The Palaeobotanist 61(2012): 75-82
0031-0174/2012 $2.00

Palaeobotanical evidence of wildfire in the Upper Permian of India: Macroscopic charcoal remains from the Raniganj Formation, Damodar Basin

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(Received 11 November, 2011; revised version accepted 9 January, 2012)

ABSTRACT

Jasper A, Guerra-Sommer M, Uhl D, Bernardes-De-Oliveira MEC, Ghosh AK, Tewari R & Secchi MI 2012. Palaeobotanical evidence of wildfire in the Upper Permian of India: Macroscopic charcoal remains from the Raniganj Formation, Damodar Basin. The Palaeobotanist 61(1): 75-82.

Macroscopic fossil charcoal has been discovered in the carbonaceous shales associated with Seam-VI of Raniganj Formation, Upper Permian, Damodar Basin, India. A pycnoxylic gymnosperm wood is described and confirms the occurrence of palaeo-wildfire in this area during the Late Permian. The integration of the data presented in the current study with previously published data for the Raniganj Formation, principally related to the occurrence of (pyrogenic) inertinites within coal layers, demonstrates that palaeo-wildfires were common events during the deposition of the preserved material. In addition, the presence of charcoal in Permian sediments associated with coal levels at different Gondwana localities demonstrates that wildfires have been relatively common events across the continent during this period.

Key-words—Charcoal, Gymnosperm woods, Palaeo-wildfires, Upper Permian, Raniganj Formation, Raniganj Coalfield, Damodar Basin.

भारत के ऊपरी पर्मियन में वन अग्नि के पुरावानस्पतिक साक्ष्यः रानीगंज शैलसमूह दामोदर द्रोणी से प्राप्त स्थूल लकड़ी के कोयले के अवशेष

एंड्रे जैसपर, मार्गोट गुऐरा-सॉमर, डाइटर उह्ल, मैरी ई सी बर्नान्डीज-डी-ऑलीवीरा, अमित के घोष, रजनी तिवारी एवं मेरिएला आइन्स सेक्वी

सारांश

रानीगंज शैलसमूह ऊपरी पर्मियन, दामोदर द्रोणी, भारत की संस्तर-षष्ठम कार्बनमय जीवाश्म शेल सहयोगी में स्थूल जीवाश्म चारकोल अन्वेषित किया गया है। घनदारुक अनावृतबीजी काष्ठ वर्णित की गई है तथा अंतिम पर्मियन के दौरान इस क्षेत्र में पुरा-दावाग्नि की घटना की पुष्टि करती है। रानीगंज शैलसमूह हेतु पूर्व में प्रकाशित आंकड़े के साथ मौजूदा अध्ययन में प्रस्तुत आंकड़े का एकीकरण, कोयला परतों के साथ (अग्निजनिक) इनर्टीनाइटों की सैद्धांतिक रुप से प्राप्ति

प्रदर्शित करती है कि परिरक्षित पदार्थ के निक्षेपण के दौरान पुरा-दावाग्नि आम घटनाएं थीं। इसके अलावा, विभिन्न गोंडवाना क्षेत्रों में कोयला स्तरों के सहयोगी पर्मियन अवसादों में चारकोल की मौजूदगी प्रदर्शित करती है कि इस अवधि में समूचे महाद्वीप में दावाग्नि सापेक्षतया आम घटनाएं रही हैं।

संकेत-शब्द—लकड़ी का कोयला, अनावृतबीजी काष्ठ, पुरा-दावाग्नि, ऊपरी पर्मियन, रानीगंज शैलसमूह, रानीगंज कोयलाक्षेत्र, दमोदर द्रोणी।

Evidências Paleobotânicas de Paleoincêndios no Permiano Superior da Índia: Registro de Charcoal Macroscópico da Formação Raniganj, Bacia Damodar Valley

RESUMO

Charcoal macroscópico fóssil foi descoberto em níveis ricos em matéria orgânica associados à Sequência VI da Formação Raniganj, Permiano Superior, Bacia Damodar Valley, Índia. Um lenho picnoxilico gimnospérmico é descrito e confirma a ocorrência de paleoincêndios vegetacionais na área durante o Neopermiano. A integração dos dados aqui apresentados com aqueles já publicados acerca da Formação Raniganj, principalmente aqueles relacionados à ocorrência de inertinitas (de origem pirogênica) em níveis de carvão, demostraram que paleoincêndios foram eventos comuns durante a deposição dos níveis estudados. Além disso, a presença de charcoal em sedimentos Permianos associados a níveis de carvão em diferentes localidades do Gondwana confirma que este tipo de evento foi relativamente comum no continente durante esse período.

Palavras-chave—Charcoal, Lenhos Gimnospérmicos, Paleoincêndios vegetacionais, Permiano Superior, Formação Raniganj, Mina Raniganj, Bacia Damodar Valley

INTRODUCTION

Fire plays an important role as a major source of disturbance in many modern ecosystems (Bowman *et al.*, 2009; Flannigan *et al.*, 2009) and it is expected that the occurrence of fire in many areas worldwide may change/increase drastically with changing climate (Flannigan *et al.*, 2009; Westerling *et al.*, 2011). Thus, it is of great interest for the understanding of the interactions between climate, fire-ecology and vegetation to study such interactions under past climate change scenarios. As such palaeobotanical studies can act as long-term experiments on time-scales not available to neo-ecologists.

A period that is of special interest for the understanding of these interactions is the Permian, as this is the only period during the history of the Earth which experienced a long term global climate change from an icehouse into a greenhouse climate after the conquest of the continents by land-plants (Gastaldo *et al.*, 1996).

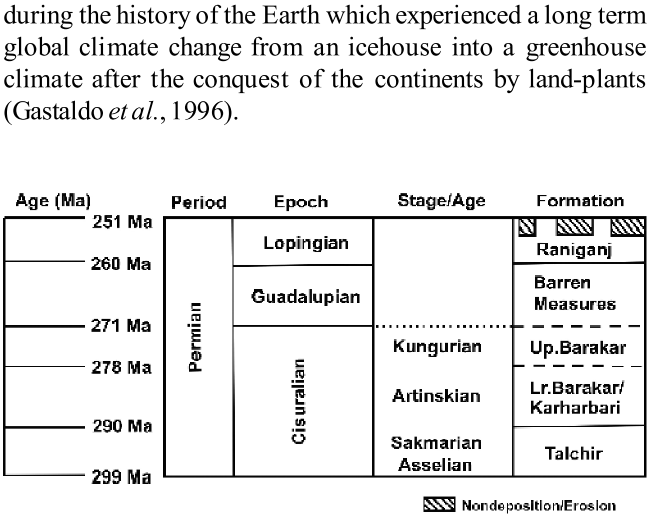

Fig. 1—Stratigraphy of Permian Gondwana in Damodar Basin (after Mukhopadhyay *et al.*, 2010).

About a decade ago there were only a few substantiated records of Permian macroscopic fossil charcoal (Scott, 2000). However, a number of studies has subsequently demonstrated the almost ubiquitous presence of macroscopic fossil charcoal in many Permian deposits from the Northern Hemisphere; i.e. North America (DiMichele *et al.*, 2004), Europe (Rößler, 2001; Uhl & Kerp, 2003; Noll *et al.*, 2003; Uhl *et al.*, 2004, 2008; Šimùnek & Martínek, 2009) and China (Wang & Chen, 2001). In contrast, for large parts of Gondwana the record of Permian macroscopic fossil charcoal is still scarce to non-existent.

Despite numerous studies on Gondwana inertinites of assumed problematic origin (cf. Scott, 2000), the first unequivocal record of charcoal as a direct palaeobotanical evidence of palaeowildfires on Gondwana was published by Glasspool (2000) based on material from the Late Permian of the Sydney Basin, Australia. Subsequent studies also confirmed the presence of charcoal in Permian sediments from South Africa (Glasspool, 2003), Jordan (Uhl *et al.*, 2007) and Brazil (Jasper *et al.*, 2008, 2011a, b). Mishra *et al.* (1990) and Navale and Saxena (1989) described high inertinite levels in Permian coals of India which are probably the result of fires. However, remains of macroscopic fossil charcoal have not been reported so far.

Jasper *et al.* (2008) demonstrated that the charcoalified remains discovered in Early Permian sediments of the Quitéria outcrop were related to basic types of gymnosperm wood and fragments of lycopsids. These authors also inferred that potential sources of ignition for the wildfires in the studied area could have been the volcanic activities in nearby areas.

In the Faxinal Coalfield, charcoal remains have also been discovered in a tonstein layer, originating from volcanic ashfall tuffs, interbedded within a coal layer (Jasper *et al.*, 2011a, b).

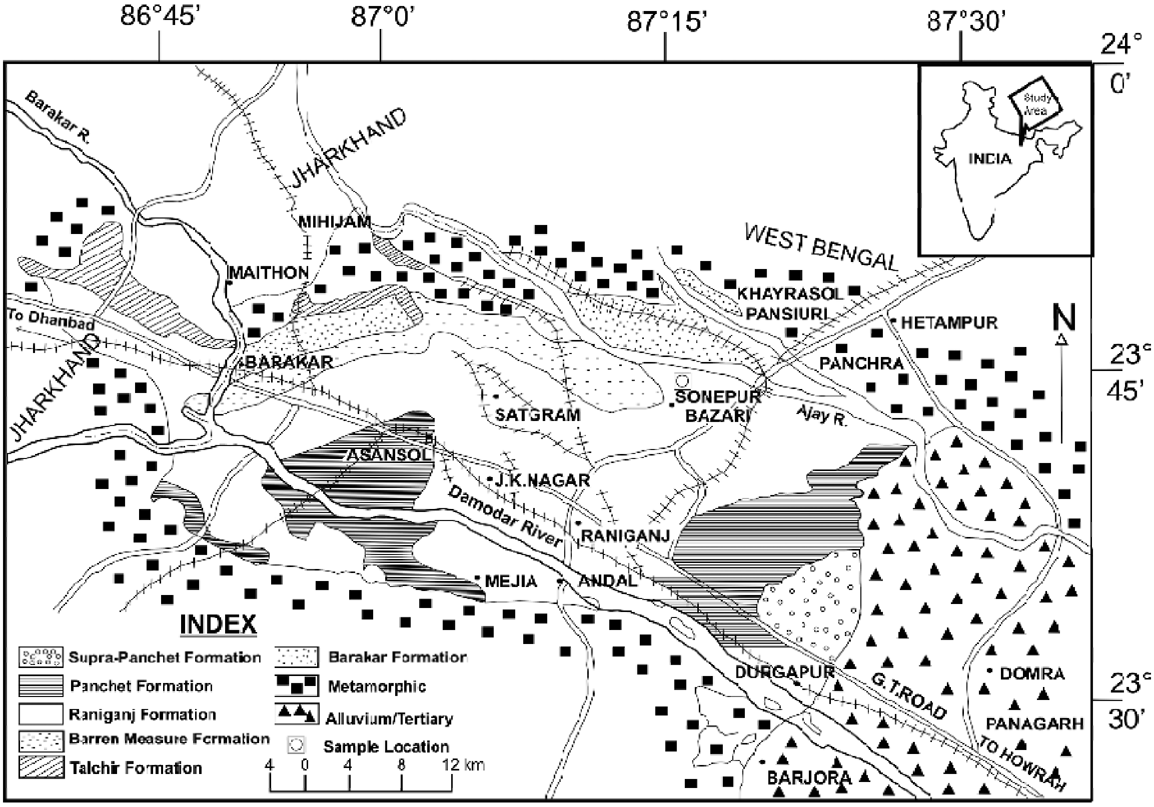

Fig. 2—Geological map of a part of the Raniganj Coalfield in the Damodar Basin, West Bengal, India showing the study area and sample location (modified after Murthy *et al.*, 2010).

Considering that the charcoal remains are preserved in this layer, the connection with the volcanic activity seems very likely.

In this context additional analyses are necessary to evaluate the palaeo-wildfire coverage on Gondwana during the Permian, the discovery of the first macroscopic fossil charcoal remains from India is very significant. In this way, this study helps to fill one of the remaining geographical gaps for the Late Palaeozoic Gondwana, describing material coming from the Upper Permian of Raniganj Formation (Lopingian), Raniganj Coalfield, Damodar Basin.

GEOLOGICAL AND STRATIGRAPHIC SETTING

Stratigraphically the Permian Gondwana of Damodar Basin includes Talchir, Karharbari, Barakar, Barren Measures and Raniganj formations (Fig. 1). Lithologically the Raniganj Formation is characterized by the association of coal, organic rich carbonaceous shale, siltstone and sandstone. However, the coal seams are usually thinner and less frequent. The sandstones vary from fine to coarse grained and the fine grained sandstones are usually micaceous. Predominantly, the sandstones are arkose to subarkose and occasionally calcareous. The carbonaceous shales are black in colour while the siltstones are grey to dark grey in colour. The maximum thickness of the Raniganj Formation in the Raniganj Coalfield is about 900 m and there are 10 coal seams (R – I to R – X) in this formation. The Raniganj Formation overlies the sandstones of the Barren Measures Formation and underlies the claystones of the Panchet Formation.

According to Murthy *et al.* (2010), the Raniganj Coalfield (23°03'-23°51' N and 86°42'-87°28' E), explored as an open pit mine, corresponds to the oriental segment of the basin, represented by an elliptical deposit with approximately 3,000 km^2. The abundance of organic rich shales in the Raniganj Formation shows levels of palaeosoils and stems in growing position. Hence, Ghosh (2002) inferred a hot humid palaeoenvironment, which is confirmed by the high percentage of *Densipollenites* pollen grains (Tewari & Tripathi, 1992). According to Mukhopadhyay *et al.* (2010) the coaly sediments were deposited during a regressive phase and represent an anoxic floodplain enabling the deposition of important peat areas which have produced economically viable coal layers at the Raniganj, Jharia and Singrauli areas.

Associated with the coal layers occurs a typical *Glossopteris* flora which reached its climax during the deposition of the Raniganj Formation and which was the main organic matter source for the Permian coals in this area. The

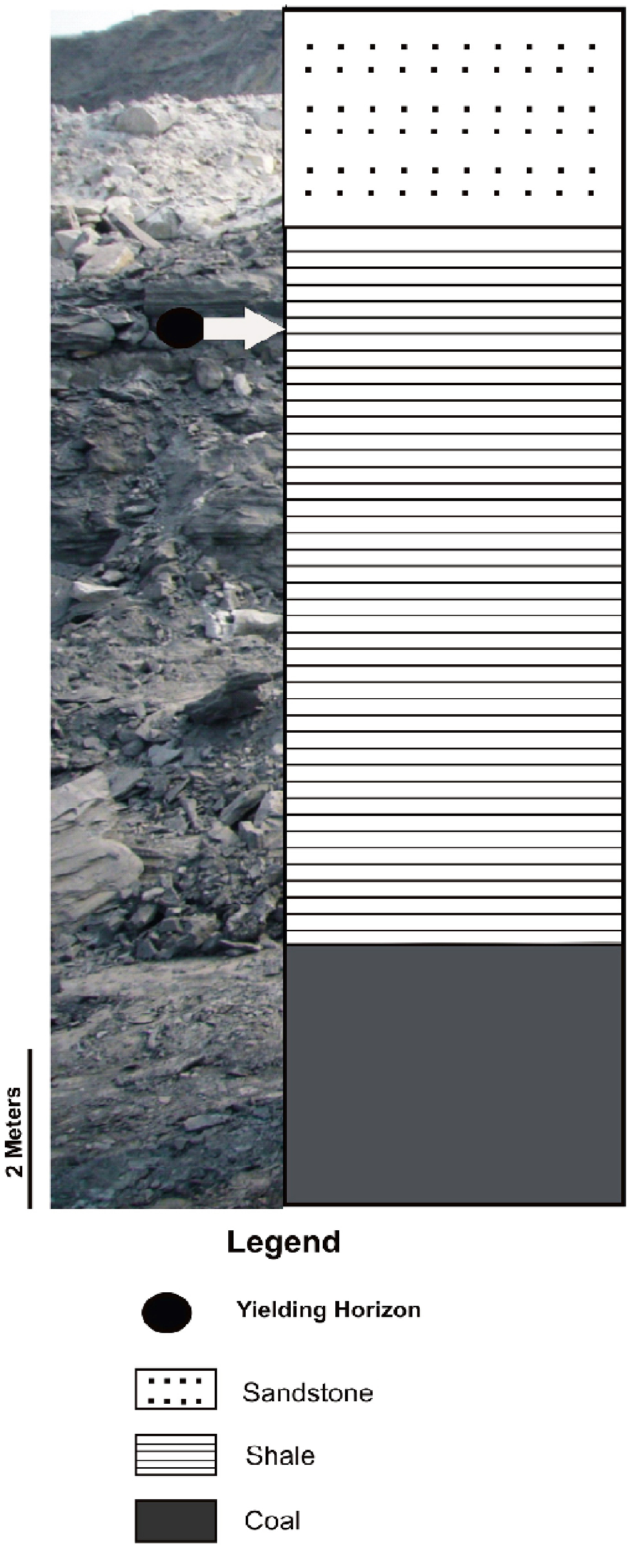

Fig. 3—Litholog of the studied section showing the location of yielding samples.

Fig. 4—Field photograph showing the location of study area.

charcoal remains studied here were collected in organic rich shale from the top of the Raniganj Formation, associated with well-preserved *Glossopteris* leaves, indicating that palaeo-wildfires affected the Upper Permian environments in this region.

MATERIAL AND METHODS

During field work of the first Indo-Brazilian Workshop (in November 2010), samples with well-preserved *Glossopteris* leaves were collected from the Open Cast Mine of Sonepur Bazari area of the Raniganj Coalfield (Fig. 2). The material for the present study comes from the shale associated with the Seam-VI of the Raniganj Formation (Figs 3 & 4). Some of these samples also include fragments of macroscopic fossil charcoal (stored in the Setor de Botânica e Paleobotânica do MCN/UNIVATES under acronym PbU, specimens 815 to 820).

The material which shows characteristics of macroscopic charcoal (black colour and streak, silky lustre, *sensu* Jones & Chaloner, 1991; Scott, 1989, 2000, 2010), was mechanically extracted from the collected hand specimens with the aid of preparation needles and tweezers under a binocular stereomicroscope in the laboratory. Due to the very fragile nature of these specimens, they could not be cleaned with water or any acids to remove adhering mineral remains or non-charred humic material.

The fragments were mounted on standard stubs with LeitC (Plano), and subsequently examined with the aid of a JEOL JSM 6490 LV Scanning Electron Microscope (SEM) at the Senckenberg Forschungsinstitut und Naturmuseum Frankfurt.

RESULTS

General characters of the charcoal remains:

The charcoal fragments measure between 0.3 x 0.1 x 0.2 and 0.6 x 0.2 x 0.4 cm and have no abraded edges. The SEM analyses, showing well-preserved anatomical details and homogenised cell-walls (Pl. 1.1), allowed to confirm that the samples were charred (*sensu* Jones & Chaloner, 1991; Scott, 1989, 2000, 2010).

However, the woody tissues, which were probably compressed during diagenesis, have been shattered into more or less small pieces (Pl. 1.2, 3). Due to this excessive mechanical damage it was not possible to observe complete tissue characteristics, thus hampering a specific taxonomic/ systematic affiliation.

Although the anatomical structures of charred soft wood are generally well preserved, charcoalification can induce changes of certain anatomical features, like the appearance of pits and especially cross-field pits (Jones & Chaloner, 1991; Gerards *et al.*, 2007). In the studied material, closing walls of pits, which are easily subjected to such changes, could not be observed. The description of the pitting is based on their apertures.

Anatomical characters of the charcoal remains:

Pycnoxylic secondary wood, in radial view tracheids is 25-30 µm in width. They exhibit uniseriate (Pl. 1.4-1.6) or biseriate bordered pitting (Pl. 1.7). Pits are circular to oval (3-7 µm in diameter) with circular to oval apertures (Pl. 1.5). When biseriate they are arranged sub-oppositely to alternate (Pl. 1.7). Rays are rare and composed of parenchymatous cells, 14-19 µm in width and 18-31 µm in height (Pl. 1.8). Rays are uniseriate and 5-7 cells high. Cross-field pits, leaf traces or growth rings are not visible.

DISCUSSION

The fragmentary nature of the charcoal remains, does not allow for establishing specific taxonomical affinities. The bordered pitting and presence of uniseriate rays only permitted to infer a gymnospermous affinity of the material. In addition, the absence of abraded edges allows the inference of an autochthonous/parautochthonous origin for the material without any considerable transport prior to burial.

Considering the association of the remains to *Glossopteris* leaves and previous studies about the Gondwanan macroscopic charcoal (Jasper *et al.* 2008; 2011a, b), the correlation with gymnosperms can be considered as an unsurprising result. This follows the tendency observed in other Permian coal bearing strata of the Gondwana, in which the fire reached the mire and the surrounding vegetation, dominated by the so called *Glossopteris* flora.

On the other hand, the additional confirmation of the occurrence of palaeo-wildfires associated with coal bearing strata of the Permian Gondwana helps to refine scenarios for such events during the period. So far such scenarios are mainly based on data from mesoscopic charcoal, from the Sydney Basin, Australia (Glasspool, 2000), and from macroscopic charcoal, from the Paraná Basin, Brazil (Jasper *et al.*, 2011b).

Despite the high concentration of inertinites in the Gondwana coals some authors prefer different explanations for the origin of these macerals in the Late Palaeozoic Gondwana (White, 1925; Jurasky, 1929; Schopf, 1975; Taylor *et al.*, 1988). However, an increasing number of localities containing macroscopic charcoal remains, like the material presented here, have recently been found in different associations all over Gondwana, which are linked to inertinite bearing coal layers or in clastic levels directly above such coals.

Recent studies (Scott & Glasspool, 2006, 2007; Scott, 2010; Hudspith *et al.*, 2011) reinforced that inertinites observed in Permian coals around the world, even in high abundance, were quite likely generated by palaeo-wildfires. The abundance of structured inertinites in Permian coals from the Sattupalli Coalfield, Godavari Graben, India, has recently been connected to such fire events (Singh *et al.*, 2011).

The autochthonous/parautochthonous origin of the charcoals studied here is a strong evidence to the fact that palaeo-wildfires in Gondwana frequently reached coal forming environments during the Permian.

CONCLUSIONS

From the evidence presented here, it is possible to draw the following conclusions:

1. The charcoalified plant remains from the Raniganj Formation testify to the occurrence of wildfire in the Damodar Basin, India during the Permian.

2. The preserved charred plant fragments support the hypothesis of autochthonous/parauthochtonous origin for the material.

3. The charred wood remains are related to gymnosperms.

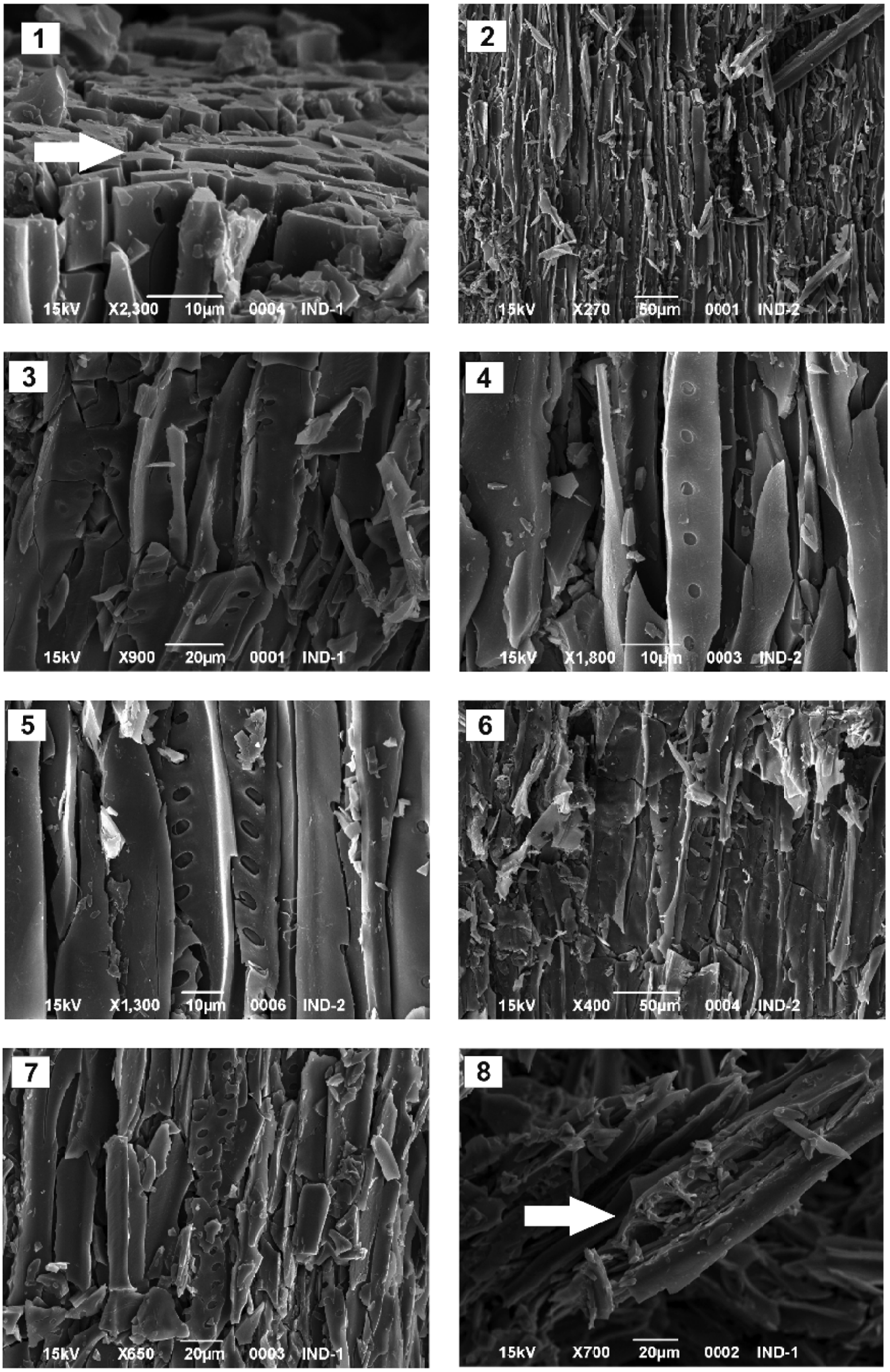
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PLATE 1

4. The frequent occurrence of palaeo-wildfires in Gondwana during the Late Palaeozoic is reinforced.

Acknowledgements—*We thank Claudia Franz, Senckenberg Forschungsinstitut and Naturmuseum Frankfurt, for technical assistance with SEM facilities. A. Jasper acknowledges financial support by FAPERGS (Project 11/1307-7) and CNPq (Projects 301671/2009-5, 401771/2010-5 and 474857/2011-5). M. Guerra-Sommer acknowledges financial support by CNPq. M.E.C. Bernardes-de-Oliveira and R. Tewari are thankful to CNPq (Brazil) and to the Department of Science and Technology (India) for the financial grants to the Indo-Brazil S & T Programme of International Cooperation (DST/INT/India/RPO-24/2007 and Brazil/CNPq Project 490829/2007). M.E.C. Bernardes-de-Oliveira is thankful to CNPq (Project 304265/2009-8); M.I. Secchi acknowledges financial grant of CAPES (master scholarship 23038.009744/2010-48), FAPERGS and CNPq. R. Tewari and A.K. Ghosh are also thankful to the Director, BSIP for his kind permission to publish this collaborative work. The authors also thank Dr Madhav Kumar, one of the referees of The Palaeobotanist for the relevant contributions to the manuscript.*

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PLATE 1

SEM images of the charcoal samples of the Raniganj Coalfield.

1. Tracheids presenting homogenized cell walls (arrow).
2. Tracheids shattered into more or less small pieces.
3. Detail of 2 exhibiting shattered characteristic of the charcoal remains.
4. Tracheids of Raniganj Coalfield wood remains exhibiting uniseriate bordered pitting, with presence of circular to oval pits tracheids.
5. Tracheids of Raniganj Coalfield wood remains exhibiting uniseriate bordered pitting.
6. Tracheids of Raniganj Coalfield wood remains exhibiting uniseriate bordered pitting.
7. Tracheids of Raniganj Coalfield wood remains with biseriate bordered pitting sub-oppositely arranged.
8. Detail of Raniganj Coalfield wood remains presenting uniseriate ray (arrow).

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