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Diagenetic xenotime age constraints on the Sanjiaotang Formation, Luoyu Group, southern margin of the North China Craton: Implications for regional stratigraphic correlation and early evolution of eukaryotes

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ABSTRACT

Eukaryote fossil-bearing Ruyang and Luoyu groups are extensively exposed along the southern margin of the North China Craton, but their age has long been a matter of controversy due to the absence of reliable radiometric dates. By dating detrital zircons and diagenetic xenotimes from the Sanjiaotang Formation of the Luoyu Group, this paper confirms that the Ruyang and Luoyu groups were deposited during the period of 1750–1400 Ma. The new age constraints suggest that the Sanjiaotang Formation is coeval with the Xiamaling Formation of the Jixian Group on the northern margin of the North China Craton. Correlation of the Luoyu Group with the Jixian Group is thus indicated. The Ruyang and Luoyu groups contain abundant fossils of eukaryotic organisms such as acritarch and macroalgae. Accordingly, eukaryotic proliferation extends back to the Mesoproterozoic, consistent with results of molecular phylogenetic analysis that a rapid morphological diversification of eukaryotic organisms occurred prior to 1400 Ma.

1. Introduction

Late Precambrian stratigraphic correlation of eukaryote-fossil bearing strata in the marginal areas of the North China Craton (NCC) and eukaryote evolutionary history have become the target of intense research (Xiao et al., 1997; Yin, 1997; Yin et al., 2004; Knoll et al., 2006; Gao et al., 2010). Zircon U–Pb ages from intrusive rocks or interbedded volcanic tuff beds within critical stratigraphic horizons have allowed establishing a solid chronostratigraphic framework for the most complete and continuous Meso-Neoproterozoic successions of the Jixian Section, northern margin of the NCC (Lu and Li, 1991; Li et al., 1995; Gao et al., 2007; L.Z. Gao et al., 2008a,b; W. Gao et al., 2008; Gao et al., 2009; Lu et al., 2008; H.K. Li et al., 2009; Zhang et al., 2009). These radiometric dates not only have contributed to the classification of the Meso-Neoproterozoic strata in the NCC, but also have provided key age constraints on the origin and evolution of eukaryotes (L.Z. Gao et al., 2008a; L.Z. Gao et al., 2008a, 2010). In contrast, the lack of reliable radiometric dates from the Proterozoic sedimentary successions of the southern margin of the NCC as represented by the Ruyang and Luoyu groups resulted in debate of their stratigraphic correlation despite extensive exposure (Wu, 2002; Gao et al., 2002).

Previously published Rb–Sr, K–Ar, Ar–Ar, and Pb–Pb ages from the Ruyang and Luoyu groups are imprecise and unreliable (Guan et al., 1988; Qiao and Gao, 1997; Liu et al., 1999), as they potentially record subsequent alteration rather than true depositional ages (e.g. Obradovich, 1988; Zhou et al., 1998; Chen et al., 2011). A carbon isotope chemostratigraphic correlation suggests a >1200 Ma age for the deposition of the Luoyu Group (Xiao et al., 1997). The Ruyang and Luoyu groups yielded abundant eukaryotes such as acritarch and macroalgae (Zhu and Chen, 1995; Yin and Gao, 1999, 2000; Yin et al., 2004, 2005). A Mesoproterozoic or Neoproterozoic affinity has been proposed (Yan and Zhu, 1992; Yin and Gao, 1999, 2000; Yin et al., 2004, 2005; Li et al., 2012), thus making a biostratigraphic correlation with fossils of the Jixian section impossible. Lithostratigraphic correlation has been attempted (Wu, 2002) but remains inconclusive.

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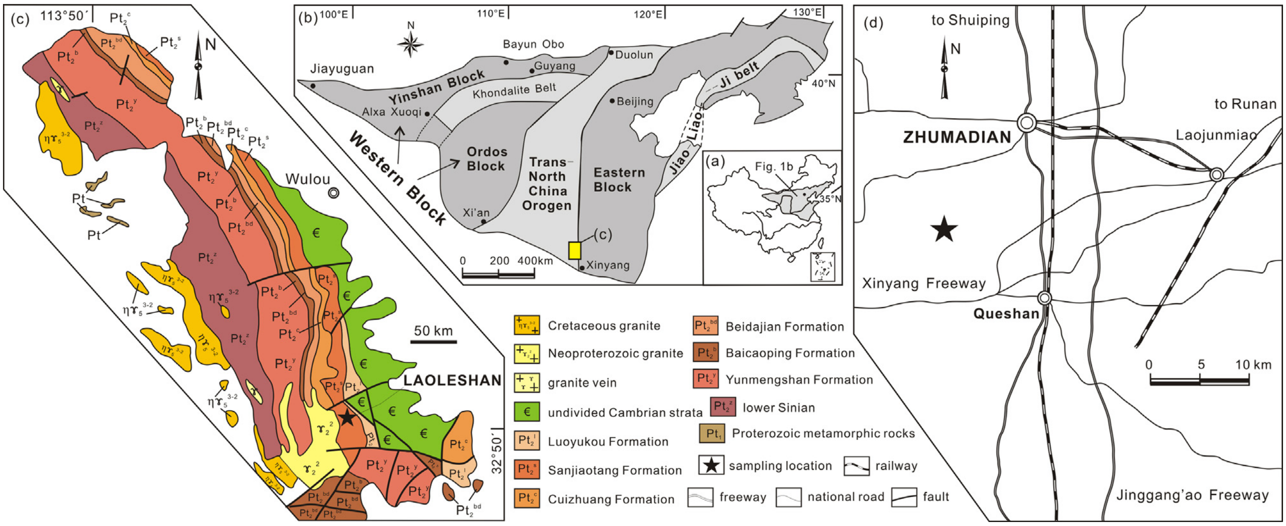

Fig. 1. (a) Outline of China showing the position of the North China Craton. (b) Tectonic map of the North China Craton composed of Western Block, Trans-North China Orogen, and Eastern Block. The study area is located in the southern end of the Eastern Block. (c) Simplified geological map of the study area. The star represents the sampling location. (d) Road map showing the location of the studied section.

Far superior to lithostratigraphic and biostratigraphic correlation schemes in the Precambrian is the dating of diagenetic minerals such as xenotime (YPO_4) in siliciclastic rocks that provide ages close to the depositional age (McNaughton et al., 1999; Rasmussen, 2005). In siliciclastic rocks, xenotime typically occurs as overgrowths on detrital zircon and frequently forms during early or burial diagenesis (Rasmussen, 2005) in the presence of sufficient supply of yttrium, rare-earth elements (REE) and phosphate by pore waters (Rasmussen et al., 1998). Compositional zoning is commonly observed in xenotime and produced by variations in the concentrations of U, Th, Y and other elements in the pore water during growth (Vallini et al., 2005). Diagenetic xenotime is a suitable mineral for U–Pb geochronology as it has adequate amounts of U (commonly >1000 ppm), low amounts of common Pb, and remains relatively unaffected by later element mobility (Fletcher et al., 2004; Rasmussen, 2005).

As diagenetic xenotime commonly represents an early diagenetic phase in siliciclastic sediments (Rasmussen, 2005), its formation age should be close to the depositional age of sedimentary rocks. With the development of secondary ion mass spectrometric (SIMS) techniques, procedures for the successful dating of diagenetic xenotime have been developed to determine proxy depositional ages (e.g. McNaughton et al., 1999; Vallini et al., 2002, 2005; Lan and Chen, 2012). The depositional age of siliciclastic rocks can be bracketed between the ages of the oldest diagenetic xenotime population and the youngest detrital zircon population.

However, xenotime growth may also take place during later episodes of the burial history of a clastic succession, exhibiting a range of ages recording later diagenetic to hydrothermal to metamorphic events (Vallini et al., 2002; Rasmussen et al., 2011), despite petrographic characteristics similar to early diagenetic xenotime (Kositcin et al., 2003). Additionally, detrital xenotime sourced from igneous rocks may be present in siliciclastic sediments, displaying identical chemical signatures to diagenetic xenotime (Van Emden et al., 1997; Rasmussen et al., 2011). Like other detrital minerals, detrital xenotime displays textural evidence for reworking, unless textural criteria have been modified by mechanical processes during burial diagenesis.

We report here U–Pb geochronological data for xenotime from sandstones of the Sanjiaotang Formation, Luoyu Group in the Laoleshan area, Zhumadian City, Henan Province to provide a minimum depositional age for this sedimentary unit by differentiating early diagenetic xenotime from detrital and later diagenetic xenotime (Fig. 1). Also from the same unit, we report ages of detrital zircon grains to provide a maximum depositional age and provide a means in tracing sediment provenance. The new ages will assist in resolving the age and correlation of the Luoyu Group and will provide key age constraints on the evolution of eukaryotes in deep time.

2. Regional geology, tectonic history and sampling location

The Archean to Paleoproterozoic basement of the North China Craton (NCC) has been divided into three major tectonic blocks, namely the Western Block, the Eastern Block, and the Trans-North China Orogen on the basis of structure, petrology, metamorphic features, and geochronology (Zhao et al., 2005, 2010; Fig. 1a and b). The discrete Eastern and Western blocks were welded together along the Trans-North China Orogen at ca. 1.85 Ga during assembly of the Columbia supercontinent (Zhao et al., 2002). Following its final amalgamation, thick and laterally widespread successions of Meso-Neoproterozoic siliciclastic and carbonate rocks were deposited (Lu et al., 2008), which are represented by the Changcheng, Jixian, and Qingbaikou groups in the depositional center around the Jixian area of the northern NCC, and by the Ruyang and Luoyu groups on the southern margin of the NCC.

The Precambrian successions are well exposed at the Laoleshan section (32°51′45.2″ N, 113°54′46.8″ E), about 14 km southwest of Zhumadian City, southern Henan Province, North China, which is located on the southern margin of the Trans-North China Orogen and Eastern Block (Fig. 1c and d). Archean–Paleoproterozoic basement gneiss and schist are unconformably overlain by Paleoproterozoic Xiong'er Group volcanic rocks (Fig. 2) dominated by basaltic andesite and andesite (Zhao et al., 2004). The Xiong'er Group volcanic rocks are mainly present in the southeastern Shanxi Province as well as the northwestern and western Henan Province with only limited outcrops around the study area where they are metamorphosed (Taiping Zhao, personal communications). Major and trace element data together with Sr–Nd isotopic compositions suggest an EM-I mantle type signature and possible crustal contamination for the Xiong'er volcanic rocks (Cui et al., 2011).

The volcanic rocks are overlain by undated siliciclastic and carbonate rocks of the Ruyang and Luoyu groups. The Ruyang Group attains a thickness of ca. 1485 m and is subdivided, in ascending order, into the Yunmengshan, Baicaoping, and Beidajian formations. Of these, the Baicaoping Formation contains acanthomorphic acritarchs (Yin and Gao, 1999; Li et al., 2012). The Luoyu Group,