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Global synchronous initiation of the 2nd episode of Sturtian glaciation: SIMS zircon U–Pb and O isotope evidence from the Jiangkou Group, South China

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ABSTRACT

Depositional age of the Xieshuihe Formation in the Nanhua Basin, South China has been controversial in the past two decades, which hampers our understanding of the synchroneity of the 2nd episode of Sturtian glaciation as well as regional stratigraphic correlation. In this study, a new SIMS zircon U–Pb age of 691.9 ± 8.0 Ma (MSWD = 1.3) was obtained from a tuffaceous siltstone bed within the upper Xieshuihe Formation in the Nanhua Basin, which is within errors consistent with the ID-TIMS U–Pb zircon age of $688.6 + 9.5/-6.2$ Ma from Yukon, Canada, the SHRIMP U–Pb zircon ages of 685 ± 7 and 684 ± 4 Ma from central Idaho, the SHRIMP U–Pb zircon age of 686 ± 4 Ma from southeastern Idaho, and the SHRIMP U–Pb age of 703 ± 6 Ma from northern Utah, North American Cordilleran margin. All these dated formations conformably underlie the upper Sturtian glaciogenic diamictite. Hence new ages suggest a maximum initiation age of ca. 690 Ma for the 2nd episode of Sturtian glaciation, which is synchronous in at least two geographically separated palaeocontinents. The commonly low $\delta^{18}O$ values (3–5‰) from the zircon grains of Xieshuihe Formation suggest an influence of glaciation during their formation, probably by means of an ice–fire interaction process as previously proposed. Additionally, new age data suggest the Xieshuihe Formation is not correlative with the Liantuo Formation/Banxi Group as previously assumed. Rather, it could be correlated with the Liangjiahe Member, Fulu Formation in South China, which is feasible in terms of sedimentology and sequence stratigraphy.

1. Introduction

The middle-late Neoproterozoic (750–580 Ma) represents a critical era during which multiple glaciations occurred and have brought remarkable impact on atmosphere, hydrosphere, and biosphere (Hoffman and Schrag, 2002). Among these, the Sturtian and Marinoan glaciations occur widely almost in all continents (Hoffman and Li, 2009), and therefore, are taken as benchmark event for global Neoproterozoic glacial stratigraphic correlations given their intimate association with banded iron/manganese formations and 'cap carbonates' (Hoffman and Schrag, 2002). The initiation and termination age of the Marinoan glaciation has been well constrained to a time interval of 650–635 Ma (Hoffmann et al., 2004; Condon et al., 2005; Calver et al., 2013). In contrast, the timing, number, and duration of the Sturtian glaciation remain disputable and unresolved (Allen and Etienne, 2008; Hoffman and Li, 2009), which continues to hamper our understanding of ice sheet dynamics during the snowball Earth interval. Within the framework of Sturtian glaciation, two episodes of glaciation as represented by two glaciogenic diamictites have been recognized (Crittenden et al., 1983; Link et al., 1994; Keeley et al., 2012; Balgord et al., 2013). Recent zircon U–Pb ages documented from northwestern Canada and South China have constrained the onset age of Sturtian glaciation to ca. 715 Ma (Macdonald et al., 2010; Lan et al., 2014). The onset age of the second episode of Sturtian glaciation was dated at ca. 690 Ma in Laurentia (Ferri et al., 1999; Lund et al., 2003, 2009; Fanning and Link, 2004, 2008; Balgord et al., 2013), but its global synchroneity remains unproved owing to lack of convincing radiometric ages.

Glaciations correlative with the Sturtian glaciation are also present in South China where they were named Jiangkou glaciation that is dividable into the earlier Chang'an glaciation and later Gucheng glaciation (Zhang et al., 2011). Whereas the onset age of Chang'an glaciation has been dated at ca. 715 Ma (Lan et al., 2014), the initiation age of Gucheng glaciation remains unclear. The Xieshuihe Formation distributed around the northwestern

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Hunan Province, South China conformably underlies the diamictite of Gucheng Member, thus ascertaining the depositional age of the upper Xieshuihe Formation would contribute to constraining the initiation age of Gucheng glaciation. Previously, a single zircon U–Pb age of ca. 687 has been obtained from the upper Xieshuihe Formation but its potential geological significance has been ignored (Yin et al., 2003; Zhang et al., 2008a). As such, it is necessary to revisit the glaciogenic Xieshuihe Formation and accurately calibrate its depositional age in order to test the synchroneity of the 2nd episode of Sturtian glaciation.

Precisely constraining the depositional age of Xieshuihe Formation also contributes to resolving the disputes on regional stratigraphic correlation. Lack of convincing radiometric dates has confused Chinese geologists more than two decades concerning the stratigraphic correlation of Xieshuihe Formation, with possible attributions to the Liantuo Formation (HBGMR, 1988; Liu et al., 1991, 1999; Huang et al., 1996; Xue et al., 2001; Yin et al., 2003; Peng et al., 2004; Wang et al., 2006), Fulu Formation (HBGMR, 1997; Zhang et al., 2003, 2008a; Peng et al., 2004; Zhang and Chu, 2006) or middle-upper Banxi Group (Zhang, 1986a,b; Wang and Suo, 1987) from different perspectives. A precise and accurate chronological solution is required in order to place the Xieshuihe Formation in an appropriate position in the stratigraphic framework of the Nanhua Basin as well as define the initiation age of the 2nd episode of Sturtian glaciation and prove its global synchroneity. The aim of this paper is to provide an accurate radiometric age control on the Xieshuihe Formation by means of dating zircon grains from interbedded tuffaceous siltstone beds. In doing so, we are trying to clarify its connection with Sturtian glaciation and its correlation with other stratigraphic units in the Nanhua Basin.

2. Geological setting and sampling location

Amalgamation of the Yangtze Block to the northwest and the Cathayia Block to the southeast along the Jiangnan/Sibao orogen led to the formation of South China Block (SCB) during the Proterozoic Sibao orogeny (Fig. 1a; Li et al., 2008a, 2009a). Subsequently, the SCB experienced intracontinental rifting along the Jiangnan orogen, and accommodated a wealthy of well-preserved Cryogenian (850–635 Ma) sedimentary and volcanic rocks in the Nanhua Basin – the largest Neoproterozoic basin in SCB (Wang and Li, 2003; Li et al., 2008b,c). The sedimentary rocks are well preserved in Hunan–Guizhou–Guangxi adjacent region of the Nanhua Basin (Figs. 1a and 2; HBGMR, 1997; Zhang et al., 2008b).

Updated geochronological and geochemical data combined with differential lithological associations mean that the Cryogenian successions are dividable into three tectonostratigraphic sequences (Fig. 2; Wang and Li, 2003; Wang et al., 2012; Lan et al., 2014, 2015). They are, in ascending order, the Sibao Group (ca. 850-820 Ma) in Guangxi and Guizhou provinces (equivalent of Lengjiaxi Group in Hunan Province and Shuangqiaoshan Group in Jiangxi Province) as the first sequence, the Banxi Group (ca. 814-715 Ma) in Hunan Province (equivalent of Danzhou Group in northern Guangxi Province and Xiajiang Group in eastern Guizhou Province) as the second sequence, and the Jiangkou Group, Datangpo and Nantuo formations (ca. 715-635 Ma) as the third sequence characterized by glacial and interglacial deposits (Fig. 2). The Jiangkou glaciogenic deposits were divided into Chang'an Formation and Fulu Formation which includes the above stadial Gucheng Member and below interstadial Liangjiehe Member (Zhang and Chu, 2006). The Dongshanfeng Formation correlates with Gucheng Member on the grounds of common presence of glacial diamictite (Fig. 3; Zhang and Chu, 2006; Zhang et al., 2008a). Likewise, the Xieshuihe Formation has been correlated with Liangjiehe Member based on their similar lithological features, they making up the Fulu Formation together with Dongshanfeng/Gucheng/Tiesiao Member (Zhang and Chu, 2006).

Around the study area, the Xieshuihe Formation/Liangjiehe Member disconformably overlies the Laoshanya Formation and is conformably overlain by the Dongshanfeng Formation/Gucheng Member (Figs. 1B and 3A, B; Liu et al., 1999; Zhang et al., 2008a). The Dongshanfeng Formation is overlain conformably by the Datangpo Formation, which also conformably underlies the Nantuo Formation. The Laoshanya Formation attains a thickness of about 180 m and is dominated by sandstone, mudstone and conglomerate intercalated with thin-bedded shale and volcanic tuff, whereas the Xieshuihe Formation has a thickness of ca. 230 m and is dominated by cross-bedded quartz sandstone, feldspar sandstone and conglomerate interacted with minor thin-bedded tuffaceous sandstone and siltstone. The sporadic occurrence of glacial characteristics such as ice wedges, glacier push structures, ice scours, and outsized clasts in the upper Xieshuihe Formation suggests it is likely infillings of incised valley on lower continental shelf to upper slope (Zhang et al., 2003, 2008a; Zhang and Chu, 2006). Chemical Index of Alteration (CIA) of the Xieshuihe Formation suggests an icehouse condition during its upper part, foreshadowing the coming of Jiangkou glaciation (Feng et al., 2004).

Sample YC27 is a grey-green tuffaceous siltstone collected from the upper Xieshuihe Formation at the Yangjiaping section (Fig. 3C), Hupingshan Town, Shimen County, Hunan Province. The sampling horizon is about 20 m away from the base of the Dongshanfeng Formation. It is composed chiefly of quartz, feldspar and clay minerals with accessory volcanic glass, biotite and iron oxides (Fig. 4). The Dongshanfeng Formation is about 3 m thick and is dominated by sandstone matrix mingled with pebbles composed of quartzite or granite in the size range of 0.4-1 cm, appearing an angular to subangular morphology (Fig. 3D). Such a lithological composition is typical of glacial diamictite (Zhang et al., 2008a, 2011).

3. Analytical methods

3.1. SIMS U–Pb analysis

Zircon concentrates were separated from ca. 1.5-kg rock samples by conventional density and magnetic separation techniques. Recovered zircon grains together with chips of zircon standards Plešovice and Qinghu were mounted in epoxy discs and polished to expose the longitudinal section of crystals for analysis. All zircons were documented with transmitted and reflected light micrographs as well as cathodoluminescence (CL) and backscattered electron (BSE) images to reveal their internal structures. The SEM instrument is operated with an accelerating voltage of 15 kV. High-quality CL images are acquired at a resolution of 1950 lines/scan at 50 ms duration. A total of 8-12 images are obtained for each sample at magnifications in the range of 130–160× to provide complete coverage of the mounted crystals.

Samples were vacuum-coated with high purity gold and U and Pb isotopes were measured utilizing the Cameca IMS 1280 at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS) in Beijing. The SIMS methodology adopted at the IGGCAS follows previously published analytical descriptions with minor modifications (Li et al., 2009b). Each spot was cleaned by rastering the primary ion beam over the target area for about two minutes prior to analysis. Monocollector mode was adopted to collect isotopic data. For normal zircon analyses, the O_2^- primary beam was accelerated at 13 kV with an intensity of about 12 nA. The aperture illumination mode (Kohler illumination) was applied in combination with a 200 μm primary beam mass filter (PBMF) aperture to produce even sputtering over the entire analyzed area. The resulted ellipsoidal spot is about 20 μm × 30 μm in size. Positive secondary