Journal of Asian Earth Sciences 108 (2015) 150–169

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Tracking deep crust by zircon xenocrysts within igneous rocks from the northern Alxa, China: Constraints on the southern boundary of the Central Asian Orogenic Belt

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ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form 7 April 2015
Accepted 15 April 2015
Available online 22 April 2015

Keywords:
Hf-in-zircon isotope
Zircon xenocrysts
Igneous
Alxa block
CAOB
North China Craton

ABSTRACT

The southern boundary of the central segment of the Central Asian Orogenic Belt (CAOB) with the Precambrian Alxa Block is not well constrained due to poor recognition of deep crust. Statistical analysis of zircon xenocrysts within igneous rocks from the northern Alxa and its adjacent regions was applied to resolve this problem. We compiled new and previously published geochronological zircon age data obtained by SHRIMP, SIMS, TIMS, and LA-ICP-MS for 316 igneous rock samples of which 61 samples contain zircon xenocrysts. New and previously published Hf isotopic compositions of these zircon xenocrysts are combined with zircon ages in this study. The zircon xenocrysts are mainly contained within Permian rocks from the Yabulai–Nurgong–Honggueryulin (YNH) zone and igneous rocks from the northwestern margin of the North China Craton (WNCC). A few xenocrysts were also found in Permian igneous rocks from the Zongnaishan–Shalazhashan (ZS) zone, Neo-proterozoic and Paleo-proterozoic intrusive rocks in the YNH zone, as well as Devonian to Carboniferous granitoids and volcanic rocks from southern Mongolia. Altogether we analyzed more than 270 zircon xenocrysts and considered only ages that are less than 10% discordant. Xenocryst ages within the Permian igneous rocks from the ZS zone are mainly around ca. 350 Ma, ca. 600 Ma and ca. 1400 Ma. The oldest age of zircon xenocrysts in this zone is similar to those of zircon xenocrysts from the CAOB (~1.1 Ga). By contrast, abundant zircon xenocrysts within Permian igneous rocks from the YNH zone show highly variable age populations at ca. 2.6–2.1 Ga, 1.8–1.6 Ga, 930–750 Ma and 460–300 Ma. Zircon xenocrysts from the ZS zone have positive $\varepsilon_{Hf}(t)$ values of +6.3 to +13.9, whereas those from the YNH zone display highly variable $\varepsilon_{Hf}(t)$ values from −16.1 to +11.6. From the southern CAOB and the ZS zone to the YNH zone, the zircon xenocrysts show a significant shift from juvenile to crustal Hf isotopic compositions, suggesting that the area between the ZS and the YNH zones constitutes the southern boundary of the CAOB in the deep crust within this region. Our study indicates that statistical analysis (or isotopic mapping) of zircon xenocrysts is an effective method to trace the nature of the deep continental crust and to separate between newly-formed orogenic domain and ancient cratons.

1. Introduction

Zircon is a common accessory mineral in many igneous rocks and has a strong resistance to mechanical and chemical breakdown over long periods of time. It can thus survives erosion and metamorphism that may have modified or destroyed its host rock (Heaman et al., 1990). Therefore, zircon preserves reliable geochemical records such as the initial isotopic magma composition at the time of crystallization, variable magmatic processes as well as source heterogeneities and/or melt contamination with mantle-derived or crustal material. It is therefore one of the most widely used minerals to date rocks and to track magma sources (e.g., Belousova et al., 2006). During the past decades, chemical and isotopic analysis of zircon has played a key role in investigating magmatic events and igneous petrogenesis (e.g., Hoskin and Schaltegger, 2003; Valley et al., 2003; Belousova et al., 2006; Liu

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http://dx.doi.org/10.1016/j.jseaes.2015.04.019
1367-9120/

et al., 2009; Castro et al., 2011; Brown, 2013) and studying the growth and/or recycling of continental crust (Wilde et al., 2001; Kemp et al., 2006; Scherer et al., 2007; Condie et al., 2009, 2011; Lissenberg et al., 2009; Siebel et al., 2009; Dhuime et al., 2012; Cawood et al., 2013; Hawkesworth et al., 2013; Buys et al., 2014; Kröner et al., 2014; Wang et al., 2014). Zircons, initially derived from source(s) or country rocks and significantly older than that of host igneous rocks, are referred to 'xenocrystic/inherited zircons', or 'zircon xenocrysts' in the literatures (Johnson, 1989; Miller et al., 2007; Zheng et al., 2011). Zircon xenocrysts have long been considered to be bothersome because they hinder the precise estimation of the emplacement age of the intrusive rocks. In most cases, they are excluded when calculating the weighted mean age without additional detailed analyses. Conversely, a growing number of studies have shown that the xenocrystic/inherited zircons record much valuable information, which can help to reveal crustal features hidden in the deep continental crust (Wright and Wyld, 1986; Evans and Zartman, 1990; Hoskin et al., 2000; Zheng et al., 2006; Liu et al., 2014) and thereby provide additional constraints on understanding crustal evolution (Hanchar and Rudnick, 1995; Siebel et al., 2009; Charlier et al., 2010; Stern et al., 2010). In some cases, the ages of zircon xenocrysts have been utilized to elucidate the nature of unexposed ancient fragments of continental lithosphere (Qiu et al., 2000; Hargrove et al., 2006; Iizuka et al., 2006; Smyth et al., 2007; Zhang et al., 2012a; Gaschnig et al., 2013; Torsvik et al., 2013; Reimink et al., 2014), and/or provide evidence of pre-existing continental crust (Siebel et al., 2009; Gao et al., 2011). In general, detailed studies of zircon xenocrysts, e.g., deep-seated xenocrysts from volcanic rocks such as lamproites (Zheng et al., 2006), kimberlite (Valley et al., 1998; Griffin et al., 2000; Nasdala et al., 2014; Ashchepkov et al., 2014) and mantle-derived magmas such as ultrapotassic rocks (Liu et al., 2014), xenoliths (Liati et al., 2004; Zheng et al., 2008; Pan et al., 2014; Tang et al., 2014), oceanic gabbros (Pilot et al., 1998) as well as granitic magmas (Smithies et al., 2001; Bea et al., 2007; Demoux et al., 2009b; Buys et al., 2014; Jeon et al., 2014) have extended our knowledge of unexposed parts of the crust through which the host magmas ascended. To better understand the significance of zircon xenocrysts in juvenile igneous rocks, Stern et al. (2010) summarized the distribution of ancient zircons in juvenile crust, and explained the occurrence of compositional dependence of igneous rocks. However, statistical analysis of the xenocryst ages and their Hf isotopic composition derived from igneous rocks has not yet been applied to reveal signatures of the deep crust.

The definition of tectonic boundaries, particularly those between orogens and cratons, is a major matter of debate, which is concerned with the tectonic evolution of a particular orogenic belt (Zhao et al., 2002; Xiao et al., 2014), and/or the geometry of the nearby craton. The Central Asian Orogenic Belt (CAOB; Jahn, 2004), or the Altaids (Sengör et al., 1993; Wilhem et al., 2012), the world's largest Phanerozoic accretionary orogenic belt, has a complex evolutionary history, represented by multi-stage subduction and juvenile crustal growth (e.g., Jahn et al., 2000; Xiao et al., 2003, 2010a; Yakubchuk, 2004; Han et al., 2011; Kröner et al., 2011; Wilhem et al., 2012; Xu et al., 2013). Despite considerable durative efforts, the southern boundary of the CAOB, particularly the boundary with the Alxa Block, is not well constrained. The Alxa Block, which occupies the major part of Alxa league of Inner Mongolia, is located to the south of the central segment of the CAOB. This block connects the Beishan fold-and-thrust belt in the west with the North China Craton (NCC) in the east (Fig. 1). In the north Alxa, there are two major ophiolite belts: the Enger Us belt in the north and the Qagan Qulu belt in the south (Li, 2006a; Wu and He, 1993; Zhang et al., 2012b). The Enger Us ophiolite belt

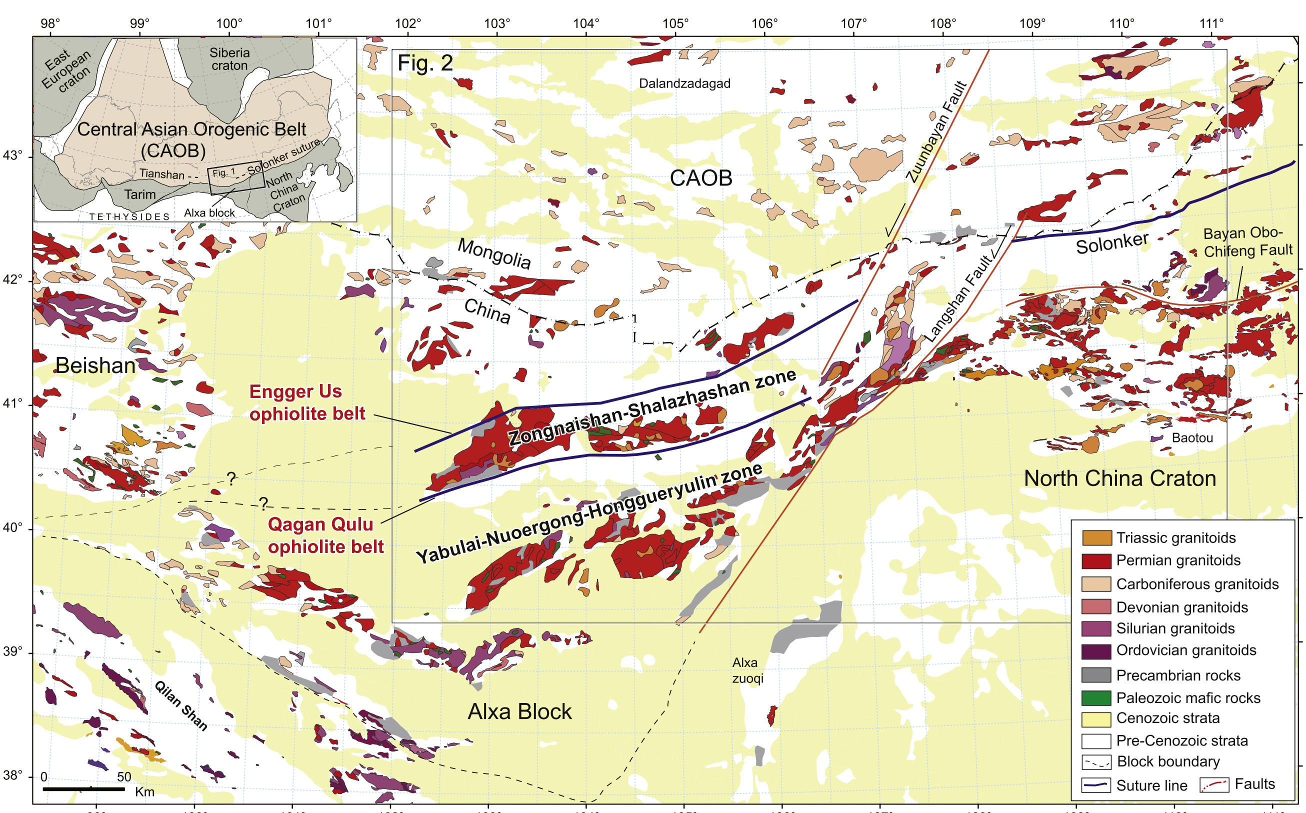

Fig. 1. Schematic geological map of the Alxa Block and surroundings showing the distribution of magmatic rocks (modified from Ren et al., 2013). Inset map shows location of the Alxa Block modified after (Sengör et al., 1993; Jahn, 2004; Wilhem et al., 2012). Main tectonic subdivisions were modified from Li (2006b). The boundary of the Alxa Block modified after (Lamb et al., 1999; Zhang et al., 2013a,b; Zhao and Zhai, 2013; Dan et al., 2014a,b).