Record of charcoal from early Maastrichtian intertrappean lake sediments of Bagh valley of Madhya Pradesh: palaeofire proxy

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Presence of charcoal in intertrappean lake sediments associated with the Malwa Group of the Deccan trap, India is recorded. The finding provides the first evidence of palaeofire in the Indian late Cretaceous. Though previous studies have shown the presence of carbonaceous clays and coal bands in the Deccan volcanic associated sediments, the presence of fossil charcoal in the sediments is rarely reported. The fossil charcoal was identified based on optical microscope, Scanning Electron Microscope and Pyrolysis-Gas Chromatography Mass Spectrometer (Py-GC-MS). This study indicates that charcoal is derived from burning of plants caused by forest fire during the Maastrichtian (Chron 30N).

Keywords: Deccan volcanism, fossil charcoal, Maastrichtian, Malwa group, palaeofire.

WORLDWIDE, charcoal accumulations are recorded in the sediments from the late Silurian and early Devonian sediments[1–3] to recent lake sediments[4–7]. In India, the fossil charcoal is reported from the subsurface sediments of middle to late Permian Raniganj Formation in the south Karanpura coal fields[8]. The fossil charcoal is widely reported from the Cretaceous sediments especially from the Cretaceous–Palaeogene (K–Pg) boundary sections[9–11]. The presence of charcoal in the sediments at K–Pg boundary is considered to be caused due to global forest fire induced by extra-terrestrial impact[12–14]. Presence of fern-spike just above the K–Pg boundary in the North American sections of Montana is considered by some workers[12] as the result of global forest fire caused by bolide impact. Such forest fire could have destroyed all the existing plant species and ferns may have been the first to get re-established and become dominant in the emerging scenario in the new ecological niche.

Previous studies[15–17] on intertrappean sediments of Padwar near Jabalpur and Mohagaon Kalan near Chhindwara in Madhya Pradesh have only recorded the presence of carbonaceous shales and coal/lignite bands. In this study area, the Geological Survey of India has established and published[18,19] the Deccan volcanic-stratigraphy of the Malwa Group based on flow to flow mapping on 1 : 50,000 scale. Accordingly, the lava flows of Malwa Group are classified as Mandleshwar, Kalisindh, Kankaria–Pirukheri, Indore, Bargonda and Singarchori formations in ascending stratigraphic order. Of these, the lowermost Mandleshwar Formation comprising seven basaltic flows and the overlying Kalisindh Formation having 11 basaltic flows are associated with intertrappean lake sediments and red and green boles. Lake sediments occur at seven stratigraphic levels within these formations. Accumulation of charcoal is recorded only in the intertrappean lake sediments in the Mandleshwar Formation exposed at 274 m amsl in the Karam river section east of Bharudpura village (Figure 1 *a*). In the area studied, four intertrappean beds are present, viz. Bagvaniya (225 m RL), NH3-Dugni (264 m RL), Bharudpura (274 m RL) and Ukala (333 m RL) at four stratigraphic levels in ascending stratigraphic order[20] (Figure 1 *a*). The charcoal-bearing sediments at Bharudpura varies in thickness from 80 to 120 cm and it comprises soft lithified shales, silicified shales and chert that is occasionally carbonaceous. In the upper parts of the sequence, the silicified shales are rich in megaplant fossils like petrified woods, impression of dicots and monocots woods and leafs (palms) associated with molluscs (mostly *Physa*, *Paludina* and *Unio*), occasional ostracods (Cyprids) and fish scales (Clupeids). The charcoal fragments are present at multiple levels in the section but is concentrated in the basal part of the sequence (Figure 1 *b*).

Accumulation of charcoal fragments varying in size from 2.5 cm to a few millimeters (<2 mm) is common in the basal part of the laminated and banded silicified shales and chert where they are found in association with gastropod (mostly *Physa* and *Paludina*) in the lower part of the sequence (Figures 1 *b* and 2 *a*). In the upper parts, the charcoal fragments are rare. The charcoal fragments were extracted in the laboratory and identified in thin sections and under the Scanning Electron Microscope (SEM). Thin section study shows that the sediments essentially comprise clay aggregates replaced by various degrees by chert (Figure 2 *b*), tongues of chert (Figure 2 *b*) with fine charcoal fragments are also seen. Invasion of silica in the charcoal fragments (Figure 2 *c*), root structures and mollusc shell fragments are commonly observed. Under the SEM well preserved vessels (15–25 μm dia.) and tracheids structures of angiosperm plants (Figure 2 *e*, *f*) and homogenized wall of the tracheids are observed which indicated burning at a high temperature[21]. The energy dispersive X-ray (EDX) analysis shows that charcoal has over 91.73 wt% of carbon, 6.10 wt% of oxygen and 2.1 wt% of sulphur (Table 1 and Figure 3). Organic geochemistry was performed using Rock-Eval 6 pyrolyser and Pyrolysis Gas Chromatography Mass Spectrometer (Py-GC-MS). Rock-Eval pyrolysis of the sample resulted in a high TOC (51.5%), low HI (2 mg HC/g

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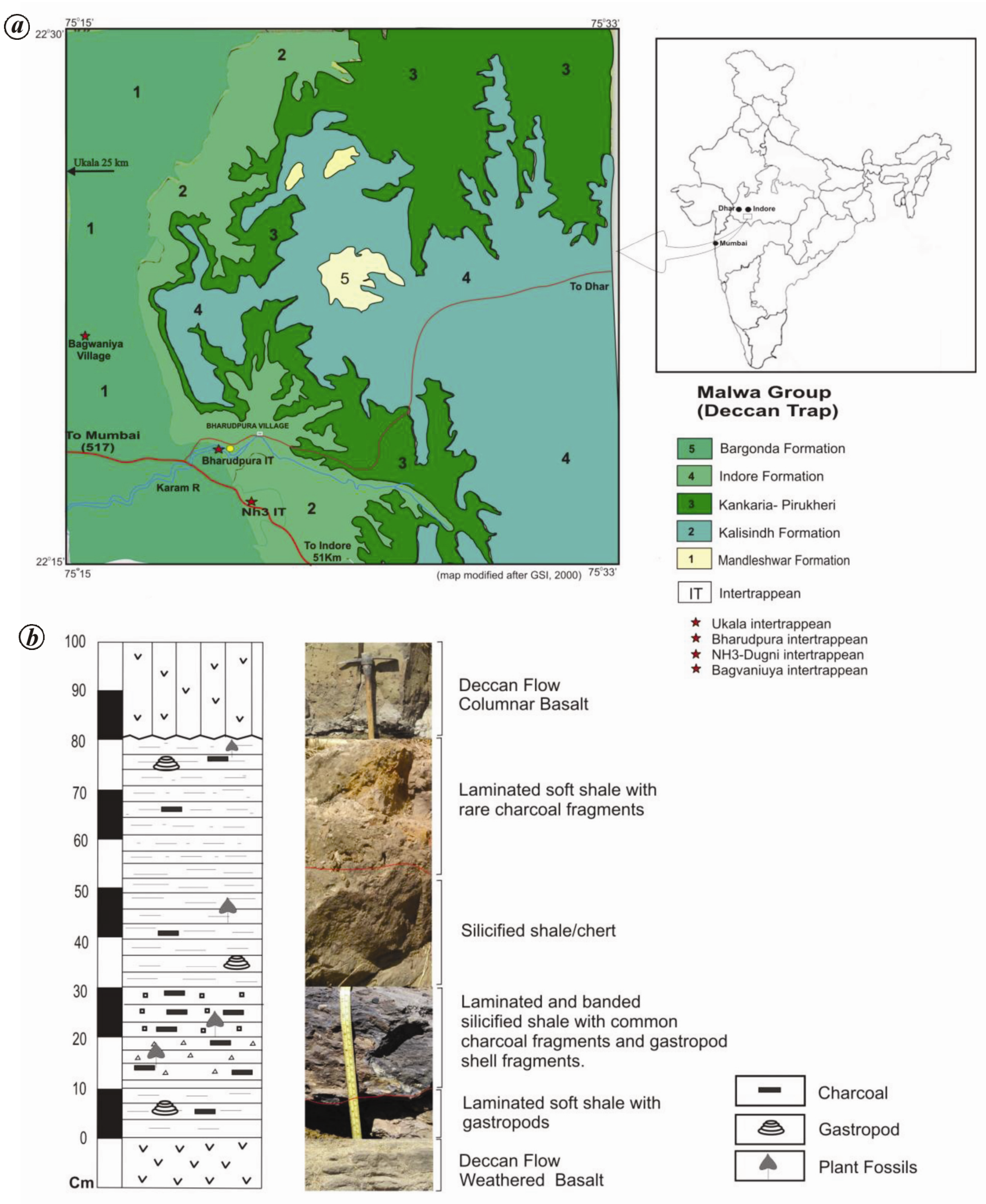

Figure 1. ***a***, Geological map of the study area showing different formations of Malwa Group and location of Bharudpura intertrappean locality. ***b***, Litholog of charcoal-bearing intertrappean section in Karam river near Bharudpura with corresponding photographic illustrations. Note that charcoal accumulation is more common in the lower part of the sequence.

TOC) and high residual carbon (RC) at 49.6% which indicates that most of the organic matter has been incinerated. Major pyrolysis products identified from Py-GC-5 MS are alkylated naphthalenes, dibenzofurans, phenanthrene and pyrolytic polycyclic aromatic hydrocarbons (PAH) such as benzofluoranthene, benzopyrene, indeno[1,2,3-c,d]pyrene, dibenzo[a,h]anthracene, benzo[g,h,i]perylene, 9H-Indeno[1,2-e]pyrene. These PAHs

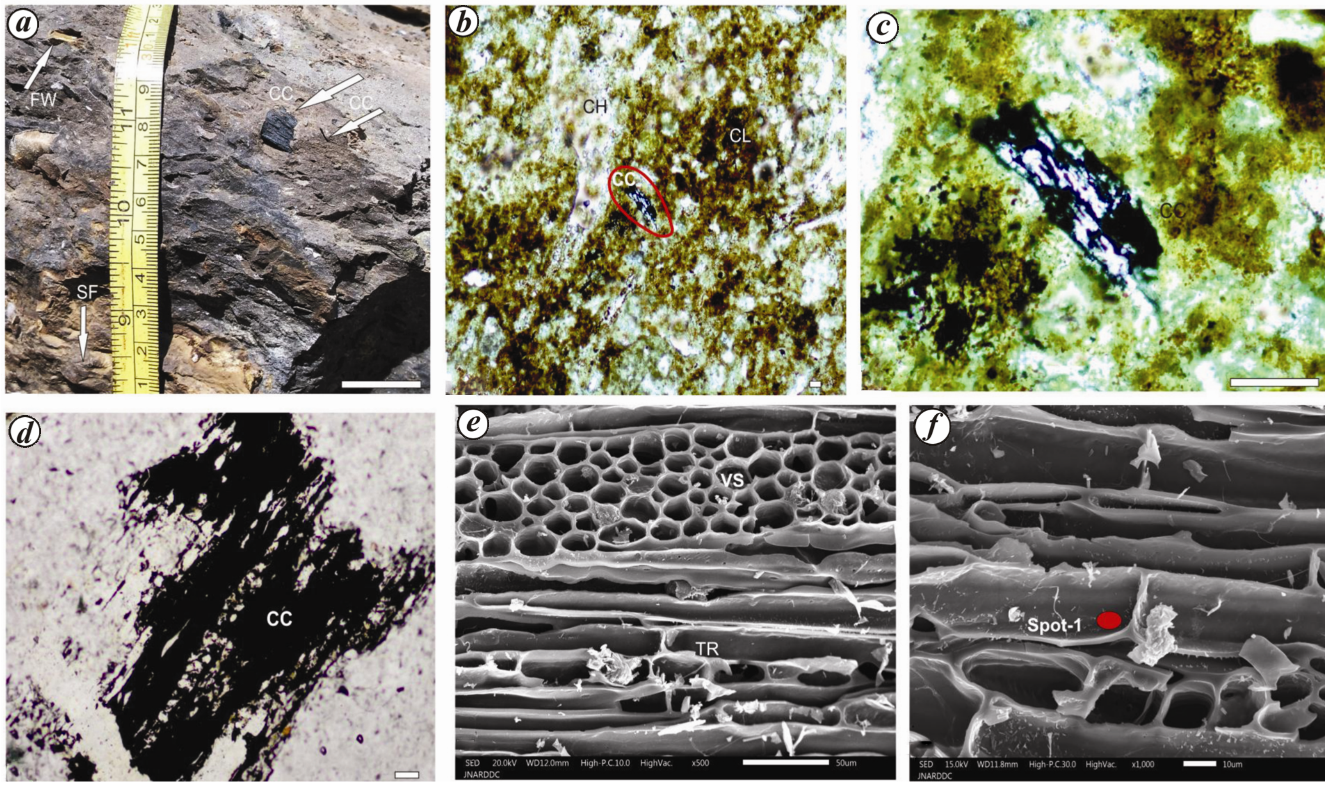

Figure 2. ***a***, Charcoal fragments in laminated and banded silicified shale in the lower part of the sequence. Arrow CC, Charcoal fragments; FW, Fossil wood fragment; SF, Shell (*Physa*) fragments. ***b***, Thin section (PLM) photograph showing silica (chert) tongues (CH) replacing clay aggregates (CL), and embedded charcoal fragment (CC). ***c***, Enlarged view of charcoal fragment as seen in ***b***. Note silica stringers and blebs in the charcoal fragment. ***d***, Charcoal showing tracheids and chert. ***e***, ***f***, Charcoal fragments under SEM: ***e***, Showing well preserved homogenised vessels (VS) and tracheids (TR) in transverse view. ***f***, Enlarge view showing the spot (spot-1) for EDX analysis. ***b***–***d***, Bar scale 40 μm.

Table 1. eZAF smart quant results

Element	Weight (%)	Atomic (%)	Net Int.	Error (%)
CK	91.73	94.45	1061.74	4.63
SK	6.10	4.71	25.23	16.65
OK	2.17	0.84	112.98	6.60

are highly peri-condensed compounds, stable over geological times and are indicators of high temperature charring of the organic matter[22,23]. We interpret that charcoal fragments are derived from forest fire in the woodland, in the vicinity of the lake developed on the lava surface. The fire could have been caused by volcanic eruption or other natural process as observed in recent forest fires. The charcoal fragments were possibly transported to the lake either by wind or streams joining the lake. The charcoal-bearing Bharudpura sediments have yielded well-preserved and diverse palynomorph assemblage such as *Aquilapollenites bengalensis*, *Gabonisporis vigourouxii*, *Psilodiporites* sp. and estuarine/brackish water environment indicators such as *Spinizonocolpites* spp., *Proxapertites operculatus* associated with marker Maastrichtian palynomorphs *Azolla cretacea*, *Triporoletes reticulatus*, *Jiangsupollis* sp., *Echitricolpites* sp. and *Scollardia conferta*. Such palynotaxa were recorded even earlier from intertrappean, from other localities[17,24]. Overall, palynoflora and associated megaflora indicates that the plant species were represented by terrestrial dicot and monocot (palm) trees, shrubs, ferns and aquatic plants.

The findings show that charcoal-bearing Bharudpura sediments are associated with Maastrichtian marker palynomorphs and are overlain by the intertrappean lake sediments at Ukala, stratigraphically higher-up in the sequence as exposed 20 km to the north-west (Figure 1 *a*). The lower and upper lava flows bracketing the Ukala intertrappean have shown the presence of normal magnetic polarity (Table 2). Well-preserved bones of the sauropod dinosaurs have been collected from the sediments and hence it is interpreted that the Ukala sediments are deposits of early Maastrichtian C30n chron. Implicitly, the underlying Maastrichtian palynomorph-bearing sediments of Bharadpura are also indicated to be deposits of early Maastrichtian C30n. Recent Ar^{39}–Ar^{40} dating and magnetostratigraphic study of the lava flows of Malwa traps also suggested that the Deccan volcanism in Malwa Plateau was initiated in C30n of Maastrichtian[25].

Globally, the presence of charcoal accumulation is reported from K–Pg boundary sections including North America[12,13] and is mostly suggested to be a result of

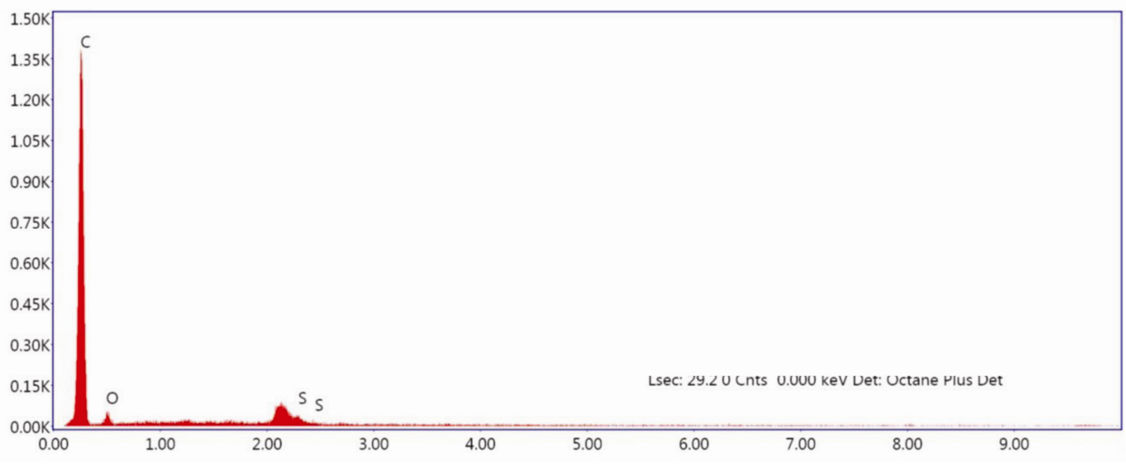

Figure 3. EDX analytical plot of charcoal fragment at spot-1 (Figure 2*f*) in tracheid showing carbon, oxygen and sulphur.

Table 2. Palaeomagnetic polarity for lava flows bracketing Ukala intertrappean sediments stratigraphically

Locality	Fm	Latitude	Longitude	El	N	Dm	Im	A95	K	Polarity
Ukala upper flow	Kalisindh Fm	22°23′41″N	75°14′25″E	338 m	2	345.8	–42.5	12	56	Normal
Ukala lower flow	Kalisindh Fm	22°23′34″N	75°14′41″E	325 m	2	327.7.	–61.4	10.2	601.9	Normal

Analysis GSI, C.R., Palmag. Lab., Nagpur.

global forest/wild fire triggered by bolide impact. The fern-spike as observed above the K–Pg boundary was considered earlier as a result of such global forest fire at the K–Pg. However, it is also suggested[12–14] that the 'fern spike' is due to the impact (blast) 'knock down' of Late Cretaceous forests, rather than destruction by forest fire.

The charcoal-bearing Bharudpura lake sediments are of early Maastrichtian age, predating the K–Pg boundary and is unrelated to bolide impact at K–Pg. It is suggested that charcoal accumulation is related to local forest fire in the surrounding woodland triggered by either volcanic eruptions or natural processes like lightening and meteorite as often observed in the recent forest fires. The presence of charcoal accumulation at multiple levels (Figure 1 *b*) in the lake sequence suggests that the forest fire was a recurrent phenomenon possibly when dry conditions existed during the history of lake sedimentation in early Maastrichtian.

1. Glasspool, I. J., Edwards, D. and Axe, L., Charcoal in the Silurian as evidence for the earliest wildfire. *Geology*, 2004, **32**, 381–383.
2. Glasspool, I. J., Edwards, D. and Axe, L., Charcoal in the Early Devonian: a wildfire-derived Konservat–Lagerstatte. *Rev. Palaeobot. Palynol.*, 2006, **142**, 131–136.
3. Edwards, D. and Axe, L., Anatomical evidence in the detection of the earliest wildfires. *Palaios*, 2004, **19**, 113–128.
4. Lacaux, J. P., Cachier, H. and Delmas, R., Biomass burning in Africa: an overview of its impact on atmospheric chemistry. In *Fire in the Environments. The Ecological, Atmospheric and Climatic Importance of Vegetation Fires, Chichester* (eds Crutzen, P. and Goldanmer, J. G.), Wiley, 1993, pp. 159–192.
5. Tinner, W., Conedera, M., Amman, B., Gaggeler, H. W., Gedye, S., Jones, R. and Sagesser, B., Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since AD 1920. *Holocene*, 1998, **8**, 31–42.
6. Pitkanen, A., Lehtonen, H. and Huttunen, P., Comparison of sedimentary microscopic charcoal particle records in a small lake with dendrochronological data: evidence for the local origin of microscopic charcoal produced by forest fires of low intensity in eastern Finland. *Holocene*, 1999, **9**, 559–567.
7. Blackford, J. J., Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. *Paleogeogr., Paleoclimatol., Paleoecol.*, 2000, **164**, 33–42.
8. Mahesh, S., Murthy, S., Chakraborty, B. and Roy, M. D., Fossil Charcoal as palaeofire indicators: taphonomy and morphology of charcoal remains in subsurface Gondwana sediments of south Karanpura coal fields. *J. Geol. Soc., India*, 2015, **85**(5), 567–576.
9. Abdalla, M. B. and Hamad, A., Fire in a *Weichselia*-dominated coastal ecosystem from the Lower Cretaceous (Barremian) of the Kurnub Group in north-west Jordan. *Cret. Res.*, 2016, **66**, 82–93.
10. MacDonald, G. M., Larsen, C. P. S., Szeicz, J. M. and Moser, K. A., The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices, *Quat. Sci. Rev.*, 1991, **10**, 53–71.
11. Brown, S. A. E., Scot, A. C., Glasspool, I. J. and Collinsen, M. E., Cretaceous wildfire and their impact on the Earth system. *Cret. Res.*, 2012, **36**, 162–190.
12. Belcher, C. M., Collinson, M. E., Sweet, A. R. and Hildebrand, A., Fireball passes and nothing burns – the role of thermal radiation in the Cretaceous–Tertiary event: evidence from the charcoal record of North America plants and the K–T boundary. *Geology*, 2003, **31**, 1061–1064.
13. Nichols, D. J. and Johnson, K. R., *Plants at the K–T Boundary*, Cambridge, UK, Cambridge University Press, 2008, p. 92.

14. Scot, A. C., Charcoal recognition, taphonomy and uses in palaeoenvironmental analysis. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 2010, **291**(1–2), 11–39.
15. Prakash, T., Singh, R. Y. and Sahni, A., Palynofloral assemblage from the Padwar Deccan intertrappean (Jabalpur), M.P. In *Cretaceous Event Stratigraphy and the Correlation of Indian Non-marine Strata* (eds Sahni, A. and Jolly, A.), Contributions from the seminar cum workshop IGCP 216 and 245, Chandigarh, 1990, pp. 68–69.
16. Srinivasan, S., Late Cretaceous egg shells from the Deccan volcano-sedimentary sequences of central India. In *Cretaceous Stratigraphy and Environment* (ed. Sahni, A.), Mem. Geol. Soc. India, 1996, vol. 37, pp. 321–336.
17. Kar, R. K., Sahni, A., Ambwani, K. and Singh, R. S., Palynology of Indian Onshore-Offshore Maastrichtian sequences in India: Implications for correlation and palaeobiogeography. *Indian J. Petrol. Geol.*, 1998, **7**(2), 39–49.
18. Geological Survey of India, Geological Quadrangle map: Indore Quadrangle, 46N, Madhya Pradesh, Published by Geological Survey of India, Kolkata, 1995 (Scale: 1 : 250,000).
19. Geological Survey of India. District Resource Map Dhar District. Central Region, Nagpur, Published by Geological Survey of India, Central Region, Nagpur, 2000.
20. Mohabey, D. M. and Samant, B., Deccan continental flood basalt eruption terminated Indian dinosaurs before the Cretaceous–Paleogene boundary. *Geol. Soc. India., Spec. Publ.,* 2013, **1**, 260–267.
21. Scot, A. C., Charcoal recognition, taphonomy and uses in palaeoenvironmental analysis. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2010, **291**(1–2), 11–39.
22. Marynowski, L. and Simoneit, B. R. T., Widespread late Triassic to early Jurassic wildfire records from Poland: evidence from charcoal and pyrolytic polycyclicaromatic hydrocarbons. *Palaios*, 2009, **24**, 785–798.
23. Venkatesan, M. I. and Dahl, J., Organic geochemical evidence for global fires at the Cretaceous/Tertiary boundary. *Nature*, 1989, **338**, 57–60.
24. Samant, B. and Mohabey, Deccan volcanic eruptions and their impact on flora: palynological evidence. *Geol. Soc. Am. Spec. Pap.*, 2014, **505**, 171–191.
25. Schobel, S., Wall, H. D., Ganerod, M., Pandit, M. K. and Rolf, C., Magnetostratigraphy and $^{40}Ar–^{39}Ar$ geochronology of the Malwa Plateau region (Northern Deccan Traps), central western India: significance and correlation with the main Deccan Large Igneous Province sequences; *J. Asian Earth Sci.*, 2014, **89**, 28–45.

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The wood-boring trace fossil *Asthenopodichnium* from Palaeocene sediments of the Barmer Hill Formation, western Rajasthan, India

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The present study documents the wood-boring trace fossil *Asthenopodichnium* from the Palaeocene sediments of the Barmer Hill Formation (BHF) in the Barmer Basin, Western Rajasthan, India. The *Asthenopodichnium* trace fossils are loosely to tightly packed, pouch-like burrows or almond-shaped structures identified as *Asthenopodichnium lignorum*, whereas lozenge and J-shaped structures are designated as *Asthenopodichnium lithuanicum*. The *A. lignorum* trace markers are considered to be the feeding and dwelling burrows produced by wood-rotting fungi, whereas *A. lithuanicum* are interpreted as feeding and dwelling burrows produced by Mayfly nymphs and larvae. The sedimentological and palaeontological studies of trace fossil-bearing horizons of BHF suggest freshwater fluvial sedimentary environment with humid to sub-humid climate.

Keywords: *Asthenopodichnium*, freshwater environment, trace-fossils, wood-rotting fungi.

GLOBALLY, the oldest wood-boring trace fossils were reported from the Carboniferous and Early Permian sediments[1–7]. Later, the diverse insect records matching the number of modern insect families were reported from Cretaceous and Neogene deposits of Germany[8,9]. All these reports were from marine sediments. However, very little is known about wood-boring trace fossils from freshwater environment. Initially, the ichnogenus *Asthenopodichnium* and ichnospecies *Asthenopodichnium xylobiontum* were described from Late Neogene wood in Austria[10]. The pouch-like *Asthenopodichnium* wood-boring trace fossils have also been reported as *A. lithuanicum*, from Neogene coal layer in northeastern Lithuania[11] and *A. xylobiontum* from Late Cretaceous Wahweap Formation, Utah, USA[12]. Subsequently, *A. lignorum* was recorded from Early Miocene of Didot Island, New Caledonia[13] and from the Upper Cretaceous Kirtland Formation of San Juan Basin, New Mexico[14]. The wood-boring *Asthenopodichnium* trace fossils from these localities are small, U-shaped or pouch-like burrow structures in wooden, organic-rich siltstone or on bone substrates[10,11].

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