. (Metzgeriales). Sharma *et al.* (2015) described a cross section of solid thallus (without aerenchyma) from Chigujri chert (Rajmahal Hills) and correlated to Metzgeriales or *Riccia*

sp. (?). Sharma (2017b) described an archegoniophore with terminal receptacle on a thallus. Detail unknown but related to Marchantiales. In the same year Sharma (2017a) described a branched leafy Jungermanniales from the Nipania chert. This is the first report from India and in petrifaction form. Sharma (2017b) also described petrified costate, unbranched narrow thalli bearing bunches of rhizoids and stalked spherical sporogonia. Further investigations are required on Nipania cherts for finding out the preserved bryophytes.

Pteridophytes – Majority of earlier workers like Oldham and Morris (1863) Feistmantel (1876, 1877, 1877a etc.), Sahni and Rao (1933), Ganju (1946), Gupta (1954), Bose and Sah (1968), Bose and Banerji (1984), Sukhdev (1970, 1970a), Sharma (1971, 1973, 1975) etc. discovered and described impressions and incrustations of pteridophytes from Indian Mesozoic rocks like Rajmahal Hills, Cutch, Jabalpur etc. Srivastava (1946) described petrified specimens of Lycopods viz. *Lycoxylon indicum* stem bearing a plectostelic vasculature from Nipania. Jacob (1950) published an account of a petrified rhizome bearing a dictyostele *Tinpaharia sinuosa* from Tinpahar, Rajmahal Hills. It had a dictyostelic vasculature and C shaped leaf traces having wavy xylem. Sharma (1971) described the anatomy of an isolated petiole having a 'C' shaped leaf trace with a peculiar xylem portion and created a new taxaon *Guptiorachis jurassica.* Vishnu mittre (1956) described an osmundaceous petrified thick rhizome *Osmundites sahnii* with well-preserved dictyoxylic stele, differentiation of inner and outer cortex and C shaped leaf traces in winged or stipulate leaf basis (Fig. 4.1). He (1959) also described new petrified rhizomes of *Solenostelopteris* as *S. nipanica* and *S. sahnii* from the Nipania cherts. Bohra and Sharma (1978) described a schizaeaceous fertile portion under the name *Schizaeangium jurassica.* Bohra and Sharma (1979) described another new species *Solenostelopteris jurassica* from Sonjori locality and assigned to the family Schizaeaceae. Sharma and Bohra (1976) had described earlier a new gleichenaceous rhizome *Actinostelopteris pakurense* from Sonajori having an angular, mixed protostele. They (1977) also described the anatomy of a petrified rhizome of *Gleichenia* having a circular mixed protostele (Fig. 3.6) from this locality. Sharma (1969, 1971, 1975) described impressions of a number of taxa of fertile ferns (Fig.1.1-10). Sharma and Bohra (1978) described the anatomy of a petrified matoniaceous rhizome with polycyclic polystele from Amarjola locality. In leaf, venation was reticulate as in *Phlebopteris* sp. (Fig. 1.11). Sahni (1936) had discovered fossils of *Matonidium* and *Weichelia* from Himmatnagar sand stone (Gujrat). Gupta (1970) published a paper on petrified rhizome *Osmundites rajmahalense* n. sp. collected from Amarjola. It had a dictyoxylic vasculature, stipulate leaf basis and C shaped leaf traces. Sharma (1973) discovered a number of well-preserved petrified rhizomes of *Osmundites*= (*Osmundacaulis* Miller) and created three new species of *Osmundacaulis, O. amarjolense, O. guptai* and *O. indica* on the basis of differences in anatomy. Sharma *et al.* (1979) also established a new species *O. estipulare* on the basis of absence of stipules in leaf bases. Tidwell (1986) suggested change in names of Indian species of *Osmundites and Osmundacaulis* to *Millerocaulis* species. Sharma (2004) and Sharma *et al.* (2013) have followed Tidwell's opinion. Bohra and Sharma (1979) published a paper on petrified pteridophytes in form of rhizome, roots and petioles from Sonajori locality. These were *Actinostelopteris pakurense, Solenostelopteris jurassica,* roots- *Filicoamyelon* sp., *Gleichenioamyelon* sp. and petiole- *Gleicheniorachis* sp. and sporangial spike – *Schizaeangium* sp. (Fig.1.12). Sporangia with apical annuli. *Setosisporites* (Fig. 1.13) and *Cicatricosisporites* types of spores. Petrified spores of other fern taxa like *Alsophilidites* (Fig.1.14) also occur frequently in Nipania chert.

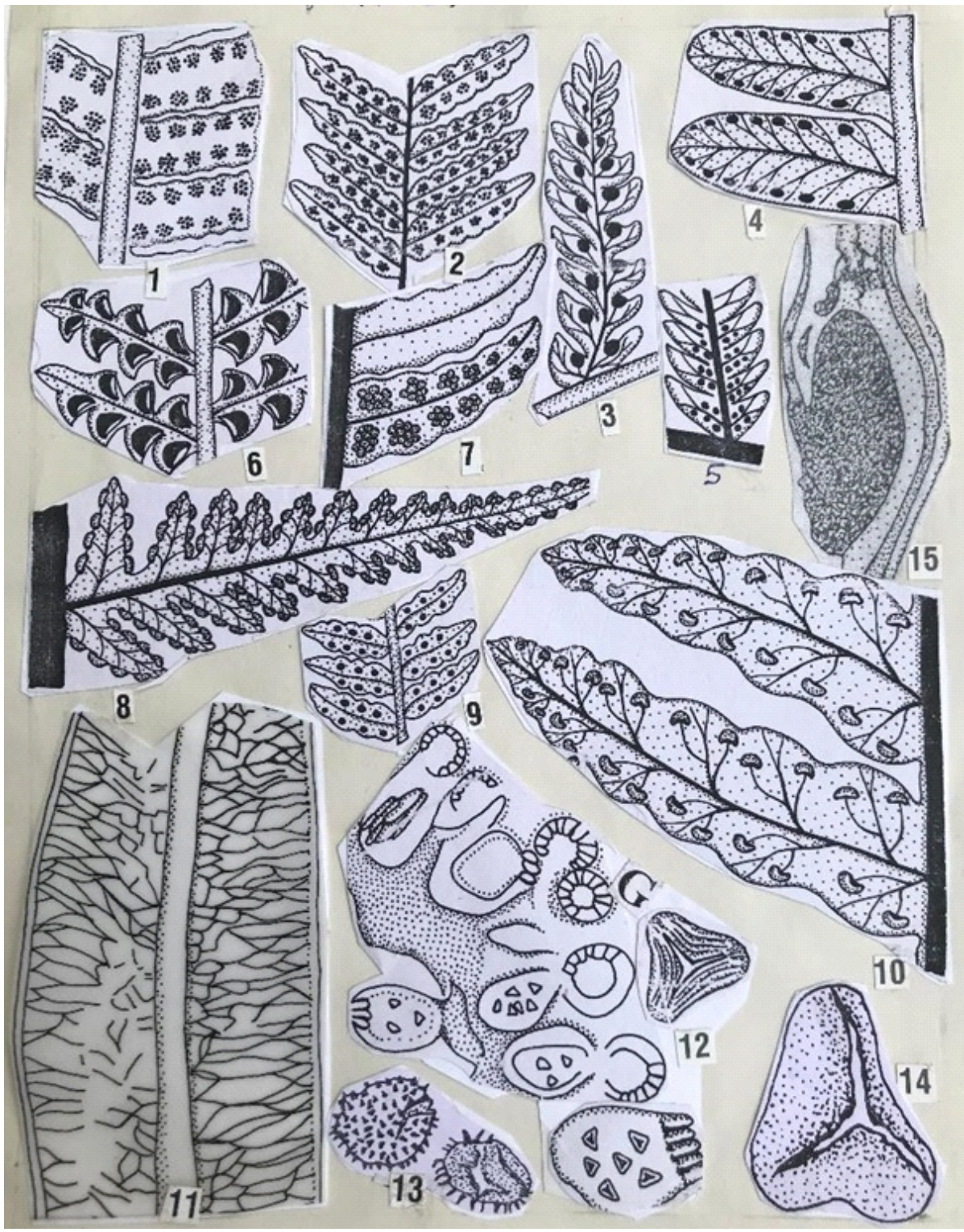

Figure 1 (1-15): 1. *Cladophlebis denticulate* fertile frond. **2.** *Gleichenia* sp. With naked sori. **3.** *Dennestaedia rajmahalensis* a pinna with sori. **4.** *Dryopteris cladophebica* with sori. **5.** *Klukia* sp. with sori. **6.** *Dicksonia speciosa* with distinct sori. **7.** *Todites indica* pinna with sori. **8.** *Dicksonia rajmahalensis* with marginal sori. **9.** *Hydentia* sp. with sori. **10.** *Dryopteris indica* with kidney shaped sori. **11.** *Phlebopteris* sp. pinna with distinctmid rib and reticulate venation. **12.** *Schizaeangium jurassica* spike with sporangia having apical annului and *Cicatricorisporites* type spores. **13.** *Setosisporites* types of spores. **14.** Alsophilidites sp. spore. **15.** *Isoetites* sp. leaf longisection with a large glossopodium and a long ligule.

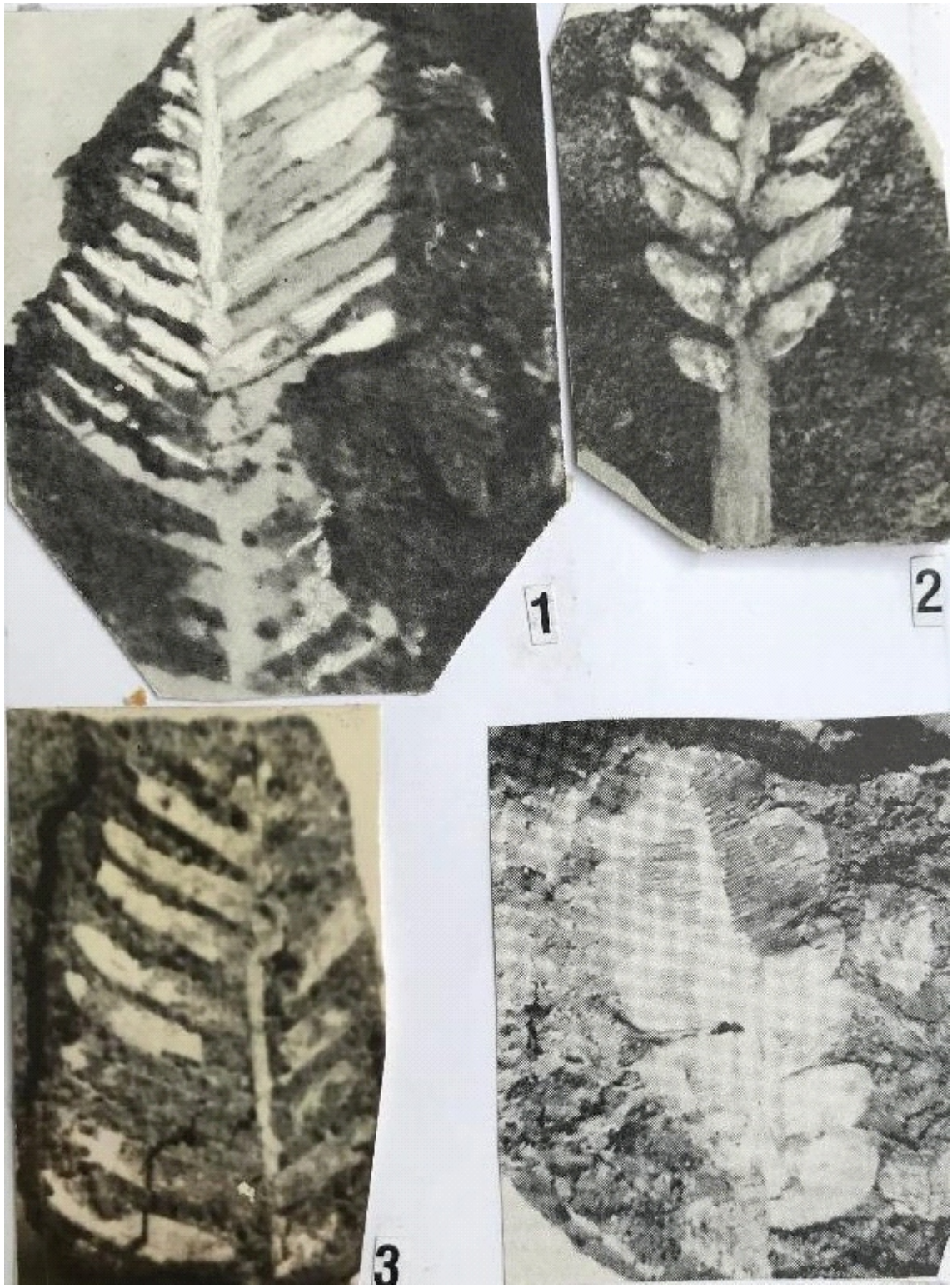

Figure 2 (1-4): Petrified leaves from Amarjola, Rajmahal Hills. **1.** *Ptilophyllum guptai.* **2.** *P. guptai* basal portion of leaf. **3.** *P. sparsifolium.* **4.** *Anomozamites amarjolense.*

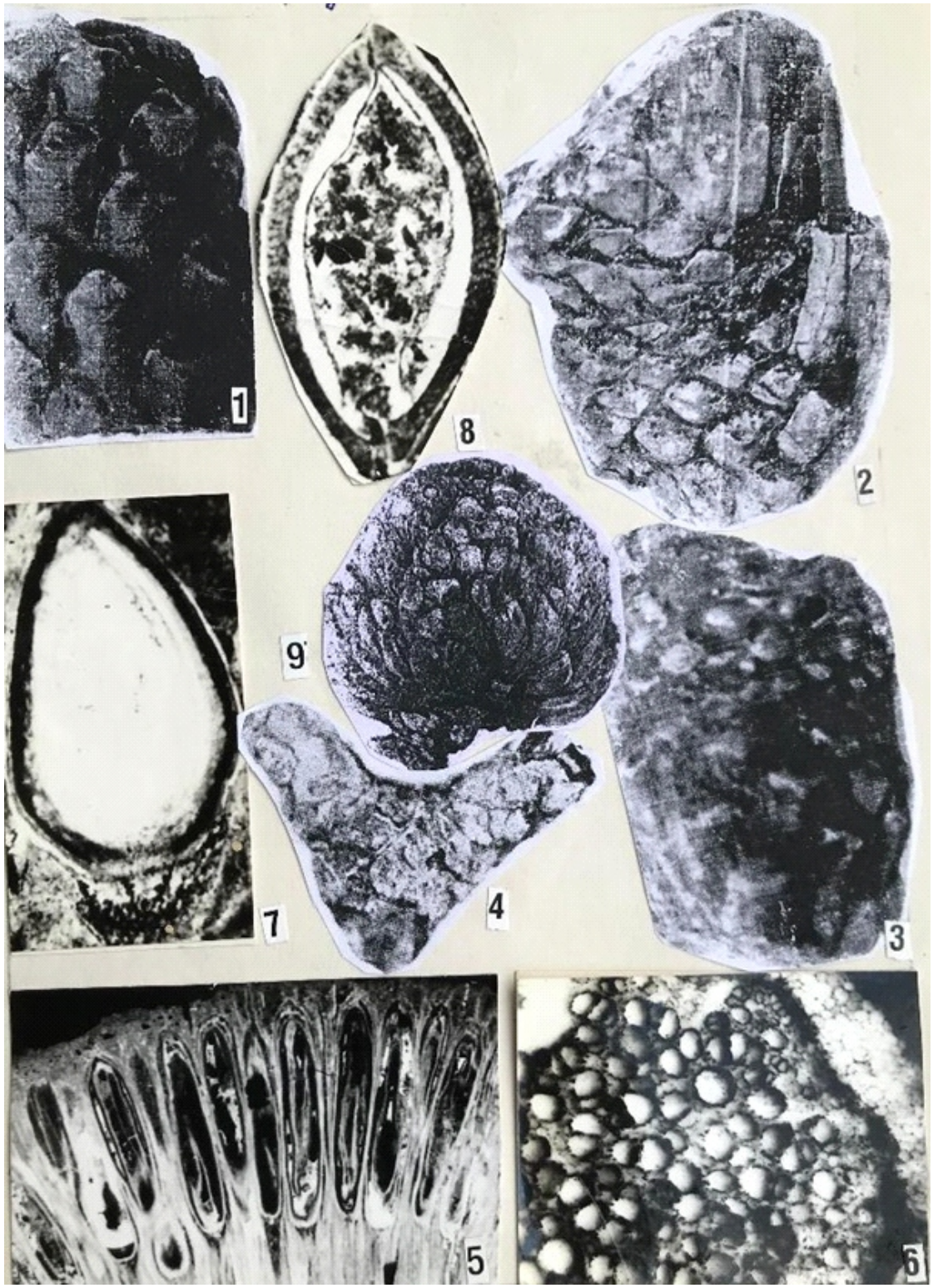

Figure 3 (1-9): 1. *Bucklandia* sp. with spirally arranged leaf bases. **2.** *Bucklandia* sahnii covered with rhomboid leaf bases. **3.** B.sahnii. **4.** B.dichotoma. **5.** *Williamsonia guptai* longisection fertile portion showing ovules and intermingled sterile scales. **6.***Gleichenia* sp. rhizome T.S.with mixed protostele. **7.** Longisection of an isolated conifer seed. **8.** Isolated conifer seed. **9.** *Lesqueria* like an early angiosperm fructification.

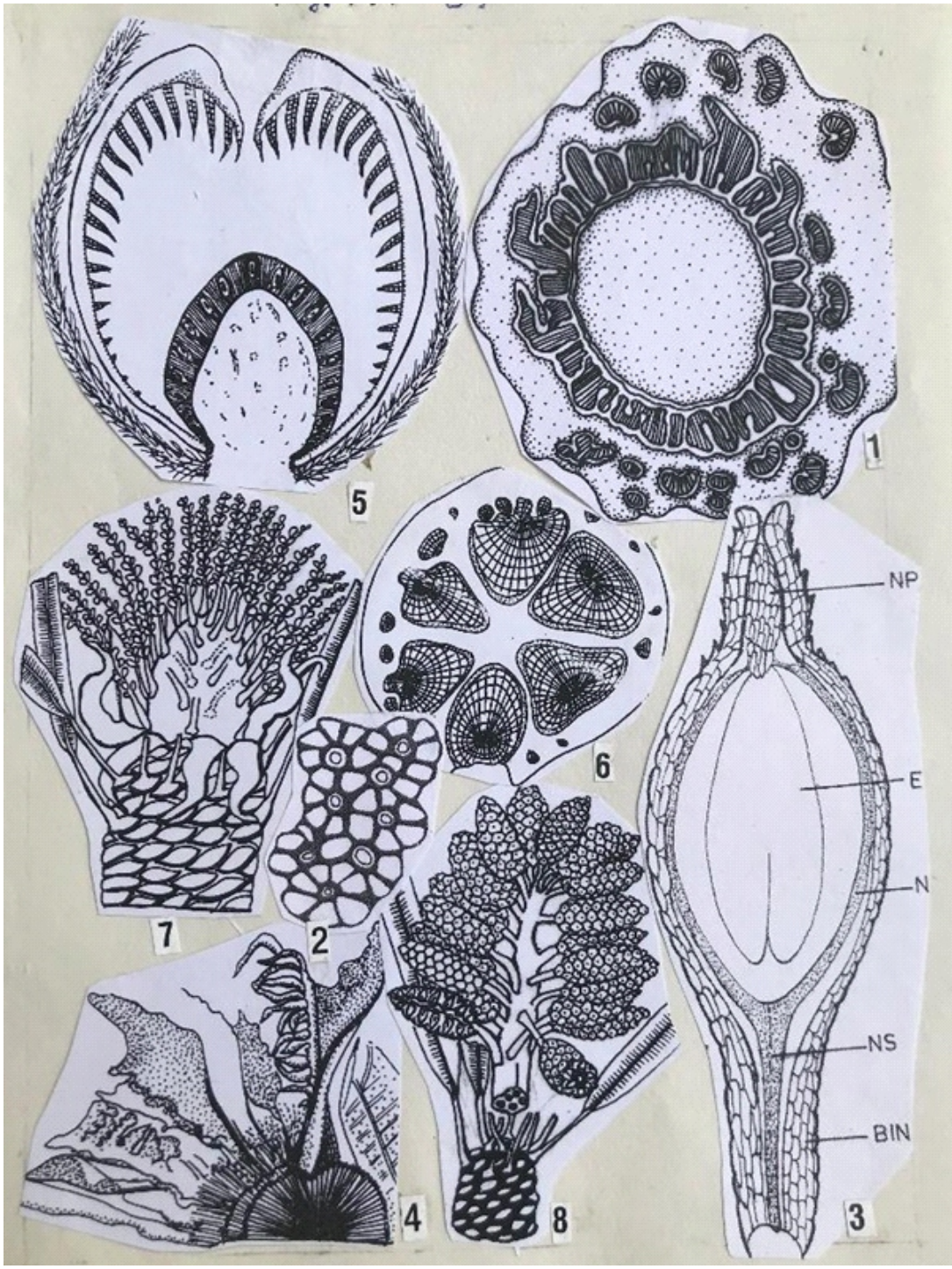

Figure 4 (1-8): 1. *Millerocaulis (Osmundites) sahnii,* C.S. rhizome with dictyoxylic stele and C- shaped leaf traces. **2.** *Williamsonia* sp. Tangential section fruit showing cicular micropyles, each surrounded by 5-7 angular interseminal scalesa. **3.** *Williamsonia* sp. longisection of a dicot seed. **4.** *Weltrichia santalensis* male fructification, microsporophylls arising from central circular receptacle and each has finger like appendages on which microsynangia were produced. **5.** *Amarjolia dactylota* a bisexual bennettitalean fructification. Centralconical receptacle is covered with seeds bearing portion and microsporophylls had finger appendages with microsynangia. **6.** *Pentoxylon sahnii* C.S. stem with 5-6 endo centric stele. **7.** A reconstruction of a male fructification *Sahnia nipaniensis.* **8.** A reconstruction of a female cone *Carnoconites compactus* arising on an axis.

Abbreviation- BIN-Basal portion of integument, NS- Nucellar stalk, N- Nucellus, E- Embryo (dicot), NP- Nucellar plug.

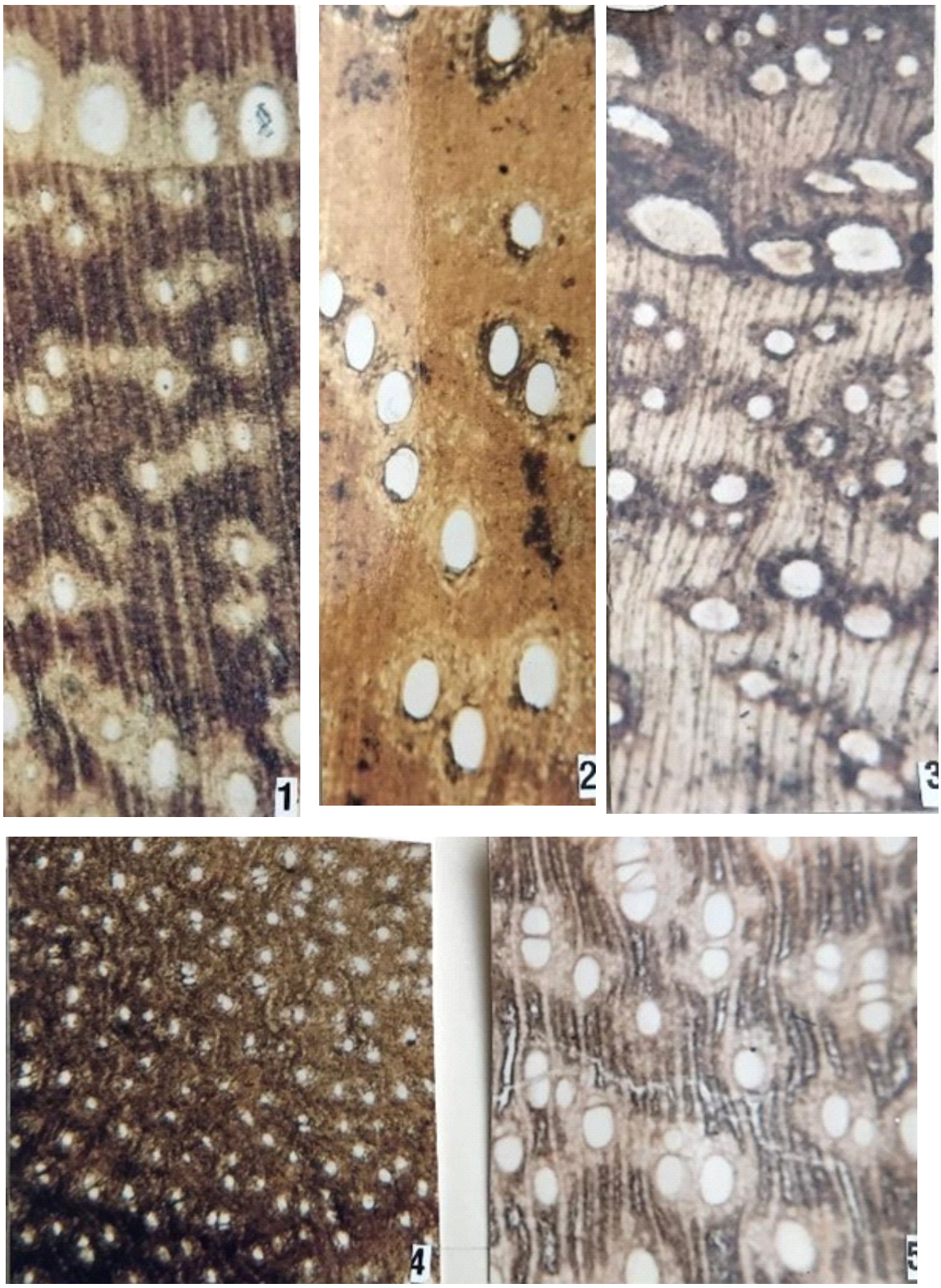

Figure 5 (1-5): Cross section s petrified woods from the Eocene of Bikaner (Rajasthan.) **1. & 3.** *Lagerstroemioxylon sahnii.* **2.** L. obliquoporatum **4.** *Anogeissoxylon harsolavense* **5.** *Terminalioxylon sharmai.*

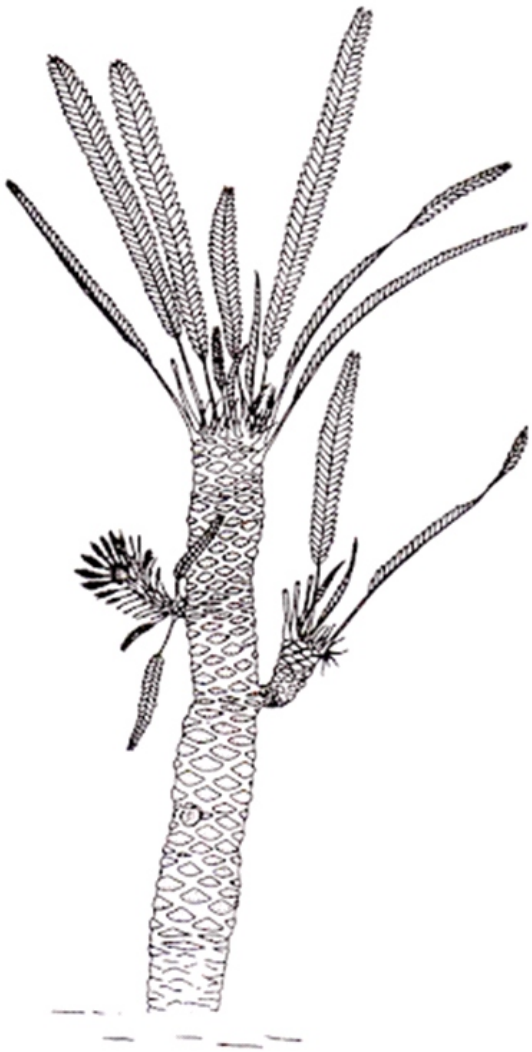

Figure 6: *Williamsonia sewardiana* Sahni- A reconstruction suggested by Sahni (1932a).

Sen Gupta (1988) published a review on fossils of the Rajmahal Hills and described only impressions like *Equisetum rajmahalense, Marattiopsis macrocarpa, Todites williamsoni, Gleichenites* sp. *Sphenopteris* sp. *Plecopteris* sp. etc.

Vishnu Mittre (1954) described an account of petrified spores and pollen grains seen in the thin slides of Nipania chert. Sah and Jain (1965) studied by maceration technique a bore hole sample obtained from a well near Mirzachouki area of the Rajmahal Hills and identified a number of spores of pteridophytes and pollen grains of gymnosperms. Sharma and Suthar (1996) described petrified spores and pollen grains in thin section of Nipania chert. Sharma (2017b) described a petrified specimen of a cylindrical fern gametophyte with fertile structures in a section of Nipania chert.

Gymnosperms– Fossil of gymnosperms are known from majority of Palaeozoic, Mesozoic and Tertiary Stratas of India. The Palaeozoic Era includes Lower Gondwana system and have yielded a large number of fossil gymnosperms generally in coal and carbonaceous rocks e.g. Raniganj, Jharia, Meghalaya, Nagpur etc. The *Glossopteris* flora dominated the vegetation including the leaves like *Glossopteris, Gangamopteris, Palaeovittaria, Rhabdotaenia* etc. For detail please see Surange et al (1974). Surange and associates at BSIP Lucknow, Pant and students at Allahabad university, Sen and Banerji Calcutta university etc. did enough work on the *Glossopteris* flora of India. Saksena and Lele studied South Rewa Gondwana basin and collected in addition to *Glossopteris* flora also the fossil *plants* of *Phyllotheca* (sphenopsid) and *Parsorophyllum* etc. and name the area Middle Gondwana land (Saksena 1952, Lele 1956, 1961, 1969). The Upper Gondwana ranges from Middle Triassic to Lower Cretaceous i.e. between the two-ice age (Triassic & Cretaceous). It includes Mahadeva Kota, Rajmahal Hills, Jabalpur and Cutch deposits. The dominating plants were Pteridosperms, Cycads, Bennettitales, Pentoxylales and conifers including Taxads. The pteridosperms included leaf genera like *Thinnfeildia* (*T. indica* Feist., *T. khatangiensis* Sen Gupta, *T. chunakhalensis* Sah & Sukhdev etc.) For detail please see Srivastava (1974) and Bose & Banerji (1984). Presence of a fruit *Caytonia indica* was also reported from Cutch. They also described several species of the frond *Pachypteris* from Kachchh (Cutch).

Cycads – From the Rajmahal Hills cycadean fronds, stems, petioles, leaflets and fructifications have been described. Oldham and Morris (1863), Feistmantel (1877) described the cycadean fronds *Pterophyllum*

(=*Nilssonia*), Cycadites, *Taeniopteris* etc. from this area. Seward (1917), Seward and Sahni (1920), Sahni and Rao (1933), Ganju (1946) Gupta (1969), Sharma (1969a) etc. used the name *Nilssonia* for *Pterophyllum* like fronds for want of preservation of epidermal and stomatal structures. *Pterophyllum* is a bennettitalean frond (stomata syndetocheilic) while *Nilssonia* has haplocheilic stomata (cycadean structure). Bose (1974) and Sen Gupta (1988) preferred to use the name *Pterophyllum* for *Nilssonia* while others noted above the name *Nilssonia.* There is need of discovery of petrified or incrustations of these two taxa for correct identification.

***Cycadites* –** Impressions of the frond occur in many localities of the Rajmahal Hills. Oldham & Morris (1863) described *C. rajmahalensis, C. conferta* and *C. blanfordi.* Feistmantel (1876) created *C. cutchense* from Cutch. Other fossil cycadean fronds are *Taeniopteris, Macrotaeniopteris, Morrisia* etc. a number of species are known of *Taeniopteris* like *T. spatulata, T. dansinervis, T. dantata, T. ensis* etc. from Nipania material. Sahni (1948) changed the name to *Nipaniophyllum raoi.* Seward (1917) used the name *Nilssonia rajmahalense for Cycadites rajmahalense.* Bose (1968a) described a poorly preserved specimen of *C. rajmahalense* while Sharma (1969a) had used much better specimens of this frond.

Stems – Gupta (1960, 1971) published an abstract in Indian Science Congress (1960) and a full paper (1971) on *Sewardioxylon sahnii* in which there are two opposite rings of collateral, conjoint and equally developed bundles, medullary bundles many of different sizes, cortical bundle present. Sharma (1971a) published further observations on *S. sahnii* and made a three-dimensional anatomy of the stem. Jain (1964) described an another petrified cycadean stem *Facisvarioxylon mehtae* from Amarjola in which the bundles were of unequal sizes. Medullary and cortical bundles were also of different sizes. In 1972 Jain called Sewardioxylon *sahnii* a junior synonym of F. *mehtae,* probably not justified. Sharma (1973) described the anatomy of a petiole *Cycadenorachis omegoides.* Suthar et al (1986) published further observations on this rachis on the basis of much better preserved and examined slides. Sharma *et al.* (2006) published anatomy of new cycadean stem, petiole and leaflet from the Rajmahal Hills. These are *Manomesarchioxylon heptaxylica* (stem), *Stangeriorachis heterospinulata* (petiole), and *Macrozamiphyllum mucilagica* (leaflet). All had peculiar anatomical characters. Cycadean monolete pollen grain are also seen in slides prepared of petrified cherts (Sharma and Suthar 1996). Ganju (1947) described an impression of a seed-bearing fructification *Baeniopsis rajmahalense,* a male fructification *Ontheaanthus polyandra* (1947a) which was later on changed to *Weltrichia polyandra* by Sitholey and Bose (1970). In 1947b Ganju described another seed-bearing fructification *Ontheostrobus sessilis.* All were poorly preserved specimens and need further investigations.

Bennttitales - These plants survived in the world from Middle Triassic to Early Cretaceous. In morphology they looked like cycads but quite different in anatomy, epidermal characters and fertile structures. Fossil representative are leaves, stems and fructifications.

Leaves– There are many taxa like *Ptilophyllum, Pterophyllum, Otozamites, Dictyozamites Anomozamites* etc.

Ptilophyllum Morr. - It is common in entire Upper Gondwana system. It was established by Morris (1840) collected from Cutch. He identified two species *P. acutifolium* and *P. cutchense.* Feistmantel (1877) created *P. brachyphyllum* and *P. tenerrimum* from the Rajmahal Hills. Sharma (1967) published a review on this taxon. Similarly, Bose and Kasat (1972) published another review on this taxon. Leaf is pinnate, pinnae attached on upper surface of rachis (Fig.2.1-3) veins many, parallel with few bifurcations. Stomata abaxial, syndetocheilic and restricted between

veins. Rachis has double U-shaped arrangement of opposite, collateral and conjoint bundles.

Pterophyllum Brong. Its leaf is pinnate, pinnae larger than thoseof *Ptilophyllum,* veins parallel with dichotomies. Many workers correlated to the cycadean frond *Nilssonia* Brong. For detail please see Bose (1974) and Sen Gupta (1988).

Otozamites Braun. – It resembles *Pterophyllum* in morphology but the pinnae have auriculate bases and veins diverging and dichotomized. Important species are *O. bengalensis, O. angustatus, O. hislopii, O. parallelis, O. rarenervis* etc. (Bose 1974, Bose & Zeba Bano 1981).

Dictyozamites Oldh. – Leaf pinnate with linear pinnae, base auriculate, venation reticulate, stomata syndetocheilic rachis has anatomy more or less identical to that of *Ptilophyllum* (Bose & Kasat 1972a, Bose & Zeba Bano 1979). Important known species are *D. falcatus* Oldh., *D. indicus* Feist., *D. hallei* Sahni and Rao, *D. bagjorensis* Jacob, *D. sahnii* Gupta & Sharma.

Anomozamites Schimper – Leaf small sized, pinnae unequal in width, parallel venation with few dichotomies, outer margin truncate or incised. Important species are, *A. fissa* Seward and Sahni, *A. amarjolense* Sharma *et al.*(Fig.2.4)

STEMS – Stem taxa are *Bucklandia* Presl. And *Sahnioxylon* Bose and Sah. ***Bucklandia*** – Its stem surface has rhomboid, spirally arranged leaf bases. Seward (1900, 1917) described the anatomy of *B. indica* Sew. Bancroft (1913) studied anatomy of Indian species of Bucklandias and noted important features. Pith and cortex large, number of bundles many in the vascular zone, endarch and have well developed secondary wood. Bose (1953) described *B. sahnii*(Fig.1.1-3) Sharma (1967a) established *B. guptai* in which leaf bases were rhomboid and distinct. Wood compact and well developed. In 1970c a new species *B. dichotoma* was established by Sharma (Fig. 1.4). Its anatomy was distinct, trcheids had spiral, scalariform and pitted types of thickening. Pit pores were elliptical and cross shaped identical to those of *Homoxylon rajmahalense* or vessel-less angiosperms. Phloem was well preserved and had distinct, uniseriate sieve plates with sieve pores.

***Sahnioxylon* (*Homoxylon*)** – Sahni received a decorticated wood with distinct growth rings from G.S.I. In anatomy Prof. Sahni found it peculiar i.e. presence of multiseriate pits having elliptical to cross shaped pits pore identical to those of vessel-less angiosperms, so he called the wood *Homoxylon rajmahalensis* (Sahni 1932). Gupta studied vessel-less angiosperms and cycadeoidias and found (Gupta 1934) that *Homoxylon* is closer to cycadeoidias than vessel-less angiosperms. Hsu and Bose (1952) also expressed a similar opinion. Bose and Sah (1954) also studied *Homoxylon* again and changed the name to *Sahnioxylon rajmahalense* on the advice of H N Andrew, (USA) because the name *Homoxylon* had already been used for a fossil conifer wood. Bose and Sah (1954) also established a new species *S. andrewsii.* It needs further investigations. Sharma *et al.* (2013) have restudied the anatomy of Indian bennettitalean woods.

FRUCTIFICATIONS– Seed bearing *Williamsonia* Carruthers, male fructification *Weltrichia* Braun are known from the Indian Mesozoic rocks. Sharma (1969) described further studies on *W. santalensis* collected from Sakrigalighat and established a new species (male) *W. campanulatiformis* collected from Dhokuti. Sharma (1970) described the structure of *Williamsonia* cf *W. scotica,* vascular organization of receptacle (Sharma 1970a) and seed structure (Sharma 1970b) (Fig. 4.3). He reported presence of pollen chamber (Sharma 1974), ovule ontogeny in *Williamsonia* (Sharma 1974a) and fruit development (Sharma 1976). In *Willamsonia* orthotropus ovules are intermingled with interseminal sterile scales (Fig.4.2 & 3.5). Sharma (1979) also reported presence of archegonia in *Williamsonia* ovule. Sharma (1977) published an illustrated review on

Indian *Williamsonia.* Further he published papers on morphology and biology of reproduction in *Williamsonia* (1984), Morphology of bennettitalean fructifications (Sharma 1990), Indian Williamsoniaceaen overview Sharma (1992), Studies on *Williamsonia* Sharma (2014b). From India a number of species of *Williamsonia* have been described as given below-

W. blanfordi Feist (1876)
W. microps Feist (1877)
W. ef. gigas Feist (1877)
Williamsonia indica Seward (1917)
W. sewardiana Sahni (1932a)
W. sahnii Gupta (1943)
W. harrisiana Bose (1968)
W. guptai Sharma (1968)
W. amarjolense Sharma (1968)
W. seniana Bose & Kasat (1969)
W. kakadbhilensis Bose & Banerji (1984)
W. trambauensis Bose & Banerji (1984)
W. sukhpurensis Bose & Banerji (1984)
Weltrichia Braun male
W. (*Williamsonia*) *santalensis* Sitholey & Bose (1953) (Sharma 1969) (Fig. 4.4)
W. (*Williamsonia*) *companulatiformis* Sharma (1969)
W. harrisiana Bose & Banerji (1984) Bisexual
Amarjolia dactylota (Bose) Bose *et al.* (1984) (Fig. 4.5)
Sharma (1982) related and derived *Williamsonia* from the Cordaitalean fructification *Cordaianthus via, Wielandialla* via and *Williamsoniella* but it is more hypothetical than the actual process. It is not final and needs further investigations.

Pentoxylales – This is an interesting group of Mesozoic gymnosperms, established by Sahni (1948) on the basis of anatomical studies and fertile structures. The material was collected from the locality Nipania in the Rajmahal Hills. This group includes-
Stem- *Pentoxylon sahnii* Sriv. (1946) (Fig. 4.6)
Nipanioxylon guptai Sriv. (1946)
Guptioxylon amarjolense Sharma (1969)
G. endocentrica Sharma (1972a) (in French)
Purioxylon jurassica Sharma (1972a)
Leaves- *Nipaniophyllum raoi* Sahni (1948)
N. hobsonii Bose et al (1985)
N. anomozamoides Sharma (1975)
N. sahnii Vishnu Mittre (1957)
N. hirsutam Bose & Sukhdev (1959)

Male fructification: *Sahnia nipaniensis* Vishnu Mittre (1953) (Fig. 4.7)

Seed fructification: *Carnoconites compactus* Sriv. (1946) (Fig. 4.8)
C. laxum Sriv. (=*C. rajmahalense* Wieland) Bose *et al.* (1984)
There are many mis-understanding about the distribution of the Pentoxyleae viz. Harris (1962, 1982), collected Pentoxyleae from New Zealand, White (1981) from New South Wales (Australia), Driman and Chambers (1985) from Australia, Cesari *et al.* (1899) from Antarctica. All these references are based on impressions or incrustations as such, the anatomy remains unknown whereas, the Pentoxyleae was established on anatomy of stem, leaves and fertile organs (Sharma 2001). Sharma (2003) criticized Cesari *et al.* (1998) paper on the presence of *Carnoconites* like cones in Antarctica. Please see Sharma *et al*. (2010) for detail.

Ginkgoales – Impressions of *Ginkgo* like leaves are known from several localities of Indian Mesozoic Strata. Sah and Jain (1965) established the new species *Ginkgoites rajmahalense* for the leaves and also identified *G. hutton* Seward on the basis of segmentation of lamina of leaves and venation pattern. Our knowledge is incomplete and further investigations are required (Sharma 1975).

Conifers – Fossils of these plants occur frequently in the Mesozoic strata of India. Lower Gondwana and the Tertiary Horizon also preserve some of the woods and twigs, but there is no comparison of the Mesozoic rocks specially of the Rajmahal Hills. For detail kindly see Bose and Maheshwari (1974) and Harsh *et al.* (2018) in Nelumbo (BSI Journal).

Fossil conifers occur in form of woods, twigs, fructifications and pollen grains. Woods of *Mesembrioxylon, Podocarpoxylon, Propodocarpoxylon, Coniferocaulon, Cupressinoxylon, Dadoxylon, Araucarioxylon, Taxaceoxylon* etc. Twigs are *Elatocldus, Indophyllum, Brachyphyllum, Allocladus,* etc. The fructifications are *Stachyotaxus, Nipaniostrobus, Nipanioruha, Mehtaia, Sitholeya,* and *Araucarites.* Isolated petrified seeds and pollen grains were also described from the Mesozoic Horizon of India (Suthar et al 1988, Fig. 3.7,8). Further investigations are required on fossil representatives of conifers from the Indian rocks.

Angiosperms – Upper Cretaceous, Tertiary and Pleistocene exposures of India possess extinct angiosperms. Some of the Early Cretaceous localities like Nipania, Amarjola and Sonajori of the Rajmahal Hills have yielded primitive angiosperms i.e. fructifications like *Lesqueria* (Fig. 3.9) of Magnoliales (Sharma 1997). From Nipania locality a cross section of a monocot leaf was also described by Sharma et al (2001). Banerji (2000) had also described the presence of some angiospermic fructifications, but details were not given as such further investigations are required on the concerned chert. Mohgaon kala and Sausar (near Chhindwara MP) are best localities of petrified woods of both monocot and dicot angiosperms. The locality has also yielded *Azolla intertrappea* Sahni & Rao (1941). In addition to Deccan Intertrappean rocks. Angiospermic fossils have also been collected and described from other places like Bikaner, Mahurajori (Nagpur), Assam, Nagaland, W. Bengal, Himalayan foot Hills, Eastern Coast, Siwaliks, etc. Important workers who did researches on fossil angiosperms include T S Mahabale, S D Chitaley & students, R N Lakhanpal, Uttam Prakash, R. dayal, N Awasthi, Rasmi Srivastava, J S Guleria, B S Trivedi, M Prasad etc. Sahni's monographic work on fossil monocotyledons was completed by Uttam Prakash and published by BSIP Lucknow (1964). In Prof. B M Johri's edited book 'Botany in India' vol 2 the chapter Palaeobotany was written by Venkatachala and Maheshwari (1995). Important center of researches on fossil angiosperms were BSIP Lucknow, Lucknow university, Poona university, Institute of science Nagpur, Jodhpur university, GSI Calcutta, ONGC Dehradun etc. Majority of above-mentioned centers have left either researches on fossil plants as a whole or shifted to other branches say Palynology. Rakesh Harsh is continuing researches on Tertiary woods and Lignite available at Palana, Barsinghsar and Gurha of Bikaner district.

Lower Devonian Rhyne chert - Prof. Lemoigne visited twice the laboratory of Dr. B D Sharma and gave piece of Rhyne chert. Sharma and associates prepared a large number of slides and described Lower Devonian fossil plants like *Rhynia, Aglaophyton, Horneophyton* etc. and added much to our knowledge about these fossil plants. References are given.

Sharma and students have deposited (in majority) the type specimens and slides used for publications at the conservatory (museum) of BSIP, Lucknow.

Teachers and students are now not interested in past history of the plants and basic botany including morphology, anatomy, Taxonomy Phylogeny, reproduction biology etc. May be palaeobotany will finish completely from the syllabi of PG classes and research scholarships by UGC, CSIR, DST etc. funding agencies. There is a dark picture for palaeobotanical studies in India.

We are thankful to all learned Botanist / Palaeobotanist who have helped us in writing this manuscript.

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