Characterization of carbon phases in Yamato 74123 ureilite to constrain the meteorite shock history

ANNA BARBARO1,*, FABRIZIO NESTOLA2,3, LIDIA PITTARELLO4, LUDOVIC FERRIÈRE4, MARA MURRI5, KONSTANTIN D. LITASOV6, OLIVER CHRIST5, MATTEO ALVARO5, AND M. CHIARA DOMENEGHETTI1

1Department of Earth and Environmental Sciences, University of Pavia, Via A. Ferrata 1, I-27100 Pavia, Italy
2Department of Geosciences, University of Padova, Via Gradeno 6, 35131 Padova, Italy
3Geoscience Institute, Goethe-University Frankfurt, Altenhöferallee 1, 60323 Frankfurt, Germany
4Department of Mineralogy and Petrography, Natural History Museum, Burgring 7, 1010 Vienna, Austria
5Department of Earth and Environmental Sciences, University of Milano-Bicocca, I-20126 Milano, Italy
6Vereshchagin Institute for High Pressure Physics RAS, Troitsk, Moscow, 108840 Russia

ABSTRACT

The formation and shock history of ureilite meteorites, a relatively abundant type of primitive achondrites, has been debated for decades. For this purpose, the characterization of carbon phases can provide further information on diamond and graphite formation in ureilies, shedding light on the origin and history of this meteorite group. In this work, we present X-ray diffraction and micro-Raman spectroscopy analyses performed on diamond and graphite occurring in the ureilite Yamato 74123 (Y-74123). The results show that nano- and microdiamonds coexist with nanographite aggregates. This, together with the shock-deformation features observed in olivine, such as mosaicism and planar fractures, suggest that diamond grains formed by a shock event (≥15 GPa) on the ureilite parent body (UPB). Our results on Y-74123 are consistent with those obtained on the NWA 7983 ureilite and further support the hypothesis that the simultaneous formation of nano- and microdiamonds with the assistance of a Fe-Ni melt catalysis may be related to the heterogeneous propagation and local scattering of the shock wave. Graphite geothermometry revealed an average recorded temperature (T_m) of 1314 °C (±120 °C) in agreement with previously estimated crystallization temperatures reported for graphite in Almahata Sitta ureilite.

Keywords: Carbon phases, diamond, graphite, ureilite meteorites, shock, impact event

INTRODUCTION

Ureilites represent the second largest group of achondrite meteorites (Goodrich 1992), with about 570 individuals with distinct names but only six observed falls (Meteoritical Bulletin Database 2020). Their formation, origin, and history are still under discussion among the scientific community. The debate about the formation of carbon phases contained in these meteorites has been going on for 80 years (see Nestola et al. 2020, and references therein).

As reported by Goodrich (1992), ureilites appear to be fractionated ultramafic igneous rocks, either magmatic cumulates (Berkley et al. 1980; Goodrich et al. 1987) or partial melt residues (Boynton et al. 1976; Scott et al. 1992) and, thus, the products of planetary differentiation processes. These conclusions were based on mineralogy, textures, fabrics, lithophile element chemistry, and on some aspects of Sm-Nd isotopic systematics (Berkley et al. 1976) observed in these meteorites (Goodrich 1992). Ureilites strongly differ from the other groups of stony meteorites (i.e., due to a high content of carbon phases and distinct oxygen isotopic composition) and, compared to chondrites, they are enriched in Mg but depleted in metal, troilite, and alkalis.

Ureilites typically contain large olivine grains and a few smaller low-Ca-clinopyroxene (pigeonite) aggregates in a fine-grained, carbon-rich matrix. Minor phases are kamacite (1–3 vol% with the Ni content up to 7.3%), troilite (1–2%), chromite (1–2%), and carbon material (up to 8.5%) (Cloutis et al. 2010; Goodrich et al. 2015). Carbon is present as diamond, usually with stacking disorder and nanotwins (Németh et al. 2014, 2020a, 2020b; Salzmann et al. 2015; Murri et al. 2019), graphite, and organic material (e.g., Sabbah et al. 2010).

The different shock levels observed in ureilites are very important for constraining their history. Shock level determination in meteorites was first proposed by Stöffler et al. (1991, 2018) and is subdivided in six stages of shock for ordinary chondrites, from low (S1) to high (S6) level of shock, based on: (1) shock effects in olivine and plagioclase (e.g., extinction, fractures, planar elements), and (2) the presence of glass and/or of high-pressure silicate phases. Recently, Nakamuta et al. (2016) adapted the shock classification based on olivine in chondrites to the observations in ureilites. For this reason, we will apply this classification in this work.

The occurrence of diamonds in ureilites poses the question of how this high-pressure mineral formed and whether diamonds in ureilites are similar or not to those formed by shock in terrestrial impact structures (e.g., Masaitis 1998; Hough et al. 1995; Koeberl...