Journal of The Palaeontological Society of India
Golden Jubilee Volume, 50(2), December 2005: 113-120

ISSN 0522-9630

PALAEOPROTEROZOIC DUBIOFOSSILS FROM INDIA REVISITED - VINDHYAN TRIPLOBLASTIC ANIMAL BURROWS OR PSEUDOFOSSILS?

H. J. HOFMANN*

DEPARTMENT OF EARTH AND PLANETARY SCIENCES, AND REDPATH MUSEUM,
McGILL UNIVERSITY, 3450 UNIVERSITY ST., MONTREAL, QC,
CANADA H3A 2A7

ABSTRACT

Purported Palaeoproterozoic triploblastic burrows from the Chorhat Formation (Semri Group, lower part of the Vindhyan Supergroup) in central India have remained controversial, Alternative explanations as inorganic structures also remain unconvincing to proponents of a burrow origin, leaving the arguments for and against biogenicity still inconclusive. The purpose of this paper is to review the evidence for a burrow origin, and to explore an alternative, abiologic explanation for the structures. They are compared to distinctive reticulate subsurface patterns on bedding and joint surfaces found in the Kaimur Group sandstones and generated during geologically more recent ferricrete formation.

Key words: Palaeoproterozoic, Vindhyan Supergroup, Chorhat Formation, Dubiofossils

INTRODUCTION

Numerous reports of supposed fossil worms and burrows in Proterozoic siliciclastic sediments have appeared in the geological literature. Few of these have stood the test of time, revealing themselves sooner or later as abiologic structures, particularly those due to shrinkage associated with sediment dewatering (e.g., Cloud, 1968; Hofmann, 1971). There are others that are difficult to explain by purely mechanical processes, and for these a biological origin has been thought reasonable. However, because such an interpretation is not universally accepted, their origin remains controversial, and new data are required to be able to move them from the dubiofossils to the realm of fossils or to the pseudofossils.

The Vindhyan Supergroup of India has not only yielded bona fide fossils, but also its share of structures that are now called dubiofossils and pseudofossils. Amongst the pseudofossils we can count a large number of markings originally believed to be the burrows, only to be revealed later as mudcrack or syneresis crack fillings. Compilations of the various Vindhyan remains can be found in Sharma *et al.* (1992), and Venkatachala *et al.* (1996).

One of the more recent claims of the existence of Vindhyan trace fossils is that by Seilacher *et al.* (1998) from the Chorhat Sandstone of the Semri Group (lower part of Vindhyan Supergroup) near Chorhat in the Son Valley of Madhya Pradesh. The structures were originally thought to be 1.1 billion years old, but subsequent dating has placed them about 500 million years earlier (Rasmussen *et al.*, 2002; Ray *et al.*, 2002). The report caused a considerable stir in the paleontological community, in no small part due to the fact that the senior author is renowned for his work on trace fossils. Thus, the structures are viewed as potentially having an important bearing on the question of the antiquity of metazoans if their interpretation can be verified. Some have questioned the burrow origin and offered other explanations (e.g., Rai and Gautam, 1999; Conway Morris, 2000; Droser in Kerr, 2002). Inasmuch as no convincing case has yet been made for either a burrow or an abiologic origin, they remain categorized as dubiofossils.

The occurrence of the Chorhat structures was on the itinerary of the International Field Workshop on the Vindhyan Basin in December 2002, organized by the Palaeontological Society of India and the University of Lucknow (see Kumar and Gupta, 2002, and Sharma, 2003), but participants were unable to relocate the exact source of the specimens illustrated in the original article. Hypotype material is available at the Peabody Museum at Yale University and at the University of Tübingen.

THE CHORHAT DUBIOFOSSILS

The intriguing bedding plane features interpreted as undermat burrows of triploblastic animals were described and illustrated by Seilacher *et al.* (1998). The sample depicted on the cover of the 2 October 1998 issue of Science (YPM 37665) is here re-illustrated by more complete photographs (Pl. I) to show additional features not displayed in the original paper, but relevant to a trace fossil interpretation. This 1.5-3 cm thick, somewhat wedge-shaped slab has horizontal dimensions of 24 x 15.5 cm, with two of the corners on one side unevenly truncated. The features of interest are developed on a weathered surface, in a 1-3 mm thick lamina of iron oxide/hydroxide-cemented sand grains, overlying a ~3 cm thick layer of buff, medium-grained quartz sandstone of the Chorhat Sandstone. The preserved parts of the structures are irregularly curving, occasionally branching furrows or channels, up to 12 cm long,

* E-mail: hofmann@eps.mcgill.ca

a few millimetres wide, and up to 1 mm deep.

Two main types are in evidence, a narrower one with curved cross section, and a wider one with flat bottom and consequently a more rectangular to trapezoidal cross section. In both varieties the inside of some bends are distinctly angulate, while the corresponding outside of the bend has a smooth, round outline. In another block (Seilacher *et al.*, 1998, Fig. 3b), a furrow length of ~18 cm is attained. Portions of some furrows have faint, slightly elevated, levee-like rims. Associated with the furrows are round to irregular, millimetre- to centimetre-wide depressions, also up to 1 mm deep, the larger ones flat-bottomed and located in isolation (Pl. I), or in loosely defined patches in the flat parts between the sinuous furrows (Seilacher *et al.*, 1998, Fig. 3b). The surface shown in Pl. I also bears small, ill-defined oblong patches of positive relief. The long furrow in Pl. I, fig. A is locally obscured by a subtriangular patch of hematite-cemented sandstone, interpreted by Seilacher *et al.* (1998, Fig. 2, arrow) as an original sand veneer, and taken as an important proof of the syngenicity and antiquity of the structures. A thin section containing the level with the furrows (Seilacher *et al.*, 1998, Fig. 5) was illustrated, but the relationship between furrow and sediment is difficult to interpret, as the section broke during preparation at the critical level of the furrows. The upper 2 mm of the fine-grained sediment has a larger concentration of cementing iron minerals and was interpreted by the authors as manifesting a microbially bound lamina; grains in this portion are less closely packed than in the underlying, slightly coarser portion of buff, fine- to medium-grained sandstone. A photo of the cut surface of the slab taken in reflected light is here presented in Pl. I, fig. C.

INTERPRETATION

In addition to the general vermiform appearance, Seilacher *et al.* (1998) adduced the following arguments to support their interpretation of a burrow origin for these structures: 1) they follow a bedding plane; 2) some have elevated rims, ascribed to pushing up of soft sediment or to a diagenetic halo more resistant to weathering; 3) they are too irregular to be syneresis cracks; 4) they are too sharply delineated to be wrinkles; 5) they are too large to be protists or fungal rhizoids; 6) their diameters vary, but remain constant within systems; and 7) the upper 2 mm of the sediment (iron-stained "dark matrix") was microbially bound, accounting for the unusual mode of preservation.

While one may concur with arguments 1, 2, 3 and 4, the raised rims in argument 2 are not all that evident, and argument 7 is an assertion that remains to be substantiated. Argument 5 has been questioned by Brasier (1998), and Conway Morris (2000). More importantly, the second part of the argument in 6 can be refuted by examining the widths and cross sections of the furrows, particularly the long furrow in Pl. I, figs. A and B. These photographs cover a more complete area of the weathered surface than what was originally portrayed. The furrow at the left of Pl. I, fig. A clearly displays a much greater variability in width than what can be ascertained from the previously published figures, attaining double, even triple the width of its narrower portions, as well as becoming more irregular in outline as the furrow widens. The large sinuous furrow in Fig. 3b in Seilacher *et al.* (1998) also shows variability in width, though much less than in YPM 37665. Such wide variability and variable cross sections seem uncharacteristic for triploblastic animal burrows in soft sediment. Moreover, there is more than a billion-year gap in the trace fossil record, between the age of the Chorhat Sandstone and the first widely accepted traces in the Ediacaran at ~ 555 Ma (Brasier, 1998; Martin *et al.*, 2000; Droser *et al.*, 2002), and the evidence from molecular biology places the origin of the Metazoa closer to ~1000 Ma (Benton and Ayala, 2003), or even later (Petersen and Butterfield, 2005).

So, if the interpretation as animal traces seems questionable, what other explanation could account for the observed morphologic features? Possibly, such simple traces could be generated by protistan slugs analogous to those of slime moulds (Conway Morris, 2000). Rai and Gautam (1999)

EXPLANATION OF PLATE I

(Scale divisions are in cm)

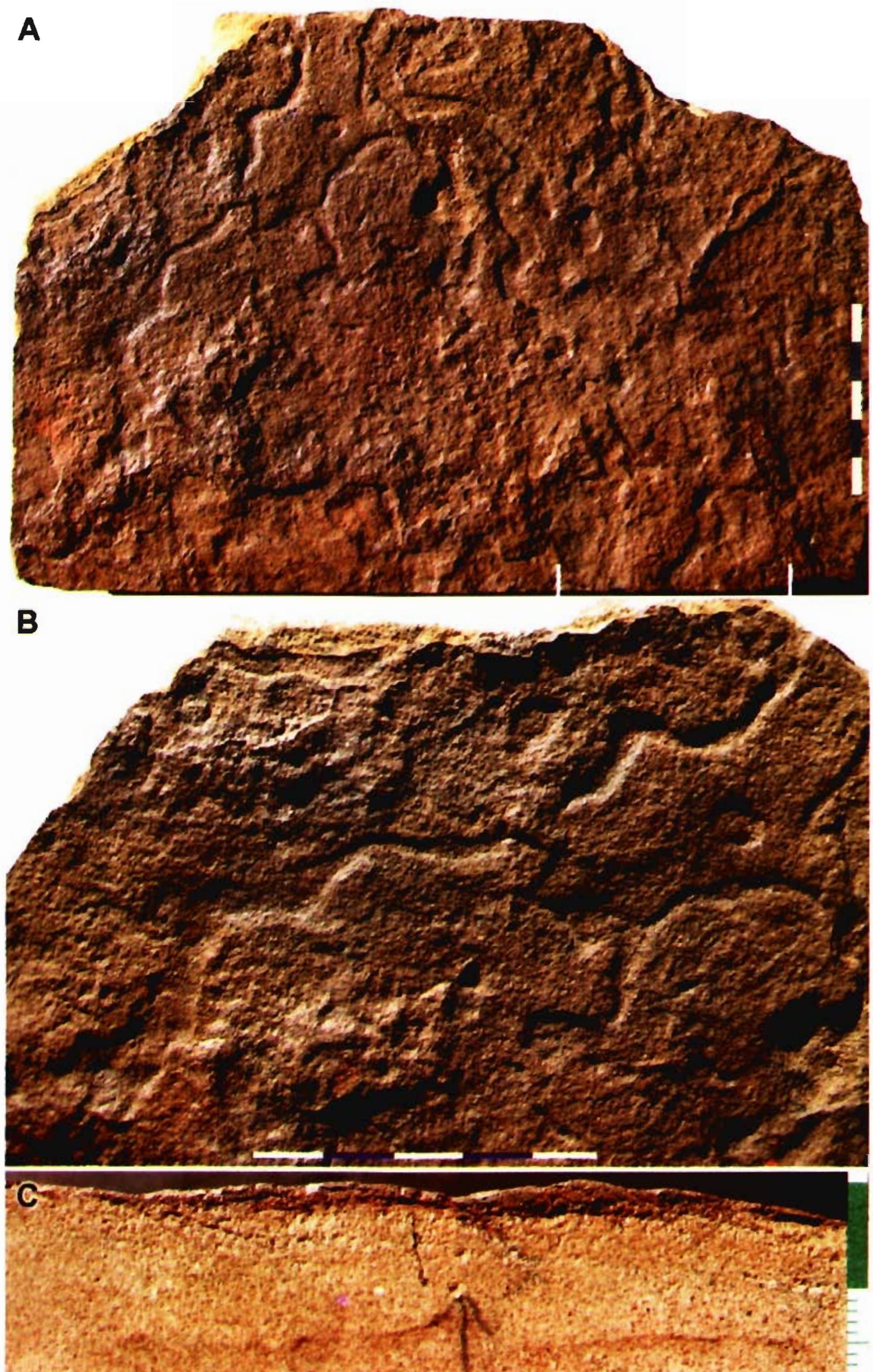
Slab with structures originally interpreted as Vindhyan worm burrows from the Chorhat area of central India (Yale Peabody Museum of Natural History, catalogue no. YPM 37665; Seilacher *et al.*, 1998).

A. General view of the upper, iron-stained weathered surface of the slab, illustrating the general pattern and size of several furrow systems and associated markings. Note the variations in width and shape of furrow cross sections along individual furrows, and also between different furrows. The short white markers along the bottom of the figure indicate the extent of the cut surface illustrated in part C.

B. Enlarged view of the main structure in the left half of part A, clearly illustrating the appreciable variability in width and cross section shape along its length. The subtriangular patch obscuring the main furrow near the centre of the photograph was considered to be original sediment covering the structures, and taken to demonstrate their age as contemporaneous with Vindhyan sedimentation.

C. Vertical section of the slab, illustrating the portion between the two white markers in part A. The ~3 cm thick medium-to fine-grained sandstone bed is overlain by an up to 3 mm-thick lamina of iron-cemented fine sand in which the structures are developed. The pencilled in arrow affixed to the specimen points to the position of one of the furrows, and perhaps the location of the slice taken for the preparation of the thin section illustrated by Seilacher *et al.* (1998, Fig. 4).

Plate I



have considered them pseudo-traces and ascribed them to algal impressions, citing as arguments 1) absence of backfill, 2) absence of microbial mat evidence, 3) an environment too energetic for delicate animals, and 4) absence of fecal structures. Droser (in Kerr, 2002) is quoted as attributing them to shrinkage cracks, features that abound on the bedding surfaces on dip slopes all along a more than 10 km long stretch of roadside exposures west of Chorhat. Nevertheless, Seilacher *et al*. (1999) maintained that the Chorhat structures do not fall into the morphospace and taphofacies of macroalgae, or of shrinkage cracks, nor any other known physical structures, and that the most critical issue is not their [burrow] nature, but their age. However, Seilacher (in Kerr, 2002) allowed that the 1600 m.y. age for the rocks hosting the structures, (Rasmussen *et al*., 2002; Ray *et al*., 2002), obtained after the publication of their original paper, makes it unlikely that they are Paleoproterozoic trace fossils, but deplored the lack of a suitable alternative explanation.

To account for the Chorhat structures, another possible abiogenic explanation is proposed here as a working hypothesis. It is based on observations of comparable structures on surfaces of somewhat younger Vindhyan sandstones exposed in roadcuts 40-80 km south of Varanasi. in southeastern Uttar Pradesh. The area lies in the easternmost part of the Vindhyan Basin, ~150m km ENE of Chorhat. The localities are described as Stops 1 and 2 in the Excursion Guide for the field trip held in conjunction with the 2002 International Vindhyan Field Workshop (Kumar and Gupta, 2002, p. 55), but other sites in the region may also provide comparable surfaces. Previous discussions of the Chorhat structures were made under the assumption that the structures date from the time of sedimentation, but this may need to be reexamined in the light of the structures discussed next.

Like the Chorhat structures, the pertinent features at Locality 1 near the village of Phulwari (see Appendix for location) occur in an iron-stained lamina atop a sandstone of the Scarp Sandstone in the upper part of the Kaimur Group. The patterns, here illustrated in Fig. 1, cover a gently dipping bedding surface in a drainage ditch, forming an irregular reticulate maze of sinuous, anastomosing paths or channels, variably 2-8 mm wide. The surface displays colour differences, from mostly yellowish and reddish brown in most parts, to a darker brown in what appears to be a more heavily weathered (or longer exposed) portion in the peripheral area (near top right of Fig. 1), like the surface of the Chorhat slab. There is an apparent hierarchy of sizes, with longer, more obvious path

Fig. 1. Field photograph of gently sloping bedding surface with pattern of anastomosing sinuous channels with narrow, slightly elevated rims of iron oxide, and intervening irregular, rounded flat areas stained by iron oxide. The sinuous elements are of variable widths, relatively iron-poor, and form a Hierarchical pattern, with the longer ones being consistently wider than the shorter ones. Note the darker brown colour of the outcrop surface in the upper right of the photo, reflecting longer exposure to recent weathering than the lighter area. Scale graduated in decimetres. Outcrop of Scarp Sandstone (upper part of Kaimur Group) at Locality 1 near Phulwari, 7.3 km S of Ahraura on the road to Robertsganj.

EXPLANATION OF PLATE II

Furrow patterns developed on steeply dipping joint planes in upper Kaimur Group sandstones at Locality 2 in long road cut on south side of main highway 8 km south of Robertsganj.

A. Steeply dipping joint surface with channel pattern outlined by ironstained rim, and irregular intervening iron-stained patches. Metric scale wedged into opened joint, in contact with ~1 cm thick iron-stained zone adjacent to joint. Dark horizontal zone at bottom is bedding.

B. Another steeply dipping joint surface covered with anastomosing pattern of channels of variable width. Area of confluence of several channels in lower right. Scale graduated in decimetres. Portions of this view are enlarged in parts

C&D. Both at the same magnification. Note the similarity in size and pattern with that of the Chorhat structures, but developed on a joint surface.

Plate II

HOFMANN

segments having greater width than shorter, subsidiary ones, reminiscent of hierarchical desiccation crack patterns, and self-organization. But unlike mudcracks, the most prominent polygons are of highly variable dimensions, with rounded-off outlines as if affected by erosion along the channel margins. The sinuous paths are somewhat variable in width, have small-scale marginal irregularities, and are delineated by narrow, slightly elevated rims of iron oxide/hydroxide. The intervening, centimetre- to decimetre-sized, irregular round polygons are also impregnated with iron oxide, whereas the path bottoms by comparison appear bleached and relatively depleted in iron.

Other patterns can be found in the upper part of the Scarp and Dhandraul sandstones of the Kaimur Group 38 km to the south, at Kawai Ghat (see Appendix for Location 2), where the features of interest are developed on steeply dipping joint planes (Pl. II) instead of bedding planes. The curvilinear patterns are similarly of variable, millimetric widths and outlined by distinct narrow rims of dark purple and brown iron oxide. Branching is in all directions, but the paths tend to have a more pronounced downslope alignment, presumably related to the steeper dip of the joint surface featuring the patterns. In the lower reaches of one surface (Pl. II, figs. C, E), several channels coalesce to form a distinct irregular, decimetre-broad region of confluence. The purple iron stain is concentrated along the joint, and penetrates the bedrock to a distance of ~1 cm from the joint plane in the example illustrated in Pl. II, fig. A.

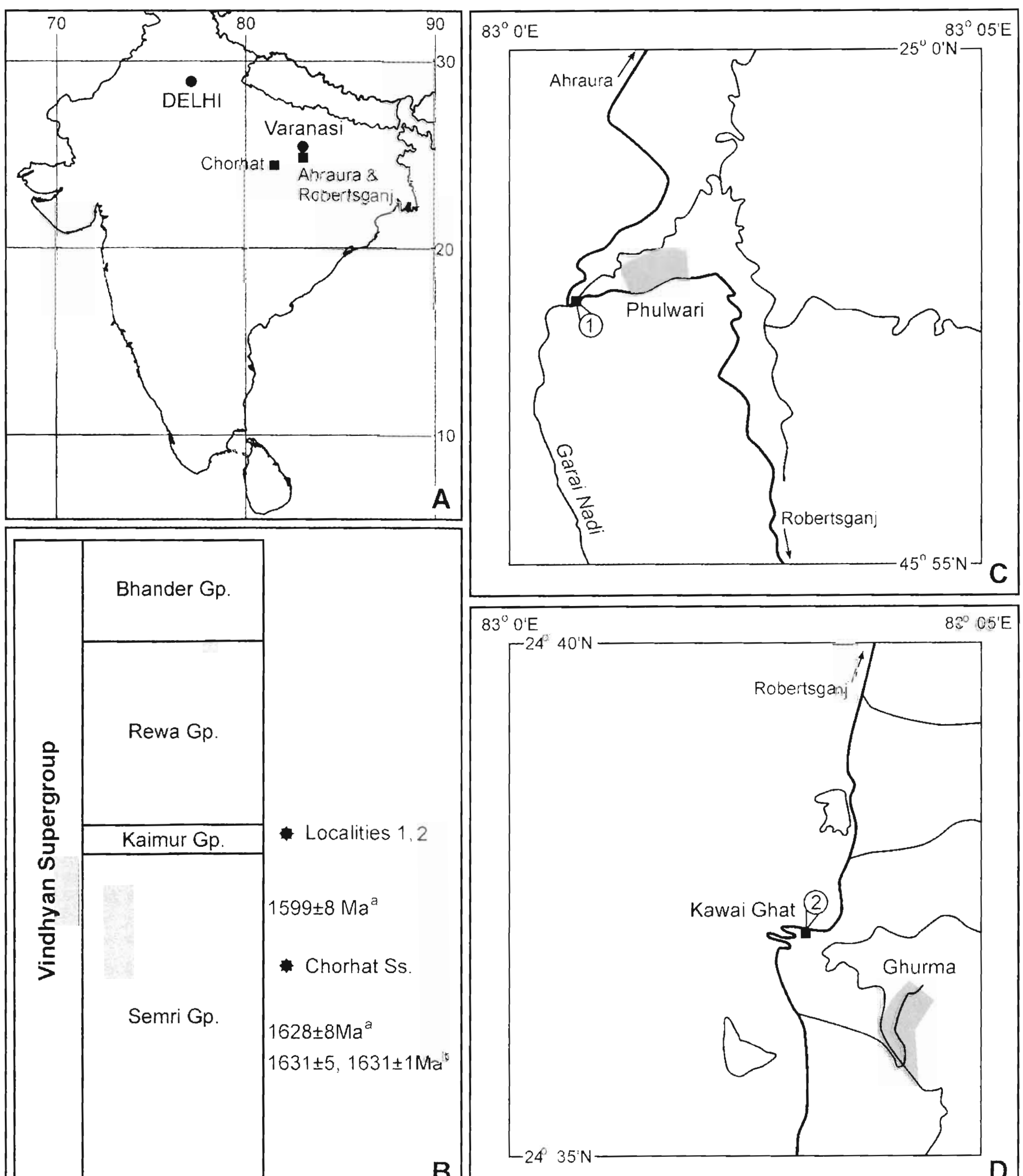


Fig. 2. Locality data. A) Index map. B) Generalized stratigraphic section of Vindhyan Supergroup showing positions of structures discussed in text. Radiometric U-Pb dates from a) Rasmussen *et al.*, 2002 and b) Ray *et al.*, 2002. c) Extract from Map Sheet 44-16, Garhwal 1:250,000, 1956 edition, with localities.

The structures here demonstrate unequivocally that these particular iron-stained, anastomosing patterns represent a general phenomenon unrelated to Vindhyan sedimentation, and are propagated along zones of permeability in consolidated rock along which a furrow or channel pattern could develop at much later times. Geologically more recent lateritic weathering, or possibly, the action of roots or burrowers come to mind. Seilacher *et al.* (1998) already discounted the latter two, but they did not consider the possibility that the patterns may be due to epigenetic chemical action related to subsurface water flow and ferricrete formation.

The patterns are unlike roots in that they clearly anastomose, are variable in width, and contain broad areas of juncture and confluence. In an earlier report on the oldest animal traces, Clemmey (1976, 1978) reported branching burrows from the ca.1 b.y. old Roan Group at Kitwe in Zambia. Cloud (1978) and Cloud *et al.* (1980) related them to a geologically recent surface in saprolite, and made a reasonable case that they represent modern termite burrows. Such an interpretation is more difficult to envisage for the Indian structures, given the size hierarchy and reticulate nature of the channels, the limited gap along the bedding and joint planes at the two occurrences, and the lack of pelletal backfill.

If the channels were not made by termites or ants during geologically recent times, it is conceivable that the structures are patterns formed as a result of advective underground movement of water and diffusion in permeable zones along joint and bedding planes, in a region of ferricrete development, where mobilization and precipitation of iron play an important role, with or without the aid of microbes. The fact that structures on steeply dipping surfaces tend to be more strongly aligned down-dip indicates the effect of a stronger vertical flow component in their formation. The iron mineralization in the steeply dipping joints at Locality 2 clearly postdates sandstone formation, and that in bedding joints at Locality 1, therefore, may be secondary as well. As the structures are secondary, and interpreted as due to chemical action, they are here considered as pseudofossils (chemical abioglyphs, or chemoglyphs). If this scenario also applies to the Chorhat "burrows", the iron oxide lamina in which they occur would be (at least in part) secondary, and not necessarily represent a fossilized microbial surface as envisaged by Seilacher *et al.* (1998). The structures at both Chorhat and at Locality 1 are within in an iron-rich lamina along a bedding surface in a region that has experienced long sustained lateritic weathering with an open chemical system. At one time or another, iron is likely to have been deposited and leached along permeable horizons by changes in Eh and/or pH in percolating subsurface waters. Multiple episodes of solution and precipitation may also be involved, resulting in a complex pattern-forming process.

The subtriangular patch of hematitic sandstone that overlies the large "burrow" in Pl. I, figs. A,B, and was taken as evidence of the Vindhyan age of the structures, could represent loose grains cemented by iron oxide derived from the oxidation of percolating solutions of iron during geologically more recent times, similar to the manganiferous cementation of the backfilling in the Zambian burrows. Such an hypothesis needs to be further evaluated, and is amenable to testing by appropriate further field and laboratory work to ascertain the fluid flow history and geochemistry. Indurated, hematite-cemented colluvium and alluvium of Neogene and earlier ages is known from many areas in the world, and similar reticulate patterns there may also provide clues to establish a more precise idea of the genesis of the Chorhat structures. Additional samples from the Chorhat and Ahraura-Kawai Ghat areas could be studied to better pin down the age of formation of the iron oxides and the sinuous patterns in both areas.

SUMMARY AND CONCLUSION

Individual furrows of the Chorhat dubiofossils, originally interpreted as trace fossils, do not have uniform widths characteristic of triploblastic animal burrows in soft sediment. They have some morphologic features that closely resemble epigenetic reticulate patterns (chemoglyphs) developed in Kaimur Group sandstones by secondary chemical action along bedding as well as joint surfaces that clearly postdate Vindhyan sedimentation. The similarities include comparable size and size variability, shape, ample branching, and association with iron-rich laminae in once permeable zones in sandstone exposed to extensive weathering in a hot and humid climate. Continued action of subsurface water, including channelized flow, may have chemically mobilized, precipitated, and leached iron repeatedly, and cemented grains of sand that now are incorporated in the dubiofossil-bearing lamina, including the subtriangular patch that covers the furrow in Pl. I, fig. B. Further work is required to test this possibility. Apart from the variable widths and the similarity to comparable geologically more recent epigenetic patterns, the existence of complex macroscopic organisms producing branching tunnels at 1.6 Ga is difficult to reconcile with molecular clock data and the absence of a record of animal burrows during a 1 billion year interval. Thus, the existence of triploblastic animal burrows at 1.6 Ga (based on the Chorhat structures) cannot be considered as established.

ACKNOWLEDGEMENTS

I thank Surendra Kumar for discussions and guidance in the field, and for the invitation to contribute to this Special Volume. Discussions with Adolf Seilacher and Friedrich Pflüger helped focus attention on looking for an alternative interpretation for their Chorhat structures. I acknowledge the help of Susan Butts and Copeland MacClintock for arranging the loan of the original hypotype specimen (YPM 37665) at the Yale Peabody Museum of Natural History. Mona Kerba-Kachaami provided technical assistance. The study was financially supported by a grant from the Natural Sciences and Engineering Research Council of Canada (NSERC).

REFERENCES

Benton, M.J., and Ayala, F.J. 2003. Dating the Tree of Life. *Sci.* **300** (5626): 1698-1700.

Brasier, M. 1998. Animal evolution: From deep time to late arrivals. *Nature*, **395** (6702): 547-548.

Clemmey, H. 1976. World's oldest animal traces. *Nature*, **261** (5561): 576-578.

Clemmey, H. 1978. World's oldest animal traces; reply. *Nature*, **275** (5678): 344-345.

Cloud, P.E. Jr. 1968. Pre-metazoan evolution and the origins of the Metazoa, p. 1-72. In: *Evolution and Environment* (Ed. Drake, E.T.), New Haven and London, Yale University Press.

Cloud, P. 1978. World's oldest animal traces; discussion. *Nature*, **275** (5678): 344.

Cloud, P., Gustafson, L.B. and Watson, J.A.L. 1980. The works of living social insects as pseudofossils and the age of the oldest known Metazoa. *Sci.* **210:** 1013-1015.

Conway Morris, S. 2000. Special Feature: The Cambrian "explosion": Slow-fuse or megatonnage? *Proc. Nat. Acad. Sci. (USA) - PNAS*, **97** (9): 4426-4429.

Droser, M.L., Jensen, S., and Gehling, J.G. 2002, Trace fossils and substrates of the terminal Proterozoic-Cambrian transition: Implications for the record of early bilaterians and sediment mixing. *Proc. Nat. Acad. Sci. (USA) - PNAS*, **99** (20):12572-12576.

Hofmann, H.J. 1971. Precambrian fossils, pseudofossils, and problematica in Canada. *Bull. Geol. Surv. Canada*, **189:** 1-146. 11

Kerr, R.A. 2002, Earliest animal tracks or just mud cracks? *Sci.* **295** (5558):1209.

Kumar, S., and Gupta, S. 2002, Field Guide Book, International Field Workshop on the Vindhyan Basin, Central India (3rd to 11th December, 2002): Lucknow, U.P., India, *Pal. Soc. India, Dept. of Geology, University of Lucknow.*

Martin, M.W., Grazhdankin, D.V., Bowring, S.A., Evans, D.A.D., Fedonkin, M.A., and Kirschvink, J.L. 2000. Age of Neoproterozoic bilatarian body and trace fossils, White Sea, Russia: implications for metazoan evolution. *Sci.* **288** (5467): 841-845.

Peterson, K.J., and Butterfield, N.J. 2005. Origin of the Eumetazoa: Testing ecological predictions of molecular clocks against the Proterozoic fossil record. *Proc. Nat. Acad. Sci. (USA) - PNAS*, **102** (27): 9547-9552.

Rai, V., and Gautam, R. 1999. Evaluating evidence of ancient animals. *Sci.* **284** (5418): 1235a.

Rasmussen, B., Bose, P.K., Sarkar, S., Banerjee, S., Fletcher, I.R., and McNaughton, N.J. 2002. 1.6 Ga U-Pb zircon age for the Chorhat Sandstone, lower Vindhyan, India: Possible implications for early evolution of animals. *Geol.* **30** (2): 103-106.

Ray, J.S., Martin, M.W., Veizer, J., and Bowring, S.A. 2002. U-Pb zircon dating and Sr isotope systematics of the Vindhyan Supergroup, India. *Geol.* **30** (2): 131-134.

Seilacher, A., Bose, P.K., and Pflüger, F. 1998. Triploblastic animals more than 1 billion years ago: trace fossil evidence from India. *Sci.* **282** (5386): 80-83.

Seilacher, A., Bose, P.K., and Pflüger, F. 1999. Evaluating evidence of ancient animals: response. *Sci.* **284** (5418): 1235.

Sharma, M. 2003. Vindhyan vagaries. *Curr. Sci.* **84** (10): 1293-1296.

Sharma, M., Shukla, M., and Venkatachala, B.S. 1992. Metaphyte and metazoan fossils from Precambrian sediments of India: a critique, p. 8-51. In: *Four decades of Indian Palaeobotany* (Eds. Venkatachala, B.S., and Singh, H.P.), Birbal Sahni Institute of Palaeobotany, Lucknow.

Venkatachala, B.S., Sharma, M., and Shukla, M. 1996. Age and life of the Vindhyans – facts and conjectures. *Mem., Geol. Surv. India*, **36**: 137-165.

Appendix

Locality 1 (see Fig. 2) is on the road from Varanasi to Robertsganj, 7.3 km S of Ahraura, at 24.959°N, 83.009°E (WGS84 coordinates, obtained by hand-held GPS receiver; the coordinates obtained from topographic map sheet 63P/1 are 24.958°N, 83.012°E). The illustrated surface is in a drainage ditch oblique to the road on the north side of the highway, in the curve just east of the bridge over a creek, opposite a prominent roadside cut with dekametre-wide trough cross-beds as the road ascends the rise eastnortheastward to Phulwari village. Locality 2 (see Fig. 2) is at the large road cut in Scarp and Dhandraul sandstones at Kawai Ghat, 8 km S of Robertsganj, extending downhill in a westerly direction from 24.621°N, 83.049°E (WGS84 coordinates, obtained by hand-held GPS receiver; the coordinates obtained from topographic map sheet 63P/2 are 24.621°N, 83.054°E). The illustrated joint surfaces are on the south side of the highway.

Manuscript Accepted September 2005