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GR Letter

New evidence for ~4.45 Ga terrestrial crust from zircon xenocrysts in Ordovician ignimbrite in the North Qinling Orogenic Belt, China

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ABSTRACT

Evidence for the earliest known terrestrial crust comes predominantly from Jack Hills in Western Australia, where hafnium isotopic results from >3.8 Ga detrital zircons indicate crustal precursors as old as ~4.4–4.5 Ga. We present evidence from magmatic cores in >3.9 Ga xenocrystic zircons from a felsic volcanic rock in the North Qinling Orogenic Belt, China, of similar Hf crustal model ages up to 4.45 Ga. These lie on the same Lu/Hf trajectory as the least disturbed Jack Hills and Apollo 14 zircons, therefore providing only the second example of the earliest known generation of continental crust on Earth. In addition, the rims of two zircon grains record later growth at 3.7 Ga and, when combined with the fact that the grains are incorporated in Paleozoic volcanic rocks, imply long-lived crustal residence within the basement of the North China Craton. These results therefore establish the wider distribution and survival of the most ancient crustal material on the Earth and highlight the possibility for the further discovery of ancient crustal remnants.

1. Introduction

Fragmentary evidence about the nature of the Earth's earliest crust has come from a small suite of >4.0 Ga detrital or xenocrystic zircons, mostly preserved in the Mt Narryer and Jack Hills belts and adjacent granitoids in the Narryer Terrane of Western Australia [see historical summary in Wilde and Spaggiari (2007) and summary of more recent work in Harrison et al. (2008), Harrison (2009) and Kemp et al. (2010)]. These Hadean zircons serve as a bridge to explore an important chapter of early Earth history, representing the time between the formation of the Earth and the preservation of the oldest known rocks. Hadean zircon occurrences are extremely rare elsewhere, although they have been reported from three other areas; the Southern Cross belt in Western Australia (Wyche et al., 2004), the Acasta gneiss complex in the Northwest Territories of Canada (Iizuka et al., 2006, 2009) and from China, both in Tibet (Duo et al., 2007) and at Qinling along the southern margin of the North China Craton (Wang et al., 2007; Diwu et al., 2010).

The large number of >4.0 Ga zircons found in the Narryer Terrane, including one with a concordant $^{207}Pb/^{206}Pb$ age of 4404±8 Ma (Wilde et al., 2001), has meant that most attention has focused on this region. Although the other occurrences tend to contain just isolated grains, they nonetheless provide an important indication of the widespread preservation of zircon from the period of Earth history before the extant rock record, limited by the 4.03 Ga components of the Acasta gneiss complex (Bowring and Williams, 1999).

The two Hadean zircons reported from China include a 4.1 Ga grain from the Burang area of Tibet (Duo et al., 2007), located in a greenschist-facies quartz schist of the Neoproterozoic Qiumgongba Group, and another ~4.1 Ga grain identified in the North Qinling Orogenic Belt (Wang et al., 2007; Diwu et al., 2010). The latter discovery occurs in the major Phanerozoic collisional belt (Fig. 1) developed between the North and South China cratons, with the zircon extracted from Ordovician arc volcanic rocks of the Caotangou Group. These rocks were dated at 456±2 Ma (Wang et al., 2007) and ascended though the North China Craton basement, where the zircon xenocryst was incorporated either from the source region or during magma ascent. As such, it is the first report of Hadean crustal material in a Phanerozoic igneous rock.

2. Geological setting and sample selection

The WNW-ESE trending Qinling Orogen (Li and Sun, 1999; Zhu et al., 2011) is located in Central China and extends along strike for nearly 2500 km (Fig. 1A). It is subdivided into the North and South Qinling Orogenic Belts (Fig. 1B), separated by the Shangnan–Danfeng suture zone. The North Qinling Orogenic Belt marked the southern margin of the North China Craton in the early Paleozoic, whereas the South Qinling Orogenic Belt was the passive continental margin of the Yangtze Craton prior to collision of the terranes in the early

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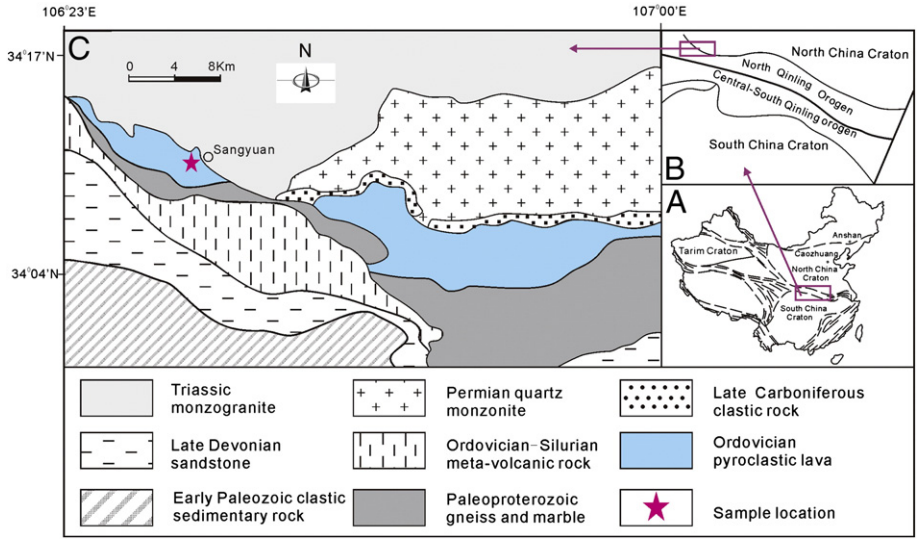

Fig. 1. (A) Location of the broad study area within China; (B) More precise location of the study area within the North Qinling Orogenic Belt; (C) Simplified geological map of the Sangyuan area in the western North Qinling Orogenic Belt, Central China.
modified from Wang et al., 2007

Mesozoic (Zhang et al., 1996; Dong et al., 2011; Zhai and Santosh, 2011).

The original Hadean zircon was extracted from an ignimbrite (welded tuff) belonging to the Ordovician Caotangou Group, which is a low grade greenschist-facies terrigeneous clastic-volcanic association (Diwu et al., 2010). The ignimbrite is exposed along the east bank of a small stream near Sangyuan, in Liangdang County, Gansu Province [GPS: Lat. 34°09′06.7″; Long. 106°31′12.0″] (Fig. 1C). The host is gray–green in color, with a massive structure and eutaxitic texture (Fig. 2A). Lithic fragments and fiamme are flattened and weakly elongated parallel to bedding. Crystal fragments mainly consist of feldspar and quartz, set in a felsophyric matrix with a microcrystalline texture that shows extensive alteration to sericite and chlorite (Diwu et al., 2010) (Fig. 2B).

In re-examining this occurrence, a suite of more than 3000 zircon grains was extracted from a new sample of ignimbrite, collected from the same outcrop where the >4 Ga grain was obtained (Diwu et al., 2010), and these were initially analyzed for U–Pb age using LA-ICP-MS techniques. From this large suite of zircons, two new grains were identified (denoted here as B and C) with ages ≥3.9 Ga. In addition, the original grain of Wang et al. (2007) (denoted here as Grain A) was re-analyzed for U–Pb age by SHRIMP, and this confirmed the original result. These new U–Pb data were originally published in Chinese (Diwu et al., 2010), but are included here (Table 1) so they are more widely available and in order that the new Lu–Hf and O data presented here can be placed in a precise temporal context.

3. Analytical methods

Both LA-ICP-MS U–Pb and trace element analysis of zircon were carried out using an Agilent 7500a ICP-MS connected to a Geolas-193 UV laser ablation system at the State Key Laboratory of Continental Dynamics, Northwest University in Xi'an. A 20 μm spot diameter was utilized in this study with a laser repetition rate of 6 Hz. The analytical procedures are described in Liu et al. (2007).

The U–Pb SHRIMP II analyses were undertaken at the Beijing SHRIMP Center, Chinese Academy of Geological Sciences, following standard operating procedures (Williams, 1998), with a mass resolution of ~5000 (1% definition). The intensity of the primary O^{-2} ion beam was 6 nA. Spot sizes ranged from 25 to 30 μm, and each site was rastered for 150 s prior to analysis to remove contamination from the gold coating. Five scans through the mass stations were made for each age determination. Standards used were SL13, with an age of 572 Ma and U content of 238 ppm (Williams, 1998), and TEM, with an age of 417 Ma (Black et al., 2004). The ratio of TEM standard analyses to unknown sample analyses was 1:3. Decay constants used for age calculation were those recommended by the Subcommission on Geochronology of the IUGS (Steiger and Jager, 1977). The measured value

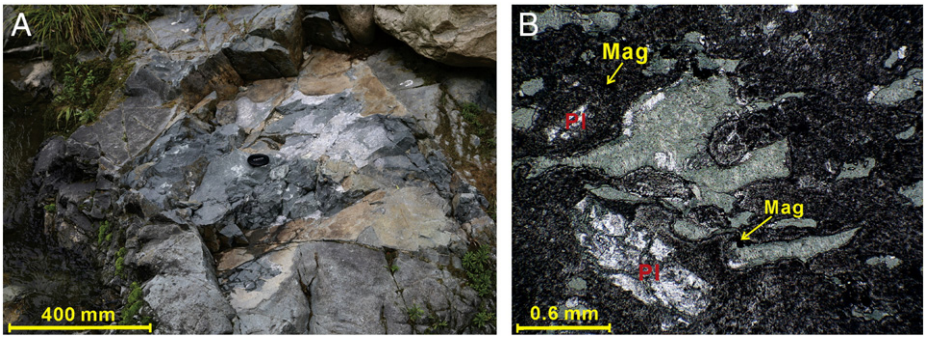

Fig. 2. Photographs showing the pyroclastic host rock to the ancient zircon xenocrysts. (A) Field photograph of sample site on the southern side of the stream in the Sangyuan area of the western North Qinling Orogenic Belt, Central China. The lens cap is 60 mm in diameter; (B) Thin section showing altered glass fiamme in recrystallized matrix dominated by sericite alteration. A feldspar phenocryst is present in lower left of image. The scale is 0.2 mm in length. Pl = plagioclase, Mag = magnetite.