

Diffusive loss of matrix-sited helium during vacuum crushing of mafic phenocrysts

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1 Introduction

Cosmogenic ³He (³He_c) is one of the most promising cosmic-ray produced nuclide, not only because its nuclear stability permits quantitative constraints over several million years of exposure, but also because its low detection limit allow quantification of young exposure events (<1000 years).

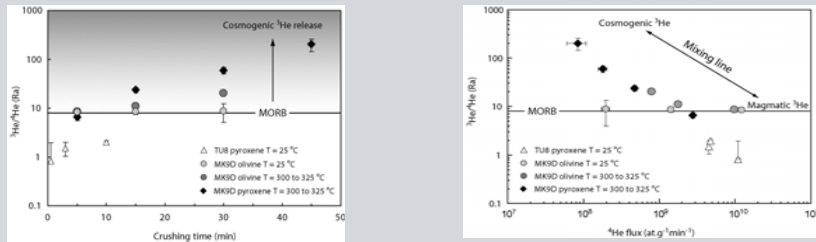
To isolate each of helium components, in the case of mafic phenocrysts (olivine and pyroxenes), vacuum crushing has been widely adopted, because of its supposed ability to selectively release the magmatic helium contained within fluid and melt inclusions without extracting matrix-sited cosmogenic ³He (Kurz, 1986). However, recent studies have demonstrated that prolonged crushing may cause the extraction of significant amount of matrix sited helium. (Scarsi, 2000)

The mechanisms controlling the release of matrix-sited ³He_c are not understood yet and this uncertainty still hampers the development of alternative strategies to avoid matrix helium losses during crushing. Several recent studies (Moreira and Madureira, 2005; Yokochi et al., 2006; Blard et al., 2006) proposed that the crushing-release of ³He_c was either controlled (i) by a mechanism involving spallation tracks, that may provide an efficient pathway for helium extraction when tracks encounter newly created fractures, or (ii) helium release at the fractured surface due to lattice distortion caused by plastic deformation of the grain during crushing.

In this study, we present results from new experiments designed to address these issues and to establish the mechanisms controlling release of ³He_c during vacuum crushing.

2 In-vacuum crushing of olivine & pyroxene

Phenocrysts of olivine (from Mauna-Kea : MK9D) and pyroxene (Mauna-Kea : MK9D, and Bolivia : TU8) were crushed under vacuum at 25°C and 300-325°C in a steel tube with a magnetic-activated slug, between 30 and 45 min.



→ During the crushing, for both olivine and pyroxene, the ⁴He flux decreases with the time of crushing following an exponential law, suggesting a single magmatic ⁴He reservoir (Scarsi, 2000).

→ At standard temperature (25°C), the ³He/⁴He ratio remains constant and equal to the magmatic ratio for the Hawaiian samples (8 Ra) (Blard et al., 2007) which primarily indicates no loss of ³He from the matrix.

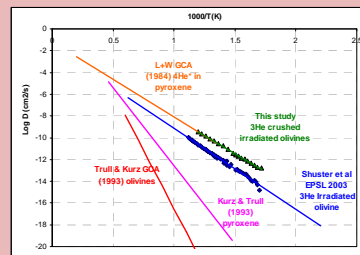
→ At high temperature (300°C to 325°C), both olivine and pyroxene are characterized by an important increase of the ³He/⁴He ratio during the crushing, suggesting a progressive loss of ³He from a reservoir that is different from the magmatic helium. These ratios correspond to a loss of 3.3% for MK9D olivine to 8.1% for MK9D pyroxene.

3 New diffusivity data from crushed irradiated olivines

Diffusion experiments have been carried out on crushed minerals in order to check if the crushing could enhance the diffusivity of the matrix-sited helium. We used irradiated olivine with very high quantity of matricial ³He.

The San Carlos (Mexico) olivines were crushed in the tube, in vacuum, at 25°C, during 25 min, while the Guadalupe Island olivines were crushed in air using a hammer.

→ Despite a slight increase in the diffusivity with both crushing mechanisms the new diffusivity data are not significantly different from those of Schuster et al. (2004) from the same samples.



background photo: MK9D olivine after crushing, sieving (39-74 micrometers) and cleaning in alcohol, seen in a binocular microscope

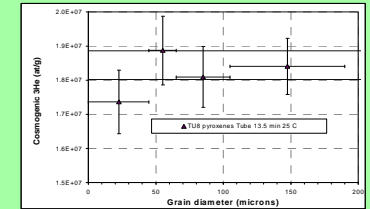
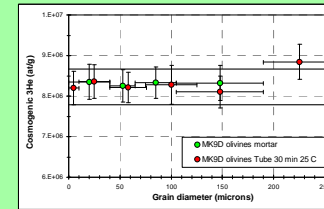
4 Cosmogenic ³He loss vs grain size

After in-vacuum crushing, the obtained powder was cleaned and sieved to yield different fractions ranging in size from <10 μm to ~200 μm. Each size fraction was thus melt in a furnace at 1600 °C to release all the matrix-sited helium.

In order to test the influence of the crushing conditions, we also measured the ³He_c concentration in different fractions from a MK9D olivine sample that was crushed in a mortar, in air, under cold conditions.

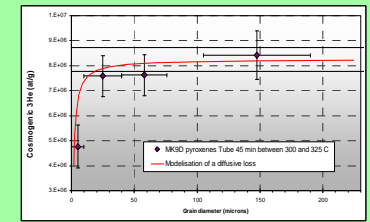
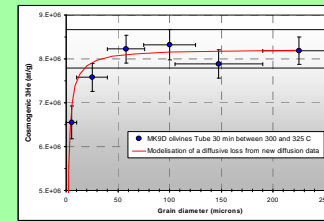
Results from samples crushed in cold conditions (25 °C)

In all these graphics, the two thick black lines indicate the range of ³He_c concentration in uncrushed samples. Shown range is ±1σ.



→ Samples crushed in cold conditions do not exhibit significant loss of ³He_c, whatever the size of the grains or the crushing method.

Results from samples crushed in hot conditions (300 °C)



→ Samples crushed in hot conditions are characterized by a significant loss only that only affects the finest fractions. The amplitude of the loss is well consistent with a thermal diffusion pattern calculated using the new diffusion data from crushed samples (see part 2)

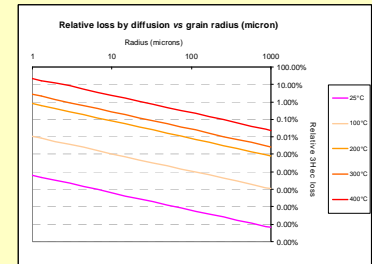
5 Conclusion

→ Significant helium extraction (>1%) was manifest only under hot conditions. Moreover, the ³He_c measured within each size fraction showed that the ³He_c loss (>20%) only affected the finest fraction (<10 μm).

The previously proposed mechanism involving spallation tracks is invalid, given the loss predicted by this model should be >10% for the <10 μm fraction, even at low temperature, and its dependence on the granulometry whatever the temperature.

Consequently, temperature appears as an essential parameter that should be carefully controlled and considered in any studies involving vacuum crushing. Using the new diffusion data from crushed minerals, it is possible to plot the theoretical loss of ³He_c as a function of the grain size and the temperature for a 10-minute crushing →

However, if we propose that volume diffusion is the predominant mechanism triggering the largest losses, our conclusions also show that other extraction mechanisms are probably responsible of a ~1% ³He_c loss, even under cold conditions. Although the nature of this mechanism is still poorly understood, this apparently unavoidable loss should be carefully considered when unshielded samples are used for measuring magmatic ³He/⁴He ratios.



References:

- M.D. Kurz, In situ production of terrestrial cosmogenic helium and some applications to geochronology, *Geochimica et Cosmochimica Acta* 50(1986) 2855-2862.
- P. Scarsi, Fractional extraction of helium by crushing of olivine and clinopyroxene phenocrysts: Effects on the ³He/⁴He measured ratio, *Geochimica et Cosmochimica Acta* 64(2000) 3751-3762.
- Blard, P.-H., Lave, J., Pik, R., Wagon, P., and Bourès, D., 2007. Persistence of full glacial conditions in the central Pacific until 15,000 years ago. *Nature* doi: 10.1038/nature06142.
- P.-H. Blard, R. Puk, J. Lave, D. Bourès, D.G. Burnard, R. Yokochi, B. Marty, F. Truesdell, Cosmogenic ³He production rates revisited from evidences of grain size dependent release of matrix sited helium, *Earth and Planetary Science Letters* 247(2006) 222-234.
- R. Yokochi, B. Marty, R. Puk, P. Burnard, High ³He/⁴He ratios in peridotite xenoliths from SW Japan revisited: Evidence for cosmogenic ³He released by vacuum crushing, *Geochemistry Geophysics Geosystems* 6(2005).
- M. Moreira, P. Madureira, Cosmogenic helium and neon in 11 Myr old ultramafic xenoliths: Consequences for mantle signatures in old samples, *Geochemistry Geophysics Geosystems* 6(2005).