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A revised paleomagnetic pole from the mid-Neoproterozoic Liantuo Formation in the Yangtze block and its paleogeographic implications

Xian-qing Jing[a], Zhenyu Yang[b,c,*], Yabo Tong[b,c], Zhirui Han[b]

[a] School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China
[b] Key Laboratory of Paleomagnetism and Tectonic Reconstruction, Ministry of Land and Resource, Beijing 100081, China
[c] Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100081, China

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ABSTRACT

The paleogeographic relationship between South China and Australia during the Neoproterozoic is still hotly debated. Although a series of propositions for the close proximity between South China and Australia are suggested, their relative positions are varied. To better constrain the paleoposition of South China, we have carried out a new paleomagnetic study from the Neoproterozoic Liantuo Formation in two localities, Yichang and Changyang, in Hubei province, China. Stepwise thermal demagnetization reveals that a late Cretaceous remagnetization (component 'L', 350–500 °C) was removed from most of the samples. A medium component ('M') isolated mainly between 350 °C and 600 °C, but in some cases with an upper limit of 640 °C, yields a mean direction of Dg = 59.5°, Ig = 64.6°, α95 = 3.7° in situ; and Ds = 81.6°, Is = 61.5°, α95 = 4.1° after tilt correction. A steeper medium-high temperature component, 'B', was separated from 71 specimens with almost the same temperature range of 'M' (Dg = 341.3°, Ig = 78°, α95 = 5.6° in situ; and Ds = 78.3°, Is = 83.8°, α95 = 6.9° after tilt correction) and is similar to the 'B' component obtained by Evans et al. (2000). In addition, a high temperature component 'H' (Ds = 102.5°, Is = 62.4°, α95 = 3.7° after tilt correction) with both reversed and normal polarity was revealed up to 690 °C, yielding a pole at 12.7° N, 157.4° E, with dp/dm = 4.5°/5.8°. A change of magnetic polarity, with 5 magnetozones defined, is revealed in our sampling section, in which a reversed-normal polarity succession in the upper part of the section may be correlative with that obtained in a section 6.5 km away by Evans et al. (2000), demonstrating the primary nature of the 'H' component. Combining our results with those of Evans et al. (2000) yields a grand mean pole from the upper Liantuo Formation at 13.2° N and 155.2° E with A_{95} = 5.3°. Considering the distribution of our sampling sites, and together with the results of a detailed recent SIMS U–Pb zircon study on the Liantuo Formation in the Three Gorges area (Lan et al., 2015), an age of 720 Ma was assigned to component 'H' and its corresponding pole. After carefully reevaluating the Neoproterozoic apparent polar wander paths (APWP) from Australia and South China, we suggest that the South China block was located to the northwest of Northern Australia during the Ediacaran period. Subsequently, the South China block moved to the northwest of Western Australia through counter-clockwise rotation of the Northern Australian craton at the later time of 550 Ma, or in the middle Cambrian.

1. Introduction

Estimation of the paleoposition of south China in the late Proterozoic is potentially important for reconstructing the Rodinia supercontinent (Li et al., 1995). Various disciplines and methods have been used to constrain its paleo-positions, including geochronology, geochemistry, sedimentary basin analysis, analysis of detrital zircon provenance, petrology, paleontology, tectono-stratigraphy and paleomagnetism. The application of these various approaches has resulted in the production of several reconstruction models during the past two decades. In these reconstructions, the South China block (SCB) either moved quickly from the central part of Rodinia in 750–780 Ma (the 'missing-link' model, Li et al., 1995, 2008; Li and Evans, 2011), and then to the north of Australia (Li and Evans, 2011) or northeast of Australia by 650 Ma (Li et al., 2008), or to the northwestern part of Australia during post-635 Ma and

* Corresponding author at: College of Resources, Environment and Tourism, Capital Normal University, 105 Xi San Huan Bei Road, Haidian District, Beijing 100048, China. Tel.: +86 10 88815152; fax: +86 1068422326.
E-mail address: yangzhenyu@cags.ac.cn (Z. Yang).

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early Paleozoic time (Yang et al., 2004; Zhang et al., 2013, 2015). On the other hand, a relatively stationary relationship between the SCB and Australia has also been suggested based on late Proterozoic, middle Cambrian and Silurian paleopoles of south China (Zhang and Piper, 1997; Yang et al., 2004), in which south China was situated in the northwestern part of Australia between the late Proterozoic and early Paleozoic.

It is clear that the paleogeographic reconstruction of South China during the late Proterozoic and early Paleozoic is hampered by the lack of reliable paleomagnetic poles. Although paleomagnetic studies of the Neoproterozoic and early Paleozoic rocks of South China have been carried out for more than three decades (Lin et al., 1985a,b; Zhang et al., 1983), only a few high quality poles are available (Evans et al., 2000; Huang et al., 2000; Yang et al., 2004; Zhang et al., 2013). A high quality 748 Ma 'Z1′ pole reported by Evans et al. (2000) was used by Yang et al. (2004) in the reconstruction of South China and Australia. Although in their reconstruction the middle Cambrian and Silurian poles are well-matched from both the Yangtze and Australia blocks, the 'Z1′ pole is not consistent with the 755 Ma Australian MDS pole. Based on the lower Triassic paleomagnetic results for the Zigui area of Shen et al. (1999), Yang et al. (2004) proposed that the discrepancy could be caused by the clockwise rotation of the sampling area at Yichang (~20°). However, Zhang et al. (2013) listed several lines of evidence indicating that no rotation occurred in the Z1 sampling region.

Recently, Zhang et al. (2013) reported a new Nantuo pole (635 Ma) that is not significantly different to the Liantuo Z1 pole, which implies that the Z1 pole may be much younger than previously thought. In addition, the age discrepancy between the Z1 pole and MDS pole must be considered in the course of directly comparing the rotated Z1 pole with the MDS pole within the Australian framework. The Liantuo Formation was first dated using SHRIMP U–Pb dating of twenty-three zircons from an interbedded tuff with a discordia lower intercept age of 748 ± 12 Ma (Ma et al., 1984). However, recent studies report generally younger ages from the Liantuo Formation (Lan et al., 2015; Zhang et al., 2006; Cui et al., 2014; Liu et al., 2008; Hofmann et al., 2011).

In order to verify whether or not there was local rotation of the Yichang area, and to determine the long-term directional change within the Liantuo Formation from the bottom to the top, we carried out a systematic paleomagnetic study of two separate sections in the Tianjiayuan and Wangjiapeng areas. The former is located 6.5 km from the section studied by Evans et al. (2000).

2. Geological setting and paleomagnetic sampling

The study areas are located in Yichang and Changyang, Hubei Province, in the northern part of the Yangtze Block, where typical Precambrian sedimentary sequences have been mapped by geological survey (Fig. 1). The stratigraphy of the study areas includes the Liantuo Formation, the Nantuo Formation, the Doushantuo Formation and the Dengying Formation, from older to younger. The Liantuo Formation consists of thick-bedded, red purple conglomerate feldspathic sandstone and quartz sandstone in the lower part; and clastic sandstone, feldspathic sandstone, silty sandstone and crystal-vitric tuff in the upper part. The Nantuo Formation (654 Ma–635 Ma, Zhang et al., 2008) consists predominantly of dark green and minor red to purple tillites that disconformably overlie the Liantuo Formation. The disconformity between the Liantuo and the Nantuo Formations may represent a ~60 Ma deposition gap (ca. 710–650 Ma). The Doushantuo Formation overlies the Nantuo Formation with an insignificant disconformity, and comprises dolomite with interlayered phosphatic shale, which was dated to ca. 635 Ma–551 Ma (Zhang et al., 2005; Condon et al., 2005; Liu et al., 2008). The Dengying Formation, continuously developed over the Doushantuo Formation, consists mainly of thick-bedded dolomite and limestone.

A total of 480 samples were collected from 40 sites using a gasoline-powered drill, including 412 (33 sites) comprising red and a few green siltstone-sandstone samples from the Tianjiayuanzi area (TL) at Yichang (GPS: 111.069° E, 30.819° N) and 68 (7 sites) comprising fine-medium-grained red-colored samples from the Wangjiapeng section (WL) at Changyang (GPS: 111.069° E, 30.538° N).

The TL area includes three sub-sections at Huajipo, Toudingshi and Tianjiayuanzi (Fig. 2). We collected samples from 9 sites from the bottom to top of the Liantuo Formation at the Huajipo subsection (Fig. 2). Because of heavy vegetation cover in the lower part of the Liantuo Formation, the samples were collected only from the uppermost parts of two other sub-sections, where the sampling layer positions were determined from the distances between the site and the boundary between the Liantuo-Nantuo Formations (Fig. 2). The Tianjiayuanzi sub-section was located on the south bank of the Yangtze River, close to the sampling locality studied by Evans et al. (2000) (Fig. 1).

The dip attitudes of the Liantuo formation are mostly directed to the SE quadrant with dip angles less than 30° in the Tianjiayuanzi sub-section (Fig. 1). Although the dip attitudes of the strata in the Wangjiapeng section are variable, the trend is approximately toward the NW and NNW (Fig. 1).

3. Laboratory techniques

In order to characterize the magnetic mineralogy, representative specimens were chosen for various rock magnetic experiments. Acquisition of isothermal remanent magnetization (IRM) was imparted using an ASC IM-10-30 impulse magnetizer and measured with a JR-6A spinner magnetometer. To further constrain the unblocking temperatures of the magnetic minerals, representative samples were magnetized sequentially along *Z*-, *Y*-, and *X*-axes at fields of 2.4 T, 0.4–0.5 T, and 0.12 T, respectively, and were then subjected to stepwise thermal demagnetization (Lowrie, 1990). The anisotropy of magnetic susceptibility (AMS) was measured using the KLY-3S Kappa-bridge.

Stepwise thermal demagnetization of pilot samples was performed using an ASC-TD48 oven in order to isolate the characteristic remanent magnetization (ChRM). After analyzing the behavior of the pilot samples, progressive thermal demagnetization was carried using 14–18 steps at a 50 °C interval for low temperatures (<300 °C), and a 20 or 30 °C interval for high temperatures (>300 °C) up to 600–660–670 °C, and finally with a 10 or 15 °C interval to 685–690 °C. The remanence of the specimens was measured using a 2G Enterprises Inc. cryogenic rock magnetometer (2G-755) housed in a magnetically shielded room. The magnetic remanence directions were analyzed using the principal component analysis method (Kirschvink, 1980) and the site-mean directions were calculated using Fisher spherical statistics (Fisher, 1953) or using the intersection of remagnetization great-circle method (McFadden and McElhinny, 1988). Palaeomagnetic software packages PMGSC (by R. Enkin) and PaleoMac (Cogne, 2003) were used to perform data analyses and produce related figures. All of the magnetic measurements were made at the Palaeomagnetism Laboratory of Nanjing University.

4. Paleomagnetic results

For most of the samples, the IRM acquisition curves show a relatively rapid increase of intensity up to 800–900 mT, but with saturation not being attained until about 1.5–1.8 T (Fig. 3C, D, G, H). This suggests that the samples contain predominantly