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Melting of crustal rocks as a possible origin for Middle Miocene to Quaternary rhyolites of northeast Hokkaido, Japan: Constraints from Sr and Nd isotopes and major- and trace-element chemistry

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ABSTRACT

Felsic volcanic rocks (mainly rhyolites) and basalts found in northeast Hokkido, Japan, result from intense volcanism during the Middle Miocene (14–9 Ma), Late Miocene (8–6 Ma) and Pliocene to Quaternary (5–2 Ma). Rhyolites were examined to determine any genetic relationship to coeval basalts, high magnesian andesite (HMA), lower crustal rocks and mantle peridotite.

Rhyolites have initial Sr and Nd isotopic ratios (SrI and NdI) which overlap with coeval north Hokkaido basaltic rocks and HMA. Previously published Sr and Nd isotopic data show that most Middle Miocene to Quaternary (14–0 Ma) basaltic rocks from north Hokkaido have a relatively narrow SrI- and NdI- range (SrI 0.70299 to 0.70400, and NdI 0.51281 to 0.51311), with no temporal variation in either SrI or NdI. Basalt and HMA from three locations are, however, more undepleted in terms of both SrI and NdI than other north Hokkaido basaltic rocks. Some of rhyolites (termed undepleted rhyolites here) have similar SrI and NdI to some north Hokkaido basalts and HMA. Rhyolites with similar SrI and NdI to other north Hokkaido basaltic rocks are termed depleted rhyolites.

Although the similarity of SrI and NdI between rhyolites and coeval basalts and HMA can be accounted for by fractional crystallization, this process is inconsistent with the REE chemistry of basalts, HMA and rhyolites, and with the results of fractional crystallization modeling. However, a few rhyolites may result from the fractional crystallization of basaltic and HMA magmas with assimilation of some metasedimentary rocks. Small degrees of partial melting of a metazomatized mantle peridotite is an unlikely mechanism to explain the genesis of rhyolites according to REE chemistry and partial melt modeling of an amphibole bearing spinel lherzolite source.

Gabbros of the Hidaka metamorphic belt are a possible source for isotopically depleted rhyolites, as both the rhyolites and gabbros have similar SrI and NdI. I-type tonalite and some gabbros in the Hidaka metamorphic belt are possible source rocks for isotopically undepleted rhyolites based on similarity in SrI and NdI. These hypotheses are supported by partial melt modeling of olivine gabbro and I-type tonalite respectively.

A possible tectono-magmatic model for the production of post-Middle Miocene rhyolites from NE Hokkaido involves upwelling of the asthenosphere during the Middle Miocene, associated with the spreading of the Kurile back-arc basin and Japan Sea back-arc basin. This would have resulted in thinning of the overlying lithosphere beneath north Hokkaido, and the production of asthenosphere-derived basaltic rocks with low SrI and high NdI throughout north Hokkaido since the Middle Miocene, but less common production of lithosphere-derived basaltic rocks and HMA (with high SrI and low NdI). Basaltic magmas formed since the Middle Miocene either erupted, or caused melting of the crust, resulting in the generation of rhyolitic magma.

1. Introduction

In the past 20 years, significant amounts of geochemical data have been accumulated for Miocene volcanic rocks of north Hokkaido (NH). Based on these data, several tectono-magmatic models have been proposed for the production of these volcanic rocks; including back-arc spreading related to the formation of the Kurile back-arc

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basin (Goto et al., 1995; Ikeda, 1998; Yamashita et al., 1999; Ikeda et al., 2000), an increase in the dip-angle of the subducting Pacific Plate (Watanabe, 1995), collision of the Eurasian, Okhotsk and Pacific Plates (Okamura et al., 1995), and upwelling of asthenospheric mantle from which extensive basaltic magmas were derived (Shuto et al., 2004).

In north Hokkaido (Fig. 1), large volumes of Middle Miocene to Quaternary felsic volcanic rocks, consisting mainly of dacite and rhyolite, are found with coeval basalts and andesites (Fig. 2). Felsic volcanic rocks are especially widespread in the eastern part of north Hokkaido (NEH) (Fig. 3). Watanabe et al. (1995) first described the geology, whole rock chemistry and Sr isotopic composition of these rhyolites in the Kitami region, and suggested that they resulted from anhydrous melting of lower crustal gabbro. Takagi et al. (1999) reported additional whole rock chemistry, and Sr and Nd isotopic compositions for the Kitami rhyolite and coeval basalt and andesite, and argued that the most likely source for rhyolites was the mantle wedge which had been metasomatized by slab-derived fluids.

However, the widespread distribution of these felsic volcanic rocks requires further examination, particularly to understand their relationship to coeval basalts, HMA, lower crustal rocks and mantle peridotite. Furthermore, examining these relationships has implications for mantle evolution and the mechanism of back-arc basin spreading.

In this paper, we present major- and trace-element chemistry, and Sr and Nd isotopic data for these Middle Miocene to Quaternary felsic volcanic rocks from northeast Hokkaido (NEH). Our study area largely overlaps with the Kitami region discussed by Watanabe et al. (1995) and Takagi et al. (1999). Using new- and previously- published geochemical, and Sr and Nd isotopic data, this study explores the possibility that partial melting of lower crustal I-type tonalite and gabbro is a likely mechanism for producing NEH felsic volcanic rocks. The study also examines the generation of rhyolites by lower crustal melting caused by heating of coeval basalt magma, possibly derived from the upwelling asthenospheric mantle associated with the opening of the Japan Sea and the Okhotsk Sea.

2. Temporal and spatial distribution of Middle Miocene to Pliocene volcanic rocks in north Hokkaido

North Hokkaido, the back-arc region behind the junction of the Quaternary northeast Japan and Kurile arcs (Figs. 1 and 2), is characterized by widespread Middle Miocene to Pliocene volcanic rocks divided into western and eastern volcanic regions (Watanabe and Yamaguchi, 1988; Watanabe et al., 1991). K–Ar age data show that Miocene to Pliocene volcanic rocks in north Hokkaido erupted during three main periods of intense volcanism, the Middle Miocene (14–9 Ma), Late Miocene (8–6 Ma) and Pliocene (5–3 Ma), although localized volcanic activity at about 18 Ma is recorded in the northern part of the region (e.g., Shibata et al., 1981; Watanabe et al., 1991; Nakagawa et al., 1993; Goto et al., 1995; Sugawara et al., 1995; Yahata and Nishido, 1995; Aoki et al., 1999; Hirose and Nakagawa, 1999; Ozawa et al., 2003). The interval from 17 to 15 Ma represents a period of volcanic quiescence in north Hokkaido. Recently, Furukata et al. (2010) showed that 20–15 Ma basaltic- and felsic-volcanic rocks in the northernmost part of Hokkaido and in parts of central Hokkaido are each composed of three rock types. Using Sr and Nd isotope data, mafic rocks are represented by basalts enriched relative to MORB (type I basalts), those which are strongly enriched relative to MORB (type II basalts), and those that are similar to EM1 (type III basalts). Felsic volcanic rocks consist of high alkali rocks, adakites, and high silica rocks.

Both the western and eastern volcanic regions of north Hokkaido are at a high angle to the northeast–southwest direction of the Quaternary Kurile volcanic zone (Fig. 2). This indicates a different tectonic setting for Middle Miocene to Pliocene and Quaternary volcanism in north Hokkaido.

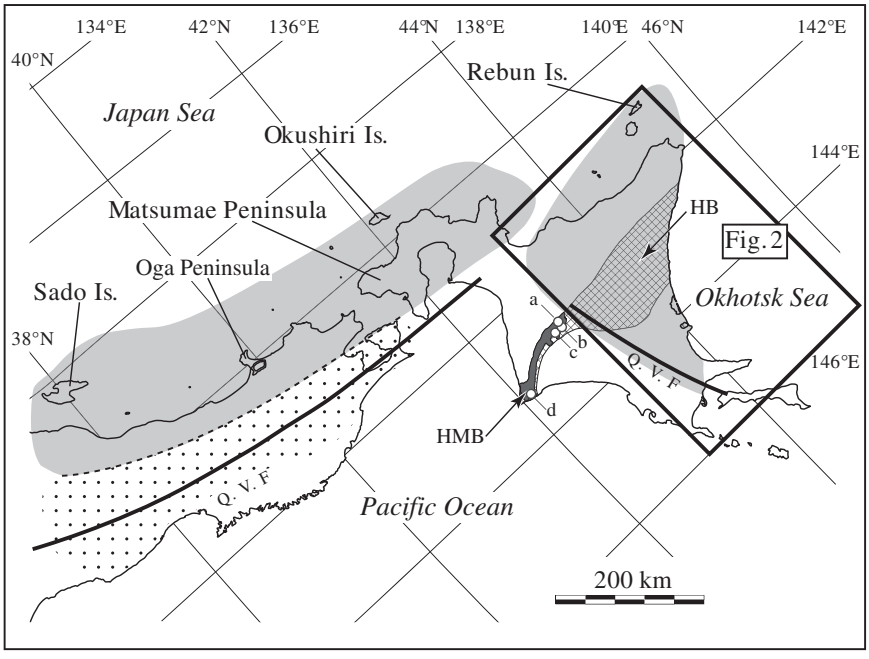

Fig. 1. Index map showing the study area and the distribution of basaltic rocks with different Sr and Nd isotopic characteristics in the NE Japan arc and north Hokkaido (modified from Shuto et al., 2004). The shaded area shows the distribution of back-arc basaltic rocks from the central NE Japan arc (with ages younger than about 15 Ma), basaltic rocks from southwest Hokkaido (with ages younger than about 16 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, HB; Hidaka belt, HMB; Hidaka metamorphic belt. Open circles show locations of gabbroic rocks and I-type tonalite in the Hidaka metamorphic belt; a: Pankenushi gabbro with Chiroro basalt dykes, b: Memurodake gabbro, c: Tottabetsu gabbro, d :I-type tonalite.