

# Studies on some compressed leaves of *Glossopteris* Brongniart from Indian Lower Gondwana

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## ABSTRACT

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The paper deals with the morphological and cuticular details of five new species of *Glossopteris* from the Lower Gondwana of India. The leaves are *G. auriculata* sp. nov., *G. kuardihensis* sp. nov., *G. truncata* sp. nov. and *G. sessilis* sp. nov. collected from the Raniganj Formation of West Bengal and *G. subcostata* sp. nov. from the Karharbari Formation of Maharashtra, India. The leaves of *G. auriculata* and *G. sessilis* are amphistomatic whereas those of *G. subcostata*, *G. truncata* and *G. kuardihensis* are hypostomatic. On the basis of attachment of the leaves, the habit of the *Glossopteris* plant is briefly discussed.

**Key-words:** *Glossopteris*, Karharbari, Lower Gondwana, Permian, Nagpur, Maharashtra, Raniganj, West Bengal.

## INTRODUCTION

The name *Glossopteris* was given by Brongniart (1828) for tongue shaped simple leaves with midrib and reticulate venation. He described and illustrated three leaves of the genus and assigned them to *Glossopteris browniana* var. *australasica*, *G. browniana* var. *indica* and *G. angustifolia*. Schimper (1869) raised the two varieties of *G. browniana* to the species rank and named them *G. browniana* and *G. indica* respectively. Since then, a large number of species of *Glossopteris* have been described across Gondwana countries. Mostly, leaves are described as impressions and compressions but some species are known from permineralized material. The majority of *Glossopteris* leaves are known with exomorphic features but Srivastava (1957), Pant (1958), Høeg and Bose (1960), Lele and Maithy (1964), Maithy (1965, 1968, 1970), Rigby (1966), Pant and Gupta (1968, 1971), Pant and Singh (1971, 1974), Banerjee (1972), Chandra and Surange (1979), Rigby et al. (1980), Chandra and Srivastava (1981), Maheshwari and Tewari (1992), Singh (2000) and Chauhan and Tiwari (2002) described the cuticular

structure with finer details.

Gould and Delevoryas (1977), Pigg (1990), Pigg and Taylor (1990, 1993) and Pigg and McLoughlin (1992) described permineralized leaves of *Glossopteris* from Australia and Antarctica. Recently, Pigg and Nishida (2006) discussed the significance of silicified plant remains of *Glossopteris*. The leaves of *Glossopteris* generally occur in detached state but some examples show their attachment with the axis (Zeiller 1896, Oldham 1897, Arber 1905, Dolianiti 1954, Pant & Singh 1974, Pant 1977, Pigg 1990)

The present paper describes five new species of *Glossopteris* with cuticular details, which are different from the species described so far. On the basis of attachment of the leaves, the habit of the *Glossopteris* plant is discussed.

## MATERIAL AND METHOD

The compressed leaves described in this paper were collected from Poidih Colliery, Damra Colliery and Kuardih Colliery of Raniganj Coalfield, West Bengal and New Manjri Colliery of Nagpur Coalfield, Maharashtra, India.

The external morphology, structure and venation of leaves were studied under strong incident light illumination. Concentration of veins was determined near the midrib and margins. Cuticles were prepared by macerating the carbonaceous material of the leaves with Schulze's method and cuticles were mounted in safranin-glycerine jelly. However, where the carbonaceous material was already partially macerated and had turned brown, they were pulled out in cellulose acetate pulls and mounted in Canada balsam.

All figured specimens and slides form part of the Divya Darshan Pant Collection, located in Palaeobotany section of Botany Department, University of Allahabad, Allahabad, India.

## DESCRIPTION

**Genus:** *Glossopteris* Brongniart

**Type species:** *Glossopteris browniana* Brongniart

*Glossopteris auriculata* D.K. Chauhan,  
Sang. Agrawal & S.P. Tiwari, sp. nov.

Plate 1, figures 1-8, text-figures 1A-F

**Diagnosis:** Leaf simple, petiolate, base cordate to auriculate, narrow, ribbon shaped, 0.7-2.5 cm wide, apex unknown, margins entire, midrib prominent, 1.5-2 mm, thick near base, basal lobes small and rounded. Lateral veins arising at angles of 40-50° but arching out and running at acute angles to midrib in apical part, at right angles in middle region of lamina and at obtuse angles in basal part. Concentration of veins 15-25 per cm near midrib, 30-40 per cm near margins, meshes short, hexagonal to polygonal throughout lamina, 1-2 x 0.5-1.0 mm near midrib. Leaf hypostomatic but a few stomata present on upper surface of lamina. Upper cuticle of lamina 3 µm thick, differentiated into vein and mesh areas. Cell wall about 2 µm thick, straight. Cells over vein areas narrow, elongated, 45-65 x 7-12 µm.

Cells over meshes irregularly arranged, rectanguloid, squarish or polygonoid, 23-50 x 20-35 µm. Hair bases present but hairs not seen. Upper cuticle of midrib 3 µm thick, cell wall straight, 3 µm thick, cells narrow, elongated, rectanguloid, 90-155 x 7-28 µm, upper cuticle of midrib also shows impressions of hypodermal cells, circular to semicircular or elliptical in shape, 60-217 x 30-60 µm. Lower cuticle of lamina about 2 µm thick, differentiated into vein and mesh areas. Cell wall 1 µm thick, straight, vein areas non-stomatiferous, showing rectanguloid cells, elongated in direction of veins, cells 20-50 x 5-10 µm, mesh areas stomatiferous, cells of mesh areas like those of mesh areas in upper cuticles, 25-50 x 12-25 µm. Distribution and orientation of stomata irregular, stomatal frequency 150 per mm<sup>2</sup>, stomata haplocheilic, subsidiary cells 4-6 like ordinary epidermal cells. Guard cells sunken in a shallow pit, 18-64 x 7-13 µm, stomatal pore up to 10 x 2 µm. Lower cuticle of midrib non-stomatiferous, about 1 µm thick, cell wall straight, 2 µm thick, cells like those of upper cuticle of midrib.

**Holotype:** Specimen No. 6389 of the Divya Darshan Pant Collection, located in Palaeobotany section of Botany Department, University of Allahabad, Allahabad, India.

**Locality and Horizon:** Poidih Colliery, Raniganj Coalfield, West Bengal, Raniganj Formation (Late Permian), Lower Gondwana.

**Discussion and Comparison:** Five incomplete leaves showing three bases and two middle regions are assigned to *Glossopteris auriculata*. The bases show rather stout petioles which are inserted at an angle so as to slope downwards from the plane of the lamina as in *Belemnopteris sagittifolia* (Pant & Choudhary 1977), *Sagittophyllum cordatosagittata* and *S. sagittata* (Chauhan 2004). It would thus appear that the lamina was held at an angle with the petiole like that

## Plate 1

*Glossopteris auriculata* sp. nov. 1. A leaf showing venation. Specimen no. 6388, ca. x3. 2. A basal fragment of leaf showing venation. Specimen no. 6389, x3. (Holotype). 3. Lower cuticle of lamina showing stomata (*st*). Slide no. 6388a, x150. 4. Upper cuticle of lamina (enlarged), showing stoma and hair bases (*hb*). Slide no. 6389a, x300. 5. Upper cuticle of midrib showing impressions of hypodermal cells. Slide no. 6389a, x200. 6. Upper cuticle of lamina showing a stoma (*st*) and hair base (*hb*). Slide no. 6389a, x150. 7. A single hair base enlarged. Slide no. 6388a, x250. 8. Upper cuticle of lamina (enlarged), showing stoma (*st*) and hair bases (*hb*). Slide no. 6389a, x300.

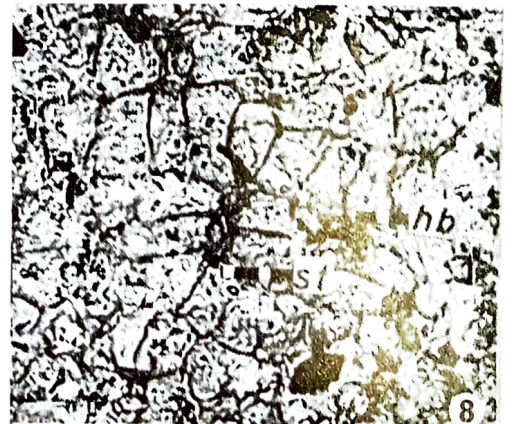
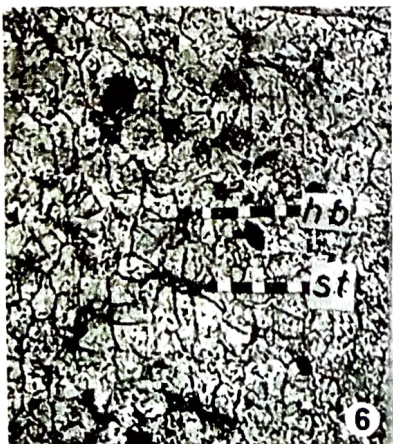
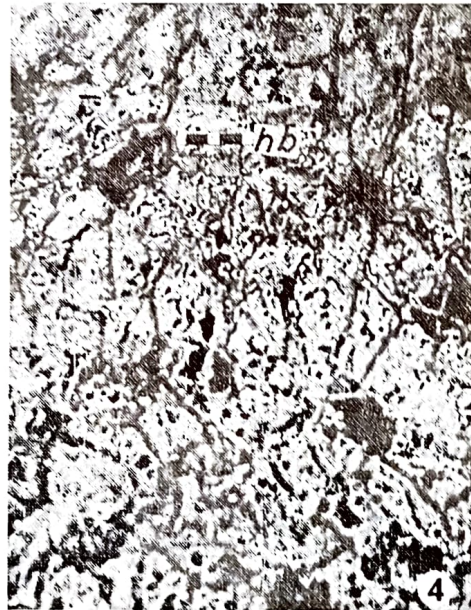
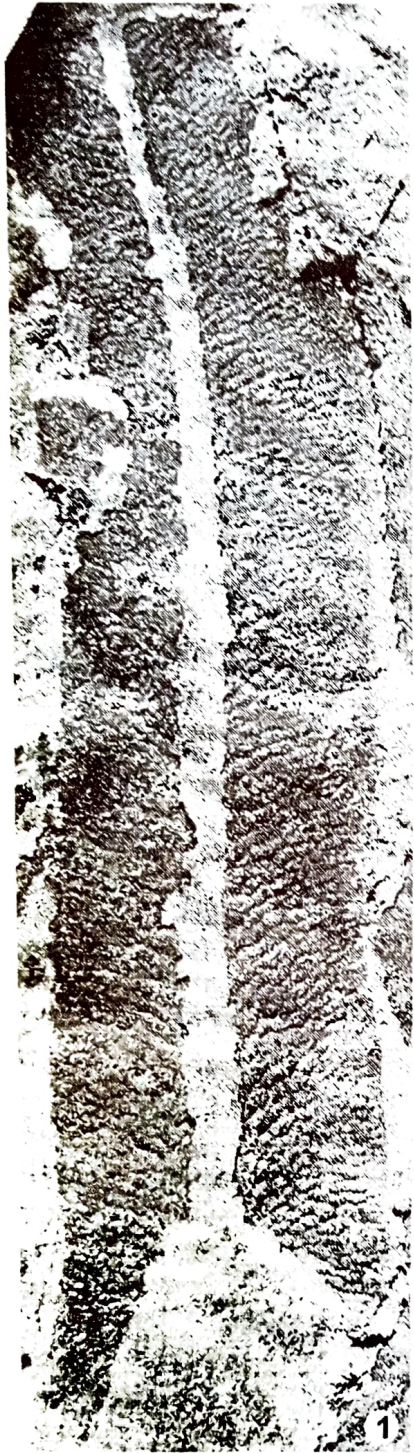
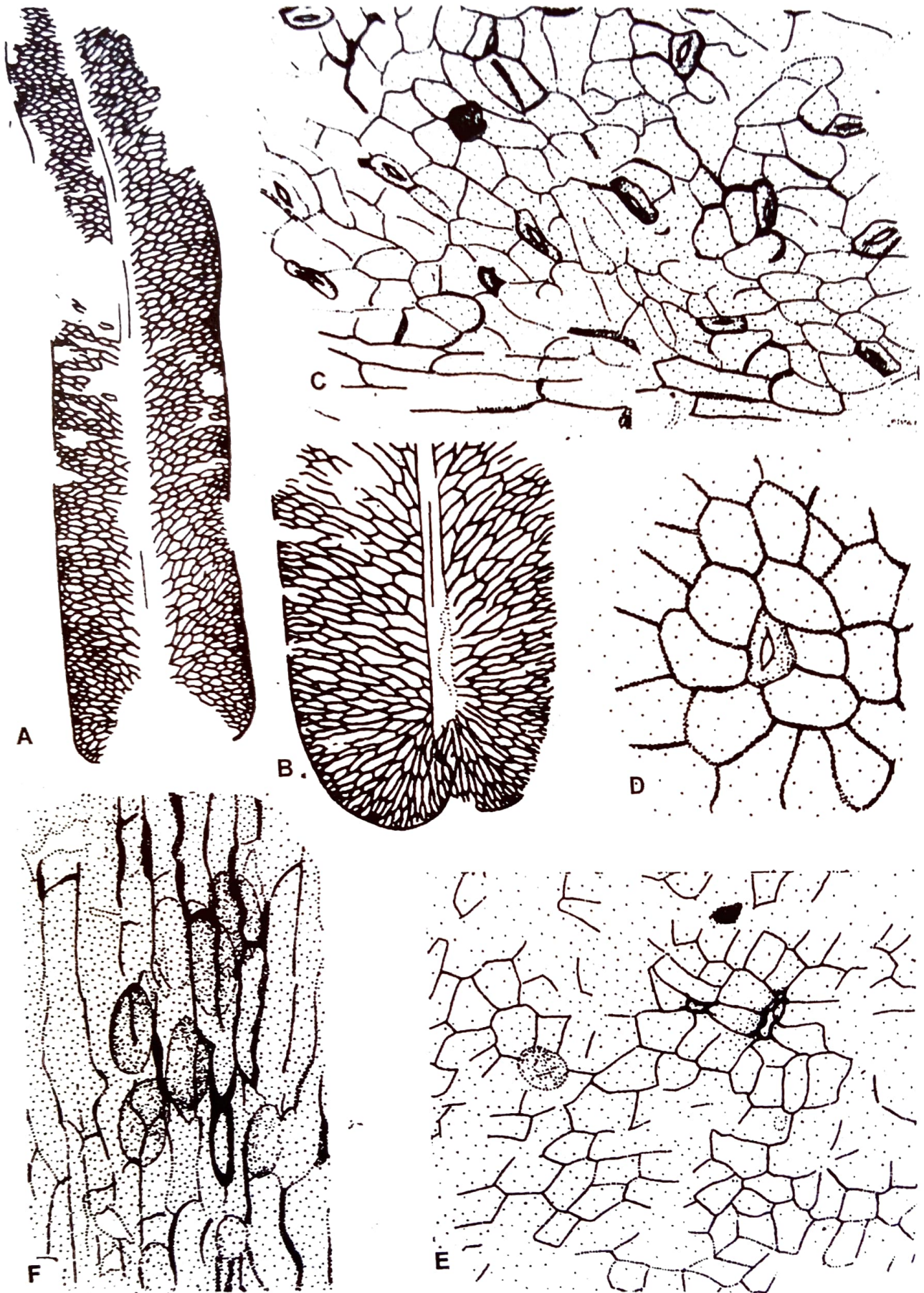


Plate 1



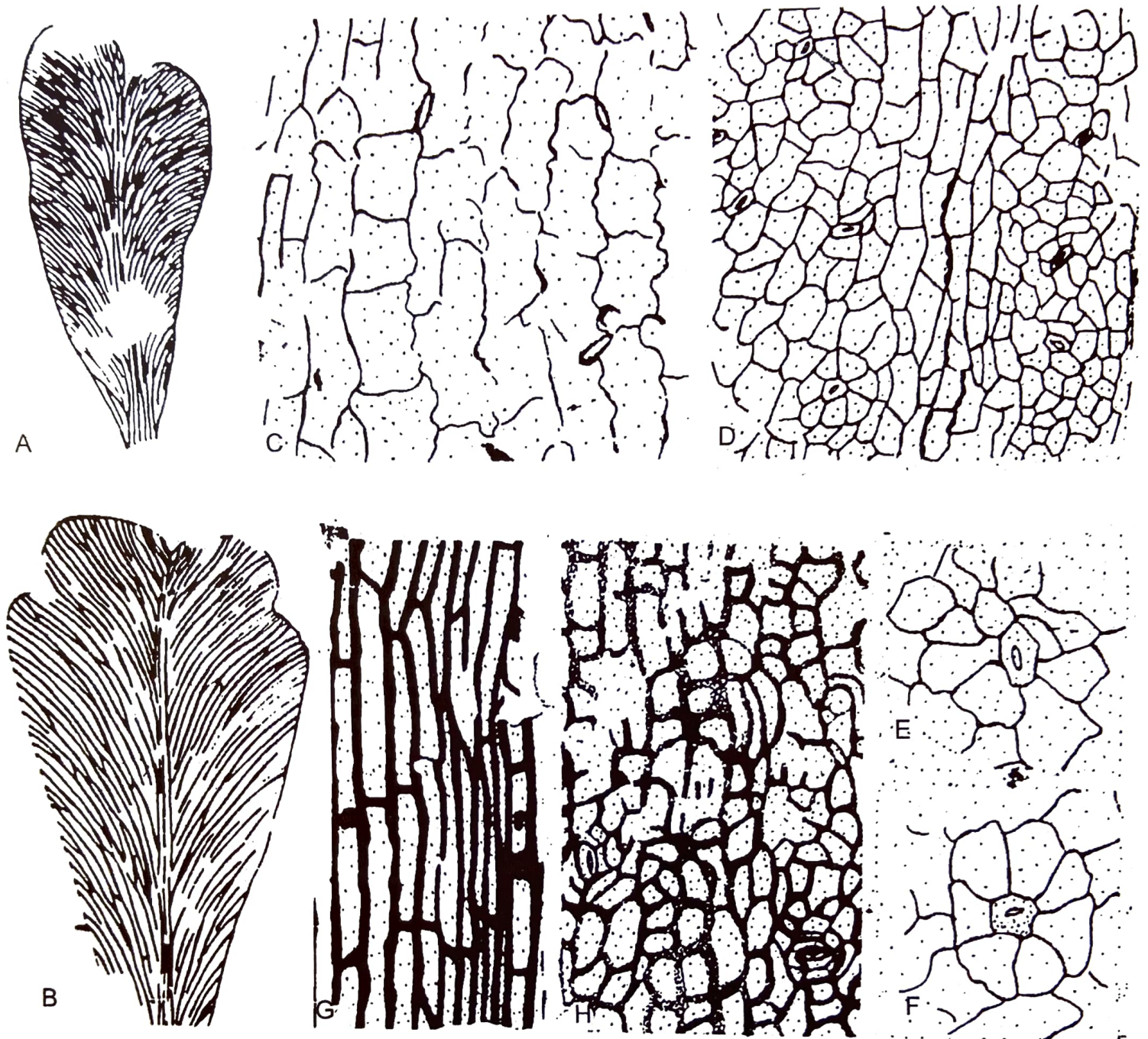
**Text-figure 1.** *Glossopteris auriculata* sp. nov. A. Leaf showing venation. Specimen no. 6388, x2.4. B. Basal fragment of leaf. Specimen no. 6389, x2.4 (Holotype). C. Lower cuticle of lamina showing vein and mesh areas. Slide no. 6388a, x180. D. A stoma enlarged. Slide no. 6388a, x270. E. Upper cuticle of lamina showing a stoma and hair base. Slide no. 6389a, x180. F. Upper cuticle of midrib showing impression of hypodermal cells. Slide no. 6389a, x180.

of modern leaves of some Araceae like *Typhonium trilobatum* and *Alocasia* species. The leaves of *Glossopteris auriculata* are somewhat comparable with those of *Glossopteris cordata* Dana, *Glossopteris feismantelii* (Feist.) Rigby and *Glossopteris cordiformis* Pant & Singh in having cordate bases but differ from them in being narrow, ribbon shaped with a different type of venation

(Table 1). Among the above previously described species, cuticles are known only in *G. cordiformis* but *G. auriculata* differs from it in showing straight walled, rather small, regularly disposed rectangular or squarish cells and in having hair bases (epidermal cells in *G. cordiformis* are arched, larger and rather irregular in shape and without hair bases).

**Table 1.** Comparative characters of *Glossopteris* having cordate bases.

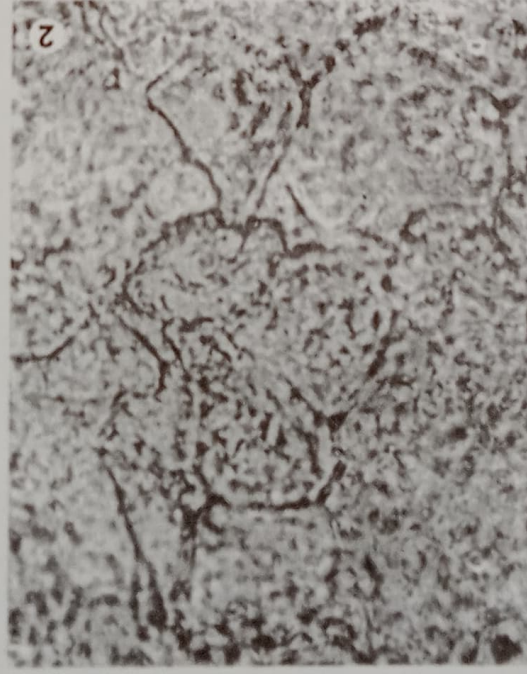
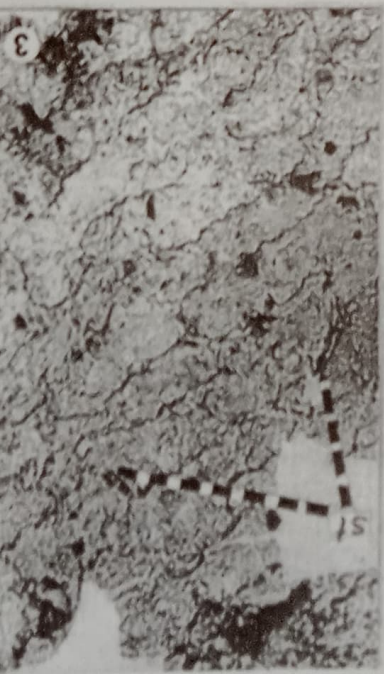
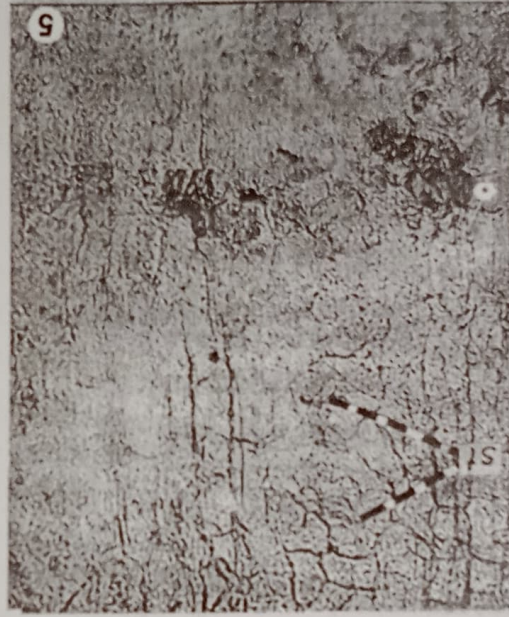
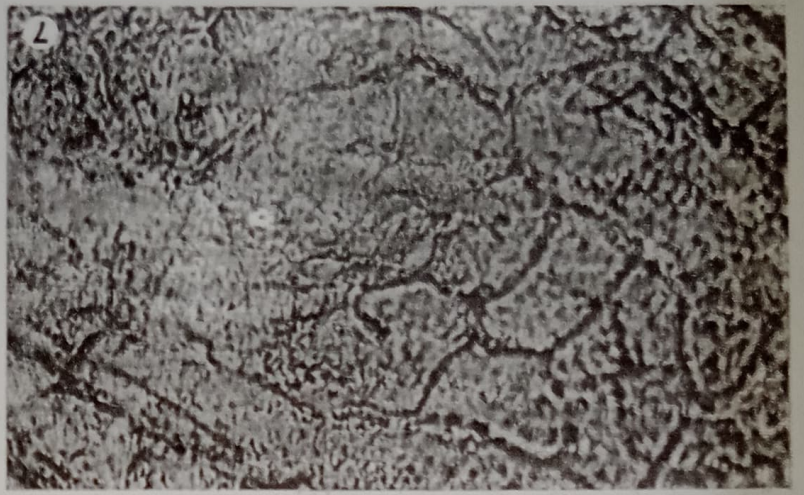
Name of species	Leaf Base	Size in cm		Vein concentration per cm		Midrib and secondary veins	Cuticles		
		Length	Width	Near midrib	Near margin		Upper cuticle of lamina	Lower cuticle of Lamina	Midrib
<i>G. cordata</i> Dana	Cordate	11.5	8-13.2	10	20-25	Midrib about 7.6 mm wide near base, gradually tapering towards apex, striated, secondary veins arising from the midrib obliquely, become almost perpendicular to it, veins dichotomise and anastomose to form open, polygonal meshes which become much shorter and narrower near margins.	-	-	-
<i>G. feismantelii</i> (Feist.) Rigby	Cordate	-	6	18-20	-	Midrib stout, angle of divergence of veins moderately acute (45°-50°) and run almost straight near base, veins anastomose to form meshes which are polygonal near midrib and narrow elongated towards margins.	-	-	-
<i>G. cordiformis</i> Pant & Singh	Cordate	-	9.4-12	9	15	Midrib 1.5 mm wide, secondary veins in middle region of leaf leaving midrib at small angles and soon arching outwards and thereafter proceeding straight to margins at angles of 45° to 75°, meshes short towards base, becoming longer in middle region, anastomose less frequent towards apex.	Non-stomatiferous, differentiated into vein and mesh areas, anticlinal walls arched, cells over meshes irregularly arranged, rectanguloid or irregular in shape, size of cells over meshes 80 µm x 37 µm. Hair bases absent.	Stomatiferous, differentiated into vein and mesh areas. Cells like upper cuticle, cell size over meshes 59 µm x 26 µm. Stomata irregularly oriented and dispersed, stomatal frequency 133 per mm <sup>2</sup> .	Cells arranged in longitudinal rows, rectanguloid, cell size 99 µm x 18 µm.
<i>G. auriculata</i> sp. nov.	Cordate or auriculate	-	1.7-2.5	15-25	30-40	Midrib prominent, 1.5-2 mm thick, secondary veins arise at angles of 40°-50°, but arching out and running at acute angles to midrib in apical part, at right angles in middle and at obtuse in basal part, meshes short, hexagonal to polygonal throughout the lamina.	A few stomata present, differentiated into vein and mesh areas, anticlinal walls straight, cells over meshes irregularly arranged, rectanguloid, squarish or polygonoid, 20-50 µm x 20-35 µm, hair bases present.	Stomatiferous, differentiated into vein and mesh area. Cells like upper cuticle, cell size over meshes 25-50 µm x 12-25 µm, distribution and orientation of stomata irregular, stomatal frequency 150 per mm <sup>2</sup> .	Cells narrow, elongated rectanguloid, cell size 90-155 µm x 7-28 µm, showing impressions of hypodermal cells.



**Text-figure 2.** *Glossopteris sessilis* sp. nov. A. A leaf showing venation. Specimen no. 63087, x2 (Holotype). B. Leaf showing venation and two marginal notches. Specimen no. 63309, x2. C. Paucistomatic surface of lamina showing straight sinuous-walled cells. Slide no. 63087b, x200. D. Multistomatic surface of lamina. Slide no. 63087a, x150. E-F. Stomata from the multistomatic surface of lamina. Slide no. 63087a, x300. G. Cuticle of midrib on multistomatic surface. Slide no. 63087e, x150. H. Cuticle of midrib on paucistomatic surface. Slide no. 63087e, x150.

## Plate 2

*Glossopteris sessilis* sp. nov. 1. A leaf showing venation. Specimen no. 63087, x2.8 (Holotype). 2. Stomata from multistomatic surface of lamina. Slide no. 63087a, x600. 3. Cuticle of paucistomatic surface of lamina showing sinuous walled cells and stomata (st). Slide no. 63087b, x200. 4. A leaf showing venation and two marginal notches (indicated by arrow). Specimen no. 63309, x1.8. 5. Cuticle of multistomatic surface of lamina showing stomata (st). Slide no. 63087a, x150. 6. Cuticle of midrib on multistomatic surface. Slide no. 63087e, x200. 7. Stomata of multistomatic surface of lamina. Slide no. 63087a, x600. 8. Cuticle of midrib on paucistomatic surface showing differentiation into stomatiferous (st) and non-stomatiferous areas. Slide no. 63087e, x150.



***Glossopteris sessilis* D.K. Chauhan,  
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Plate 2, figures 1-8, text-figures 2A-H

**Diagnosis:** Leaves simple, sessile, obovate, apex retuse, 3-4 x 1.5-2.0 cm, midrib entire, midrib 2 mm wide at base, persistent to the apex, lateral veins arising at angle of 20°-30° from midrib, arching outwards and reaching margins at angles of 55°-60° to midrib. Concentration of lateral veins 25-30 per cm near midrib, 30-35 per cm near margins, meshes narrow elongated, 2-5 x 0.5 mm near midrib, 2-5 x 0.2 mm near margins. Leaves amphistomatic, cuticle of paucistomatic surface of lamina 2 µm thick, differentiation of vein and mesh areas obscure, cell wall 2 µm thick, straight to sinuous, cells in vein areas arranged in files parallel to veins, trianguloid to rectanguloid, 20-80 x 10-40 µm, cells in mesh areas irregularly arranged, trianguloid to polygonoid, 60-90 x 15-70 µm, surface of cells mottled, stomata confined to mesh areas, irregularly arranged and oriented, stomatal frequency 28 per mm<sup>2</sup>, stomata haplocheilic, subsidiary cells 4-7, like ordinary epidermal cells, guard cells sunken in a shallow pit, stomatal pit 8-12 x 6-10 µm, cuticle of midrib on paucistomatic surface 5 µm thick, cell wall straight, 4 µm thick differentiated into vein and mesh areas, cells of vein areas rectanguloid, 30-90 x 10-25 µm, cells of mesh areas trianguloid to rectanguloid, 30-65 x 15-45 µm, stomata over midrib like those on multistomatic surface of lamina. Cuticle of multistomatic surface of lamina 2 µm thick, sharply differentiated into vein and mesh areas, cells of vein areas narrow, rectanguloid, 60-110 x 30-45 µm, mesh areas stomatiferous, distribution and orientation of stomata like paucistomatic surface, stomatal frequency 132 per mm<sup>2</sup>, subsidiary cells 4-7, often with shorter radial walls, monocyclic or partially amphicyclic, cells of mesh areas trianguloid, polygonoid or irregular, 35-70 x 10-35 µm, cuticle of midrib on multistomatic surface 4 µm thick, non-stomatiferous,

cell wall 5 µm thick, cells rectanguloid, arranged in longitudinal files, 60-115 x 5-10 µm.

**Holotype:** Specimen No. 63087 of the Divya Darshan Pant Collection, located in Palaeobotany section of Botany Department, University of Allahabad, Allahabad, India.

**Locality and Horizon:** Damra Colliery, Raniganj Coalfield, West Bengal, Raniganj Formation (Late Permian), Lower Gondwana.

**Description and Comparison:** *Glossopteris sessilis* is based on three, more or less complete leaves (Specimen No. 63309, Plate 2, figure 4, text-figure 2B show two additional shallow notches). The stomata of multistomatic surface usually show subsidiary cells which are clearly differentiated from the epidermal cells (the stomata on the paucistomatic surface have subsidiaries which are usually like ordinary epidermal cells). The differentiated subsidiary cells which have shorter radial walls are often flanked by an encircling cell which has a thinner wall from its adjacent subsidiary cell. This may indicate that such flat subsidiary cells and their adjacent encircling cells were formed by divisions in a previous generation of neighbouring cells surrounding the stomata. *Glossopteris sessilis* may be compared with leaves of *G. retusa* Maheshwari (1965) and *G. pandurata* Pant & Gupta (1971). However, the leaves of *G. sessilis* are sessile while those of *G. retusa* have short winged petioles. Further comparison between the two species is not possible because the fine structure of *G. retusa* is unknown. The leaves of *G. pandurata* differ from *G. sessilis* in being fiddle shaped and its apex has no perceptible notches. Moreover, *G. pandurata* unlike *G. sessilis* shows interstitial fibres and its little known characters of cuticles are different. In its venation, *G. sessilis* is similar to *G. angusta* (Pant & Gupta 1971) but leaves of *G. sessilis* are obovate and amphistomatic whereas those of *G. angusta* are oblanceolate and hypostomatic.

**Plate 3**

*Glossopteris subcostata* sp. nov. 1. A leaf showing undulate margins. Specimen no. 63321, ca. x2.5 (Holotype). 2. Upper cuticle of lamina. Slide no. 63322e, x200. 3. A celloidin pull of entire leaf showing venation. Slide no. 63321b, x1.5. 4. Upper cuticle of midrib showing stomata (sr). Slide no. 63322a, x150. 5. Lower cuticle of lamina showing stomata (sr). Slide no. 63322a, x150. 6. Upper cuticle of lamina near midrib. Slide no. 63322g, x250. 7. Upper cuticle of lamina. Slide no. 63322a, x150.



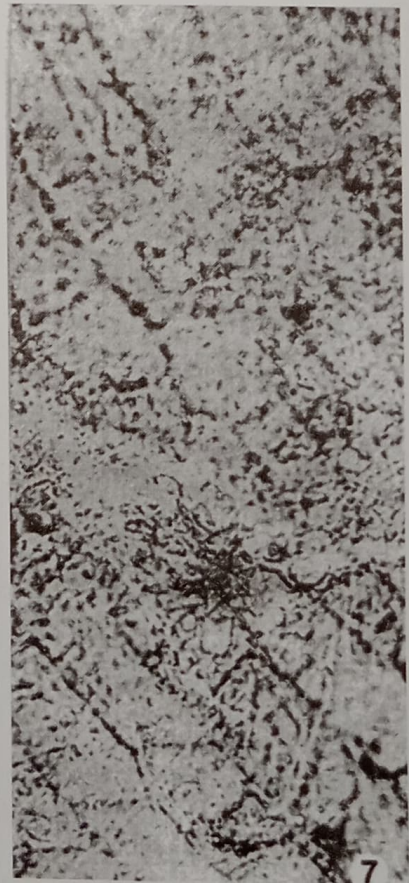
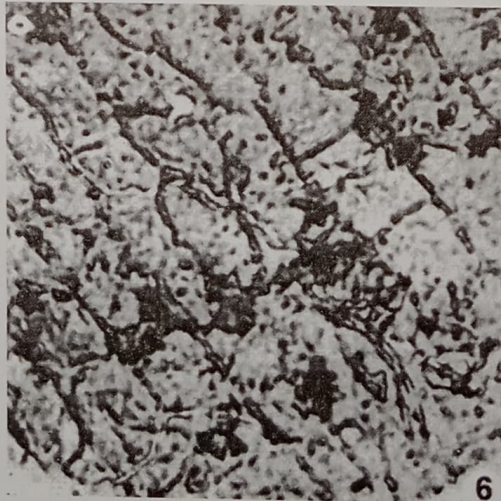
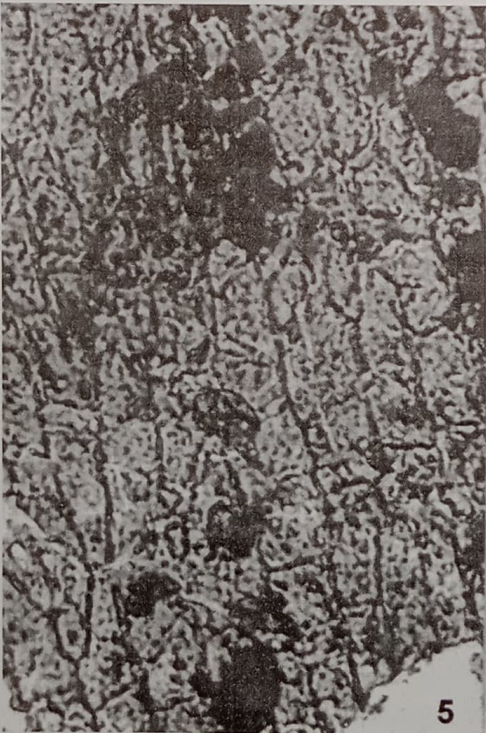
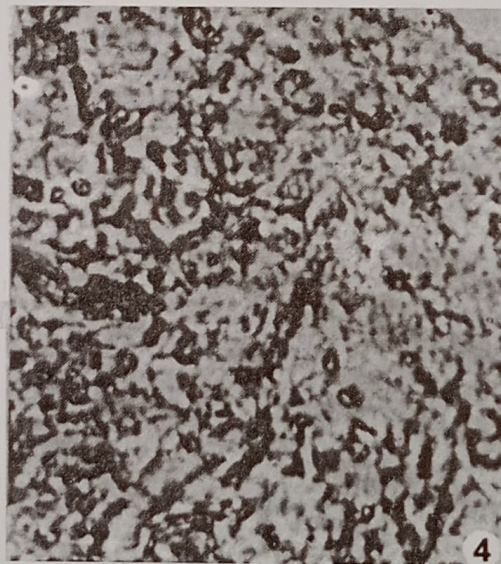
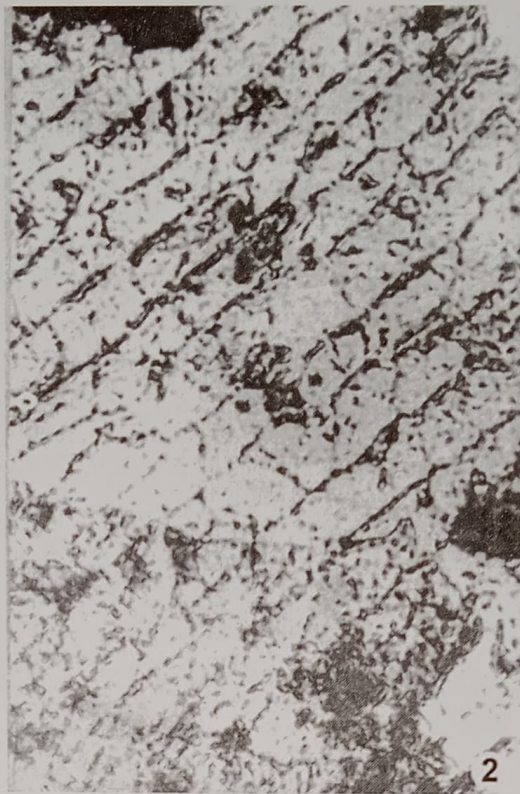
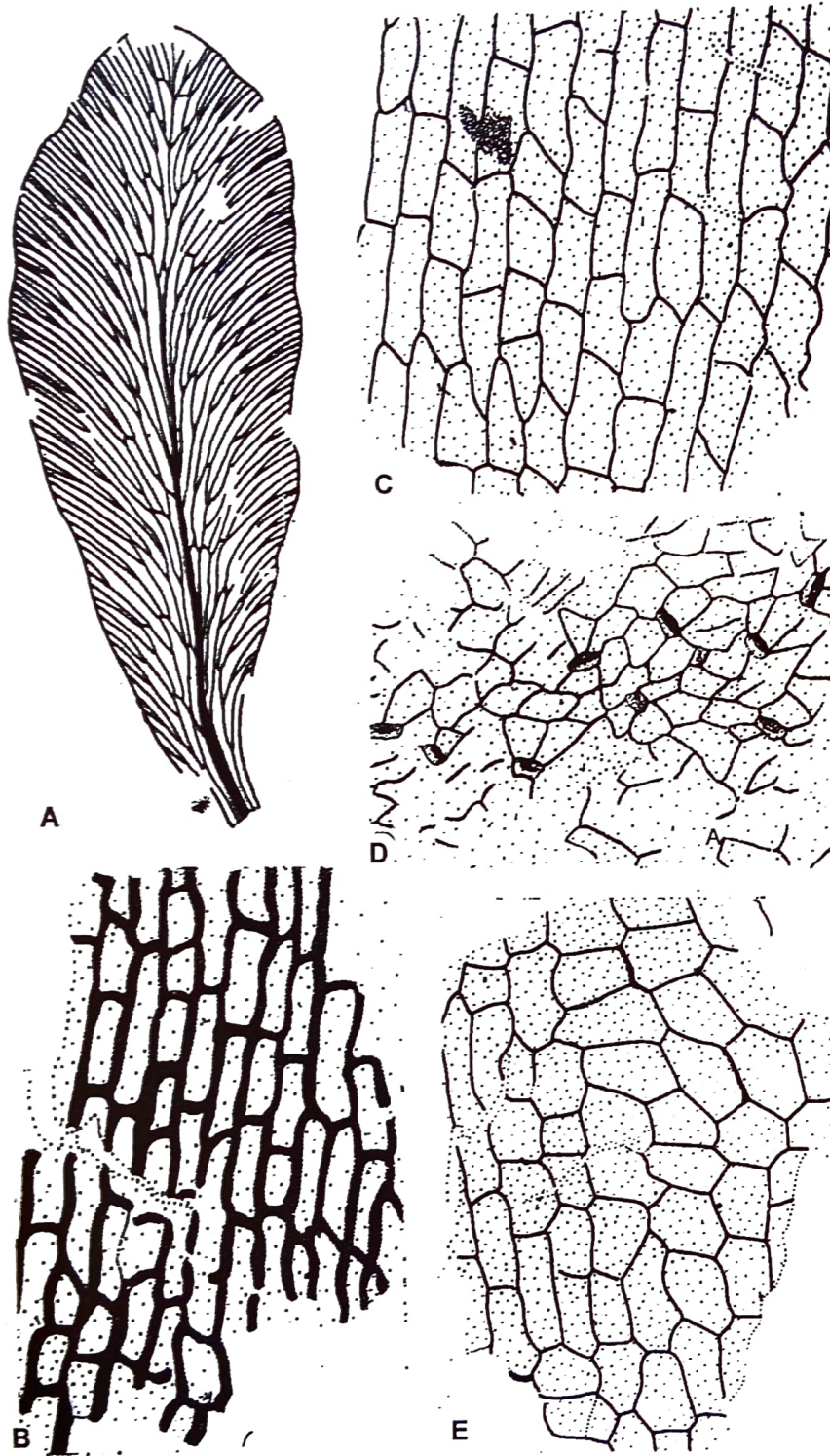


Plate 3



**Text-figure 3.** *Glossopteris subcostata* sp. nov. A. A leaf showing venation. Slide no. 63321b, ca. x2. B. Upper cuticle of midrib. Slide no. 63322g, x150. C. Upper cuticle of lamina near midrib. Slide no. 63322e, x150. D. Lower cuticle of lamina. Slide no. 63322c, x100. E. Upper cuticle of lamina. Slide no. 63322e, x150.

#### Plate 4

*Glossopteris truncata* sp. nov. 1. A leaf showing venation. Specimen no. 68601, ca. x1.3 (Holotype). 2. Lower epidermis of lamina showing stomata (st). Slide no. 68601e, x150. 3. Tracheids from midrib showing scalariform thickenings. Slide no. 68601g, x450. 4. Upper epidermis of lamina. Slide no. 68601a, x150. 5. Upper epidermis of midrib. Slide no. 68601a, x150. 6. Upper epidermis of lamina showing vein and mesh areas. Slide no. 68601b, x250. 7. A stoma (st) enlarged. Slide no. 68601f, x600.

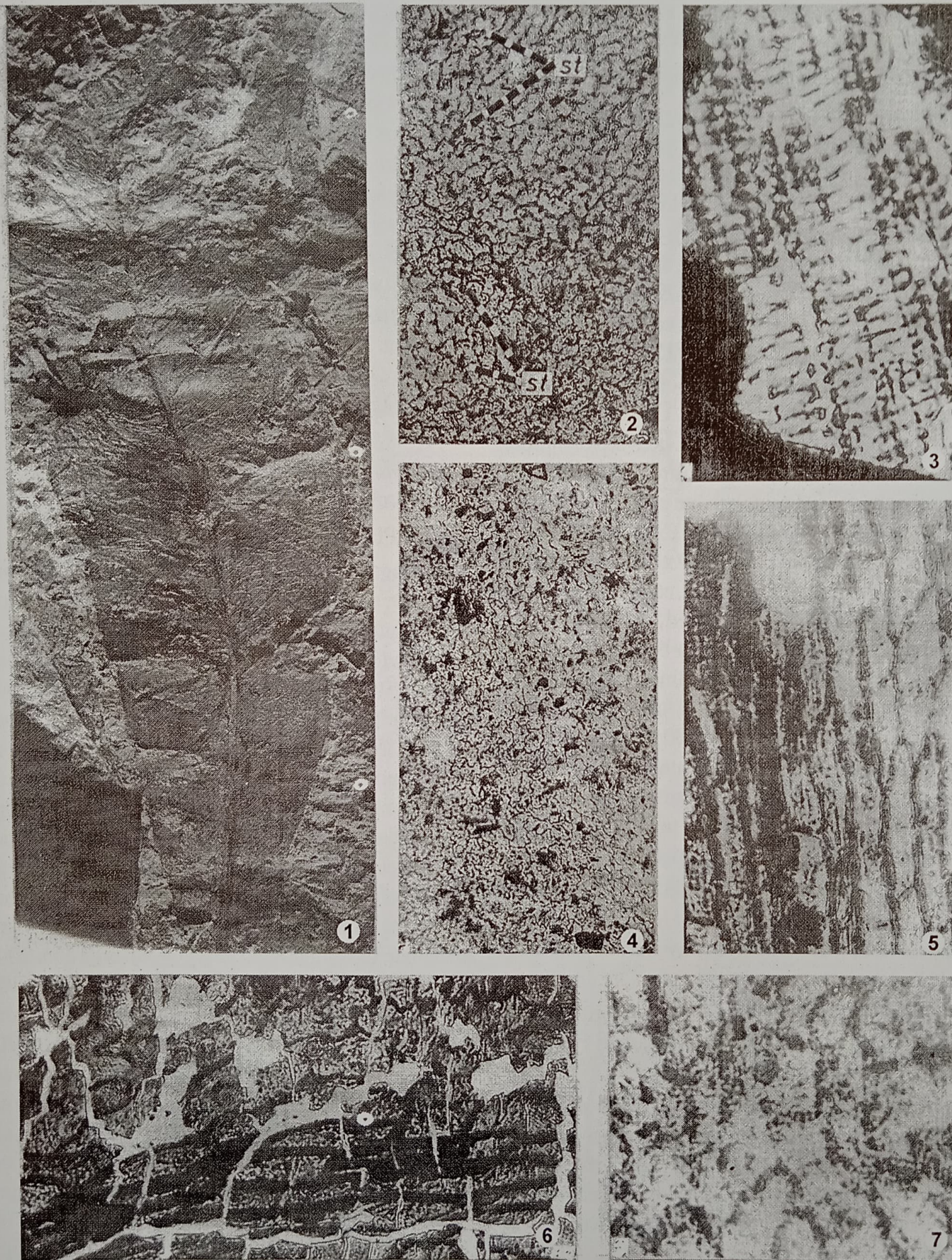


Plate 4

***Glossopteris subcostata* D.K. Chauhan,  
Sang. Agrawal & S.P. Tiwari, sp. nov.**

Plate 3, figures 1-7, text-figures 3A-E

**Diagnosis:** Leaves simple, spatulate, sessile or subsessile, length up to 5.2 cm, breadth 2 cm, apex rounded, margins slightly undulated. Midrib about 1.5 mm wide at base and showing 2-3 longitudinal strands, evanescent in one third apical part of lamina. Lateral veins up to 175  $\mu\text{m}$  thick arising at angle of 10-15°, thereafter arching outwards and reaching margins at angles of 30-49° to midrib. Lateral veins showing cross connections only near midrib but elsewhere forked although rare cross connections sometimes seen near margins. Interstitial fibres present. Leaf hypostomatic, upper cuticle of lamina 3  $\mu\text{m}$  thick, non-stomatiferous, differentiated into vein and mesh areas, cell wall 5  $\mu\text{m}$  thick, straight, cells of vein areas are rectanguloid, longer than broad, 70-120 x 26-30  $\mu\text{m}$ . Cells of mesh areas rectanguloid to squarish, 50-110 x 30-50  $\mu\text{m}$ . Upper cuticle of midrib about 5  $\mu\text{m}$  thick, cell wall about 8  $\mu\text{m}$  thick, straight, cells rectanguloid, 60-140 x 30  $\mu\text{m}$ . Lower cuticle of lamina like upper but thinner (about 1  $\mu\text{m}$  thick) with obscured cell outlines, stomatiferous. Anticlinal walls of cells about 1  $\mu\text{m}$  thick, stomata irregularly dispersed and oriented in mesh areas but absent over veins. Stomatal frequency 159 per  $\text{mm}^2$ . Stomatal pit 33-45 x 12-18  $\mu\text{m}$ , stomatal pore 12-18 x 3  $\mu\text{m}$ . Lower cuticle of midrib 3  $\mu\text{m}$  thick, cell wall 5  $\mu\text{m}$  thick, otherwise like upper cuticle of midrib.

**Holotype:** Specimen No. 63321 of the Divya Darshan Pant Collection, located in Palaeobotanical section of Botany Department, University of Allahabad, Allahabad, India.

**Locality and Horizon:** New Manjri Colliery, Nagpur Coalfield, Maharashtra, Karharbari Formation (Permian), Lower Gondwana.

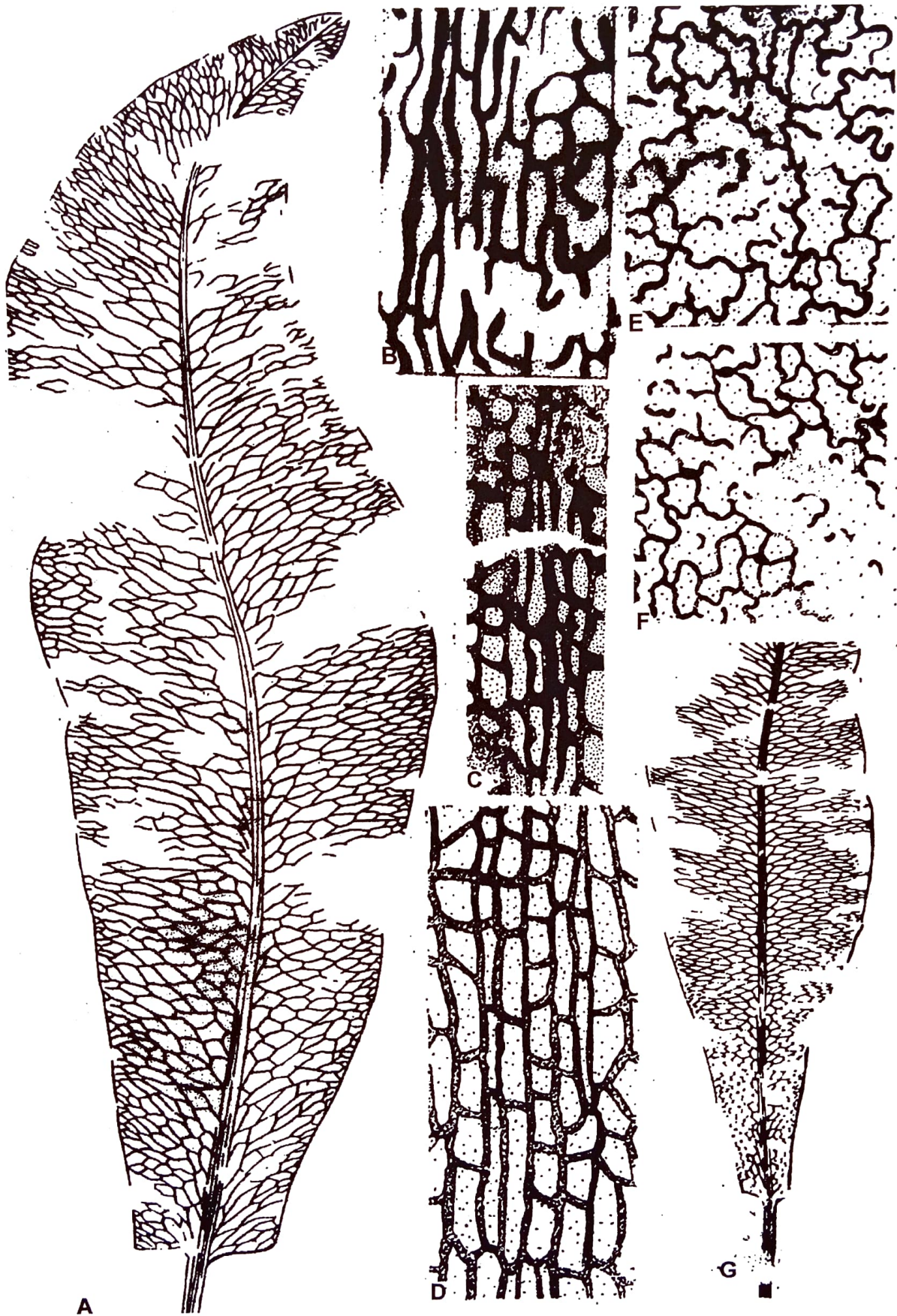
**Discussion and Comparison:** The species is based on four well preserved specimens including one complete leaf and three fragments. The carbonaceous substance of the leaves is preserved over black shale. It is mostly brown due to partial natural maceration. In one case (Specimen No. 63321 b), the whole substance of the leaf was transferred on a slide to see the details

of venation. Some of the veins at the margins form marginal loops by curving upwards and joining adjacent veins. However, no tracheidal thickenings could be seen in the loops and it was not possible to confirm whether the loops were formed by tracheids or thick-walled cells. In having an apically evanescent midrib *Glossopteris subcostata* resembles *Glossopteris decipiens* Feistmantel and *Glossopteris zeilleri* Pant & Gupta. The presence of interstitial fibres in *G. zeilleri* brings it even closer to *G. subcostata*, although the shape, size and venation of the three species is quite different. The venation and accompanying cuticular structure of *G. subcostata* make it unique among all previously described species and it is therefore, assigned to a new species *G. subcostata*.

***Glossopteris truncata* D.K. Chauhan,  
Sang. Agrawal & S.P. Tiwari, sp. nov.**

Plate 4, figures 1-7, text-figures 4A-G

**Diagnosis:** Leaf simple, lanceolate, petiolate, base truncate, apex acute, length about 13 cm, width up to 4 cm, margins entire or slightly undulate, midrib about 2 mm wide near base, persistent up to apex, lateral veins up to 125  $\mu\text{m}$  thick, arising at angles of 15°-40° from midrib. Concentration of veins 8-10 per cm near midrib, 15-20 per cm near margins. Meshes hexagonal to polygonal, 2-4 x 1-3 mm near midrib, 0.5-2.0 x 0.5-1.0 mm near margins. Leaves hypostomatic, upper epidermis of lamina showing differentiation of vein and mesh areas. Cell wall up to 5  $\mu\text{m}$  thick, cells over veins rectanguloid, narrower, elongated, longer than broad, 55-165 x 10-35  $\mu\text{m}$ , straight walled. Cells of mesh areas irregular, rectanguloid to polygonoid, 50-125 x 30-85  $\mu\text{m}$ . Cell wall sinuous, wave lengths of sinuosities 9-25  $\mu\text{m}$ , amplitudes 5-12  $\mu\text{m}$ . Cells over midrib arranged in longitudinal rows, rectanguloid, 80-170 x 10-30  $\mu\text{m}$ , cell wall straight about 8  $\mu\text{m}$  thick. Lower epidermis of lamina like upper but stomatiferous, stomata irregularly dispersed in mesh areas and irregularly oriented, frequency 38 per  $\text{mm}^2$ , guard cells 22-32 x 8-12  $\mu\text{m}$ , stomata pores 11-13 x 5-6  $\mu\text{m}$ , subsidiary cells 4-7 like ordinary epidermal cells. Cells over lower epidermis of midrib like those of its upper epidermis.



**Text-figure 4.** *Glossopteris truncata* sp. nov. A. A leaf showing venation. Specimen no. 68601, ca. x1.5 (Holotype). B. Upper epidermis of lamina near midrib showing straight walled cells. Slide no. 68601a, x125. C. Lower cuticle of midrib. Slide no. 68599g, x125. D. Upper cuticle of lamina. Slide no. 68599e, x125. E. Upper cuticle of lamina. Slide no. 68601a, x125. F. Lower epidermis of lamina. Slide no. 68601e, x125. G. A leaf showing venation. Specimen no. 68599, x0.8.

**Holotype:** Specimen No. 68601 of the Divya Darshan Pant Collection, located in Palaeobotanical section of Botany Department, University of Allahabad, Allahabad, India.

**Locality and Horizon:** Damra Colliery, Raniganj Coalfield, West Bengal, Raniganj Formation (Late Permian), Lower Gondwana.

**Description and Comparison:** The species is based on one complete leaf and four fragments of basal and middle parts of leaves. The apical portion of leaves is generally curved on one side. The pulls of naturally macerated substance of leaves near midrib show straight walled cells in lamina, which gradually become sinuous towards the margins. The pulls of midrib show tracheids about 12  $\mu\text{m}$  wide with reticulate or scalariform thickenings. *Glossopteris truncata* may be compared with *G. elongata* Dana and *G. maculata* Pant & Singh in having more or less similar venation pattern, but their bases are quite different (*G. elongata* has cuneate, *G. maculata* has tapering and *G. truncata* has truncate bases.). Further, *G. elongata* is about 2.5 cm wide but *G. truncata* is about 4 cm wide. Further comparison of *G. elongata* and *G. truncata* is not possible because the finer details of *G. elongata* are unknown. In apex, *G. truncata* differs from *G. maculata* because *G. truncata* has acute apex while *G. maculata* has obtuse apex.

***Glossopteris kuardihensis* D.K. Chauhan,  
Sang. Agrawal & S.P. Tiwari, sp. nov.**

Plate 5, figures 1-5, text-figures 5A-G

**Diagnosis:** Leaves simple, petiolate, apex acute, lamina lanceolate, tapering towards base, margins entire. Leaves 17-19 x 4-4.5 cm, petiole up to 1.5 cm long and 2 mm thick. Midrib prominent, extending from base to apex, consisting many longitudinal strands. Midrib 2 mm thick near base, gradually becoming thin near apex. Lateral veins arise from midrib at an angle of 17-29°

and diverge towards the margin at an angle of 55°-65°. Concentration of veins near midrib 9-15 per cm and near margin 12-16 per cm. Lateral veins anastomose to form meshes. Meshes polygonal, much longer than broad, 5-8 x 1-1.5 mm near midrib and 3.5-6 x 0.5-1.0 mm near margin. Leaf hypostomatic, cuticle 2  $\mu\text{m}$  thick. Upper cuticle differentiated into vein and mesh areas, cells over veins rectanguloid, narrow, elongated, longer than broad. Cells 87-125 x 15-20- $\mu\text{m}$ , cell wall straight. Cells in mesh areas irregular, rectanguloid to polygonoid, shorter or longer than broad, 90-150 x 50-60  $\mu\text{m}$ . Cell wall sinuous, wavelength of sinuousities 20 to 80  $\mu\text{m}$ , amplitude of sinuousities 10 to 25  $\mu\text{m}$ . Lower cuticle of lamina differentiated into mesh and vein areas as in upper cuticle. Cells over mesh areas are irregular in shape, 35-125 x 13-33  $\mu\text{m}$  wide, sides of cells sinuous, wavelength of sinuousities 25  $\mu\text{m}$  - 90  $\mu\text{m}$  and amplitude 5  $\mu\text{m}$  to 12  $\mu\text{m}$ . Stomata irregularly arranged, guard cells 25  $\mu\text{m}$  in length and 4.5  $\mu\text{m}$  in width, stomatal pore 11  $\mu\text{m}$  long, subsidiary cells five in number like epidermal cells. Cells over upper cuticle of midrib rectangular, arranged end to end. Cell wall straight, 2.5  $\mu\text{m}$  thick. Cells 50-200 x 15-40  $\mu\text{m}$ , cells over lower cuticle of midrib like those of upper, arranged in longitudinal rows, 85-125 x 15-20  $\mu\text{m}$ .

**Holotype :** Specimen No. 66525 of the Divya Darshan Pant Collection, located in Palaeobotanical section of Botany Department, University of Allahabad, Allahabad, India.

**Locality and Horizon:** Kuardih Colliery, Raniganj Coalfield, West Bengal, Raniganj Formation (Late Permian), Lower Gondwana.

**Description and Comparison:** Two small leafy twigs of *Glossopteris kuardihensis* are collected from Kuardih Colliery of Raniganj Coalfield, West Bengal, India. Each leafy twig appears to be dwarf shoot in which five leaves are attached in close spirals. The

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## Plate 5

*Glossopteris kuardihensis* sp. nov. 1. An axis (ax) having leaves attached in close helix. Specimen no. 66525, x0.7 (Holotype). 2. Lower cuticle of midrib. Slide no. 66525a, x480. 3. Upper cuticle of lamina showing sinuous walled epidermal cells. Slide no. 66525b, x480. 4. Upper cuticle of lamina showing vein and mesh areas. Slide no. 66525b, x125. 5. Lower cuticle of lamina showing a stoma. Slide no. 66525c, x150.

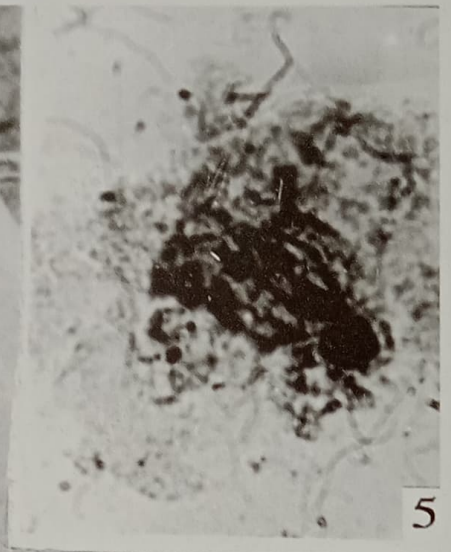
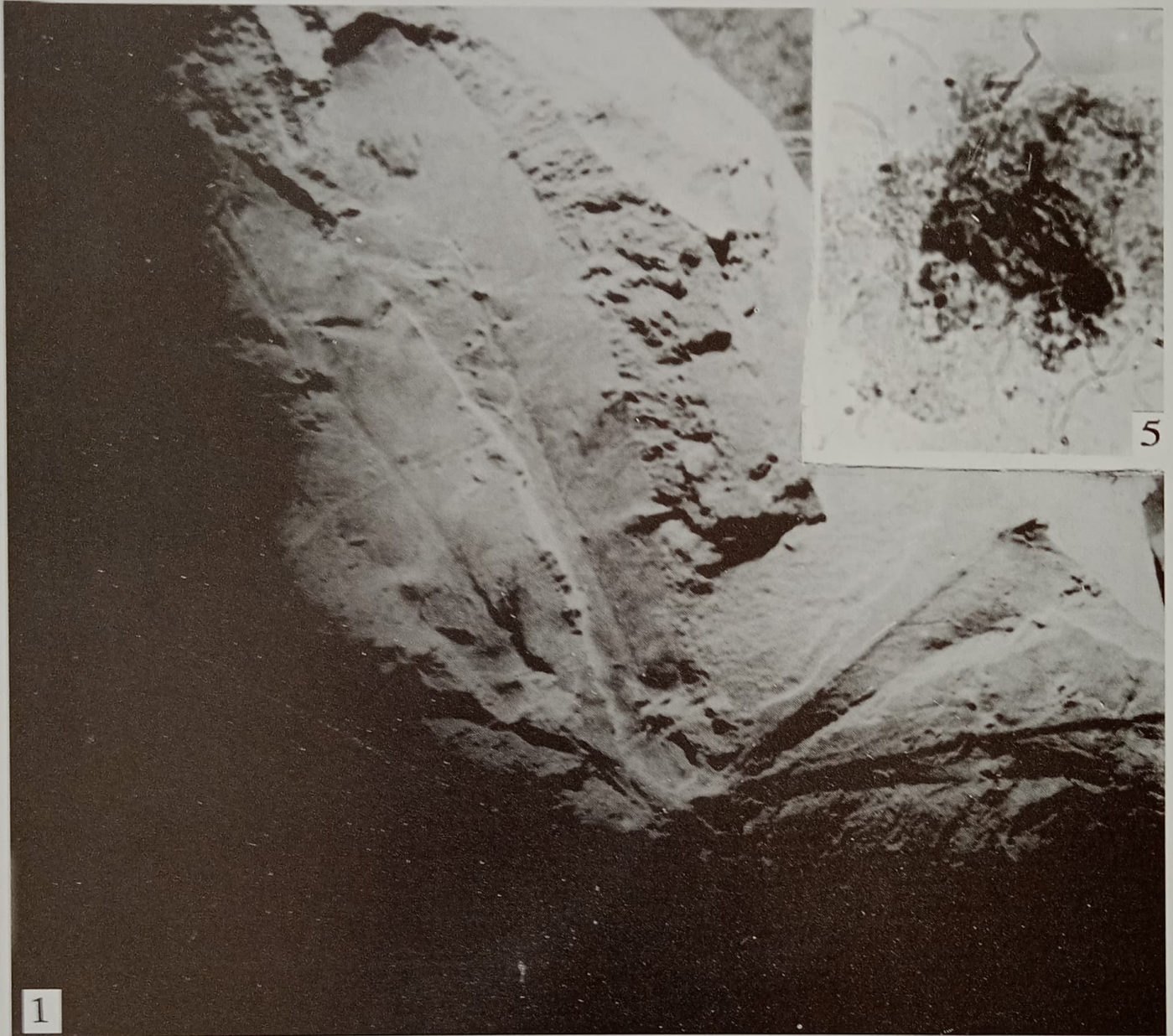
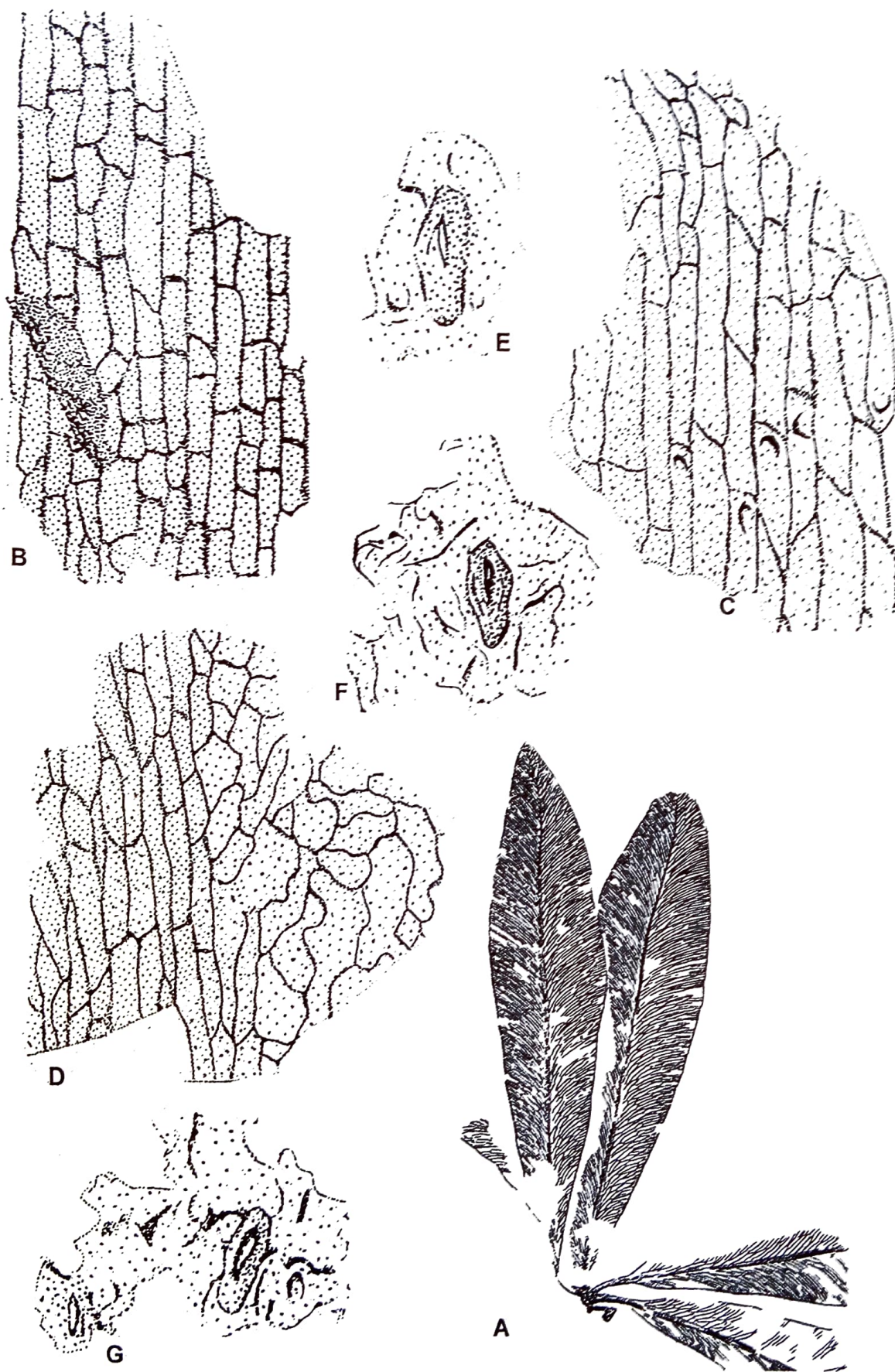


Plate 5



**Text-figure 5.** *Glossopteris kuardihensis* sp. nov. A. A leafy twig showing five leaves attached to an axis in close helix. Specimen no. 66525, x1.0 (Holotype). B. Upper cuticle of midrib. Slide no. 66525a, x190. C. Lower cuticle of midrib. Slide no. 66525d, x190. D. Upper cuticle of lamina showing vein and mesh areas. Slide no. 66525b, x190. E-G. Fragments of lower cuticle showing stomata. Slide no. 66525c, x260.



attached leaves of *Glossopteris kuardihensis* sp. nov. are comparable with the attached leaves of *G. maculata* Pant & Singh (1974), *G. sastrii* Pant & Singh (1974), *G. oldhamii* Pant & Singh (1974). All these leaves are petiolate and attached to dwarf shoots. Leaves of *G. maculata* are comparable with *G. kuardihensis* in their external and internal characters but they differ in size and venation pattern. The concentration of veins in *G. kuardihensis* is 11 – 14 per cm near midrib and 14 – 17 per cm near margin, in *G. maculata* it is 5 – 13 per cm near midrib and 13 – 20 per cm near margins. Meshes in *G. kuardihensis* are 7 x 1.2 mm near midrib and 4.5 x 0.9 mm near margins while in *G. maculata* it is 2.5 x 1.5 mm near midrib and 1.6 x 0.6 mm near margin. *G. kuardihensis* closely resembles *G. sastrii* in shape and size of leaf and both have sinuous walled polygonal cells, but the difference is in their vein concentration. Further the subsidiary cells are like other epidermal cells in *G. kuardihensis*, but in *G. sastrii* the subsidiary cells are papillate and thick walled on the side facing stomata and over arch guard cells. Vein concentration in *G. kuardihensis* is also different from *G. sastrii*. In *G. sastrii* it is 4-9 per cm near midrib and 10 – 20 per cm near margin. *G. kuardihensis* and *G. oldhamii* also differ in their vein concentration. In *G. oldhamii* vein concentration is 8-10 per cm near midrib and 15-32 per cm near margin. Further in *G. kuardihensis* cells, all over the lamina (except over midrib) are polygonal and sinuous walled but in *G. oldhamii* cells over lamina near midrib are straight walled and elsewhere slightly wavy. Surface of the most of the cells of upper cuticle of *G. oldhamii* show small median papillae but papillae are restricted to the few cells of lower cuticle of midrib in *G. kuardihensis*. Helical arrangement of leaves of *G. kuardihensis* are also comparable with petrified leaves of *G. skaarensis* Pigg and *G. schopffii* Pigg, but other details are quite different. *G. kuardihensis* can be compared with the leaves of *G. petiolata* Pant & Gupta (1971) and *G. waltonii* Pant & Gupta (1971). Though the leaves of *G. petiolata* and *G. waltonii* are not attached to the axes but they resemble in their external features. The size and shape of *G. kuardihensis* is very close to *G. petiolata* but in *G. petiolata* vein concentration is 16-22 per cm near midrib and 24-30 per cm near margin.

Cells of upper and lower cuticle in *G. petiolata* are straight walled or arched while in *G. kuardihensis* they are sinuous walled. In *G. petiolata* cells over vein in lower cuticle are papillate. Few papillae are found over lower cuticle of midrib in *G. kuardihensis*. *G. waltonii* resembles with *G. kuardihensis* in having sinuous walled polygonal cells. The difference in size and shape of the leaves is insignificant, but meshes in *G. waltonii* are bigger (8 x 0.6 mm near midrib, 6 x 0.4 mm near margin) than that of *G. kuardihensis* (6.5 x 1.2 mm near midrib, 5 x 0.9 mm near margin). In *G. waltonii* surface of the upper and lower cuticles occasionally show small median papillae and guard cells are also over arched by the rudimentary papillae of subsidiary cells. *Glossopteris* leaves similar to those of *Glossopteris kuardihensis* are compared in Table-2.

## DISCUSSION

Five new species of *Glossopteris* are described in the present paper. *Glossopteris auriculata* sp. nov. shows an auriculate or cordate base and a narrow ribbon shaped lamina. The lamina is inserted at an angle to the petiole and this may suggest that the habit of plants of *Glossopteris auriculata* may also have been like that of *G. cordata*, *G. cordiformis*, *Belemnopteris* and *Sagittophyllum*, all of which are comparable, in this character, with leaves of the present day *Sagittaria* (Alismataceae), Araceae, Aristolochiaceae, Convolvulaceae and others.. Indeed, if the resemblance between such fossil leaves and the extant leaves mentioned above is any indication of their habit, they could have been lianas or their stems may have been geophilous or climbing with petioles growing upwards, as was also suggested for *Belemnopteris* (Pant & Choudhury 1977).

As against such petiolate leaves, the clearly non-petiolate leaves of *Glossopteris sessilis* sp. nov. and *Glossopteris subcostata* sp. nov. show a clear cut at the base, which suggests that the leaves were abscised by the formation of abscission layer. The leaves of *G. sessilis* are also unusual in being amphistomatic and show two kinds of stomata on their two faces: the stomata of multistomatic surface show subsidiary cells which are arranged in a more or less regular ring and those on the paucistomatic side have subsidiary cells like ordinary epidermal cells.

The leaves of *Glossopteris subcostata*, collected from Karharbari Formation, New Manjari Colliery, Nagpur Coalfield, have midribs which are ill-defined in the apical parts. The lateral veins anastomose and form meshes only near the midrib but rarely fuse elsewhere. All the same, near the margins, these lateral veins usually bend forwards as in *Glossopteris colpodes* Pant (1958) and their ends sometimes fuse with the end of the next vein to form loops or a marginal vein. Such loops have been shown to be present in *Glossopteris* leaves for the first time.

The leaves of *G. subcostata* could point towards the hypothetical group "Protoglossopterids" of Plumstead (1969) who believed that the group had *Glossopteris* like simple leaves but they were strikingly small and devoid of midrib as well as anastomoses between veins. Thus in the characters of its midribs and lateral veins, *G. subcostata* is only a degree ahead of the Protoglossopterids. In the midrib character,

*G. subcostata* appears as a connecting link between *Gangamopteris* and *Glossopteris*. Although, Talchir-Karharbari floral assemblage of glossopterid vegetation has dominance of leaves without a midrib like *Noeggerathiopsis*, *Rubidgea*, *Euryphyllum* and *Gangamopteris*. There are leaves of *Glossopteris* where the midrib is evanescent near the apex like in *G. decipiens*, *G. fusa*, *G. zeilleri* and *G. subcostata*. It is tempting to imagine that the midrib evolved by crowding parallel veins in the median longitudinal axis of the lamina and that such crowding may have started first at the base and only later extended to the apex

Lele (1976) suggested that there is a marked correlation between the abundance of midribless leaf forms and colder climate that prevailed during the Talchir-Karharbari sedimentation. But it will be quite premature to give such ideas about the evolution of the midrib because present day plants with and without midrib grow with almost equal frequency in cold as well as hot climates.

Table 2. Showing comparative characters of *Glossopteris* species which are similar to *G. kuardihensis* sp. nov.

Name of the species	Petiole	Size of leaf LxW (in cm)	Vein concentration / cm		Size of mesh (LxW in mm)		Leaf cuticle	Nature of cell wall	Shape of epidermal cells in mesh areas	Size of epidermal cells in mesh areas (in µm)		Sinuosities of sides of epidermal cells (in µm)		Papillae
			Near midrib	Near margin	Near midrib	Near margin				Upper cuticle	Lower cuticle	amplitude	wave-length	
<i>G. maculata</i> Pant & Singh	Present	9.8 x 3.8	5-13	13-20	2.5x 1.5	1.6 x 0.6	Hypos-tomatic	Sinuous	Irregular, rectanguloid to polygonal	86-48.5	88x38	6	22	Absent
<i>G. oldhamii</i> Pant & Singh	Present	15.4 x 6.8	8-14	15-32	7 x 1	5 x 0.5	Hypos-tomatic	Sinuous	Irregular or polygonal	94 x 51	65 x 44	11	27	Present over upper cuticle
<i>G. petiolata</i> Pant & Gupta	Present	19 x 2.7	16-22	24-30	6.7 x 0.57	5.4 x 0.46	Hypos-tomatic	Straight or arched	rectanguloid or polygonal	78 x 55	38 x 22	-	-	Present over veins in lower cuticle
<i>G. sastrii</i> Pant & Singh	Present	14 x 4	4-9	10-20	5.2 x 1.8	5.8 x 0.9	Hypos-tomatic	Sinuous	Irregular or polygonal	81 x 30	85 x 23	5	11	Subsidiary cells showing prominent or obscure papillae
<i>G. waltonii</i> Pant & Gupta	Absent	15 x 4.5	19-26	30-36	8 x 0.6	6 x 0.4	Hypos-tomatic	Undulate or sinuous	Irregular to polygonal	101 x 29	38 x 30	1.5	12	Present over lower cuticle, subsidiary cells and some cells of upper cuticle
<i>G. kuardihe-nsis</i> sp. nov.	Present	18 x 4.5	9-15	12-17	7x1	4.5x 0.9	Hypos-tomatic	Sinuous	Irregular or polygonal	120 x 55	64 x 25	13	45	Present over lower cuticle of midrib

The leafy twig of *G. kuardihensis* appears to be a dwarf shoot in which five leaves are attached in close spirals. This helical type of attachment of *Glossopteris* leaves has also been reported in anatomically preserved specimens of *G. skaarensis* and *G. schopfii*, in which Pigg (1990) reported 2/5 phyllotaxy.

Following types of leaf attachment have been reported by various authors in different species of *Glossopteris*: 1. Leaves attached in apparent whorls on dwarf shoots, e.g. *G. maculata*, *G. sastrii* and *G. oldhamii*. 2. Leaves attached in close spirals on dwarf shoots, e.g. *G. schopfii*, *G. skaarensis* and *G. kuardihensis*. 3. Leaves spirally attached on long shoots, e.g. *G. linearis*, *G. talbragarensis*. 4. Leaves attached in alternate fashion, e.g. *G. angustifolia*, *G. pandurata* and *G. taenioides*.

On the basis of different types of attachment of leaves of *Glossopteris*, one can speculate on the diversity in the habit of the plant of *Glossopteris*. Some of the *Glossopteris* plant could be large trees with a long and dwarf shoot system like that of modern *Ginkgo biloba*. This type of reconstruction of *Glossopteris* plant was proposed by Pant and Singh (1974), Gould and Delevoryas (1977) and Pant (1999). Other plants, where *Glossopteris* leaves are arranged in terminal whorls, might have been looking like the living plant of *Sciadopitys verticillata*. Some *Glossopteris* plants could have been woody shrubs, still others where leaves have cordate bases and stout petioles, these leaves might had geophillous stems like that of extant *Hemionites*, *Calocasia*, *Typhonium trilobatum*. The diversity in the habit of *Glossopteris* is also supported by different types of fructifications.

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