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Compositional and Sr–Nd–Hf isotopic variations of Baijingsi eclogites from the North Qilian orogen, China: Causes, protolith origins, and tectonic implications

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ABSTRACT

Eclogites from the Baijingsi area in the North Qilian orogen at NW China were analyzed for major and trace element abundances as well as Sr, Nd, and Hf isotope ratios to evaluate the impacts from subduction processes on these compositional parameters and to reveal the complexity in protolith characteristics. The major element compositions of the Baijingsi eclogites are within the ranges for basalts. However, the absence of systematic variations among major oxides indicates varying extents of metamorphic modifications. Seven samples are characterized by profound Nb and Ta depletions. Six of them form coherent trends in the La versus Th, HFSE, and LREE plots. They are classified as the Group 1 samples. Other eight samples, referred to as the Group 2 samples, define distinct La–Zr and La–Sm trends and have flat variation patterns with slight Th–Nb–Ta–LREE depletions in the primitive mantle-normalized multiple-element diagram. Group 1 dominates the $^{87}Sr/^{86}Sr$–$^{87}Rb/^{86}Sr$, $^{143}Nd/^{144}Nd$–$^{147}Sm/^{144}Nd$ and $^{176}Hf/^{177}Hf$–$^{176}Lu/^{177}Hf$ trends for relatively larger variations in the isotope and abundance ratios. Based on the errorchron ages from the samples, closure temperatures of the isotope systems, and isotope ratio versus 1/X plots (e.g., $^{87}Sr/^{86}Sr$–1/Sr), it is inferred that the Rb–Sr isotope system was subjected to metamorphic modification, whereas the Sm–Nd and Lu–Hf isotope systems mainly reflect protolith characteristics. In addition to the Nb and Ta depletions, the Group 1 samples generally have $\varepsilon_{Hf}(510)$ values (protolith initial at 510 Ma) higher than those of MORB at a given $\varepsilon_{Nd}(510)$, reflecting derivation from relatively high Lu/Hf ratio sources. They also plot within the fields for arc lavas in the Ta/Yb–Th/Yb and Th–Ta–Hf/3 diagrams. All these features are consistent with derivation from protoliths of an arc origin. In contrast, the Group 2 samples have $\varepsilon_{Nd}(510)$ values slightly higher than those of the Group 1 samples at a given $\varepsilon_{Hf}(510)$, plotting on the low $\varepsilon_{Nd}(510)$ margin of the MORB field. They also deviate from the Ta/Yb–Th/Yb trend defined by MORB and OIB toward higher Th/Yb values within the fields of back-arc basin basalts. Therefore, it is inferred that the protoliths of the Group 2 samples were generated as back-arc basin basalts possibly associated with the protoliths of the Group 1 samples in a common supra-subduction zone. The $\varepsilon_{Nd}(510)$–$\varepsilon_{Hf}(510)$ relationship of the Baijingsi eclogites shows an affinity to the Indian ocean type mantle, implying protolith generation at the southern hemisphere on the margin or a fragment of the Gondwana continent, most likely in the Qilian Block. Based on the current tectonic configuration, a southward subduction is required for protolith generation and might eclogitize the arc protoliths by subduction erosion. Alternatively, the northward subduction in a bidirectional subduction system might become dominant during the amalgamation of the Qilian Block and the North China Craton to eclogitize the arc protoliths in the Qilian Block. Resolving these two possibilities requires more petrological, geochemical, and structural evidence from the North Qilian orogen.

1. Introduction

Eclogite compositions, as complements to arc lava compositions, reveal element fractionation during slab subduction and improve our understanding on element distribution among geochemical reservoirs

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in the Earth (e.g., Becker et al., 1999, 2000; Rudnick et al., 2000; John et al., 2004; Xiao et al., 2013a). Element variations and isotope ratios of eclogites also characterize the nature of protoliths, providing constraints on the tectonic evolution at convergent margins (e.g., Jahn, 1999; Murphy et al., 2006; Song et al., 2006; Liu et al., 2007; Zhang et al., 2008; Song et al., 2009; Liu et al., 2010; Zirakparvar et al., 2013). However, erroneous conclusions may be drawn, if the effects of metamorphic modifications that changed the chemical nature of the protoliths are not adequately considered.

Compared to those from other renowned suture zones, such as the Dabie–Sulu and Alpine orogens, the eclogites from the Qilian orogenic belt at northwestern China (Fig. 1) are not as intensively documented in terms of geochemical characteristics and associated implications. Zircon ages, mineral compositions, and the occurrence of lawsonite together led to an inference of a cold subduction (Zhang et al., 2007). Element fractionations resulted from such a cold subduction were only recently addressed (Xiao et al., 2013a). Based on bulk trace element compositions, Song et al. (2009) proposed that the Qilian eclogites have a MORB or an OIB affinity. They also inferred that the protoliths of these eclogites were formed as a part of a mature large ocean basin, which has been referred to as the Paleo-Qilian Ocean (e.g., Wu et al., 1993; Liu et al., 2006; Song et al., 2006; Tung et al., 2012, 2013). In contrast, Xiao et al. (2013a) identified the influence of arc-related materials on the eclogite compositions. The inconsistency has yet been resolved. Furthermore, these inferences on protolith characteristics were derived from a limited trace element database and have not been verified by isotope data, imposing uncertainties on the associated tectonic models.

In this contribution, we determined the major and trace element abundances as well as Sr, Nd, and Hf isotope ratios for 16 Qilian eclogite samples. The data were critically analyzed to address the effects of metamorphic modifications on protolith compositions. Then, we deduced protolith characteristics and interpreted their tectonic significances. We also reported data for two schist samples to strengthen the arguments based on the eclogite data.

2. Geological backgrounds

The Qilian orogen (or fold) belt is the NW–SE trending highland region in northwest China (Fig. 1). It is fault-bounded by the Tarim Block to the northwest, the Qaidam Block to the southwest, the Alxa Block to the northeast, and the Qinling orogen to the southeast (Fig. 1). Since the 1970s, this region has been divided into three sub-parallel belts based on rock assemblages (Fig. 1). The North Qilian Belt, from where the samples were collected, comprises Cambrian–Ordovician sedimentary rocks (Feng and He, 1996), ophiolites (Yang et al., 2002; Hou et al., 2006; Tseng et al., 2007), arc volcanic and granitic rocks (Wu et al., 2004), mélange, and metamorphic rocks including greenschists, blueschists, eclogites (Wu et al., 1993; Song et al., 2004; Zhang et al., 2007), metasediments and minor slices of ultramafic rocks. The Central Qilian Belt is composed of Meso-Neoproterozoic basement dominated by granitic gneiss with subordinate volumes of siliciclastic and carbonate metasedimentary rocks (Tung et al., 2007; Xu et al., 2007). The basement is unconformably overlain by Paleozoic to Cenozoic formations consisting of sedimentary and low-grade metamorphic rocks (Xiao et al., 2009; Xu et al., 2010). The granitic intrusions are of Neoproterozoic to lower Paleozoic ages, mostly the latter (Tung et al., 2013). The South Qilian Belt consists of Cambrian to Ordovician marine sediments, oceanic crustal fragments, lava flows, pyroclastic rocks (Pan et al., 2002; Xu et al., 2006), and arc volcanic rocks (Xiao et al., 2009). They are unconformably overlain by Devonian conglomerates (Zhao et al., 2004). Also occurred are the folded Silurian flysch sediments and Caledonian granitic intrusions (Xu et al., 2006).

Tectonically, the North Qilian Belt has been considered as a suture zone between the southern Central Qilian Belt and northern Alxa Block

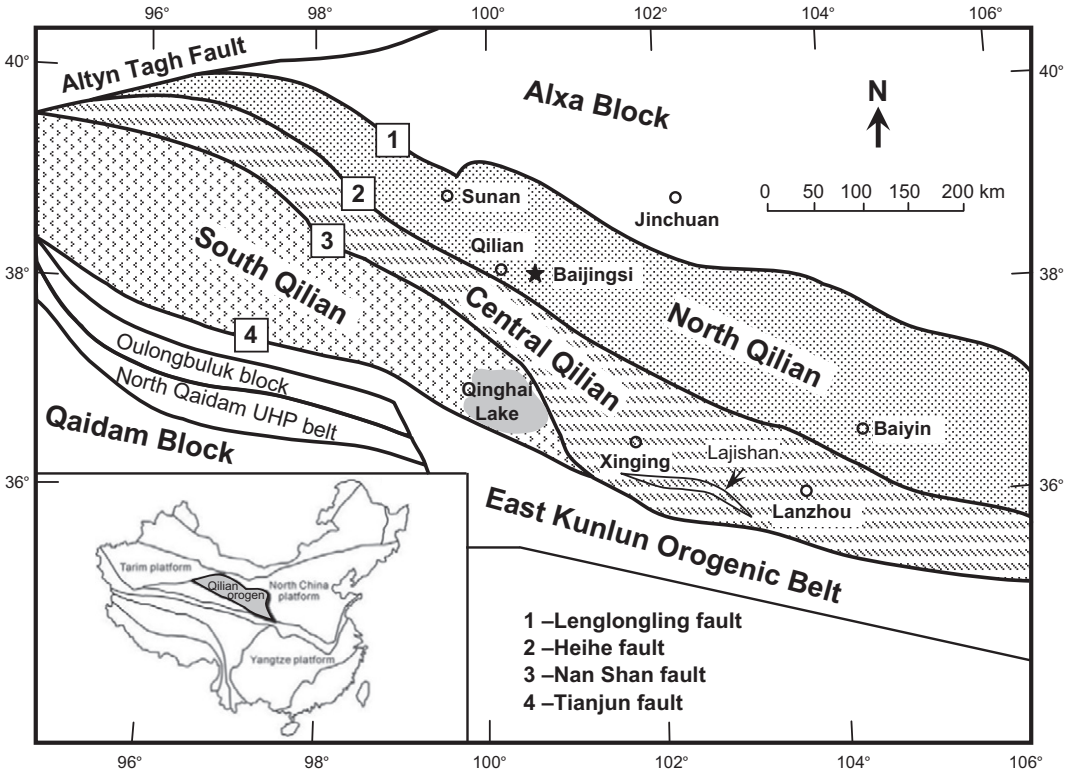

Fig. 1. Schematic map modified from Xiao et al. (2009) showing the locations of three sub-parallel belts constituting the Qilian orogen in NW China and the locations of the major cities and counties (open circles). See text for the lithological characteristics of the North, Central, and South Qilian Belts. Eclogite samples were collected from three outcrops at the Baijingsi area (the star) about 30 km east of the Qilian county. The insert shows the locations of the Qilian orogen (highlighted in gray) in China.