ABSTRACT


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*, *Tiviapollis*, *Pracopolipollis* 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 (filiicopsids 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.
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 85°42' is commonly known as East Bokaro Coalfield (EBC) which is an area of about 237 km$^2$ and located between latitudes 23°44’ & 23°49’ N and longitudes 85°42’ & 86°4’ 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 23°47’40” to 23°48’28” N and longitudes 85°50’37” to 85°51’50” 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; Srikantha Murthy et al., 2010; Srikantha 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 Lugui 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, Srikantha 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 overlies 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).](image-url)
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. Interbedded 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
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

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

Table 1—Generalized stratigraphic succession of the East Bokaro Coalfield (after Raja Rao, 1987).
**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. sparsus*). 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 & Aggarwal, et al., 2015; Jha & Aggarwal, 2015) in having similar

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**Fig. 3—Reports of Late Permian palynoassemblage from the Gondwana Basins of Peninsular India.**
Table 2—Reports of Late Permian palynoassemblage from the Indian Peninsula.

<table>
<thead>
<tr>
<th>Gondwana Basins</th>
<th>Coalfields/Area</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damodar Basin</td>
<td>Karanpura Coalfield</td>
<td>Srikanta Murthy et al., 2014.</td>
</tr>
<tr>
<td></td>
<td>Raniganj Coalfield</td>
<td>Srikanta Murthy, 2010; Srikanta Murthy et al., 2010; Vijaya, 2011; Bharadwaj &amp; Tiwari, 1977; Tiwari &amp; Singh, 1983; Singh &amp; Tiwari, 1982; Rana &amp; Tiwari, 1980; Tiwari et al., 1992.</td>
</tr>
<tr>
<td></td>
<td>East Bokaro Coalfield</td>
<td>Vijaya et al., 2012; Srikanta Murthy et al., 2016; Present study—Sawang OCM</td>
</tr>
<tr>
<td></td>
<td>Sohagpur Coalfield</td>
<td>Ram–Awatar et al., 2004;</td>
</tr>
<tr>
<td>Satpura Basin</td>
<td>Shivapura Coal Mine</td>
<td>Srikanta Murthy et al., 2013.</td>
</tr>
<tr>
<td></td>
<td>Tamia Ghat Road</td>
<td>Kumar, 1996.</td>
</tr>
<tr>
<td></td>
<td>Near Sukhtawa nala</td>
<td>Bharadwaj et al., 1978.</td>
</tr>
<tr>
<td></td>
<td>Amavaram Area</td>
<td>Srivastava &amp; Jha, 1991</td>
</tr>
<tr>
<td></td>
<td>Mailaram Area</td>
<td>Srivastava &amp; Jha, 1990</td>
</tr>
<tr>
<td></td>
<td>Budharam Area</td>
<td>Srivastava &amp; Jha, 1995</td>
</tr>
<tr>
<td></td>
<td>Sattupalli Area</td>
<td>Srivastava &amp; Jha, 1992</td>
</tr>
<tr>
<td></td>
<td>Chintalapudi</td>
<td>Jha, 2008.</td>
</tr>
<tr>
<td></td>
<td>Gauridevpet Area</td>
<td>Jha et al., 2014.</td>
</tr>
<tr>
<td></td>
<td>Manuguru Area</td>
<td>Srivastava &amp; Jha, 1992</td>
</tr>
<tr>
<td></td>
<td>Mamakannu Area</td>
<td>Aggarwal et al., 2015.</td>
</tr>
</tbody>
</table>

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*, *Arcuatisporites*, *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*, *Brevitriteles*, *Horriditriteles*, *Denispollenites*, 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* (= *Arcuatisporites*), *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 *Arcuatisporites* indicating the presence of conifers in the peat forming vegetation. Conifers are considered to be extra–basinal or hinterland elements, which typically...
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 grew in hyphrophilous 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 palaeoemire 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 Striatabdopodocarpites–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 Gondwanan 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 characters, such as thin central body, diversity in striation and haploxylonoid construction in the present palynoassemblage indicate warm climate (Tiwari & Tripathi, 1987). On the basis of palynofossil 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, cordaites together with pteridophytes (lycopsids and filicopsids).
- The morphological studies in the present palynoassemblage indicate warm climate during the deposition of sediments.

### Table 3—Palynoassemblage of Sawang Open Cast Mine.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Palynocomposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC M 4</td>
<td>Arcuatipollenites</td>
</tr>
<tr>
<td>SOC M 10</td>
<td>Scheuringipollenites</td>
</tr>
<tr>
<td>SOC M 13</td>
<td>Falcisporites</td>
</tr>
</tbody>
</table>
| SOC M 14   | poor in the assemblage |}

- Dominance of striate bisaccate genera chiefly Striatabdopodocarpites (20–32%) followed by Faunipollenites (20–26%). Other stratigraphically significant taxa bisaccate, viz. Crescentipollenites (2–4%), Verticipollenites (2–3%), Rhizomaspora (2–10%), Striatis (2–5%) and Distriatis (0–2%). Taeniata genera include
- Striatopodocarpites–Faunipollenites (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 Striimonosaccites (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%).
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