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Tatapania gen. nov., a possible cone of *Schizoneura gondwanensis* Feistmantel from the Late Permian in the Tatapani-Ramkola Coalfield, India

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ABSTRACT

Singh KJ, Chandra S & Saxena A 2011. *Tatapania* gen. nov., a possible cone of *Schizoneura gondwanensis* Feistmantel from the Late Permian in the Tatapani-Ramkola Coalfield, India. The Palaeobotanist 60(2): 251-263.

Tatapania-a new genus of equisetalean fructifications, is represented by oblong-ovate bractless cones recorded from the Late Permian strata exposed in Banki Rivulet in Tatapani-Ramkola Coalfield, Chhattisgarh State, India. This is the first record of compact, conical and possibly terminal sphenophyte cones from the Lower Gondwana. The cones may have been related to *Schizoneura gondwanensis* as these are found in association with sterile equisetalean stems and leaves of *Schizoneura gondwanensis* in the same beds.

Two new species, viz. *Tatapania indica* and *T. obcordata*, have been instituted for the genus. Both species closely resemble cones of modern *Equisetum*. The presence of a compact cone similar to that of an extant *Equisetum* as early as Late Permian of Gondwana is interesting, especially when no member of Palaeozoic sphenophytes possessed such compact cones. The present find also supports the hypothetical model of Naugolnykh (2004a) wherein he proposed the evolution of the compact strobilus and peltate sporangiophore in modern *Equisetum* from the Late Palaeozoic ancestors. The double or single cones of *Tatapania* have been placed intermediate between *Equisetites arenaceus* with three cones attached together and *Neocalamites carreri* having single cone in the Naugolnykh's evolution model of *Equisetum.* A reconstruction of *Schizoneura gondwanensis* plant having *Tatapania* cones attached on the apices of the leaf bearing branches has been attempted.

Key-words—Sphenophyte, Equisetales, Fructification, Peltate disc, Terminal cone, Late Permian.

तातापानिया नव वंश, भारत में तातापानी-रामकोला कोयला क्षेत्र के पश्च पर्मियन से प्राप्त *साइज़ोन्युरा गोंडवानेन्सिस* फाइस्टमेंटल का एक संभाव्य शंकु

कमलजीत सिंह, शैला चंद्रा एवं अंजु सक्सेना

सारांश

तातापानिया-इक्वीसीटालीन फलन का एक नवीन वंश, तातापानी-रामकोला कोयला क्षेत्र, छत्तीसगढ़ राज्य, भारत के बंकी-उपनदी में अनावरित पश्च पर्मियन स्तरी से अभिलिखित आयतरूप-अंडाकार सहपत्रिका रहित शंकु द्वारा रूपायित है। निचले गोंडवाना से संहत, शंक्वाकार एवं संभवतया अंतस्थ स्फीनोफाइट शंकुओं का यह पहला अभिलेख है। शंकुओं का संबंध *साइज़ोन्यूरा गोंडवानेन्सिस* से रहा होगा क्योंकि ये उन्हीं संस्तरों में *साइज़ोन्यूरा गोंडवानेन्सिस* के अनुवर इक्वीसीटालीन तनों व पत्तियों के संगुणन सहित पाए गए हैं।

दो नए वंश अर्थात *तातापानिया इंडिका* एवं टी.*ऑब्कोर्डेटा* वंश हेतु संस्थापित हैं। दोनों वंश आधुनिक इक्वीसेटम के शंकुओं से घनिष्ठता से साम्य रखते हैं। गोंडवाना की पश्च पर्मियन की तरह पहले एक मौजूदा *इक्वीसेटम* के सदृश संहत शंकु की विद्यमानता दिलचस्प है, विशेषतः जिस समय पुराजीवी शेनोफाइटों का कोई भी सदस्य ऐसे शंकुओं से युक्त था। मौजूदा प्राप्ति नौगॉल्नीख (2004क) के परिकल्पनात्मक मॉडल का भी समर्थन करती है जिसमें उन्होंने पश्च पुराजीवी

पूर्वजों से आधुनिक *इक्वीसेटम* में संहत शंकु व पेल्टेट बीजाणुधानीधर का विकास प्रस्तुत किया था। एक साथ संलग्न तीन शंकुओं सहित *इक्यूसेटाइटिस एरेनासियस* के बीच *तातापानिया* के युग्म या एकल शंकु मध्यवर्ती हैं और *नियोकैलामाइटिस कर्रेरी, इक्वीसेटम* नौगॉल्नीख के विकास मॉडल में एकल-शंकु युक्त हैं। पर्ण दिक्कोण शाखाओं के एपिक्स पर संलग्न *तातापानिया* शंकुओं युक्त *साइज़ोन्यूरा गोंडवानोन्सिस* की पुनर्संरचना का प्रयास किया गया है।

संकेत-शब्द—स्फेनोफाइट, इक्वीसीटेल्स, फलन, पेल्टेट चक्रिका, अंतस्थ शंकु, पश्च पर्मियन।

INTRODUCTION

The existence of the sphenopsids can be traced from the Early or Middle Devonian rocks, however they flourished luxuriantly during the Carboniferous Period and had maximum diversity at this time. The group then gradually declined and at present its only survivor is the genus *Equisetum* with around fifteen species (Taylor *et al*., 2009). Many sphenopsids were massive arborescent species during the Carboniferous Period, particularly in the northern hemisphere. In contrast, in the southern hemisphere they were herbaceous during Permo-Carboniferous times with comparatively few species.

The sphenopsids form a sizeable portion of the Glossopteris flora, and belong to the genera *Sphenophyllum, Trizygia, Benlightfootia, Raniganjia, Bengalia, Barakaria, Lelstotheca, Annularia, Schizoneura, Phyllotheca, Lobatannularia, Gondwanophyton, Paracalamites* (all leaf forms) and the leafless equisetalean stems. However, the reports of fertile organs are few in the Lower Gondwana flora in comparison to the rich and diverse fertile sphenopsids of the northern Carboniferous-Permian Euramerican and Angara floras represented by *Sphenophyllum, Parasphenophyllum, Archaeocalamites, Calamites, Neocalamites, Annularia, Asterophyllites, Lobatannularia, Dicalamophyllum, Umbellephyllites, Cruciaetheca, Paracalamitina* and *Equisetites*.

The strobili of different species of *Sphenophyllum* (known from both European and North American floras) were initially kept in a morphogenus *Sphenophyllostachys* which later on transferred to the genus *Bowmanites* (Hoskins & Cross, 1943) with its widely known species *dawsonii.*

The calamitean cones are generally referred to the morphogenus *Calamostachys* represented by a number of species. *Calamostachys americana* from the Upper Pennsylvanian of North America (Arnold, 1958) is one of the largest species of this genus and *C. binneyana* is the best known and commonly occurring species, that is common in the coal measures in Europe and also known from the Pennsylvanian of North America (Taylor, 1967). Another calamitean cone, *Palaeostachya* reported from the Mississippian to Pennsylvanian of Europe is quite similar to *Calamostachys. Palaeostachya vera* is described from the Lower Coal Measures of England (Seward, 1898).

Equisetinostachys known from the Permian of the middle Fore-Urals, Russia (Naugolnykh, 1998, 2004a) is a very typical sphenopsid reproductive structure of Tchernoviaceae family. The other very peculiar taxon, i.e. *Paracalamitina striata*, also from Tchernoviaceae is known from the uppermost Lower Permian Pechora Cis-Urals, Russia (Naugolnykh, 2002, 2004b).

The first authentic record of equisetalean fructification in the Gondwana has been reported on *Phyllotheca australis* from Upper Late Permian of Australia (Townrow, 1955). Meyen

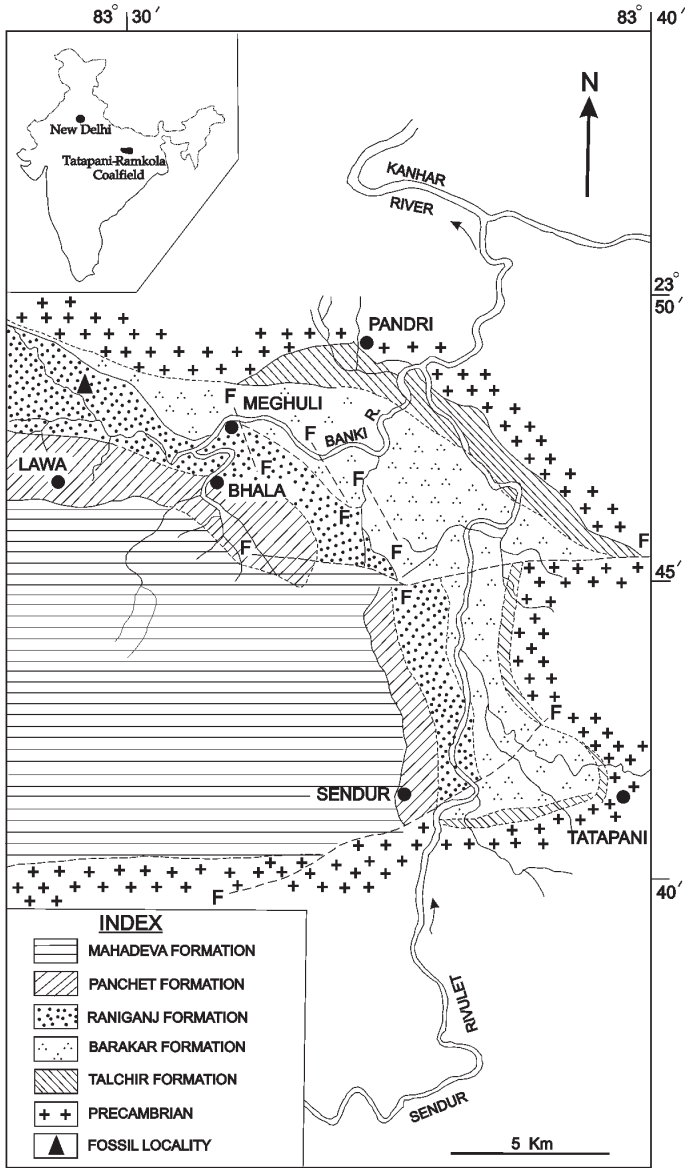

Fig. 1—Geological map of a portion of the Tatapani-Ramkola Coalfield, Sarguja District, Chhattisgarh State showing the collection locality (after Raja Rao, 1983).

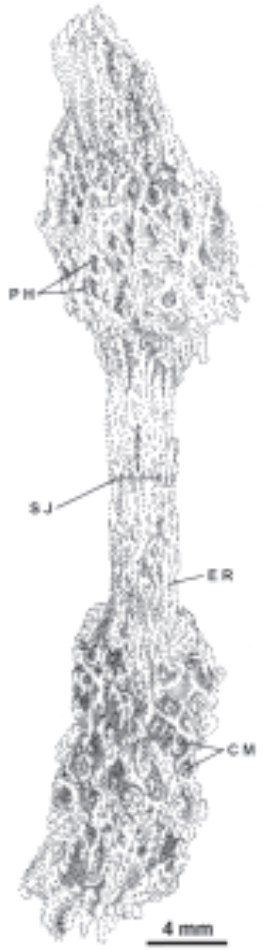

Fig. 2—*Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. Two oblong to ovate strobili arranged oppositely and attached base to base with two stalks. Polygonal or hexagonal discs (Peltate heads, PH) with circular marks (CM) inside, equisetalean ribs (ER) on the stalks, and stalk joint (SJ) can be seen. BSIP Specimen No. 39278. Scale bar = 4 mm.

Fig. 3—*Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing the line drawing of a compact, oblong to ovate single strobilus, attached to a stalk. Hexagonal or polygonal discs (peltate heads, PH) with circular marks (CM) and equisetalean ribs (ER) can be seen on the strobilar surface. BSIP Specimen No. 39279. Scale bar = 4 mm.

(1971) placed this fructification under a new genus as *Gondwanostachys australis* and established family Gondwanostachyaceae to accommodate it. *Cruciaetheca*, a genus of equisetalean sphenophytes from the Early Permian of Argentina (Cüneo & Escapa, 2006) has characters intermediate between those of families Tchernoviaceae and Gondwanostachyaceae.

Equisetites is a morphogenus that incorporates casts, impressions and compressions of the stems which resemble very closely with the extant genus *Equisetum*. The genus has been reported from numerous localities worldwide including Europe, North America, Middle and South America, Antarctica, China, India and New Zealand. Majority of the specimens are known from the Triassic but several reports are also from the Carboniferous. The most completely known species in *Equisetites* is *E. arenaceus* from the Upper Triassic of Germany (Kelber & Van Konijnenburg-Van Cittert, 1998).

Etheridge (1903) figured a specimen from the Upper Coal Measures of New South Wales, Australia where four partially preserved leaves of *Schizoneura* are shown along with a pair of terminal, compact, 20-25 mm long strobili (in Surange, 1966, fig. 16A, page 33). The preservation of these strobili was so poor that no details of the cone were described. Srivastava (1952, 1954) and Surange (1955) described isolated compact strobili from Late Permian of the Raniganj Coalfield, India as cones of *Schizoneura gondwanens*is. Later Surange (1966) discarded his own interpretation of these fructifications as equisetalean cones on the basis of their greater similarity with *Glossopteris* fructifications.

Kon'no (1960) described well-preserved equisetalean fructification as *Manchurostachys* attached to *Schizoneura manchuriensis* from the Penchihu Coalfield in northeastern China. Cones attached with another species of the genus *Schizoneura*, i.e. *S. paradoxa* have been described from the Grès al Voltzia Formation, Lower Triassic (Buntsandstein) of France (Grauvogel-Stamm, 1978) and placed under the genus *Echinostachys*.

Rigby (1972) reported *Notocalamites askosus* from the Early Permian of Brazil. Appert (1977) described a number of cones under a new taxon *Sakoarota polyangiata* from the Lower Gondwana of the Sakoa Coal Basin, southwest Malagasy. Pant *et al*. (1981) described *Giridia indica* as the possible cone of *Phyllotheca indica* from the Karharbari Formation in the Giridih Coalfield, India. Srivastava (1992) described another species of *Giridia*, i.e. *G. barakarensis* from the Barakar Formation of Raniganj Coalfield, India. Recently, Banerjee & D´ Rozario (1999) have described three putative equisetalean fructifications, *Rajmahaliastachys elongata*, *Tulsidabaria indica* and *Sharmastachys pendulata* from the late Early Permian of the Saharjuri Coalfield, India.

The present study deals with a new genus of equisetalean fructifications with two species, viz. *Tatapania indica* and *T. obcordata* recorded from the Late Permian strata exposed in Banki Rivulet in the Tatapani-Ramkola Coalfield, Chhattisgarh, India. We have compared the specimens with a large variety of fertile forms related to the sphenopsids, however these do not resemble any of the fructifications described so far from the Lower Gondwana. We also observed that both these species resemble very closely with the cones of modern *Equisetum* on the basis of the presence of similar kind of hexagonal discs on the surface of the present specimens and the lack of bracts or sheaths in the cones. *Tatapania* has been related to the leaf genus *Schizoneura gondwanensis* as the present cones are found preserved along with many sterile equisetalean stems and leaves of *Schizoneura gondwanensis* in the same beds. A reconstruction of *Schizoneura gondwanensis* plant having *Tatapania* cones growing on the apices of the leaf bearing branches has been attempted (Fig. 7).

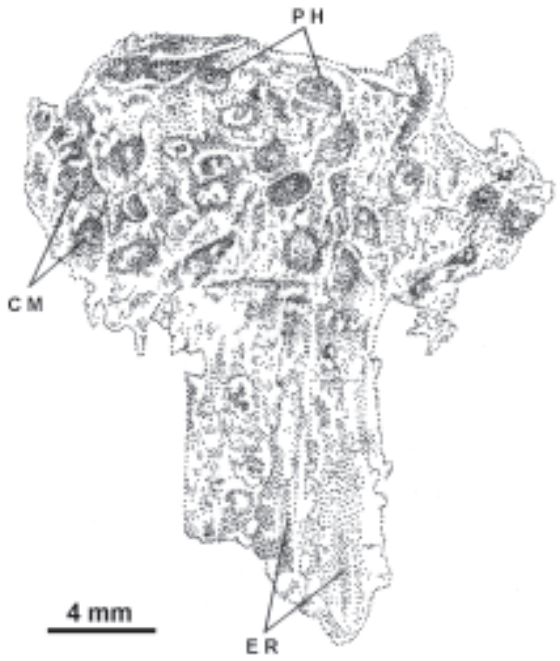

Fig. 4—*Tatapania obcordata* Singh, Chandra and Saxena gen. et sp. nov. showing the line drawing of a compact, obcordate to reniform strobilus having a truncate apex and cordate to cuneate base. Hexagonal to polygonal discs (peltate heads, PH) having circular marks (CM) in the centre can be seen on the surface of the strobilus, and equisetalean ribs (ER) are present on the stalk. BSIP Specimen No. 39280. Scale bar = 4 mm.

GEOLOGICAL SETTING

The Tatapani-Ramkola Coalfield, located between latitudes 23°35' & 23°55' N and longitudes 83°00' & 83°40' E in the Surguja District of Chattisgarh State in central India, is considered to be the western extension of Damoder-Koel Valley Basin. It is indeed a composite basin comprising a northern strip of coal-bearing rocks, referred to as the Tatapani Coalfield, and a southern one called the Ramkola Coalfield (Raja Rao, 1983). The coalfield is represented usually by a plain area with minor undulations and is flanked on all sides by hillocks of Precambrian rocks. The sediments are mostly covered by alluvium and the outcrops are present along the rivers and their tributaries. The Gondwana sediments in the Tatapani-Ramkola Coalfield have been classified into Talchir, Barakar, Barren Measures, Raniganj, Panchet and Mahadeva formations (Fig. 5).

Palaeobotanical studies in this coalfield regarding megafossils are limited to two localities (Bose *et al*., 1977; Chandra *et al*., 2008) while extensive palynological studies have been carried out (Srivastava *et al*., 1997; Kar, 2001, 2003; Srivastava & Kar, 2001; Kar & Srivastava, 2003).

MATERIAL AND METHODS

The equisetalean cones form a part of megafossil collection made from the Late Permian (Raniganj Formation) shale sediments exposed along the bank of Banki Rivulet (latitude 23°48'30" N and longitude 83°29'00" E) near Lawa Village in the Tatapani-Ramkola Coalfield, Chhattisgarh, India (Fig. 1). The fossils are preserved as impressions on fine-grained siliceous, compact, lilac coloured shales. The three specimens described here are completely coated with white powdery substance that can be removed easily with a needle. Very small fragments of organic matter are preserved on two of the specimens.

Age	Group	Formation	Lithology
Recent		Alluvium	
Cretaceous ?		Basic Intrusives	Dolerite dykes
Late Triassic?	Upper Gondwana	Mahadeva	Thick, cross-bedded coarse- grained ferruginous sandstones with alternating bands of red clays (200+ m).
Early Triassic	-Do-	Panchet	Yellowish, fine-grained micaceous sandstones, alternating with red and green siltstones, shales and clays (800+ m).
Late Permian	Lower Gondwana	Raniganj	Micaceous fine-grained ripple laminated sandstones, grey and carbonaceous shales and shaly coal bands (400+ m).
Middle Permian	-Do-	Barren Measures	Ironstone shales showing box structure, fine-grained sandstone, shales and argillaceous sandstones (120-200 m).
Early Permian	-Do-	Barakar	Medium to coarse-grained pebbly arkosic sandstone, conglomerates, grey and carbonaceous shales and coal seams (450+ m).
Early Permian	-Do-	Talchir	Diamictite, olive-green needle **s**hales, siltstone, fine-grained sandstones and varves (150+ m).
----------Unconformity----------			
Archaean			Granites, gneisses, mica schists, phyllites and quartz veins.

Fig. 5—Generalized stratigraphic sequence in the Tatapani-Ramkola Coalfield (after Raja Rao, 1983; Srivastava *et al*., 1997).

The shale bed is about 20 cm thick and occurs as surface exposures instead of a well-preserved vertical section. The bed also contains many species of *Glossopteris,* for example, *Glossopteris indica, G. retifera, G. nautiyalii, G. communis, G. tenuifolia* and *G. searsolensis.* The other fossils collected from these beds are *Schizoneura gondwanensis,* equisetalean stems and a few scale leaves. The entire flora indicates a Late Permian age for the beds. The carbon fragments were macerated in Schulze's solution and KOH but no spore/pollen could be recovered from them. The specimens have been photographed using a Nikon-D2X, 35 mm digital camera and measured to document the morphological details.

Repository—All the described specimens are lodged in the Repository of Museum of Birbal Sahni Institute of Palaeobotany, Lucknow vide Statement No. 1147 and Museum Specimen Nos. 39278-39280.

SYSTEMATICS

Phylum—SPHENOPHYTA

Order—EQUISETALES

Family—EQUISETACEAE

Genus—TATAPANIA gen. nov.

Type Species—*Tatapania indica* gen. et sp. nov.

Diagnosis—Oblong-ovate/obcordate compact strobili having an obtuse to truncate apex and slender stalk at the cuneate base; polygonal or hexagonal discs present on the

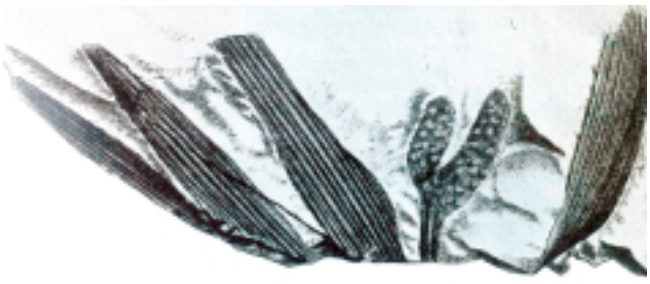

Fig. 6—Etheridge's (1903) specimen of *Schizoneura gondwanensis* showing terminal portion of a leaf bearing branch with four partially preserved leaves and a stalk bearing two strobili (reproduced from Surange, 1966; fig. 16, p. 33).

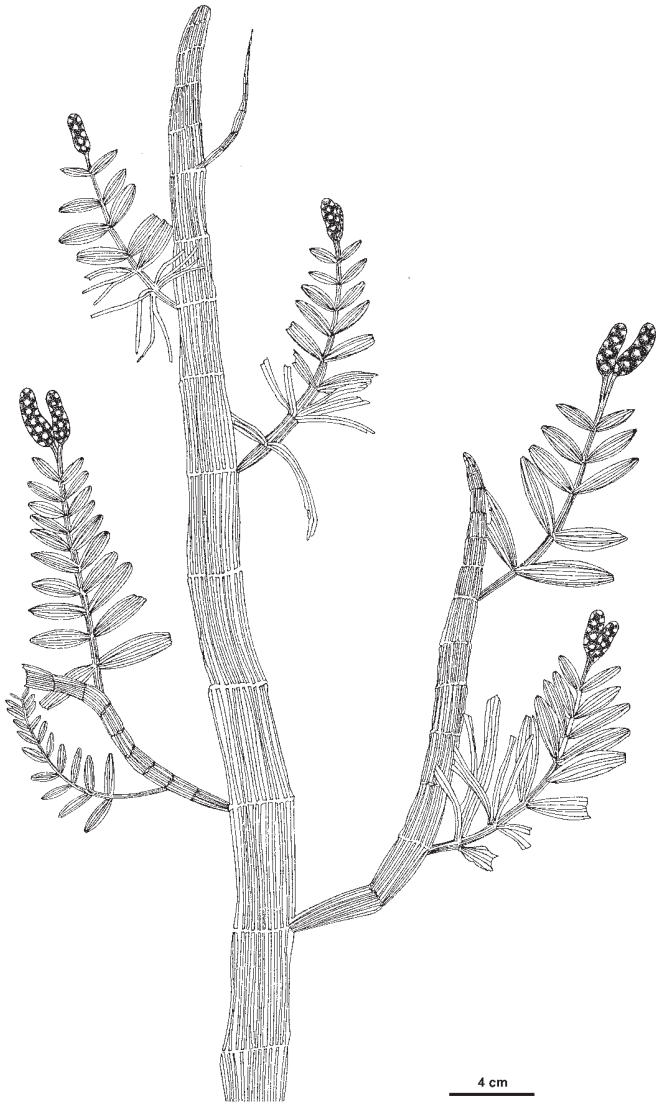

Fig. 7—Reconstruction of the *Schizoneura gondwanensis* plant, showing a main stem giving out alternate branches that ultimately possess finer branches bearing leaves on the nodes. *Tatapania* cones are shown attached on the apices of the leaf bearing lateral branches (modified after Chandra, 1992). Scale Bar = 4 cm.

surface of strobili, centre of each disc having a circular mark, bract/vegetative leaf sheaths absent in the strobili, nodes and internodes not seen, one or two strobili borne on terminal stalks, structures of sporangiophores and sporangia not known.

Etymology—The new genus is named after the Tatapani-Ramkola Coalfield, India.

Tatapania indica sp. nov. (Pl. 1.1-5; Pl. 2.1-3; Figs 2, 3)

Holotype—BSIP Specimen No. 39278, Lucknow, India.

Diagnosis—Single or double cones/strobili borne terminally on stalk; strobili compact, oblong to ovate in shape having an obtuse apex and cuneate base, measure 13-34 mm in length and 7-20 mm in width, length/width ratio of strobili about 2-1.5 : 1; polygonal or hexagonal discs with circular mark in the centre, present on the surface of strobili.

Occurrence—Banki Rivulet (latitude 23°48'30" N and longitude 83°29'00" E) section near Lawa Village, Tatapani-Ramkola Coalfield, India. Late Permian.

Description—This species is based on two impression specimens. Specimen No. 39279 (Pl. 1.2; Pl. 2.1-3) is a single compact strobilus having an obtuse apex and a cuneate base and measuring 34 mm in length and 20 mm in width at its widest part. Length/width ratio is 1.5 : 1. Present portion of stalk measures 14 mm in length and 7 mm in width is attached to the base of this strobilus. The stalk has eight distinct equisetalean ribs (ER) on its surface (Pl. 2.1, 2). The strobilus is not seen attached to its parent equisetalean axis. Small ill-preserved polygonal or hexagonal discs/heads (PH) with circular marks (CM) in the centre can be seen at certain places on the surface of the specimen. These discs are 1.4 to 2 mm in diameter (Pl. 1.2; Pl. 2.1, 3). Most probably the hexagonal or polygonal discs represent the peltate heads (PH) of the stalked sporangiophores on the axis and the circular elevated mark (CM) in the centre of each disc could be the point of attachment of the sporangiophores with the peltate head. Unfortunately we could not extract any information regarding the sporangiophores, sporangia and the spores from this strobilus.

Specimen No. 39278 (Pl. 1.1, 3-5) shows two different sized strobili arranged oppositely. Both are oblong to ovate in shape and have obtuse apices and cuneate bases. The lower

PLATE 1

1. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing magnified, oblong-ovate upper strobilus in figs 4 & 5. The polygonal discs or heads (PH, peltate heads) with circular marks (CM) in the centre can be seen at certain places. BSIP Specimen No. 39278. Scale bar = 3 mm.
2. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing enlargement of a portion of a strobilus in (Pl. 2.1), depicting polygonal or hexagonal discs (peltate heads, PH) having circular marks (CM) in the centre. BSIP Specimen No. 39279. Scale bar = 1 mm.
3. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing oblong to ovate, downward facing strobilus in figs 4 & 5 enlarged. Polygonal or hexagonal discs or heads (peltate heads, PH) with circular marks (CM) in the centre can be seen at certain places. The strobilus is attached to a stalk having longitudinal equisetalean ribs (ER). BSIP Specimen No. 39278. Scale bar = 3 mm.

4, 5. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing two oblong to ovate strobili arranged oppositely and attached base to base by stalks joining at a common point (SJ, stalk joint). BSIP Specimen No. 39278. Scale bars = 4 mm each.

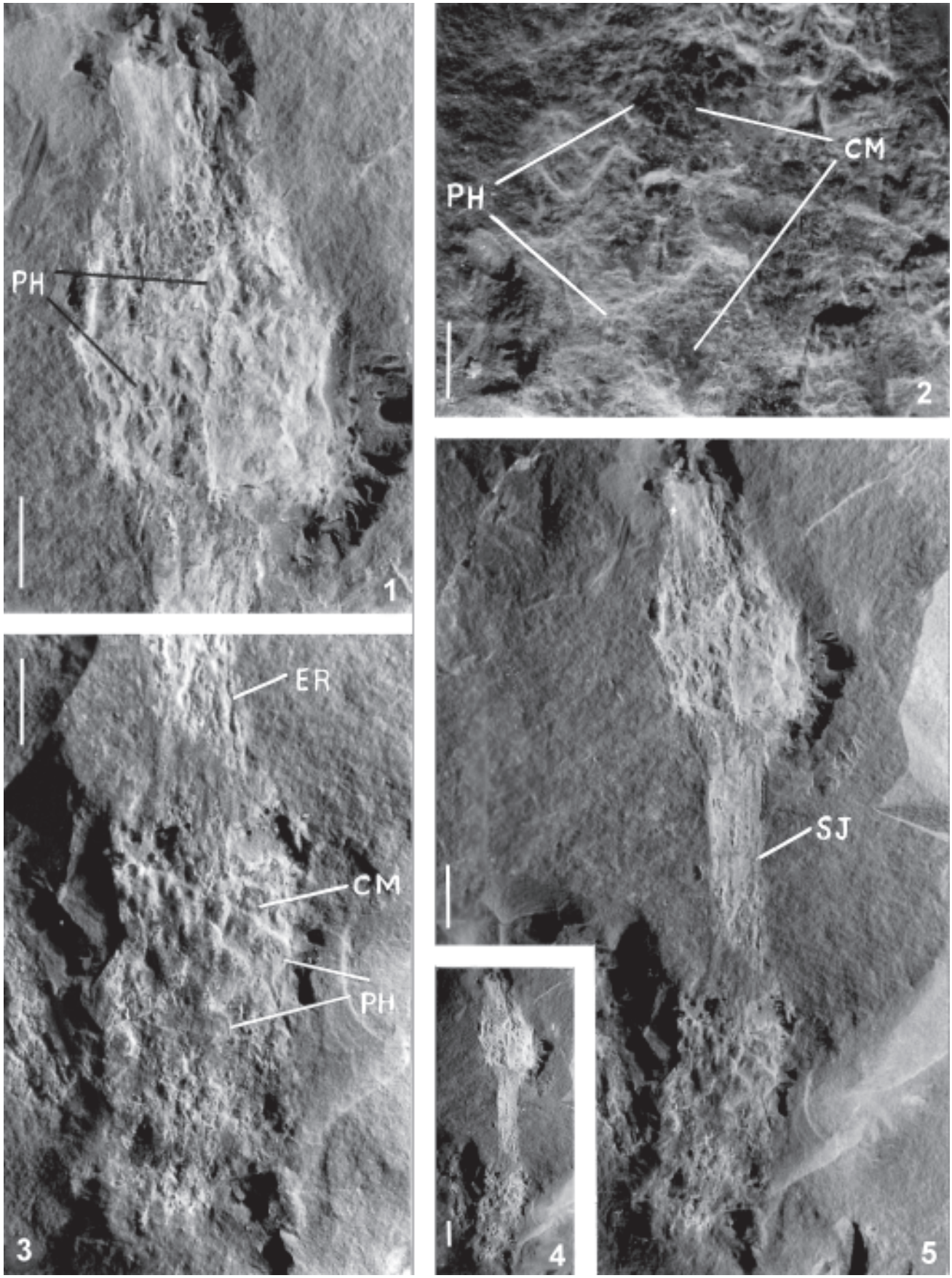

PLATE 1

strobilus is 13 mm long and 7 mm wide while the upper one is 15 mm long and 9 mm wide. Both the strobili in this specimen are attached basally by stalks measuring 9 and 8 mm in length, joining at a common point (SJ, stalk joint, Pl. 1.4, 5). The stalks are equally wide, i.e. 3.5 mm. It appears that the two strobili with their respective stalks were borne on a single common stalk. Like Specimen No. 39279 these strobili also have 1-1.3 mm wide polygonal or hexagonal discs/heads (PH), preserved at some places (Pl. 1.1, 3). There is no evidence of sporangiophores, sporangia and spores within these strobili.

Bract sheaths or vegetative leaf sheaths, as well as nodes and internodes have not been seen in any of the three strobili.

Tatapania obcordata sp. nov. (Pl. 2.4, 5; Fig. 4)

Holotype—BSIP Specimen No. 39280, Lucknow, India.

Diagnosis—Single compact obcordate–reniform strobilus borne terminally on stalk, apex truncate, base cordate to cuneate in shape; bract or vegetative leaf sheaths, nodes and internodes absent in strobilus, polygonal or hexagonal discs with circular mark in the centre, present on the surface of strobilus.

Occurrence—Banki Rivulet (latitude 23°48'30" N and longitude 83°29'00" E), section near Lawa Village, Tatapani-Ramkola Coalfield, India. Late Permian.

Description—This species is based on a single impression fossil. The strobilus is compact, obcordate to reniform in shape with a truncate apex and cordate to cuneate base. The strobilus measures 12 mm in length and 19 mm in width. L/W ratio is 0.6 : 1. A small stalk (12 mm long and 7 mm wide) with equisetalean ribs (ER) is attached to the base of the strobilus. The fructification is not attached to its parent equisetalean axis. Small ill-preserved polygonal or hexagonal discs/heads (PH) measuring 1.7-2 mm in breadth are seen at certain places on the surface of the strobilus (Pl. 2.5).

REMARKS AND COMPARISON

The sphenopsids are characterized by the presence of distinct nodes and internodes on both rhizomatous as well as on the upright axes. The latter produce whorls of leaves at the nodes and the internodal region of the axes has regularly spaced longitudinal ribs and the furrows. The reproductive organs in the sphenopsids are generally loosely arranged strobili or cones that consist of a central axis bearing whorls of branches known as sporangiophores containing sporangia (Taylor *et al*., 2009). The presence of longitudinal ribs on the stalks and polygonal-hexagonal discs on the surface of *Tatapania* strobilus confirms its association with the sphenopsids.

The present specimens are compared with a large variety of fertile forms related to the sphenopsids, however they do not resemble exactly with any of the fructifications described so far from the Gondwana. The following account shows how *Tatapania* is different from the known forms.

The genus *Tatapania* is completely different from the known phyllothecan cones like *Gondwanostachys* (cone of *Phyllotheca australis*) as well as *Giridia indica* and *Giridia barakarensis* (possible cones of *Phyllotheca indica*); *Calamostachys* and *Palaeostachya* (fertile cones of *Calamites*) and *Sakoarota polyangiata* (an equisetalean species from Malagasy) in being terminal in position, possessing compact strobili that lack bracts or vegetative leaf sheaths and the internodes. In all these above mentioned taxa barring *Gondwanostachys*, the sporangiophores are borne in the whorls at the nodes subtended by the bract sheaths or the vegetative leaf sheaths and hence they are not compact strobili. In case of *Gondwanostachys* the bractless sporangiophores are borne in single whorls of six to eight in the lower part of fertile internodes and are protected by enveloping leaf whorl below.

Similarly the sphenophyllalean fructification *Bowmanites* has variable number of sporangiophores and sterile bracts that are arranged in whorls on the nodes of the axis and therefore is completely different from the compact *Tatapania* cones lacking any sort of sterile bracts, nodes and internodes.

Equisetinostachys sp., a nonstrobilar form from Permian of Russia is somewhat close to *Tatapania* in having bractless peltate sporangiophores, however the arrangement of sporangiophores on the axis is quite different from that of *Tatapania*. The sporangiophores occur in regular clusters on the primary axis and form distinct intercalary fertile zones that are internodal and these fertile internodes are separated from each other by whorls of sterile leaves (Figs 10.85 & 10.86, in Taylor *et al*., 2009), therefore *Equisetinostachys* sp. is unlike

PLATE 2

1, 2. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. Specimen showing a compact, oblong to ovate single strobilus attached to a stalk having distinct equisetalean ribs (ER) on its surface. Polygonal or hexagonal discs (peltate heads, PH) can be seen at certain places. BSIP Specimen No. 39279. Scale bars = 4 mm each.

3. *Tatapania indica* Singh, Chandra and Saxena gen. et sp. nov. showing enlargement of a portion in the middle part of the strobilus in fig. 1 depicting polygonal discs (peltate heads, PH) with circular marks (CM) in the centre. BSIP Specimen No. 39279. Scale bar = 2 mm.

4, 5. *Tatapania obcordata* Singh, Chandra and Saxena gen. et sp. nov. Specimen showing a compact, obcordate to reniform strobilus with a truncate apex and cordate to cuneate base. The strobilus is attached to a stalk having equisetalean ribs (ER). Polygonal discs (peltate heads, PH) having circular marks (CM) in the centre can be seen at many places. BSIP Specimen No. 39280. Scale bars = 4 mm & 3 mm respectively.

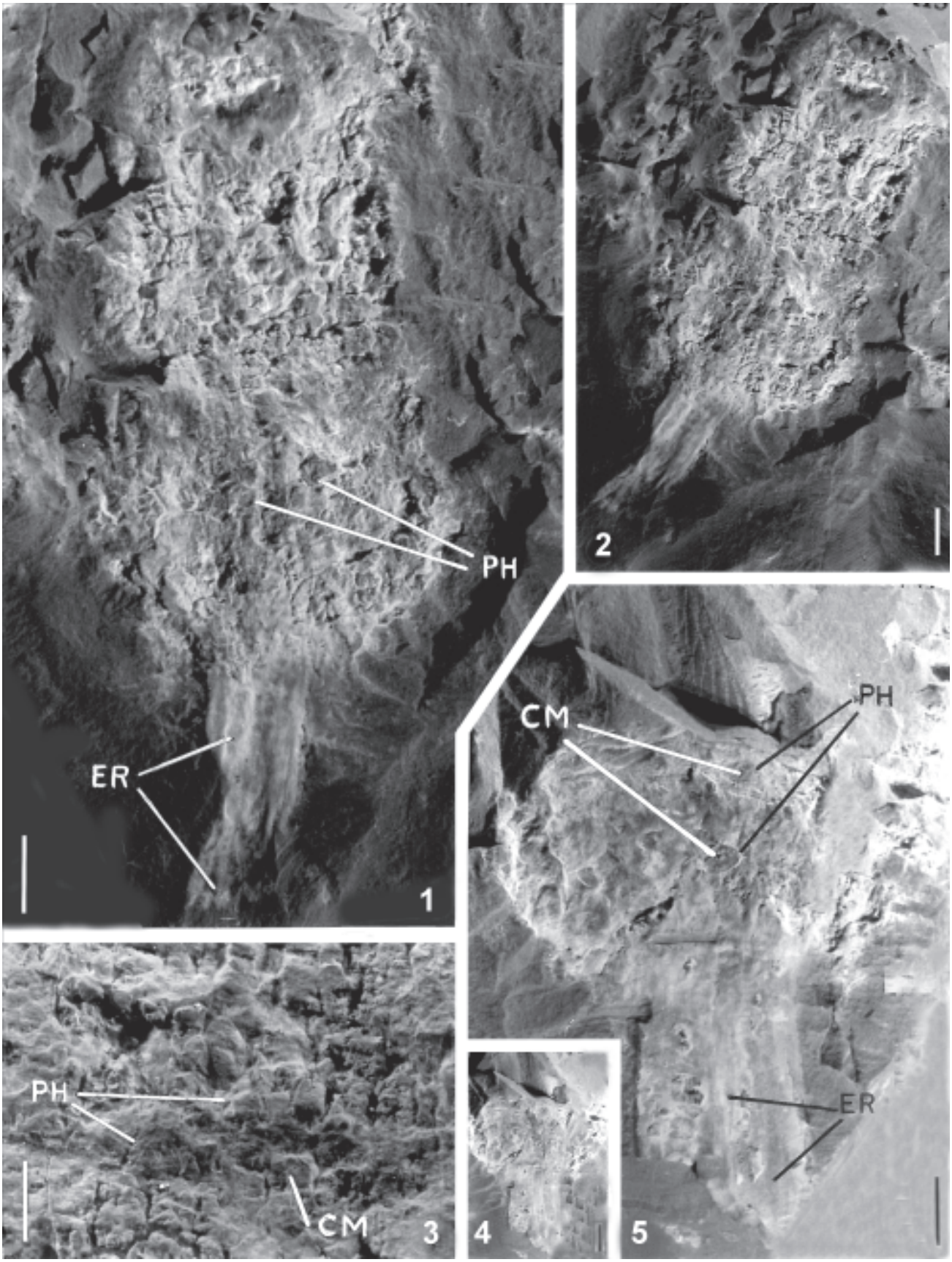

PLATE 2

Tatapania that lacks any kind of sterile leaves and the internodes in its compact cones.

In *Paracalamitina striata*, also from the Permian of Russia, a single fertile zone is present in a near-terminal position in almost every leafy lateral branch. This fertile zone exists along a single internode and consists of six longitudinal rows of fertile units, each row is composed of 9-19 stalked sporangiophores whose heads are subrectangular in shape. Generally, one whorl of sterile leaves occurs above the fertile internode (Figs 10.86 & 10.87, in Taylor *et al*., 2009). Hence, *Paracalamitina striata* closely compares with *Tatapania* in morphological features. Both the fructifications are bractless and terminal in position. *Paracalamitina* is found attached to the leafy branches with the help of ribbed stalks, however, *Tatapania* is preserved in detached condition. The cones of *Tatapania* are oblong-ovate in shape while *Paracalamitina striata* has cylindrical ones having a single whorl of sterile leaves attached above the fertile internode. Such sterile leaves are lacking in *Tatapania*. The peltate sporangiophores in *Paracalamitina striata* are usually subrectangular while *Tatapania* has hexagonal or polygonal shaped scars (probable sporangiophores) on its surface.

In *Cruciaetheca* the reproductive structures are arranged into series of contiguous fertile internodes bounded by unmodified leaf whorls. Each fertile internode consists of three to five whorls of four to six cruciate sporangiophores which are covered by a leaf whorl on the above side. Therefore, *Cruciaetheca* is not a compact and terminal cone and completely different from *Tatapania.*

Equisetites with numerous species is very similar to *Tatapania* in many aspects as both the forms have compact cones that lack bracts and the leaf-sheaths as well as nodes and internodes. The cones in *Equisetites* are constructed of whorls of stalked, peltate sporangiophores with hexagonal heads, however *Tatapania* lacks such visible sporangiophores although hexagonal scars/heads are there. In *Equisetites* the cones are produced on the apex of the fertile branches that emerge laterally from the main stem while *Tatapania* cones seem to be terminally attached to the leaf bearing finer branches. The strobili in *Equisetites* are generally oval and obovate (three strobili in *E. arenaceus*) and have non-apiculate apex (not pointed at the apex) however, *Tatapania* cones are oblong to ovate in shape having obtuse to truncate apex and therefore different from *Equisetites*.

Manchurostachys (fructification of *Schizoneura manchuriensis*) has alternating clusters of sporangiophores surrounded by a completely united large sterile leaf sheath, thereby differing from the naked *Tatapania* strobili. *Echinostachys* (cone of *Schizoneura paradoxa*) is closely comparable with *Tatapania* as both the forms have compact cones lacking bracts and the leaf-sheaths and both have whorls of peltate sporangiophores arranged around a central axis. However, *Echinostachys* is a little different from *Tatapania* in having quite narrow stalks attached laterally on the axils or the nodes of the leaf bearing axis (Fig. 10.102, in Taylor *et al*., 2009), against the wider stalks in *Tatapania* that hold the fertile cone on the apices of the leaf bearing axis.

Another equisetalean fructification *Notocalamites askosus* Rigby is somewhat closer to *Tatapania* in possessing a strobilar form and complete absence of sterile bracts. Unlike the compact strobili in *Tatapania*, *Notocalamites* has unbranched, sac-like sessile sporangia arranged loosely in whorls at the nodes (Rigby, 1972, Pl. 1, figs 1-4), thus differs from *Tatapania*.

Tulsidabaria indica Banerjee & D'Rozario (1999) like *Tatapania* is a bractless fructification but borne on either side of a node of an equisetalean stem, alternated by whorls of 8-9 leaves, thereby differing from *Tatapania* in being a non-compact nodal fructification.

Tatapania indica and *T. obcordata* can be compared very closely with two equisetalean cones, *Sharmastachys pendulata* Banerjee & D'Rozario (1999) and *Rajmahaliastachys elongata* Banerjee & D'Rozario (1999) on the pretext that both have elongated and stalked strobili attached to equisetalean stems like *Tatapania.* Although the bracts are absent in *Sharmastachys pendulata,* the strobilus itself has 24-25 nodes, each bearing elaborate sporangiophores which completely dissociates it from *Tatapania* as the latter had compact strobili lacking any nodes between the sporangiophores. Similarly *Rajmahaliastachys* has an elongated strobilus similar to the present cones but unlike them, it possesses 8-12 whorls of bracts in between the whorls of sporangia, again debarring its association with *Tatapania*.

DISCUSSION

The presently described specimens of *Tatapania indica* and *Tatapania obcordata* are found preserved along with many sterile equisetalean stems and the twigs of *Schizoneura gondwanensis* in the present collection. Although they are not organically attached to the foliage yet we assign them as the strobili/cones of *Schizoneura gondwanensis* on the basis of the following indirect evidences.

They are certainly equisetalean fertile structures as their stalks have definite equisetalean ribs, ER (Pl. 1.3; Pl. 2.1, 5). Two of our Specimens (Nos. 39278 and 39279) closely compare with the cones of *Schizoneura australis* described by Etheridge 1903, pp. 234) in gross morphology, particularly the compact nature of the strobili. The species *Schizoneura australis* Etheridge was later merged with *Schizoneura gondwanensis* by Arber (1905). Etheridge's specimen of *Schizoneura gondwanensis* consisted of terminal portion of a leaf bearing branch with four partially preserved leaves and a stalk bearing two strobili, Fig. 6. The bigger strobilus measures 30 mm in length and 8 mm in breadth, and the smaller one is 20 mm in length and 7 mm in breadth. Etheridge mentioned that the

cones seem to be attached to the stem by a very short stalk. However, this is not at all clear from his photograph.

Our Specimen, No. 39278 (Pl. 1.4, 5) also has a pair of strobili of different sizes borne on separate, but identical stalks. The strobili are arranged oppositely and their respective stalks join at a common point (SJ, stalk joint). This kind of opposite placement of the strobili suggests that these might have been borne perpendicularly on a common stalk that ultimately attached to the main axis of the sterile stem. In the present study this common stalk has not been preserved. The second Specimen (No. 39279) has a single stalked strobilus of similar morphology to Specimen No. 39278. The shape of the third strobilus (Specimen No. 39280) is somewhat different but again appears to be a compact cone.

Although the sporangiophores and the sporangia could not be seen preserved in any of the strobili, the hexagonal or polygonal discs/heads present at certain places on the surfaces of these strobili might represent the peltate heads (PH) of the stalked sporangiophores on the axis as is seen in the modern cones of *Equisetum*. The compact cones attached to the *Schizoneura gondwanensis* leaf-bearing branch in Etheridge's collection and somewhat similar compact cones in the present collection, also preserved along with many *Schizoneura* sterile leaves, demonstrate that all these strobili belong to *Schizoneura gondwanensis* and had a strong resemblance to the modern cones of *Equisetum*.

Schizoneura gondwanensis appears to be a herbaceous plant, reaching up to few meters in height as evidenced by the specimens reported by Feistmantel (1880, 1881). It has a main stem with alternate branches that ultimately possess opposite leaflets/leaves on finer branches. The ridges and grooves, placed opposite at the nodes can be seen on each and every branch of the plant including the main stem and the branches having leaf sheaths/leaves. The leaves are borne at the nodes of the finer branches. They are separated into two equal, lanceolate or oblong-oval lobes having strong veins, running almost parallel and converging at the base and the apex (Chandra, 1992). The wider stalks (average width 5-7 mm) in all the three strobili of *Tatapania* and also the presence of ribs on their surfaces suggest that they were the continuation of the apical most part of the leaf bearing ribbed axes. This leads into conclusion that the compact cones of *Tatapania* were attached on the apices of the leaf bearing finer branches of *Schizoneura gondwanensis* (Fig. 7) either singly or in pairs, and not attached laterally on some axils or on the nodes as has been seen in *Neocalamites carreri* and *Echinostachys* (cone of *Schizoneura paradoxa*) where the fructifications have very narrow stalks. The smooth continuance and not the abrupt constriction of the strobilar bases with their stalks in *Tatapania* further confirms their terminal existence as has been found in the extant *Equisetum lyellii* (in Taylor *et al*., 2009) where the apical portion of the main stem develops into a terminal cone with no apparent differences seen between the cone stalk and the cone base and it looks inseparable from the main axis.

The present find also strengthens the hypothetical model of Naugolnykh (2004a) wherein, he proposed the evolution of the compact strobilus and peltate sporangiophore in modern *Equisetum* from the late Palaeozoic ancestors like *Equisetinostachys*, *Paracalamitina striata*, *Equisetites arenaceus* and *Neocalamites carreri*. The double or single cones of *Tatapania* can be placed intermediate between *Equisetites arenaceus* with three cones attached together and *Neocalamites carreri* having single cone in the Naugolnykh's evolution model of *Equisetum*. The terminal cones in *Equisetites arenaceus* and *Tatapania* grew on the lateral branches and never on the main stems however, in case of extant *Equisetum* they are always attached terminally on the main stem. The presence of a compact cone similar to that of a modern *Equisetum* as early as in the late Palaeozoic of Gondwana is interesting, especially when none of the members of Palaeozoic Sphenophyllales or Equisetales (Calamitaceae, Tchernoviaceae, Gondwanostachyaceae and Equisetaceae) possessed such compact cones.

CONCLUSIONS

The presently described strobili/cones do not resemble any of the fructifications related to the sphenopsids reported so far from the Lower Gondwana and therefore, assigned a new genus *Tatapania* with *Tatapania indica* and *T. obcordata* as new species. This is the first record of a compact, bractless and possibly terminal sphenophyte cones from the Lower Gondwana. Both these species resemble very closely with the fertile cones of modern *Equisetum* as they have similar kind of hexagonal discs on their surfaces and also lack bracts or sheaths in the cones. These discs might represent the peltate heads of the stalked sporangiophores as seen in the cones of *Equisetum.*

The compact cones attached to the *Schizoneura gondwanensis* leaf-bearing branch in Etheridge's collection and somewhat similar cones in the present collection, also preserved along with many *Schizoneura* sterile leaves, demonstrate that all these strobili belong to *Schizoneura gondwanensis* plant. The presence of definite ribs on their stalks also confirm their association with equisetalean group of plants. The wider stalks in *Tatapania* strobili and also the presence of ribs on their surfaces suggest that they are the continuation of the apical part of the leaf bearing ribbed axes. The smooth continuance of the strobilar bases with their stalks in *Tatapania* further confirms their terminal existence as has been found in the modern *Equisetum* where the apical portion of the main stem develops into a terminal cone with no apparent differences seen between the cone stalk and the cone base and it looks inseparable from the main axis. Thus, it is presumed

that the compact cones of *Tatapania* are attached either singly or in pairs on the apices of the leaf bearing finer branches of *Schizoneura gondwanensis*.

The double or single cones of *Tatapania* are placed intermediate between *Equisetites arenaceus* with three cones attached together and *Neocalamites carreri* having single cone in the Naugolnykh's (2004a) evolution model of *Equisetum*, wherein, he proposed the evolution of the compact strobilus and peltate sporangiophore in modern *Equisetum* from the late Palaeozoic ancestors like *Equisetinostachys*, *Paracalamitina striata*, *Equisetites arenaceus* and *Neocalamites carreri* in ascending order.

A reconstruction of *Schizoneura gondwanensis* plant having *Tatapania* cones attached on the apices of the leaf bearing branches has been attempted (Fig. 7). The present observations on *Tatapania* combined with other evidences including Etheridge's (1903) collection of *Schizoneura* suggest that the extant genus *Equisetum* might have descended from the Gondwanan taxon *Schizoneura gondwanensis*. The oppositely placed two bigger sized lanceolate leaf sheaths attached on the nodes in *Schizoneura gondwanensis* might have transformed into very small pointed leaf-sheaths of the extant *Equisetum* during the course of evolution through geologic time. Furthermore, the production of cones on the leaf bearing lateral branches also ceased and ultimately only a single terminal cone on the main axis evolved as seen in modern *Equisetum*.

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