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A pseudo adakite derived from partial melting of tonalitic to granodioritic crust, Kyushu, southwest Japan arc

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ABSTRACT

Cretaceous peraluminous granitic intrusions occur in Kyushu in the southwest Japan arc as batholiths or stocks accompanied by metaluminous tonalite to granodiorite. The peraluminous intrusions are classed as adakitic based on Sr/Y–Y (ppm) relationships, but they contain abundant K-feldspar, a phase not common in typical adakites. To consider their significance in the arc system, we investigated the Tsutsugatake stock as representative of the intrusions exposed in central Kyushu. The Tsutsugatake rocks are mainly garnet-bearing two-mica leuco-granitoids. Their Sr/Y ratios and rare earth element concentrations are appropriate for adakite, but K_2O/Na_2O ratios (0.53–1.43), and Al_2O_3 (13.7–15.0 wt.%), MgO (0.20–0.55 wt.%), Sr (207–462 ppm), Cr ($\leq$12 ppm), and Ni ($\leq$8 ppm) contents differ from those of typical adakite.

Geochemical modeling shows that the petrogenesis of the Tsutsugatake stock can be explained by partial melting of arc-type tonalite or adakitic granodiorite under middle to lower crustal conditions, leaving amphibole and plagioclase as residual phases. The differences between the Tsutsugatake stock and classical adakites lie in their source rocks and melting conditions. The Tsutsugatake source was not basaltic, and the melting pressure was insufficient to stabilize garnet. The Tsutsugatake rocks are here designated "pseudo adakites". Such "pseudo adakites" may be found in both modern and ancient arcs, and would play an important role in crustal evolution as a member of the recycled constituent.

1. Introduction

Adakite was initially defined from Cenozoic volcanic rocks derived from partial melting of young and hot basaltic slab subducted at convergent plate margins (Defant and Drummond, 1990). The rock type is characterized by unusual geochemical features, namely $SiO_2 \geq 56$ wt.%, $Al_2O_3 \geq 15$ wt.% at $SiO_2 = 70$ wt.%, $K_2O/Na_2O \leq 0.5$, Sr>400 ppm, Y$\leq$18 ppm, Yb$\leq$1.8 ppm, and the lack of Eu anomalies (Defant and Drummond, 1990; Drummond et al., 1996; Martin, 1999). Sr/Y vs Y (Defant and Drummond, 1990) and $(La/Yb)_N$ vs Yb_N (Martin, 1987) discrimination diagrams are widely used to define adakite. These geochemical characteristics are required for slab melting under pressures high enough to stabilize garnet±amphibole without plagioclase (e.g., Kay, 1978; Defant and Drummond, 1990; Rapp et al., 1991; Sen and Dunn, 1994; Peacock et al., 1994; Drummond et al., 1996; Martin, 1999).

Petrogenetic models of adakite have recently been examined in a number of studies. Castillo (2006) overviewed adakite and its petrogenesis. Adakites span a range from pristine slab melts (e.g., Defant and Drummond, 1990), to adakite–peridotite hybrid melts (e.g., Yogodzinski et al., 1995), through to high-Mg and -Sr andesitic melts derived from peridotite metasomatized by slab melts (e.g., Martin et al., 2005). However, other work suggests that adakitic magma can be produced in both arc and non-arc settings by other processes, such as cold-slab subduction. Such adakites may be produced by the melting of thickened lower crust (e.g. Atherton and Petford, 1993; Hou et al., 2004); interaction between peridotite and lower crust melts, followed by delamination of the lowermost crust into the mantle (e.g. Xu et al., 2002); or high-pressure crystal fractionation of basaltic magmas (e.g. Macpherson et al., 2006). Despite these varying origins, all adakites and adakitic rocks (including plutonic equivalents) satisfy the classification criteria of the two discrimination diagrams noted above.

Cretaceous peraluminous granitic rocks are extensively exposed in the central and northern parts of Kyushu in the southwest Japan arc. Most of these rocks plot within the adakite field on the Sr/Y vs Y diagram, but all contain abundant K-feldspar, a mineral phase that is not common in adakitic rocks (Kamei, 2004). We here investigate the Tsutsugatake stock, a peraluminous intrusion exposed in central Kyushu, from both the petrographic and geochemical viewpoints. Although the compositions of the Tsutsugatake stock satisfy the

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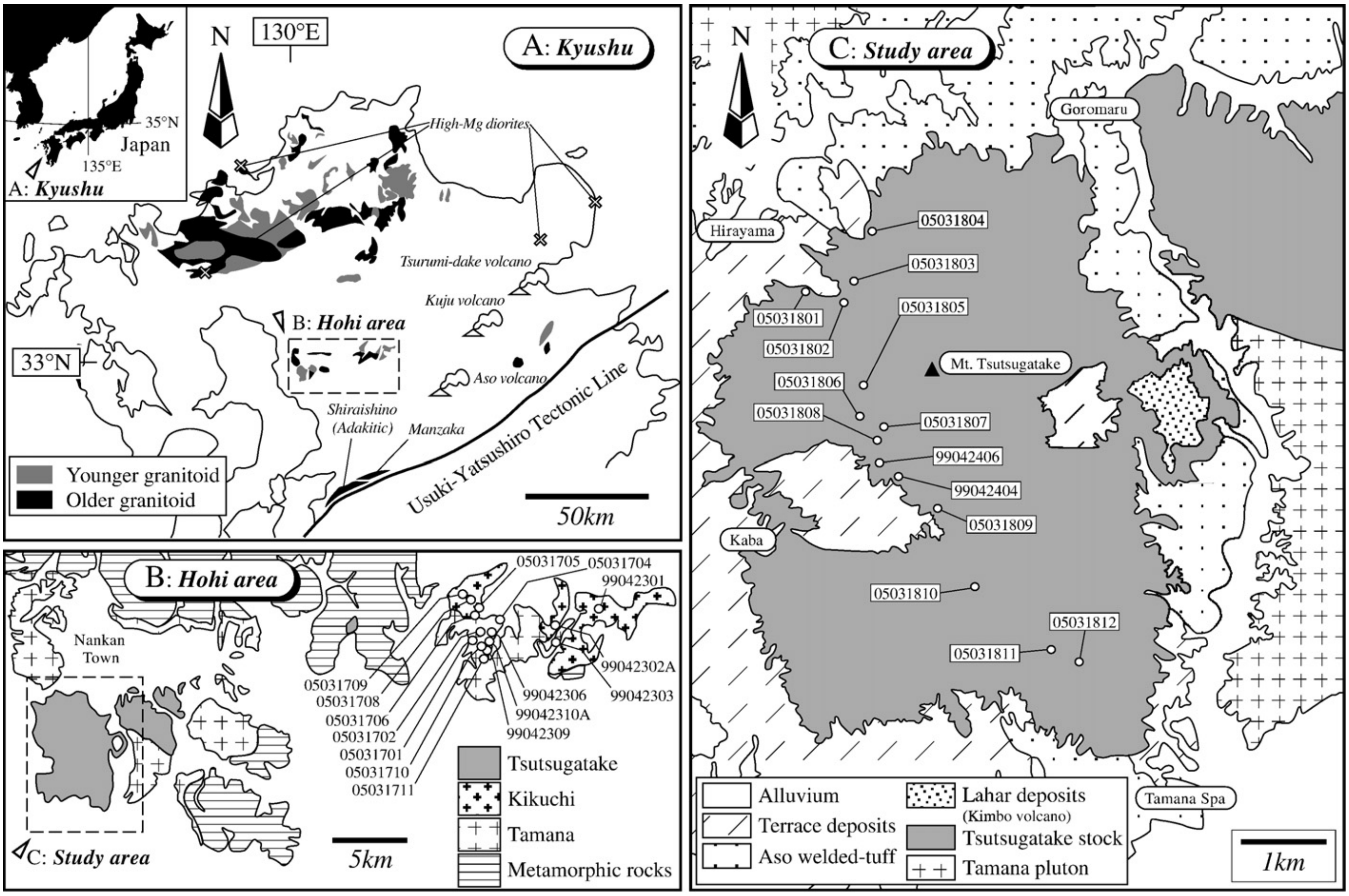

Fig. 1. Geological map for Cretaceous granitic rocks in Kyushu in the southwest Japan. A: Distributions of granitoids. B: Cretaceous granitoids in the Hohi area. C: Study area around Mt. Tsutsugatake. Numbers are sample locations.

features of adakites in terms of Sr/Y–Y relations and rare earth element (REE) contents, other parameters conflict with an adakitic character.

In this paper, we describe the rocks of the Tsutsugatake stock as “pseudo adakites”. Although the term “adakite” is traditionally used for volcanic rocks (Defant and Drummond, 1990; LeMaitle et al., 2002), many plutonic equivalents are genetically similar to adakite (e.g. Martin, 1999; Martin et al., 2005). Consequently, both volcanic and plutonic analogs of the Tsutsugatake-type magma genesis may be defined as “pseudo adakite”.

2. Geological outline

Cretaceous granitic rocks are extensively exposed in northern and central Kyushu Island (Fig. 1A). They intrude various lithologies, including low- and high-pressure type metamorphic rocks, accretionary complexes, and coeval Cretaceous volcanic rocks. Cretaceous granitic activity in north-central Kyushu ranges from 121 to 76 Ma in age (Osanai et al., 1993; Kamei et al., 1997; Owada et al., 1999). The granitic rocks are divided into “older” and “younger” types on the basis of both lithology and intrusive order (Karakida, 1985; Owada et al., 1999; Kamei, 2002) (Fig. 1A). The two types have different mineral components, with the older type containing hornblende, and the younger type mostly muscovite and/or garnet without hornblende. Furthermore, older type intrusions are mainly tonalite to granodiorite, whereas the younger types are mostly granodiorite to granite. In addition to these intrusions, the adakitic Shiraishino pluton and high-Mg diorite were also emplaced in north-central Kyushu during the Cretaceous (Kamei, 2004; Kamei et al., 2004; Yuhara and Uto, 2007) (Fig. 1A).

The younger type rocks in Kyushu are of peraluminous composition, and have adakitic signatures on the Sr/Y vs Y diagram (Kamei, 2002, 2004) (Fig. 2). The lithology of the younger type differs from the adakitic Shiraishino pluton and the high-Mg diorites, which mainly consist of metaluminous rocks and always contain hornblende (Kamei, 2004; Kamei et al., 2004). The Tsutsugatake stock, one of the younger type intrusions, occupies a small mountainous area (ca 100 km^2) in the Hohi area of central Kyushu (Fig. 1A and B). We selected this stock to investigate the petrology and petrogenesis of the younger type, because its mineral assemblage is representative of the younger intrusions. The Tsutsugatake stock contains abundant K-feldspar with traces of muscovite and/or garnet, and lacks

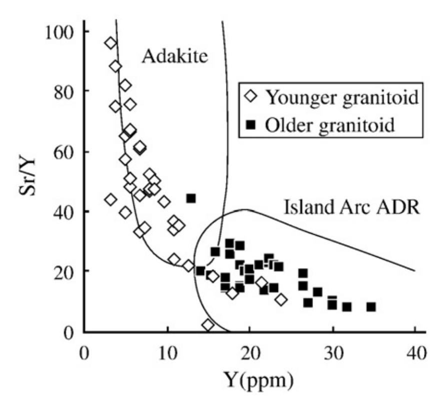

Fig. 2. Sr/Y vs Y diagram for Cretaceous granitoids in Kyushu. Data sources are from Kamei (2004). Adakite and Island Arc andesite–dacite–rhyolite (ADR) fields are from Defant et al. (1991).