Cenozoic denudation of Scotland from (U+Th)/He apatite thermochronology

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Deposition of clastic sediments offshore N. Britain was synchronous with the eruption of voluminous basaltic volcanic rocks in the early Tertiary. This is taken as strong evidence for uplift driven exhumation in response to the impact of the proto-Icelandic plume. Plume tectonism and sedimentation processes are linked through the record of onshore denudation. To date, the timing, magnitude and spatial variability of early Tertiary onshore exhumation remains poorly constrained. The apatite (U+Th)/He thermochronometer has provided the first determination of the timing and amount of Cenozoic denudation. We seek to address three questions:

1) What are the magnitudes and rates of denudation in the early Tertiary?

2) Can early Tertiary denudation be resolved from other Mesozoic/Cenozoic denudation events?

3) Was denudation accommodated via reactivation of major structures such as the Great Glen Fault (GGF)?

The study area straddles the GGF with granitic samples obtained from vertical (~1 km) traverses in the Strontian and Ballachulish plutons. The samples can be subdivided into three structural blocks, with data from each block defining approximately linear age-elevation trends (~10m/My). Sea level samples on either side of the GGF have ages of 85±5 Ma, suggesting that vertical motion on the GGF was not involved in Tertiary denudation. The easternmost block defines an age elevation trend (from 69±4 Ma at 195 m. to 195±12 Ma at 1001 m.) and is interpreted as a fossil He partial retention zone (HePRZ). In this case exhumation must have occurred ~69±4 Ma, approximately consistent with early Tertiary denudation at 55-62 Ma (constrained by volcanism and sedimentation offshore). As the sample from the traverse base is close to the base of the HePRZ, an estimate of the amount of denudation can be made. Assuming geothermal gradients of 20-35°C/km indicates that 1.6 to 3.0 km of total denudation has occurred in the region. Combining these estimates with the inferred duration of volcanism (~7 My) we obtain erosion rates between 200 and 400 m/My. As significant erosion may have continued after the cessation of volcanism, these rates are considered maxima. However, the low elevation samples do not show ages younger than early Tertiary, indicating that they were exhumed to a position in the upper part of, or significantly above, the HePRZ. Therefore Neogene denudation (assuming the above geothermal gradients) is constrained to be ≤0.9-1.6 km. Glacial driven erosion in the Quaternary could account for ~50-200 m. erosion further reducing the amount of Neogene denudation to ≤0.7-1.5 km.

The closure temperature of the Lu-Hf isotopic system in apatite

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Introduction

Dating of ancient high-grade metamorphic terranes allow direct insight into the tectonic and thermal processes that occurred at middle to lower crust level below orogenic belts. Existing dating methods for minerals in metamorphic rocks have been shown to record either crystallization ages or ages corresponding to the temperature at which diffusion of the parent and daughter isotopes ceased (cooling ages). Here, we present the first Lu-Hf dates obtained for metamorphic apatites by a new Lu-Hf separation technique. The studied apatites come from the Adirondack Lowlands and Otter Lake area in the Grenvillian Province and from Black Hills, South Dakota.

Results and conclusions

Comparison of the Lu-Hf dates with ages obtained by sequential Pb step leaching (PbSL) for the same crystals show that closure of the Lu-Hf isotopic system occurs prior to U-Pb closure in apatite.

We find that the Lu-Hf systematics in cm-sized apatite crystals can remain closed during upper amphibolite metamorphism (~650 °C), whereas mm-sized apatites record ages corresponding to Lu-Hf closure during cooling through 600 to 550 °C. The Lu-Hf system in apatite is therefore a strong new dating tool for assessing the extent, timing and duration of high-grade metamorphic processes.