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Two new species of *Belemnopteris* Feistmantel from the Lower Gondwana of India

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ABSTRACT. Compressed *Belemnopteris* leaves have been collected from Raniganj Formation of West Bengal, India. Their morphological features and epidermal characters are different from previously described species of the genus. The new specimens are assigned to *Belemnopteris pantii* sp. nov. and *Belemnopteris feistmantelii* sp. nov.

The leaves are characterized by their sagittate or slightly hastate base with tricostate venation having one median costa and two lateral costae. Leaves are hypostomatic. The habit and mode of attachment of *Belemnopteris* leaves are discussed in the light of comparison with certain extant members of the family Araceae that also have stout petioles and hastate or sagittate leaves.

KEYWORDS: *Belemnopteris*, geophilous habit, *Glossopteris*, haplocheilic stomata, tricostate venation, Upper Permian.

INTRODUCTION

The genus *Belemnopteris* was instituted by Feistmantel (1876, 1881) from the Raniganj Formation of the Raniganj coalfields in West Bengal, India. The type species of the genus, *Belemnopteris woodmasoniana*, was illustrated as an arrow head-shaped leaf with the lamina divided into three almost equal triangular lobes. The venation is tricostate having one median costa and two lateral costae. The median costa extends towards the leaf apex while the lateral ones pass down the centre of each lobe. Secondary veins anastomose to form hexagonal to polygonal meshes. Schopf (1970) reported *Belemnopteris* sp. from Upper Permian of Lower Gondwana strata of Antarctica and Lacey van Dijk and Gordon Gray (1975) described *Belemnopteris elongata* from South Africa. Rigby (1978) also reported *Belemnopteris* from Australia. Two more species viz., *Belemnopteris sagittifolia* and *B. pellucida* were reported by Pant and Chaudhury (1977) from the Raniganj Formation of Raniganj coalfield. Recently the present authors have collected several additional *Belemnopteris* leaves from the Raniganj Formation of West Bengal. Their morphological and epidermal features differ considerably from other established species of this genus and are therefore, assigned to two new species viz., *Belemnopteris pantii* sp. nov. and *B. feistmantelii* sp. nov. The habit of the plants and their possible affinities with other glossopterids are also discussed.

MATERIAL AND METHODS

Several compressed fossil *Belemnopteris* leaves were collected from Ardhgram colliery of Bankura district and Damra colliery of Burdwan district in West Bengal, India. The organic matter of the specimens had turned brown due to partial natural oxidation. The external form and venation pattern were examined using strong unilateral illumination under a stereo binocular microscope. Macerated carbonaceous substances were taken out in cellulose acetate pulls, which were subsequently mounted in Canada Balsam (Lang 1926) and studied under transmitted light microscope. Cuticles were prepared by maceration of the leaf substance by concentrated Nitric acid and Potassium chlorate (Schulze's fluid), and mounted in safranin glycerin jelly. The values given after the range of variation are means of thirty readings.

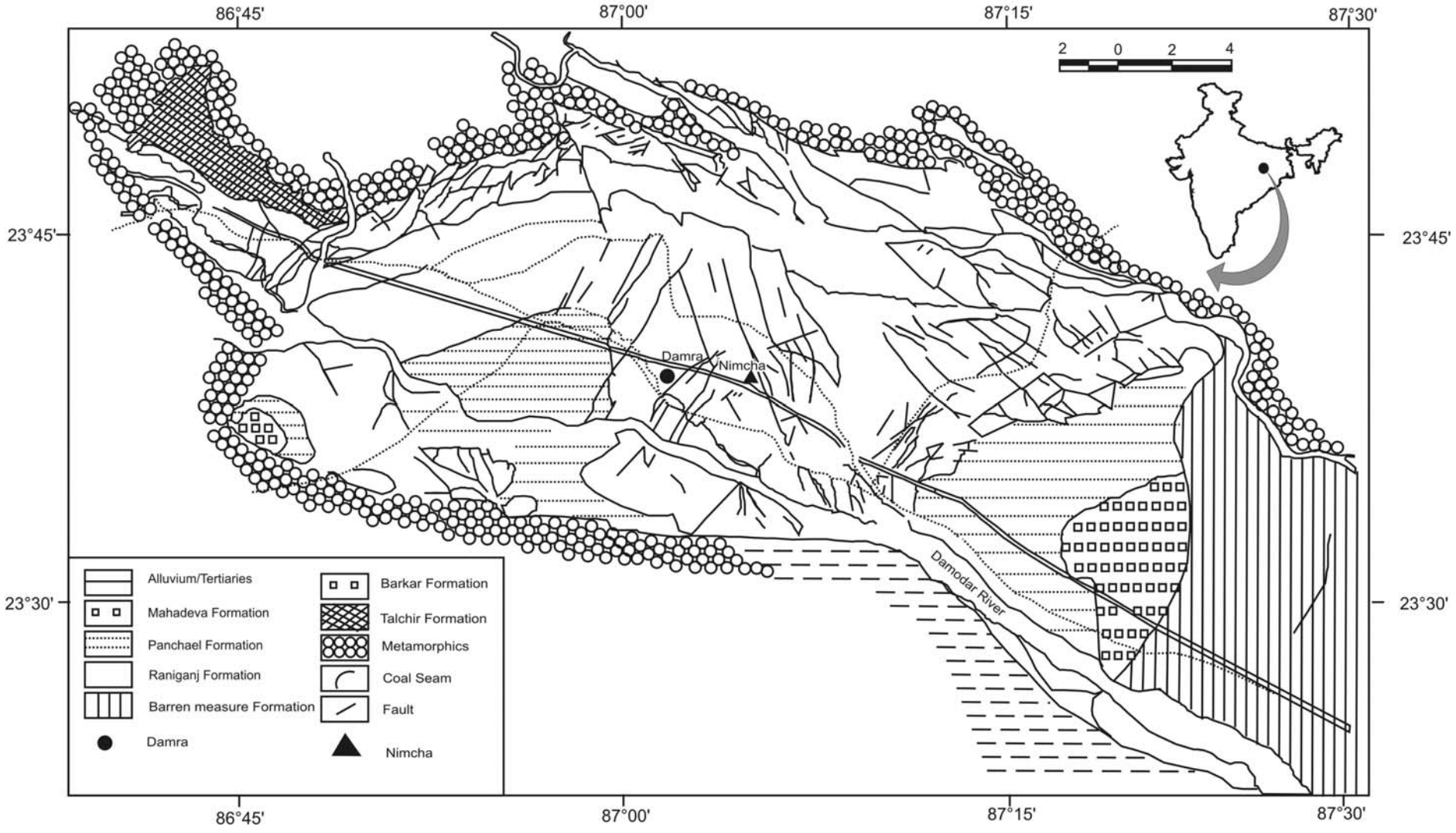

Fig. 1. Geological map of Raniganj coal field showing the fossil localities.

OBSERVATIONS

Belemnopteris pantii sp. nov.

(Pl. 1, fig. 1, Pl. 2, figs. 1–6, Pl. 3, figs 1–2; Figs 2A, 3A-E, 5B)

Diagnosis. Leaves simple, petiolate, base sagittate or hastate, more or less contracted above basal lobes, margins entire or slightly undulate, apex acute. Leaves up to 12 cm long and 4 cm wide. Basal lobes 1.2–2.5 cm long and 1.8–1.9 cm wide (2 cm long × 1.8 cm wide) with acute apex. Median costa 0.4 mm thick near base, evanescent only near apices of basal lobes, lateral costa inserted at an angle of 120° to 125° to the median costa. Secondary veins up to 40 µm thick arising at an angle of 40° from midrib near base, 55° near apex, anastomose to form hexagonal to polygonal meshes. Vein concentration, 9–12 per cm near midrib and 14–20 per cm near margin. Interstitial fibers present between veins. Petiole about 7 cm long and 3 mm thick, showing longitudinal striations. Leaves hypostomatic. Cells of upper epidermis of lamina not differentiated between vein and inter-vein areas. Cells of lower epidermis of lamina differentiated by size and shape between vein and mesh areas. Stomata present only in mesh areas, irregularly oriented, haplocheilic, subsidiary cells generally 5, rarely 6, frequency of stomata 32 per mm^2. Stomatal index 19. Surface of subsidiary cells and their sides towards stomatal pit often thickly cutinized. Guard cells sometimes

Fig. 2. *Belemnopteris pantii* sp. nov. **A** – A cluster of leaves showing hastate leaves and stout petioles directed towards a common point of attachment. Holotype No. 66517, × 0.8

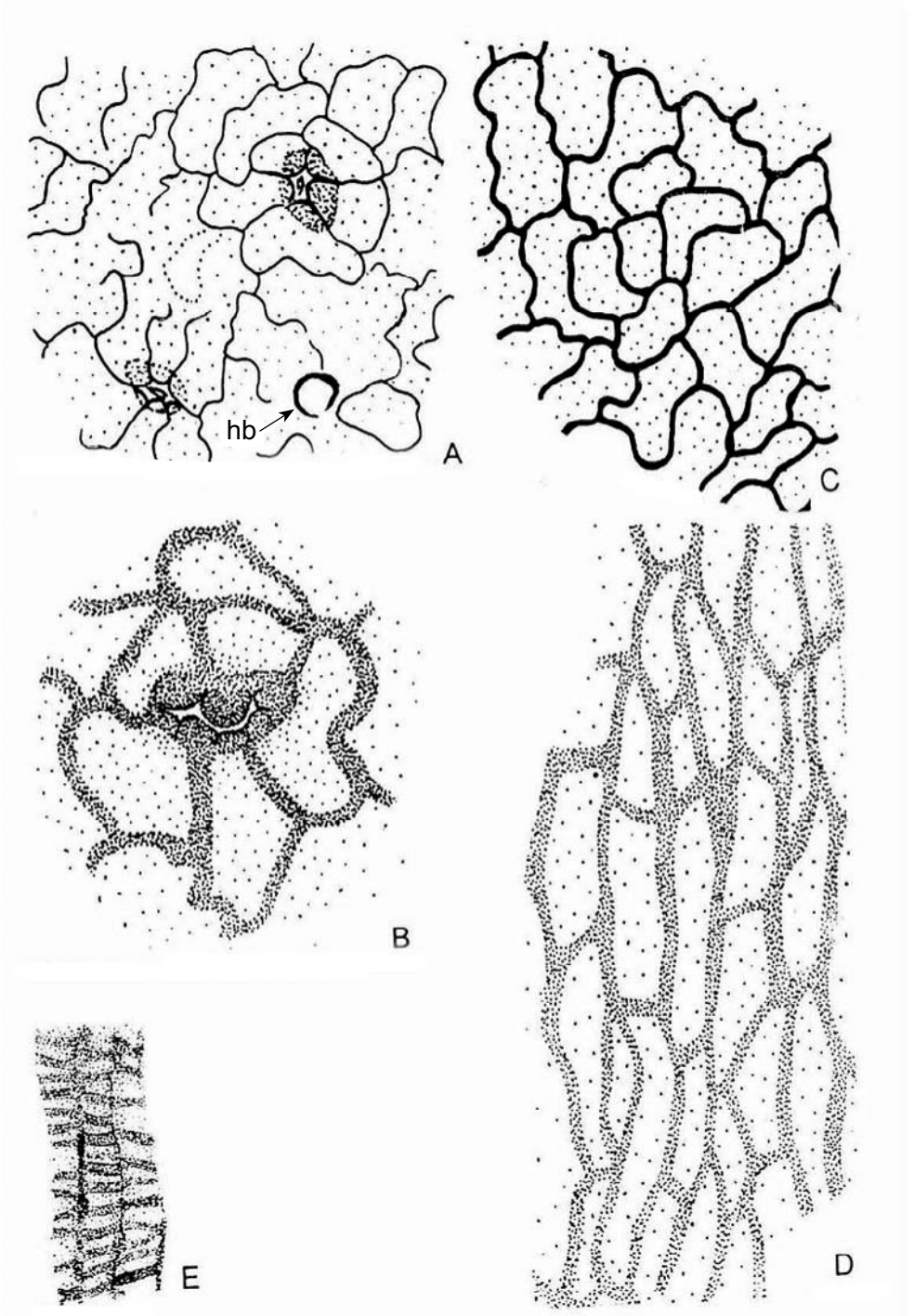

Fig. 3. *Belemnopteris pantii* sp. nov. **A** – Lower epidermis of leaf showing stomata and hair base (**hb),** specimen No. 66517b, × 300; **B** – A stoma further enlarged to show overarching of subsidiary cells, specimen No. 66517b, × 450; **C** – Upper epidermis of the leaf showing sinuous-walled cells, specimen No. 66517d, × 300; **D** – Straight-walled cells over midrib, specimen No. 66517c, × 300; **E** – Tracheids from midrib showing spiral thickenings, specimen No. 66517c, × 600

sunken and protected by thickened papillae of subsidiary cells. Hair bases present. Cells over upper epidermis of midrib rectangular and arranged in longitudinal rows. Stomata rare. Cells over petiole straight walled and rectangular, arranged in files.

Holotype. Specimen No. 66517 of the Agharkar Museum, Department of Botany, University of Allahabad, Allahabad. India.

Locality and Horizon. Nimcha colliery, Burdwan district and Damra colliery, Burdwan district, West Bengal, India. Raniganj Formation, Upper Permian of Lower Gondwana. India.

Etymology. The species is named to honour late Professor D.D. Pant, a great palaeobotanist and an authority on Gondwana fossils.

Description. The species is based on seven leaves, apparently arranged in whorl. The petioles are stout. The actual attachment of the petiole is missing but the apex appears to have emerged from a common point. Interstitial fibers are evident between the veins. Secondary veins anastomosing to form hexagonal to polygonal meshes which are 3–7 mm long × 1.5 mm wide near midrib, 2.0–4.5 mm long × 0.8–1.5 mm wide near margin and 1.0–6.0 mm long × 0.6–1.2 mm wide between midrib and margin. The interstitial fibers are present between veins. Cells of the upper epidermis are not differentiated into vein and mesh areas. Cells are irregularly arranged, which are rectangular to polygonal, 72 µm long 26 µm wide. Cell walls are sinuous, 4 µm thick. The wavelength of cell wall sinuosity is 7.5–20.0 µm and amplitude is 5.0–15.0 µm. Cells of the lower epidermis of the lamina are differentiated into vein and mesh areas. Cells above veins are narrow and rectangular, arranged in files, 20–25 µm long × 10–20 µm wide (60 µm long × 15.5 µm wide) with straight 5 µm thick cell walls. Cells over mesh areas are irregular and polygonal, 45–75 µm long × 20–25 µm wide (64 µm long – 21 µm wide). The cell walls are sinuous and the wavelength of cell wall sinuosity varies from 7.5 to 17.0 µm (12 µm) and amplitude 7–10 µm (9 µm). Cell walls are 2.5 µm thick. The stomata are present only in mesh areas, irregularly oriented and haplocheilic. Stomatal pore are 12.5 to 20.0 µm long × 2.0 to 2.5 µm wide (16.0 µm long × 2.5 µm wide). The guard cells sometimes sunken and protected by thickened papillae of subsidiary cells. The hair bases are present (Pl. 2 fig. 6). Pulls of the midrib often show tracheids, which are about 7.5 µm wide, with scalariform or reticulate thickenings (Pl. 2, fig. 5). The cells over the midrib of upper epidermis are rectangular and arranged in longitudinal rows (Pl. 2, fig. 4), 100–180 µm long × 18–20 µm wide (140 µm long × 20 µm wide). The cells over petiole are straight-walled and rectangular, arranged in files, 120 µm long × 25 µm wide. The cell walls are about 10 µm thick.

Comparison. *Belemnopteris pantii* is quite different from *B. woodmasoniana* in its external morphology. In the later, the basal lobes

Table 1. Showing comparative characters of various species of genus *Belemnopteris* Feistmantel

Name of the species	Size of leaf (in cm)	Shape of leaf	Apex	Ratio between Lamina and basal lobes	Thickness of lateral costae (µm)	Concentration of veines/cm		Size of epidermal cells (in µm)		Sinuosities of epidermal cells (in µm)		Stomatal frequency (per mm)	Stomatal index	Avarage size of stomatal pore (in µm)	Interstitial fibres between veins	Hair base
						Near midrib	Near margin	Upper epidermis	Lower epidermis	Amplitude	Wavelength					
B. wood-masoniana Feistmantel	10.5×5.5	Cordato sagittate	Obtuse	1:1	–	6–8	6–8	–	–	–	–	–	–	–	–	–
B. sagitifolia Plant & Chaudhury	5 to 16×0.4 to 7.5	Sagittate or rarely hastate	Acute	4–6:1	124–207	6–13	10–18	107×52.5	104.5×45.5	15.5	31–39	9	5	39.5×7.5	Absent	Absent
B. pellucida Plant & Chaudhury	16×5 to 7.5	Cordato sagittate	Acute	–	88–130	8–9	9–12	112×43	82.5×45.5	7	31–33	24	9	31.5×7	Absent	Absent
B. pantii sp. nov.	12×4	Sagittate or slightly hastate	Acute	6:1	300	9–12	14–20	72.5×26.5	64×21	9	7.5–17.5	32	19	16×2.5	Present	Present
B. fiestmantelii sp. nov.	20 to 35× 7 to 9	Sagittate	–	4:1	200	10–12	17–18	92×40	72×30	5	15–30	4	–	18×4	Absent	Absent

are as long as the rest of the lamina while in the former the main lamina is about six times longer than the basal lobes. Further, the lateral costae in *B. woodmasoniana* are of the same thickness as the median costa and the meshes are of uniform shape and size through out the lamina, but in *B. pantii* the lateral costae are much thinner than the median costa and the meshes are of different shape and size near the midrib and margins of lamina. Further comparison is not possible because the structural details of *B. woodmasoniana* are unknown.

A comparison of *Belemnopteris pantii* sp. nov. and *B. sagittifolia* shows that the leaves of both species are more or less similar in external morphology and venation pattern but are different in epidermal characters. In *B. pantii* sp. nov., the subsidiary cells are papillate and arranged like other epidermal cells whereas subsidiary cells of *B. sagittifolia*, are arranged in a ring and the epidermal cells are mottled but such mottles are absent in *B. pantii* sp. nov. Hair bases and interstitial fibers are also absent in *B. sagittifolia*. *B. pantii* sp. nov. also differs from *B. pellucida* in external form, venation pattern and epidermal characters (see Table 1).

Belemnopteris feistmantelii sp. nov.

(Pl. 3, fig. 3, Pl. 4, figs 1–2, Pl. 5, figs 1–6; Fig. 4, A–E)

Diagnosis. Leaves simple, petiolate, slightly contracted above basal lobes, margin undulated, base sagittate. Leaves up to 20 cm long × 7.0 cm wide, basal lobes 4.8–5.0 cm long × 2.9–3.0 cm wide. Median costa 1.5 mm wide near base persisting to apex. Lateral costae 0.2 mm thick near base, inserted at an angle of 120°–140° with midrib. Apices of basal lobes obtuse or acuminate. Secondary veins 30 µm thick arising at an angle of 55° from midrib near base and 70° near apex, anastomosing to form hexagonal meshes to polygonal meshes. Vein concentration 10–12 per cm near midrib and 17–18 per cm near margin. Leaves hypostomatic. Upper epidermal cell of lamina not differentiated into vein and mesh areas. Lower epidermis of lamina differentiated into vein and mesh areas.

Holotype. Specimen No. 66521 of the Agharkar Museum, Department of Botany, University of Allahabad, Allahabad. India.

Locality and Horizon. Nimcha colliery of Burdwan district, West Bengal, India. Raniganj Formation of Lower Gondwana (Upper Permian), India.

Etymology. The species is named in honour of Ottoker Feistmantel who started work on Gondwana fossil flora of India and created this genus.

Description. The species is based on two leaves. The leaves are arrowhead shaped with well-developed basal lobes. The basal lobes constitute about one fourth of the lamina length. The lamina is slightly contracted just above the basal lobes. The median costa is grooved and projected towards the lower surface of the leaf. Petioles are not always exposed on splitting the shale and whenever the petioles are present they are seen slopping up or down from the bedding plane of the lamina. It appears that the lamina stood in the life at an angle to the petiole. Meshes of secondary venation are 6.0 mm long × 1.8–2.0 mm wide near midrib, 2.5 mm–3.0 mm long × 0.8 mm–1.0 mm wide near margin and 5.0 mm–6.0 mm long × 1.0 mm–1.5 mm wide between midrib and margin. Leaves are hypostomatic. Upper epidermal cells of the lamina are not differentiated into vein and intervein areas. Cells are irregularly arranged, rectangular to polygonal, 50–125 µm long × 30–50 µm wide (90 µm long × 40 µm wide). Cell walls are sinuous and about 4.0 µm thick. The wavelength of cell sinuosity is 20–25 µm (22 µm) and amplitude 5.0–7.5 µm (6.0 µm). The lower epidermis of lamina is differentiated into vein and mesh areas. Cells of the vein area are narrow, rectangular and arranged in files, 35–115 µm long × 15–30 µm wide (76 µm long × 18 µm wide). Cell walls are straight, 5–6 µm thick. The cells over mesh areas are irregular and polygonal, 35–140 µm long × 20–45 µm wide (72 µm long × 30 µm wide). The cell walls are sinuous, with wavelengths of cell wall sinuosity vararying from 15–30 µm (26 µm) and amplitude 3–8 µm (5 µm) with the cell wall being 5 µm thick. Stomata is present only in mesh areas which are irregularly oriented, haplocheilic, stomatal pore 10–28 µm long × 3–5 µm wide (18 µm long × 4 µm wide). The subsidiary cells are usually 5, rarely 6 in number, like ordinary epidermal cells. The stomatal frequency is 4 per mm^2. Pulls of the midrib region show tracheids about 7.5 µm wide, which show scalariform, reticulate or pitted elements. The epidermal cells near midrib are straight walled,

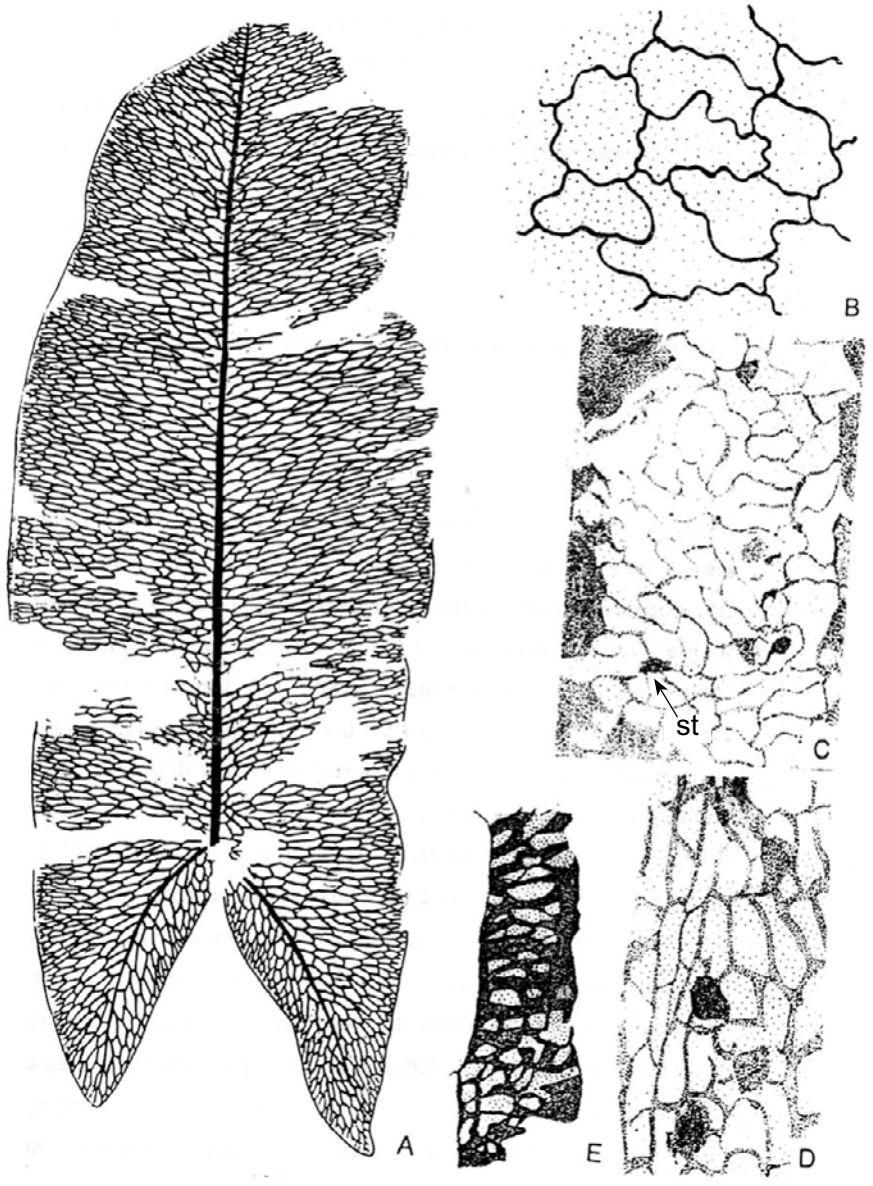

Fig. 4. *Belemnopteris feistmantelii* sp.nov. **A** – A leaf showing venation. Holotype 66521 × 1.3. **B** – Upper epidermis of lamina showing sinuous-walled cells, specimen No. 66521a, 230; **C** – Lower epidermis of lamina showing stomata (st), specimen No. 66521b,. × 110;. **D** – Upper epidermis near midrib showing straight-walled cells, specimen No. 66521d, × 130; **E** – Tracheids from midrib showing scalariform thickenings, specimen No. 66521c, × 400

gradually becoming wavy and sinuous walled towards the margin. The surface of epidermal cells is not mottled. The cells of upper epidermis over midrib region are trianguloid, thick, straight walled, 75–125 µm long × 20–25 µm wide (85 µm long × 25 µm wide), cell wall about 5 µm thick. The cells over the midrib of the lower epidermis is 50–75 µm long × 12.5–17.5 µm wide (67.5 µm long × 16.0 µm wide), and the wall about 4 µm thick and without stomata.

Comparison. *Belemnopteris feistmantelii* sp. nov. is comparable to some extent with other species of the genus. *Belemnopteris feistmantelii* sp. nov, *B. pantii* sp. nov., and *B. sagittifolia* are similar in shape but *B. feistmantelii* sp. nov. is larger in size than other species. It is also different than *B. pantii* in stomatal frequency and epidermal details (Table 1).

DISCUSSION

Feistmantel (1876, 1881), Arber (1905) and Surange (1966) regarded *Belemnopteris* as a fern. Feistmantel (1876) compared it with two extant ferns, *Hemionites cordifolia* (now *Hemionites arifolia*) and *Pteris sagittifolia*

(now *Doryopteris sagittifolia*). *Belemnopteris* and these two species of ferns are similar only in shape of their leaves, venation pattern and sinuous walled epidermal cells. The cuticles of *Hemionites arifolia* and *Doryopteris sagittifolia* are delicate and the guard cells of the stomata are surrounded by three neighbouring irregular epidermal cells while the cuticles of *Belemnopteri*s are maceration resistant and show haplocheilic stomata with sunken guard

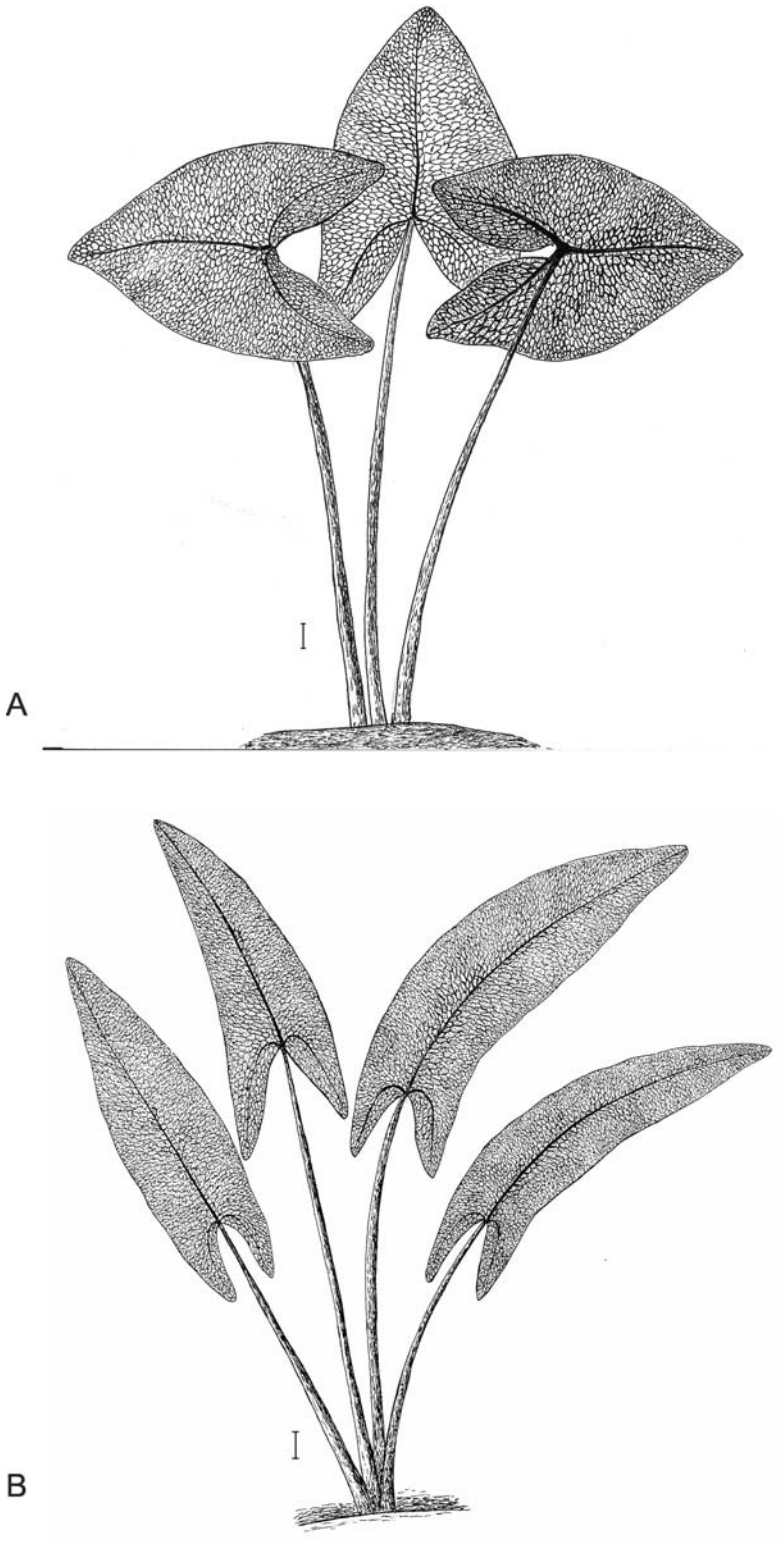

Fig. 5. Suggested reconstructions of the plants of *Belemnopteris.* **A** – *Belemnopteris woodmassoniana* Feistmantel **B** – *Belemnopteris pantii* sp. nov.

cells surrounded by 5–6 thick-walled overarching papillate subsidiary cells. The xylem elements of the midrib show bordered pits, which is an uncommon character in ferns. On the basis of these features Pant and Chaudhury (1977) emended the diagnosis of *Belemnopteris* and suggested it to be a gymnosperm allied to *Glossopteris*. Furthermore, ferns bear sori on the under surface of their leaves while no sori or any other fern like reproductive structure has been reported in *Belemnopteris* leaves. These authors also mentioned that *Belemnopteris elongata* (Lacey van Dijk & Gordon Gray, 1975) has very small basal lobes, which lack tricostate venation and appear like mere outgrowths of the midrib at the base. To accommodate such leaves, which resemble *Belemnopteris* but differ in other characters, Pant et al (1984) and Chauhan (2004) instituted a new genus *Sagittophyllum* and transferred *Belemnopteris elongata* into the new combination *Sagittophyllum elongata* which also included the genus *Surangephyllum* of Chandra and Singh (1986).

Kovacs-Endrody (1990) re-emended the diagnosis of *Belemnopteris* and emphasized the importance of leaf shape, which is arrowhead- or halberthead-like. Other distinctive features of the genus according to Kovacs-Endrody are the presence of a tricostate midrib and secondary venation of the basal lobes arising from both the sides of the lateral costae in contrast to *Sagittophyllum*, where the secondary venation of basal lobes arises from thicker veins along the basiscopic margins in a pedate manner. The secondary veins in *Belemnopteris* are deeply impressed; possibly they were raised on the underside of the leaf.

HABITAT, ECOLOGY AND STRATIGRAPHY

A cluster of seven leaves of *Belemnopteris pantii* sp. nov. whose stout petioles are directed towards a common point of attachment and emerge at an angle suggest a geophilous habit like extant *Typhonium trilobatum*, *Caladium bicolor* and species of *Alocasia* of the family Araceae. Plants of *Belemnopteris pantii* and *B. woodmasoniana* are being reconstructed (Fig. 5A, B) on the basis of the similarities of these leaves with the members of the family Araceae mentioned above. The presence of thin cuticles, naturally macerated substance of lamina and geophilous habit suggest that *Belemnopteris* was a sciophyte and was one of the constituents of the herbaceous and under storey vegetation that had covered the floor of Permian Gondwana forests. Insect eaten leaves of *Belemnopteris* (Chauhan et al. 1985) and the presence of ground dwelling flying blattoids (Pant & Srivastava 1995) during the Permian suggest that these insects had an easy access to low lying leaves of ferns, sphenopsids and some glossopterids and were able to consume living leaves and fructifications of *Glossopteris* and leaves of *Belemnopteris*.

The stratigraphic value of the genus *Belemnoptreris* has been considered by Chauhan & Tiwari (1983). The presence of *Belemnopteris pellucida* (Kovacs-Endrody 1990) in the Ecca Group, South Africa offers additional evidence towards a correlation with the late Permian Raniganj Formation flora of India. The distribution of *Scutum*, *Palaeovittaria*, *Rhabdotaenia* and *Cyclodendron leslii* offers further support to this correlation.

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PLATES

Plate 1

Belemnopteris pantii sp. nov.

1. A cluster of leaves showing hastate bases and stout petioles (**p**) directed towards a common point of attachment, Holotype No. 66517 × 0.7

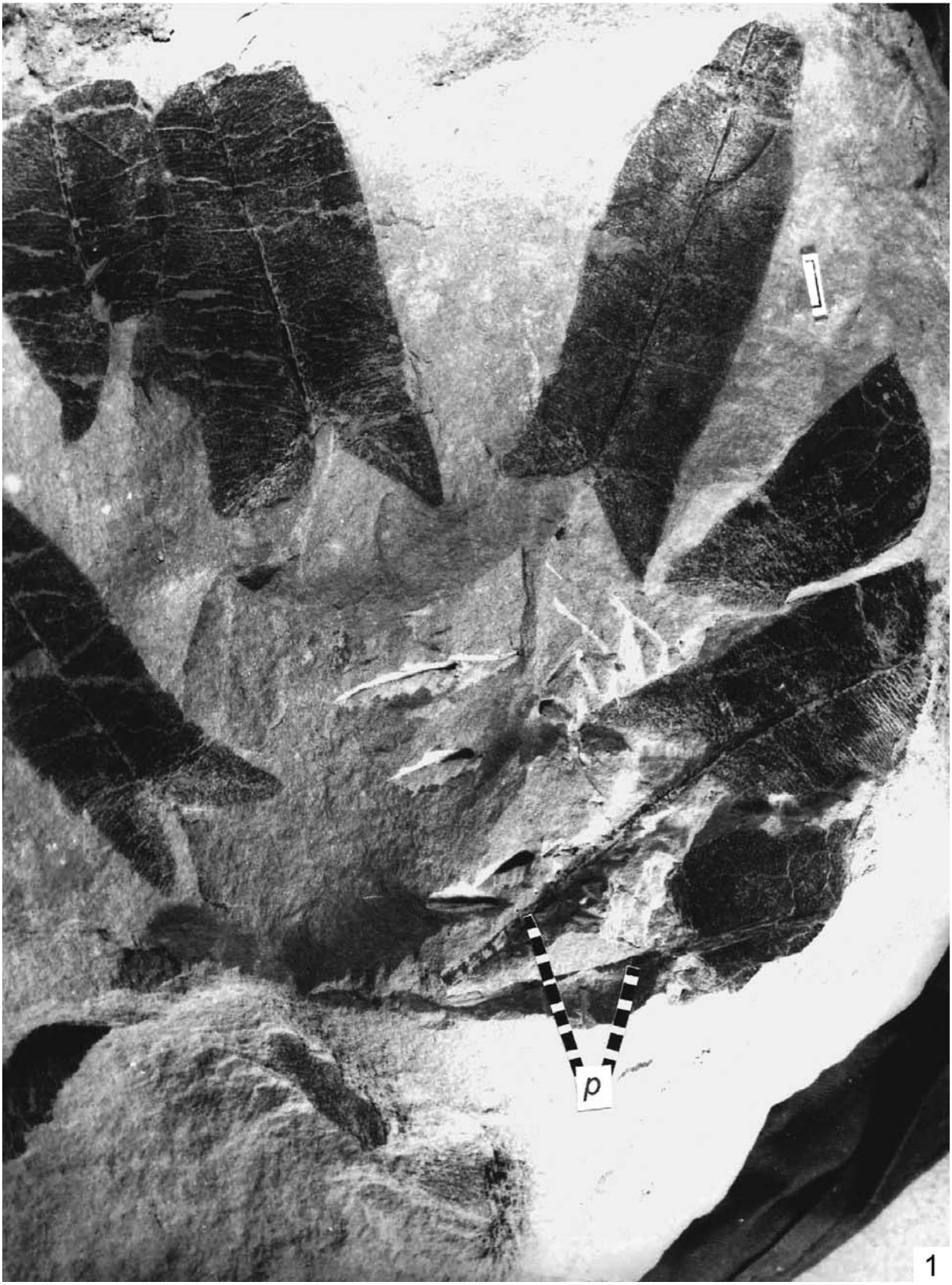
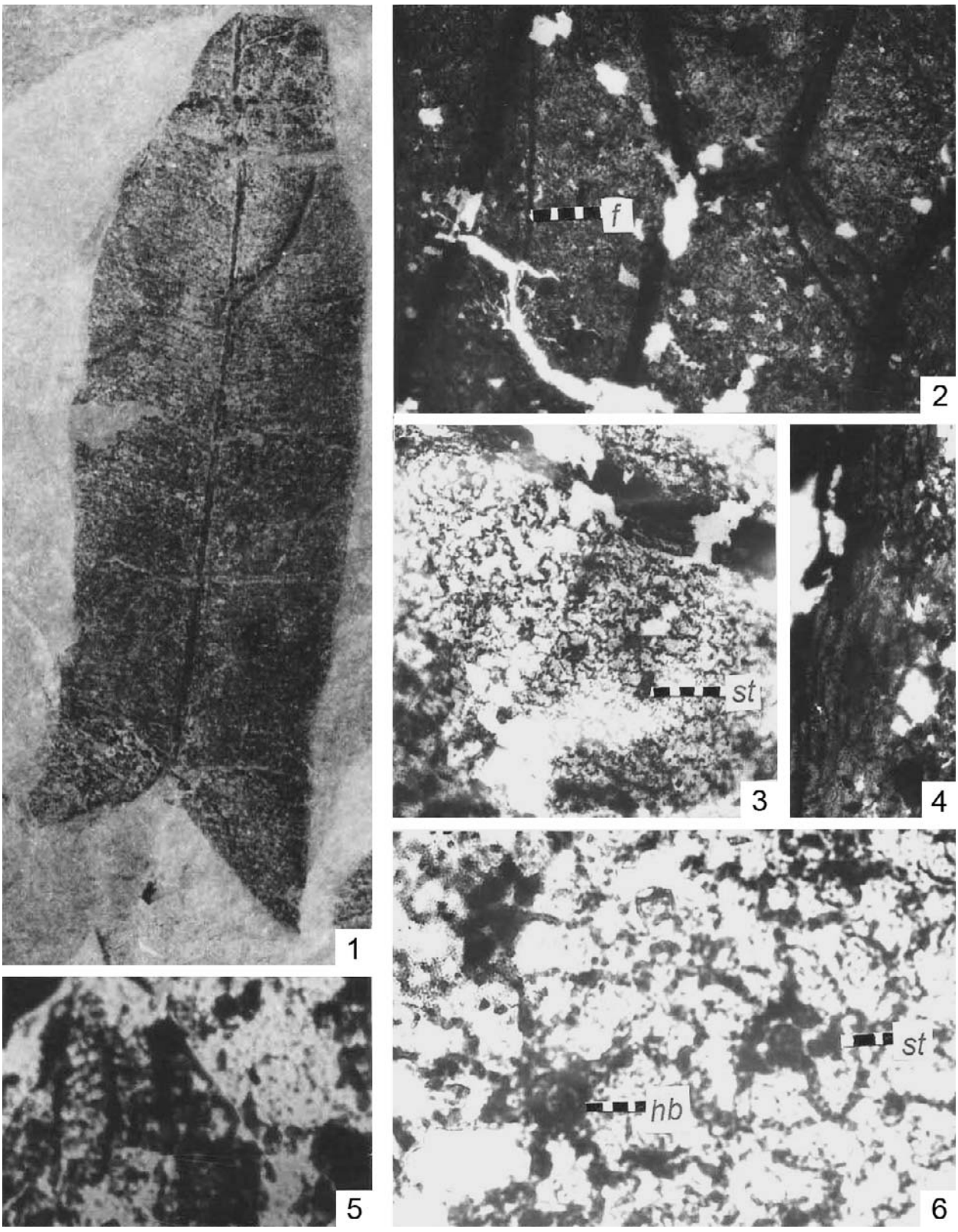

p
1

Plate 2

Belemnopteris pantii sp. nov.

1. A single leaf enlarged to show venation, specimen No. 66517, × 1.2
2. An epidermal pull showing interstitial fibers (**f**) between the veins, specimen No. 66517a, × 62
3. Lower epidermis of leaf showing stomata (**st**) specimen No. 66517b, × 120
4. Straight walled cells over midrib region, specimen No.66517c, × 120
5. Tracheids from midrib region showing reticulate thickenings, specimen No. 66517c, × 600
6. A portion of lower epidermis magnified to show stomata (**st**) and hair base (**hb**), specimen No. specimen 66517b, × 480


f
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6

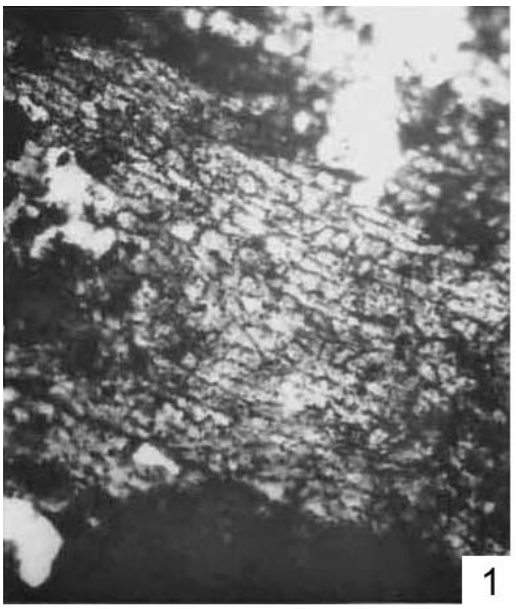
Plate 3

Belemnopteris pantii sp. nov.

1. A portion of epidermis of petiole, specimen No. 66517d, × 125
2. A portion of lower epidermis of lamina showing cells of vein (**v**) and mesh (**m**) areas, specimen No. 66517d, × 120

Belemnopteris feistmantelii sp. nov.

3. A leaf showing venation. Holotype No. 66521, × 1.1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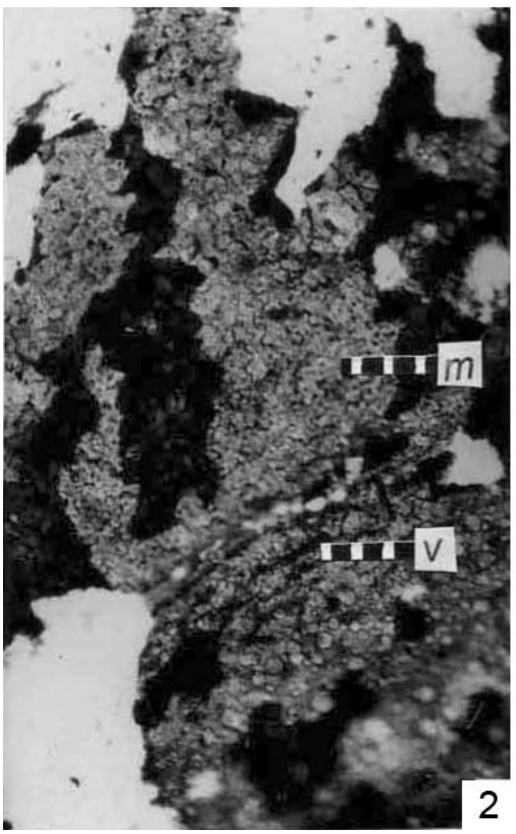
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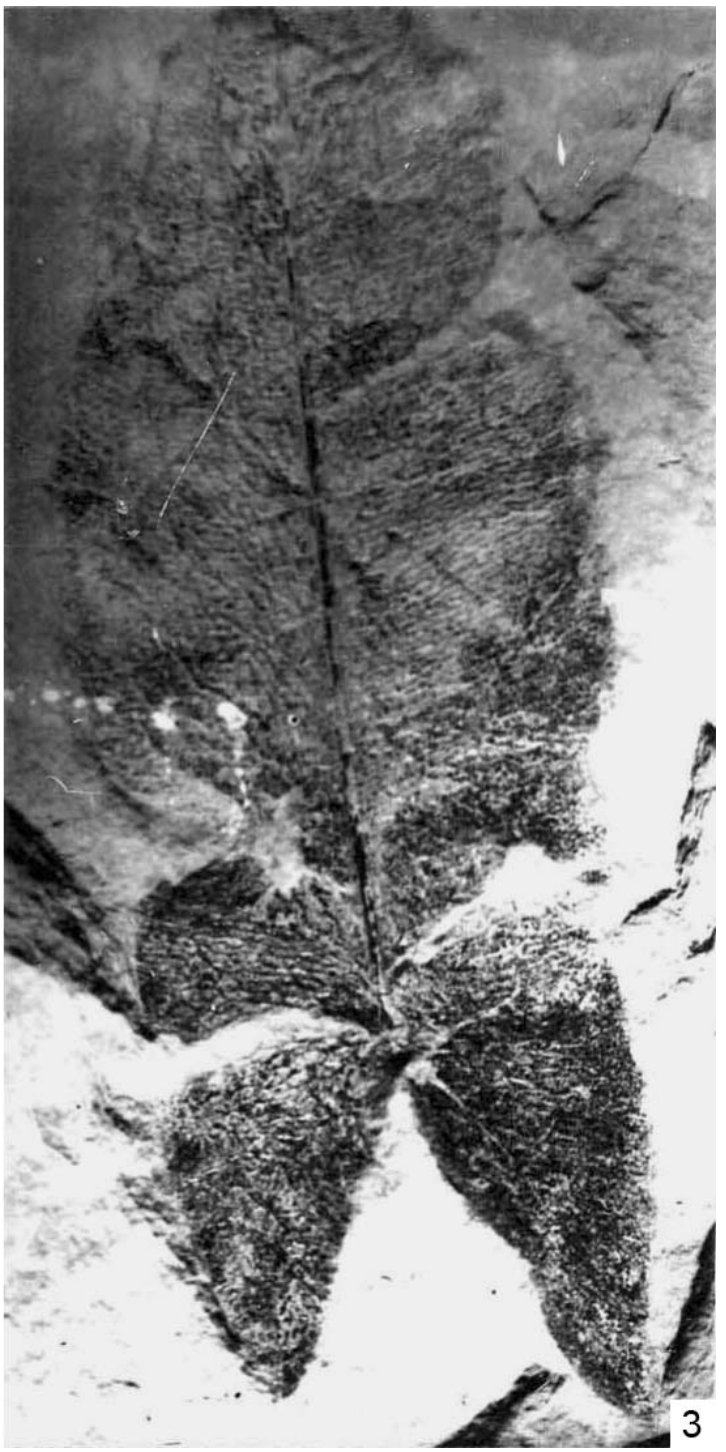
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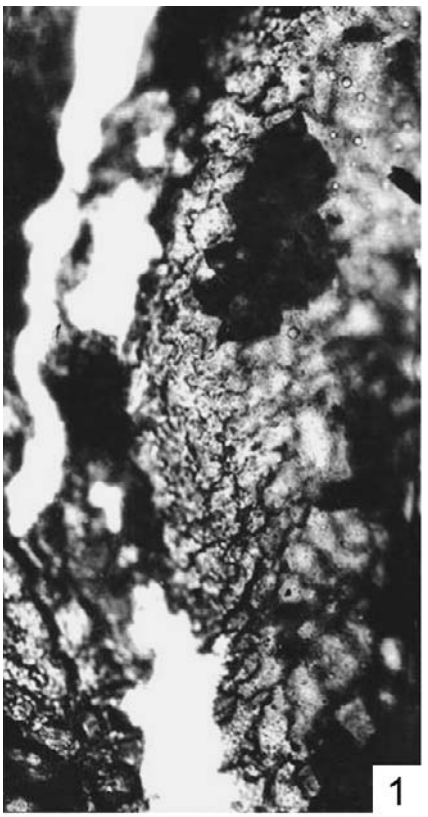
Plate 4

Belemnopteris feistmantelii sp. nov.

1. Upper epidermis of lamina showing sinuous walled cells, specimen No. 66521a, × 120
2. Lower epidermis of lamina showing stomata (**st**), specimen No. 66521b, × 110
3. Tracheids from midrib showing scalariform thickening and pits, specimen No. 66521c, × 480
4. Portion of upper epidermis near midrib showing straight walled and undulated cells, specimen No. 66521d, × 120
5. Lower epidermis of lamina showing stomata (**st**), specimen No. 66521e, × 120
6. A single stoma magnified, specimen No. 66521e, × 480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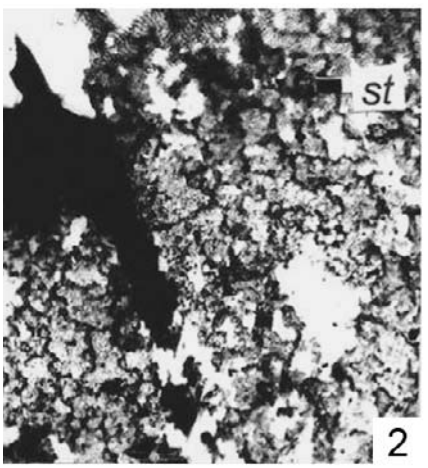
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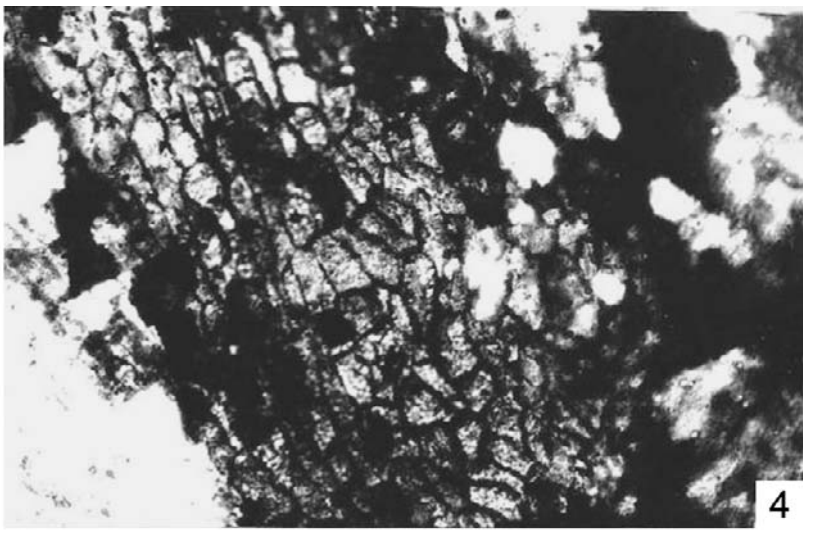
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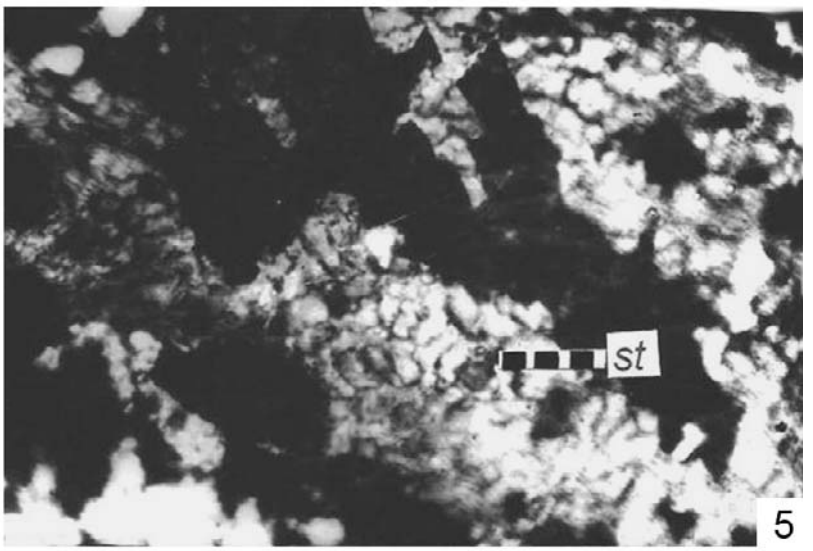
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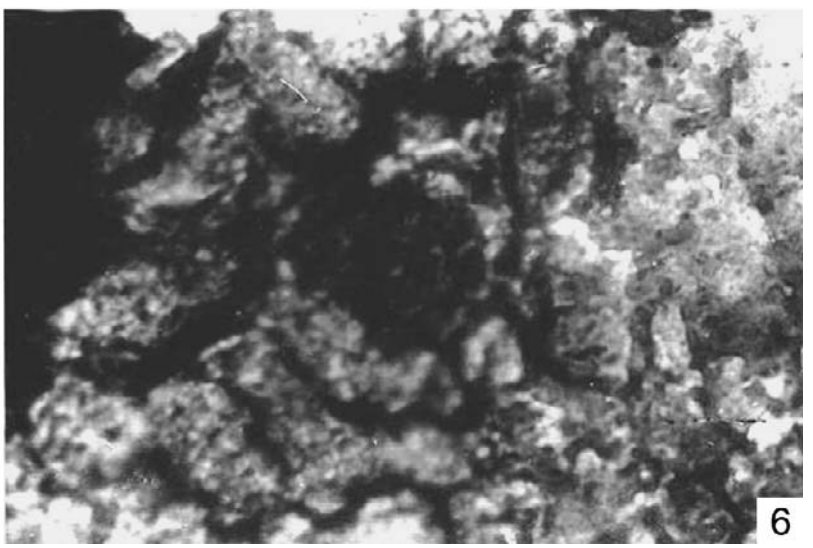
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