論文内容の要旨

論文題目　Incremental melting process and thermal evolution of an upwelling mantle: constraints from back arc volcanisms in the eastern margin of the Eurasian Plate

上昇マントルの累進的融解プロセスと熱進化：
ユーラシア大陸東縁部背弧火成活動からの制約

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ABSTRACT

Continental back arc volcanisms are widely distributed around the Pacific Ocean. Although origin of the volcanisms have been attributed to their own local sources, general characteristics of back arcs, such as high surface heat flow (>70mW m-2), slow upper mantle velocity, thin effective elastic thickness (<30km), and high temperature lithosphere from peridotite xenoliths indicate high temperature at the upper mantle and that mantle flow carries heat into back arc and mantle wedge. Because the intraplate volcanisms do not show systematic temporal and spatial variation like a hot spot track, origin of each volcanism have been attributed to these small scale mantle upwelling for each magmatism. Although missing 30 % of surface heat flow is attributed to small scale intraplate volcanisms, how the mantle upwells or how melting occurs within the mantle has not been clarified yet.

Temporal change of the amount of melt produced in an upwelling mantle is the most important information relevant to the basalt genesis and the dynamics of melting in the upper mantle. Although this issue has been addressed by experimental and thermodynamic approaches, convincing petrologic constraints from natural samples are still quite few. If an upwelling mantle melts near fractionally and quickly separates melt to the Earth’s surface without pondering and aggregation on its way up, basalt magma, particularly less differentiated alkaline basalt, is potentially a good tracer of the melting history.

We made systematic geological, petrologic, and geochemical investigations on an intraplate continental alkaline basaltic volcanism (Kita-Matsuura basalt) in southwestern Japan to reveal the melting history in the upper mantle on the time scale of 2Myr and the horizontal scale of 35km.

Eastern margin of the Eurasian Plate is one of the most extensive regions of the Cenozoic back arc volcanisms on earth, most of which are distributed between the Siberian and North China Cratons. Cenozoic volcanisms of the northwestern Kyushu, western end of the southwestern Japan, is one of the typical back arc volcanisms in the eastern Asia and is characterized by eruption of extensive mildly alkaline to alkaline basalt from late Miocene. Kita-Matsuura basalt, centered at the Cenozoic northwestern Kyushu volcanism, was active from 8.5 to 6.0 Ma under compressional stress state and the present volume is nearly a half of Cenozoic basalts observed in the southwestern Japan.

We investigated four sections from the basement to the top to cover the whole distribution of the Kita-Matsuura basalt. The volcanism initiated from mildly alkaline basalt (low- SiO_2 group) followed by sub-alkaline basalt (medium to high- SiO_2 group) in the western and central sections, while the eastern section produced mildly alkaline basalt (low- SiO_2 group) almost all the way up to the uppermost horizon. Each SiO_2 group is clearly distinguished by a specific assemblage of fractionated crystals to produce the major element variation, which can be explained neither by crystal fractionation nor crustal assimilation to each other. Estimated water content in primary melts is at most 2.0 wt% for low- and medium- SiO_2 groups by using Ca-Na partitioning between plagioclase and melt. If we take water as complete incompatible element, water content of the mantle is calculated to be less than 0.2 wt% and does not have much effect on estimation of pressure by comparing with anhydrous peridotite melting experiments. Average segregation depths of estimated primary melts for each group were estimated by comparing to anhydrous melting experiments; they are 3.1-2.9, 2.8-2.6, and 2.0-1.8 GPa for low-, medium-, and high- SiO_2 groups respectively.

Major element variations such as K_2O, TiO_2, Na_2O, and Al_2O_3/TiO_2 of primary melts suggest increase of melting degree from low- to high-SiO_2 group. A linear relationship between Al_2O_3/TiO_2 and melting degree based on compilation of anhydrous peridotite melting experiments enables us to estimate differences of melting degree between low- and medium- SiO_2 groups and between medium- and high- SiO_2 groups equally as ~6 ± 3wt%. The chondrite-normalized REE patterns of primary melts show strong enrichment of LREE with almost linear and variable inclination from LREE to HREE. LREE/HREE and MREE/HREE decrease with time in every section and the ratios are smaller in the western sections than in the eastern sections. Trace element variations cannot be explained by batch, fractional, accumulate, or stepwise melting of any depleted MORB mantle or primitive mantle, requiring near fractional (critical) melting of an single enriched mantle source in the garnet to spinel stability field from low- to high- SiO_2 groups.

Assuming homogeneous peridotite mantle as a source, these lines of temporal and spatial variations of both major and trace elements with geological evidence indicating compressional stress state suggest that a chemically homogeneous diapiric upwelling mantle with arched isotherms melted progressively from garnet to spinel stability fields at the velocity of 2 cm/year and generated the Kita-Matsuura basalt volcanism.

Consequently, we estimated melt production rate (dF/dP) and long term eruption rate (dV/dt) as representative parameters which describe characteristics of melting of an upwelling mantle. Combination of melting pressure and relative degree of melting of the three lava groups shows that the melt production rate dF/dP is 1.7 ~ 2.4 %/kbar at 3.1 – 2.6 GPa and 0.7 %/kbar at 2.6 – 1.8 GPa, respectively. Melt production rate decreased during upwelling of the mantle, which is contrasting to increase of production rate for MORB generation as mantle ascends (e.g., Asimow et al., 1997; Yang et al., 1998). In addition, from total amount of present volcanic rocks (~50 km^3) and duration of activity (~2 Myr), long term eruption rate is calculated to be $2.5x10^4$ m^3/yr, which value is almost identical to that of the other intraplate volcanisms and one of the least rate among the volcanisms on earth. The decrease of melt production rate and quite small long term eruption rate of a diapirically upwelling mantle shown from natural sample for the first time suggests that melting process is different from an ideal steady state adiabatic melting.