A New Age Constraint on the Onset of the Neoproterozoic Glaciations in the Yangtze Platform, South China

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ABSTRACT

A sample from the top of the Banxi Group (early Neoproterozoic) in Hunan Province (South China) was dated by the SHRIMP zircon U-Pb method. The resulting age of 725 ± 10 Ma probably solves the debate between the synglacial and the preglacial correlation of the Liantuo Formation and indicates that the Liantuo Formation most likely correlates with the preglacial Banxi Group. Since the Banxi (Danzhou) Group is upwardly transitional to the glacial Jiangkou Group, the age becomes a new maximum age constraint on the onset of the Jiangkou glaciation, which therefore most likely correlates with the Sturtian glaciation.

Online enhancement: appendix table.

Introduction

Along with the approval of the Ediacaran Period and System by the International Union of Geological Sciences in 2004 (Knoll et al. 2004), the definition of the "Cryogenian" Period and System is currently being considered under the auspices of the Subcommission on Neoproterozoic Stratigraphy. If the glacial and preglacial transition could be one of the criteria in defining the base of the Cryogenian, then the transitional boundary between the Neoproterozoic glaciations and the preglacial strata in South China is important because in many other continents, the Sturtian glacial deposits generally rest on an extensive unconformity.

The Sturtian, Nantuo, and Gaskiers glaciations in the Neoproterozoic are well known. The first two occurred at around 710 and 640 Ma, respectively, and are generally considered to be the most severe glaciations in Earth history, and the oceans were postulated to be frozen (Hoffman 2005). There is probably another older Kaigas glaciation (>741 and <771 Ma; Frimmel and Fölling 2004). Would it be possible that the Jiangkou glaciation in the Yangtze platform correlates with it? To answer this question and to define the possible base of the Cryogenian in South China, we used the SHRIMP zircon U-Pb method to date a tuffaceous siltstone sample from the top of the Banxi Group (middle Neoproterozoic) in Hunan Province.

Geologic Setting

At the base of the Neoproterozoic successions in the Yangtze platform is a major unconformity likely to represent the ~1.1–0.9-Ga Sibao/Jinning orogeny and the crustal doming and erosion caused by the ~825-Ma mantle plume (Li et al. 1995, 1999, 2003*a*, 2003*c*; Li 1999; Cao 2000; Jiang et al. 2003; Zhang et al. 2003*b*; Lu et al. 2004; Wang et al. 2006). The age of the base of the succession is dated at ~820 Ma (fig. 1; Wang and Li 2003; Wang et al. 2003).

The Neoproterozoic succession comprises the Ediacaran and Nanhuan System (National Committee on Stratigraphy 2001), in which the Nanhuan is defined similarly to the Cryogenian (Gradstein et al. 2004). However, in this article, the Nanhuan (or Cryogenian) is assumed to include the Neoproterozoic glaciations only, and the interval below it is informally named as the Yangzian (fig. 1). Complete Nanhuan succession in the Yangtze platform,

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System	A: YS Xue et al. (2001)		B: J Wang &ZX Li (2003)		C: XJ Peng et al. (2004)		D: QR Zhang & XL Chu (2006)	
	Yichang	N Guangxi	Yichang	N Guangxi	Yichang	N Guangxi	Yichang	SE Guizhou
Nanhuan “Cryogenian”	(660 Ma) Nantuo	Silikou	Nantuo	Silikou	Nantuo	(680 Ma) Nantuo	Nantuo	(635 Ma) Silikou
	Datangpo	Datangpo	Datangpo	Fulu	Datangpo	Datangpo	Datangpo	Datangpo (663 Ma)
	Gucheng (700 Ma)	Tie’si’ao	Gucheng	Chang`an	Gucheng	Gucheng	Gucheng	Jiangkou: Fulu: Gucheng
	(730 Ma) ***Liantuo*** (750 Ma)	Fulu			***Liantuo***	(746-728 Ma) Fulu		Jiangkou: Fulu: Liangjiehe
		Chang`an				Chang`an		Jiangkou: Chang`an
Yangzian “Tonian”	Banxi	Banxi (~850 Ma)	(748 Ma) ***Liantuo***	Danzhou (~820 Ma)		Gaojian (<819 Ma)	(748 Ma) ***Liantuo***	Danzhou (~820 Ma)

Figure 1. Four classification and correlation models of the Nanhuan System in the recent decade.

particularly in Hunan and Guizhou provinces and the Guangxi Region, is classified into the upper glacial Nantuo or Silikou Formation, the interglacial Datangpo Formation, and the lower glacial Jiangkou Group (fig. 1*D*).

The studied unit is at the top of the Banxi Group in Hunan Province. The sedimentary facies of the upper Banxi (or Gaojian) Group (fig. 1*A*, 1*C*) in Hunan Province varies from erosive oldland in the north to deep-water facies in the south (fig. 2). The thickness of the fluvial-littoral facies ranges from 0 to 1000 m, the littoral-offshore facies from 600 to more than 1400 m, and the pelagic facies from less than 1000 to more than 4000 m (Hunan

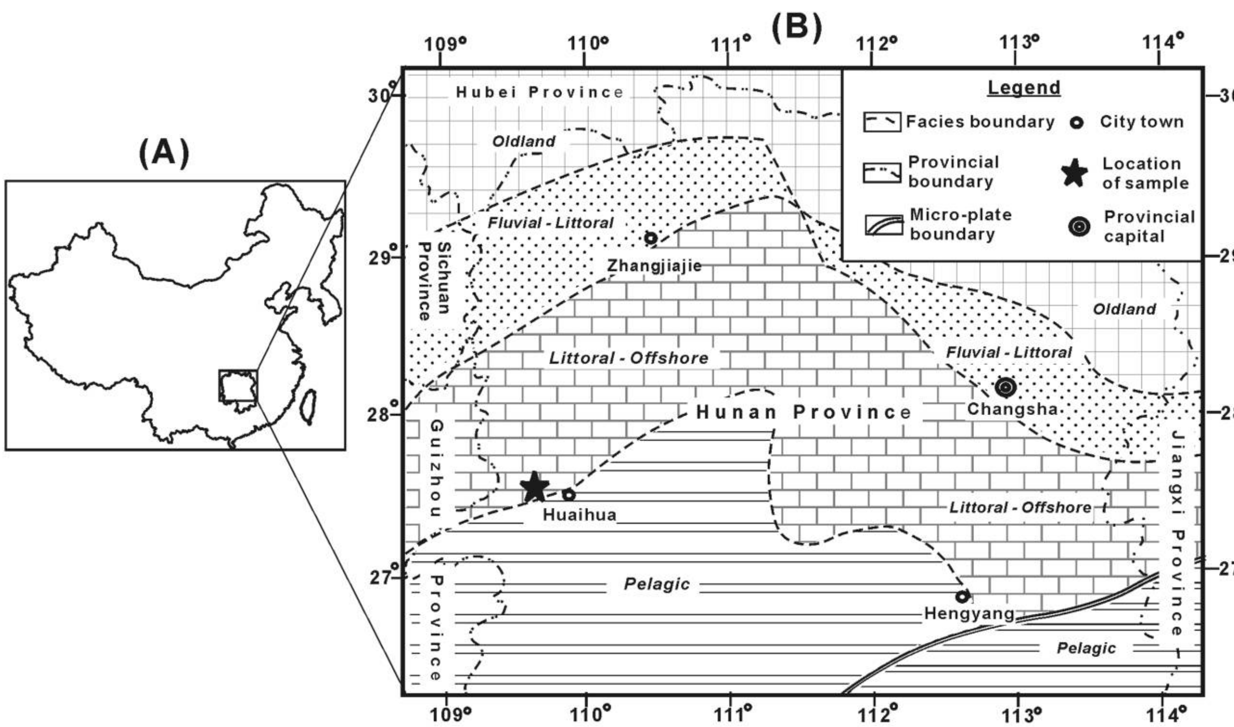

Figure 2. The sedimentary environments of Hunan Province of the upper Banxi Group (adapted from Hunan BGMR 1997). *A*, Outline of China mainland and Hunan Province. *B*, Inset in *A*. The star shows the location of sample 0509.

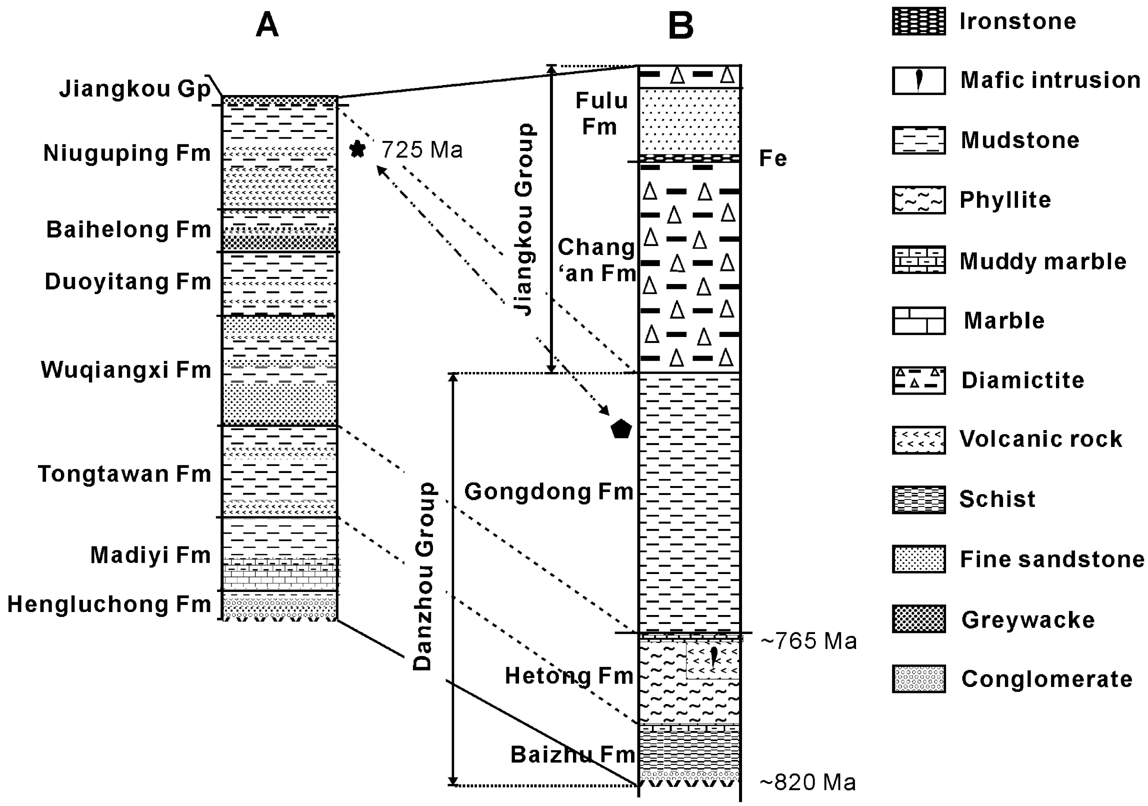

Figure 3. Relative stratigraphic horizon of sample 0509. *A*, The typical section of the Niuguping Formation in Zhijiang County and the Banxi Group in Hunan Province (Hunan BGMR 1997). *B*, The continuous section in Northern Guangxi (Guangxi BGMR 1985). The asterisk in *A* is the location of sample 0509, and its possible relative level in *B* is shown by the pentagon.

BGMR 1997). The variation in thickness reflects changes of the sedimentary environments and accommodation within the basin and was probably controlled by the capability of the uplift and erosion during the Nanhuan glaciations; the further to the north they were, the more the preglacial succession was eroded (Zhang et al. 2003*a*).

Sample 0509 was collected from the type section of the Niuguping Formation (fig. 3*A*), the youngest unit of the Banxi Group in Hunan Province (Tang et al. 1994; Hunan BGMR 1997). The star in figure 2 is the location of the sample (E 109°42.4′, N 27° 35.9′). Overlying the Niuguping Formation is the Jiangkou Group (fig. 3*A*), and the contact between them is disconformable.

The thickness of the Niuguping Formation is 720 m (fig. 3*A*). Except for the 273-m thickly bedded mudstone at the top, the rest is composed mainly of middle-bedded tuffaceous silty mudstone with intercalated tuffaceous siltstone (Hunan BGMR 1997). Sample 0509 is about 300 m below the upper boundary of the Niuguping Formation (fig. 3*A*, *asterisk*). It is a pale green and finely laminated tuffaceous siltstone.

Zircon U-Pb Dating

Zircon concentrates were extracted from the rock sample using standard density and magnetic separation techniques. About 200 grains of representative zircon crystals from the sample, together with zircon standard TEMORA, were mounted in an epoxy mount. Both optical photomicrographs and cathodoluminescence (CL) images were taken for guiding analytical spot selection. Measurements of U, Th, and Pb were conducted using the SHRIMP II ion microprobe at the Beijing SHRIMP Center, Chinese Academy of Geological Sciences. U-Th-Pb ratios were determined relative to the TEMORA standard zircon ($^{206}Pb/^{238}U = 0.0668$, corresponding to 417 Ma; Black et al. 2003), and the absolute abundances were calibrated to the standard zircon SL13 (U = 238 ppm) using operating and data processing procedures similar to those described by

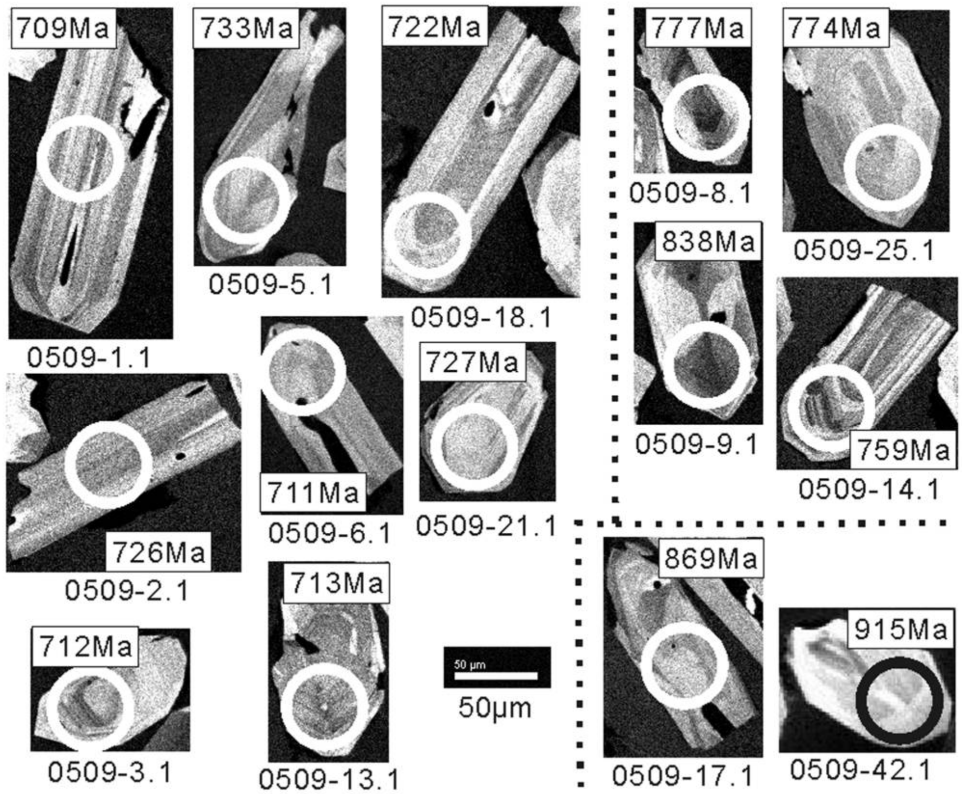

Figure 4. Cathodoluminescence (CL) images of representative measured zircon grains from sample 0509. The scale bar is 50 μm.

Williams (1998). The common Pb component was estimated from ^{204}Pb counts, and an average crustal composition (Cumming and Richards 1975) appropriate to the age of the mineral was assumed. Data reduction was carried out using Squid, version 1.02, and Isoplot/Ex, version 2.49 (Ludwig 2001*a*, 2001*b*). U-Pb zircon data are presented in table A1 (available in the online edition or from the *Journal of Geology* office) and figure 5. Uncertainties in individual analyses are reported at the 1σ level; mean ages for ^{206}Pb/^{238}U results are quoted at the 95% confidence level.

The analyzed zircon grains are prismatic and colorless; about half of them are transparent, and the rest are translucent. The lengths of the zircon grains range from 80 to 170 μm. They are mainly euhedral and subordinately stubby. The CL images (fig. 4) show two types of internal structure: those with normal to medium brightness and oscillatory zoning indicate a magmatic origin, and those with strong brightness, with faint planar or linear zoning and relics of zoning in a few structureless grains, probably indicate that the magmatic domains were variously modified by metamictization.

Sixty-nine analyses were made on 65 zircon grains. Zircon ^{206}Pb/^{238}U ages are scattered between ~702 and ~915 Ma (fig. 5), forming a multi-

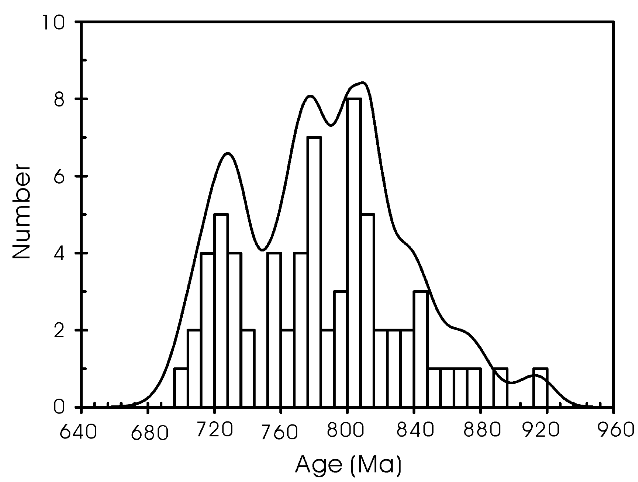

Figure 5. Histogram and probability plot of detrital zircon spot ages for sample 0509. Probability curve represents the best fit of age distribution.

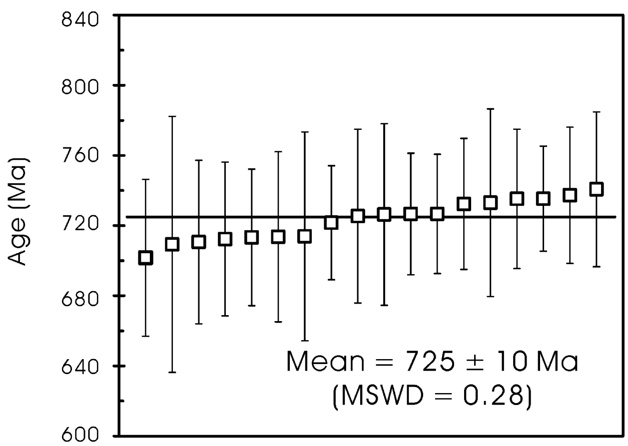

Figure 6. Weighted average of the youngest zircon population.

peaked distribution. Forty-five of 69 analyses fall in a range between ∼750 and ∼850 Ma, with two peaks at ∼780 and ∼810 Ma, coincident with the two major activities of regional magmatism (e.g., Li et al. 2003*a*, 2003*c*). Six analyses yielded $^{206}Pb/^{238}U$ ages between ∼850 and ∼915 Ma, with the older and younger ones being comparable with the timing of the Sibaoan synorogenic plutonism (e.g., Li et al. 2006; Ye et al. 2007) and the postorogenic igneous rocks (Li et al. 2003*b*, 2008) in South China. The remaining 18 analyses have indistinguishable $^{206}Pb/^{238}U$ ratios within errors, yielding a weighted average of 725 ± 10 Ma (figs. 5, 6).

Discussion

The Neoproterozoic succession is conformable from preglacial to glacial intervals in a deep-water environment (Guangxi BGMR 1985; Guizhou BGMR 1987, 1997; Zhang et al. 2003*a*). However, the age of the onset of the Jiangkou glaciation is alternatively estimated at 740 ± 16 (Compston 1982; Liu et al. 1991), 758 ± 23 (Yin et al. 2003), or 800 ± 10 Ma (Hunan BGMR 1997).

These estimated ages for the onset of the Jiangkou glaciation depended mainly on the ages of the Liantuo Formation. Wang et al. (1981), Liao (1981), and Guizhou BGMR (1997) considered the Liantuo Formation to be correlated with the record of the interglacial stage between the Nantuo and the Chang'an glaciations. Lu et al. (1985) proposed that the shallow-water Liantuo Formation correlates with the deep-water glacial Chang'an Formation. Liu et al. (1980, 1991), however, suggest that the Liantuo Formation is preglacial and correlates with the Banxi Group.

Four classification and correlation models are shown in figure 1. Each model is illustrated by two sections: one from Yichang in Hubei Province represents the shallow-water succession, and one from the northern Guangxi Region signifies deep-water deposition. It is obvious that the four models comprise two groups. One includes the models in figure 1*A* (Xue et al. 2001) and 1*C* (Peng et al. 2004), where the Liantuo Formation (in bold italics) is considered to be the record of an interglacial episode, whereas the models in figure 1*B* (Wang and Li 2003) and 1*D* (Zhang and Chu 2006) form another group in which the Liantuo Formation is considered to be a preglacial unit.

The Liantuo Formation was one of the well-dated units in the Yangtze platform before 1990. One SHRIMP zircon age from a tuff bed about 40 m from the base is 748 ± 12 Ma (Ma et al. 1984), and another SHRIMP zircon age from its middle-upper part is 740 ± 16 Ma (Compston 1982). Either of these two ages was considered to be the age of the interglacial by the models in figure 1*A* and 1*C*. However, the age of 748 ± 12 Ma in the models in figure 1*B* and 1*D* was speculated to be the maximum age constraint for the onset of the Neoproterozoic glaciation.

Zheng (2003) recalculated the age of the Liantuo Formation by using the original data of the 748 ± 12 Ma age (Ma et al. 1984) and by following the approach of Compston et al. (2002) for identification of inherited zircons in volcanic rocks. Zheng (2003) argued that the recalculated isochron age of 766 ± 18 Ma is probably more representative of the unit. There is a similar age of 765 ± 14 Ma (Zhou et al. 2007) from the middle Danzhou Group (fig. 3*B*); therefore, it is reasonable to correlate the Liantuo Formation with the middle of the Banxi Group.

The age of the onset of the Neoproterozoic glaciations in the Yangtze platform is not directly available from materials around the boundary between the Chang'an Formation and the Banxi/Danzhou Group (figs. 1, 3*B*), and it was usually estimated to be ∼750 Ma, according to the age of the Liantuo Formation (Xue et al. 2001; Yin et al. 2003; Zheng 2003). Accordingly, the Jiangkou glaciation is possibly coeval with the Kaigas glaciation in Namibia. However, the age of 725 ± 10 Ma from sample 0509 provides a new maximum constraint on the age of the onset of the Jiangkou glaciation (fig. 3).

Apparently, the age of 725 ± 10 Ma provides an additional criterion for the correlation of the

Liantuo Formation. The age of 725 ± 10 Ma for the top of the Banxi Group supports the correlation of the Liantuo Formation with the Banxi Group, as suggested by Wang and Li (2003), Zhang et al. (2003*a*), and Zhang and Chu (2006; see fig. 1*B*, 1*D*), rather than with the Jiangkou Group, the Fulu Formation, or the Chang'an Formation (fig. 1*A*, 1*C*).

Conclusions

The SHRIMP U-Pb age of 725 ± 10 Ma for the youngest zircon population of sample 0509 provides a maximum age constraint on the onset of the Jiangkou glaciation (Sturtian) in the Yangtze platform. The top surface of the Banxi Group should be younger than 725 ± 10 Ma, and the Liantuo Formation in the Yangtze Gorges area probably correlates with the middle part of the Banxi/Danzhou Group. Accordingly, the Jiangkou glaciation is probably coeval with the Sturtian glaciation rather than the Kaigas glaciation.

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