



New *Megasphaera*-like microfossils reveal their reproductive strategies

Yuan Zhang, Xingliang Zhang*

State Key Laboratory of Continental Dynamics and Shaanxi Key Laboratory of Early Life and Environment, Department of Geology, Northwest University, Xi'an 710069, China



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ABSTRACT

New occurrence of Ediacaran Weng'an Biota-type microfossil assemblage has been discovered from the base of the Dengying Formation in Zhenba County, Shaanxi Province, South China. The assemblage is dominated by spherical microfossils ranging from 200 to 1200 μm in diameters. Based on the size and morphological features, two genera and three species have been identified, i.e. *Megasphaera inornata*, *M. ornata* and *Spirallicellula bulbifera*. Morphological analyses reveal three types of reproduction, i.e. binary fission, budding, and multiple fission, which are widely distributed among protist and metazoan lineages. Besides, a physiological phenomenon of "ornament growth" has been discovered among *M. ornata*. These again raise difficulties in determining biological affinities of *Megasphaera*-like microfossils. The new microfossil assemblage shares the most common elements of embryo-like microfossils with the Weng'an biota. However, those Large Acanthomorphic Acritarchs (LAAs) with great capacity for biostratigraphic correlation are not present. The age of the new assemblage is constrained within the Ediacaran, contemporary with or slightly younger than the Weng'an Biota by regional correlation. The new finding not only extends the geographical distribution of the Ediacaran phosphatized biotas in South China, but also provides valuable fossil materials for studying ontogenesis and evolution of early microscopic organisms and taphonomy of phosphatized soft-bodied fossil Lagerstätte.

1. Introduction

Since the discovery of phosphatized soft-bodied fossils from limestone concretions interbedded in the Furongian Alum Shale in southern Sweden (Müller, 1979), more occurrences of similar style of preservation have been found in strata ranging from Ediacaran to Lower Ordovician in a number of areas worldwide, especially in South China (Maas et al., 2006; Dong et al., 2004, 2005; Qian, 1977; Chen and Liu, 1986). However, apart from the Ediacaran Weng'an biota, all other occurrences are Phanerozoic in age.

Phosphatized Konservat Lagerstätte is able to preserve delicate soft and hard parts, even subcellular structures of organisms (Wilby and Briggs, 1997; Martill, 1988; Schultze, 1989), and thus provides important taphonomical windows for investigating early life evolution. Particularly microscopic and soft-bodied organisms whose fossilization and terminal appearance solely rely on exceptional taphonomical conditions like phosphatization or silicification, had dominated a long history of organic world before Cambrian. The study of Konservat Lagerstätte prior to the Cambrian explosion is becoming considerably more significant. The Weng'an biota has received a great attention of world scientists largely because it is Ediacaran in age and contains abundant phosphatized non-skeletal fossils (Xiao et al., 1998; Xiao and

Knoll, 1999; Xue et al., 1995; Zhang et al., 1998). The new fossil assemblage recovered from the basal phosphatic horizon of the Ediacaran Dengying Formation in Southern Shaanxi is dominated by spherical microfossils, associated with some columnar or tubular microfossils (described elsewhere). In this article, we report the spherical microfossils because they show various reproductive strategies and have biostratigraphic importance.

2. Geological setting

The studied area is located in the south part of Shaanxi Province, tectonically south to the Qinling Orogen and traditionally thought to be in the northwestern margin of the Yangtze block. However, recent investigation indicated that the area maybe an isolated block far away from Yangtze block during and before Cambrian (Yang et al., 2015b). The working section, named as Lianghekou section, is situated at Lianghekou village of Zhenba County, approximately 19 km south-eastern from Zhenba Town, with the GPS coordinates N32°22'59.4", E107°59'39.0", where Cryogenian to Cambrian strata are well exposed.

The Ediacaran Dengying Formation in the Lianghekou section is unconformably underlain by the clastic of the Doushantuo Formation

* Corresponding author.

E-mail address: xzhang69@nwnu.edu.cn (X. Zhang).

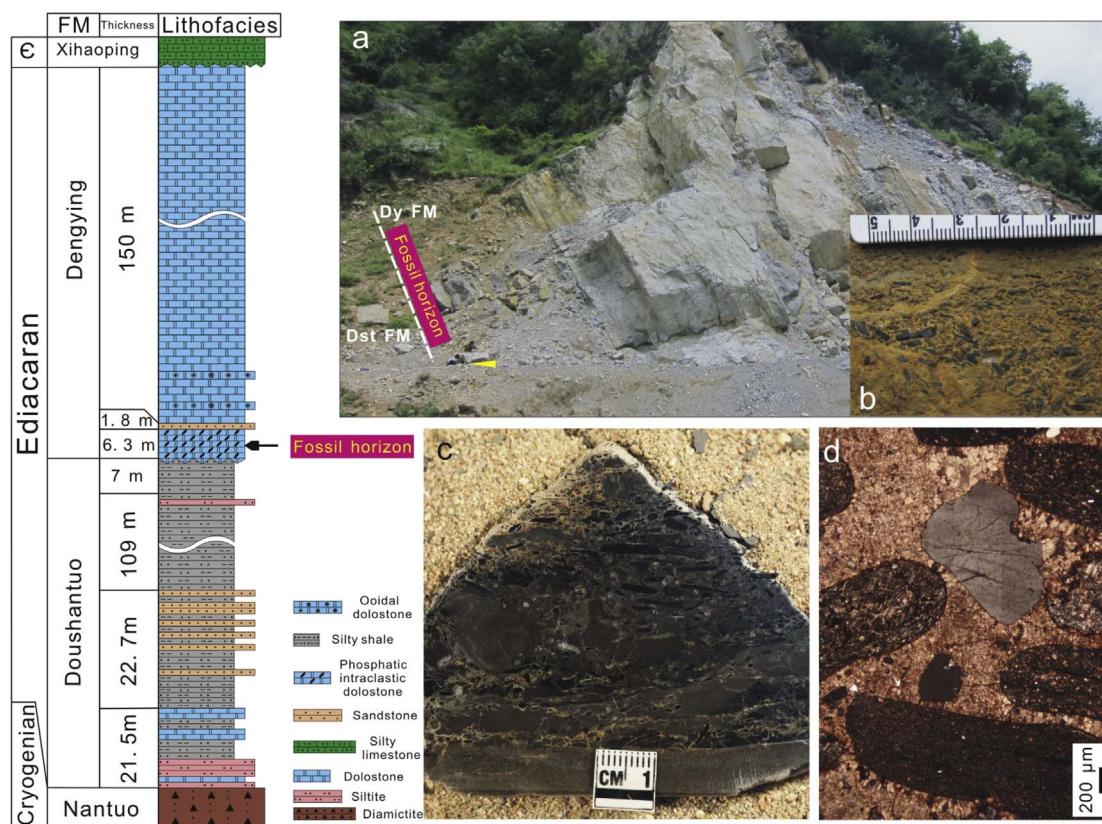


Fig. 1. Stratigraphic column and petrologic characters of fossiliferous horizon. (a), outcrops of studied Lianghekou Section, the white dotted line represents boundary between Doushantuo Formation (Dst FM) and Dengying Formation (Dy FM), note the person as scale bar (yellow arrowhead). (b), rock sampled from the fossiliferous horizon. (c), vertical-level polished surface of hand specimen. (d), petrographic thin-section photographed under cross-polarized lights. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and is unconformably overlain by the lower Cambrian Xihaoping Formation composed of dark colored silty limestones. The Dengying Formation here can be subdivided into three lithostratigraphic units (Fig. 1).

The basal unit is about six meters thick, composed of grey dolostones with abundant phosphatic intraclasts and compressed lens. The mid unit is two meters in thickness, comprising grayish white, medium-bedded, fine-grained sandstones intercalated with medium-bedded dolostones. The upper unit is around 150 m thick, mainly composed of grayish white massive dolostones intercalated with many layers of oolitic dolostones. Chert nodules and stromatolites are quite common in this upper dolostone unit.

The phosphatic intraclasts from the base of Dengying Formation were sampled for fossils. They turn out to be quite fossiliferous, containing predominantly spherical microfossils. The intraclasts are generally millimeter- to centimeter-sized and discoid in overall shape, showing poorly directive arrangement (Fig. 1b and c), indicating a secondary storm deposition of shallow marine facies. In composition, they are not purely phosphatic, containing considerable amount of organic matter and terrigenous material. Detrital sediments within the intraclasts are poorly sorted and rounded, including chert, quartz, feldspar, and clays as well (Fig. 1d).

Carbon isotopes of the dolomites from studied section indicated that the basal unit of Dengying Formation might be correlated to the upper part of Hamajing Member and top of algae-dolostone Member of Dengying Formation in Yangtze Gorge area and Ningqiang area respectively (Chen et al., 2015).

It's interesting that, no phosphatic sediments in lower Dengying Formation had been reported in adjacent area. Instead, Ediacaran phosphatic sediments in South China are mainly occurs in Doushantuo Formation (Tang et al., 1987; Yang et al., 2015a). The sources of these

transformed phosphatic intraclasts, although is still uncertain, may from older Doushantuo sediments.

3. Methods

Rocks were sampled from the fossiliferous horizon, dolomite with abundant phosphatic intraclasts from the basal Dengying Formation. Parts were used to make petrographic thin sections, and the rest were fragmented then etched using diluted acetic acid (~10%). Digestion-residues collection and acetic-acid replenishment were repeated every 48 h. As the result, phosphatized microfossils were released from the matrix. Acid-resistant residues were handpicked under microscope after gentle washing and drying. Up to now, approximately 100 kg of rocks were processed, and more than six thousands specimens of spherical microfossils were recovered.

Fossils were photographed under the field emission Scanning Electron Microscope (SEM) FEI Quanta 400 FEG. To investigate their internal structures, a number of microfossils were re-embedded in epoxy and then thin-sectioned in controlled orientation. Thin sections were examined under a transmitted light microscope. A portion of selected specimens were processed using micro-CT. All the microfossils described below are deposited in the Department of Geology, Northwest University, Xi'an, China.

4. Description of spherical microfossils

Microfossils are preserved as spheroids of variable size, ranging from 200 μm to 1200 μm in diameters (Fig. 2). The plastic deformation (Fig. 3g), decomposed remains like ambient inclusion trails (She et al., 2016) (Fig. 3a) and microbiogenic filaments (Fig. 3e, f) are common in specimens, which indicate that they were biogenetic and soft-bodied.

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