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Origin of Late Paleogene to Neogene basalts and associated coeval felsic volcanic rocks in Southwest Hokkaido, northern NE Japan arc: Constraints from Sr and Nd isotopes and major- and trace-element chemistry

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ABSTRACT

Basalts and felsic volcanic rocks (mainly dacite and rhyolite) found in southwest Hokkaido, northern part of the NE Japan arc, result from protracted volcanism during the Oligocene (34–30 Ma), Early Miocene (25–17 Ma), Middle Miocene (16–12 Ma), Late Miocene (10–5 Ma), Pliocene (4 Ma) and Quaternary (2 Ma), thus spanning the pre-Japan Sea opening to post-opening stages.

The majority of basaltic rocks after about 16 Ma show depleted Sr (SrI) and Nd (NdI) isotopic signatures compared with some Middle to Early Miocene basalts, which strongly resemble, in terms of both timing and extent, the change in SrI and NdI values for back-arc basaltic rocks of the central NE Japan arc. However, significant differences exist for younger basaltic rocks, in that basaltic rocks with depleted SrI and NdI signatures are found from the Middle Miocene onwards throughout the eastern-, transitional- and western-volcanic zones in SW Hokkaido, whereas in the central NE Japan arc, basaltic rocks with similar isotopic signatures are confined to the back-arc side.

Felsic volcanic rocks in southwest Hokkaido have SrI and NdI values, which overlap with coeval southwest Hokkaido basaltic rocks. Although the relationship between mafic and felsic rocks could be attributed to fractional crystallization, this process is inconsistent with REE chemistry, as total REE do not increase systematically from basaltic rocks to felsic volcanic rocks. Alternatively, lower crustal mafic rocks, represented by gabbroic and amphibolitic xenoliths found in basaltic rocks at Itinome-gata (Oga Peninsula), are a possible source for Late Paleogene to Quaternary felsic magmas, as both felsic volcanic rocks and xenoliths have similar SrI and NdI.

A possible tectono-magmatic model for the production of post-Late Paleogene volcanic rocks from SW Hokkaido commences in the Oligocene (34 Ma) with asthenospheric mantle upwelling followed by partial melting to generate basalt magma (Matsue basalt) with depleted SrI and NdI, followed by interaction of asthenosphere-derived basalt magmas with overlying subcontinental lithosphere. In the Early Miocene (25–17 Ma), asthenospheric upwelling triggered partial melting of the overlying lithospheric mantle from which most basalts with undepleted SrI and NdI values were derived. During the Middle Miocene (16–12 Ma), thinning of the overlying lithosphere due to the opening of the Japan Sea resulted in asthenospheric upwelling which reached the region beneath the present NE Japan arc volcanic front. Partial melting of the asthenosphere led to generation of voluminous basalt magma with depleted SrI and NdI values throughout southwest Hokkaido. Most basaltic rocks that erupted since the Late Miocene are considered to have also formed from asthenospheric mantle. Basaltic magmas formed since the Oligocene have either been erupted, or fluxed and heated the lower crust from which coeval felsic magmas were generated.

1. Introduction

Throughout the opening of the Japan Sea and Kurile back-arc basins, drifting and thinning of the subcontinental lithosphere were closely associated with upwelling of the asthenosphere into the eastern marginal part of the Eurasian continental lithosphere (e.g., Ishimoto et al., 2006; Nohda et al., 1988; Sato et al., 2007; Shuto et al., 1993, 2004; Tatsumi et al., 1988). This would have led to progressive change in the composition of the magma source for Late Paleogene to Quaternary basaltic rocks from the back-arc margin of the Northeast Japan arc and North Hokkaido over time (Fig. 1).

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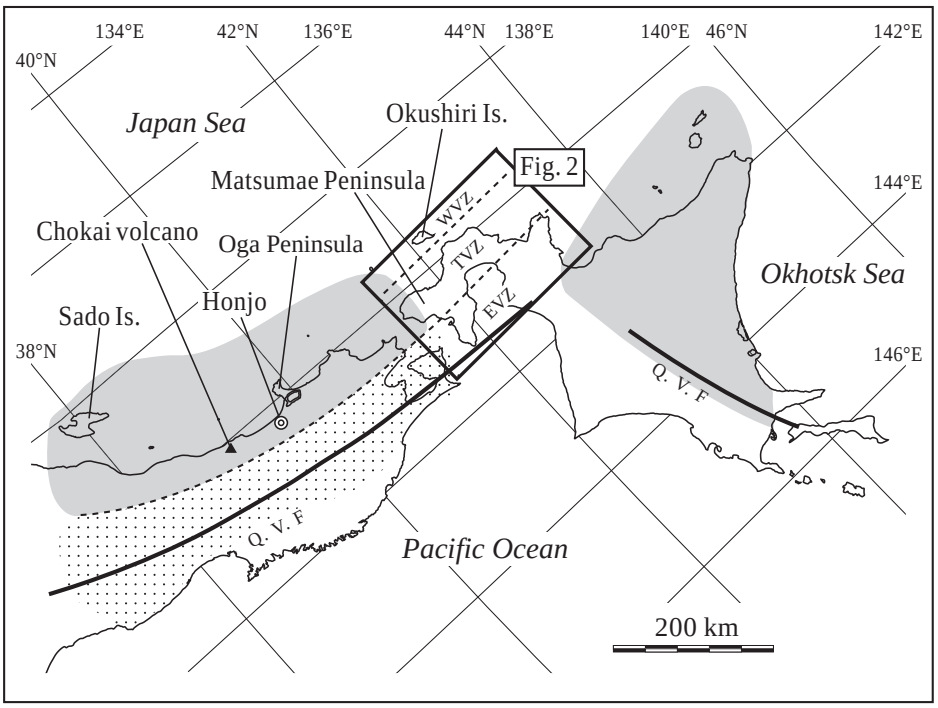

Fig. 1. Index map showing the study area and the distribution of basaltic rocks with different Sr and Nd isotopic characteristics in the NE Japan arc and North Hokkaido (modified from Shuto et al., 2004). The shaded area shows distribution of the NEJ back-arc basaltic rocks, with ages younger than about 15 Ma, and the NH basaltic rocks, with ages younger than about 12 Ma, produced from a depleted magma source region in the upper mantle. Dotted area shows distribution of basaltic rocks, with ages between 25 Ma and present, produced from an undepleted magma source region. Q.V.F; Quaternary volcanic front in the NE Japan arc and Hokkaido. Is.; Island. EVZ, TVZ and WVZ in SW Hokkaido (Fig. 2) show an eastern volcanic zone, a transitional volcanic zone, and a western volcanic zone respectively.

Temporal variations in the Sr and Nd isotopic compositions of Late Paleogene to Quaternary basaltic rocks and their source mantle in the NE Japan arc have been discussed in connection with tectonic evolution, involving upwelling of asthenosphere into continental lithosphere beneath the arc (e.g., Kurasawa and Konda, 1986; Nohda et al., 1988; Ohki et al., 1994; Pouclet et al., 1995; Sato et al., 2007; Shuto et al., 2006; Shuto et al., 1993; Tatsumi et al., 1988; Ujike and Tsuchiya, 1993). These studies have revealed that the isotopic signature of basaltic rocks from the NE Japan back-arc margin (NEJ back-arc basalts) changed drastically from undepleted to depleted at around 15 Ma.

A similar concept of asthenospheric mantle upwelling was advocated by Shuto et al. (2004) for the generation of basaltic rocks from North Hokkaido (NH). They demonstrated that most basaltic rocks younger than 12 Ma in this area are isotopically similar to NEJ back-arc basalts younger than about 15 Ma. Sr and Nd isotope chemistry of basaltic rocks from the NE Japan arc and North Hokkaido are consistent with upwelling of asthenospheric mantle that accompanied spreading, resulting in the Japan Sea back-arc basin (the Japan Sea) and the Kurile back-arc basin (the Okhotsk Sea). Thus, Shuto et al. (2004) pointed out that this tectono-magmatic event took place in the upper mantle over an extensive region extending from the back-arc margin of the NE Japan arc to North Hokkaido during the Middle Miocene.

However, little is known about the Sr and Nd isotope compositions of Late Paleogene to Neogene basaltic rocks from southwest Hokkaido (SW Hokkaido) situated at the northern end of the NE Japan arc, which adjoins the southernmost part of the Kurile arc (Fig. 1). In SW Hokkaido, basaltic rocks are accompanied by significant volumes of coeval felsic volcanic rocks, including silicic andesite, dacite and rhyolite. Eruption of these rocks over a 220 km (N–S) × 140 km (E–W) area in SW Hokkaido (Fig. 1) during the Oligocene (34–30 Ma), Early Miocene (25–17 Ma), Middle Miocene (16–12 Ma), Late Miocene (10–5 Ma), Pliocene (4 Ma) and Quaternary (2 Ma) spans the pre- to post-opening stages of the Japan Sea.

In this paper, we present major- and trace-element chemistry, and Sr and Nd isotopic data for these Late Paleogene to Quaternary basaltic and felsic volcanic rocks from SW Hokkaido. Coupled with the data of Sato et al. (2007), Shuto et al. (1992), and Yamamoto et al. (1991), we examine secular variations in the magma source beneath SW Hokkaido, and evaluate the genetic relationship between basaltic and felsic volcanic rocks.

2. Geologic background

Oligocene to Early Miocene volcanism (i.e., 35–16 Ma) of the NE Japan arc took place mainly on land (e.g., Ohguchi, 1983, 2002; Tsuchiya, 1995; Yagi et al., 2001). During this time, the NE Japan back-arc was characterized by eruption of mainly calc-alkaline andesite and dacite, and tholeiitic and alkali basalt with moderate to high contents of HFSE (high field strength elements) (Fukase and Shuto, 2000; Okamura et al., 1993; Sato et al., 2007; Shuto et al., 2006; Yagi et al., 2001; Yamamoto et al., 1991). Basaltic and associated felsic rocks exposed on Okushiri Island, Matsumae Peninsula, and the Oga Peninsula, in the Honjo area and on Sado Island, are petrologically and chemically similar to volcanic rocks from continental rift zones, such as the Rio Grande rift (e.g., Barberi et al., 1982), suggesting that this part of the NE Japan arc was produced in response to rifting of the Eurasian continental arc during the pre-opening stage of the Japan Sea (Fukase and Shuto, 2000; Sato et al., 2007; Shuto et al., 2006; Yagi et al., 2001; Yamamoto, 1993).

In contrast to Oligocene to Early Miocene volcanism, Middle Miocene volcanism of the back-arc margin of the NE Japan arc is distinctly bimodal, characterized by voluminous basaltic and felsic (dacitic to rhyolitic) volcanic rocks, with only minor andesite (e.g., Konda, 1974; Shuto et al., 1993). Shuto et al. (1997) and Yamaji and Sato (1989) suggested that this bimodal volcanism took place within submarine grabens which may have formed in response to the opening of the Japan Sea. The petrology and geochemistry of basaltic rocks produced at this time have been ascribed to generation from hot asthenosphere which upwelled into the subcontinental lithosphere beneath the back-arc