The Palaeobotanist 63(2014): 137–155
0031–0174/2014

Reappraisal of the genus *Dicroidium* Gothan from the Triassic sediments of India

PANKAJ K. PAL[1*], AMIT K. GHOSH[2], RATAN KAR[2], R.S. SINGH[2], MANOBIKA SARKAR[1] AND RESHMI CHATTERJEE[2]

[1]*Department of Botany, UGC Centre of Advanced Study, University of Burdwan, Burdwan–713 104, West Bengal, India.*
[2]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[*]*Corresponding author: pkpalbot@gmail.com*

(Received 28 August, 2014; revised version accepted 25 September, 2014)

ABSTRACT

Pal PK, Ghosh AK, Kar R, Singh RS, Sarkar M & Chatterjee R 2014. Reappraisal of the genus *Dicroidium* Gothan from the Triassic sediments of India. The Palaeobotanist 63(2): 137–155.

The genus *Dicroidium* Gothan, belonging to Corystospermaceae, is characterised by pinnately compound leaves with proximally forked primary rachis. The genus was earlier included under the genus *Thinnfeldia* Ettingshausen. *Dicroidium* is the most consistent macrofloral element in the Triassic strata of Southern Hemisphere. The present reassessment deals with the morphotaxonomy and stratigraphic significance of the species of *Dicroidium* in India. A critical review of the literature reveals that the specimens of *Dicroidium* described so far from India require reassessment, because same morphotypes have often been placed under different species names and sometimes dissimilar elements have been assigned to the same species. In view of this, a thorough analysis of Indian *Dicroidium* was undertaken based on fresh collections along with the species described earlier by previous workers.

The present reappraisal reveals that the genus in the Triassic of Peninsular India is represented by eight species. These are *D. hughesii* (Feistmantel) Lele, *D. zuberi* (Szajnocha) Archangelsky, *Dicroidium* sp. cf. *D. crassinervis* (Geintz) Anderson & Anderson, *D. townrovii* Retallack, *D. nidpurensis* Bose & Srivastava, *D. gopadensis* Bose & Srivastava, *D. giarensis* Pal and *Dicroidium* sp. In Indian peninsula, appearance of *Dicroidium* heralds the onset of Triassic sediments belonging to the early Triassic Panchet Formation (Induan). In the younger sequence of Triassic, i.e. during late Triassic Tiki and Parsora formations (Carnian to Norian–Rhaetian), the diversity and species richness of the genus gradually enhanced and *Dicroidium* foliages became the most predominant component of Triassic macroflora of India. The genus does not occur in strata younger than the Triassic and thereby the total extinction of *Dicroidium* signifies the end of the Triassic Period.

Key–words—Reappraisal, Dicroidium, Triassic, India.

भारत के ट्रायसिक अवसादों से प्राप्त डाइक्रोइडियम वंश का पुनर्मूल्यांकन

पंकज पाल, अमित कुमार घोष, रतन कर, आर.एस. सिंह, मनोबिका सरकार एवं रेशमी चटर्जी

सारांश

कोरिस्टोस्पर्मेसी से संबंधित *डाइक्रोइडियम* गोथान वंश को समीपस्थ दुशाखी प्राथमिक प्राक्ष के साथ फैली हुई मिश्रित पत्तियों द्वारा लक्षणित किया गया है। इस वंश को पहले *थिन्नफेल्डिया* एटिंगशोसेन वंश के अंतर्गत सम्मिलित किया गया था। *डाइक्रोइडियम* दक्षिणी गोलार्ध के ट्रायसिक सतहों में सबसे अधिक दृढ़ दीर्घपुष्पी तत्व है। वर्तमान पुनर्मूल्यांकन भारत में *डाइक्रोइडियम* प्रजाति की आकारवर्गिकी तथा स्तरिकी महत्व का व्यवहार करता है। ज्ञान की आलोचनात्मक समीक्षा प्रकट करती है कि भारत से अब तक वर्णित *डाइक्रोइडियम* के नमूनों को पुनर्मूल्यांकन की आवश्यकता है क्योंकि इसी प्रकार के आकार–प्रकार के नमूनों को विभिन्न प्रजातियों के नामों के अंतर्गत प्रायः रखा गया है और कई बार भिन्न तत्वों को उसी प्रजाति का नाम दिया गया है। इस दृष्टिकोण से, भारतीय *डाइक्रोइडियम* का पूर्व कार्मिकों द्वारा वर्णित प्रजातियों के साथ–साथ ताजा संग्रहण के आधार पर पूर्णरूप से विश्लेषण कर लिया गया था।

वर्तमान मूल्यांकन प्रकट करता है कि प्रायद्वीपीय भारत के ट्रायसिक में इस प्रजाति को 8 प्रजातियों द्वारा प्रदर्शित किया गया है। ये *डी. हयुसाई* (फाइस्टमेंटल) लेले, *डी. जुबेरी* (स्जाजनोचा) आर्चेन्जलस्काई, *डी. क्रेसीनर्विस* (जींटज़) एंडर्सन व एंडर्सन, *डी. टाऊनरोवी* रिटेलक, *डी. निदपुरेंसिस* बोस व श्रीवास्तव, *डी. गोपाडेंसिस* बोस व श्रीवास्तव, *डी. गायरेंसिस* पाल तथा *डाइक्रोइडियम* प्रजाति हैं। भारतीय प्रायद्वीप में, *डाइक्रोइडियम* का रूप प्रारंभिक ट्रायसिक पंचेत शैलसमूह (इंडुअन) से संबंधित ट्रायसिक अवसादों के आक्रमण की घोषणा करता है। ट्रायसिक के तरूण अनुक्रम में अर्थात् अंतिम ट्रायसिक टिकी एवं परसोरा शैलसमूहों (कार्नियन से नोरियन–रेशियन) के दौरान, वंश की विभिन्नता व प्रजाति प्रचुरता धीरे–धीरे बढ़ती है और *डाइक्रोइडियम* पत्ते भारत के ट्रायसिक दीर्घपुष्पी के सबसे अधिक पूर्व प्रमुख अवयव हुए। यह वंश ट्रायसिक से तरूण सतहों में नहीं पाया जाता है और उनके द्वारा *डाइक्रोइडियम* का संपूर्ण नाश ट्रायसिक अवधि के अंत का संकेत करता है।

सूचक शब्द—पुनर्मूल्यांकन, *डाइक्रोइडियम*, ट्रायसिक, भारत।

INTRODUCTION

PROXIMALLY forked pinnately compound leaf, the marker of early Mesozoic floras of the Southern Hemisphere, was initially included in the genus *Thinnfeldia* Ettingshausen (1852). Gothan (1912) separated some of the forms from the unforked Northern Hemisphere genus *Thinnfeldia* and assigned them to the generic name *Dicroidium*. The separation was justified, but this concept gained very slow acceptance. Opinions remained divided regarding the choice of using the two generic names. Some authors preferred to use the name *Thinnfeldia* more or less in a comprehensive sense; others had their own reasons for considering *Dicroidium* Gothan as a separate genus from *Thinnfeldia*. The reason regarding the controversy was that the characteristic features for separating *Dicroidium* from *Thinnfeldia* had not been unanimously accepted because there was a paucity of data on the cuticles of *Dicroidium*. In due course, general consensus gradually developed in favour of distinguishing the two genera. Contribution by Townrow (1957) provided new light on this issue and it became a useful advancement on the original ideas of Gothan (1912). A number of points regarding the diagnostic characters of *Dicroidium* and *Thinnfeldia* became clearer and at the same time certain discrepancies, which in the past had largely led to more confusion, were resolved. For example, certain fertile fragments described by Walkom (1917) as fertile leaves of *Thinnfeldia* were later proved to belong to an entirely different plant *Asterotheca* (Townrow, 1957).

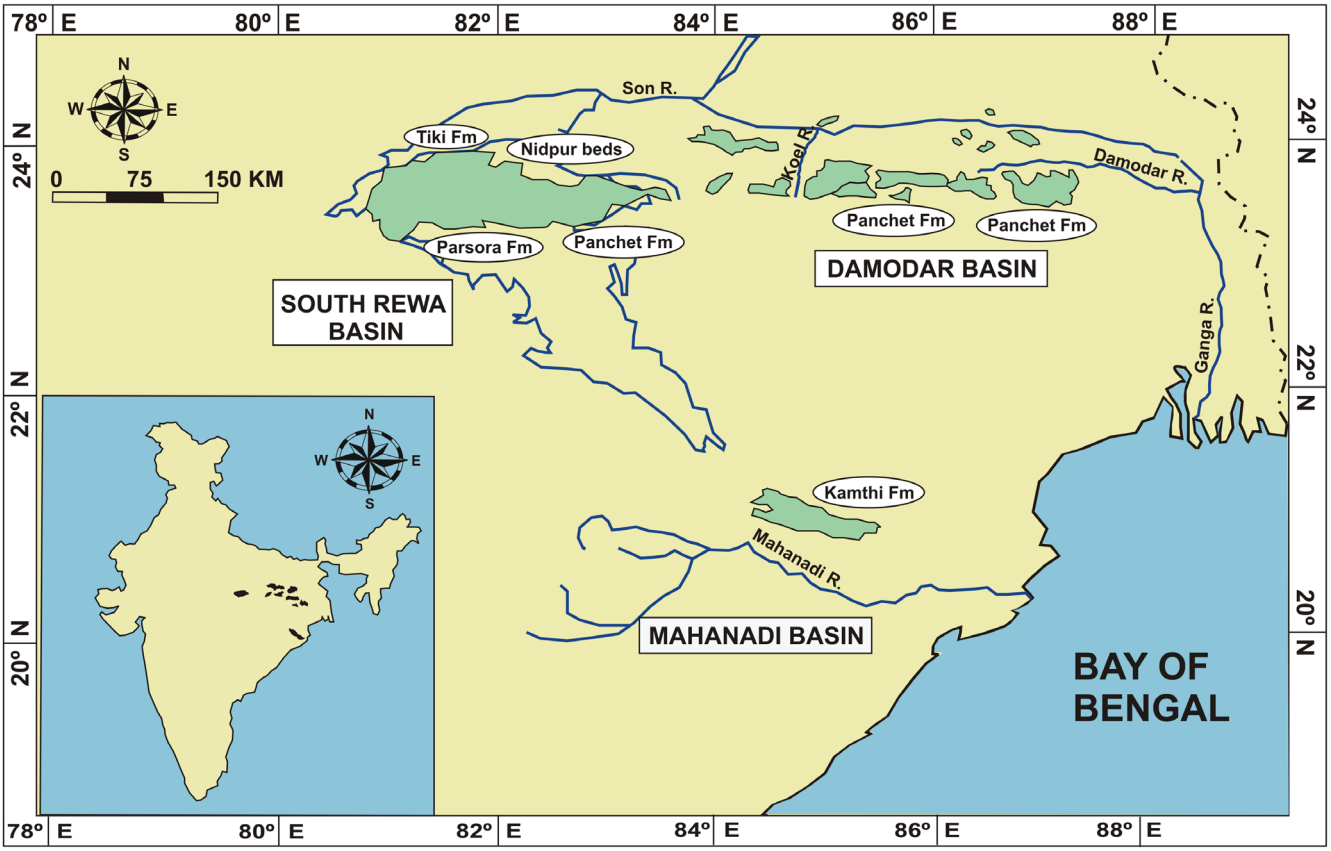


Fig 1—Part of Indian peninsula showing the Gondwana basins and different Triassic formations.

***Dicroidium* (Type species: *D. odontopteroides*)**	***Thinnfeldia* (Type species: *T. rhomboidalis*)**
Primary rachis proximally forked dichotomously.	Primary rachis not dichotomously forked.
Leaf amphistomatic.	Leaf hypostomatic.
Stomata over main rachis transversely oriented.	Stomata over main rachis longitudinally oriented.
Stomata evenly distributed all over the lamina.	Stomata on lamina restricted mostly in intervenal bands.
Stomatal apparatus bilaterally symmetrical; stomatal pit rectangular, subsidiary cells typically four, differentiated into two polar and rest lateral.	Stomatal apparatus radially symmetrical; stomatal pit rounded and surrounded by a regular ring of subsidiary cells.
Anticlinal walls of epidermal cells sinuous, sometimes with cutin projections and periclinal wall of each epidermal cell is typically with a solid papilla.	Anticlinal walls of epidermal cells straight and periclinal wall flat.

Table 1—Distinguishing features of the genera *Dicroidium* and *Thinnfeldia*.

The genera *Dicroidium* and *Thinnfeldia* can be differentiated by a number of distinguishing features (Table–1). Moreover, stratigraphic as well as geographical distribution of the two genera are different. *Dicroidium* is essentially a Southern Hemisphere genus and never occurs beyond the Triassic, while *Thinnfeldia* is essentially a Northern Hemisphere genus occurring mostly in rocks of Jurassic age. Dichotomous forking of main rachis is a characteristic feature of the pteridospermous leaves of Palaeozoic; however, *Dicroidium* is the only known Mesozoic form that exhibits the proximal forking of principal rachis.

Considering the vegetational dynamics and stratigraphy, *Dicroidium* is the most significant floral element of Southern Hemisphere Triassic sequences. *Dicroidium* foliages in association with its microsporangiate organs, *Pteruchus* and ovulate structures, *Umkomasia* constitute the most preponderant elements in the Triassic deposits of India, Australia, South Africa, Argentina, Madagascar and Antarctica (Bose *et al.,* 1990).

In Peninsular India, the Triassic succession is well developed in Damodar, Mahanadi, Narmada, Pranhita and Godavari Valley basins including Satpura and South Rewa Gondwana basins. The sequence is also known to occur in the subsurface of the Rajmahal Basin, where it is represented by the part of the Dubrajpur Formation (Tripathi *et al.,* 1990). However, in none of the areas the sequence is complete. Therefore, interbasinal correlation has been done on palaeontological and lithological attributes. A generalised classification of Triassic Gondwana in Peninsular India has been given in Table–2 (based on Roy Chowdhury *et al.* 1975; Sastry *et al.,* 1977; Pal, 1984a, b, 1996; Kutty *et al.,* 1988; Srivastava & Jha, 1990; Pal & Ghosh, 1997; Dutta, 2002, 2004; Ghosh *et al.,* 2007; Mukherjee *et al.,* 2012).

Amongst the Triassic outcrops in India, species of *Dicroidium* are known to occur in the Panchet Formation of Damodar Valley Basin, Pathargarh beds of Kamthi Formation in the Mahanadi Valley Basin, the Panchet Formation of Ramkola–Tatapani Coalfield and Nidpur beds, Tiki and Parsora formations of South Rewa Gondwana Basin (Fig. 1).

Occurrence of *Dicroidium* in India was first recorded by Lele (1962) when he included a number of leaf forms previously described as *Danaeopsis* by Feistmantel (1882) and *Thinnfeldia* by Seward (1932) together with the specimens of his own collections from the Parsora Formation. The specimens from Parsora Formation were predominantly preserved as impressions on red siltstones and rarely as compressions with some patches of epidermis preserved as ferruginous crust. These crusts revealed some details of the epidermal features when studied under bright–field microscope with strong incident light. Lele (1962) described altogether four species, viz. *Dicroidium hughesii, D. odontopteroides, D. sahnii* and *Dicroidium* sp. cf. *D. feistmantelii*. Satsangi (1973) reported the occurrence of ?*Dicroidium* from the Panchet Formation of Raniganj Coalfield based on few fragments of pinnate fronds preserved as impressions. The same material along with a few freshly collected specimens were subsequently described and figured by Banerji and Bose (1977) as ?*Dicroidium*/*Lepidopteris*. Bose and Banerji (1976) described a few fragmentary leaf impressions as *Dicroidium* sp. from the Panchet Formation of Auranga Coalfield. Bose and Srivastava (1971) described three new species of the genus, viz. *D. nidpurensis*, *D. papillosum* and *D. gopadensis* based on compression specimens from the Nidpur beds of South Rewa Gondwana Basin. Pal (1984b) described the morphographic and cuticular features of *D. hughesii, D. zuberi* and *D. coriaceum* and instituted a new species, *D. giarensis* from the Tiki Formation of South Rewa Gondwana Basin. Further, Pal (1985) figured two specimens of *D. hughesii* and Pal and Sur (2003) described *D. zuberi* from the Dhaurai Hill beds of Parsora Formation of South Rewa Gondwana Basin. Pal *et al.* (1991) and Pal and Ghosh (1997) reported the occurrence of *D. zuberi, D. superbum* and *D. giarensis* from

the Pathargarh beds of Kamthi Formation in the Mahanadi Valley Basin.

A critical review of the literature reveals that the specimens of *Dicroidium* described so far from India require reassessment, because same type of materials have often been placed under different species names and sometimes dissimilar elements have been assigned to same species. In view of this, a thorough analysis of Indian *Dicroidium* was undertaken based on material worked out by previous authors together with fresh collections.

MATERIAL AND METHODS

The present reassessment is based on the specimens from the following localities:

i. Panchet Formation exposed along Iria Nala Section, near Premnagar Village, Balrampur District, Chhattisgarh.
ii. Panchet Formation exposed along Sukri River Section, near Deobar Village, Latehar District, Jharkhand.
iii. Nidpur beds exposed on the south bank of Gopad River, near Nidpur Village, Sidhi District, Chhattisgarh.
iv. Pathargarh beds of Kamthi Formation, near Pathargarh Village, Dhenkanal District, Odisha.
v. Giar beds of Tiki Formation exposed along the Son River section, near Giar Village, Shahdol District, Chhattisgarh.
vi. Tiki Formation exposed on the east bank of Janar River, near Harai Village, Shahdol District, Chhattisgarh.
vii. Parsora Formation exposed on the west bank of Ghorari Nala, near Parsora Village, Umaria District, Chhattisgarh.

Detailed morphographic study of the macrofossils was made under reflected light using a Leica Wild M420 Stereo–binocular microscope. The specimens were photographed with a Nikon D2X digital camera under strong reflected light at various angles. Cuticular preparations were studied in Olympus BX 50 bright–field microscope for detailed study of epidermal features and text figures were redrawn. All the figured specimens and slides are housed in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow and in the Repository of Department of Botany (Palaeobotany and Palynology Section), UGC Centre of Advanced Study, University of Burdwan, West Bengal.

SYSTEMATICS

Genus—DICROIDIUM Gothan 1912

Dicroidium hughesii (Feistmantel) Lele 1962

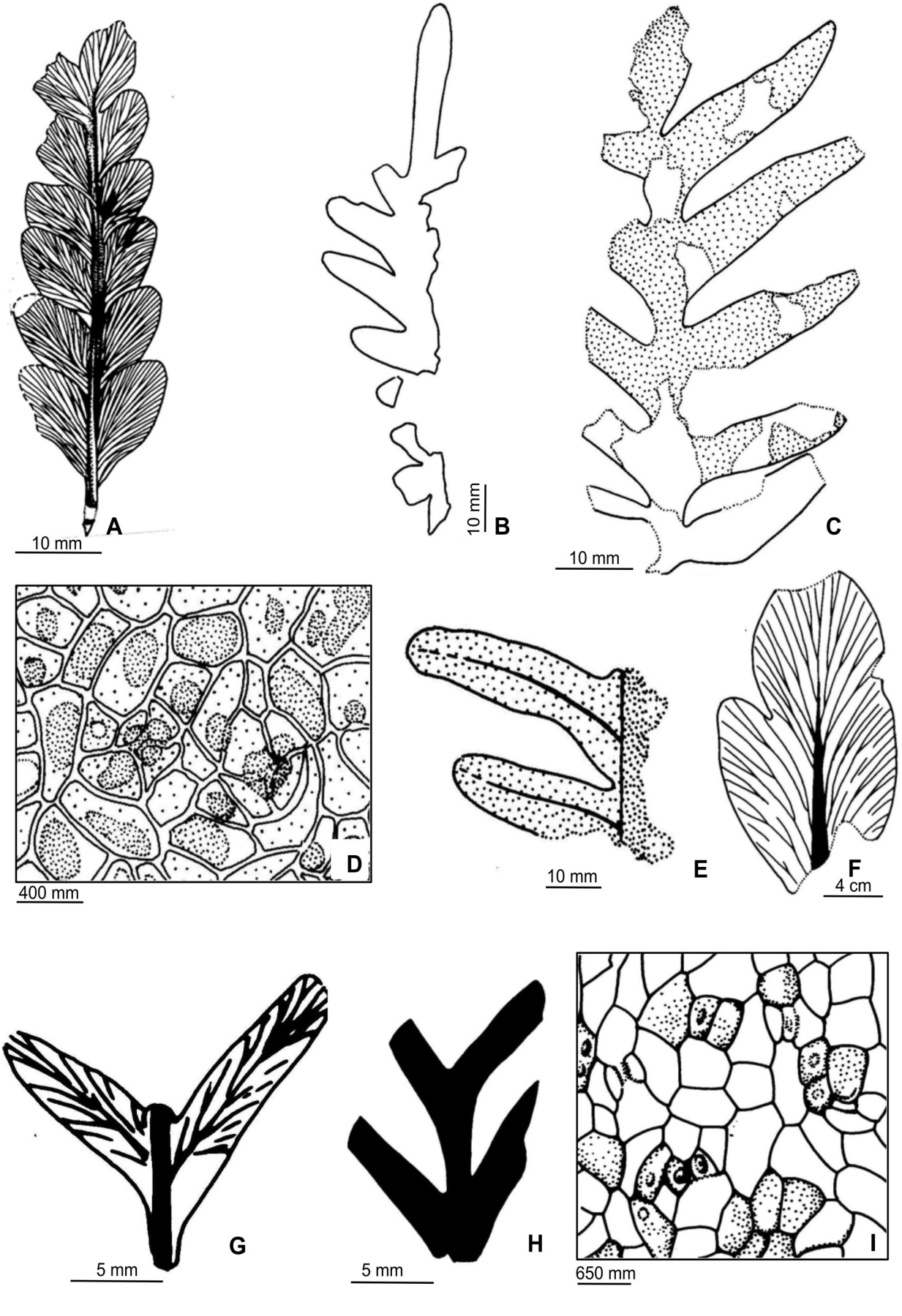
(Pl. 1.1–2; Figs 2, A–E)

1882 *Danaeopsis hughesii* Feistmantel; p. 25; pl. 4, fig. 1; pl. 5, figs 1, 2; pl. 6, figs 1, 2; pl. 7, figs 1, 2; pl. 8, figs 1–5; pl. 9, fig. 4; pl. 10, fig. 1; pl. 14, fig. 1.
1932 *Thinnfeldia (Danaeopsis) hughesii* (Feistmantel) Seward; p. 239.
1956 *Thinnfeldia (Danaeopsis) hughesii* (Feistm.) Seward, Lele: p. 24–25; pl. 2, figs 8, 12, 14, 15, 24; text–fig. 1.
1962 *Dicroidium hughesii* (Feistmantel) Lele: p. 56–59; pl. 3, figs 14–22; text–figs 6A–Q.
1962 cf. *Dicroidium hughesii* (Feistm.) Lele: p. 59–61; pl. 4, figs 23–33; text–figs 4A,B.
1912 *Dicroidium odontopteroides* (Morr.) Gothan, Lele: p. 51–54 (part), pl. 1, fig. 3; text–figs 2C–E.
1984b *Dicroidium hughesii* (Feistmantel) Lele, Pal: p. 257; pl. 2, figs 13–18; text–figs 2A, B; 3A–E.
1985 *Dicroidium hughesii* (Feistmantel) Lele; Pal: p. 224; pl. 1, figs 6, 7.
1990 *Dicroidium hughesii* (Feistmantel) Lele; Pal *et al.*: p. 1–3; figs 1–4.

Description—Leaf up to 50 cm long, once–pinnate, imparipinnate. Rachis proximately forked once. Pinnae opposite or subopposite, typically oblong to lanceolate, gradually becoming shorter towards leaf base, at extreme base near the forking of the rachis pinnae becoming almost orbicular in shape; each pinna attached by whole broad base with basiscopic margin decurrent along the rachis; lateral margin of pinna entire; apex obtuse or subacute. Typically each pinna with a distinct midvein, beside midvein a few veins arise directly from the rachis; secondary veins arising at angles of about 40˚, slightly arching, mostly once forked. Leaf amphistomatic, venal region with files of elongated cells; other epidermal cells mostly isodiametric–polygonal, cells of upper surface mostly with rounded corners and larger in size than those of the lower surface; cell outline straight; surface smooth or with a low solid papilla, papillae rare on upper surface but frequent on lower one. Stomata slightly less in number on upper surface, irregularly distributed and oriented; subsidiary cells 4–6 (typically 4) in number, two polar and rest lateral; on upper surface subsidiary cells rarely with a low solid papilla, on lower surface subsidiary cells often papillate.

→

Fig 2—A–E. *Dicroidium hughesii* (Feistmantel) Lele. A. from Panchet Formation of Ledho Nala Section (figured in Memoirs Geological Survey of India, Palaeontologica Indica Ser. XII, Pl. XXIII A). B. Specimen No. 35618 from Tiki Formation of Janar River Section. C. Specimen No. BSIP 35619 from Tiki Formation of Janar River Section. D. Slide No. 35619–1 from Tiki Formation of Janar River Section showing thicker side of cuticle of lamina with two stomata and epidermal cells. E. Specimen No. BSIP 35617 from Tiki Formation of Janar River Section. F. *Dicroidium zuberi* (Szajnocha) Archangelsky, from Tiki Formation of Janar River Section showing venation pattern. Slide No. BSIP 35631–4. G–I. *Dicroidium* sp. cf. *D. crassinervis* (Geinitz) Anderson & Anderson. G. Slide No. BSIP 35640–1 from Tiki Formation of Janar River Section showing venation pattern. H. Specimen No. BSIP 35639 from Tiki Formation of Janar River Section. I. Slide No. BSIP 35640–2 from Tiki Formation of Janar River Section showing thinner cuticle surface of lamina with epidermal cells and a few stomata.


A
10 mm
B
10 mm
C
10 mm
D
400 mm
E
10 mm
F
4 cm
G
5 mm
H
5 mm
I
650 mm

Stomatal pit typically rectangular; guard cells sunken, thinly cutinised; aperture slit–like.

Occurrence—Tiki and Parsora formations, South Rewa Gondwana Basin.

Remarks—Feistmantel (1882) figured some specimens from the Parsora Formation of South Rewa Gondwana Basin as *Danaeopsis hughesii*. Seward transferred this taxon to Ettingshausen's genus *Thinnfeldia* and then Gothan assigned it to his newly established genus *Dicroidium*. Lele (1956) based on a fresh collection from the Parsora Formation, described this species as *Thinnfeldia (Danaeopsis) hughesii* (Feistm) Seward. In a latter work, Lele (1962) described it under the genus *Dicroidium*, as *D. hughesii*. The specimens from Parsora Formation are preserved as impressions. Lele (1962) studied the epidermal feature of some of these specimens under strong reflected light. Pal (1984b) described compression specimens of *D. hughesii* from the Janar River Section of the Tiki Formation. However, there is some disagreement between the two published accounts of the epidermal features of *D. hughesii*, one from the impression specimen by Lele, and the other based on the compression specimens by Pal (1984b). Both these accounts agree that the leaf was amphistomatic. But, Lele (1962) stated that the stomata on upper surface are very rare and probably occur on or close to the midvein. On the other hand, in the compression specimens, Pal (1984b) described stomata occurring throughout the upper surface of the leaf. In view of this situation, the specimens of both types of preservation have been re–examined for a better understanding of this taxonomically as well as stratigraphically important taxon. A good many specimens of *D. hughesii* have been collected from the Tiki and Parsora formations. Since the specimens from the Tiki Formation possess well preserved phytoleimma, cuticular surfaces of an entire pinna could be prepared. Such preparations reveal the amphistomatic nature of the leaf with stomata evenly distributed over the entire leaf surface without any tendency to concentrate over the midrib. Stomatal frequencies on upper and lower leaf surfaces are 44 mm^2 and 65 mm^2 respectively. On the other hand, specimens from the Parsora Formation are purely impressions in fine–grained ferruginous sandstones and devoid of any phytoleimma. However, in some specimens, a ferruginous crust is present at places that show the epidermal features to certain extent under strong reflected light. Lele (1962) made his study by this technique after peeling off small pieces of crust. Lele (1962) could not find a stoma in the upper surface away from the midrib region and therefore, he believed that stomata on the upper surface are very rare and probably occur on or close to the midvein. However, it should be noted that to understand the stomatal distribution by studying such tiny bits of crust is very difficult. Moreover, preservation is so poor that it is often quite difficult to recognize a stoma properly. In Parsora specimens, on the upper surface of the leaf, stomata occur over the midvein as well as in the lamina away from the midvein; moreover, a stoma also can be seen (Lele, 1962; pl. 3, fig. 17) showing a laminar portion. Several specimens of *D. hughesii* collected from the Parsora Formation depict the proximal forking of the rachis. But all the specimens so far recovered from the Tiki Formation are broken at their bases and thus the proximal forked regions of the fronds are missing. However, in some specimens, two leaf–fragments are preserved in such a way that they appear to belong to a forked frond. In all available morphographical as well as epidermal features, the compression specimens from the Tiki Formation are indistinguishable from those of the Parsora Formation. Specimens of *Dicroidium odontopteroides* described by Lele (1962) are likely to be smaller forms of *D. hughesii*. Similar specimens from Tiki Formation (Pal, 1984b) have been identified as *D. hughesii* based on gross features as well as cuticular details.

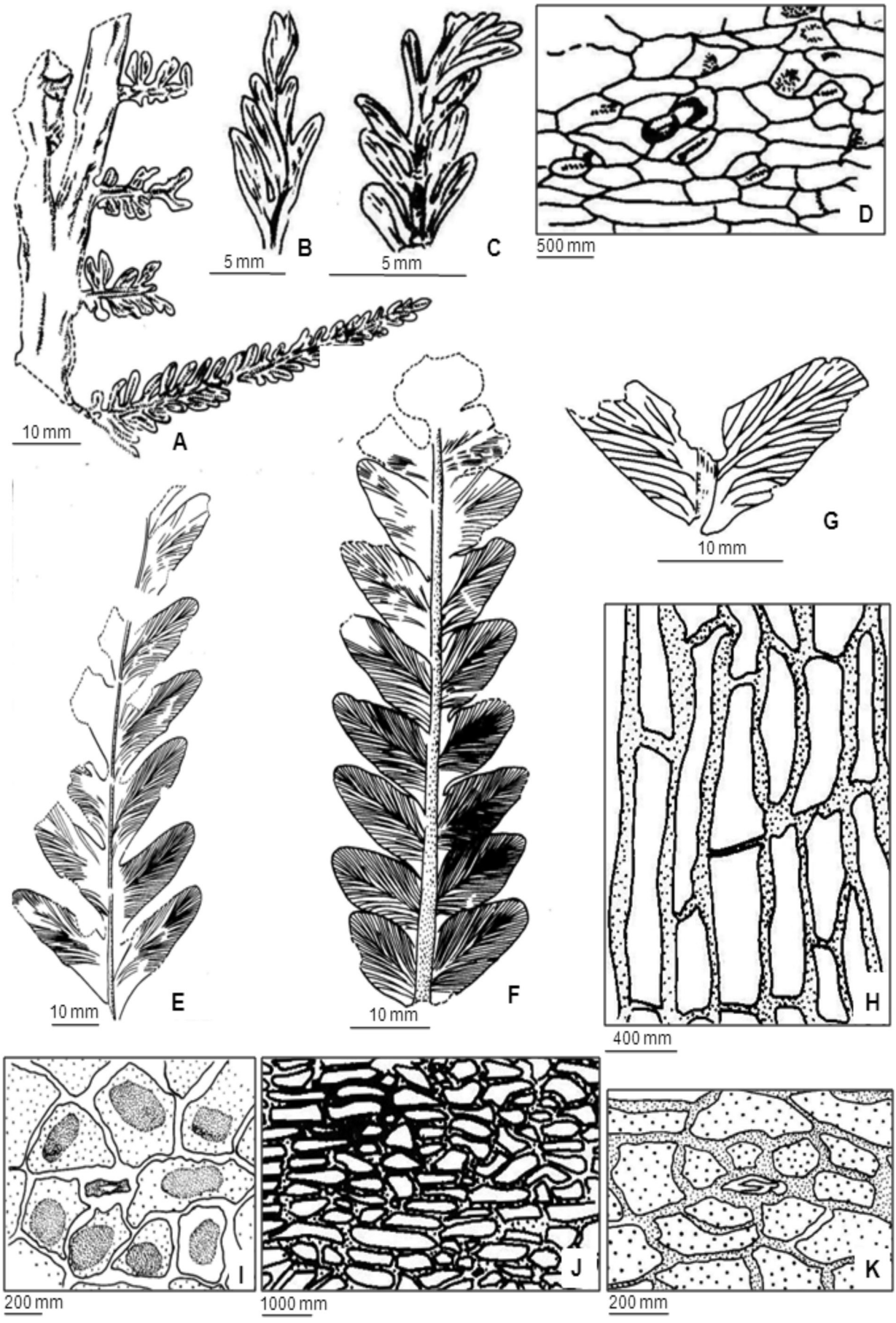
Dicroidium hughesii occurs rather infrequently in the lower part of Tiki Formation (Carnian). However, it is of common occurrence in the Parsora Formation (Norian–Rhaetian). Beyond Parsora Formation, the species is not known so far.

Dicroidium zuberi (Szajnocha) Archangelsky, 1968

(Pl. 1.3–6; Fig 2, F)

1932 *Thinnfeldia sahnii* Seward; p. 235; pls. 8–9, figs 1–4.
1955 *Thinnfeldia* (Morris) Feistmantel; p. 25; pl. 1, fig 4; text–figs 2.
1962 *Dicroidium odontopteroides* (Morris) Gothan; Lele: p. 51 (part); pl. 1, figs 1, 2, 4–7; text–figs 2A, B; 3A–C; 4A–C.
1962 *Dicroidium* sp. cf. *D. feistmantelii* (Johnston) Gothan; Lele: p. 54–56; pl. 2, figs 8–13; text–figs 5A–F.
1969 *Parsorophyllum indicum* Lele, p. 314–317; pl. 1, fig. 1.

Fig 3—A–D. *Dicroidium townrovii* Retallack. A. Specimen No. BU P/15 from Pathargarh beds of Kamthi Formation. B. Slide No. BSIP 8143 from Tiki Formation of Janar River Section. C. Slide No. BSIP 8142 from Tiki Formation of Janar River Section. D. Slide No. BSIP 8142–1 from Tiki Formation of Janar River Section showing epidermal cells and a few stomata. E–K. *Dicroidium nidpurensis* Bose & Srivastava. E. Specimen No. BSIP 81/1521 from Nidpur beds of Gopad River Section. F. Specimen No. BSIP 85/1521 from Nidpur beds of Gopad River Section. G. Slide No. BSIP 33943 from Nidpur beds of Gopad River Section showing venation pattern of the pinnules. H. Slide No. BSIP 33946–1 from Nidpur beds of Gopad River Section showing rachis cuticle with a few stomata and epidermal cells. I. Slide No. BSIP 33952–1 from Nidpur beds of Gopad River Section showing a single stoma. J. Slide No. BSIP 33945–1 from Nidpur beds of Gopad River Section showing lower surface of lamina with a few stomata and epidermal cells. K. Slide No. BSIP 33945–1 from Nidpur beds of Gopad River Section showing a single stoma.


A
10 mm
B
5 mm
C
5 mm
D
500 mm
E
10 mm
F
10 mm
G
10 mm
H
400 mm
I
200 mm
J
1000 mm
K
200 mm

1963 *Dicroidium sahnii* (Seward) Rao and Lele: p. 9; pl. 1, figs 1–5; text–figs 1–4.

1984b *Dicroidium zuberi* (Szajnocha) Archangelsky; Pal: p 257–260, 275; pl. 3, figs 20–32; pl. 10, figs 90–91; pl.11, figs 92–93; text–figs 4A–N, 5A–D, 17A–E.

1991 *Dicroidium zuberi* (Szajnocha) Archangelsky; Pal, Chakraborty, Ghosh & Ghosh: p.123; pl.1, figs 4,5.

1997 *Dicroidium zuberi* (Szajnocha) Archangelsky; Pal & Ghosh: p. 84; pl.1, figs 8, 9; text–figs 1J.

2003 *Dicroidium zuberi* (Szajnocha) Archangelsky; Pal & Sur: p. 69, figs 2A–D.

Description—Leaf up to 21 cm long, bipinnate. Rachis proximately forked once. Pinnae opposite or subopposite, imparipinnate. Largest available pinna measures 8 cm long and 3 cm wide. Pinna rachis are 2–5 cm wide, possess a distinct median ridge. Pinnules closely spaced, often touching or overlapping each other; rhomboidal or broadly oval, 4 x 3 to 18 x 16 mm in size; usually slightly contracted at base; margins entire or slightly lobed; apex obtuse. Terminal pinnule oval or oblong in shape, 3 or 4 veins arise close to basiscopic side of pinnule base, each of these veins fork 1–3 times and arch towards margins. Substance of lamina is thick. Cuticles of pinnule on both surfaces are more or less similar, rarely one surface slightly thinner, 6 μm thick, amphistomatic. Epidermal cells mostly isodiametric–polygonal, at places slightly elongate, anticlinal walls 3–4 μm thick, usually straight, slightly undulate, rarely cell outlines with ± 2 μm high cutin processes; periclinal wall usually having a low solid papilla, papilla often relatively more distinct on thicker surface. Stomatal frequency almost similar on both surfaces, evenly distributed over entire surface, irregularly oriented. Subsidiary cells 4 to 6 in number, mostly 5, occasionally differentiated into polar and lateral subsidiary cells, very rarely papillate. Rarely subsidiary cells of adjacent stomata are in close contact with each other. Stomatal pit typically rectangular, thickly cutinised on lateral sides; guard cells sunken, thinly cutinised, aperture slit–like. Encircling cells are absent. Rachis cuticle is about 8 μm thick (one surface slightly thicker than the other), amphistomatic. On thicker side, cells usually longitudinally elongate, at places isodiametric–polygonal. Stomata mostly transversely or obliquely oriented, rarely longitudinally placed. Other details are similar to the ones occurring over the pinnule surfaces.

Occurrence—Panchet Formation, Ramkola–Tatapani Coalfied, Balrampur District, Chhattisgarh. Tiki and Parsora formations, South Rewa Gondwana Basin and Pathargarh beds of Kamthi Formation, Mahanadi Valley Basin.

Remarks—Some specimens from the Parsora Formation earlier described by Lele (1962, pl. 1, figs 1, 2, 4–7; text–figs 2 A, B; 3 A–C; 4 A–C) as *D. odontopteroides* have been assigned to *D. zuberi* with respect to the shape of lamina segments, venation pattern and epidermal features. Specimens of *D. sahni* described by Rao and Lele (1963) and those of *Dicroidium* sp. cf. *D. feistmantelii* described by Lele (1962) from the Parsora Formation have also been included in *D. zuberi.* Both *D. sahnii* and *D. feistmantelii* have already been merged with *D. zuberi* by Retallack (1977) and Anderson and Anderson (1983). A new genus *Parsorophyllum* was instituted by Lele (1969) and some specimens of Parsora Formation were described as *Parsorophyllum indicum*. Those specimens were earlier described by Lele (1956) as *Thinnfeldia odontopteroides*. The specimens are hereby included under *Dicroidium zuberi* because of their deltoid pinnules with typical venation pattern characteristic of the species, e.g.3–4 dichotomously branched primary veins concentrating at a basiscopic point.

Dicroidium zuberi is the most consistently occurring species in the Triassic succession of Peninsular India. The species has been recently recorded from the outcrop of Iria Nala Section, near Premnagar Village, Balrampur District, Chhattisgarh (Ramkola–Tatapani Coalfield) belonging to Panchet Formation (Pl. 1.6). *Dicroidium zuberi* occurs in abundance in the Tiki (Carnian) and Parsora (Norian–Rhaetian) formations of South Rewa Gondwana Basin.

Dicroidium* sp. cf. *D. crassinervis

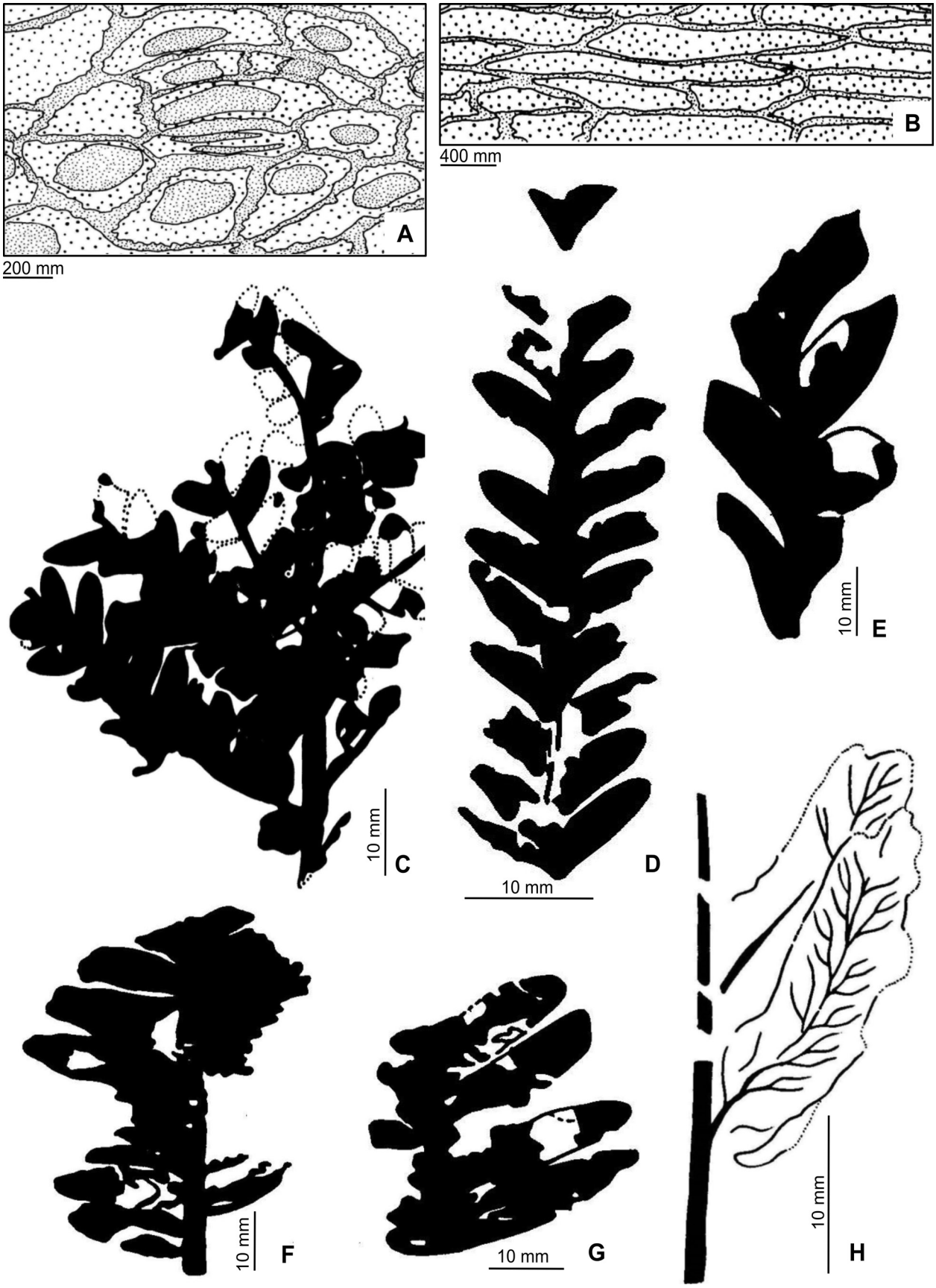
(Pl. 1.8; Fig 2, G–I)

1984b *Dicroidium* sp. Pal: p. 260–261; pl. 4, figs 33–40; text–figs 6 A–F.

Description—Leaf at least once pinnate. Pinna subopposite, elliptic or linear lanceolate, 4–11 mm long and 2–3 mm wide, attached by whole base, basiscopic margin decurrent, lateral margins entire, apex obtuse. Midvein distinct in the basal half of the pinna, evanescent towards apex. Lateral veins arising at an acute angle, once or twice forked. Cuticle of lamina about 2.5 μm thick, one surface slightly thicker than the other. Epidermal cells mostly polygonal, ± isodiametric on thicker side, veins marked by rows of elongated cells, on both surfaces few rows of elongated cells present along lamina margin. Anticlinal walls of epidermal cells straight, often faintly sinuous, periclinal wall with a low solid papilla. Stomata more or less represented, numerous on both surfaces

→

Fig 4—A–B. *Dicroidium nidpurensis* Bose & Srivastava. G. Slide No. BSIP 33962–1 showing epidermal cells from non–stomatiferous area of vein region. H. Slide No. BSIP 33962–1 showing a single stoma. C–E. *Dicroidium nidpurensis* Bose & Srivastava. A. Specimen No. BSIP 33952–1 from Nidpur beds of Gopad River Section. B. Specimen No. BSIP 33930 from Nidpur beds of Gopad River Section. C. Specimen No. BSIP 33993 from Nidpur beds of Gopad River Section. F–H. *Dicroidium gopadensis* Bose & Srivastava. D. Specimen No. 33961 from Nidpur beds of Gopad River Section. E. Specimen No. BSIP 33958 from Nidpur beds of Gopad River Section. F. Specimen No. BSIP 86/1521 from Nidpur beds of Gopad River Section.


A
200 mm
B
400 mm
10 mm
C
10 mm
D
10 mm
E
10 mm
F
10 mm
G
10 mm
H

of lamina, evenly distributed and irregularly oriented. Subsidiary cells mostly 4 (2+2) in number, sometimes 5; often subsidiary cell bears a low papilla on its surface. Stomatal pit rectangular, guard cells sunken, common wall between guard cells and lateral subsidiary cells thickened, aperture slit like or narrowly elliptic. Frequently lateral subsidiary cells accompanied by and encircling cell outside it. Rachis cuticle about 3 μm thick, one surface slightly thicker than the other. Cells of median region rectangular or square, serially arranged, more distinct on thicker side. Cells of marginal region polygonal, ± isodiametric. Anticlinal walls of epidermal cells straight or minutely sinuous, periclinal wall with a papilla. Stomata sparse, irregularly distributed and oriented.

Occurrence—Tiki Formation, South Rewa Gondwana Basin.

Remarks—A few specimens from the Harai Member of Tiki Formation were described by Pal (1984b) as *Dicroidium* sp. Pal (1984b) compared his material with *Dicroidium coreaceum* (Johnston) Townrow. However, on the basis of available gross morphological characters, venation pattern and epidermal features; the specimens are closely comparable to those of *Dicroidium crassinervis* (Geinitz) Anderson and Anderson (1983). Considering the poor preservation potential of the specimen, it has been assigned here as *Dicroidium* sp. cf. *D. crassinervis*. The species occurs sporadically in the Tiki Formation of South Rewa Gondwana Basin.

Dicroidium townrovii Retallack 1977

(Pl. 1.7; Figs 3, A–D)

1984b *Dicroidium coreaceum* (Johnston) Townrow; Pal: p. 274–275; pl. 10, figs 82–89; text–figs 6 A–E.
1991 *Dicroidium superbum* (Shirley) Townrow; Pal *et al.*: p. 123; pl. 1, fig. 6.
1997 *Dicroidium superbum* (Shirley) Townrow; Pal and Ghosh: p. 84; pl. 1, fig 10; text–fig 1K.

Description—Leaf bipinnate. Primary rachis about 7 mm wide, proximately forked once, bearing pinnae at angle of about 60˚. Pinna lanceolate, imparipinnate, 4 cm long. Pinna rachis proximally 1 mm wide, gradually narrowing towards apex bearing subopposite ly arranged pinnules. Pinnules lanceolate (typically 4 mm long and 1 mm wide) with slightly contracted bases, entire to slightly lobed margins and acute to sub–acute apices. Venation sphenopteroid, single vein enters a pinnule and just after reaching the leaf–base it forks twice or thrice. Lamina cuticle about 2.5 μm thick, amphistomatic, stomata more numerous on one surface than on the other. Epidermal cells usually isodiametric polygonal, sometimes elongated. Cells along lamina margin often narrow, rectangular. Anticlinal walls of epidermal cells slightly sinuous, often with cutin projections, at places broken by pits; periclinal wall with a papilla, sometimes papillae indistinct or absent. Stomata irregularly distributed and obliquely or longitudinally placed, imperfectly dicyclic. Subsidiary cells basically four in number, two polar and two lateral, very often lateral subsidiary cells radially divided. Subsidiary cells are usually with a papilla over its surface, rarely papillae overhanging the stomatal pit. Usually stomata are well–separated, very rarely subsidiary cells of adjacent stomata touching each other. Stomatal pit typically rectangular. Guard cells thinly cutinised, aperture usually exposed, at places slightly sunken. Rachis cuticle about 3 μm thick, amphistomatic. Cells rectangular, more or less serially arranged, more distinct on one surface than on the other, sometimes cells isodiametric, cell outlines straight or slightly sinuous, frequently with cutin projections, surface smooth or with a faint papilla. Stomata sparse, transversely or obliquely oriented.

Occurrence—Pathargarh beds, Kamthi Formation, Mahanadi Valley Basin and Tiki Formation, South Rewa Gondwana Basin.

Remarks—Pal (1984b) described some specimens from Giar Member of the Tiki Formation, as *Dicroidium coriaceum* (Johnston) Townrow. Critical analysis reveals that the material belong to *Dicroidium townrovii* Retallack (1977), instead of *D. coriaceum.* The specimens from the Pathargarh beds of Kamthi Formation in Mahanadi Valley Basin figured by Pal *et al.* (1991) and Pal and Ghosh (1997) as *Dicroidium superbum* are also assignable to *D. townrovii* Retallack. The species is rather uncommon in both Kamthi and Tiki formations. A specimen from Kamthi sequence depicts the proximal forking of primary rachis (Pl.1.7).

Dicroidium nidpurensis Bose & Srivastava, 1971

(Pl. 2.1–2; Fig. 3, E–K; Fig. 4, A–E)

1971 *Dicroidium nidpurensis* Bose and Srivastava; p. 43–46; pl. 1, figs 1–8; pl. 2 fig. 16; text–figs 2A–O, 3A–G.

PLATE 1 →

1–2. *Dicroidium hughesii* (Feistmantel) Lele, from Tiki Formation of Janar River Section. 1. Specimen No. BSIP 35617. 2. Specimen No. BSIP 35614.
3–6. *Dicroidium zuberi* (Szajnocha) Archangelsky, 3–5. Specimens from Tiki Formation of Janar River Section. 3. Specimen No. BSIP 35624. 4. Specimen No. BSIP 35627. 5. Specimen No. BSIP 35626. 6. Specimen from Panchet Formation of Ramkola–Tatapani Coalfied, Balrampur District, Chhattisgarh. Specimen No. BSIP 8400/35.
7. *Dicroidium townrovii* Retallack, from Pathargarh beds of Kamthi Formation.Specimen No. BU P/15.
8. *Dicroidium* sp. cf. *D. crassinervis* (Geinitz) Anderson & Anderson, from Tiki Formation of Janar River Section. Specimen No. BSIP 35639.

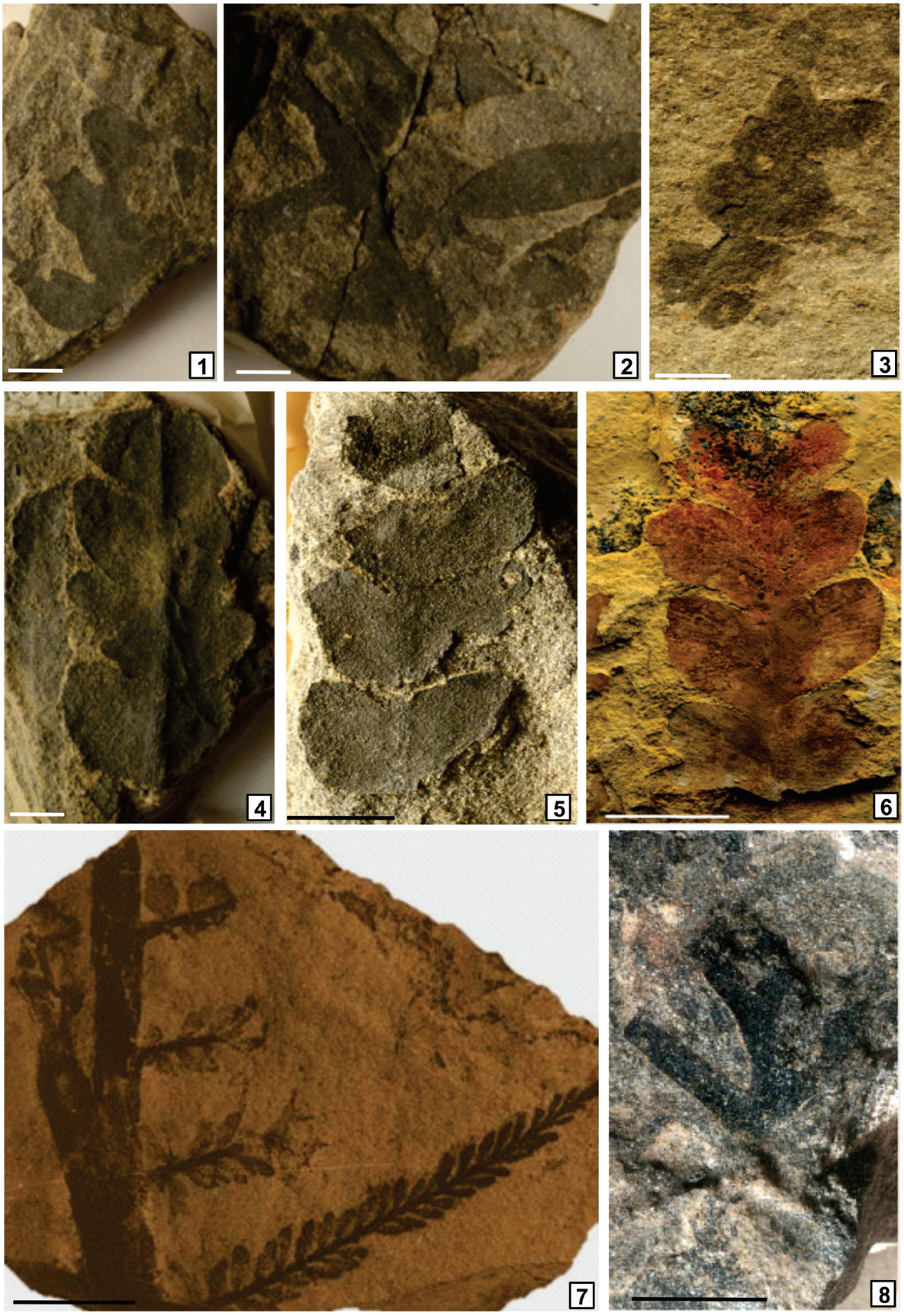


PLATE 1

1971 *Dicroidium papillosum* Bose and Srivastava; p. 46–49; pl. 2, figs 9–15; pl. 3, figs 14–22; text–figs 4F–H, 5A–C.

1976 *Dicroidium* sp. B Banerji, Maheshwari and Bose; p. 68; pl. 3, figs 36, 37; text–figs 6D, E.

Description—Frond bipinnate, largest specimen measuring 12 cm in length and 9.9 cm in breadth (range noted 4.6–12 x 2.9–9.9 cm). Rachis fairly thick, showing minute lumps and irregular wrinkles, sometimes finely striate, 2–6 mm wide. Pinnae alternate or sub–opposite, arising at an angle of about 40–60º, near apex making an angle of about 40º; pinnae measuring 3–7 cm in length, 2–3 cm in breadth. Pinna rachis finely striate or at times with tiny lumps. Pinnules arising at an angle of about 50–70º, inserted laterally but somewhat closer to upper surface of rachis, broadly oval to lanceolate, lower most pinnule on lower side more or less rhomboid in shape, with obtuse to rounded apex, pinnule nearest to main rachis on upper side more or less semi circular to circular in shape. Margin entire or slightly notched near base, acroscopic margin constricted, basiscopic margin slightly decurrent. Veins finely marked, odontopteroid type. Cuticle of the main rachis thick, both surfaces similar in structure. Epidermal cells elongate and arranged in longitudinal direction, rectangular to rhomboid; lateral walls straight and end–walls oblique, rarely straight. Surface wall is generally smooth, sometimes thickened but without definite papillae. Stomata sparsely distributed. Guard cells weakly cutinised, subsidiary cells 4–5 in number. Aperture is slit–like. Cuticle of pinna–rachis is similar to that of main rachis, only ordinary epidermal cells slightly smaller in size and not so thickened. Cuticle of lamina on both surfaces more or less of similar thickness, about 6 μm thick. Upper surface not showing clearly marked vein cells (no distinct stomatal and non–stomatal zones). Cells mostly polygonal, a few rectangular or isodiametric, cells along veins wherever recognisable are mostly polygonal; lateral and end–walls straight, broken by pits or sinuous; surface wall mostly with solid circular or oval papillae, sometimes cells are merely thickened. Stomatal appertures amphicyclic or incompletely amphicyclic, subsidiary cells 4–7, mostly 5 in number, surface wall papillate or non–papillate. Stomatal pit is rectangular. Guard cells cutinised, sunken. Lower surface showing distinct stomatal and non–stomatal zones, occasionally a few stomata occurring along vein cells as well. Cells along veins more or less rectangular or polygonal, serially arranged; lateral and end walls sinuous, pitted or straight; surface–wall thickened or with a solid papilla. Cells within stomatal zone without any definite arrangement, polygonal, lateral and end–walls mostly sinuous, surface merely thickened or papillate. Stomata irregularly distributed, mostly longitudinally oriented, a few obliquely or transversely placed, sparse, never sharing a common subsidiary cell. Subsidiary cells 4–7, usually 5; lateral and end–walls like ordinary epidermal cells; surface wall with or without papillae. Encircling cells like ordinary cells. Nature of stomatal pit and guard cells similar to those on upper side.

Occurrence—Nidpur beds, South Rewa Gondwana Basin.

Remarks—Compressions of *Dicroidium nidpurensis* and *Dicroidium papillosum* were described from the Nidpur beds by Bose and Srivastava (1971). In gross features and venation pattern the two sets of specimens are indistinguishable. According to Bose and Srivastava (1971) their cuticular features are also similar, except for the presence of papillae over epidermal cells in specimens of *Dicroidium papillosum* and their absence in specimens of *Dicroidium nidpurensis*. This papillate or non–papillate epidermal cells had been the basis of separation of *Dicroidium papillosum* and *Dicroidium nidpurensis* by the authors of the two species. It may be noted that the cuticle of the genus *Dicroidium* as a whole is papillate, however, the frequencies and nature of papillae vary from species to species, even amongst the specimens of a same species. Further, the feature is dependent on the nature of preservation of the cuticle; in ill–preserved material the papillae become obscure. Therefore, institution of a separate species based only on absence of papillae over epidermal cells is in no way justified. Moreover, in specimens of *Dicroidium nidpurensis,* as described by Bose and Srivastava (1971), the surface of epidermal cells in all probabilities represents ill–preserved papillae. In some specimens figured by Bose and Srivastava (1971) such ill–preserved papillae are visible. As such, the specimens of both the species appear to belong to the same species and therefore, be described as *Dicroidium nidpurensis* Bose and Srivastava

Dicroidium nidpurensis is one of the most abundantly occurring elements in Nidpur beds and the species is not known from elsewhere.

Dicroidium gopadensis Bose & Srivastava, 1971

(Pl. 2.5; Figs 4, F–H)

1971 *Dicroidium gopadensis* Bose and Srivastava; p. 49; pl. 3, figs 23; pl. 4 figs 24–30; text–figs 4A–E, 5D–E.

1976 *Dicroidium* sp. C Banerji, Maheshwari and Bose; p. 68; pl. 3, figs 38; text–figs 6B.

Description—Pinnate fronds, broken at both ends, measuring 3.5–6.1 cm in length and 2.3–4.7 cm in breadth. Rachis about 2–3 mm wide, finely striate in longitudinal direction. Pinnules 1.9–2.7 cm long and 0.9 cm broad, arising at an angle of about 40–70˚, typically 45˚; ovate to broadly lanceolate, closely set, almost touching each other, distinct pinnule absent towards the apex, instead pinnules notched (pinnatifid). Pinnule margin entire, rarely slightly wavy at places, sometimes near apex somewhat dentate; apex rounded or obtuse; acroscopic margin contracted, basiscopic margin decurrent. Veins distinct, one principal vein arise from rachis, forming a midvein, also in some cases near

Standard scale / Gondwana basins			DAMODAR VALLEY BASIN	KOEL VALLEY BASIN	RAJMAHAL BASIN	SOUTH REWA BASIN	SATPURA BASIN	PRANHITA-GODAVARI VALLEY BASIN	MAHANADI VALLEY BASIN
EARLY JURASSIC						Hartala Hill Beds		Dharmaram Formation	
T R I A S S I C	LATE	RHEATIAN				Parsora Formation			
		NORIAN			Dubrajpur Formation			Maleri Formation	
		CARNIAN				Tiki Formation			Pathargarh Beds
	MIDDLE	LADINIAN	Supra-Panchet Formation	Mahadeva Formation			Bagra Beds	Bhimaram Formation	
		ANISIAN					Denwa Formation		
	EARLY	SYTHIAN	Panchet Formation	Panchet Formation		Nidpur Beds / Panchet Formation	Pachmari Formation / Almod Formation	Yerrapalli Formation / Mangli Beds	Sarimunda Hill Beds
LATE PERMIAN			Raniganj Formation	Raniganj Formation		Pali Formation	Bijori Formation	Kamthi Formation	Kamthi Formation

Table 2—A generalised classification of Triassic Gondwana in Peninsular India (based on Roy-Chowdhury *et al.*, 1975; Sastry *et al.*, 1977; Pal, 1984a, b, 1996; Kutty *et al.*, 1988; Srivastava & Jha, 1990; Pal & Ghosh, 1997; Dutta, 2002, 2004; Ghosh *et al.,* 2007, Mukherjee *et al.,* 2012; Geological Time Scale after Gradstein *et al.,* 2012).

the base a few smaller lateral veins arise directly from the rachis. Midvein giving rise to secondaries at narrow angles, secondary veins forked or unforked, divide once or twice. Lamina does not form distinct pinnules near apex, quite a few veins arise directly from rachis without forming distinct midvein. Lamina cuticle similar on both surfaces, about 2.5 μm thick, amphistomatic. Both surfaces show distinct stomatal and non stomatal bands. Non stomatal bands 3–4 cells wide, cells rectangular or with pointed ends, serially arranged; lateral and end walls undulate; surface–wall mostly thickened, sometimes with a circular or oval solid papillae lying mostly close to one end. Stomatal bands sometimes 2–4 stomata wide but usually 3–4 stomata wide, stomata generally irregularly scattered, mostly longitudinally or obliquely oriented, very rarely orientation is transverse. Subsidiary cells 4–7 in number, mostly 5; cell wall wavy or slightly undulate, surface papillate or non papillate; when papillate, papillae mostly solid. Guard cells sunken, finely striate in transverse direction. Encircling cells have distinct papillae or sometimes only slightly thickened. Ordinary epidermal cells polygonal, irregularly packed; lateral and end walls sinuous or undulate; surface wall mostly papillate. Papillae circular or oval, solid, very rarely hollow. Rachis cuticle on both surfaces similar, about 2.5 μm thick. Cells rectangular or rhomboid in shape, lateral walls straight and end–walls oblique; surface–wall mostly smooth, sometimes slightly thickened. Stomata longitudinally oriented, subsidiary cells mostly 5, cell wall slightly wavy at places, surface smooth or thickened. Guard cells sunken. Aperture slit like.

Occurrence—Nidpur beds, South Rewa Gondwana Basin.

Remarks—As compared to *Dicroidium nidpurensis, D. gopadensis* is less common in the Nidpur beds. Banerji *et al.* (1976) described *Dicroidium* sp. C from Nidpur. The specimens, in form and venation pattern, are similar to those of *D. gopadensis*, however, Banerji *et al.* (1976) refrained from assigning their specimens to *D. gopadensis* because of the absence of cuticular features.

Dicroidium giarensis Pal, 1984b

(Pl. 2.3)

1984b *Dicroidium giarensis*, Pal, p. 271–274; pl. 9, figs 75–81; text–figs 14A–G, 15 A–F.
1991 *Dicroidium giarensis* Pal; Pal *et al*.: p.123; pl. 1, fig. 7.
1997 *Dicroidium giarensis* Pal; Pal and Ghosh: p. 84; pl. 1, fig. 7.

Description—Pinnate frond; rachis 3–5 mm wide. Pinnae alternate, opposite or subopposite, arising at angle of 50˚–60˚, elliptic–oblong, 1–1.5 cm long and 5–8 mm broad, attached by broad base, acroscopic margin constricted, basiscopic margin decurrent, lateral margins entire or at places wavy. Venation consisting of 2–3 veins tending to concentrate at one basiscopic point, uppermost vein strongest, fork 3 to 5 times and supplying major part of lamina, lower veins forking once or twice. Rachis cuticle about 2 μm thick, amphistomatic, frequency of stomata slightly more on lower side. Epidermal cells at places tending to be serially arranged, squarish, rectangular or polygonal, cells towards margin slightly more elongated; anticlinal walls undulated or rarely at places straight; periclinal wall unspecialised or with a faintly marked, 15 μm in diameter papilla. Stomata irregularly distributed, transversely or obliquely oriented, rarely longitudinally placed. Subsidiary cells 4–6 in number, rarely two adjacent stomata sharing a common subsidiary cell, surface wall mottled or papillate. Stomata pit mostly rectangular, sometimes broadly oval; guard cells sunken, thinly cutinised, aperture narrowly elliptic. Lateral subsidiary cells sometimes with one or rarely with two encircling cells. Cuticle of lamina about 1.5 μm thick, one surface slightly thicker than the other, amphistomatic with more or less similar frequency of stomata on both surfaces. On thicker surface cells along veins often rectangular, tending to be serially arranged. Ordinary epidermal cells on both surfaces polygonal. Cell outlines sinuous, surface usually papillate, papillae hollow, more distinct on thicker side of lamina cuticle, sometimes cells devoid of papillae. Stomata irregularly distributed and oriented. Stomata more or less exposed or with exposed poles and sunken aperture. Subsidiary cells 4–7 in number, usually 4 or 5, on thicker side subsidiary cells mostly papillate, sometimes papillae overhanging the stomatal pit, on thinner side subsidiary cells usually devoid of papillae. Stomatal pit broadly oval or rectangular, guard cells thinly cutinised, aperture narrowly elliptic. Common wall between guard cell and lateral subsidiary cell little more cutinised in stomata with sunken aperture. Lateral subsidiary cell with one or two encircling cells outside it.

Occurrence—Pathargarh beds, Kamthi Formation, Mahanadi Valley Basin and Tiki Formation, South Rewa Gondwana Basin.

Remarks—The species *Dicroidium giarensis* was instituted by Pal (1984b) based on morphographical features and cuticular details of specimens collected from the Tiki Formation of South Rewa Gondwana Basin. Later, Pal *et al.* (1991) and Pal and Ghosh (1997) reported the occurrence of this species from the Pathargarh beds of Kamthi Formation, Mahanadi Valley Basin. Though, the species is of common occurrence in the Tiki Formation, its occurrence in Kamthi Formation is very rare.

***Dicroidium* sp.**

(Pl. 2.4)

1976 *Dicroidium* sp. Bose and Banerjee: p. 142; pl. 2, fig. 18–20.

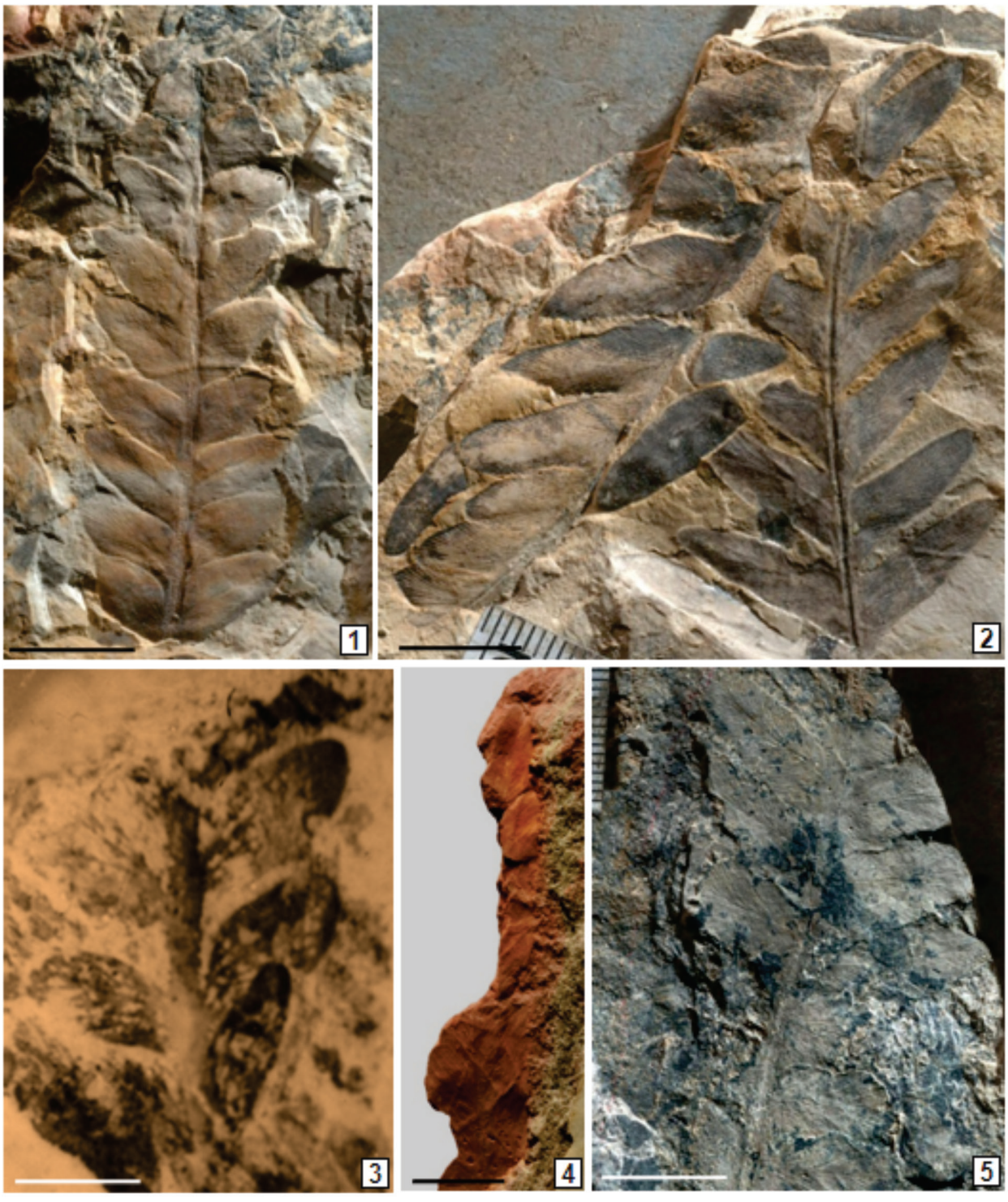


PLATE 2

1–2. *Dicroidium nidpurensis* Bose & Srivastava, from Nidpur beds of Gopad River Section.1. Specimen No. BSIP 85/1521. 2. Specimen No. BSIP 81/1521.

3. *Dicroidium giarensis* Pal, from Pathargarh beds of Kamthi Formation. Specimen No. BU P/16.

4. *Dicroidium* sp., from Nidpur beds of Gopad River Section. Specimen No. BSIP 35174/1246.

5. *Dicroidium gopadensis* Bose & Srivastava, from Nidpur beds of Gopad River Section. Specimen No. BSIP 33961.

Species of *Dicroidium*	Phyllotaxy	Shape of pinnules	Dimension of the pinnules (in mm)	Venation	Stomatal distribution	Shape of the stomatal apertures	Papillae
D. hughesii	Once pinnate; imparipinnate; opposite to subopposite pinnules	Oblong-lanceolate	Length-10.0 Breadth-2.7	Distinct midvein, secondary veins arise at an angle of about 40˚, once forked.	Amphistomatic; stomata slightly less in number compared to upper surface; irregularly distributed and oriented.	Subsidiary cells 4 -6 (average 4) in number, 2 polar and rest lateral; epidermal cells mostly isodiametric-polygonal, larger in size on upper surface; stomatal pit typically rectangular; guard cells sunken, thinly cutinised; aperture slit - like	Single low solid papilla; rare on upper surface but frequent on lower one.
D. zuberi	Bipinnate; imparipinnate; opposite to subopposite pinnules.	Rhomboidal or broadly oval	Length-4.0 Breadth-18.0	Veins arise close to base, each of these forks 1-3 times	Amphistomatic; stomatal frequency evenly distributed on both the surface, irregularly oriented.	Subsidiary cells 4 to 6 in number (average 5), occasionally differentiated into polar and lateral subsidiary cells; stomatal pit typically rectangular, thickly cutinised on lateral sides; guard cells sunken, thinly cutinised, aperture slit-like.	Rarely papillate.
D. sp. cf. *crassinervis*	Once pinnate; subopposite pinnules.	Elliptic or linear lanceolate	Length-11.0 Breadth-3.0	Midvein distinct, gradually vanishes towards apex. Lateral veins arise at an acute angle, once or twice forked.	Amphistomatic; stomatal frequency roughly similar on both surfaces, evenly distributed and irregularly oriented.	Subsidiary cells mostly 4 (2+2) in numbers, sometimes 5; stomatal pit rectangular, aperture slit like or narrowly elliptic. Frequently lateral subsidiary cells accompanied by encircling cell outside it.	Subsidiary cells often bear a low papilla on its surface.
D. townrovii	Bipinnate; subopposite pinnules.	Lanceolate	Length-4.0 Breadth-1.0	Sphenopteroid venation, single vein supply a pinnule, forks twice or thrice	Amphistomatic; stomata irregularly distributed and obliquely or longitudinally placed.	Imperfectly dicyclic, subsidiary cells 4 in number, 2 polar and 2 lateral, very often lateral subsidiary cells radially divided. Stomatal pit typically rectangular	Subsidiary cells usually with a papilla often overhanging the stomatal pit.
D. nidpurensis	Bipinnate; alternate to subopposite pinnules.	Oval to lanceolate, rhomboidal in shape.	Length-7.0 Breadth-3.0	Veins finely marked, odontopteroid type	Amphistomatic; stomata sparsely distributed.	Stomatal apparatus amphicyclic or incompletely amphicyclic, subsidiary cells 4-7, (average 5), rectangular to slit-like aperture.	Subsidiary cells papillate, sometimes non-papillate.
D. gopadensis	Pinnate; pinnules closely set, almost touching each other	Ovate to lanceolate	Length-2.7 Breadth-0.9	Distinct midrib, lateral veins arise directly from rachis	Amphistomatic; irregularly scattered, longitudinally, obliquely or transversely oriented.	Subsidiary cells 4-7 in number, (average 5); epidermal cells polygonal, irregularly packed; slit-like aperture.	Cells papillate to non-papillate.
D. giarensis	Pinnate; alternate, opposite or subopposite pinnules.	Elliptic to oblong.	Length-1.5 Breadth-0.8	Venation consists of 2-3 veins that tend to concentrate in one basiscopic point.	Amphistomatic, frequency of stomata more on lower surface, irregularly distributed.	Subsidiary cells 4 – 6 in number, rarely two adjacent stomata sharing a common subsidiary cell. Stomatal pit mostly rectangular, aperture elliptic.	Papillated cells.
Dicroidium sp.	Once pinnate with alternate or subopposite closely set pinnules	Elliptic to oval	Length-3.2 Breadth-1.8	Venation odontopteroid, 3 – 4 veins enter the basiscopic half of the pinna, forks 1 - 4 times	Not preserved	Not preserved	Not preserved

Table 3—Characteristic morphological and cuticular features of the species of *Dicroidium* from India.

Description—Leaf at least once pinnate; rachis 1.0–1.5 mm wide, bearing closely set pinnae in alternate or sub–opposite manner; pinna broadly elliptic to oval, apex obtuse, lateral margins entire, acroscopic basal margin slightly constricted, basiscopic basal margin quite decurrent; Venation odontopteroid, 3–4 veins entering the basiscopic half of the pinna forking 1–4 times, uppermost vein strongest, fork 3–4 times and reaching major part of the lamina, lower veins fork once or twice.

Occurrence—Panchet Formation, Auranga Coalfield, Latehar District, Jharkhand, Daomodar Valley Basin.

Remarks—The description is based on a few fragmentary specimens of pinnately compound fronds described earlier by Bose and Banerjee (1976) as *Dicroidium* sp, from the Panchet Formation of Auranga Coalfield. The shape, size and venation pattern of lamina segments of the specimens are comparable with those of *D. odontopteroides* (Morris) Gothan and *D. dubium* (Feistmantel) Gothan. However, owing to very fragmentary nature of the specimen, it is unjustified to assign the specimen to any particular species.

DISCUSSION

Morphological features of eight species of *Dicroidium* have been reassessed in the present paper. A summary given in Table–3 that clearly demarcates both the characteristic morphological and cuticular features of the species.

Amongst the eight species of *Dicroidium* known from Peninsular India*, D. hughesii* occurs preponderantly throughout the Parsora Formation and occasionally in the Tiki Formation. Tiki Formation has been dated as Carnian and the Parsora Formation has been dated as Norian–Rhaetian (Roy Chowdhury *et al.*, 1975; Sastry *et al.*, 1977; Pal, 1984a, b, 1996; Kutty *et al*., 1988; Srivastava & Jha, 1990; Pal & Ghosh, 1997; Dutta, 2002, 2004; Ghosh *et al.* 2007; Mukherjee *et al.*, 2012). Therefore, in India, *D. hughesii* is restricted to late Triassic (Carnian to Norian–Rhaetian). *D. zuberi* has recently been recorded from the early Triassic, Panchet Formation (Induan) of Ramkola–Tatapani Coalfield (Chhattisgarh), South Rewa Gondwana Basin. This particular species is of most common occurrence in the Tiki and Parsora formations of South Rewa Gondwana Basin. However, it is rather infrequent in the Pathargarh beds of Kamthi Formation, Mahanadi Valley Basin. Thus, *D. zuberi* is a long ranging form and it stratigraphically ranges from early Triassic to late Triassic. *Dicroidium* sp. cf. *D. crassinervis* occurs only in the lower part of Tiki Formation (late Triassic, Carnian). *D. townrovii* and *D. giarensis* are known to occur in the upper part of Tiki Formation and Pathargarh beds of Kamthi Formation (late Triassic, Carnian). *D. nidpurensis* and *D. gopadensis* have so far been recorded only from the Nidpur beds of South Rewa Gondwana Basin (early Triassic, Induan–Olenekian). Fragmentary specimens, assigned as *Dicroidium* sp., are known to occur in the Panchet Formation in Auranga Coalfield (early Triassic, Induan). Stratigraphic distribution of individual species in the Triassic succession of Peninsular India has been graphically represented in the Table–4.

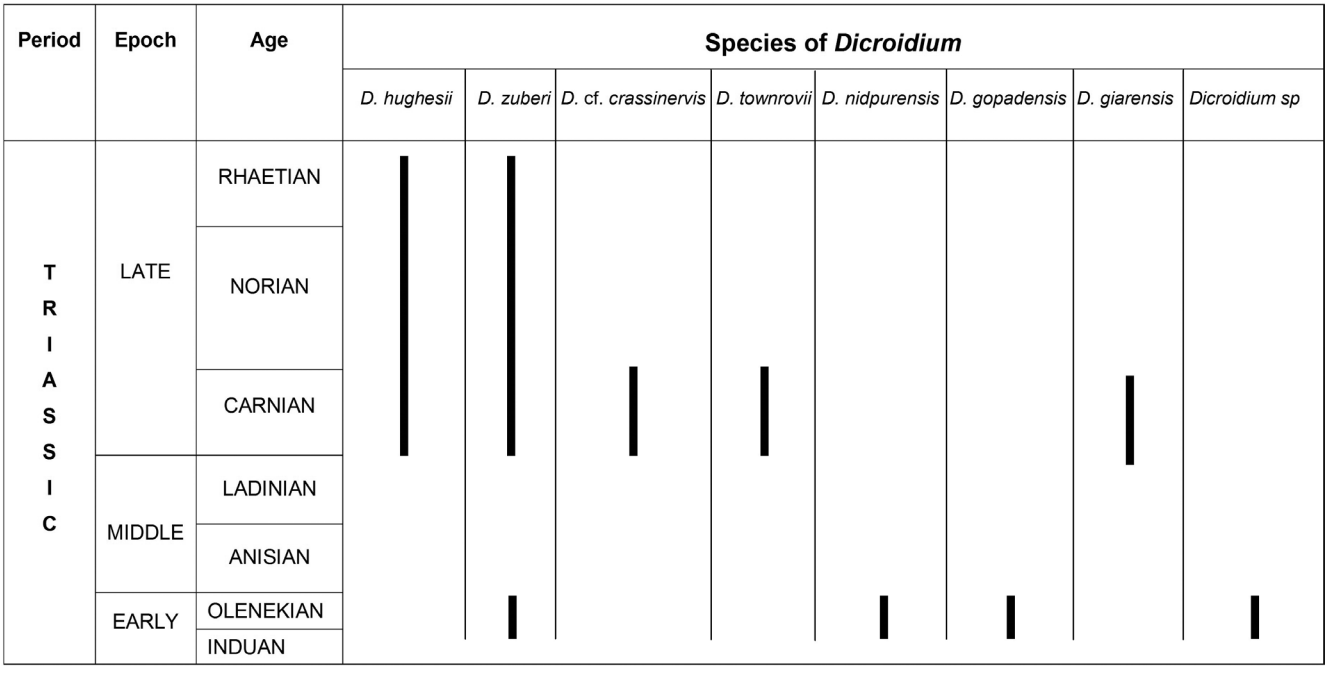


Table 4—Stratigraphic distribution of species of *Dicroidium* in the Triassic succession of Peninsular India.

CONCLUSION

Throughout the Southern Hemisphere, corystospermaceous fronds belonging to the genus *Dicroidium* are the most commonly occurring elements in the Triassic strata. Besides, the genus never occurs beyond the limits of the Triassic. In view of its wide geographical distribution but a restricted geologic range, *Dicroidium* is one of the few plant taxon that is regarded as a valid index genus for stratigraphic correlations. Across Gondwana, through the Triassic, the *Dicroidium* flora was very much diverse and prolific (Chatterjee *et al.*, 2013). During the late Triassic, Gondwana was intact and that facilitated the wide geographical distribution of the dominant corystosperms (Chatterjee & Scotese, 1999; McLoughlin, 2001). *Dicroidium* has long been considered an index taxon of the Gondwana Triassic replacing the widespread Glossopteris flora after the end–Permian mass extinction (Retallack, 1995). However, record of dispersed *Umkomasia*, the ovuliferous fructification of Corystospermales, within a typical Glossopteris flora from the late Permian Raniganj Formation of India (Chandra *et al.*, 2008) indicates that corystosperms may have appeared in Gondwana during the end of the Permian. *Dicroidium* has also been reported from the Upper Permian of Jordan where it is associated with Cathaysian elements (Kerp *et al.,* 2006; Hamad *et al.,* 2008). Chatterjee *et al.* (2013) suggested that in all possibilities, corystosperms may have originated in the equatorial region during the late Permian and eventually became widespread in the Southern Hemisphere Triassic.

Since the first record of the genus in India by Lele (1962), quite a number of species have been described from time to time by several workers.

The present study reveals that:

- In India, *Dicroidium* is represented by altogether eight species, viz. *D. hughesii, D. zuberi, Dicroidium* sp. cf. *D. crassinervis, D. townrovii, D. nidpurensis, D. gopadensis, D. giarensis* and *Dicroidium* sp.
- Amongst these, *D. zuberi* is a long ranging form that occurs right from early Triassic to late Triassic.
- *Dicroidium* sp. occurs sporadically in the early Triassic beds of Panchet Formation in the Auranga Coalfield. During the late Triassic, Tiki and Parsora formations of South Rewa Gondwana Basin and Pathargarh beds of Kamthi Formation in the Mahanadi Valley Basin respectively, the genus achieved significant diversification both quantitatively and qualitatively.
- The youngest geologic record of *Dicroidium* is from the Norian–Rhaetian sediments of Parsora Formation (South Rewa Gondwana Basin).

It may be concluded, based on the present reassessment, that early Triassic succession represented by the sediments of Panchet Formation (Induan) in the Auranga Coalfield and Ramkola–Tatapani Coalfield constitutes the first appearance and the Parsora Formation of South Rewa Gondwana Basin represents the last appearance of the genus *Dicroidium* in India.

Acknowledgements*—The authors are thankful to the Director, Birbal Sahni Institute of Palaeobotany for his kind permission to publish this collaborative work.*

REFERENCES

Anderson JM & Anderson HM 1983. Palaeoflora of Southern Africa: Molteno Formation (Triassic). Volume 1, Part 1. Introduction, Part 2. *Dicroidium*: 227. A.A. Balkema, Rotterdam.

Archangelsky S 1968. Studies on Triassic fossil plants from Argentina. IV, The leaf genus *Dicroidium* and its possible relation to *Rhexoxylon* stems. Palaeontology 11: 500–512.

Banerji J & Bose MN 1977. Some Lower Triassic plant remains from Asansol region, India. Palaeobotanist 24: 202–210.

Banerji J, Maheshwari HK & Bose MN 1976. Some plant fossils from the Gopad River Section near Nidpur, Sidhi District, Madhya Pradesh. Palaeobotanist 23: 59–71.

Bose MN & Banerji J 1976. Some fragmentary plant remains from the Lower Triassic of Auranga Valley, district Palamau. Palaeobotanist 23: 139–144.

Bose MN & Srivastava SC 1971. The genus *Dicroidium* from the Triassic of Nidpur, Madhya Pradesh, India. Palaeobotanist 19: 41–51.

Bose MN, Taylor EL & Taylor TN 1990. Gondwana floras of India and Antarctica–a survey and reappraisal. *In*: Taylor TN & Taylor EL (Editors)–Antarctic Paleobiology, Chapter 10: 118–148. Springer–Verlag, New York.

Chandra S, Singh KJ & Jha N 2008. First report of the fertile plant genus *Umkomasia* from Late Permian beds in India and its biostratigraphic significance. Palaeontology 51: 817–826.

Chatterjee S & Scotese CR 1999. The breakup of Gondwana and the evolution and biogeography of the Indian Plate. Proceedings of the National Science Academy 65A: 397–425.

Chatterjee S, Tewari R & Agnihotri D 2013. A *Dicroidium* flora from the Triassic of Allan Hills, South Victoria Land, Transantarctic Mountains, Antarctica. Alcheringa 37: 209–221.

Dutta PK 2002. Gondwana lithostratigraphy of Peninsular India. Gondwana Research 5: 540–553.

Dutta PK 2004. Gondwana Lithostratigraphy of Peninsular India: Reply. Gondwana Research 7: 608–612.

Ettingshausen C 1852. Begrűndung einiger neuen oder nicht genau bekannten Arten der Liasund der Oolithflora. Abhandlungen der Kgl–K Geologischen Reichsanstalt 1: 1–10.

Feistmantel O 1882. The fossil flora of Gondwana system in India–1. The fossil flora of South Rewa Gondwana Basin. Memoirs of Geological Survey of India. Palaeontologica Indica Ser. 12: 1–52.

Ghosh SC, Pal TK & Nandi A 2007. First record of an aquatic beetle larva (Insecta: Coleoptera) from the Parsora Formation (Permo–Triassic), India. Palaeontology 50: 1335–1340.

Gothan W 1912. Über die Gattung *Thinnfeldia* Ettingshausen. Abhandlungen der Naturhistorischen Gesellschaft zu Nürnberg 19: 67–80.

Gradstein FM, Ogg JG, Schmitz MD & Ogg GM 2012. The Geologic Time scale, Elsevier Science, Amsterdam, The Netherlands, 1144 pp.

Hamad AA, Kerp H, Vörding B & Bandel K 2008. A Late Permian flora with *Dicroidium* from the Dead Sea region, Jordan. Review of Palaeobotany and Palynology 149: 85–130.

Kerp H, Hamad A, Vording B & Bandel K 2006. Typical Triassic Gondwanan floral elements in the Upper Permian of the paleotropics. Bulletin of the Geological Society of America 34: 265–268.

Kutty TS, Jain SL & Roy Chowdhury T 1988. Gondwana sequence of the northern Pranhita–Godavari Valley: its stratigraphy and vertebrate faunas. Palaeobotanist 36: 214–229.

Lele KM 1956. Plant fossil from Parsora in the South Rewa Gondwana Basin, India. Palaeobotanist 4: 23–34.

Lele KM 1962. Studies in the Indian Middle Gondwana Flora–1. On *Dicroidium* from the South Rewa Gondwana Basin. Palaeobotanist 10: 48–68.

Lele KM 1969. The problem of Middle Gondwana in India. Proceedings of the 22nd International Geological Congress, New Delhi 9: 181–202.

McLoughlin S 2001. The breakup history of Gondwana and its impact on pre–Cenozoic floristic provincialism. Australian Journal of Botany 49: 271–300.

Mukherjee D, Ray S, Chandra S, Pal S & Bandopadhyay S 2012. Upper Gondwana Succession of the Rewa Basin, India: Understanding the Interrelationship of Lithologic and Stratigraphic Variables. Journal of the Geological Society of India 79: 563–575.

Pal PK 1984a. Some fragmentary plant remains from the Hartala Hill, South Rewa Gondwana Basin, India. Palaeobotanist 32: 126–129.

Pal PK 1984b. Triassic plant megafossils from the Tiki Formation, South Rewa Gondwana Basin, India. Palaeobotanist 32: 253–309.

Pal PK 1985. Palaeobotany and stratigraphy of the Dhaurai Hill beds, South Rewa Gondwana Basin, India. Geophytology 15: 224–225.

Pal PK 1996. Stratigraphy of Post Barakar Sequence in Johilla–Son Valley, South Rewa Gondwana Basin, India. *In*: Pal PK (Editor)–Contemporary Thoughts in Plant Sciences, Academic Staff College, Burdwan University, April 1996: 103–108.

Pal PK, Chakraborty U, Ghosh AK & Ghosh A 1991. Triassic plant megafossils from the Kamthi Formation of Talcher Coalfield, India–A new report. Indian Journal of Geology 63: 119–125.

Pal PK & Ghosh AK 1997. Megafloral zonation of Permian–Triassic sequence in the Kamthi Formation, Talcher Coalfield, Orissa. Palaeobotanist 46: 81–87.

Pal PK & Sur D 2003. First record of *Dicroidium zuberi* from the Parsora Formation of India. Journal of Botanical Society of India 57: 67–70.

Rao AR & Lele KM 1963. On the cuticle of *Dicroidium (Thinnfeldia) sahnii* (Seward) with some observations on the genera *Thinnfeldia* and *Dicroidium*. Palaeobotanist 11: 7–12.

Retallack GJ 1977. Reconstructing Triassic vegetation of eastern Australasia: A new approach for the biostratigraphy of Gondwanaland. Alcheringa 1: 247–277.

Retallack GJ 1995. Permian–Triassic life crisis on land. Science 267: 77–80.

Roy Chowdhury HK, Sastry MVA, Shah SC, Singh G & Ghosh SC 1975. Triassic floras in India. *In*: Campbell KSW (Editor)–Gondwana Geology. 3rd International Gondwana Symposium, Canberra: 149–159. Australia National University Press.

Sastry MVA, Acharyya SK, Shah SC, Satsangi PP, Ghosh SC, Raha RK, Singh G & Ghosh RN 1977. Stratigraphic Lexicon of Gondwana Formation of India. Geological Survey of India, Miscellaneous Publication No. 36: 1–170.

Satsangi PP 1973. Some new plant fossils from the Panchet Formation of Raniganj Coalfield. Indian Minerals 27: 76–78.

Seward AC 1932. On some fossil plants from the Parsora Stage, Rewa. Records of the Geological Survey of India 66: 235–243.

Srivastava SC & Jha N 1990. Permian–Triassic palynofloral transition in Godavari Graben, Andhra Pradesh. Palaeobotanist 38: 92–97.

Townrow JA 1957. On *Dicroidium*, probably a pteridospermous leaf, and other leaves now removed from this genus. Transactions of the Geological Society of South Africa 60: 21–60.

Tripathi A, Tiwari RS & Kumar P 1990. Palynology of the subsurface Mesozoic sediments in Rajmahal Basin, Bihar. Palaeobotanist 37: 367–388.

Walkom AB 1917. The flora of the Ipswich and Walloon Series (c) Filicales, etc. Geological Survey of Queensland Publication (Palaeontological Papers) 257: 1–67.