

Research Paper

# In situ cosmogenic $^{10}\text{Be}$ in olivines and pyroxenes

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Received 6 February 2007; received in revised form 23 August 2007; accepted 26 November 2007

Available online 11 January 2008

## Abstract

This study proposes an efficient new cleaning procedure for measuring in situ cosmogenic  $^{10}\text{Be}$  in olivines and pyroxenes. This chemical routine is specially designed to decontaminate the abundant meteoric  $^{10}\text{Be}$  from these minerals. The method was tested on mafic minerals from basaltic flows of Mt. Etna volcano and from Hawaiian flows and moraines. A sequential dissolution test shows that  $^{10}\text{Be}$  concentrations decrease with the number of cleaning steps until reaching a constant value. This is a necessary condition to demonstrate the efficiency of the method in properly decontaminating samples of meteoric  $^{10}\text{Be}$ . Moreover, cross-calibration with cosmogenic  $^3\text{He}$  measured within the same samples yielded a sea level high-latitude production rate of  $4.5 \pm 0.4 \text{ at g}^{-1} \text{ a}^{-1}$  for cosmogenic  $^{10}\text{Be}$  in mafic minerals. This rate is within  $1\sigma$  uncertainty of empirically or model-derived rates for  $^{10}\text{Be}$  on the same targets. Such concordance supports the consistency of the new method.

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**Keywords:** Cosmogenic; Beryllium; Helium; Olivine; Pyroxene; Chemical cleaning routine; Calibration; Lava flows; Production rate; Mt Etna; Mauna Kea

## 1. Introduction

Cosmogenic nuclides produced in terrestrial rocks provide an efficient way to quantify several Earth-surface processes (Gosse and Phillips, 2001). To be reliably interpreted, most terrestrial cosmogenic nuclides (TCN) must be measured within specific pure mineral phases because: (i) the nuclide production rates, which depend on the major elements composition, may vary from one mineral to another (Masarik and Reedy, 1995), and (ii) the crystalline structure governs the capacity of retention of TCN (Trull et al., 1991), and the decontamination of an atmospheric component (when it exists) (Brown et al., 1991). Until now, applications of TCN have been restricted to the following systems:

(i)  $^{10}\text{Be}$ ,  $^{14}\text{C}$ ,  $^{21}\text{Ne}$  and  $^{26}\text{Al}$  in quartz (e.g., Nishiizumi et al., 1986; Lifton et al., 2001; Graf et al., 1991);

- (ii)  $^3\text{He}$  and  $^{21}\text{Ne}$  in olivines, pyroxenes, garnets apatite, zircon and iron oxides (e.g. Kurz, 1986a; Marti and Craig, 1987; Gayer et al., 2004; Kober et al., 2005; Farley et al., 2006);
- (iii)  $^{36}\text{Cl}$  in Ca- or K-rich phases (e.g. Phillips et al., 1986; Stone et al., 1996).

Thus, exposure history applications are limited to a small number of TCN-minerals systems. In particular, mafic environments have been restricted to the stable noble gases  $^3\text{He}$  and  $^{21}\text{Ne}$  and to the radioactive nuclide  $^{36}\text{Cl}$ . However, the application of  $^{36}\text{Cl}$  may be limited by half-life considerations ( $T_{1/2} = 301 \text{ ka}$  for  $^{36}\text{Cl}$ ). Consequently, the capacity to measure a longer-lived radioactive isotope in olivines or pyroxenes may have important implications for geomorphological studies in mafic environments, such as dating of burial events (e.g. Granger et al., 1997), or the determination of successive exposure histories (e.g. Blard et al., 2006a).

The major limitation for measuring in situ cosmogenic  $^{10}\text{Be}$  ( $^{10}\text{Be}_c$ ) is the complete removal of the atmospheric contamination from the mineral phase of interest

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(Brown et al., 1991). Cosmogenic  $^{10}\text{Be}$  is also produced in the atmosphere through cosmic ray interactions with  $^{14}\text{N}$  and  $^{16}\text{O}$ , the average flux of atmospheric  $^{10}\text{Be}$  being about three orders of magnitude higher than the integrated production rate of in situ  $^{10}\text{Be}_c$  produced within  $1\text{ cm}^3$  of surficial rock (Monaghan et al., 1986). This meteoric  $^{10}\text{Be}$  ( $^{10}\text{Be}_m$ ) may then be incorporated into weathered mineral zones via superficial circulations of meteoric waters. Reliable measurement of the  $^{10}\text{Be}_c$  concentration within weathered minerals thus requires an efficient procedure to remove this  $^{10}\text{Be}_m$  contamination. In the case of quartz, a chemical treatment based on hydrofluoric acid (HF) step dissolution was demonstrated to be an efficient process to remove  $^{10}\text{Be}_m$  (Brown et al., 1991). In one particular study focusing on olivines (Nishiizumi et al., 1990), this method showed quite promising results but, in other cases, HF step dissolution appears to be unsuitable for olivines (Seidl et al., 1997) and pyroxenes (Ivy-Ochs et al., 1998).

In an attempt to extend the use of  $^{10}\text{Be}_c$  to mafic minerals, we developed an original decontamination procedure for olivines and pyroxenes. This treatment was tested on variously altered olivines and clinopyroxenes from surficial samples of Quaternary lava flows of Mt. Etna volcano (Sicily,  $38^\circ\text{N}$ ) and from one flow and boulders on two moraines of the Late Pleistocene glaciation of Mauna Kea (Hawaii,  $19^\circ\text{N}$ ). The  $^{10}\text{Be}$  measurements are combined with independent determination of the in situ cosmogenic  $^3\text{He}$  ( $^3\text{He}_c$ ) concentrations in the same samples. This multi-nuclide approach helps verify the chemical procedure and provides a means to estimate the  $^{10}\text{Be}_c$  production rate in the samples we measured.

## 2. Geological setting and samples

Olivines and clinopyroxenes are suitable minerals for measuring  $^3\text{He}_c$  with a low analytical uncertainty ( $1\sigma < 10\%$ ) (e.g. Ackert et al., 2003; Blard et al., 2006b). Moreover,  $^3\text{He}_c$  production rate in these phases is reasonably well constrained (between 115 and 128 at  $\text{g}^{-1}\text{ a}^{-1}$ ) by empirical determinations (e.g. Kurz et al., 1990; Cerling and Craig, 1994; Ackert et al., 2003; Licciardi et al., 2006; Blard et al., 2006b). Consequently, coupled determination of  $^3\text{He}_c$  and  $^{10}\text{Be}_c$  in the same exposed samples can be used to calibrate  $^{10}\text{Be}$  production rates, and, importantly, to crosscheck the efficiency of the new chemical method proposed here.

The surficial samples studied here belong to two different geological settings: lava flows from Mt. Etna volcano (Sicily,  $38^\circ\text{N}$ ), and lava flow and moraine boulders from Mauna Kea (Hawaii,  $19^\circ\text{N}$ ).

Mount Etna (Sicily,  $38^\circ\text{N}$ ) flows have several characteristics that make it favorable to test the reliability of  $^{10}\text{Be}_c$  measurement in clinopyroxenes. First, its Quaternary trachybasalts have a primordial Ar composition with an atmospheric  $^{36}\text{Ar}/^{40}\text{Ar}$  ratio, and are thus well suited for accurate K–Ar dating (Gillot et al., 1994). Second, these basalt surfaces have several features, such as preserved ropes and tumuli, which suggest erosion has been minimal since the initiation of exposure. Third, most of the Etnaites are sufficiently rich in phenocrysts (from 2% to 4% in mass) to yield enough pure clinopyroxenes (several grams) for measurement of  $^{10}\text{Be}_c$ . Three samples from two different flows were considered here (Table 1). Two samples (SI41 and SI27a) were

Table 1  
Samples description

Sample	Mineral phase studied	Altitude (m)	Latitude	Longitude	Surface description	Thickness (cm)	K–Ar age/exposure duration <sup>a</sup> (ka $\pm$ 1 $\sigma$ )
Mt. Etna (Sicily)							
Nave flow (top)							
SI27a	70% pyroxenes 30% olivines	1195	37°49'.39N	14° 54'.96E	Ropy basaltic flow	5	32 $\pm$ 4
Nave flow (bottom)							
SI41	Clinopyroxenes	820	37°50'.91N	14° 50'.10E	Ropy basaltic flow	15	33 $\pm$ 2
Piano Della Lepre flow							
SI43	Clinopyroxenes	2070	37°42'.57N	15° 1'.55E	Ropy basaltic flow	15	10 $\pm$ 3
Mauna Kea (Hawaii)							
Moraines							
MK11	Olivines	3590	19°47'.74N	155°29.54W	Boulder (1 m height)	3	15 $\pm$ 2
MK12C	Olivines	3190	19°47'.05N	155°30.09W	Boulder (2.5 m height)	3	18 $\pm$ 2
Waimea airport flow							
MK4	Olivines	840	19°59'.32N	155°40.00W	Ropy basaltic flow	3	149 $\pm$ 23

<sup>a</sup>Flows ages are from K–Ar dating (Blard et al., 2005; Wolfe et al., 1997). Hawaiian moraines ages are from  $^3\text{He}_c$  dating of several boulders of the same glacial deposit (Blard et al., 2007).

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