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Terrestrial cosmogenic 3He: where are we 30 years after its discovery?

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It is now 30 years since cosmogenic ^{3}He has been detected for the first time in a terrestrial sample (Kurz, 1986). ^{3}He is now a widely used geochemical tool in many fields of Earth sciences: volcanology, tectonics, paleoclimatology. ^{3}He has the advantage to have a high "production rate" to "detection limit" ratio, allowing surfaces as young as hundred of years to be dated. Although its nuclear stability implies several limitations, it moreover represents a useful alternative to 10Be in mafic environments.

This contribution is a review of the progresses that have been accomplished since this discovery, and discuss strategies to improve both the accuracy and the precision of this geochronometer.

1) Measurement of cosmogenic ^{3}He

Correction of magmatic ^{3}He. To estimate the non-cosmogenic magmatic ^{3}He, Kurz (1986) invented a two steps method involving crushing of phenocrysts (to analyze the isotopic ratio of the magmatic component), followed by a subsequent melting of the sample, to extract the remaining components, including the cosmogenic ^{3}He:

$^{3}\mathrm{He}_c = {}^{3}\mathrm{He}_{melt} - {}^{4}\mathrm{He}_{melt}$ x $(^{3}\mathrm{He}/^{4}\mathrm{He})_{magmatic}$ (1)

Several studies suggested that the preliminary crushing may induce a loss of cosmogenic ^{3}He (Hilton et al., 1993; Yokochi et al., 2005; Blard et al., 2006), implying an underestimate of the cosmogenic ^{3}He measurement. However, subsequent work did not replicate these observations (Blard et al., 2008; Goerhing et al., 2010), suggesting an influence of the used apparatus. An isochron method (by directly melting several phenocrysts aliquots) is an alternative to avoid the preliminary crushing step (Blard and Pik, 2008).

Atmospheric contamination. Protin et al. (in press) provides robust evidences for a large and irreversible contamination of atmospheric helium on silicate surfaces. This unexpected behavior may reconcile the contrasted observations about the amplitude of crushing loss. This undesirable atmospheric contamination is negligible if grain fractions smaller than 150 mm are removed before melting.

Correction of radiogenic ^{4}He and nucleogenic ^{3}He. Equation 1 is valid only if the ^{4}He extracted by melting is entirely magmatic. To account for a possible radiogenic ^{4}He component, it is crucial to properly estimate the radiogenic ^{4}He production rate, by measuring the U, Th and Sm concentrations of both phenocryst and host, and the phenocryst size. Estimating the nucleogenic ^{3}He also requires measuring Li in the phenocryst.

Accuracy of analytical systems. A recent inter-laboratory comparison involving 6 different groups indicated systematic offsets between labs (up to 7%) (Blard et al., 2015). Efforts must be pursued to remove these inaccuracies.

2) Production rates

Absolute calibration. There are 25 ^{3}He calibration sites among the world, from -47˚S to 64˚N in latitude, and from 35 to 3800 m in elevation. After scaling these production rates to sea level high latitude, this dataset reveals a significant statistical dispersion (ca. 13%). Efforts should be focused on regions that are free of data and others, such as the Eastern Atlantic that yields values systematically off.

^{3}He/^{10}Be cross calibrations. Some studies (Gayer et al., 2004 ; Amidon et al., 2009) identified an altitude dependence of the ^{3}He/^{10}Be production ratio in the Himalayas, while other data from the Andes and Africa did not (Blard et al., 2013b ; Schimmelpfennig et al., 2011). There is thus a crucial need for new data at high and low elevation, with and without snow, to precisely quantify the cosmogenic thermal neutron production. Artificial target experiments may also be useful.