Available online at www.sciencedirect.com

ScienceDirect

Geochimica et Cosmochimica Acta 212 (2017) 196–210

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

The parent body controls on cosmic spherule texture: Evidence from the oxygen isotopic compositions of large micrometeorites

M. van Ginneken[a,b,*], J. Gattacceca[c], P. Rochette[c], C. Sonzogni[c], A. Alexandre[c], V. Vidal[c], M.J. Genge[a]

[a] *IARC, Department of Earth Science and Engineering, Imperial College London, Exhibition Road, London SW7 2AZ, UK*
[b] *Department of Earth Sciences, The Natural History Museum, Cromwell Road, London SW7 5BD, UK*
[c] *CNRS/Aix-Marseille Université, IRD, Collège de France, CEREGE UM34, Aix-en-Provence, France*

Received 1 September 2016; accepted in revised form 8 May 2017; available online 16 May 2017

Abstract

High-precision oxygen isotopic compositions of eighteen large cosmic spherules (>500 μm diameter) from the Atacama Desert, Chile, were determined using IR-laser fluorination – Isotope Ratio Mass spectrometry. The four discrete isotopic groups defined in a previous study on cosmic spherules from the Transantarctic Mountains (Suavet et al., 2010) were identified, confirming their global distribution. Approximately 50% of the studied cosmic spherules are related to carbonaceous chondrites, 38% to ordinary chondrites and 12% to unknown parent bodies. Approximately 90% of barred olivine (BO) cosmic spherules show oxygen isotopic compositions suggesting they are related to carbonaceous chondrites. Similarly, ~90% porphyritic olivine (Po) cosmic spherules are related to ordinary chondrites and none can be unambiguously related to carbonaceous chondrites. Other textures are related to all potential parent bodies. The data suggests that the textures of cosmic spherules are mainly controlled by the nature of the precursor rather than by the atmospheric entry parameters. We propose that the Po texture may essentially be formed from a coarse-grained precursor having an ordinary chondritic mineralogy and chemistry. Coarse-grained precursors related to carbonaceous chondrites (i.e. chondrules) are likely to either survive atmospheric entry heating or form V-type cosmic spherules. Due to the limited number of submicron nucleation sites after total melting, ordinary chondrite-related coarse-grained precursors that suffer higher peak temperatures will preferentially form cryptocrystalline (Cc) textures instead of BO textures. Conversely, the BO textures would be mostly related to the fine-grained matrices of carbonaceous chondrites due to the wide range of melting temperatures of their constituent mineral phases, allowing the preservation of submicron nucleation sites. Independently of the nature of the precursors, increasing peak temperatures form glassy textures.

Keywords: Micrometeorites; Cosmic spherules; Oxygen isotopes; Laser fluorination; Parent bodies

Abbreviations: CS, cosmic spherule; TFL, terrestrial fractionation line; TAM, Transantarctic Mountains

* Corresponding author at: Laboratoire G-Time, Université Libre de Bruxelles, Av. F.D. Roosevelt 50, 1050 Brussels, Belgium. Department of Analytical, Environmental and Geo- Chemistry, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, Belgium.
E-mail address: Matthias.Van.Ginneken@ulb.ac.be (M. van Ginneken).

http://dx.doi.org/10.1016/j.gca.2017.05.008
0016-7037/

1. INTRODUCTION

Micrometeorites are extraterrestrial particles 10 μm–2 mm in size, which represent in terms of mass the most important part of the flux of extraterrestrial material to accrete to the Earth's surface (Rubin and Grossman, 2010). One of the most important objectives of studies on micrometeorites is to identify their parent bodies. Studies based on petrographic and mineralogical evidence have suggested that between 75% and 99% of unmelted micrometeorites ≤250 μm in size should have fine-grained precursors similar to the matrices of carbonaceous chondrites (Engrand and Maurette, 1998; Noguchi et al., 2002; Taylor et al., 2012).

The measurement of the triple isotopic composition of oxygen is a powerful tool for the classification of planetary materials and allows correlation with known parent bodies in the solar system (Clayton et al., 1991; Clayton and Mayeda, 1999). A clear distinction, for example, between ordinary chondrites and carbonaceous chondrites is possible because, on a $\delta^{17}O/\delta^{18}O$ chart, the former plots above the terrestrial fractionation line (hereafter TFL and defined by $\delta^{17}O = 0.52 * \delta^{18}O$), whereas, except for the CI chondrites that overlap the TFL, the latter plots below the TFL. Studies based on ion microprobe analyses have shown that the oxygen isotopic bulk compositions of micrometeorites mostly plot below the TFL, therefore suggesting that these particles have carbonaceous chondrite-related precursors (Clayton and Mayeda, 1999; Engrand et al., 2005; Taylor et al., 2005; Yada et al., 2005). However, the large analytical uncertainties of ion microprobe analyses (±1–2.75‰ on $\delta^{18}O$, ±0.7–1.7‰ on $\delta^{17}O$, and ±0.6–1.7‰ on $\Delta^{17}O$ for individual analyses; Engrand et al., 2005; Yada et al., 2005) mean that values close to the compositional field of ordinary chondrites ($\Delta^{17}O \approx 0.5$–1.5‰) overlap with the TFL, preventing a clear identification of the parent bodies of these micrometeorites. Recent studies aiming at determining the oxygen isotopic composition of melted micrometeorites from the Transantarctic Mountains (TAM) > 500 μm in size, have used the IR-laser fluorination – Isotope Ratio Mass spectrometry (IRMS) technique (Cordier et al., 2011a; Suavet et al., 2010, 2011; Cordier and Folco, 2014). An advantage of this technique is its high reproducibility and accuracy which allow a clear identification of micrometeorites having oxygen isotopic compositions plotting close to the TFL (e.g., ordinary chondrite-related precursors). An important conclusion from these studies is that in the size fractions studied, the contribution of micrometeorites having ordinary chondrite-related precursors is significant (i.e., between 30% and 70%).

Suavet et al. (2010) noted that micrometeorites plot in four discrete groups on a three-oxygen diagram, each linked to distinct parent bodies. In particular, the discovery of micrometeorites having oxygen isotopic compositions that are not linked to any known parent body showed that micrometeorites include samples of small solar system objects not sampled by meteorites.

The main aim of this study is to further identify the parent bodies of cosmic spherules using high resolution oxygen isotopes by IR-laser fluorination-IRMS and thus to examine whether the textural types of cosmic spherules relate to parent body or are imposed by the nature of melting in the atmosphere as suggested by Suavet et al. (2010) on a much smaller dataset. If texture could be used as a proxy for parent body then the contribution of different sources to the Earth's extraterrestrial dust flux could be evaluated using data from thousands of characterized particles rather from just a limited number of particles for which oxygen isotope data is available. Cosmic spherules (CS, i.e. fully melted micrometeorites) from the Atacama Desert are used in this study since they not only include large enough particles (i.e. >500 μm) to perform IR-laser fluorination-IRMS but also provide a useful comparison to the previously analyzed TAM collection particles that will allow study of the distribution of the parent bodies of CSs.

2. MATERIALS AND METHODS

2.1. Samples

Cosmic spherules were randomly extracted from soil collected in 2006 in the Atacama Desert (Chile) at 24.43°S, 70.31°W following a methodology developed in Antarctica (Rochette et al., 2008). Hutzler et al. (2016) have shown that this area yields a meteorite density of the order of 100 meteorite >10 g/km^2, and exposure ages >5 Ma. This explains the high density of micrometeorites in the sampled soil. Soil was first sieved (200–800 μm), and then submitted to magnetic separation. Micrometeorites were then hand-picked from the magnetic fraction under a binocular microscope, on the basis of their spherical shape and dark color. This technique yielded over 2000 magnetic CSs, lacking the non-magnetic V-type CSs, which mainly consist of glass (Genge et al., 2008). The present study focuses on 18 CSs >500 μm in size. Their masses range from 235 to 627 μg (530–820 μm in diameter, respectively). Prior to analyses of the triple isotopic composition of oxygen, CSs showing obvious effects of terrestrial weathering under SEM (e.g., silicate crystal dissolution; Van Ginneken et al., 2016) were treated with HCl in order to remove possible alteration products, such as carbonates and sulfates, which may affect the primary isotopic signature of the particles. Several non-destructive techniques were used to characterize these CSs before the oxygen isotope measurements. In addition to 14 particles already collected and studied by Kohout et al. (2014), four CSs, #10.16, #10.17, #10.18 and #10.20, were selected at CEREGE (Aix-en-Provence, France) for oxygen isotope analyses (Fig. 1).

2.2. Characterization methods

2.2.1. Petrography

Information on the external structure of these four particles was gathered using a LEO 1455 environmental