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Palynology and palaeoenvironment of Late Permian Sawang OCM, East Bokaro Coalfield, Damodar Basin, India

SRIKANTA MURTHY* AND A. RAJANIKANTH

Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226 007, India.
**Corresponding author: srikanta_murthy22@rediffmail.com*

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ABSTRACT

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Palynodating of Sawang Open Cast Mine (OCM) section from East Bokaro Coalfield, Damodar Basin has been done. Recovered palynofossils are characterized by the dominance of *Striatopodocarpites–Faunipollenites* complex. The other stratigraphically significant taxa recorded from this section are *Guttulapollenites hannonicus*, *Crescentipollenites fuscus, Rhizomaspora indica, R. triassica, Distriatites* sp., *Weylandites lucifer, Microfoveolatispora gondwanensis, Dictyotriletes invisus, Indotriradites* spp., *Arcuatipollenites pellucidus, Alisporites indicus* and *Klausipollenites schaubergeri*. Other rare palynotaxa include *Parasaccites, Corrisaccites, Dicapipollenites, Striomonosaccites, Barakarites*, *Plicatipollenites*, *Scheuringipollenites, Densipollenites, Callumispora, Tiwariasporis, Praecolpatites* and *Distriatites*. On the basis of the total palynocomposition, the studied section has been dated as Late Permian age. This age correlation also gets support from comparative studies with similar palynoassemblages known from other coalfields of Indian Gondwana basins such as Damodar, Son–Mahanadi, Rajmahal, Wardha–Godavari and Satpura basins of India and from known Gondwanan continents. Palynofossil evidences indicate prevalence of warm and humid conditions. The dominance of conifers and subdominance of Glossopterids, cordaites and low percentage of triletes (filicopsids and lycopsids) suggests that the Inland Sawang OCM was deposited under freshwater environment.

Key–words—Palynofossils, Late Permian, Sawang Open Cast Mine, Palaeoenvironment, Bokaro Coalfield, Damodar Basin, Jharkhand.

भारत की दामोदर द्रोणी के पूर्वी बोकारो कोयला क्षेत्र की अंतिम पर्मियन सवंग ओ सी एम का पुरागाणुविज्ञान एवं पुरापर्यावरण

श्रीकांत मूर्ति एवं ए. रजनीकांत

सारांश

दामोदर द्रोणी के पूर्वी बोकारो कोयला क्षेत्र से प्राप्त सवंग विवृत खान (ओ सी एम) का परागाणु कालनिर्धारण कर दिया गया है। प्राप्त परागाणुविज्ञान जीवाश्म *स्ट्रिएटोपोडोकार्पाइटिस – फॉनीपॉल्लेनाइटिस* सम्मिश्रण की प्रभुत्वता से अभिलक्षणित है। इस खंड से अभिलिखित अन्य स्तरिक रूप से सार्थक टैक्सा *गुट्टुलापॉल्लेनाइटिस हन्नोनिकस, क्रेसेंटीपॉल्लेनाइटिस फस्कस, राइज़ोमास्पोरा इंडिका, आर. ट्रिएसिका, डिस्ट्रीआटाइट्सि* जाति, *वीलंडीटाइट्सि लुसीफर, माइक्रोफेविओलाटिस्पोरा गोंडवानेन्सिस, डिक्टीओट्रिलेटीज इन्वीसस, इंडोट्रिरेडाइटिस* जातियां, *अर्कुएटिपॉल्लेनाइटिस पेल्लुसाइडस, अलीस्पोराइटिस इंडिकस* और *क्लॉसीपॉल्लेनाइटिस स्कोबर्गेरी* हैं। अन्य दुर्लभ परागाणु टैक्सा में *पैरासैक्काइटिस, कोरींसेक्काइटिस, डिकपीपॉल्लेनाइटिस, स्ट्रिमोनोसेक्काइटिस, बराकराइटिस, प्लिकेटीपॉल्लेनाइटिस, स्युरिंगीपॉल्लेनाइटिस, डेन्सीपॉल्लेनाइटिस, केल्लुमिस्पोरा, तिवारीआस्पोरिस, प्रीकॉल्पाटाइट्सि* एवं *डिस्ट्रीएटाइट्सि* सन्निहित हैं। समग्र परागाणु संघटन के आधार पर, अध्ययन किया गया खंड अंतिम पर्मियन काल के रूप में कालनिर्धारण किया गया है। यह आयु सहसंबंध भारतीय गोंडवाना द्रोणियों जैसे कि दामोदर, सोन–महानदी, राजमहल, वर्धा–गोदावरी व भारत की सतपुड़ा द्रोणियों और ज्ञात गोंडवाना की अंतर्वस्तुओं के अन्य कोयला क्षेत्रों से ज्ञात सदृश परागाणुसमुच्चयों के साथ तुलनात्मक अध्ययनों से भी समर्थन प्राप्त करते हैं। परागाणुजीवाश्म प्रमाण कोष्ण एवं आर्द्र स्थितियों की व्यापकता इंगित करते हैं। शंकुवृक्षों की प्रभुत्वता और ग्लोसोप्टेरिड, कॉर्डेटीज की उपप्रभुत्वता तथा त्रिअरीय की अल्प प्रतिशतता (फ्लिकॉप्सिड व लायकॉप्सिड) सुझाते हैं कि अंतर्देशीय सवंग ओ सी एम अलवणजल पर्यावरण के अधीन निक्षेपित हो गया था।

सूचक शब्द—परागाणुजीवाश्म, अंतिम पर्मियन, सवंग विवृत खान, पुरापर्यावरण, बोकारो कोयला क्षेत्र, दामोदर द्रोणी, झारखंड।

INTRODUCTION

THE Damodar Basin is an important Indian coal basin and spreads in the Indian states of West Bengal and Jharkhand. Important coalfields in this basin are Raniganj, Jharia, East Bokaro, West Bokaro, Ramgarh, South and North Karanpura. The Bokaro Coalfield is situated in Hazaribagh and Giridih districts of Jharkhand State. The basin is an elongated strip of Gondwana sediments stretching over 64 km from east to west and 12 km in width. The name Bokaro was given by Williams (1846–47) after the Bokaro River which flows for a distance of about 40 km in this region. This coalfield has been divided into two distinct zones, East Bokaro Coalfield (EBC) and West Bokaro Coalfield (WBC) in the Lugu Hill massif (Dutt, 1944–51; Kumar & Sahay, 2001). Further, the part of the coalfield, east of longitudes 85º42' is commonly known as East Bokaro Coalfield (EBC) which is an area of about 237 km^2 and located between latitudes 23º44' & 23º49' N and longitudes 85º42' & 86º4' E in Damodar Basin (Raja Rao, 1987). The Sawang OCM situated in the north–western part of the EBC and its geographical location is marked by latitudes 23º47'40" to 23º48'28" N and longitudes 85º50'37" to 85º51'50" E and included in Survey of India Toposheet No.73E/13 (Pophare & Varade, 2004a, b). The coal–bearing sediments of Sawang area have unconformable contact with the underlying metamorphic rocks (Pophare *et al.,* 2008). The generalized stratigraphic succession of the East Bokaro Coalfield after Raja Rao (1987) is shown in Table 1.

The Indian Gondwana basins are rich in palynofossils (Tiwari, 1999). Various formations of these basins have yielded rich palynofloral assemblages representing lower, middle and upper Permian ages. The palynology of Damodar Basin is well established–(Bharadwaj, 1962; Bharadwaj & Salujha, 1964; Bharadwaj & Srivastava, 1969; Kar, 1968; Tiwari & Singh, 1981; Tiwari & Tripathi, 1992; Srikanta Murthy *et al.,* 2010; Srikanta Murthy *et al.,* 2014).

Negligible palynological work has been done till now in the Bokaro Coalfield. Lele (1973) recovered two micro–floral assemblages belonging to the Talchir Formation from the Dudhi River section, West Bokaro Coalfield. An Olenekian palynoflora was recovered by Pal and Ghosh (1994) from the Panchet Formation exposed at the base of Lugu Hill from Bokaro Coalfield. Vijaya *et al*., (2012) carried out a detailed palynological study from Borehole EBM–1 (East Bokaro Coalfield, Muditoli Block,) and suggested a Permian age for this borecore sequence. Recently, Srikanta Murthy *et al.,* (2016) carried out palynological and petrographical studies from Borehole EMB–2 (western part of East Bokaro Coalfield) and suggested Permian age.

The present investigation is focused on the palynology of the sediments located above the coal seam in Sawang OCM Section (Fig. 2A). Palynodating and correlation have been attempted, and palaeoenvironment has also been inferred. Comparisons with other Late Permian palynofossils of Gondwanan basins in Peninsular India, Australia, Antarctica, Africa and South America have also been done.

GENERAL GEOLOGY OF THE COALFIELD

The Gondwana sediments in the EBC are represented by Talchir, Barakar (Early Permian), Barren Measures Raniganj (late Permian), Panchet (early Triassic) and Supra Panchet (middle to late Triassic) formations (Table 1, after Raja Rao, 1987). The scattered rocks of Talchir Formation unconformably overlie the basement rocks in the north–eastern periphery of the coalfield, and includes tillite, greenish

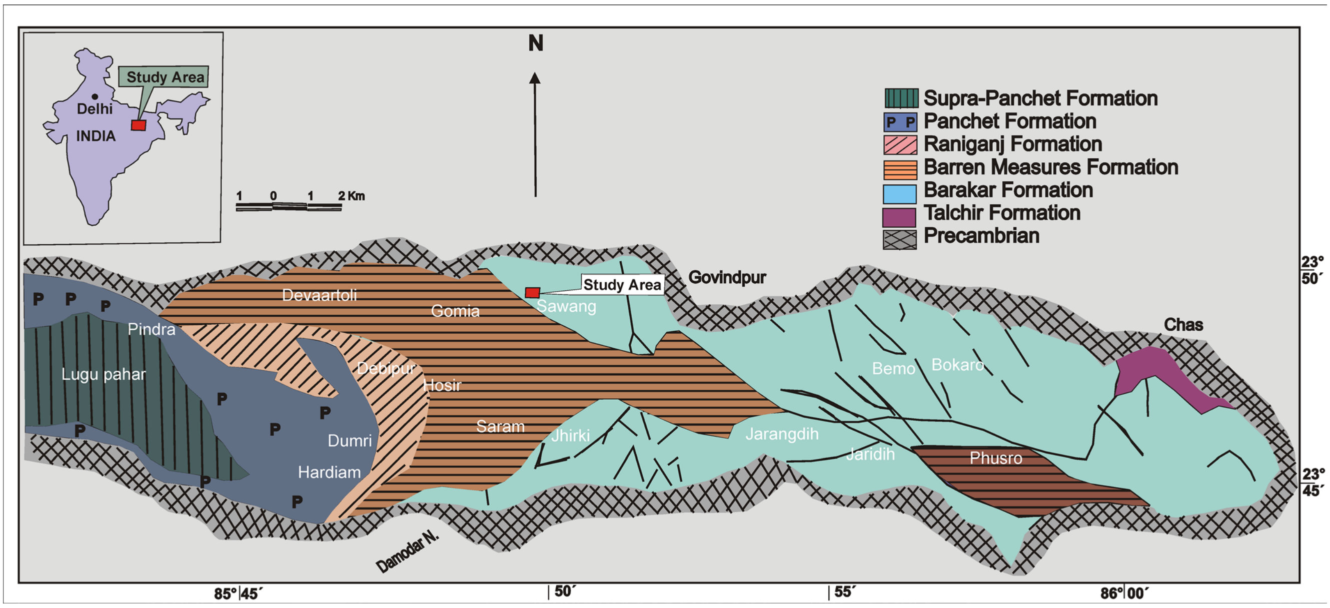

Fig. 1—Geological map of East Bokaro Coalfield showing the location of the study area (after Raja Rao, 1987).

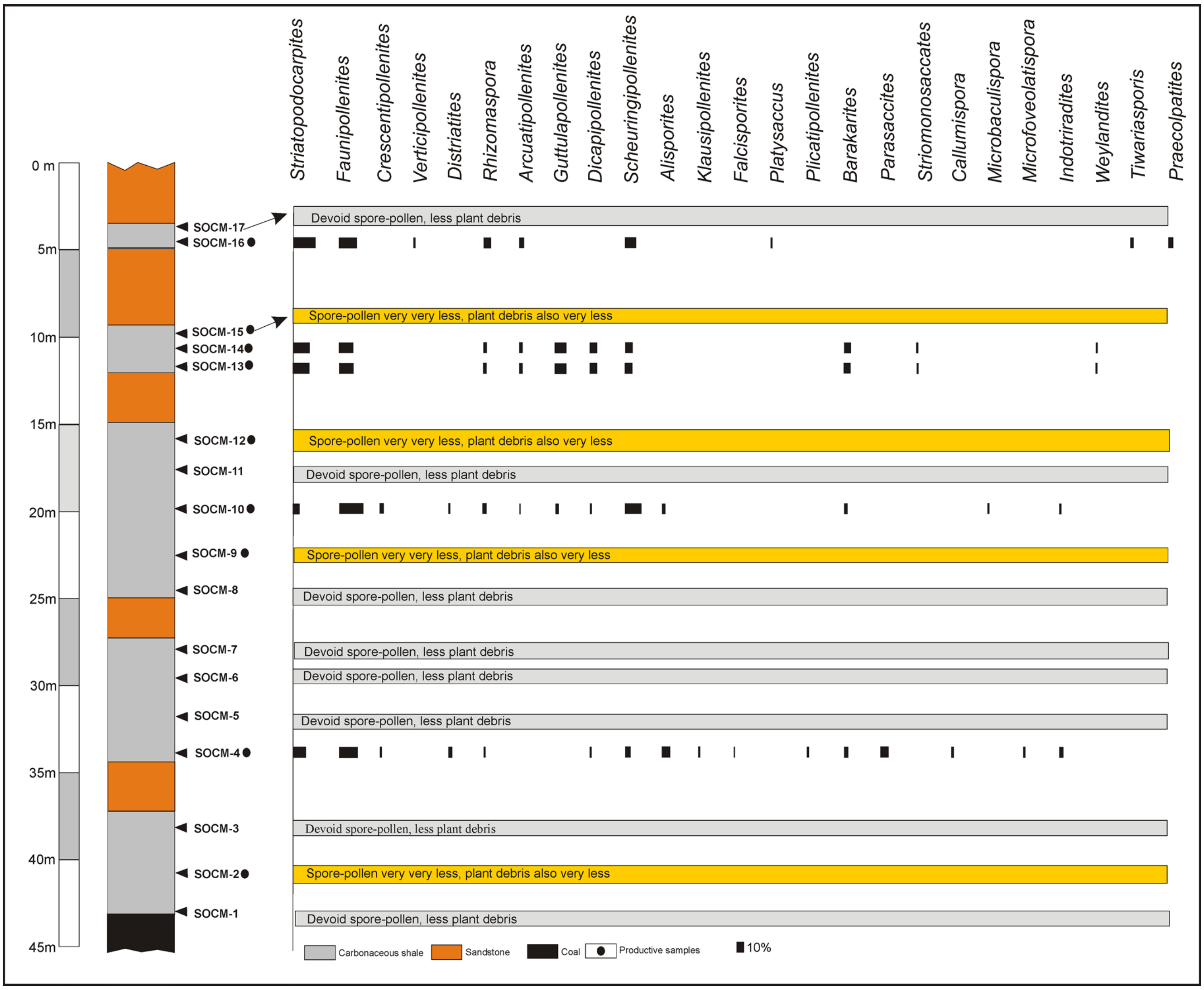

Fig. 2—A. Litholog and positions of samples. B. Distribution of palynotaxa in the Sawang OCM, East Bokaro Coalfield, Jharkhand; Dominant (>20%), subdominant (10–19%), common (5–9%), fair (2–4%) and poor (<2%).

sandstones and needle shale sediments. The major part of this basin to the east is occupied by Barakar Formation, which rests over the Talchir Formation and in other places the Barakar Formation rest directly on the Precambrian basement. This formation comprises coarse–grained arkosic sandstones, fine–grained laminated sandstones, grey shales, carbonaceous shales and coal seams. The crescentic outcrops of Barren Measures overlie the Barakar Formation and are exposed in the central, north–western and south–western regions, comprised of alternation of flaggy, cross–bedded, ripple–laminated ferruginous sandstones and shale beds. The successive overlying Raniganj Formation has a large spread along the base of the Lugu Hill and the formation is composed of medium to coarse–grained sandstones, shales and a few thin coal seams. The younger Panchet Formation occupies a vast area along the northern, eastern, and southern flanks of Lugu Hill and is composed of fine–grained, greenish, micaceous sandstones and greenish shales, course–grained brownish–yellow, ferruginous sandstones and greenish chocolate sandy shales. The youngest strata in this coalfield, the Supra–Panchet Formation, consists of coarse clastics and rests over the Panchet Formation with an apparent angular unconformity, and this unconformable junction can be observed on the eastern face of the Lugu Hill. The composition of this formation is mostly coarse–grained ferruginous sandstones with lenses of pebbles. Interbeded within the sandstones are a few thin beds of red clays (Fig. 1).

MATERIALS AND METHOD

The studied material comprises seventeen samples collected from the Sawang OCM section which is situated

Age	Formation	Lithology
Lower Cretaceous	Intrusive	Lamprophyre and dolerite dykes and sills
Upper Triassic	Supra–Panchet (Mahadeva ?)	Coarse–grained ferruginous sandstone, pebbly sandstone and red clay (600 m).
	UNCONFORMITY	
Lower Triassic	Panchet	Greenish micaceous sandstone, buff fine–grained sandstone, red and green shale (500–600 m).
Upper Permian	Raniganj	Medium–to–coarse grained calcareous, sandstone, fine–grained greenish sandstone, grey shale, carbonaceous shale and thin coal seams (600 m).
Middle Permian	Barren Measures	Flaggy, fine–grained ferruginous sandstone micaceous sandy shale and black shale with siderite band (500 m).
Lower Permian	Barakar	Coarse–grained arkosic sandstone, fine–grained laminated sandstone, grey shale, carbonaceous shale and coal seams (900 m).
U–Carboniferous to L–Permian	Talchir	Tillite, greenish sandstones and needle shale
Pre–Cambrian	Pre–Cambrian	Granite gneisses, amphibolites and Mica schist

Table 1—Generalized stratigraphic succession of the East Bokaro Coalfield (after Raja Rao, 1987).

in the north–western part of the EBC. The succession is approximately of 45 m thick section and the lithofacies comprises mainly of carbonaceous shales, fine–grained sandstones and coal (Fig. 2A). 50 grams of each sample were taken and crushed (2–4 mm) and treated with 40% Hydrofluoric acid for 3–4 days to remove the silica content. Thereafter, the samples were washed thoroughly with distilled water to remove the acid content. The resultant residue was oxidized with concentrated Nitric acid and then treated with 10% Potassium Hydroxide solution. Five slides were prepared from each residue and the palynofossils were examined under standard light microscope (Olympus BX61 with DP–25 camera using Cell A software). Of the seventeen samples analysed, nine yielded pollen–spores which have been used for palynodating of the sediments (Fig. 2B).

PALYNOLOGICAL ANALYSIS

Out of the nine yielding samples, five samples (i.e. SOCM 4, 10, 13, 14 and 16) were rich in palynofossils, while four samples SOCM 2, 9, 12 and 15 were poor in palynofossils but rich in plant debris and amorphous organic matter. Besides, the remaining of samples (SOCM 1, 3, 5, 6, 7, 8, 11 and 17) were devoid of palynofossils and also poor in plant debris. The preservation of the palynofossils is variable within the samples, and recovery is low to moderate, light yellowish to dark brown, distorted, broken to fairly well–preserved (Pl. 1). The percentage frequency of the palynofossils is given in Figure 2B and indicated as dominant (more than 20%), subdominant (between 10–20%), common (between 5–9%), fair (between 2–4%) and poor (less than 2%) (Table 3).

The statistical analysis carried out in the studied section reveals that the pollen grains are more frequent compared to spores. Among the pollen, the representatives of striate bisaccate genera *Striatopodocarpites* (*S. labrus, S. ovalis, S. ovatus, S. subcircularis*) are the dominant taxa followed by *Faunipollenites varius*. The other associated common striate bisaccate taxa which characterise the assemblage include *Crescentipollenites fuscus*, *Verticipollenites gibbosus, Rhizomaspora (R. indica, R. triassica), Striatites varius* and

PLATE 1

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1. *Cyclogranisporites* sp.
2. *Callumispora* sp.
3. *Dictyotriletes invisus* Bharadwaj & Salujha (1964)
4. *Indotriradites korbaensis* Tiwari (1964)
5. *Indotriradites sparsus* Tiwari (1965)
6. *Parasaccites obscurus* Tiwari (1965)
7. *Scheuringipollenites maximus* (Hart) Tiwari (1973)
8. *Guttulapollenites hannonicus* Goubin (1965)
9. *Dicapipollenites* sp.
10. *Tiwariasporis novus* (Srivastava) Bharadwaj & Dwivedi (1981)
11. *Faunipollenites varius* Bharadwaj (1962)
12. *Striatopodocarpites labrus* Tiwari (1964)
13. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.,* (1974)
14. *Rhizomaspora triassica* Tiwari & Rana (1981)
15. *Striatites varius* Kar (1968)
16. *Platysaccus densicorpus* Anand–Prakash (1972)
17. *Falcisporites zapfei* Leschik emend. Klaus (1963)
18. *Alisporites indicus* Bharadwaj & Srivastava (1969)
19. *Klausipollenites schaubergerii* Potonié & Klaus (1954)
20. *Arcuatipollenites pellucidus* (Goubin) Tiwari & Vijaya (1995)

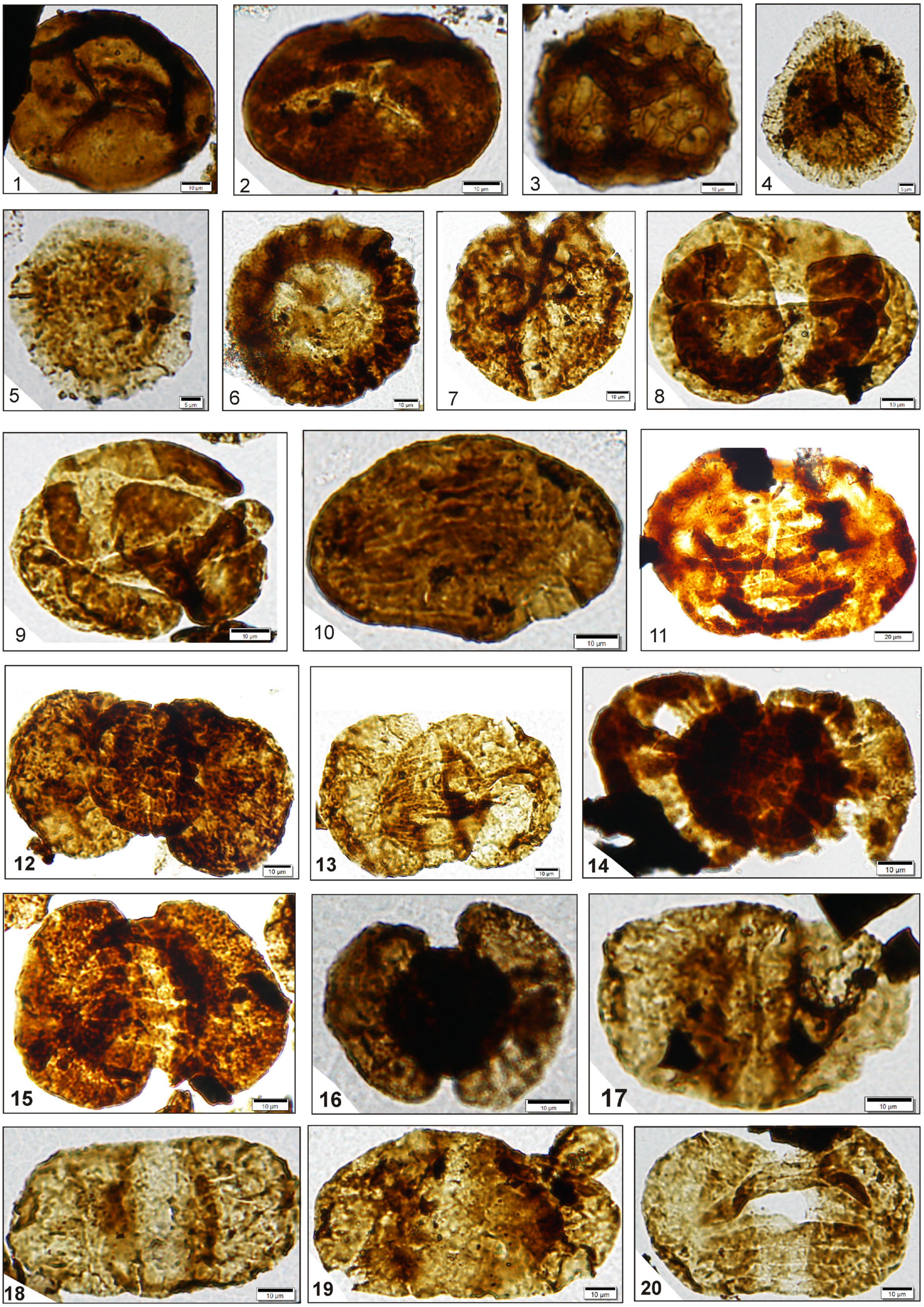

PLATE 1

Distriatites sp. Taeniate genera include *Arcuatipollenites* (*A. pellucidus* and *A. ovatus*), *Guttulapollenites hannonicus*, *Dicapipollenites* sp.*;* nonstriate bisaccate forms mainly include *Scheuringipollenites* (*S. barakarensis, S. tentula* and *S. maximus*) and others which are poor in frequencies, such as *Alisporites indicus*, *Falcisporites zapfei*, *Klausipollenites schaubergeri* and *Platysaccus densicorpus*. The monosaccates are poor in the assemblage and are represented by *Parasaccites obscurus*, *Plicatipollenites* sp., *Barakarites* sp. and *Striomonosaccites* sp. Inaperturate pollen are represented by *Weylandites* (*W. indicus, W. irregularis*)*, Tiwariasporis novus* and *Praecolpatites* sp. The spores are meagre and represented by *Callumispora gretensis, Callumispora* sp., *Microfoveolatispora gondwanensis, Dictyotriletes invisus, Convertubisporites* and *Indotriradites* (*I. korbaensis, I. sparus*). The palynoassemblage mostly represent gymnosperm pollen in dominance, and pteridophytic spores are less in numbers.

The studied palynocomposition compares well with the *Striatopodocarpites–Faunipollenites* Palynozone–A (R–II B) in the Raniganj Formation of the Damodar Basin, which is dated as late Permian in age (Tiwari & Tripathi, 1992).

CORRELATION

The Gondwana sequences of peninsular India exhibit different sedimentation patterns in each basin due to variable deposition in linear, fault bounded belts in which recurrent uplift and subsidence at varying rates created different tectonic regimes (Jha *et al.,* 2014). Therefore, there are problems in inter–basinal correlations in the lithological context. However, they display broad similarities of palynoassemblages at the generic levels, thus favouring correlations within the Gondwana basins in peninsular India (Fig. 3, Table 2) and other Gondwana continents, viz. Australia, Antarctica, Africa and South America.

Correlations with other Gondwana basins of peninsular India

The late Permian palynofossils of the present study are well correlated with other Gondwana basins of peninsular India, such as Damodar Basin (Bharadwaj & Tiwari, 1977; Rana & Tiwari, 1980; Singh & Tiwari, 1982; Tiwari & Singh, 1983; Tiwari & Tripathi, 1992; Srikanta Murthy, 2010; Srikanta Murthy *et al.,* 2010; Vijaya, 2011; Vijaya *et al.,* 2012; Srikanta Murthy *et al.,* 2014; 2016); Son–Mahanadi Basin (Srivastava *et al.,* 1977; Tiwari & Ram–Awatar, 1989; Tripathi & Bhattacharya, 2001; Srivastava & Kar, 2001; Kar, 2003; Kar & Srivastava, 2003; Ram–Awatar *et al.,* 2004); Satpura Basin (Bharadwaj *et al.,* 1978; Kumar, 1996; Srikanta Murthy *et al*., 2013); Rajmahal Basin (Tripathi, 1986, 1989) and Wardha–Godavari basins (Srivastava & Jha, 1988, 1990, 1991, 1992, 1995; Jha & Srivastava, 1996; Jha *et al.,* 2007, 2014; Jha, 2008; Aggarwal, *et al.,* 2015; Jha & Aggarwal, 2015) in having similar

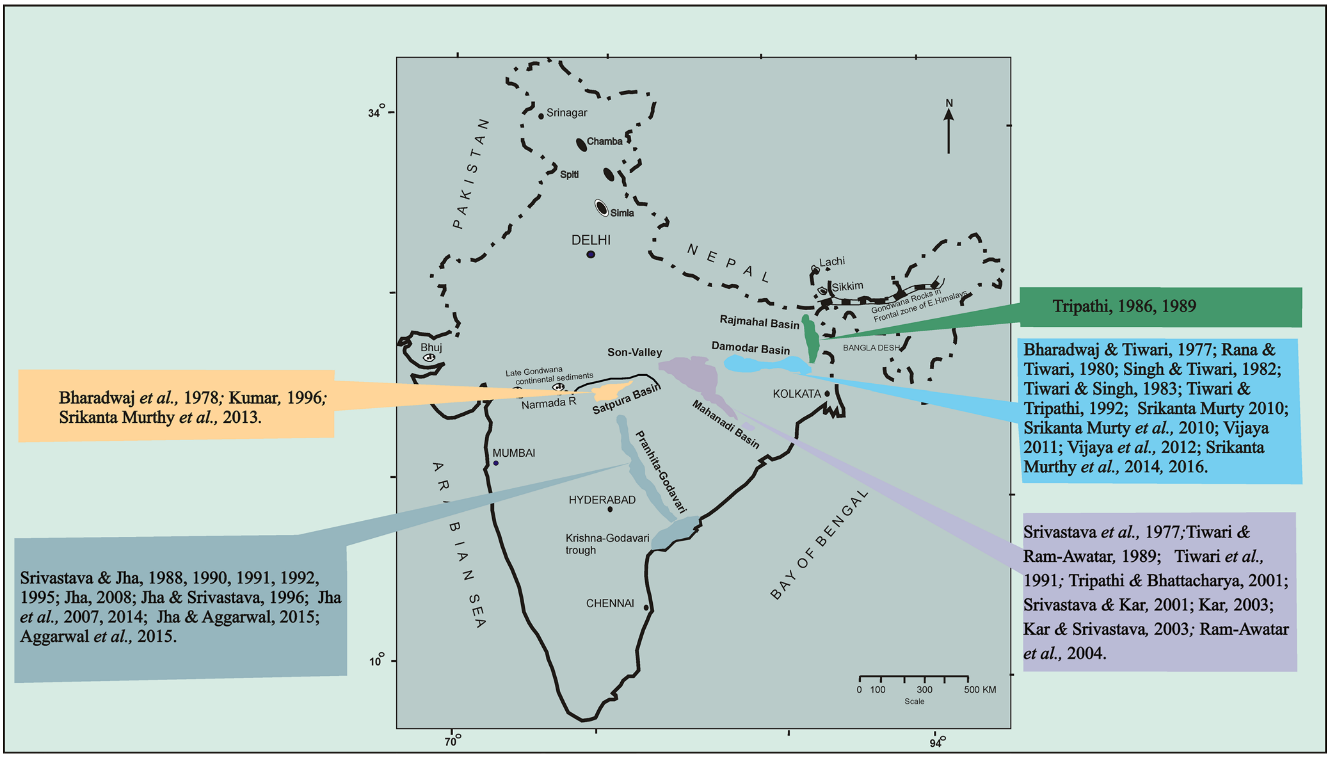

Fig. 3—Reports of Late Permian palynoassemblage from the Gondwana Basins of Peninsular India.

Gondwana Basins	Coalfields/Area	References
Damodar Basin	Karanpura Coalfield	Srikanta Murthy *et al.,* 2014.
	Raniganj Coalfield	Srikanta Murthy, 2010; Srikanta Murthy *et al.,* 2010; Vijaya, 2011; Bharadwaj & Tiwari, 1977; Tiwari & Singh, 1983; Singh & Tiwari, 1982; Rana & Tiwari, 1980; Tiwari *et al.,*1992.
	East Bokaro Coalfield	Vijaya *et al.,* 2012; Srikanta Murthy *et al.,* 2016; Present study–Sawang OCM
Son–Mahanadi	Talchir Coalfield	Tripathi & Bhattacharya, 2001.
	Johilla Coalfield	Tiwari & Ram–Awatar, 1989.
	Sohagpur Coalfield	Ram–Awatar *et al.,* 2004;
	Tatapani–Ramkola	Kar, 2003; Kar & Srivastava, 2003; Srivastava & Kar, 2001; Srivastava *et al.,* 1977.
Satpura Basin	Shivapura Coal Mine	Srikanta Murthy *et al.,* 2013.
	Tamia Ghat Road	Kumar, 1996.
	Near Sukhtawa nala	Bharadwaj *et al.,* 1978.
Wardha–Godavari Basin	Kamptee Coalfield	Srivastava & Jha, 1988, Jha & Srivastava, 1996.
	Amavaram Area	Srivastava & Jha, 1991
	Mailaram Area	Srivastava & Jha, 1990,
	Budharam Area	Srivastava & Jha, 1995.
	Sattupalli Area	Srivastava & Jha, 1992.
	Chintalapudi	Jha, 2008.
	Gauridevpet Area	Jha *et al.,* 2014.
	Manuguru Area	Srivastava & Jha, 1992.
	Kachinapalli	Jha & Aggarwal, 2015.
	Mamakannu Area	Aggarwal *et al.,* 2015.
Rajmahal Basin	Birbhum Coalfield	Tripathi, 1986, 1989.

Table 2—Reports of Late Permian palynoassemblage from the Indian Peninsula.

palynoassemblages, such as dominance of *Striatopodocarpites* spp. and *Faunipollenites* spp. in association with other stratigraphically significant palynofossils, such as *Platysaccus, Crescentipollenites*, *Weylandites, Striomonosaccites, Barakarites, Alisporites*, *Falcisporites*, *Klausipollenites*, *Rhizomaspora, Arcuatipollenites, Microfoveolatispora, Dictyotriletes* and *Indotriradites*. Even though, these basins show a broad similarity, slight differences are also recorded from Sawang OCM in not having some palynofossils like *Corisaccites, Gondisporites, Lundbladispora, Distriatites, Brevitriletes, Horriditriletes, Densipollenites,* etc.

Correlation with the late Permian Gondwana counterparts

The late Permian assemblage of the present study is also correlatable with other Gondwana continents such as Antarctica (Balme & Playford, 1967; Kemp, 1973; Kyle & Schopf, 1982; Playford, 1990; Lindstrom, 1996); Australia (Foster, 1979, 1982); Africa (Falcon, 1975; Anderson, 1977; Hankel, 1992; Modie & Le Herisse, 2009); South America (Marques–Toigo, 1991; Souza & Marques–Toigo, 2003, 2005; Souza, 2006; Gutierrez *et al.,* 2011) in having dominant striate bisaccate pollen grains mainly *Striatopodocarpites* and *Faunipollenites* (= *Protohaploxypinus*) and presence of some common taxa such as *Guttulapollenites*, *Lunatipollenites* (=*Arcuatipollenites*), *Scheuringipollenites*, *Alisporites* and *Klausipollenites*.

PALAEOENVIRONMENT

The palynological analysis from the Sawang OCM shows the dominance of striate bisaccates–*Striatopodocarpites, Faunipollenites (= Protohaploxypinus), Crescentipollenites, Verticipollenites, Rhizomaspora, Striatites,* and taeniate bisaccate *Arcuatipollenites* indicating the presence of conifers in the peat forming vegetation. Conifers are considered to be extra–basinal or hinterland elements, which typically

Sample No.	Palynocomposition
SOCM 4 SOCM 10 SOCM 13 SOCM 14 SOCM 16	Dominance of striate bisaccate genera chiefly *Striatopodocarpites* (20–32%) followed by *Faunipollenites* (20–26%). Other stratigraphically significant taxa bisaccate, viz. *Crescentipollenites* (2–4%), *Verticipollenites* (2–3%), *Rhizomaspora* (2–10%), *Striatites* (2–5%) and *Distriatites* (0–2%). Taeniate genera include *Arcuatipollenites* (1–6%), *Guttulapollenites* (4–17%), *Dicapipollenites* (2–11%); nonstriate bisaccate forms mainly include *Scheuringipollenites* (7–20%) and others which are poor in frequencies, such as *Alisporites* (4–11%), *Falcisporites* (2–3%), *Klausipollenites* (0–1%) and *Platysaccus* (0–2%). The monosaccate are poor in the assemblage and are represented by *Parasaccites* (2–11%), *Barakarites* (4–7%), *Plicatipollenites* (0–2%) and *Striomonosaccites* (0–6%). *Inaperturopollenites* pollen are represented by *Weylandites* (2–5%), *Tiwariasporis* (0–4%) and *Precolpatites* (0–6%). The spores are meagre and represented by *Callumispora* (0–3%), *Microfoveolatispora* (0–2%), *Dictyotriletes* (0–4%), *Convertubisporites* (0–2%) and *Indotriradites* (0–2%).

Table 3—Palynocomposition of Sawang Open Cast Mine.

show several adaptations for survival in drier habitats. Monosaccate forms are poor in percentage and low in diversity being represented by *Parasaccites, Plicatipollenites, Barakarites* and *Striomonosaccites,* reflecting the presence of Cordaites also in the peat forming flora. Cordaites pollen prefers mesophilous palaeoenvironment which is inhabited in well drained and low land substrates (Taylor & Taylor, 1993). Fragmentary presence of Cordaites suggests incursion of remnants of a parautochthonous seasonal dryland flora in the depositional environment (Jasper *et al.*, 2006). The nonstriate bisaccate pollen is represented by glossopterids such as *Scheuringipollenites, Alisporites, Falcisporites, Klausipollenites* and *Platysaccus,* indicating their prevalence in the peat forming vegetation. Glossopterids grew in mesophilous to xerophilous palaeoenvironment and flourished in lowland peats; while conifers survived in areas distant to the mires (Knoll & Nicklas, 1987). The trilete spores are relatively low in percentages and represented by Filicopsids (*Microbaculispora, Microfoveolatispora, Dictyotriletes*) and Lycopsids (*Indotriradites*) and are related to herbaceous and arborescent groups, which flourished in hygrophilous and mesophilous environments (Cazzulo–Klepzig *et al.,* 2005). The abundance conifer pollen in the present assemblage suggests the dominance of arborescent vegetation in the form of a forest swamp, probably in a small distant marginal part of the mire. The growth of herbaceous lycopsids and filicopsids probably favoured a flooding environment (Dimichele & Phillips, 1985). The overall palynological analysis suggests that the Sawang OCM palaeomire occupied inland areas of the basin and was deposited under fresh water environment.

DISCUSSION

Three palynoassemblage zones have been identified by Tiwari and Tripathi, 1992 in the late Permian of the Damodar Basin namely, *Densipollenites indicus* Assemblage Zone or Zone VII, indicating Barren Measures Formation (Kulti Formation), *Gondisporites raniganjensis* Assemblage Zone or Zone VIII representing lower part of Raniganj Formation and *Densipollenites magnicorpus* Assemblage Zone or Zone IX marking the upper part of Raniganj Formation. The sediments of the present study are palynologically dated to the lower part of Raniganj Formation, which is of late Permian age belongs to *Striatopodocarpites–Faunipollenites* zone–A (Tiwari & Tripathi, 1992). Other forms like *Crescentipollenites, Arcuatipollenites, Alisporites, Klausipollenites, Falcisporites* and *Guttulapollenites,* which are quantitatively less, also support this view. It can be concluded that the Sawang OCM section is dated as late Permian on the basis of above palynological evidences. Further, this palynoassemblage is compared well with previously known late Permian palynoassemblages from other Gondwana basins in peninsular India and also with gondwanan continents such as Australia, Africa, Antarctica and South America. The morphological characters, such as thin central body, diversity in striation and haploxylonoid construction in the present palynocomposition indicate warm climate (Tiwari & Tripathi, 1987). On the basis of palynofossils composition, the present Sawang OCM succession represents a peat–forming community mainly composed of gymnosperms (conifers, glossopterids and cordaites) together with pteridophytes (lycopsids and filicopsids).

CONCLUSIONS

- Late Permian age is proposed for the sediments from the Sawang open cast mine on the basis of palynological study.
- Palynological study also revealed that the peat forming vegetation mainly composed of gymnosperms represented by glossopterids, conifers, cordatites together with pteridophytes (lycopsids and filicopsids).
- The morphological studies in the present palynocomposition indicate warm climate during the deposition of sediments.

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REFERENCES

Anand–Prakash 1972. *Sporae dispersae* in the coals of Pench–Kanhan and Pathakhera Coalfield (M.P.), India. Palaeobotanist 19: 206–210.

Aggarwal N, Jha N, Joshi H & Mishra S 2015. Dispersed organic studies in Permian succession Mamakanu Block of Godavari Graben, south India. Journal of Indian Geological Congress 7(2): 5–15.

Anderson JM 1977. The biostratigraphy of the Permian and Triassic. Part 3. A review of Gondwana palynology with particular reference to the northern Karoo Basin, South Africa. Memoirs of Botanical Survey of South Africa 41: 1–188.

Balme BE & Playford G 1967. Late Permian plant microfossils from the Prince Charles Mountains, Antarctica. Revue de Micropalaeontologie 10: 179–192.

Bharadwaj DC 1962. The miospore genera in the coals of Raniganj Stage (Upper Permian), India. Palaeobotanist 9: 68–106.

Bharadwaj DC & Dwivedi A 1981. *Sporae dispersae* of the Barakar sediments from south Karanpura Coalfield, Bihar, India. Palaeobotanist 27: 21–94.

Bharadwaj DC & Salujha SK 1964. Sporological study of seam VIII in Raniganj Coalfield, Bihar, (India) Part I–description of *sporae dispersae*. Palaeobotanist 12: 181–215.

Bharadwaj DC & Srivastava SC 1969. Some new miospores from Barakar Stage Lower Gondwana, India. Palaeobotanist 17: 220–229.

Bharadwaj DC & Tiwari RS 1977. Permian–Triassic Miofloras from the Raniganj Coalfield, India. Palaeobotanist 24: 26–49.

Bharadwaj DC, Tiwari RS & Anand–Prakash 1978. Palynology of Bijori Formation (Upper Permian) in Satpura Gondwana Basin, India. Palaeobotanist 25: 70–78.

Bharadwaj DC, Tiwari RS & Kar RK 1974. *Crescentipollenites* gen. nov.: a new name for hitherto known *Lunatisporites* Leschik from the Lower Gondwanas. Geophytology 4: 141–146.

Cazzulo–Klepzig M, Menegat R & Guerra–Sommer M 2005. Palynology and palaeobotany in the reconstruction of landscape units from the Candiota Coalfield, Permian of Paraná Basin, Brazil. Revista Brasileira de Paleontologia 8: 83–98.

Dutt AB 1944–51. East Bokaro Coalfields. *In:* Raja Rao CS 1987 (Editor)—Coalfields of India. Bulletin Geological Survey of India A IV, 45: 1–9.

Dimichele WA & Phillips TL 1985. Arborescent Lycopod reproduction and paleoecology in a coal–swamp environment of late Middle Pennsylvanian age (Herrin Coal, Illinois, USA). Review of Palaeobotany and Palynology 44: 1–26.

Falcon R 1975. Palynostratigraphy of the Lower Karroo sequence in the central Sebungwe District, Mid–Zambezi Basin, Rhodesia. Palaeontologia Africana 18: 1–29.

Foster CB 1979. Permian plant microfossils of the Blair Athol Coal Measures, Baralaba Coal Measures, and Basal Rewan Formation of Queensland. Geological Survey of Queensland publications, 372. Palaeontological Paper 45: 1–244.

Foster CB 1982. Biostratigraphic potential of Permian spore–pollen floras from GSQ Mundubbera 5 and 6, Taroom trough. Queensland Government Mining Journal 83: 82–96.

Goubin N 1965. Description et repartition des principaux pollenites Permiens, Triassiques et Jurassiques des Sondages du Bassin de Morondava (Madagascar). Revue Institut Francais du Petrole 20: 1415–1461. (in French)

Gutiérrez PR, Zavattieri AM, Ezpeleta M & Astini RA 2011. Palynology of the La Veteada Formation (Permian) in the Sierra De Narva´ ez, Catamarca province, Argentina. Ameghiniana, Torno 48: 154–176.

Hankel O 1992. Late Permian to early Triassic microfloral assemblages from the maji ya chumvi Formation, Kenya. Review of Palaeobotany and Palynology 72: 129–147.

Jasper A, Menegat R, Guerra–Sommer M, Cazzulo–Klepzig M & Souza PA 2006. Depositional cyclicity and paleoecological variability in an outcrop of Rio Bonito Formation, Early Permian, Paraná Basin, Rio Grande do Sul, Brazil. Journal of South American Earth Sciences 21: 276–293.

Jha N 2008. Permian Triassic palynofloral transition in the Sattupalli area, Chintalapudi sub–basin, Godavari Graben, Andhra Pradesh, India. Journal of Palaeontological Society of India 53: 159–168.

Jha N & Aggarwal N 2015. Peat–Forming environment of coal–bearing Permian sediments in Kachinapalli area of Godavari Graben, India. Revista Brasileora De paleontologia 18(2): 239–250.

Jha N, Pauline Sabina K, Aggarwal N & Mahesh S 2014. Late Permian palynology and depositional environment of the Chintalapudi Sub–basin of Godavari Basin, Andhra–Pradesh, India. Journal of Asian Earth Sciences 79: 382–399.

Jha N, Tewari R & Rajanikanth A 2007. Palynology of Permian Gondwana sequence of Umrer Coalfield, Maharashtra. Journal of Geological Society of India 69: 851–857.

Jha N & Srivastava SC 1996. Kamthi Formation palynofloral diversity; *In:* Guha PKS, Sengupta S, Ayyasami K & Ghosh RN (Editors)–Gondwana Nine, Calcutta: Oxford & IBH Publishing Co. 1: 355–368.

Kar RK 1968. Palynology of North Karanpura Basin, Bihar, India–5. Palynological assemblage of the borecore K2, Raniganj Stage (upper Permian). Palaeobotanist 17: 101–120.

Kar R 2003. Palynological recognition of Barren Measures sediments (Middle Permian) from Tatapani–Ramkola Coalfield, Chhattisgarh, India. Indian Gondwana Geological Magazine 6: 239–244.

Kar R & Srivastava SC 2003. Palynological delimitation of the coal bearing Lower Gondwana sediments in the Southern Part of Tatapani–Ramkola Coalfield, Chhattisgarh, India. Journal of Geological Society of India 61: 557–564.

Kemp EM 1973. Permian flora from the Beaver Lake area, Prince Charles Mountains Antarctica; 1. Palynological investigation of samples. Australian Bureau of Mineral Resources, Geology and Geophysics, Palaeontological Papers 126: 7–12.

Klaus W 1963. Sporen aus dem südalpinen Permin. Geological Jahrb Bundesanst 106: 229–361.

Knoll J & Nicklas E 1987. Adaptation, plant evolution, and the fossil record. Review of Palaeobotany and Palynology 72: 886–887.

Kumar P 1996. Permo–Triassic palynofossils and depositional environment in Satpura Basin, Madhya Pradesh. Geophytology 25: 47–54.

Kumar U & Sahay AV 2001. Prospects of coal bed methane in Jarangdih–Asnapani Graben, East Bokaro coalfields, Bihar, India. *In*: Proceedings International Seminar on "Coal Bed Methane–Prospects and Potentialities"; South Asian Association Economic Geologist: 49–56.

Kyle RA & Schopf JM 1982. Permian and Triassic palynostratigraphy of the Victoria Group, Trans Antarctic Mountains. *In*: Craddock (Editor)–Antarctic Geoscience: 649–659.

Lele KM 1973. Studies in the Talchir flora of India–10. Early and late Talchir microfloras from the West Bokaro Coalfield, Bihar. Palaeobotanist 22: 219–235.

Lindstrom S 1996. Late Permian Palynology of Fossilryggen, Vestfjella, Dronning Maud Land, Antarctica. Palynology 20: 15–48.

Marques–Toigo M 1991. Palynobiostratigraphy of the southern Brazilian Neopalaeozoic Gondwana Sequence. *In*: Ulbrich H & Rocha Campos AC (Editors)–Gondwana Seven: 503–515. Institute of Geoscience. USP, São Paulo.

Modie BN & Le Herisse A 2009. Late Palaeozoic palynomorphs assemblages from the Karoo Supergroup and their potential for biostratigraphic correlation, Kalahari Karoo basin, Bostwana. Bulletins Geoscience 84: 337–358.

Pal PK & Ghosh AK 1994. Miofloral assemblage from Deoli Member of Panchet Formation in the East Bokaro Coalfield, India. IX International Gondwana Symposium, Hyderabad, India: 22–23 (Abstract).

Playford G 1990. Proterozoic and Palaeozoic palynology of Antarctica: a review. *In*: Taylor TN & Taylor EL (Editors)—Antarctica Paleobiology: Its role in the reconstruction of Gondwana: 51–70. Springer–Verlag New York, Inc.

Pophare AM & Varade AM 2004a. Coal Bed Methane Exploration: A case study from Sawang Colliery, East Bokaro Coalfield, Jharkhand, India. Gondwana Geological Magazine 19: 37–55.

Pophare AM & Varade AM 2004b. Coal Bed Methane potential of coal seams in Sawang Colliery, East Bokaro coalfields, Jharkhand, India. Indian Journal of Petroleum Geology 13: 41–53.

Pophare AM, Mendhe VA & Varade A 2008. Evaluation of Coal Bed Methane potential of coal seams of Sawang Colliery, Jharkhand, India. Journal Earth System Science 117: 121–132.

Potonié R & Klaus W 1954. Eingie sporengattungen des alpine Salzgebirges. Geological Jahrb 68: 517–546. (in German)

Raja Rao CS 1987. Coalfields of India. Bulletin Geological Survey of India, A–IV 45(I): 1–60.

Ram–Awatar, Mukhopadhyay A & Adhikari S 2004. Palynostratigraphy of sub–surface Lower Gondwana, Pali sediments, Sohagpur Coalfield, M.P., India. Palaeobotanist 53: 51–59.

Rana V & Tiwari RS 1980. Palynological succession in Permian–Triassic sediments in borehole RNM–3, East Raniganj Coalfield, West Bengal. Geophytology 10: 180–124.

Singh V & Tiwari RS 1982. Patterns of miofloras through Permo–Triassic transition in bore–hole RAD–2, East Raniganj Coalfield, West Bengal. Geophytology 12: 181–186.

Souza PA 2006. Late Carboniferous palynostratigraphy of the Itarare Subgroup, northern Parana Basin, Brazil. Review of Palaeobotany and Palynology 138: 9–29.

Souza PA & Marques–Toigo M 2003. An overview on the palynostratigraphy of the Upper Paleozoic strata of the Brazilian Parana Basin. Revista del Museo Argentino de Ciencias Naturales 5: 205–214.

Souza PA & Marques–Toigo M 2005. Progress on the Palynostratigraphy of the Permian strata in Rio Grande do Sul State, Parana Basin, Brazil. Annals of the Brazilian Academy of Sciences 77(2): 353–365.

Srikanta Murthy 2010. Palynostratigraphy of the Permian succession in Borehole RJS–2, Raniganj Coalfield, Damodar Basin, West Bengal. Journal of Indian Geological Congress 2(2): 83–90.

Srikanta Murthy, Chakraborthi B & Roy MD 2010. Palynodating of subsurface sediments, Raniganj Coalfield, Damodar Basin, West Bengal. Journal of Earth System Science 119: 701–710.

Srikanta Murthy, Tripathi, A, Chakraborti B & Singh UP 2014. Palynostratigraphy of Permian Succession from Binja Block, South Karanpura Coalfield, Jharkhand, India. Journal of Earth System Science 123: 1895–1906.

Srikanta Murthy, Mahesh S & Roy JS 2016. Palyno–petrographical Facet and Depositional Account of Gondwana sediments from East Bokaro Coalfield, Jharkhand, India. Journal of Geological Society of India 88: 549–558.

Srikanta Murthy, Vijaya & Vethanayagam SM 2013. Palynostratigraphy of Permian succession in the Pench Valley Coalfield, Satpura Basin, Madhya Pradesh, India. Journal of the Palaeontological Society of India 58: 241–250.

Srivastava SC, Anand–Prakash & Kar R 1977. Palynology of Permian–Triassic sequence in Iria Nala, Tatapani–Ramkola Coalfield, India. Palaeobotanist 46(1): 75–80.

Srivastava SC & Jha N 1988. Palynology of Kamthi Formation from Chelpur area, Godavari Graben, Andhra Pradesh, India. Palaeobotanist 35: 342–346.

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

Srivastava SC & Jha N 1991. Palynological dating of coal seams in Amavaram area, Khammam District, A.P., India. Geophytology 20: 161.

Srivastava SC & Jha N 1992. Palynostratigraphy of Permian sediments in Manuguru area, Godavari Graben, Andhra Pradesh. Geophytology 22: 103–110.

Srivastava SC & Jha N 1995. Palynostratigraphy and correlation of Permian–Triassic sediments in Budharam Area, Godavari Graben, India. Journal of the Geological Society of India 46: 647–653.

Srivastava SC & Kar R 2001. Palynological Dating of some Permian outcrops from Iria Valley, Tatapani–Ramkola Coalfield, M.P., India. Proceedings of National Seminar on Recent Advances in Geology of Coal and Lignite Basins of India, Calcutta. Geological Society of India, Special Publication. No. 54: 97–102.

Taylor TN & Taylor EL 1993. The biology and evolution of fossil plants. New Jersey, Prentice–Hall Inc., 982 p.

Tiwari RS. 1964. New miospore genera in the coals of Barakar Stage (Lower Gondwana) of India. Palaeobotanist 12: 250–259.

Tiwari RS 1965. Miospore assemblage in some coals of Barakar Stage (Lower Gondwana) of India. Palaeobotanist 13: 168–214.

Tiwari RS 1973. *Scheuringipollenites,* a new name for the Gondwana sporomorphs so far assigned to *"Sulcatisporites* Leschik 1955" Senckenb. Leth. 54: 105·117.

Tiwari RS 1999. The palynological succession and spatial relationship of the Indian Gondwana sequence. PINSA 65: 329–375.

Tiwari RS & Ram–Awatar 1989. *Sporae–dispersae* and correlation of Gondwana sediments in Johilla Coalfield, Son Valley Graben, Madhya Pradesh. Palaeobotanist 37: 94–114.

Tiwari RS & Rana V 1981. *Sporae dispersae* of some Early and Middle Triassic sediments from Damodar Basin, India. Palaeobotanist 27: 190–220.

Tiwari RS & Singh V 1981. Morphographic study of some dispersed trilete miospores (Sub–infraturma–Varitrileti) from the Lower Gondwana of India. Palaeobotanist 27(3): 253–296.

Tiwari RS & Singh V 1983. Miofloral transition at Raniganj–Panchet boundary in East Raniganj Coalfield and its implication on Permian–Triassic time boundary. Geophytology 13: 227–234.

Tiwari RS & Tripathi A 1987. Palynological zones and their climate inference in the coal bearing Gondwana of Peninsular India. Palaeobotanist 36: 87–101.

Tiwari RS & Tripathi A 1992. Marker Assemblage–Zones of spores and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India. Palaeobotanist 40: 194–236.

Tiwari RS & Vijaya 1995. Differential morphographic identity of Gondwana palynomorphs. Palaeobotanist 44: 62–115.

Tripathi A 1986. Upper Permian palynofossils from the Rajmahal Basin, Bihar. Bulletin of Geological Mineral & Metallurgical Society of India 54: 265–271.

Tripathi A 1989. Palynological evidence for the presence of Upper Permian sediments in northern part of Rajmahal Basin. Journal of the Geological Society of India 34: 198–207.

Tripathi A & Bhattacharya D 2001. Palynological resolution of upper Permian sequence in Talchir Coalfield, Orissa, India; Proceedings of National seminar on Recent Advances in Geology of Coal and Lignite basins of India, Kolkatta 1997. Geological Survey of India Special Publications 54: 59–68.

Vijaya 2011. Palynostratigraphy of subsurface Upper Permian and Mesozoic Succession, Rakshitpur area, Raniganj Coalfield, West Bengal. Palaeoworld 20: 61–74.

Vijaya, Srikanta Murthy, Chakraborty B & Jyoti SR 2012. Palynological dating of subsurface coal bearing horizon in East Bokaro Coalfield, Damodar Basin, Jharkhand. Palaeontographica–B 288: 41–63.

Williams DH 1846–1847. Lower Gondwana coalfields of India by Cyril S. Fox.–Memoirs of the Geological Survey of India 59: 119.