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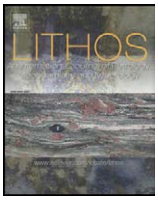

Sr–Nd–Pb isotope mapping of Mesozoic igneous rocks in NE China: Constraints on tectonic framework and Phanerozoic crustal growth

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ABSTRACT

New Sr–Nd–Pb isotope dataset of Mesozoic igneous rocks shows that the NE China can be subdivided into four Sr–Nd–Pb isotope provinces: (1) the northern Hinggan Mountains (NHM) region; (2) the southern Hinggan Mountain (SHM)–Yanji-Liaoyuan (YL) region; (3) the Zhangguangcai Range–Jiamusi (ZGJ) Block; and (4) the exotic Wandashan massif (WDM). The Wandashan massif contains Mesozoic (high-μ)-type oceanic island basalts (HIMU-OIBs) with highly radiogenic Pb isotopic compositions (e.g., $^{206}Pb/^{204}Pb(i) = 18.9–22.7$), quite different from other regions that have moderately radiogenic Pb (i.e., $^{206}Pb/^{204}Pb(i)$) is generally less than 18.6. These HIMU-OIBs also show negative $\Delta 7/4$ and $\Delta 8/4$ values, signatures of Southern Gondwanaland Continent. By contrast, the majority of Mesozoic igneous rocks in other areas of NE China have positive $\Delta 7/4$ and $\Delta 8/4$ values, akin to the Northern Laurasian Continent. Such isotopic variations were probably due to the enrichment processes mainly caused by Paleozoic Paleo-Asian ocean subduction and to some extent by subduction of the Paleo-Pacific Ocean since early Mesozoic.

The mantle-derived rocks in the NHM region is characterized by moderately radiogenic Nd and Pb isotopic compositions ($\varepsilon_{Nd}(t) = -0.2$ to $+3.6$ and $^{206}Pb/^{204}Pb(i) = 18.3–18.6$). Compared with the NHM region, the mantle-derived magmas in the SHM–YL region show wider Nd isotopic variation ($\varepsilon_{Nd}(t) = -1.1$ to $+6.6$) and less radiogenic Pb ($^{206}Pb/^{204}Pb(i) = 18.1–18.4$). Along the Hegenshan-Solonker suture distributes an early Cretaceous felsic magmatic belt with highly positive-ε_{Nd} ($\varepsilon_{Nd}(t) = +4.0$ to $+5.9$) and radiogenic Pb compositions ($^{206}Pb/^{204}Pb(i) = 18.4–18.6$), suggesting that it was not only an important Phanerozoic crustal growth belt but also a zone containing significant volume of pelagic sediments or their metamorphosed derivates. Adjacent to the Hengenshan ophiolite occurs a suite of andesites showing nonradiogenic Nd ($\varepsilon_{Nd}(t) = -10.5$ to -6.3) and Pb ($^{206}Pb/^{204}Pb(i) = 17.22–17.26$), as well as DUPAL Pb isotopic signatures. These features indicate the existence of “old” lower continental crust beneath the area.

Compared with the majority of crust-derived rocks in the NHM and SHM–YL regions ($\varepsilon_{Nd}(t) = -2.9$ to $+6.8$ and $^{206}Pb/^{204}Pb(i) = 17.4$ to 18.6), the Mesozoic granitoids in the ZGJ block have relatively less radiogenic Nd ($\varepsilon_{Nd}(t) = -2.9$ to $+2.1$) and more radiogenic Pb composition ($^{206}Pb/^{204}Pb(i) = 18.2$ to 18.9). Considering that the Paleozoic granitoids have nonradiogenic Nd ($\varepsilon_{Nd}(t) < -6$), we suggest that pelagic sediments or their metamorphosed derivates were an important crustal component in the region.

The new isotope mapping results suggest that during Mesozoic time the crustal growth mainly occurred around the collisional sutures (e.g., the Hegenshan-Solonker suture) and/or along the major lithosphere-scale faults (e.g., the Tan-Lu fault), in which highly positive-ε_{Nd} rocks are distributed. However, the extent of Mesozoic crustal growth was subordinate relative to the Paleozoic time in terms of Nd isotopic evolution. Generation of Mesozoic voluminous felsic magmas in NE China was mainly ascribed to remelting, recycling and redistribution of the preexistent crustal components (juvenile and “old” crustal components), which had been juxtaposed during the tectonic evolution of the Paleo-Asian Ocean.

1. Introduction

Isotope mapping is a powerful tool for identification and delineation of lithotectonic units, including basement domains (Zartman, 1974; Taylor and McLenann, 1985; Chen and Jahn, 1998; Zhang et al., 1995; Zhu, 1990; Zhou et al., 2001; Dickin and McNutt, 1989). Where isotopic differences exist between different tectonic units, isotope mapping can provide constraints on the location of lithospheric boundary faults, crustal and lithospheric evolution and on paleo-plate reconstruction.

The first Pb isotope mapping was done by Zartman (1974), who divided the Mesozoic and Cenozoic igneous rocks and hydrothermal ore deposits in the North American Cordilleran Range into three

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distinct Pb isotope provinces. Based on Nd model age mapping, Dickin and McNutt (1989) identified a crustal-scale suture separating an Archean foreland from a Proterozoic mobile belt in the Grenville province of Ontario, Canada. Similarly, Zhu (1990) used Pb isotopes to divide the China continent into six mineralization zones. Zhang et al. (1995) used the feldspar Pb isotope data for Mesozoic granites and whole-rock Pb isotopic compositions of basement rocks to divide the eastern China continent into ten Pb isotope provinces. In addition, Sr–Nd isotope mapping of Mesozoic felsic igneous rocks and Precambrian basement in SE China suggested multi-stage crustal growth (Chen and Jahn, 1998), and Sr–Nd–Pb isotope mapping has divided the northern North China Block (NCB) into three east-trending tectonic units (Zhou et al., 2001).

The Central Asian Orogenic Belt (CAOB), or Altaids, extends from the Urals to the Pacific Ocean and from the Siberian and East European (Baltica) cratons to the North China (Sino-Korean) and Tarim cratons (Zonenshain, 1973; Mossakovsky et al., 1993; Yakubchuk, 2004; Windley et al., 2007). Growth was initiated at ca. 1.0 Ga (Khain et al., 2003) and continued to ca. 250 Ma (Sengör et al., 1993; Xiao et al., 2009). In the eastern CAOB, it is considered that the Paleo-Asian Ocean was ultimately closed at the Hegenshan-Solonker suture (Xiao et al., 2003, 2004; Jian et al., 2008). Compared with classical collisional orogens, such as the Alps and the Himalayas, the CAOB lacks extensive ancient gneiss terranes that represent former continental fragments, as well as molasse-filled foredeeps that generally form between them (Sengör et al., 1993). Instead, it is composed mainly of subduction-accretion complexes, intruded by vast plutons of mainly arc origin, and is covered in places by the volcanic derivatives of that plutonism (Sengör et al., 1993; Sengör and Natal'in, 1996; Xie, 2000; Windley et al., 2007). As the most important site for Phanerozoic crustal growth and recycling, the subduction- accretion complexes added ~5.3 million km^2 of material to the Asian continent, half of which may be of juvenile origin (Sengör et al., 1993; Jahn et al., 2000a,b; Kovalenko et al., 2004).

The northeastern (NE) part of China lies in the eastern CAOB. Paleomagnetic evidence and geophysical observations imply that the ultimate collision event between the North China–Mongolian Block and the Siberia Craton took place no later than middle Jurassic (Zhao et al., 1990; Kuzmin et al., 1996; van der Voo et al., 1999). During the late Mesozoic, regional tectonic activity was dominated by faulting and rifting (Li and Yang, 1987; Meng, 2003; Wang et al., 2006), triggering the formation of basin and range tectonics and extensive calc-alkaline magmatism, analogous to the basin and range province in northwestern America (Ge et al., 1999; Guo et al., 2001; Fan et al., 2003; Lin et al., 2003; Hawkesworth et al., 1995).

Mesozoic volcanic rocks and their intrusive counterparts occupy a large part of NE China as shown in Fig. 1 (Wu et al., 2000; Lin et al., 2003). Felsic lavas and plutons are dominant with subordinate mafic rocks. During the past two decades, many studies examined the origins of these voluminous magmas (e.g., Zhao et al., 1989; Lin et al., 2003; Ge et al., 1999; Wei et al., 2001; Wu et al., 2000, 2002, 2003a,b, 2004; Jahn et al., 2000a,b, 2001, 2004; Fan et al., 2003; Guo et al., 2001, 2009b; Gao et al., 2005; Chen et al., 2006; Zhang et al., 2008a, 2010; Ying et al., 2010). Nevertheless, their origins, and the role this magmatism played in the Phanerozoic crustal growth of the region, remains unclear. For instance, Wu et al. (2000, 2002, 2003a,b) proposed that the I-type granitoids in NE China were melts derived from a mixture of juvenile crust and old metamorphic basement, while A-type granitic plutons might be tectonically linked with an early Mesozoic lithospheric delamination event. Based on geochemical differences and on the relationship with contemporaneous basaltic lavas, three types of late Mesozoic felsic volcanic lavas have been identified from the Hinggan Mountain area of NE China. These are: (1) an intermediate to felsic suite, interpreted as the result of fractional crystallization (FC), possibly accompanied by assimilation (AFC), from mantle-derived magmas which are now represented by associated basaltic lavas (e.g., Guo et al., 2001; Fan et al., 2003); (2) felsic magmas formed through melting of crust at various levels (Guo et al., 2009b); and (3) adakitic dacites derived through melting of eclogitic mafic lower crust (Gao et al., 2005). Nevertheless, irrespective of which group they fall into, most of the Mesozoic felsic igneous rocks have relatively radiogenic Nd compositions ($\varepsilon_{Nd}(t)>0$) and young Nd model ages ($T_{DM2}<1.0$ Ga), and were thought to be linked to significant Phanerozoic crustal growth (Fan et al., 2008).

In this paper, we present the results of Sr–Nd–Pb isotope mapping based on a synthesis of a dataset containing more than 300 samples of Mesozoic igneous rocks and related Paleozoic mafic rocks in NE China. Our aims are to better understand the tectonic framework of the region and to elucidate the role of Mesozoic magmatism in Phanerozoic crustal growth of the eastern part of the CAOB. In order to avoid any ambiguity, the term "crustal growth" in this paper means production of juvenile material through a series of mantle–crust differentiation processes, and only involves processes of addition but not destruction or recycling (Jahn et al., 2000a,b).

2. Regional geology

The NE China region covers an area more than 1,000,000 km^2, throughout which terrestrial Meso-Cenozoic sediments are well developed. The tectonic evolution of the region was controlled by the subduction and accretion of the Paleo-Asian Ocean during the Paleozoic, and northwestward subduction and accretion of the Pacific Plate to the Eurasia Continent since the late Mesozoic. The regional tectono-magmatic activity can be briefly summarized as the following stages: (1) Neoproterozoic to Paleozoic crustal accretion related to subduction of the Paleo-Asian Ocean, characterized by formation of subduction-accretion complexes and the accompanied emplacement of voluminous magmas with juvenile signature (e.g., Shao, 1991; Sengör et al., 1993; Sengör and Natal'in, 1996; Robinson et al., 1999; Wilde et al., 2000; Xiao et al., 2003, 2004; Badarch et al., 2002; Khain et al., 2003; Shi et al., 2004; Jia et al., 2004; Windley et al., 2007; Li, 2006b; Miao et al., 2008; Jian et al., 2009); (2) the subsequent uplifting of the orogenic belt in response to collision between the North China–Mongolian Block and the Siberian Craton in the early Mesozoic (Liu et al., 2005, 2007; Buslov et al., 2004; Wu et al., 2004), during which magmatism was rare; (3) post-orogenic extension since late Jurassic (Guo et al., 2001; Zhang et al., 2004a,b; Fan et al., 2003; Meng, 2003; Lin et al., 2003; Wang et al., 2002, 2006; Li, 2006a; Li et al., 2007), with voluminous eruption and emplacement of predominantly intermediate to felsic magmas and subordinate mafic counterparts; and (4) the subduction of Pacific Ocean since late Cretaceous (Tang et al., 1995; Zhao et al., 1994; Faure and Natal'in, 1992; Northrup et al., 1995; Taira, 2001), which caused eruption of the Paleocene adakitic andesites and the Tertiary–Quaternary basalts (e.g., Guo et al., 2007, 2009a; Liu et al., 2001).

This complex and protracted tectonic history has meant that dividing this region into various tectonic components remains controversial, and several different tectonic division schemes have been proposed in the past decades. For instance, Wang (1982) divided NE China into the western 'Siberian–Mongolian continental margin' and the eastern 'Wandashan massif,' a segment of the 'Circum-Pacific tectonic domain,' separated by the Misan-Dunhua fault (F5 in Fig. 1). Cao et al. (1987) considered that the Songliao basin and the area to the east belonged to the Circum-Pacific tectonic domain and that the western part of the Songliao basin could be divided into the 'Sino-Korean block' and the 'Siberian block,' separated by the Hegenshan-Solonker suture (F1 in Fig. 1). Tang (1989) considered the NE China area as the 'Inner Mongolia–Hinggan crustal growth zone.' Ren et al. (1990) divided the region into the western 'Mongolia–Hinggan orogenic belt' and the eastern 'Jiamusi-Bulieya massif.' Based on differences in the feldspar Pb isotope compositions of Mesozoic