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The Significance of Monazite U-Th-Pb Age Data in Metamorphic Assemblages; A Combined Chemical and Isotopic Study

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Of the U-Th- rich accessory phases commonly used in geochronology, monazite is fast becoming the mineral of choice in the dating of medium to high-grade metamorphism in orogenic belts. However, unlike common rock forming minerals, such as garnet, the interpretation of metamorphic monazite U-Th-Pb isotopic data is highly problematic - due largely to a poor understanding of the reactions responsible for the formation and breakdown of monazite during regional metamorphism. This problem is further compounded by a general lack of consistency in high precision U-Th-Pb ages from crystal to crystal (e.g. Parrish, 1995). Thus, at present, despite its chronological utility the application of metamorphic monazite U-Th-Pb dating to geological problems is severely limited.

In this contribution we apply secondary ion mass spectrometry techniques to provide *in situ* U-Th-Pb isotopic measurements of monazites, both included within garnet porphyroblasts and in the matrix of several upper amphibolite-grade rocks from the Himalaya. This approach has the enormous advantage over conventional U-Th-Pb investigations, or more traditional ion probe techniques, in that the textural relationships of monazite are retained. Although the technique has been used before, this contribution involves several novel and important advances. Firstly, we present a full U-Th-Pb dataset for the analysed monazites so that we are not reliant simply on ^{207}Pb-^{206}Pb (e.g. DeWolf et al., 1993) or ^{232}Th-^{208}Pb ages (Harrison et al., 1995). This approach allows us to apply the critical test of concordance to our data. Secondly, we also present estimates of the timing of local garnet growth, independently established using Sm-Nd chronometry. We are thus able to demonstrate, for the first time, that the ages of monazite inclusions in garnet are similar to, or slightly older than, the occluding porphyroblast. As a result, we can combine precise U-Th-Pb ages on monazite inclusions with thermobarometric data from garnet. In addition, this realisation allows us to calculate that in these pelitic assemblages monazite begins to grow at upper greenschist facies (~550ºC at <6kbar).

U-Th-Pb isotopic analyses of matrix grains indicates that matrix monazites are either the same age as the included population (indicating growth at greenschist grade) or are around 5 to 10Ma younger. Detailed chemical analyses of monazite grains indicates that some portions of matrix grains are also chemically distinct from their included counterparts. X-ray maps of Y content show that when a matrix monazite analysis is ~5 Ma younger than the included population, the sampled monazite is Y depleted relative to the included grains. Given that the predominant sink for Y in amphibolite grade metapelites is garnet (e.g. Ayres, 1997), this observation suggests these portions of the matrix grains grew after garnet had crystallised. We are therefore able to place additional constraints on the crystallisation period of the garnet porphyroblast, and the conditions under which this portion of monazite grew can be calculated (upper amphibolite facies; ~700ºC at 10kbar).

The extreme rims of matrix monazites are commonly enriched in Y and are ~10Ma younger than the included grains. Assuming that garnet is controlling the HREE budget, an increase in available Y may relate to garnet breakdown. The period of extreme rim growth coincides with a period of decompression in these rocks, and garnet adsorption during decompression is consistent with textural observations and phase relations calculated for these samples. This approach therefore also allows the duration of metamorphism to be directly dated. In addition, when combined with thermobarometry of the rock-forming minerals, first order approximations of the heating and burial rate can be calculated.

This study illustrates that metamorphic monazite undergoes a complex growth history during regional metamorphism. Until a full understanding of the reactions responsible for its growth and breakdown are recognised the true power of metamorphic monazite chronometry will not be realised. However, we demonstrate that by retaining textural relationships relative to major fabric-forming phases through the application of *in situ* analytical techniques, metamorphic monazite is able to provide temporal information on significant portions of the prograde P-T path of metamorphic pelites. Future geochronological work of this sort, incorporating more detailed studies of Y and HREE distribution in both the dated monazite and major porphyroblast phases, will no doubt further the utility of metamorphic monazite.

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