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RAPID COMMUNICATION

# The fingerprint of Precambrian basement in the Chinese Central Tianshan: evidence from inherited/xenocrystic zircons of magmatic rocks

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**Abstract**

The Central Asian Orogenic Belt is an accretionary orogen with many distinct terranes including the Chinese Central Tianshan, whose Precambrian tectonic affinity is not yet clearly known. We present Precambrian age spectra of inherited/xenocrystic zircons from magmatic rocks in the Chinese Central Tianshan, collected from published papers. The age patterns are dominated by zircons with ages ranging from 3261 to 541 Ma. These spectra provide robust clues regarding the Precambrian affinity of the Chinese Central Tianshan. The age spectra record two major tectonothermal events, represented by salient age peaks of *c*. 950 and 900 Ma within the 'Grenville Orogeny' period, and age peaks at *c*. 750 and 630 Ma, synchronous with magmatic events corresponding to Rodinia break-up. These results are consistent with the hypothesis that the Chinese Central Tianshan was part of the Tarim craton during Precambrian time as well as documenting its incorporation into, and separation from the Rodinia landmass.

Keywords: inherited zircon, Precambrian, Chinese Central Tianshan, Tarim, Rodinia.

## 1. Introduction

The fish-shaped Chinese Central Tianshan (CCT) is a component of the Central Asian Orogenic Belt (CAOB). Located on the southernmost margin of the CAOB, the CCT is bounded to the north by the Bingdaban–Weiya shear zone and to the south by the Baluntai fault, consisting of a wide western domain and a narrow eastern domain.

Located in NW China (Fig. 1a), the Tarim Block is composed of three major Precambrian uplifts including the Tieklik, the Altyn Tagh (or Dunhuang) and the Kuruqtagh blocks (Lu *et al*. 2008). Taking the Kuruqtagh uplift as an example, the Precambrian basement rocks within the Tarim Block are widely exposed and well studied. From the oldest to the youngest, distinct geological units composing the Tarim Block include: the Neoarchaean Tuoge Complex (tonalite–trondhjemite–granodiorite (TTG) suites); the Palaeoproterozoic Xingditage Group (paragneisses); the Mesoproterozoic Aierjigan Group (metasedimentary rocks); and the Neoproterozoic Kuruqtagh Group (volcanic rocks and tillites; Ge *et al*. 2013). Precambrian plutonic rocks are ubiquitous in the Tarim Block (e.g. Zhu *et al*. 2008; Shu *et al*. 2011; Long *et al*. 2012).

According to palaeogeographic and geological evidence, the CCT (Fig. 1b) was argued to be part of Tarim Block during the Precambrian era (Charvet, Shu & Laurent-Charvet, 2007). Evidence cited to support this connection includes the fact that they both contain similar types of Precambrian crustal rocks, metamorphic grades and magmatic events (Ma *et al*. 2013). If the CCT is a rifted part of the original Tarim Block, then it is possible that at least some of the Precambrian basement 'fingerprint' should match that of the Tarim Block. The Precambrian evolutionary history of the CCT is poorly known owing to limited geochronological and geological data from magmatic rocks.

The few Precambrian ages known from magmatic rocks in the CCT include a 1832 ± 48 Ma (upper intercept zircon U–Pb) age from granodiorite in the Kawabulake region (Xiu, Yu & Li, 2002), a 1218 ± 17 Ma (upper intercept zircon U–Pb) age on the Weiya granitic gneiss (Liu *et al*. 2004), a *c*. 1.4 Ga U–Pb age (weighted mean) on the Xingxingxia granitic gneiss (Hu *et al*. 2006), a 926 ± 8 Ma (zircon SHRIMP U–Pb weighted mean) age on the Bingdaban granitic gneiss (Chen *et al*. 2009), a *c*. 630 Ma age from a granitic gneiss in the Baluntai area (Chen *et al*. 2012), *c*. 942 Ma gneissic granites in the Kawabulake region (Peng *et al*. 2012), a 740 Ma A-type granite in the Hongliujing region (Lei *et al*. 2013), 945 ± 6 and 942 ± 6 Ma granitic gneisses in the Alatage region (Huang *et al*. 2014), and *c*. 880 Ma orthogneiss in the Xingxingxia region (He *et al*. 2014). These limited data attest to the sporadic and unsystematic nature of Precambrian geological studies in the CCT. Moreover, no Neoarchaean TTG suites, Palaeo-Mesoproterozoic intrusions or Neoproterozoic mafic dyke swarms such as those present in the Tarim Block were identified within the CCT. The focus of this study is to remedy the poor areal and temporal coverage of ages within the CCT.

Magmatic rocks provide crucial information for understanding the evolutionary processes of continental crust and the provenance of crustal material. In particular, granitoid rocks are fundamental targets for studying the histories of continental blocks and fragments (Frost *et al*. 2001). In addition, mafic intrusions or their eruptive products provide geochemical and isotopic clues that aid in understanding the

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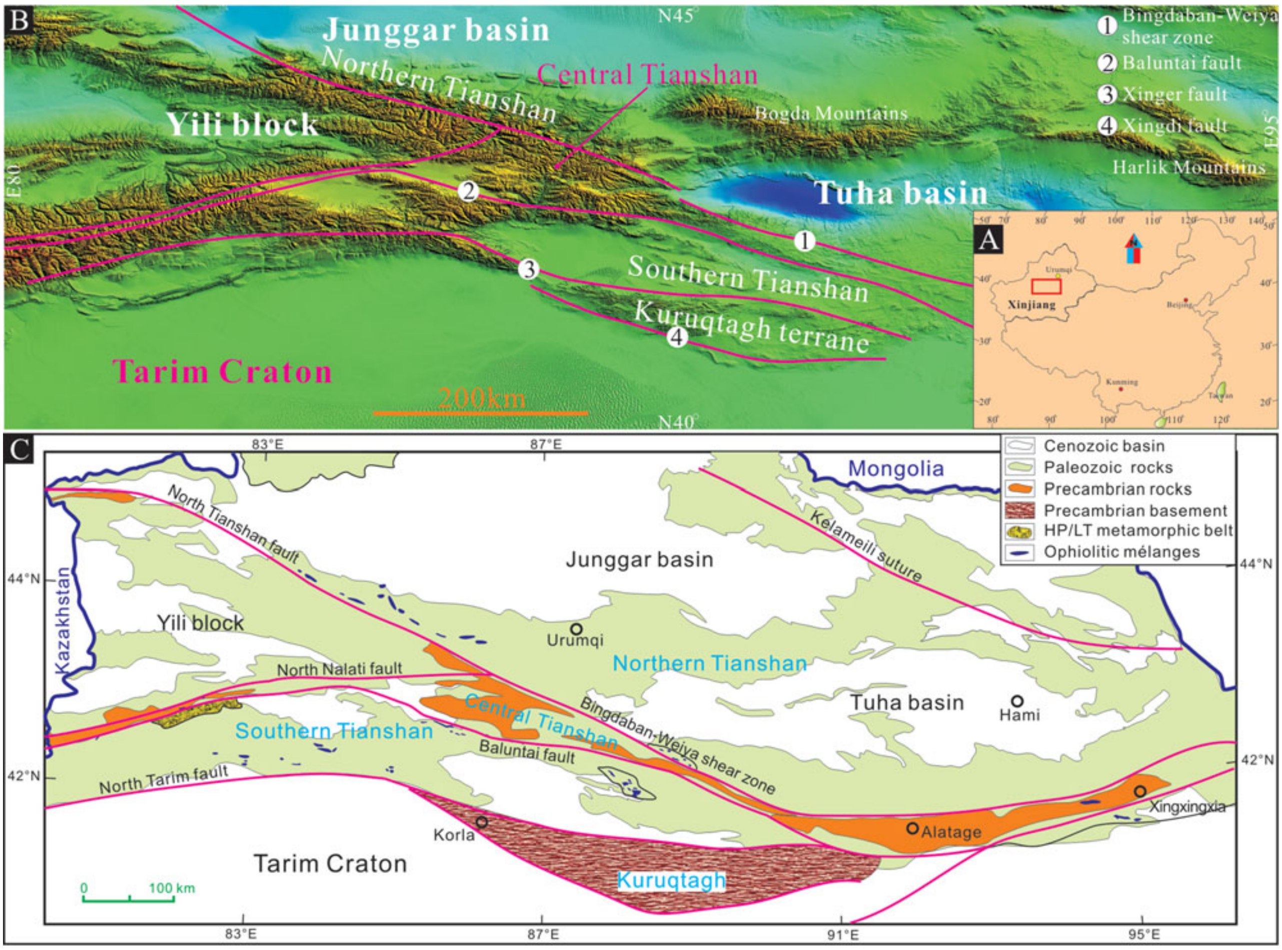


Figure 1. (Colour online) (a) The studied location in Xinjiang, NW China. (b) Simplified tectonic outline of the Chinese Tianshan. (c) Simplified geological map for the Chinese Central Tianshan and its adjoining area (modified from He *et al.* 2014).

tectonic setting and nature of deeply buried basement. This is owing to the fact that they bring fragments of the underlying material to the surface during their ascent. As a refractory mineral, zircon has a high U–Pb closure temperature (> 800 °C) and is resistant to subsequent destruction such as possible re-melting, metamorphism and chemical diffusion. Owing to its chemical and physical durability, zircon is used in a wide range of geological investigations including the evolutionary history of the Earth's crust (Finch & Hanchar, 2003). Unlike zircons in sedimentary rocks, whose provenances are uncertain, the provenances of inherited/xenocrystic zircons from magmatic rocks are local and originated within the crust, in particular, those captured by mafic rocks originated from very deep sources. From this perspective, the inherited/xenocrystic zircons of magmatic rocks play an important role in documenting the geological history of the studied region (de la Rosa, Jenner & Castro, 2002; Smyth *et al*. 2007).

Voluminous inherited/xenocrystic zircon age data of magmatic rocks in the CCT and its surrounding areas were collected from published literature. In this paper, we present a synthesis of these zircon age data and discuss their implications and the affinity of the CCT with the Tarim Block and the Rodinia supercontinent.

## 2. Geological setting

Located in Xinjiang province (NW China), the Chinese Tianshan is one of the major Phanerozoic accretionary orogens in central Asia (Allen, Windley & Zhang, 1993), bounded by the Junggar basin to the north and the Tarim Block to the south. As the southernmost margin of the CAOB, the Chinese Tianshan was formed through a protracted series of collisional tectonics, including the subduction of oceanic crust and the accretion of microcontinents (Charvet, Shu & Laurent-Charvet, 2007). Consequently, nearly all the smaller oceanic basins from the Chinese Tianshan region of central Asia were destroyed in Late Carboniferous – Early Permian times during the final closure of the Palaeo-Asian Ocean (Allen, Windley & Zhang, 1993; Windley *et al*. 2007). Geographically, the Chinese Tianshan belt can be subdivided into the Chinese Western and Eastern Tianshan sub-regions along the Urumqi–Korla line. Geographic and tectonic differences further define the Chinese Eastern Tianshan into Northern, Central and Southern Tianshan belts. These belts are separated from one another by two Palaeozoic faults (northern Bingdaban–Weiya shear zone and southern Baluntai fault; Charvet, Shu & Laurent-Charvet, 2007).

In the CCT, the Precambrian basement rocks are mainly exposed in the Baluntai, Sangshuyuanzi, Alatage, Kawabulake, Jianshanzi, Xingxingxia and Weiya areas (Fig. 1c), consisting of the Xingxingxia, Kawabulake and Tianhu groups (Hu *et al.* 1986; Gao *et al.* 1993). The Palaeo- to Mesoproterozoic aged (~ 1900–1400 Ma) Xingxingxia Group is composed of gneisses, schists, migmatites and marbles, and metamorphosed under lower amphibolite- to granulite-facies conditions (Hu *et al.* 1986). The upper Mesoproterozoic Kawabulake Group, which is mainly scattered in the Kawabulake and Alatage regions, comprises low-grade metamorphic

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granitic gneisses, schists, carbonatites and minor terrestrial and tuffaceous clastic rocks (Gao *et al.* 1993; Xiu, Yu & Li, 2002). The 1000–660 Ma Tianhu Group is mainly exposed between the Tianhu and Xingxingxia areas and is dominated by medium-grade metamorphic volcanic rocks, clastic rocks and carbonatites (Hu *et al.* 1986; He *et al.* 2014).

The geological history and tectonic affinity of the CCT are contested. Among the models are those which postulate that the CCT is a late Palaeozoic volcanic arc (Chen *et al.* 1999); a piece of Palaeoproterozoic (2.0–1.8 Ga) mantle-derived accreted crust (Hu *et al.* 2000); a discrete block (Liu *et al.* 2004 and references therein); formed by arc accretionary processes of Baltica (He *et al.* 2014); a rifted part of the Tarim Block before the Cambrian (Shu, Charvet & Ma, 1998; Charvet, Shu & Laurent-Charvet, 2007).

We test the model that posits that the CCT was an integral part of the Tarim Block during Precambrian time. It is argued that southward subduction of the Palaeo-Asian Ocean beneath the Tarim Block during Cambrian time led to the separation of the CCT from the Tarim Block (Wang *et al.* 2011). In this complicated process, the CCT volcanic arc and Southern Tianshan Ocean were formed owing to subduction (and back-arc spreading) within the Tarim Block. During this process, voluminous subduction-related intrusions and eruptions were emplaced in the CCT region. These magmatic products are widely distributed in the CCT, and can be roughly divided into two temporal bins (early and late Palaeozoic; Liu *et al.* 2004). The early Palaeozoic magmatism was related to the subduction of the Palaeo-Asian Ocean, whilst the late Palaeozoic magmatism was likely related to the collisional, accretionary or post-collisional events after the closure of the Palaeo-Asian Ocean.

## 3. Analytical methods and results

The study of detrital zircons is widely employed to investigate crustal evolutionary history, crustal growth and magmatic events (e.g. Condie *et al.* 2009; Belousova *et al.* 2010; Rojas-Agramonte *et al.* 2011; Kröner *et al.* 2011); however, there are some defects inherent in traditional detrital zircon studies. Firstly, the specific provenance of the detrital zircons is difficult to uniquely determine. Secondly, we note that detrital zircons sampled from sedimentary rocks may be reworked/recycled many times. Finally, peaks in age spectra may reflect differences in the preservation potential of sedimentary rocks rather than crustal generation (Moecher & Samson, 2006; Andersen, 2014).

In this paper, we use only age spectra derived from inherited or xenocrystic zircons from magmatic rocks. By focusing on inherited/xenocrystic zircons from magmatic rocks we hope to eliminate some of the uncertainties inherent in traditional detrital zircon studies. Inherited/xenocrystic zircons are captured by magma during its ascent through the crust. All the studied plutons are autochthonous to the CCT and thus provide a reliable sampling of the local basement, which allows a direct comparison of the CCT basement with other terranes and continents (see Hargrove *et al.* 2006; Smyth *et al.* 2007).

$^{207}$Pb–$^{235}$U and $^{207}$Pb–$^{206}$Pb ages in younger zircons have lower precision than $^{206}$Pb–$^{238}$U ages owing to low abundance of $^{235}$U and much less $^{207}$Pb in the U–Pb isotopic system. So, in general $^{206}$Pb–$^{238}$U age is adopted for zircons $< 1000$ Ma. Nevertheless, the $^{206}$Pb–$^{238}$U age generally underestimates the actual age owing to Pb loss for discordant zircons, whilst the $^{207}$Pb–$^{206}$Pb age is much closer to the primary crystallization age. Therefore, the $^{207}$Pb–$^{206}$Pb age is used for zircons older than 1000 Ma (Ireland *et al.* 1998). If only one age ($^{207}$Pb–$^{206}$Pb or $^{207}$Pb–$^{235}$U or $^{206}$Pb–$^{238}$U) was reported, we used that age without regard to the cutoff limits stated above.

We have collected inherited/xenocrystic zircons ages (380 grains from 55 published papers and our unpublished analysis) from magmatic rocks to produce age spectra (Figs 2, 3). The zircon U–Pb data show a wide age range of 3261–542 Ma (compiled data are shown in the online Supplementary Material available at http://journals.cambridge.org/geo) and reveal multiple source ages for basement rocks within the CCT. We note three distinct age populations: Palaeoarchaean–Mesoproterozoic (3261–1000 Ma), early Neoproterozoic (1000–900 Ma) and middle Neoproterozoic (750–630 Ma). In the oldest age population of 3261–1000 Ma, there is no pronounced age peak, owing to the low relative probability compared with younger zircons. The two younger age populations of 1000–900 Ma and 750–630 Ma show conspicuous age peaks of *c.* 950, 900, 750 (with two subordinate age peaks of 815 and 710 Ma) and 630 Ma (with a subordinate age peak of 550 Ma; Figs 2, 3).

## 4. Discussion and conclusions

Although detrital zircon studies provide important clues regarding provenance, the results can be non-unique. Inherited/xenocrystic zircons provide a better insight into the nature of the basement rocks through which the magmatic products ascended.

Of the 380 grains utilized in our study, approximately 30 % (108 zircons) of the analyses were derived from mafic rocks (basalt, diabase, gabbro and mafic granulite). These rocks likely sampled the deeper regions of the crust and/or mantle beneath the CCT. A smaller number of analyses (13 grains) were taken from Neoproterozoic and Mesoproterozoic plutons that tapped the older basement rocks in the region. A total of 179 analyses were taken from granitoid rocks that intruded crystalline basement within the CCT rather than Phanerozoic sedimentary rocks. Source region determinations for the remaining 80 grains were problematic, but the authors of the papers argued that all were derived from basement materials within the CCT.

The age distribution spectra in this study reveal some fundamental characteristics. Figure 2 shows a broad range of Precambrian ages from Palaeoarchaean (3261 Ma) to late Neoproterozoic (∼ 542 Ma). Within that spread, we identify two pronounced early Neoproterozoic age peaks at *c.* 950 and 900 Ma along with two conspicuous middle Neoproterozoic age peaks at *c.* 750 and 630 Ma.

This large population of Precambrian zircons is striking given the limited exposure of Early Precambrian rocks in the CCT (XBGMR 1992; Liu *et al.* 2004; Lei *et al.* 2013). The data suggest that there is a reservoir of Precambrian crust beneath the CCT.

Within the CCT (Fig. 1c), Hu *et al.* (1986) and Gao *et al.* (1993) have identified the Precambrian basement to be comprised of the Xingxingxia, Kawabulake and Tianhu groups, with formation ages of Palaeo- to Mesoproterozoic, late Mesoproterozoic and Neoproterozoic, respectively. Gao *et al.* (1993) argued that these three groups in the CCT are comparable to the Yangjibulake, Aierjigan and Paergang groups in the Kuruqtagh region of the NE Tarim Block on the basis of similar rock assemblages, metamorphism and structural features. Protoliths of the metamorphic rocks of the Xingxingxia Group (CCT) and Yangjibulake Group (NE Tarim Block) consist of flysch and volcanic rocks. The Kawabulake Group (CCT) is composed of marble and dolomite, as is the Aierjigan Group (NE Tarim Block). Although less diagnostic, it is interesting to note that both marbles contain *Colonnella* and *Conophyton* stromatolite fossils.

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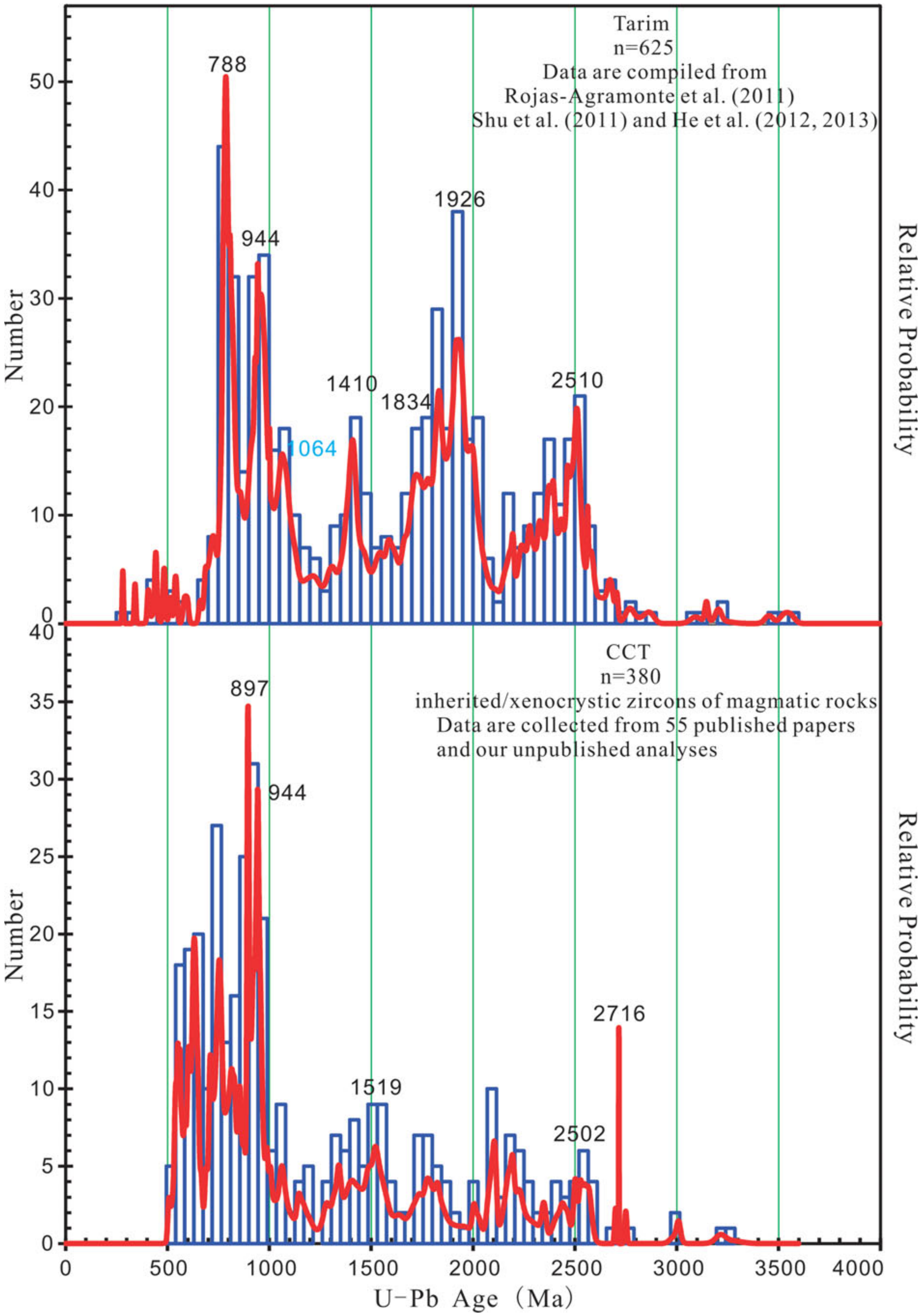


Figure 2. (Colour online) Relative U–Pb age probability for the zircons collected from the literature and a comparison with data from the Tarim Block.

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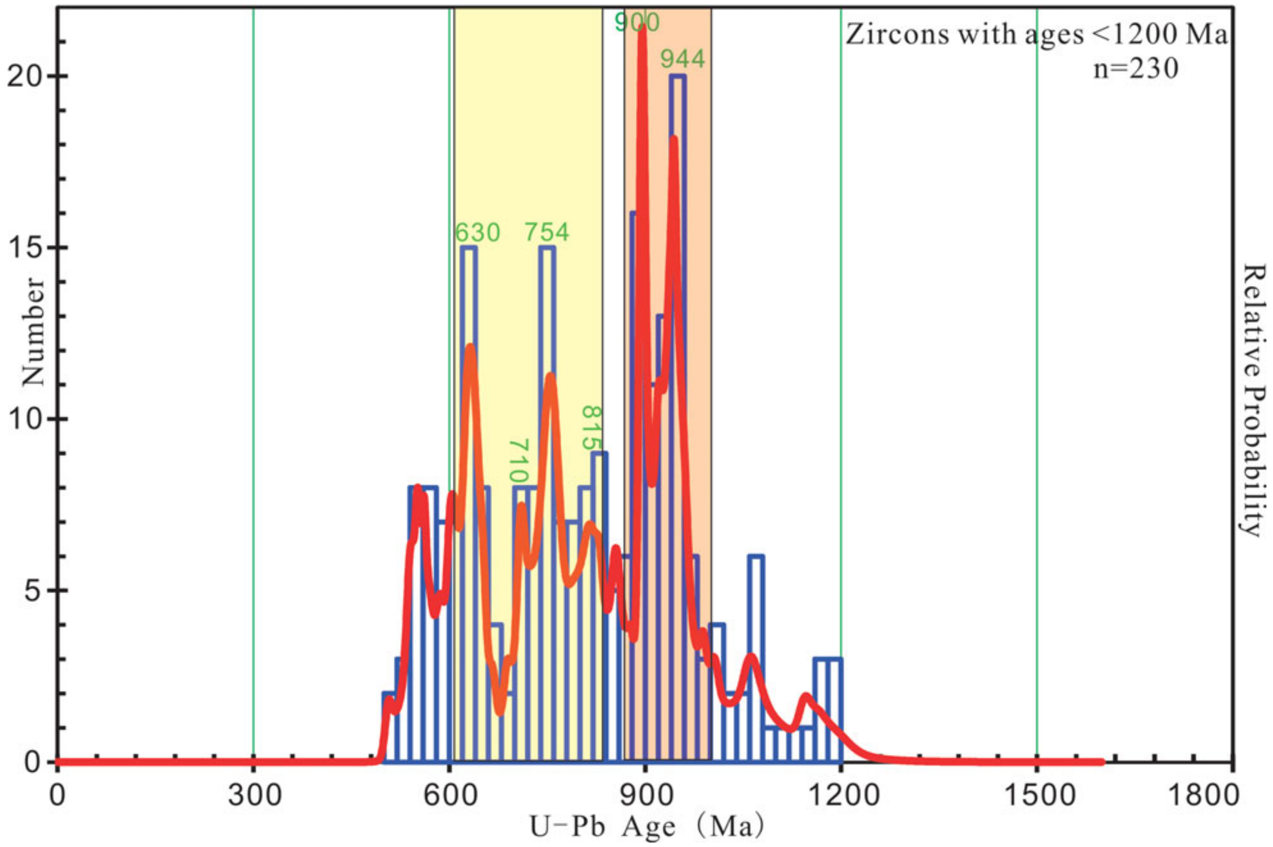


Figure 3. (Colour online) Age spectra for zircons with ages < 1200 Ma.

This correlation between the NE Tarim Block and the CCT is further supported by the age spectra depicted in Figure 2 (Shu, Charvet & Ma, 1998; Charvet, Shu & Laurent-Charvet, 2007; Wang *et al*. 2011; Ma *et al*. 2013; Rojas-Agramonte *et al.* 2011; Shu *et al.* 2011; He *et al.* 2012, 2013). The combination of geological evidence and zircon age comparisons provides support for the conclusion that the CCT was originally part of the Tarim craton.

The late Mesoproterozoic–Neoproterozoic Rodinia supercontinent is thought to comprise most of the extant cratonic regions of the globe that coalesced during the 1300–900 Ma interval (Dalziel, 1991; Moores, 1991; Meert & Torsvik, 2003; Ernst, Buchan & Campbell, 2005; Li *et al*. 2008; Meert, Pandit & Kamenov, 2013; Meert, 2014). Based on geochronological and Nd isotopic data, Liu *et al*. (2004) and Li *et al*. (2007) suggested that some granitoid gneisses in the eastern segment of the Central Tianshan terrane were formed in a late Mesoproterozoic continental margin arc setting, associated with the assembly of the Rodinia supercontinent. In this respect, it is hypothesized that the Neoproterozoic age peaks in our CCT spectra (950 and 900 Ma) may indicate that the CCT (and the Tarim Block) belonged to Rodinia during the latter phases of supercontinent assembly (Shu *et al*. 2011).

Additional evidence for 'Rodinia-age' magmatic and metamorphic events in the CCT can be found in the 948–926 Ma granitic gneisses found in the Laerdundaban and Bingdaban regions (Chen *et al.* 2009), and in the *c.* 942 Ma gneissic granites in the Xingxingxia and Kawabulake regions (Hu *et al.* 2010; Peng *et al.* 2012). In addition, Hu *et al.* (2006) contended that a 1.4 Ga granodioritic gneiss in the Xingxingxia region was affected by 1.1–0.9 Ga metamorphism. These Grenvillian ages between 1.0 and 0.8 Ga are very similar to those observed in the Tarim craton (Xu, Z. Q. *et al.* 2013 and references therein). Ge *et al.* (2014) considered that the metamorphic events in the Tarim Block are the result of accretionary orogenesis that peaked around 950 Ma. We argue that the similarities between the CCT and the Tarim Block constitute a 'proto-Tarim' craton involved in the assembly of Rodinia.

Li *et al*. (2008) argued that shortly after the Rodinia supercontinent formation, a series of mantle avalanche events triggered superplume activity beneath Rodinia. Evidence for this superplume activity includes the occurrence of (1) a global sedimentary hiatus resulting from superplume-induced crustal unroofing, (2) continental rifting, (3) intracontinental mafic/ultramafic intrusions, (4) bimodal intrusions or volcanic rocks (Paulsson & Andreasson, 2002), (5) mafic dyke swarms (Zhu *et al*. 2008) and (6) felsic intrusions due to crustal melt and/or magma differentiation (Li *et al*. 2008). The 900–850 Ma bimodal rift magmatism in Taimyr, Scandinavia and Scotland was interpreted as forming during the attempted break-up of Rodinia (Paulsson & Andreasson, 2002). However, more recent evidence on intra-continental mafic/ultramafic intrusions, mafic dyke swarms, bimodal intrusions/volcanic rocks and alkaline granites suggests that the widespread superplume event did not take place until *c.* 830 Ma, marking the onset of Rodinia break-up (Li *et al.* 2008).

Widespread Neoproterozoic ultramafic/mafic intrusions, mafic dyke swarms and bimodal volcanic rocks have been identified within the Tarim Block (Xu *et al*. 2005; Zhang *et al*. 2007; Zhu *et al*. 2008; Zhang *et al*. 2009). Based on the geochronological data from these magmatic bodies, Zhu *et al*. (2008) summarized at least three pulses of magmatism (at *c.* 830–800 Ma, *c.* 790–740 Ma and *c.* 650–630 Ma) within the Tarim Block. Coincidently, upper Neoproterozoic sediments in the NW Tarim Basin, consisting of the non-marine Sugetbrak Formation and marine Qegebulake Formation, are

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indicative of a synrift succession, in other words, late Neoproterozoic rifting (Turner, 2010). Recently, Xu, B. *et al.* (2013) reported ages on two basaltic flows with weighted mean ages of 615.2 ± 4.8 Ma and 614.4 ± 9.1 Ma in the Sugetbrak Fm. Based on these data, they suggested that igneous activity related to the break-up of the Neoproterozoic Rodinia supercontinent lasted until at least 614–615 Ma.

These younger magmatic (∼ 600 Ma) episodes are not found in the CCT as only *c.* 740 Ma alkaline granites are reported from the Hongliujing region within the CCT (Lei *et al.* 2013). These are considered to be a product of the Neoproterozoic break-up of Rodinia. We note that our zircon data show two pronounced middle Neoproterozoic age peaks of *c.* 750 and 630 Ma (with subordinate peaks of *c.* 810 and 710 Ma; Figs 2, 3). Coincidently, these age peaks fall into the age ranges of *c.* 830–800 Ma, 790–740 Ma and 650–630 Ma. These intriguing results are consistent with our interpretation that the CCT also documents the break-up of Rodinia, as suggested by Lei *et al.* (2013).

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### Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S0016756814000314

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