Earth and Planetary Science Letters 468 (2017) 1–10

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Phanerozoic magmatic tempos of North China

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ARTICLE INFO

Article history:
Received 15 August 2016
Received in revised form 16 March 2017
Accepted 20 March 2017
Available online 6 April 2017
Editor: A. Yin

Keywords:
Solonker Suture
detrital zircon
Hf isotope
Central Asian Orogenic Belt
delamination
Yanshan

ABSTRACT

Detrital zircons from northeast China record cyclic magmatism along the northern and eastern margins of the North China block during late Paleozoic time and Mesozoic time, respectively. The late Paleozoic zircons record three magmatic flare-ups with a period of ~60 m.y. that occurred within a magmatic arc constructed along the Paleoasian (northern) margin of North China, and are accompanied by negative $\varepsilon_{Hf}(t)$ excursions representing shortening and increased crustal melting over the duration of each flare-up. The intervening magmatic lulls are accompanied by rapid positive $\varepsilon_{Hf}(t)$ excursions signifying influxes of juvenile magma into the arc, probably during extension and foundering of underlying melt residua. The lack of similar isotopic patterns in zircons derived from contemporaneous intrusions into older continental settings inboard of the arc indicate that this process was restricted to the arc itself. Mesozoic magmatism in North China occurred along the Paleo-Pacific margin following closure of the Paleoasian Ocean, and exhibits a ~50 m.y. periodicity that is out-of-phase with that of the Paleozoic arc. Although the tectonic setting of North China during Mesozoic time is complex and still controversial, it is possible that this younger periodicity is governed by similar processes as those that dominated the Paleozoic arc. This is a testable hypothesis that warrants further attention. Crustal shortening was widespread in North China during Mesozoic time, and documented lithosphere removal events in eastern North China occurred during the Mesozoic magmatic lulls. Lithospheric thickening/foundering cyclicity, well-documented in Cordilleran arc systems, may be a common process in continental arcs through space and time.

1. Introduction

The genesis and growth of buoyant, felsic continental crust requires some mechanism by which mafic constituents of mantle melts be segregated and returned to the mantle, leaving behind continental crust of dominantly andesitic composition (Rudnick, 1995). One persuasive theory as to how this occurs is via segregation and density-driven foundering of eclogitic lower crust or melt residue into the convecting mantle (Kay and Mahlburg-Kay, 1993). Density-driven removal of continental lithosphere has now been implicated in a variety of tectonic settings (Gao et al., 2004; Garzione et al., 2000, 2008; Zandt et al., 2004), but is most commonly associated with thickened crust along convergent continental margins (Kay and Mahlburg-Kay, 1991). Magmatism along convergent continental margins (i.e. in continental volcanic arcs) tends to occur in pulses (flare-ups or high-flux episodes) with a regular period of between 20 and 60 m.y. (Paterson and Ducea, 2015). The causes of this periodicity may be internal or external to the arc. One model to explain the observed tempo of Cordilleran magmatic arcs involves the growth and periodic foundering of crustal melt residua from beneath continental arcs that are undergoing crustal thickening (DeCelles et al., 2009). A superb tracer of this process is the isotopic character of the melts over time (in most studies, initial ε_{Nd}), which tracks melt sources and varies systematically with respect to each flare-up in a manner that is difficult to envision occurring in any other setting.

Models for Cordilleran magmatic cyclicity are supported by excellent control on plate tectonic boundary conditions, the timing of continental shortening events, and petrological data on igneous sources within the arc system (DeCelles et al., 2009; Paterson and Ducea, 2015). These controls are lacking in many other arc systems. However, the strong correlation between flare-ups and radiogenic isotope character in the Cordillera appears to be a defining characteristic of lithospheric thickening/foundering cyclicity, and one that would be enhanced in areas with a greater distinction between the isotopic signature of the mantle and continental melt sources involved. Because the $\varepsilon_{Nd}(t)$ and $\varepsilon_{Hf}(t)$ isotopic character of continental crust is age-dependent, studies of young arc systems developed on extremely old continental blocks should provide a good test of whether the correlation between

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http://dx.doi.org/10.1016/j.epsl.2017.03.022

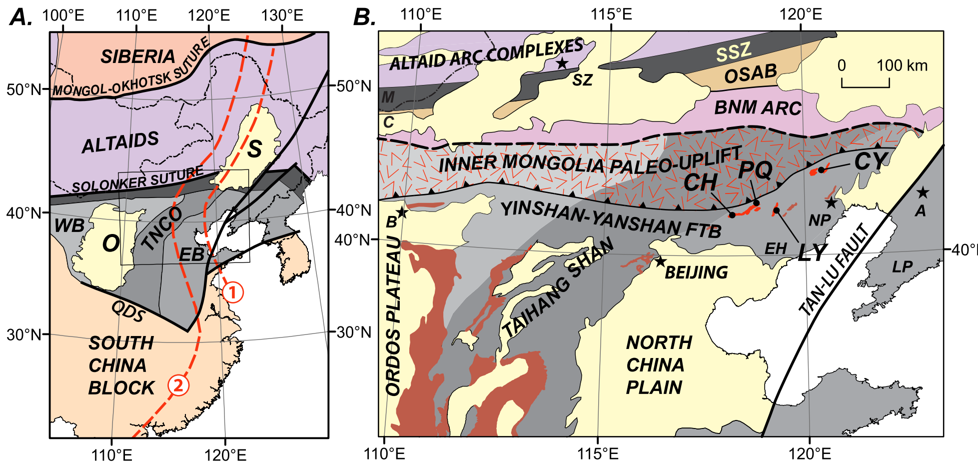

Fig. 1. Geotectonic maps of the North China block and environs. Left panel (A) shows major tectonic provinces and boundaries of east Asia; North China shown in gray. Eastern Block (EB), Western Block (WB), and Trans-North China Orogen (TNCO) shown as shades of gray within North China; boundaries from Zhao (2013). QDS = Qinling–Dabie suture; O = Ordos stable block; S = Songliao Basin. Red lines denote (1) western limit of Late Triassic–Middle Jurassic volcanism, and (2) western limit of Late Jurassic–Early Cretaceous volcanism, from Wu et al. (2011) and Zhou et al. (2006). Dark gray area south of Solonker Suture represents the accretionary complex along the northern margin of North China, shown in more detail in right panel. Right panel (B) is detail of area shown by rectangle in left panel, using same color scheme to denote tectonic elements. Additional tectonic elements shown are SSZ = Solonker Suture Zone; OSAB = Ondor Sum Accretionary Belt; BNM = Bainaimiao Arc. IMPU arc denoted by random "V" pattern. Dashed line north of the arc denotes approximate northern limit of Archean continental crust of North China (compiled from Zhang Shuanhong et al., 2014 and Zhao, 2013), and barbed line to its south symbolizes the approximate location of major thrust fault system bounding its southern margin (Zhang Shuanhong et al., 2014). Areas discussed in text are: A = Anshan; B = Baotou; EH = East Hebei; NP = Nanpiao; NW = Ningwu; SZ = Sonid Zuoqi; WH = Western Hills. Sampling locations for this study are: CH = Chengde (Xiabancheng); CY = Chaoyang; LY = Lingyuan; PQ = Pingquan. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

flare-ups and isotopic character holds for continental arcs in other regions.

The North China block of east Asia is one of the oldest crustal blocks in the world (Zhao, 2013). This paper describes the results of a large-N (N = number) study of detrital zircon U–Pb ages ($N = 4687$) and $\varepsilon_{\mathrm{Hf}}(t)$ analyses ($N = 585$) from the North China block that reflect the initiation, development, and destruction of a late Paleozoic volcanic arc along its northern margin. Three well-resolved flare-ups occur with a period of ∼60 m.y. and increasing intensity over the 170 m.y. lifespan of the arc, very similar to the tempo of magmatism in other continental arc systems. Following the extinction of this arc by closure of the Paleo-Asian Ocean (Xiao et al., 2003), a second arc system associated with Paleo-Pacific subduction developed (Wu et al., 2011). These two continental arc systems provide an excellent natural laboratory for examining the processes leading to crustal growth along convergent continental margins.

2. Tectonic setting

2.1. The North China block

The North China block is a fragment of Archean–Paleoproterozoic crust that was a stable craton from ca. 1650 Ma until the initiation of subduction along its northern and southern margins. It consists broadly of two crustal blocks (Eastern and Western blocks, EB and WB, Fig. 1) sutured together across an orogenic belt, variably termed the Central Orogenic Belt (COB) (Kusky and Li, 2003), or Trans-North China Orogen (TNCO, Fig. 1) (Zhao, 2001). The timing of assembly of North China across this orogenic belt is controversial, with some workers placing the collision along an earliest Paleoproterozoic COB at ca. 2.5 Ga (Kusky, 2011; Kusky and Li, 2003), and others placing it along a later Paleoproterozoic TNCO at ca. 1.85 Ga (Zhao, 2001, 2013). In any case, it is abundantly clear from detrital zircon work in North China that the Eastern Block is characterized by two major events, one at ∼2.5 Ga and the other at ∼1.85 Ga (Cope et al., 2005; Yang et al., 2006); the latter event may reflect collision across the TNCO (Zhao, 2001) or an event that affected the entire northern margin of the North China block (Kusky, 2011). The Eastern Block of North China is also known to contain an older nucleus: zircon U–Pb ages of up to 3.8 Ga have been reported from metamorphosed trondhjemite and quartz diorite in the Anshan and East Hebei regions (Liu et al., 2008; Wan et al., 2009; Zhao, 2013) (A and EH, Fig. 1).

The period between ∼1650 and 450 Ma lacks significant magmatic activity in northern North China, save for rift-related diabase sills found in some Mesoproterozoic sedimentary sequences (Zhang et al., 2009b). During the billion-year period following widespread Mesoproterozoic magmatism, North China is considered to have been a stable craton (hence the widely used term "North China Craton" to refer to the block, despite the fact that it is no longer a craton, *sensu stricto*). Mesoproterozoic–Ordovician marine strata spanning this age range in North China are thought to represent a north-facing passive margin sequence (Meng et al., 2011), developed following Mesoproterozoic rifting of North China from the Columbia supercontinent (Zhang et al., 2009b; Zhao, 2013).

2.2. The IMPU: active northern margin of North China

A magmatic belt along the northern margin of the NCB initiated in Paleozoic time (Cope et al., 2005; Zhang et al., 2007), following Late Silurian–earliest Devonian accretion of the early Paleozoic Bainaimiao arc to the north-facing passive margin of North China (Zhang Shuanhong et al., 2014). The magmatic belt, termed the Inner Mongolia Paleo-uplift (IMPU) because it is characterized by Mesozoic strata overlying crystalline basement once regarded as Precambrian in age (Zhang et al., 2009a), was emplaced into the preexisting Paleoproterozoic and Archean crust of North China, and extends the full length of the continental margin (Xiao et al., 2003). Recent studies of Carboniferous–Permian plutons composing the IMPU along the northern margin of North China reveal that they are mainly hydrous, calc-alkaline or high-K calc-alkaline intrusives with negative $\varepsilon_{\mathrm{Nd}}(t)$ values, negative $\varepsilon_{\mathrm{Hf}}(t)$ values, and $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}_{\mathrm{i}}$ of ca. 0.704–0.706 (Bai et al., 2012; Zhang et al., 2009a; 2007), indicating that they were emplaced in an Andean-style volcanic arc.