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Pyrite Framboids Showing Pseudomorphisms of Microbial Colonies within the Permian *Zoophycos* Spreiten from Southeastern Australia

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INTRODUCTION

Trace fossil *Zoophycos* is the highly complex burrow system with compositional, structural, developmental, operational/algorithmic, hierarchical/modular and ecological/physiologic complexities (Miller, 2003). It is one of the most distinctive and widespread trace fossils, and ranges from the Early Cambrian to the Holocene (Löwemark and Schäfer, 2003). It occurs in a wide variety of depositional settings, involving carbonate, terrestrial and volcanoclastic rocks and in sedimentary environments from sublittoral to deep sea (Ekdale and Lewis, 1991). The sophisticated and enigmatic *Zoophycos* or *Zoophycos* group has attracted much interest for more than a century and continues to challenge geological community. Current controversies are mainly concerned with the morphology, taxonomy, palaeoenvironmental distribution, constructional mode and evolution of the burrow system, and the characteristics and ethology of the *Zoophycos*-maker as well as the relationships between macro the *Zoophycos*-maker and microbes (Bromley and Hanken, 2003; Löwemark and Schäfer, 2003; Kotake, 1989; Seilacher, 1967).

MATERIALS AND METHODS

The *Zoophycos* material was obtained from the Westley Park Sandstone Member at the base of the Middle Permian (Wordian) Broughton Formation, at Black Head, Gerroa, in the southern Sydney basin, southeastern Australia (Fig. 1). The Westley Park Sandstone Member is mainly composed of green-grey, massive siltstone and fine-grained tuffaceous greywacke. It is 190 m thick, generally flat lying, with a regional dip of about two degrees and localized dip of up to 12 degrees towards the north to northwest. The strata contain abundant the body fossils, including brachiopods, bivalves, gastropods, crinoids, sponges, bryozoans, conulariids, fragmental plant materials, and the trace fossils, including *Zoophycos*, *Rosselia*, *Chondrites* and *Palaeophycus*. The fossils are associated with abundant dropstones (ice-rafted debris), glendonites and hummocky cross-bedding. These features indicate that the strata containing the *Zoophycos* were deposited in a glaciomarine environment influenced by storm activity and volcanism.

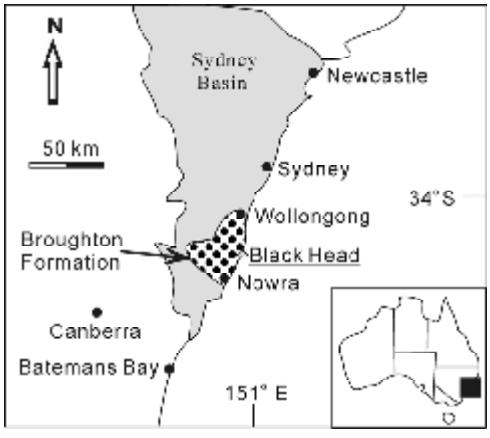

Figure 1. Locality of the studied *Zoophycos* hosted in the Westley Park Sandstone Member, the base of the Middle Permian Broughton Formation from Black Head, the southern Sydney basin, southeastern Australia.

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After the initial ichnological and petrographical work, the freshly broken and polished greywacke/siltstone surfaces containing *Zoophycos* spreiten and fragments of the host strata were selected, cleaned, and coated with carbon and gold, respectively. They were then analyzed both micrographically and chemically in a Quanta 200 Environmental Scanning Electron Microscope (ESEM) equipped with Energy Dispersive X-ray Spectrometric Microanalysis (EDXSM).

RESULTS

The observed *Zoophycos* shows a conical form consisting of a series of spreiten, which radiate from a central shaft (9–35 mm in diameter, 100–120 mm in height) that is perpendicular to the bedding surface and curve distally in either the sinistral or dextral manner. In vertical cross-section, *Zoophycos* is usually composed of a series of imbricate or superposed spreiten that are distally arranged in rows sub-parallel to the bedding surface. No or little compaction has been observed in the central shaft and spreiten.

Both thick (10–25 mm) and thin (<10 mm) minor lamellae have been distinguished in the same sample or outcrop; the former mainly consists of coarse clastics (feldspar and quartz) poor in organic matter and with dropstones, and appears light-grey in colour, whereas the latter is enriched in finer-grained sediments, clay minerals and organic matter and with no dropstones, and tends to be dark-grey in colour.

The spreiten consist of both major lamellae and the oblique minor lamellae between the major lamellae. The minor lamellae appear as crescents or rounded chevrons. The direction of the crescents within any one spreite is always the same. It is commonly seen that the top of a spreite is truncated by succeeding spreiten. Occasionally, due to their sometimes sub-parallel nature, a spreite will disappear completely, having been cut off by an overlying slightly oblique spreite. The *Zoophycos* herein is tentatively referred to as *Zoophycos* cf. *caudagalli* Vanuxem, 1842. No marginal tube has been observed. Within the spreite structures, we have not observed any homogeneous filling, fecal pellets and any sign of re-exploitation of the minor lamellae.

Two types of pyrite framboids (PF1 and PF2) have been found within the minor lamellae of the *Zoophycos* spreiten (Figs. 2, 3). PF1 are composed of non-sheathed, hollow or infilled sub-micron balls with or without a smooth opening (Fig. 2a–d). PF2 consist of sheathed, hollow sub-micron balls with thick wall (Fig. 3a–d). PF1 occur only within the thick, light-grey minor lamellae and shallowly penetrate into or adhere to broken surfaces or crystal surfaces of the detrital feldspar and quartz. PF2, on the other hand, are only restricted to the thin, dark-grey minor lamellae. In generally, all the framboids are framboidal or spheroidal, 6–12 μm in diameter and consist of orderly arranged, equidimentional and equimorphic sub-micron balls with 0.5–0.8 μm in diameter; they are highly abundant and occur in an orderly arrangement of equal density and in good state of preservation within the minor lamellae. No similar framboids have been found outside the minor lamellae. A systematic geochemical analysis of the framboids measured by EDXSM indicates that the main elements of the sub-micron balls are iron, sulfur, carbon and oxygen. All the balls and ball sheaths coated with gold or carbon within the framboids contain the element carbon.

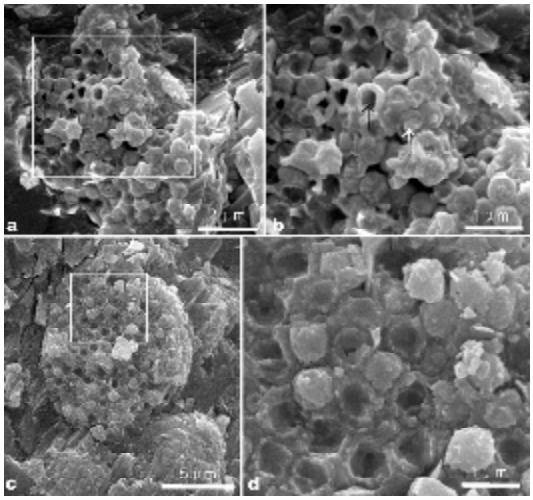

Figure 2. Scanning electron microscope images showing the pyrite framboids (PF1) interpreted as microbial colonies within the light-grey minor lamellae of *Zoophycos* spreiten. (a–d) PF1 consist of non-sheathed, hollow (black arrow in (b)) and infilled (white arrow in (b)) sub-micron balls with smooth opening, (b) is the close-up of (a), and (d) is the close-up of (c). PF1 shallowly penetrate into surfaces of the detrital feldspars in (a) and (c).

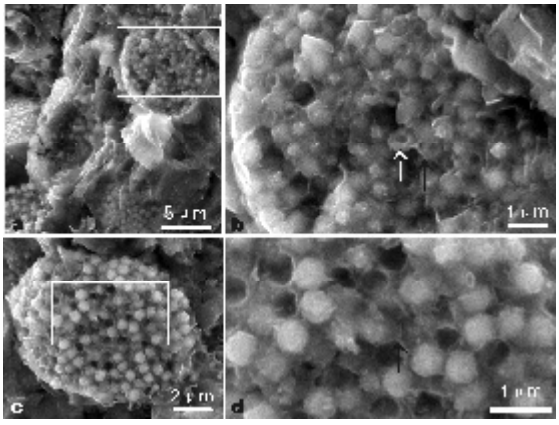

Figure 3. Scanning electron microscope images showing the pyrite framboids (PF2) interpreted as microbial colonies within the dark-grey minor lamellae of *Zoophycos* spreiten. (a–d) the PF2 consist of sheathed (black arrows in (b) and (d)) and hollow (white arrow in (b)) sub-micron balls with thick wall, (b) is the close-up of (a), and (d) is the close-up of (c). PF2 are hosted in the environment rich in clay mineral and organic material in (a) and (c).

CONCLUSIONS

Based on our study of *Zoophycos*, the following conclusions can be made.

(1) Herein pyrite framboids are the pyritized remains of framboidal microbial colonies enriched within *Zoophycos* spreiten from the Middle Permian glaciomarine greywacke of the Westley Park Sandstone Member within the Broughton Formation in the southern Sydney basin of southeastern Australia. The framboids are composed of both non-sheathed (PF1) and sheathed (PF2) sub-micron balls. Both PF1 and PF2 occur in rhythmic alternation within the thick, light-grey and thin, dark-grey minor lamellae of *Zoophycos* spreiten. No similar framboids have been found in the surrounding host strata.

(2) The fact that the overlying spreiten cut the underlying ones indicates that the *Zoophycos* from the study area is of an upward construction. The rhythmic alternation of both the thick, light-grey and thin, dark-grey minor lamellae within *Zoophycos* spreiten may be suggestive of a gardening manner of the *Zoophycos*-maker responding to the warm and cold changes, food supply in pulses and variations of sedimentation rate for planting and culturing microbial colonies under the condition of a glaciomarine environment at the high latitudes.

(3) The highly complex and orderly *Zoophycos* in external morphology and internal texture herein documented from the southern Sydney Basin hinted that the *Zoophycos* would be the multifunctional garden that was carefully constructed by the *Zoophycos*-maker, where the trace-maker may have intentionally created optimal conditions (substrate types and the quality and quantity of food) for planting and culturing microbes and selectively and periodically introduced sediments rich in clastics, organic matter and clay minerals or other useful components through the central shaft from the seafloor above into the spreiten for the microbial colonies to cultivate and feed on.

(4) It is proposed that the *Zoophycos*-producer symbiosed with microbial colonies on the mutual basis of the food supply and redox conditions.

REFERENCES CITED

Bromley, R. G., Hanken, N. M., 2003. Structure and Function of Large, Lobed *Zoophycos*, Pliocene of Rhodes, Greece. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 192: 79–100

Ekdale, A. A., Lewis, D. W., 1991. The New Zealand *Zoophycos* Revisited: Morphology, Ethology and Paleoecology. *Ichnos,* 1: 183–194

Kotake, N., 1989. Paleoecology of the *Zoophycos* Producers. *Lethaia,* 22: 327–341

Löwemark, L., Schäfer, P., 2003. Ethological Implications from a Detailed X–Ray Radiograph and ^{14}C Study of the Modern Deep-Sea *Zoophycos*. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 192: 101–121

Miller, W. III., 2003. Paleobiology of Complex Trace Fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 192: 3–14

Seilacher, A., 1967. Bathymetry of Trace Fossils. *Marine Geology,* 5: 413–428