Formation of plutons constrained by plagioclase diffusion modelling with an example from the Mikawa area, Japan

*Tokiyuki Morohoshi[1], Ken Yamaoka[1], Tsuyoshi Iizuka[1], Simon Richard Wallis[1]

1. Department of Earth and Planetary Science, The University of Tokyo

The processes that lead to the formation of plutons and the magma chambers they represent is an unresolved important problem in the study of magmatic systems. In early studies of this problem models were commonly invoked that involved large amounts of magma being intruded in a short space of time, followed by solidification associated with crystal differentiation. However, the advent of high-precision geochronology, in particular U–Pb dating of zircon, and its application to plutons has shown that large plutons can form over time scales of several million years. This result combined with the recognition of different units with plutons has shown that piecemeal growth histories with pulses of magma intrusion over a long period of time need to be considered. Thermal modelling using contact metamorphic zones surrounding plutons can be used to examine the associated changes in temperature in time for different parts of the growing pluton. This temperature history is important because it controls the amount of melt in the magma chamber which in turn determines whether this can be erupted or not. However, the models do not resolve to any high degree the frequency of magma intrusion or the accretionary style of the intruded magma. The result is considerable uncertainty concerning the history of the magma temperature and how the melt fraction changes with time.

One of the most common minerals found in plutonic rocks is plagioclase. Plagioclase is known to have a pronounced compositional zoning in both major and trace elements. The zoning commonly shows a non-equilibrium distribution even for elements that diffuse quite rapidly. The limited effects of diffusion suggest that the magma body has been at relatively low-temperatures for much of its history. In principle it should be possible to constrain the thermal histories for the pluton that are compatible with the zoning. Based on these considerations, we conducted a study to assess the utility of chemical diffusion in plagioclase from inside of plutons to constrain the time scales and temperature history of growing magma bodies. This method has been well applied to volcanic rocks as diffusion chronometry, but there are no reports on the applicability of this method to plutonic rocks. In this study, we used forward modelling to assessment, in which the several thermal histories and the zoning structure of plagioclase typical of plutons were used to calculate the assumed diffusion of Sr, Ba and La. This range of different elements covers a broad range of diffusion rates. Chemical analysis with high spatial resolution is required for the application of this method to real samples. We used a LA-ICP-MS (Laser-Ablation Inductively Coupled Plasma Mass Spectrometry) to measure spots with diameters of 10~30 micrometers. The resulting profiles were compared to the model results and used to discriminate different thermal histories.

We also carried out a preliminary study of how these results can be applied to problems on the pluton scale using samples from the Shinshiro tonalite and Busetsu granite in the Ryoke belt. They are expected to have contrasting thermal histories from greatly different width of contact metamorphic zones. Samples were collected from the center and margins of the Shinshiro tonalite and the margins of the Busetsu granite to examine possible differences in the chemical profiles of plagioclase grains. Chemical profiles for Sr, Ba, and La were analyzed using LA-ICP-MS and the results compared with the calculation results. Although the interpretation of the results is still in progress, the results suggest that a significant difference can be detected in the possible duration of high T conditions in the samples obtained from the margins of both bodies. A combination of this method with the thermal modeling constrained by information from contact metamorphic zones has good potential to improve our understanding the thermal history of plutons.

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