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Variations in the geochemical structure of the mantle wedge beneath the northeast Asian marginal region from pre- to post-opening of the Japan Sea

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ABSTRACT

Deep asthenospheric processes and the dynamic mechanism of magmatism in the northeast Asian marginal region are of significant interest but have been difficult to study in detail. We completed comprehensive studies on Japan Sea basalts including petrography, whole-rock major and trace elements, Sr–Nd–Pb isotopic compositions, and K–Ar geochronology, then combined our results with previous research to study the tectonic evolution of northeast Asia. The Japan Sea basalts, divided into Upper and Lower layers of Site 794 (US794, LS794), and Upper and Lower layers of Site 797 (US797, LS797) based on their stratigraphic level, belong to the calc-alkalic series and are characterized by flat HREE with significantly positive anomalies of Ba, Sr, and Pb, and slight anomalies of Eu ($\delta Eu = 0.81–1.21$). The US797 sample group has lower LREE, LILE and relatively depleted radioactive isotope ratios ($^{87}Sr/^{86}Sr = 0.704051–0.704254$; $^{143}Nd/^{144}Nd = 0.513035–0.513139$; $^{206}Pb/^{204}Pb = 17.758–18.223$), whereas the sample groups LS797, US794, and LS794 have relatively higher incompatible elements and slightly enriched isotopic values ($^{87}Sr/^{86}Sr = 0.704248–0.705222$; $^{143}Nd/^{144}Nd = 0.512705–0.512917$; $^{206}Pb/^{204}Pb = 18.077–18.377$) due to the involvement of Pacific subducted fluid and sediments. K–Ar and $^{40}Ar–^{39}Ar$ geochronological data indicate age ranges of LS797, US794, and LS794 samples of $17.7 \pm 0.5–21.2 \pm 0.8$ Ma, significantly older than those of US797 ($15.1 \pm 0.9–17.2 \pm 0.7$ Ma). Our data compiled with other data show sharply defined Sr–Nd isotopic variations of the Cenozoic basalts from Sikhote-Alin, the Japan Sea, the back-arc side of NE Japan and SW Hokkaido, and north Hokkaido from a slightly enriched to a depleted isotopic signature at 23–24 Ma, 17 ± 2 Ma (15–19 Ma), 15 Ma, and >12 Ma, respectively, indicating that the upwelling asthenosphere beneath northeast Asia progressed eastward relative to the lithosphere. We conclude that the temporal and spatial variations of basaltic magma sources in the northeast Asian marginal region are closely associated with the extension of the Japan Sea.

1. Introduction

The Japan Sea, northeast Japan arc and Hokkaido make up an integrated and typical back-arc basin and island arc system that, with the related Sikhote-Alin region in far eastern Russia, comprise the northeastern margin of the Eurasian continent (Fig. 1). At this margin, volcanism occurred continuously from the early Miocene to the Quaternary, with obvious zonal distribution of volcanic features from the northeast Japan arc to Hokkaido (Fukase and Shuto, 2000; Kondo et al., 2000; Nohda, 2009; Ohki et al., 1995; Okamura et al., 2005; Shuto et al., 1993, 1997, 2004, 2006). The early Miocene to middle Miocene back-arc spreading of the Japan Sea, associated with drifting and thinning of subcontinental lithosphere and upwelling of the asthenosphere, began the process of change from a continental margin environment to the present back-arc basin and island arc setting, and the formation of the northeast Asian integral tectonic framework (e.g., Garfunkel et al., 1986; Hager et al., 1983; Ishimoto et al., 2006; Otofuji et al., 1985; Shuto et al., 1993, 2004; Tatsumi et al., 1988). Concurrent and subsequent to this back-arc spreading, the magma sources beneath the geotectonic unit consisting of the Sikhote-Alin region, the Japan Sea, northeast Japan, and Hokkaido changed regularly. Thus, rocks in this geotectonic unit (Sikhote-Alin, Japan Sea, northeast Japan, and Hokkaido) provide an excellent opportunity to study the temporal changes in the magma source that accompany the evolution of subduction- and extension-related volcanism during the opening of a typical back-arc basin. Because of the considerable changes in the tectonic environment and magma source from the pre- to the post-opening stage, we divided the tectonic evolution process into two stages, namely the pre-opening stage and the syn- and post-opening stage.

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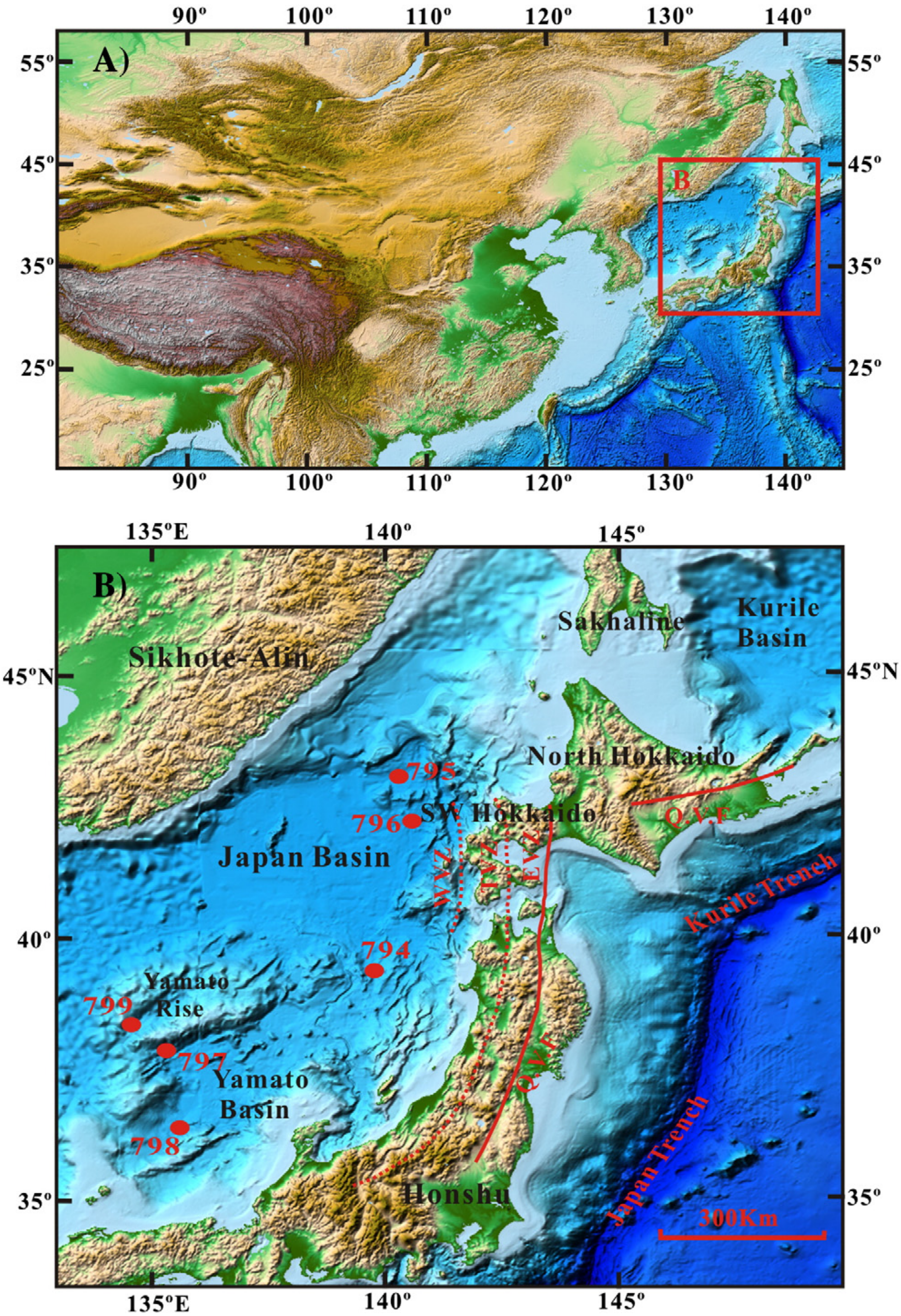

Fig. 1. Index map showing the study area for the northeast Asian margin (A), Sikhote-Alin, Japan Sea, NE Japan arc and Hokkaido (B) (modified from Takanashi et al., 2011). In Fig. 1B, the dotted line represents the boundary of different volcanism of NE Japan arc and Hokkaido; Q.V.F. represent Quaternary volcanic front in the NE Japan arc and Hokkaido. EVZ, TVZ and WVZ in SW Hokkaido respectively represent an eastern volcanic zone, a transitional volcanic zone, and a western volcanic zone.

Previous studies of the magma sources of the Japan Sea, northeast Japan, Hokkaido and the Sikhote-Alin volcanics concluded that the apparently regular variations of the Sr–Nd isotopic compositions were associated with asthenospheric upwelling and extension of the Japan Sea (e.g., Nohda, 2009; Nohda et al., 1988; Ohki et al., 1995; Okamura et al., 2005; Pouclet et al., 1995; Sato et al., 2007; Shuto et al., 1993, 2006; Tatsumi et al., 1988; Ujike and Tsuchiya, 1993). However, these studies focused only on basaltic magma sources in a limited area covering a certain time span (Sato et al., 2007; Shuto et al., 2004, 2006), and did not consider the Sikhote-Alin, the Japan Sea, northeast Japan, and Hokkaido as an entire geotectonic unit to reasonably interpret the plate tectonic evolution and deep asthenospheric processes of the Eurasian continent's northeast margin. Significantly, the point-in-time sequence of changes in the Sr–Nd isotopic composition of the volcanic rocks has a geographic regularity from the Sikhote-Alin region via the Japan Sea to the Japan Arc, suggesting the presence of a certain direction and rhythm of asthenosphere flow beneath northeast Asia (Nohda, 2009). However, given that the generation and formation of andesite or rhyolite may be influenced by crustal contamination or magma mixing (e.g., Yamashita et al., 1999), geochemical characteristics cannot