LA-Q-ICP-MS apatite U/Pb geochronology using common Pb in plagioclase: Examples from layered mafic intrusions

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ABSTRACT

Apatite geochronology is a versatile method for providing medium temperature history constraints of magmatic and metamorphic rocks. The LA-ICP-MS technique is widely applied to U/Pb geochronology using various minerals. Apatite U/Pb geochronology, in contrast to e.g., zircon, is compromised by variable amounts of common Pb incorporated into the crystal during growth. Magmatic apatite often shows a sufficient spread in data to obtain a precise and accurate lower intercept age. If this is not the case, the initial Pb isotopic composition needs to be estimated to obtain accurate and precise age information from apatite. Two approaches are common, one being the estimation of common Pb from a Pb evolution model and the other being the measurement of a coexisting mineral phase that tends to incorporate Pb but not U, e.g., feldspar. Most recent studies applying LA-ICP-MS to the analysis of Pb isotopes in feldspar utilize either multicollector or magnetic sector mass spectrometers. In this study we first evaluate the application of quadrupole mass spectrometry for apatite U/Pb geochronology combined with Pb isotopic measurements in feldspar and compare the results with modeled initial Pb isotopic compositions. The resulting age information is accurate and precise despite using plagioclase rather than K-feldspar, as is normally used, to define initial Pb isotopic compositions. We apply this method to apatite-bearing gabbroic rocks from layered intrusions (Bushveld, Bjerkreim-Sokndal, Hasvik, and Skaergaard) ranging in age from ca. 2 Ga to ca. 55 Ma and generate metamorphic/cooling ages generally consistent with the known geologic history of these intrusions.

Keywords: Apatite, feldspar, common Pb, quadrupole ICP-MS, laser ablation

INTRODUCTION

Apatite is a valuable mineral for geochronology as it occurs as an accessory mineral in magmatic, sedimentary, and metamorphic rocks. In many cases U/Pb ages from apatite agree with zircon in rapidly cooling intrusive rocks (Oosthuyzen and Burger 1973). Nevertheless, substantial differences between U/Pb apatite and zircon ages are observed due to Pb loss or slow cooling (Cliff and Cohen 1980; DeWitt et al. 1984) as the Tc (closure temperature) of zircon and apatite differ significantly, at >900 °C (Lee et al. 1997) and 450–550 °C (Cherniak et al. 1991; Chamberlain and Bowring 2000; Schoene and Bowring 2007) or 375–570 °C (Cochrane et al. 2014), respectively. The Tc of apatite depends on grain size and composition, and is close to the 40Ar/39Ar hornblende Tc of ~550 °C (Harrison 1982), and can therefore be used as a medium-temperature thermochronometer. The cooling rate associated with igneous rocks is mainly controlled by size and stagnation depth of an intrusion and may lead to significant differences in the mineral cooling ages.

In contrast to zircon, apatite tends to incorporate not only U but also Pb during crystallization. For this reason U/Pb data need to be corrected for PbC (common Pb) if there is not enough spread in data to derive a lower intercept age to obtain accurate ages. This is not only true for the samples analyzed but also for the reference material (Chew et al. 2014). For the PbC correction the initial Pb isotopic composition needs to be established. This can be obtained from the two-stage Pb evolution model of Stacey and Kramers (1975), which is an iterative approach. Alternatively, the initial PbC can be derived from the analysis of the Pb isotopic composition of a paragenetic mineral phase like feldspar that tends to incorporate Pb rather than U and thus records the initial PbC isotopic composition at time of crystallization.

In most Pb isotopic studies on feldspar, K-feldspar is used, limiting this technique to evolved samples. It has been considered that plagioclase may incorporate U during crystallization, affecting the 207Pb/206Pb ratio. Schwarze and Miller (1968) found 0.004–0.030 ppm lattice bound U in K-feldspar and 0.003–0.180 ppm affecting the 207Pb/206Pb ratio. Nevertheless, Flowerdew et al. (2012) reported high and variable U contents in a K-feldspar sample leading to large uncertainties in 207Pb/206Pb initial ratios, which might have resulted from partial re-equilibration of Pb isotopes during a late phase of metamorphism. Pb/Pb in feldspar is marked by a Tc of ~700 °C (Cherniak 1995) and can be re-equilibrated during high-grade metamorphic events. Due to the lower Tc of apatite of 375–570 °C this resetting of the Pb isotopic composition in feldspar would have no or little effect on the accuracy and precision of apatite geochronology.

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