Dating of granulite facies metamorphism and depletion: SIMS chronometry of micron-scale monazite inclusion in garnet

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Introduction

It is difficult to obtain precise ages that give reliable information on the timing of the highest temperature history in granulite terrains. This is because the isotopic closure temperatures of most minerals are significantly lower than those achieved during granulite grade metamorphism. Monazite is a common accessory mineral in high-grade metamorphic rocks and, unlike zircon, is rarely inherited. It appears to retain Pb even at high temperature (725±25°C, Copeland *et al.*, 1988) and offers potential to provide reliable chronological information of the high-grade parts of metamorphic thermal history as already demonstrated (DeWolf *et al.*, 1993; Zhu *et al.*, 1993). Of particular importance is the relatively common occurrence of monazite as inclusions in garnet. Because garnet has a very high closure temperature for Pb-isotopes (>800°C, Mezger *et al.*, 1989), it may serve to armour monazite inclusion and provide age information on the higher temperature part of the record. It may even be possible to obtain the age information on the prograde part of granulite metamorphism from the monazite inclusion in garnet. Here we report the results of in situ ion probe dating of monazite occurring as micron-scale inclusions in garnet as well as discrete grains of monazite in matrix from the samples of the Lewisian complex.

Geological setting

The Lewisian complex of NW Scotland is one of the world's classic Precambrian high-grade metamorphic terrains. Well-known features of the granulites include the unusually high metamorphic temperature experienced by the terrain and its extreme depletion of heat producing elements (U, Th, K). The history of the terrain has been systematically documented by many workers using U-Pb zircon, Pb-Pb whole rock and mineral separates, Sm-Nd whole rock and mineral separates. In the central region, the granulite facies metamorphism has commonly been considered to peak at ~2660 Ma (Pidgeon and Bowes, 1972) on the basis of U-Pb zircon dating, but recently an age of ~2710 Ma has been suggested for the high-grade metamorphism (Corfu *et al.*, 1993).

Methods, Results and Discussion

The samples studied are metasedimentary rocks from the central Lewisian region. Monazite grains were located in polished petrological thin sections by detailed optical microscopy and SEM study and their Pb isotope compositions analysed *in-situ* using the ISOLAB-120 operated at ~7000 resolving power as detailed elsewhere (DeWolf *et al.*, 1993; Belshaw *et al.*, 1994).

Two small monazite grains (~20 and ~15μ respectively) included in the central part of garnets give 207Pb/^{206}Pb ages of 2761±12 Ma and 2757±35 Ma respectively. Five cores of six large discrete matrix grains (~150 to 400μ) analysed give ^{207}Pb/^{206}Pb ages consistent with each other of ~2740 Ma, and the intermediate parts and one core of the grains yield the age of ~2710 Ma, consistent with the recently reported Pb-Pb zircon age of ~2710 Ma, while the rims and small discrete grains of monazite yield the significantly younger ages. Both the ages obtained here of ~2760 Ma and ~2740 Ma are significantly older than the ages of peak metamorphism previously obtained using many methods. All the six large discrete grains analysed are zoned. Some cores are with embayed morphology of the form not expected for detrital grains, and the possibility that the entire grains are detrital in origin is not entertained further. The *REE* distribution patterns of the zoned monazite grains show remarkably little difference between different grains and between core and rim of the same grain which demonstrates a constant *REE* supply to the monazites at their various stages of growth and argues against any portion of the grains been of very different provenance, i.e. inherited or detrital.

On the other hand, the plot of Th/U versus age

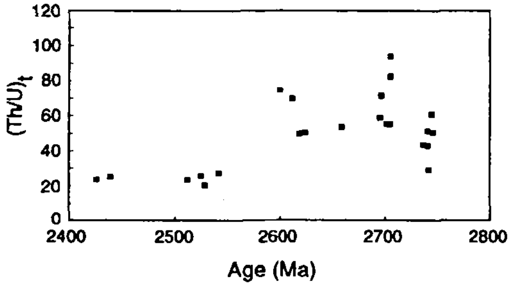

FIG. 1. Plot of Th/U ratio at time of formation $(Th/U)_t$, calculated from $^{208}Pb/^{206}Pb$ *vs.* Age. Sample 86004.

(Fig.1) might be taken to suggest that U was depleted relative to Th during the period from ~2760 Ma to ~2710 Ma, and then Th was depleted relative to U after the age of ~2710 Ma, if it is assumed that the Th/U is partitioned in constant proportion into the monazites. This trend of Th/U change is consistent with the conclusion obtained by several studies that U depletion occurred earlier than Th depletion in the Lewisian complex during high-grade metamorphism (Fowler, 1986; Cohen *et al.*, 1991).

It should be noted that the oldest age was obtained from the very small monazite inclusion in garnet. This shows that the host mineral garnet has the ability to shield the monazite inclusion within it from resetting by granulite metamorphism, and indicates that some garnet in the Lewisian granulites was also formed very early. The oldest ages obtained may date from a period before the terrain was finally depleted in U.

Concluding remarks

Because methods of isotope chronology often require mechanical separation of mineral phases, the associated textural and spatial information is lost. Furthermore, it is presently impossible to separate the minerals as small as 10 to 20 microns, although they may contain important information on metamorphic history and crustal evolution. Such small size grains of monazite have been successfully analysed *in-situ* in polished petrological thin sections and the chronological information likely on the prograde part of granulite metamorphism has been obtained. Thus this study demonstrates that the combination of SIMS chronology with detailed petrography offers a significant advance in the study of these materials.

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