

The effect of fluid alteration in Antarctic chondrites

Ryoga Maeda^{1,2,3}, Steven Goderis², Akira Yamaguchi⁴, Vinciane Debaille³ and Philippe Claeys²

¹Submarine Resources Research Center (SRRC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan

²Archaeology, Environmental changes, and Geo-Chemistry (AMGC), Vrije Universiteit Brussel, Belgium

³Laboratoire G-Time, Université libre de Bruxelles, Belgium

⁴National Institute of Polar Research, Japan

Introduction

Since the first systematic meteorite recovery expedition in Antarctica was conducted in 1973 and followed by expeditions until the present [1], the Antarctic meteorite collection plays a pivotal role for cosmochemistry as the recovered fragments constitute by number more than 60% of the population of all meteorites collected to date. Meteorites accumulate due to the very slow movements of the glacial ice (~several tens of m/year for the inland ice) and following upward ice movement. Although Antarctic meteorite finds are typically better protected from terrestrial weathering by burial in the ice than meteorites collected from hot deserts, the exposure of Antarctic meteorites to the extreme Antarctic climate during an extended period of time can still lead to physical and chemical alteration [2]. As such, previous studies examined the effect of Antarctic alteration not only using mobile elements but also (relatively) immobile elements, such as the rare earth elements (REEs) [3]. However, no systematic studies regarding the effects on REEs are available for chondrites and the detailed mechanisms of the alteration remain poorly understood. Therefore, we evaluated the effect of Antarctic alteration on REEs in H chondrites (HCs), particularly focusing on their Sm-Nd and Lu-Hf isotope systematics, and investigated the underlying alteration mechanism, using a comprehensive analysis combining bulk analysis with *in-situ* measurements.

Experimental

Ten Antarctic HCs and three HCs collected from hot deserts were characterized for their elemental abundances and Sm-Nd and Lu-Hf isotopic compositions using ICP-OES, ICP-Q-MS, and MC-ICP-MS. The corresponding polished thick sections (PTS) of each sample as well as those of four HC falls were also used to obtain elemental maps using μ -XRF and LA-ICP-TOF-MS. Finally, the major and trace element abundances in the constituent minerals and cracks of the samples were determined using EPMA and LA-ICP-SF-MS [4-6].

Results and Discussion

According to our results, the modal and elemental abundances in Antarctic HCs appear to be in good agreement with the published data obtained for fresh falls regardless of their degrees of weathering [7]. The Sm-Nd and Lu-Hf isotopic compositions of the characterized HCs fall within the range measured for both HC falls and falls of other chondrite groups (Fig.

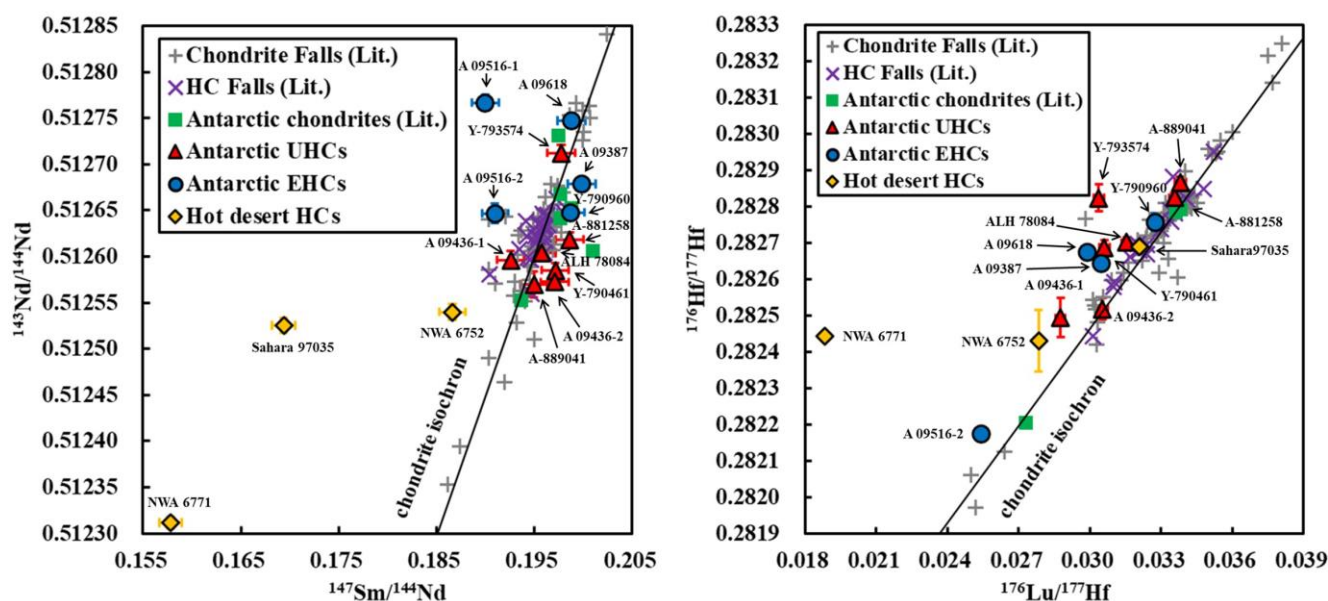


Fig. 1. Sm-Nd and Lu-Hf isotopic compositions of Antarctic unequilibrated (U) HCs, Antarctic equilibrated (E) HCs, and HCs collected from hot deserts together with their literature values (Lit.) of chondrite falls, HC falls, and Antarctic chondrites.

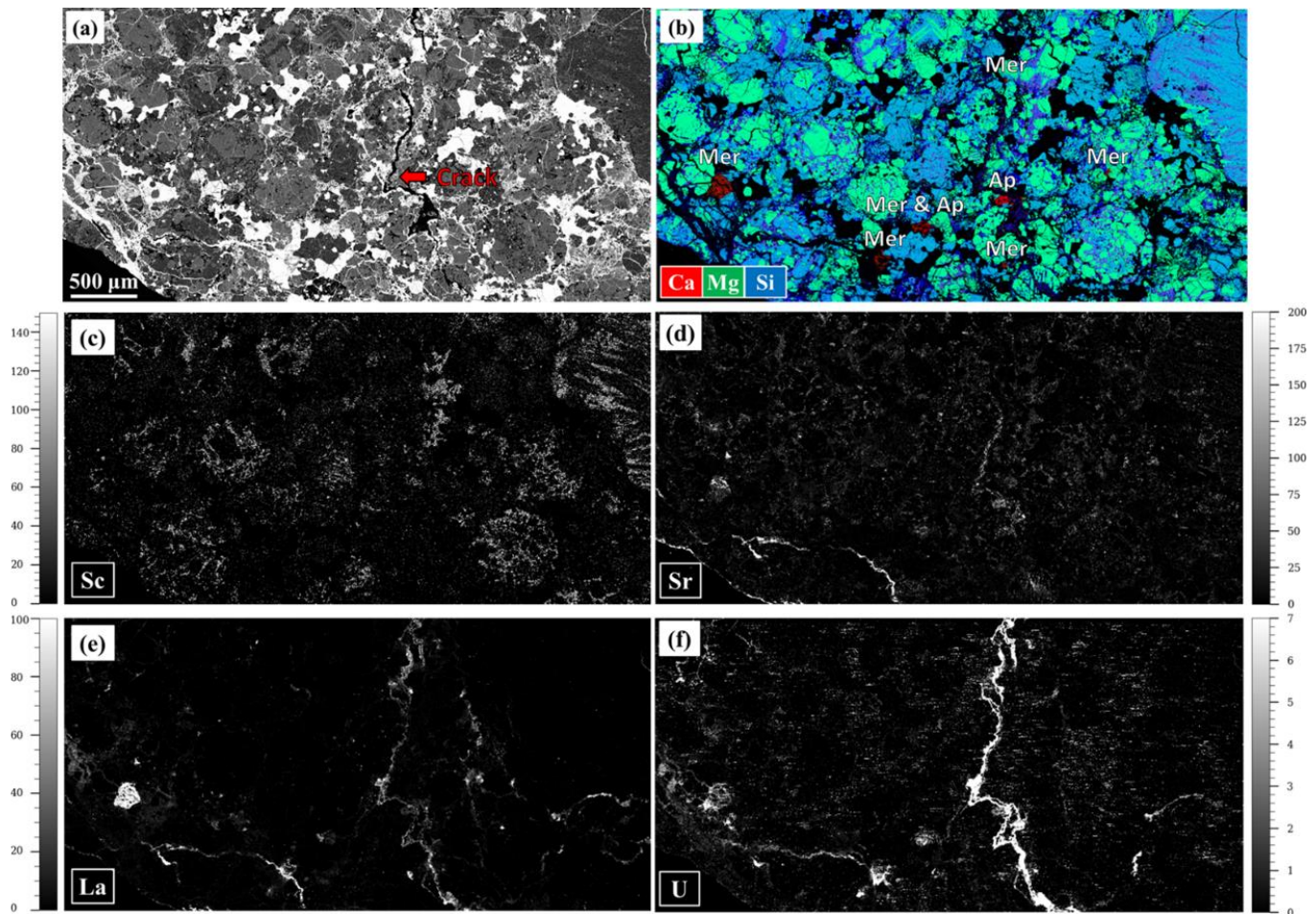


Fig. 2. BSE image and (semi-)quantitative element maps for A 09618 (H5). (b) Mer: merrillite; Ap: chlorapatite. Concentration scale bars for (c) to (f) are expressed in ppm.

1). However, a heavily altered Antarctic HC, A 09516 (H6), indicates various element losses including for the REEs, disturbing their Sm-Nd and Lu-Hf isotopic compositions. Such high elemental losses reflect partial dissolution of Ca-phosphates during alteration because the elemental losses cannot be explained by a simple loss of Ca-phosphates.

On the other hand, their trace elemental distributions based on LA-ICP-TOF-MS mapping and line-scanning by LA-ICP-SF-MS display that a considerable amount of REEs, Th, and U, and in some cases only Ce resides in cracks (Fig. 2). These cracks appear to accumulate unbound REEs locally accompanied by Th and U relative to the major element abundances, especially P and Si. As these remarkable features are observed mostly in heavily weathered samples but not in less altered samples including falls, the elemental mobilization is interpreted to result from the partial dissolution of Ca-phosphate phases taking place when fluids pass through the meteorite interiors during terrestrial weathering, which is consistent with the interpretation based on the results of the bulk analysis.

In conclusion, this study demonstrates that Antarctic HCs commonly retain their original chemical and mineralogical compositions regardless of their degrees of weathering even though the corresponding PTSs exhibit localized element mobilization and re-deposition, indicating that the fluid alteration occurs at the micro-scale only and its effect at the bulk scale is generally limited. This confirms the usefulness of Antarctic meteorites for some radiogenic age determinations such as the Sm-Nd and Lu-Hf systems. However, when the partial dissolution of Ca-phosphate phases by fluids during terrestrial weathering is extensive, both the elemental and isotopic compositions of the sample are modified, in some cases accompanied by severe degrees of mineralogical alteration [4, 6].

References

- [1] Debaille *et al.* (2023) *Antarctic Rec.*, accepted.
- [2] van Ginneken *et al.* (2022) *Meteorit. Planet. Sci.* **57**, 1247-1266.
- [3] Crozaz *et al.* (2003) *Geochim. Cosmochim. Acta* **67**, 4727-4741.
- [4] Maeda *et al.* (2021) *Geochim. Cosmochim. Acta* **305**, 106-129.
- [5] Maeda *et al.* (2023) *J. Anal. At. Spectrom* **38**, 369-381.
- [6] Maeda *et al.* (2023) *Meteorit. Planet. Sci.* **58**, 1018-1038.
- [7] McSween *et al.* (1991) *Icarus* **90**, 107-116.