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Late Permian macrofloral remains from the Bijori Formation, Satpura Gondwana Basin and their biostratigraphic implications

Anju Saxena[1], Suyash Gupta[2], S. Suresh K. Pillai[3], Srikanta Murthy[4*], Deepa Agnihotri[5], Ranjit Khnagar[6], Savita C.[7] and Merajjuddin Khan[8]

[1, 2, 3, 4*, 5]Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow–226007, India. E-mail: [1]anju_saxena2002@yahoo.co.in, [2]suyash.gupta@bsip.res.in, [3]ssureshk_pillai@bsip.res.in, [4*]srikanta_murthy@bsip.res.in, [5]deepa_agnihotri@bsip.res.in
[6, 7, 8]Geological Survey of India, Central Region, Seminary Hills, Nagpur–440006, India. E-mail: [6]ranjitkhangar@gmail.com, [7]svtchaurpagar@gmail.com, [8]meraj.gsi@gmail.com
[*]Corresponding author

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ABSTRACT

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The present study deals with macrofloral assemblage of Bijori Formation, Satpura Gondwana Basin. The Bijori Formation is traditionally equated with the Raniganj (Son and Damodar basins), Kamthi Formation (Mahanadi and Wardha basins) and Pachhwara Formation (Rajmahal Basin). Due to the absence of coal seams in Bijori and Pachhwara formations these formations are often considered to be relatively younger than the Raniganj Formation. The present macrofloral assemblage of the Bijori Formation shows dominance of the genus *Glossopteris* with 18 species (*Glossopteris angustifolia* Brongn., *G. communis* Feistm., *G. churiensis* Ashw. K. Srivast., *G. formosa* Feistm., *G. gondwanensis* D.D. Pant & K.L. Gupta, *G. gopadensis* J. Banerji et al., *G. indica* Schimp., *G. intermedia* Feistm., *G. longicaulis* Feistm., *G. nakkarea* Sh. Chandra & Surange, *G. recurva* D.D. Pant & Rama Sh. Singh, *G. sastrii* D.D. Pant & Rama Sh. Singh, *G. searsolensis* D.D. Pant & Rama Sh. Singh, *G. stenoneura* Feistm., *G. taeniensis* Sh. Chandra & Surange, *G. tenuifolia* D.D. Pant & K.L. Gupta, *G. zeilleri* D.D. Pant & K.L. Gupta and *Glossopteris* sp.) along with *Chierophyllum maithyi* Pillai and *Vertebraria indica* (Unger) Feistm. Most of the species, recorded herein, are of small and medium size with narrow to moderate meshes. Though the assemblage is devoid of pteridophytic elements and scale leaves as reported earlier, it broadly resembles the floral assemblage of Raniganj Formation (late Permian age) of Damodar Basin. Additionally, it is comparable with the late Permian flora of other Indian Gondwana basins. The relatively small and narrow form of leaves is indicative of the prevalence of semi-arid conditions probably inhibiting the normal growth of Glossopteris plants. It also reflects that the Glossopteris flora was on the verge of decline towards the end Permian.

Keywords: Macrofossils, Glossopteris flora, Bijori Formation, Late Permian, Satpura Basin

INTRODUCTION

The Gondwana sedimentary successions in India are extensively developed in four major master basins namely, Son-Mahanadi, Damodar, Satpura, and Wardha-Godavari, and are primarily considered to be fluvio-lacustrine in origin (Figure 1). The extensive

exposures of these sedimentary sequences range in age from the early Permian to the Jurassic/Cretaceous periods and are very well exposed in all these basins. The sedimentary sequences pertaining to the Permian period are the major store house of the coal deposits in India. The Permian deposits are cateogerized in five formations, their standard nomenclature in stratigraphical order is: Talchir, Karharbari, Barakar, Barren Measures and Raniganj. Some of these formation are recognized with different names in different basins (Table 1).

The Satpura Gondwana Basin encompasses Narsinghpur, Chhindwara, Betul and Hoshangabad districts of Madhya Pradesh (between 22°06' and 22°28' N latitude and 77°48' and 78°53' E longitude) (Figure 1) and have very good exposures of Permian and Triassic sequences. The coal bearing sequence in Satpura Basin is the Barakar Formation. The overlying Motur Formation is equivalent to the Barren Measures Formation (Table 2). The topmost Bijori Formation is considered as equivalent to the Raniganj Formation of Damodar Basin and is compared with the non-coaliferous Kamthi Formation of Mahanadi and Wardha basins, and the Pachhawara Formation of Rajmahal Basin. These formations are considered younger in age (Srivastava & Agnihotri 2010a). The Bijori Formation was primarily identified on lithological basis and was named after the village Bijori (22°22' N: 78°30' E) in Chhindwara district, Madhya Pradesh (Medlicott, 1873). The thickness of the sediments generally varies from 180–250 m. However, Pascoe (1959) estimated the thickness up to ~600 m. The lithology and its relationship with underlying Motur Formation and overlying Triassic sediments of Pachmarhi Formation has been discussed in detail by Crookshank (1936).

The lithological architecture of the Bijori Formation shows great deal of variations. In the type area exposed in the Denwa River section, near Bijori village, it is characterized with thick bands of carbonaceous sandstone, red clay and fine carbonaceous shale. Whereas, near Tamia village, in the middle part, it shows buff coloured clays, argillaceous shales alternating with sandstone and thin bands of carbonaceous shale in the eastern part of the basin, the argillaceous facies is devoid of carbonaceous shale. Chakraborty and Sarkar (2005) discussed in detail the facies architecture of the Bijori Formation and envisaged depositional environment of this formation to be lacustrine in nature. The sedimentological evidence of Bijori Formation points towards lacustrine origin (lake delta) and wave-current depositional regime.

Like other Gondwana basins, Satpura Gondwana Basin has been studied in detail by many workers and plant fossil assemblages are mainly known from the Talchir, Barakar and Bijori formations (Feistmantel 1879a, b, 1881, Fox 1934, Crookshank 1936, Srivastava & Agnihotri 2009, 2010a, b, 2012, Agnihotri 2011, Pillai 2011). The macroplant fossils mainly belong to the genera *Schizoneura, Pecopteris, Neomariopteris, Santhalea, Trizygia,*

Table 1. Correlation of Late Palaeozoic Gondwana basins (after Mukhopadhyay et al. 2010).

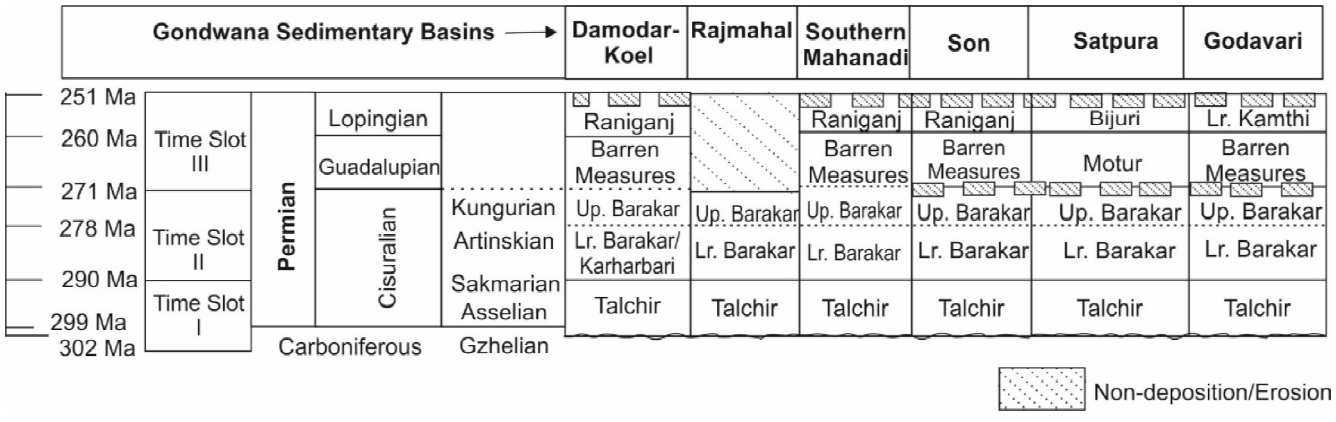

Table 2. General stratigraphic succession of Satpura Gondwana Basin (after Chakraborty & Sarkar 2005).

Formation	Lithology	Thickness	Age
Upper Gondwana			
Bagra	Conglomerate, pebbly sandstone, red mudstone; abundant calcareous nodules	~ 500 m	Jurassic (?)
	———— Unconformity ————		
Denwa	Red mudstone and heterolithic strata alternate with metre-thick fine to coarse sandstone; caliche profiles common	300–450 m	Anisian Lower Triassic
Pachmarhi	Very coarse pebbly sandstone with minor grey/red mudstone. Multi-storeyed sandstone with large compound bed forms	500–800 m	
	———— Unconformity ————		
Lower Gondwana			
Bijori	Fine to very coarse sandstone alternate with carbonaceous shale and thin coal beds. Abundant plant impressions, roots and wave-generated structures	800–1000 m	Upper Permian (Kazanian-Tatarian)
Motur	Thick red mudstone-dominated succession with embedded lenses and sheets of medium to very coarse sandstone; mudstone may be white, green or purple or dark grey; silicified wood fossils common. Sandstone to mudstone ratio varies from 1:10 to 3:1. Cross-beds abundant in sandstone; calcareous nodules of pedogenic origin typify red mudstone	330–480 m	Lower Permian (Ufimian–Kazanian)
Barakar	Quartzo-feldspathic, medium to very coarse sandstone. Sandstone white to yellowish orange; three major coal seams and associated carbonaceous shales interbedded with sandstone in the upper part of the formation. Contact with Motur Fm. sharp to gradational. Decimetre-scale cross-beds typical of sandstone; wave ripple and parallel lamination common in coal-shale units	140–225 m	Lower Permian (Artinskian)
Talchir	Boulder-pebble conglomerate, pebbly sandstone and khaki green shale	100–250 m	Upper Carboniferous (?)
	——— Unconformity ————		
	Gneisses, quartzites, granites, etc.		Precambrian

Gangamopteris, Glossopteris, Rhabdotaenia, Noeggerathiopsis, Vertebraria, scale leaves and equisetalean stems. However as compared to the other contemporaneous formations, the macrofloral studies of Bijori Formation are few. Crookshank (1936) documented the Bijori flora without proper illustrations and photographs. More recently, Srivastava and Agnihotri (2010a) carried out a comprehensive study of plant fossils of Bijori Formation and discussed their significance in understanding the extent and decline of the Glossopteris flora. Palynologically, the Bijori Formation is well studied and is considered to be equivalent to the Raniganj Formation based on striate-bisaccate dominant mioflora characterized by *Densipollenites* and *Corisaccites-Gutlulapollenites* and also some other miospores indicating a Permo-Triassic affinity (Bharadwaj et al. 1978). In a recent finding, a new invertebrate trace fossil *Palliedaphichnium gondwanicum* is recorded from palaeosols of the Bijori Formation consisting of burrows and chambers filled with pellets and is attributed to millipedes (Agnihotri et al. 2021). The co-occurrence of abundant plant remains in the same level indicates probable consumption of leaf litter by the invertebrates.

The present study deals with the macroflora of the Bijori Formation. These are comparable with the flora of the Raniganj Formation of Damodar Basin besides showing resemblance with the contemporaneous elements of other equivalent Indian Gondwana formations.

STUDY AREA AND GEOLOGICAL SETTING

In the Satpura Gondwana Basin, the main coalfields are Pench, Mohpani, Pathakhera and Kanhan. The fossils of the present study were collected from the Pench Valley Coalfield which extends between 22°09' and 22°14' north latitude and 78°40' and 78°55' east longitude and is more or less continuous with the Kanhan Valley (Figure 1). The Pench Valley Coalfield extends from the east-west direction from Sirgora (east) to Datla

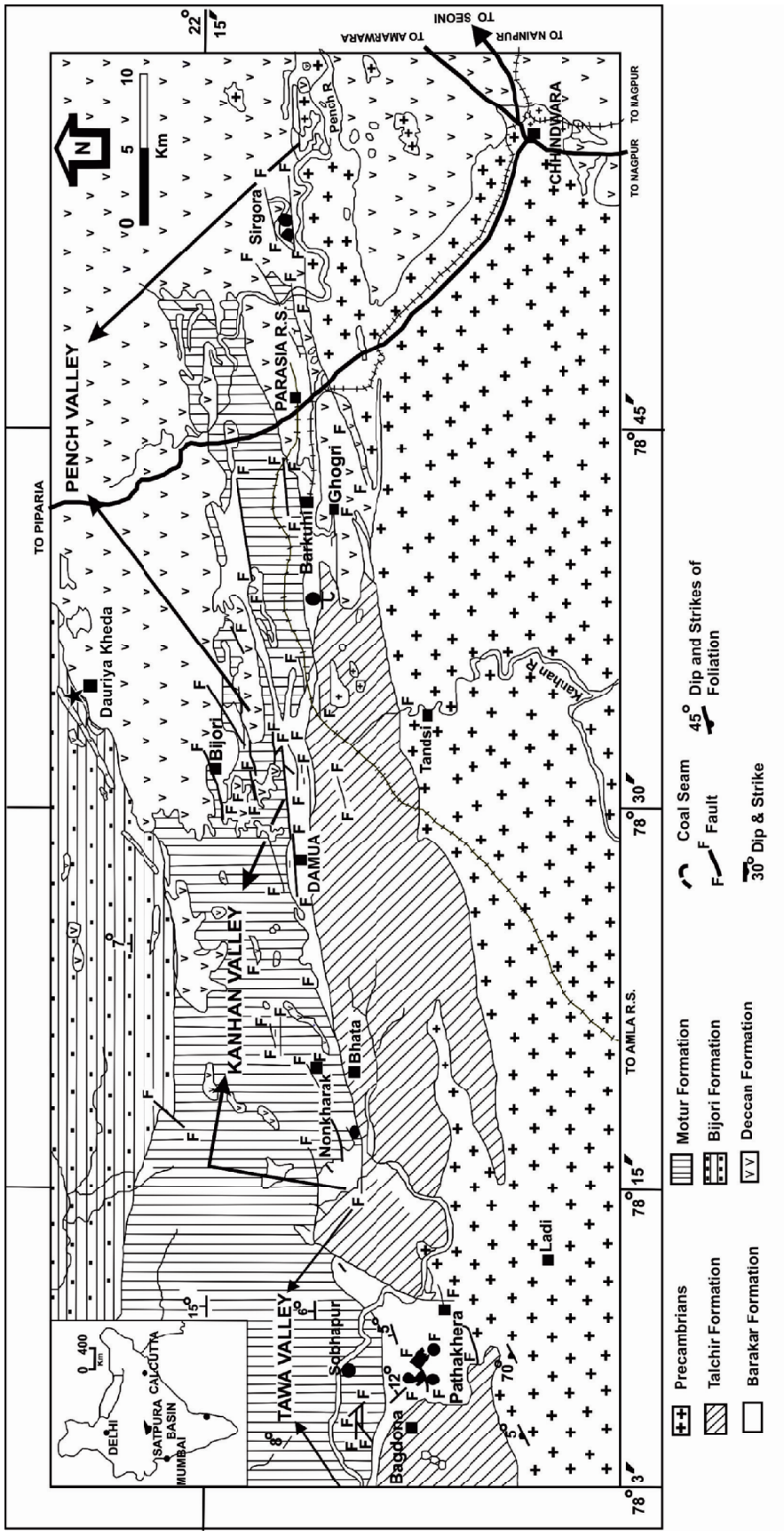

Figure 1. Geological map of Satpura Gondwana Basin (after Singh & Shukla 2004). A star shaped symbol, near Dauriya Kheda village (about 10 km NNE of Bijori), denotes the sample locality.

(west) Colliery. The Barakar Formation is the coal bearing formation in the Pench Valley Coalfield and is 350–400 feet thick. It consists of coarse sandstones, carbonaceous shales, shaly coal seams and good coal seams. The coal seams extend in a continuous patch from Barakuhi through Chandmeta and Parasia to the Pench River near Chhinda. In addition, there are disconnected areas of the Barakar Formation in various places. The overlying Motur Formation chiefly consists of yellow coarse sandstones and red mottled and buff clays of about 2000 feet thickness.

MATERIAL AND METHODS

The samples for the present study were collected from an outcrop section exposed in the Pench Valley near Dauriya Kheda village (about 10 km NNE of Bijori) in Chhindwara district, Madhya Pradesh. Altogether, 28 samples were collected from ~2 m thick grey shale unit sandwiched between thick sandstone units (Figure 2). The assemblage includes impressions of leaves and roots. Different morphological features such as shape of the leaf, nature of apex and base, midrib, type of meshes and the venation pattern have been taken into account for the identification of the leaves. The methodology as given by Chandra and Surange (1979) has been adopted for the description of various species of the genus *Glossopteris*. The specimens are measured and photographed using Sony HX 400 digital camera to record the morphological characters. All the specimens documented in this paper are deposited in the repository of the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow vide Statement No. 1589 and Museum Specimen Nos. 42131–42145.

SYSTEMATIC PALAEOBOTANY

Phylum: *Tracheophyta* Sinnott ex Caval.-Sm.

Class: *Ginkgoopsida* Engler

Order: *Ginkgoales* Gorozh.

Family: *Ginkgoaceae* Engler

Genus: *Cheirophyllum* D.D. Pant & Sudh. Singh 1978

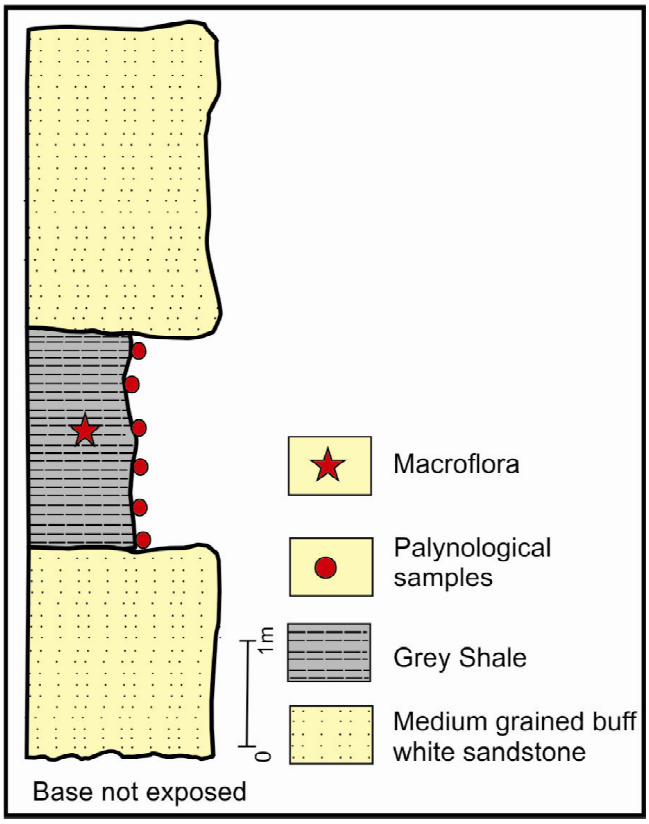

Figure 2. Litholog of the outcrop section near Dauriya Kheda village (about 10 km NNE of Bijori) in Chhindwara district, Madhya Pradesh, depicting different lithounits and shale unit yielding megafossil assemblage.

Type Species: *Cheirophyllum lacerata* (Feistm.) D.D. Pant & Sudh. Singh 1978

Cheirophyllum maithyi Pillai 2012

Figure 5.B

Remarks: The preserved leaf is small and is 2.2 cm long and 0.9 cm broad. The leaf is simple, lamina spathulate contracted towards base, apex not preserved, the upper part of the lamina is wide, lamina with longitudinal ridges, ridges dichotomize in the upper part but do not anastomose. There is one distinct median longitudinal ridge present up to middle part of the lamina. The present leaf is comparable with *Cheirophyllum maithyi* as described by Pillai (2012, Plate 1, figures 1–3) in its overall morphology. Pant and Singh (1978) erected a new combination as *Cheirophyllum lacerata* including some of the taxa identified as *Noeggerathiopsis lacerata* (Feistmantel 1886) and

genus *Palmatophyllites* (Maithy 1965). Pant and Singh (1978) discussed that recognizable allies of *Cheirophyllum* are unknown, and even a broad group affinity is uncertain. However, few workers relate it with *Ginkgoales*.

Class: *Dictyopteridiopsida* Doweld

Order: *Glossopteridales* Melville

Family: *Glossopteridaceae* Trapl

Genus: *Glossopteris* Brongn. ex Brongn. 1831

Type species: *Glossopteris browniana* Brongn. ex Brongn. 1831

Glossopteris angustifolia Brongn. 1828

Figure 5.D

Remarks: Only one specimen is present in the collection. Leaf nearly complete, narrow-oblanceolate in shape; apex somewhat rounded base not preserved. Leaf measures 2 cm long and 0.9 cm broad at its widest part, margin entire. Midrib flat, striate, lateral veins emerge at acute angle, and meet margin at 45º–60º, dichotomize and anastomose to form narrow, elongated meshes. Mesh size ranges between 3–4 mm in length and 0.2–0.3 mm in width in the middle region of the lamina. Vein density is 26–32/cm^2. Specimen is comparable with *G. angustifolia* described by Brongniart (1828, Plate 63, figures 1, 1a), Chandra and Surange (1979, Plate 13, figure 5, Plate 19, figure 7, Plate 42, figure 2) Chandra and Singh (1992, Plate 1, figures 1, 3, Plate 2, figures 1, 4) Tewari (2007, Plate 2, figure 1, Plate 3, figure 5, Plate 5, figure 4) and Singh and Saxena (2015, Plate I, figure 4).

Glossopteris churiensis Ashw. K. Srivast. 1977

Figure 6.E

Remarks: There is only one leaf in the collection of size 1.5 cm long and 0.8 cm broad. Preserved leaf is small, broad, oblanceolate in shape, and apex is obtuse. Lateral veins arise at an angle of 45° and travels towards the margin. Meshes are narrow and elongated. The present leaf specimen is comparable with specimens of *Glossopteris churiensis* in its overall morphology as described by Srivastava (1977, Plate 2, figures 8, 9), Chandra and Surange (1979, Plate 1, figure 10, Plate 17, figure 14, Plate 26, figure 5), Singh et al. (2006, Plate 3, figure 4) and Saxena et al. (2020, Figure 4e).

Glossopteris communis Feistm. 1879b

Figure 3.E

Remarks: Only one leaf in the collection, measuring 9 cm in length and 5 cm in width. The leaf is of medium size. Apical and basal parts of the leaf are not preserved. The midrib is 0.4 mm broad at base and tapers towards upper part. The lateral veins arise at an angle of 45° and move towards margin with arching backwards. Veins are dense and run parallel to each other forming long and narrow meshes. Veins are dense throughout the leaf. The present leaf specimen is comparable with the holotype of *Glossopteris communis* Feistm. 1879b (Plate 17, figures 1, 2), re-described by Chandra and Surange (1979, Plate 1, figures 2, 3) (Geological Survey of India specimen nos. 5022 and 5087), in their general shape and venation pattern. The specimen is also comparable with the specimens described by Chandra and Singh (1992, Plate 1, figure 5, Plate 2, figure 5), Singh et al. (2006, Plate 4, figure 3), Singh et al. (2011, Plate 1, figure 1, Plate 5, figure 1), Srivastava et al. (2012, Plate 1, figure e) and Singh and Saxena (2015, Plate 3, figure 4) in their overall morphological details.

Glossopteris formosa Feistm. 1881

Figure 6.C

Remarks: The preserved leaf is small narrow and 2.5 cm long and 0.6 cm broad in size. The basal part of leaf is not preserved. The apex is obtuse having entire margin. Midrib narrow and attenuates towards apex. Secondary veins arise at an angle of 20° and travel

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Figure 3. A. *Glossopteris zeilleri* D.D. Pant & K.L. Gupta 1968, BSIP Museum Specimen No. 42131a. **B.** *Glossopteris sastrii* D.D. Pant & Rama Sh. Singh 1974, BSIP Museum Specimen No. 42131b. **C.** *Glossopteris longicaulis* Feistm. 1879, BSIP Museum Specimen No. 42134. **D.** *Glossopteris* sp., BSIP Museum Specimen No. 42132b. **E.** *Glossopteris communis* Feistm. 1879, BSIP Museum Specimen No. 42132a. **F.** *Glossopteris* sp., BSIP Museum Specimen No. 42136. (Scale bar 5 mm for all the figures).

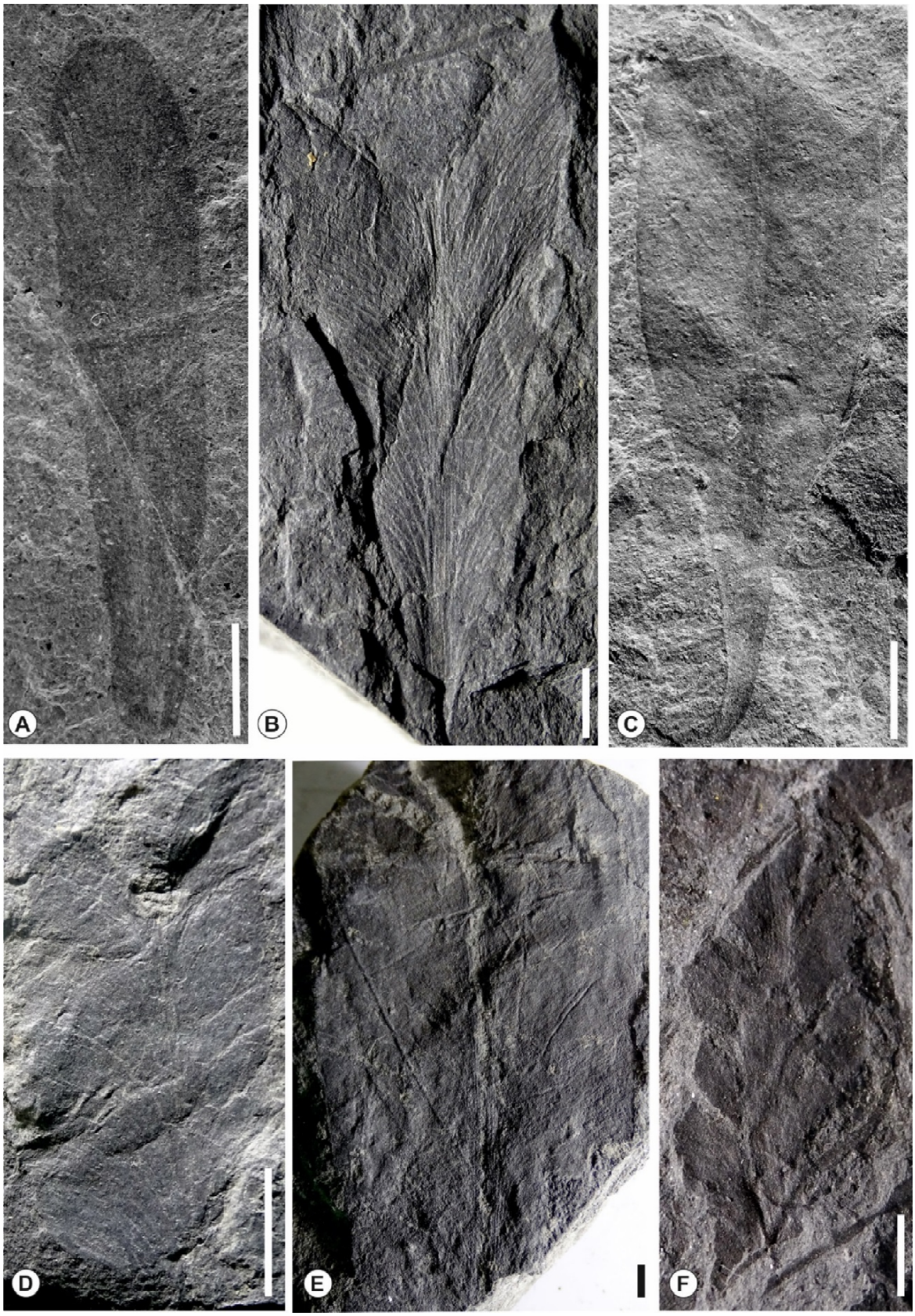

Figure 3

straight towards the margin. The meshes are large throughout the preserved leaf. The preserved leaf is comparable with *Glossopteris formosa* as described by Feistmantel (1881, Plate 39A, figures 3–7), by Srivastava (1956, Plate 4, figure 26) and with the specimens described by Chandra and Surange (1979, Plate 21, figure 4, Plate 44, figure 6).

Glossopteris gondwanensis D.D. Pant & K.L. Gupta 1971

Figure 4.D, 6.A

Remarks: There are two small leaves in the collection of size 2–3 cm long and 0.5–0.7 cm broad. The leaves are narrow. Midrib is 0.5–0.7 mm broad and reach apex. The angle of emergence of secondary veins is less than 15°. The secondary veins are short and broad throughout the lamina. The present leaf impression is comparable with the holotype specimen of *G. gondwanensis* described by Pant and Gupta (1971, Plate 16, figure 2) and with the specimens described by Chandra and Surange (1979, Plate 13, figures 3, 6, Plate 22, figure 7, Plate 23, figures 4, 10, Plate 44, figures 1, 3), Chandra and Singh (1992, Plate 12, figure 4, Plate 13, figure 2), Singh and Saxena (2015, Plate II, figure 6) and Saxena et al. (2019, figure 6d).

Glossopteris gopadensis J. Banerji et al. 1976

Figure 5.C

Remarks: Two specimens in the collection. Leaves small, narrow strap shaped, leaf almost complete, measures 4.6 cm in length and 0.5 cm in width, length : width ratio approx. 8:1, apex appears to be acute, base acute normal; midrib narrow and persistent, does not show much tapering; secondary veins arise at an angle of about 45° or little more, reach margin with gentle curves. Veins wavy, meshes elongate narrow and are of equal size throughout the lamina. The specimens show close resemblance to the holotype specimen described by Banerji et al. (1976, Plate 1, figures 13–15), specimens illustrated by Chandra and Surange (1979, Plate 12, figures 2, 3, Plate 18, figure 8, Plate 44, figure 5) and Chandra and Singh (1992, Plate 5, figure 3, Plate 6, figure 2). The species is known to occur in early Triassic Panchet Formation.

Glossopteris indica Schimp. 1869

Figure 4.C

Remarks: Only one specimen is present in the collection, preserved leaf is small and measures 2.8–0.75 cm. Leaf is oblanceolate and very narrow. Midrib is broad and tapers towards the apical part of the leaf. The angle of emergence of veins is less than 45°. The meshes are broad near midrib and narrow near the margin. The vein density is more towards the margin than near the midrib. Lateral veins run parallel to each other till they reach the margin. The specimen is comparable with the lectotype specimen of *G. indica* Schimp. 1869 designated by Rigby et al. (1980, figures 38, 39, 40, 41) in having ovate-lanceolate shape; distinct midrib, broad meshes near midrib and narrow near margin and in venation pattern. The species is very common in the Lower Gondwana formations of India and reported and described by several workers. Specimen is also comparable with the *G. indica* as described by Srivastava et al. (2012, Plate 1, figure f), Srivastava and Agnihotri (2010a, Plate 2, figure 4), Singh and Saxena 2015 (Plate 2, figure 3), Saxena et al. (2019, figure 9a) and Saxena et al. (2020, figure 4F).

Glossopteris intermedia Feistm. 1880

Figure 4.B, 5.G, 6.B, D

Remarks: There are three small leaves in the collection measuring 1.8–3 cm in length and 0.5–0.7 cm in width. The basal parts of the leaves are not preserved. Midrib 2–4 mm broad. The leaves are

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Figure 4. A. *Glossopteris stenoneura* Feistm. 1877, BSIP Museum Specimen No. 42135a. **B.** *Glossopteris intermedia* Feistm. 1880, BSIP Museum Specimen No. 42137a. **C.** *Glossopteris indica* Schimp. 1869, BSIP Museum Specimen No. 42137b. **D.** *Glossopteris gondwanensis* D.D. Pant & K.L. Gupta 1971, BSIP Museum Specimen No. 42135b. **E.** *Glossopteris zeilleri* D.D. Pant & K.L. Gupta 1968, BSIP Museum Specimen No. 42133. **F.** *Glossopteris recurva* D.D. Pant & Rama Sh. Singh 1974, BSIP Museum Specimen No. 42144a. (Scale bar 5 mm for all the figures).

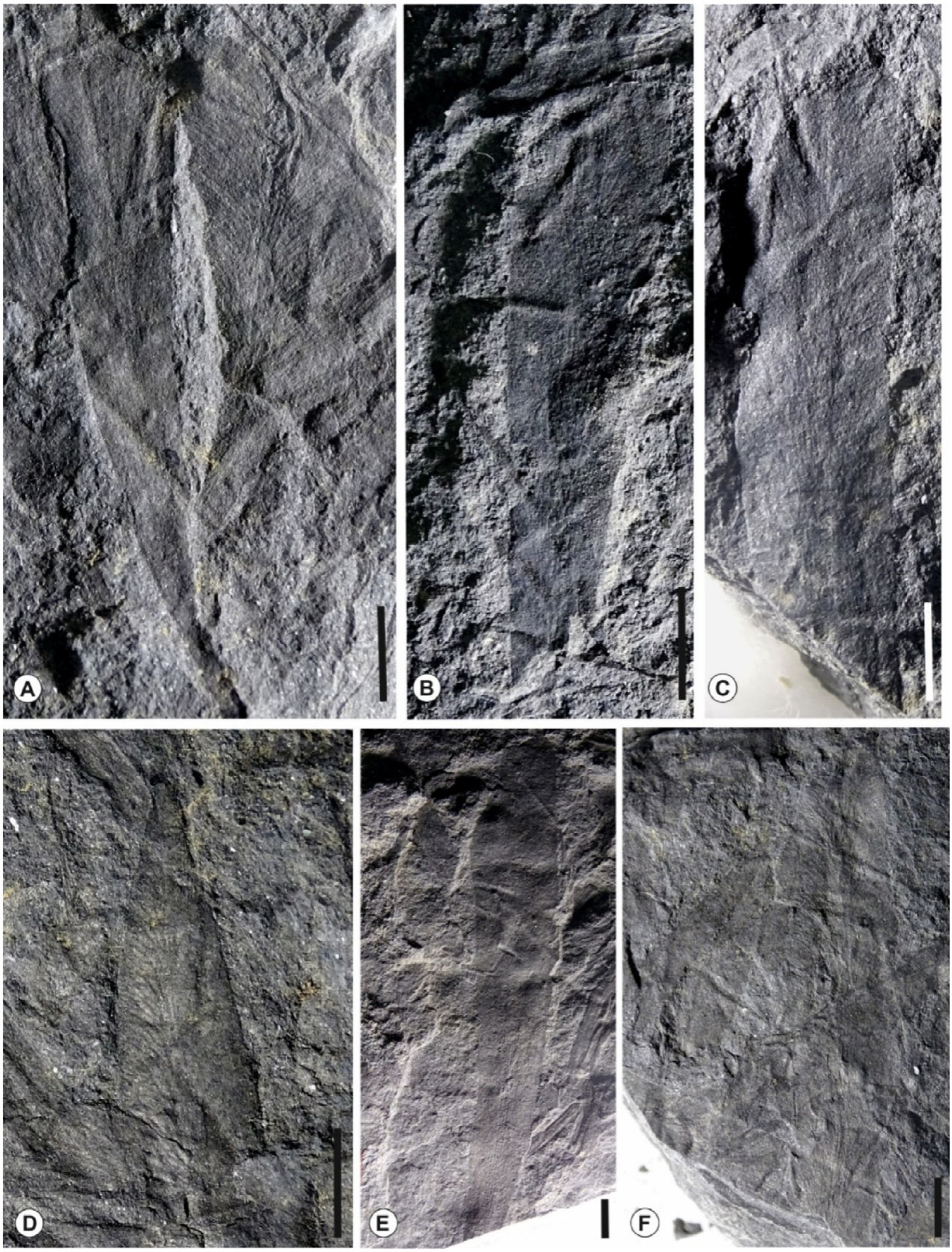

Figure 4

narrow and elliptical in shape. The leaves have acute apices and entire margin. The midrib is broad in lower part and narrow towards apex. Angles of emergence of veins are less than 40°. The meshes are polygonal, broad and uniform throughout the lamina. Specimens are comparable with the holotype specimen Feistmantel 1881 (Plate 39A, figure 6), which was described as *G. browniana* but later on retained as a distinct species by Chandra and Surange (1979). The specimens also show close resemblance with the leaf described by Maheshwari (1965), Pillai et al. (2018, Plate 2, figure 1) and Saxena et al. (2020, Figure 4C) in their overall venation pattern. Medium size, very narrow elliptic shape with a length width ratio approximately 8:1, acute apex and thick midrib are the distinguishing characters of this species.

Glossopteris longicaulis Feistm. 1879b

Figure 3.C

Remarks: One incomplete leaf is present in the collection. Only the lower half of the leaf is preserved measuring 3.5 cm in length and 1.4 cm in width, base attenuate with long petiole. Margin entire, midrib distinct, flat striated, 1 mm broad in basal part, persistent into the petiolar part. The secondary veins arise from the midrib at an angle of about 45º, then arch out to the margin. The meshes are long and polygonal in shape. The present leaf is similar to the specimen of *Glossopteris longicaulis* Feistm. (1879b, Plate 31, figures 1, 3) and Chandra and Surange (1979, Plate 1, figure 4, Plate 15, figure 13) in having a distinct petiolar base and venation pattern. The leaf also shows resemblance to the specimens described by Tewari and Srivastava (2000, Plate 1, figure 3), Agnihotri et al. (2016, Plate 3, figure 1), Tewari et al. (2017, Plate 4, figures 4, 5), Pillai et al. (2018, Plate 2, figure 4) and Saxena et al. (2019, Plate I, figure 2) in its characteristic morphology.

Glossopteris nakkarea Sh. Chandra & Surange 1979

Figure 5.H

Remarks: The preserved small leaf is 3.8 cm long and 0.8 cm broad. Preserved leaf is narrow linear-lorate in shape and apex is acute. Midrib is narrow and tapers towards the apex. The lateral veins arise at an angle of 45° and reach the margin. Meshes are elongate and straight. The venation is dense near the margin. The present leaf is comparable with the holotype specimen of *Glossopteris nakkarea* Sh. Chandra and Surange (1979, Plate 47, figure 2, specimen No. 34063) and the specimen described by Saxena et al. (2016, Plate 1, figure 3, Plate 2, figure 1) in overall morphological details.

Glossopteris recurva D.D. Pant & Rama Sh. Singh 1974

Figure 4.F

Remarks: Leaf is small and the preserved part is 3.7 cm long and 0.7 cm broad, base is not preserved. The shape of leaf is oblong lorate and apex is obtuse. Midrib is 1.5 mm broad at base and narrows towards the apex. The secondary veins arise at angle of less than 45° and form thin and narrow meshes of equal size. The leaf closely resembles with the holotype specimen of *Glossopteris recurva* D.D. Pant & Rama Sh. Singh (1974, Plate 31, figure 61) and specimens described by Chandra and Surange (1979, Plate 42, figure 4), Saxena et al. (2016, Plate 2, figure 2) and Saxena et al. (2020, figure 6D). The other closely comparable forms of this taxon are *Glossopteris zeilleri* and *G. vulgaris*. *Glossopteris zeilleri* is a

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Figure 5. A. *Glossopteris taeniensis* Sh. Chandra & Surange 1979, BSIP Museum Specimen No. 42138. **B.** *Cheirophyllum maithyi* Pillai 2012, BSIP Museum Specimen No. 42141a. **C.** *Glossopteris gopadensis* J. Banerji et al. 1976, BSIP Museum Specimen No. 42145a. **D.** *Glossopteris angustifolia* Brongn. 1828, BSIP Museum Specimen No. 42141b. **E.** *Vertebraria indica* (Unger) Feistm. 1877, BSIP Museum Specimen No. 42139. **F.** *Glossopteris* sp., BSIP Museum Specimen No. 42145. **G.** *Glossopteris intermedia* Feistm. 1880, BSIP Museum Specimen No. 42144b. **H.** *Glossopteris nakkarea* Sh. Chandra & Surange 1979, BSIP Museum Specimen No. 42144c. **I.** *Glossopteris tenuifolia* D.D. Pant & K.L. Gupta 1968, BSIP Museum Specimen No. 42140. (Scale bar 5 mm for all the figures).

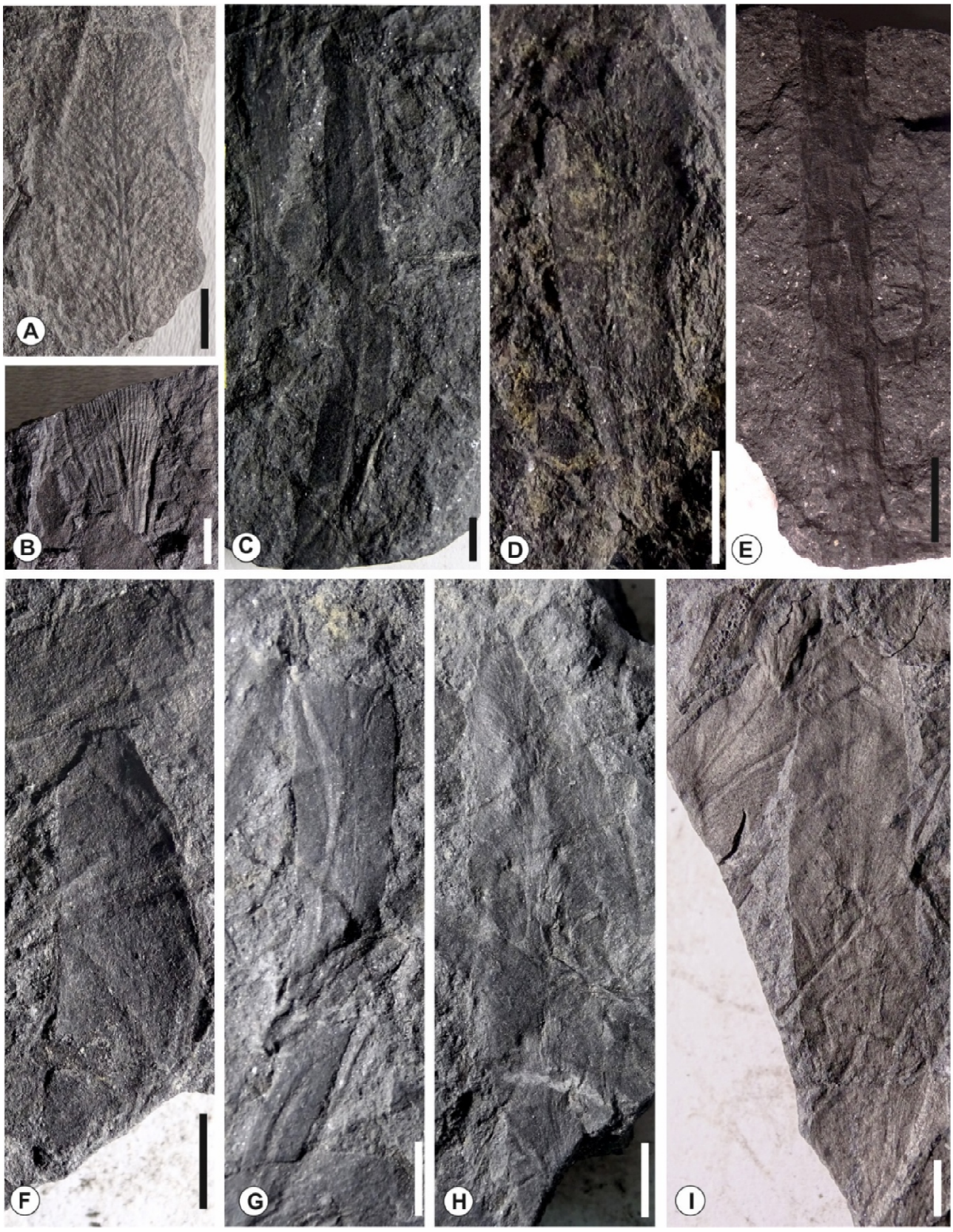

Figure 5

spatulate leaf with dense venation and evanescent midrib, whereas *G. vulgaris* is almost same size as *G. recurva* but is a narrower form with distinct apex and base and thinner veins.

Glossopteris sastrii D.D. Pant & Rama Sh. Singh 1974

Figure 3.B

Remarks: The preserved medium sized leaf is 5 cm long and 2 cm broad. The upper part of the leaf is not preserved. The leaf is narrow and elliptical in shape. The midrib is broad near base and taper towards the apex. Veins arise at an angle of 45°. Meshes are large near the midrib and narrow near margin. The leaf is similar to the specimens described as *Glossopteris sastrii* by Pant and Singh (1974, Plate 27, figures 33–39, Plate 35, figure 92) in its morphology and venation pattern. The specimen is also comparable with the specimens illustrated by Chandra and Surange (1979, Plate 39, figure 2) and Chandra and Singh (1992, Plate 13, figure 3).

Glossopteris searsolensis D.D. Pant & Rama Sh. Singh 1974

Figure 6.F

Remarks: An incomplete leaf impression is present in the collection. The upper part of the leaf is preserved measures 4.2 long and 2 cm broad. The leaf is small and shape is oblong. The apex is obtuse. The midrib is thin. Secondary veins arise at an angle of 45°. Meshes are narrow near margin and broader near midrib. The leaf is comparable with holotype specimen of *Glossopteris searsolensis* described by Pant and Singh (1974, specimen no. 4147) and specimens described by Chandra and Surange (1979, Plate 23, figures 6, 12, Plate 47, figure 1). The species was erected by Pant and Singh (1974) based on cuticular features, but later Chandra and Surange (1979) revealed that it has distinct morphological features. Specimens also show accordance with the specimens described by Singh et al. (2006, Plate 3, figure 5) and Saxena et al. (2020, figure 5C).

Glossopteris stenoneura Feistm. 1877

Figure 4.A

Remarks: The preserved leaf is small measuring 2.9 cm long and 0.8 cm broad, midrib 0.5 mm broad. Secondary veins arise from midrib at an angle of less than 45°graceful curve backwards before reaching the margin. Meshes are elongate and narrow. The present specimen closely resembles with the lectotype of *G. stenoneura* figured by Chandra and Surange (1979, Plate 1, figure 7, vide specimen no. GSI 5269 of Feistmantel (1881, Plate 32A, figure 3, Plate 33A, figure 1) in its venation pattern. It is also comparable with *G. stenoneura* as described by Chandra and Singh (1992, Plate 3, figure 2, Plate 4, figure 4), Tewari and Srivastava (2000, Plate 1, figure 2), Tewari (2008, Plate 2, figure 2, Plate 4, figure 6), Srivastava and Agnihotri (2010a, Plate 3, figure 1) Singh et al. (2011, Plate 4, figure 3), Srivastava et al. (2012, Plate 1, figure g), Singh and Saxena (2015, Plate I, figure 1) and Saxena et al. (2020, figure 6A) in overall morphology.

Glossopteris taeniensis Sh. Chandra & Surange 1979

Figure 5.A

Remarks: The preserved leaf is small, 2.5 cm long and 1 cm broad. The shape of the leaf is broad and obovate. Apex is obtuse. Midrib is prominent and tapers towards margin. The secondary veins arise at angle of about 45°. The meshes are broad near midrib and narrow near margin.The leaf specimen shows close resemblance with the type specimen described by

→

Figure 6. A. *Glossopteris gondwanensis* D.D. Pant & K.L. Gupta 1971, BSIP Museum Specimen No. 42142a. **B.** *Glossopteris intermedia* Feistm. 1880, BSIP Museum Specimen No. 42141c. **C.** *Glossopteris formosa* Feistm. 1881, BSIP Museum Specimen No. 42142b. **D.** *Glossopteris intermedia* Feistm. 1880, BSIP Museum Specimen No. 42143a. **E.** *Glossopteris churiensis* Ashw. K. Srivast. 1977, BSIP Museum Specimen No. 42143b. **F.** *Glossopteris searsolensis* D.D. Pant & Rama Sh. Singh 1974, BSIP Museum Specimen No. 42142c. (Scale bar 5 mm for all the figures).

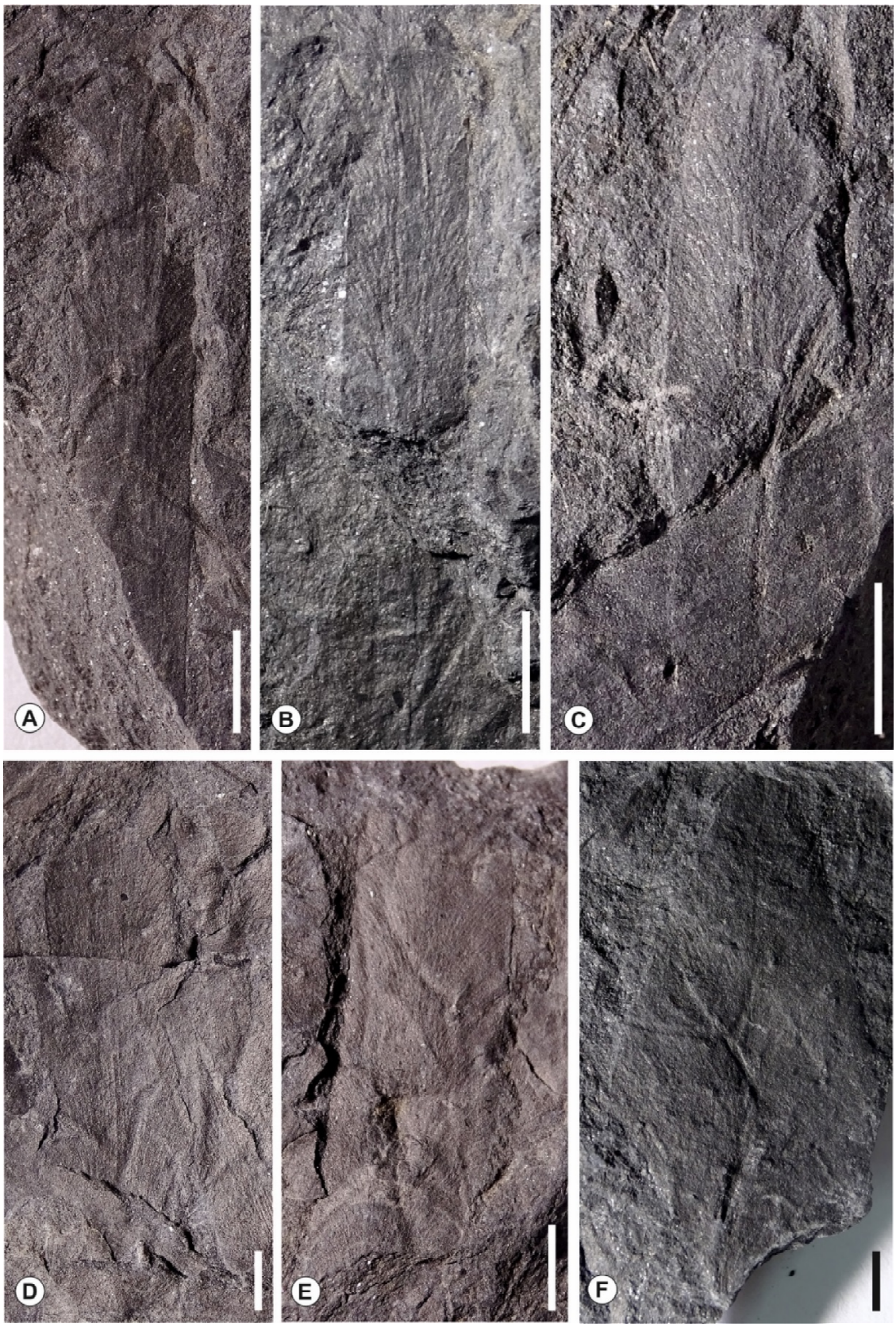

Figure 6

Chandra and Surange (1979, Plate 23, figures 7, 9, Plate 43, figure 5) and is one of the smallest leaf of *Glossopteris*. Our specimen is also comparable with specimens described by Srivastava (1977, Text-figures 19A, 47I) as *Glossopteris browniana* and Srivastava (1977, Text-figures 27C, 49A) as *G. conspicua* from Auranga Coalfield but later designated as *G. taeniensis*. The species is comparable with *G. rewaensis* and *G. barakarensis*. *G. rewaensis* is bigger leaf with small and broad meshes whereas, *G. barakarensis* is larger leaf with horizontal venation and narrower and longer meshes. The specimen also resembles with those described by Saxena et al. (2020, figure 5A).

Glossopteris tenuifolia D.D. Pant & K.L. Gupta 1968

Figure 5.I

Remarks: The preserved leaf is 5 cm long and 1 cm broad. The size of leaf is small and shape is linear-lorate . The midrib is thin and tapers towards apex. Secondary veins arise at an angle of less than 45°. The meshes are long and narrow throughout the lamina. The leaf resembles with the specimens of *Glossopteris tenuifolia* described by Pant and Gupta (1968, Plate 21, figure 15) and Chandra and Surange (1979, Plate 6, figure 1, Plate 15, figure 10, Plate 17, figure 10, Plate 42, figures 1, 6) in overall shape, length to width ratio and venation pattern. Leaves are also comparable with *G. tenuifolia* as described by Chandra and Singh (1992, Plate 4, figure 1, Plate 5, figures 1, 2), Singh and Chandra (2000, Plate 3, figures 2, 3), Singh et al. (2006, Plate 1, figure 4), Tewari (2008, Plate 2, figures 5, 9, Plate 3, figure 4, Plate 4, figure 5), Tewari et al. (2012, figures 7c, d), Singh and Saxena (2015, Plate I, figure 2, Plate II, figures 1, 2) and Saxena et al. (2020, figures 5G, 6C). It is also one of the most commonly distributed species in the Permian strata of India.

Glossopteris zeilleri D.D. Pant & K.L. Gupta 1968

Figure 3.A, 4.E

Remarks: There are two preserved leaves in the collection, 3.2–6.5 cm long and 0.7–1 cm broad. The shape of the leaf is narrow and oblanceolate. The leaf has distinct midrib which is 0.6–0.8 mm broad at base. Apex is obtuse. The veins arise at an angle of about 10°–20°) and reach the margin. Meshes long and narrow near midrib and short and narrow near margin. The leaf is comparable with the specimens of *G. zeilleri* described by Pant and Gupta (1968, Plate 21, figure 20), Chandra and Surange (1979, Plate 6, figure 4), Singh et al. (2006, Plate 1, figure 5) and Singh and Saxena (2015, Plate IV, figure 1) in nature of apex and having narrow, elongate meshes throughout the lamina.

***Glossopteris* sp.**

Figure 3.D, F, 5.F

Remarks: Three incomplete specimens are present in the collection. Preserved leaves range 2.3–2.8 cm in length and 1–1.5 cm in width. Midrib distinct and 0.9–1.1 mm broad. Secondary veins arise at an angle of about 45° and reach the margin with gentle curves. The present leaves belong to *Glossopteris* sp. as midrib is present but due to the lack of other distinctive morphological features species rank could not be ascertained.

Vertebraria indica (Unger) Feistm. 1877

Figure 5.E

Remarks: Incomplete root axis, preserved horizontally and branched. The axis measures 6.3 cm long and 0.7 cm broad. Two rows of distinctive unequal rectangular area measuring 0.7–1.3 mm width are seen. It is similar with *Vertebraria indica* (Unger) Feistm. 1877 described by Joshi et al. (2015, figure 3d).

DISCUSSION AND CONCLUSIONS

The Post-Barakar Permian sequences in Satpura Gondwana Basin are recognized by Motur and Bijori formations. The Motur Formation is correlated with the Barren Measures Formation of Son-Mahanadi and Damodar basins, whereas, the Bijori Formation is traditionally equated with the Raniganj Formation (Son and Damodar basins), Kamthi Formation (Mahanadi and Wardha basins) and Pachhwara Formation (Rajmahal Basin) (Srivastava 1997, Srivastava &

Agnihotri 2010a). Due to the absence of coal seams in Bijori and Pachhwara formations, these formations are often considered to be relatively younger than the Raniganj Formation (Prasad 1985, Pal & Ghosh 1997). In the present assemblage, the macrofloral assemblage of the Bijori Formation has the dominance of the genus *Glossopteris* with 18 species (*Glossopteris angustifolia*, *G. communis, G. churiensis, G. formosa, G. gondwanensis, G. gopadensis, G. indica, G. intermedia, G. longicaulis, G. nakkarea, G. recurva, G. sastrii, G. searsolensis, G. stenoneura, G. taeniensis, G. tenuifolia, G. zeilleri* and *Glossopteris* sp.), along with *Chierophyllum* (*C. lacerata*), *Vertebraria* (*V. indica*) and stem axes. Most of the species recorded herein are small and medium size. The assemblage is devoid of any pteridophytic elements and scale leaves as reported in previous studies. A distinct macrofloral assemblage recovered from the different localities of Bijori Formation has been discussed in detail by Srivastava and Agnihotri (2010a). The assemblage comprises of pteridophytic remains (*Santhalaea bansoliensis, Neomariopteris* sp. and *Trizygia speciosa*), *Glossopteridales* (*Glossopteris* with 20 species, *Vertebraria indica* and *Cordaicarpus* seeds) and equisetalean axes. The leaves recovered from the Bijori Formation are small and linear-lanceolate in shape with narrow meshes, unlike the leaves recorded from the coaliferous sequences of Raniganj Formation of Son and Damodar basins. The present assemblage has some of the common elements as previously reported from the Bijori Formation by Srivastava and Agnihotri (2010a) namely *G. angustifolia, G. communis, G. gopadensis, G. indica, G. searsolensis, G. stenoneura, G. tenuifolia* and *Vertebraria indica*. Interestingly, Srivastava and Agnihotri (2010a) also observed the abundance of narrow-elongate and small sized *Glossopteris* species in their assemblage.

Similar observations were also made by Singh and Saxena (2015), where a distinct late Permian macrofloral assemblage was recorded from the Raniganj Formation of Jhingurdah colliery, Singrauli coalfield, Son Basin. They argued that occurrence of relatively small sized leaves (as compared to the size of similar species reported from the Raniganj or Lower Kamthi formations of other basins/ coalfields) (Singh & Chandra 1987) of different *Glossopteris* species in the assemblage indicate semi-arid conditions prevailing in the area during Lopingian; that probably retarded the normal growth of these plants (Singh & Saxena 2015). They further opined that, such non-congenial climatic conditions probably did not allow the glossopterids to flourish as is evidenced by the fact that the recorded flora was completely devoid of fructifications which is also the case in present assemblage too. It was also envisaged, that the absence of the groups *Lycopodiales*, *Sphenophyllales*, *Filicales*, *Ginkgoales* and *Coniferales* in the assemblage indicates that this palaeogeographic region might not had been suitably cool and humid to facilitate the growth of these shade loving under storied plants.

The overall general composition of the flora of the Bijori Formation (this study and previous studies) suggests the relationship of assemblages with the late Permian flora of Raniganj Formation in having glossopterid and pteridophytic association (Surange 1975, Srivastava 1997, Chandra & Chandra 1987, Srivastava & Agnihotri 2010a). However, the floral composition recorded from the Bijori and Pachhwara formations by various workers reveals their distinct conformation led to the argument of their younger age (Chandra & Singh 1992, Prasad et al. 1987). Moreover, the occurrence of some of the *Glossopteris* species and their continuation into the early Triassic strata also suggest some limited correlation with the Kamthi and Pachhwara formations. Likewise, the relatively low species richness and quantitative diversity as evidenced by the floral records of Kamthi/Bijori/ Pachhwara represents that in all likelihood the Glossopteris flora survived in impoverish climatic set up with stunted forms of glossopterids and few explanatory records of pteridophytes during the transitional phases from the Permian to Triassic (Lele 1976, Chandra 1992, Goswami et al. 2018, Saxena et al. 2019). This is further substantiated by the presence of invertebrate ichnogenus *Palliedaphichnium gondwanicum*–a burrow recorded from the Bijori

Formation (Agnihotri et al. 2021); characterized with chambers and presence of abundant pellets in burrows also indicates that the paleoclimate showed adverse conditions, at least seasonally.

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