Nitrogen in diamond-free ureilite Allan Hills 78019: Clues to the origin of diamond in ureilites

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Abstract—Nitrogen and noble gases were measured in a bulk sample and in acid-resistant carbon-rich residues of the ureilite Allan Hills (ALH) 78019 which has experienced low shock and is free of diamond. A small amount of amorphous carbon combusting at ≤500 °C carries most of the noble gases, while the major carbon phase consisting of large crystals of graphite combusts at ≥800 °C, and is almost noble-gas free. Nitrogen on the other hand is present in both amorphous carbon and graphite, with different δ15N signatures of −21‰ and +19‰, respectively, distinctly different from the very light nitrogen (about −100‰) of ureilite diamond. Amorphous carbon in ALH 78019 behaves similar to phase Q of chondrites with respect to noble gas release pattern, behavior towards oxidizing acids as well as nitrogen isotopic composition. In situ conversion of amorphous carbon or graphite to diamond through shock would require an isotopic fractionation of 8 to 12% for nitrogen favoring the light isotope, an unlikely proposition, posing a severe problem for the widely accepted shock origin of ureilite diamond.

INTRODUCTION

Ureilites are an enigmatic group of achondritic meteorites and exhibit several unusual features. They are ultramafic rocks composed mostly of coarse-grained olivine and clinopyroxene in a carbonaceous matrix. They show both primitive and igneous features. Among the primitive ones is that they contain carbon in concentrations comparable to or sometimes even greater than those found in carbonaceous chondrites. Carbon in ureilites is mainly present in one of three forms: graphite, diamond and cohenite (Goodrich, 1992; Mittlefehldt et al., 1998); in addition the presence of amorphous carbon has been inferred for Allan Hills (ALH) 78019 (Wacker, 1986; Ott et al., 1985a). Though the occurrence of diamond (of presolar type) is common in primitive chondrites, diamond in achondrites is rare. The origin of the diamond in ureilites has been a highly debated topic for more than three decades, and is still not settled. Since almost all ureilites have experienced some degree of shock, it has been suggested that diamond was produced by the shock conversion of graphite (Lipschutz and Anders, 1961; Lipschutz, 1964). But the shock origin of diamond is unable to explain several features of ureilites. One of the major problems for a shock origin of diamond is the absence of primordial noble gases in graphite, which is supposed to be the precursor of diamond in the shock model (since diamond carries most of the primordial trapped gases). At the same time it has been proposed that diamond can also be produced under low pressure in a plasma by a chemical vapor deposition process (Arrhenius and Alfvén, 1971; Matsuda et al., 1991). Based on the correlation of noble gas elemental abundance pattern with their respective first ionization potential, Göbel et al. (1978) have suggested that the noble gases were trapped into diamond in ionized state from the solar nebula. A low-pressure nebular origin of diamond is further supported by laboratory simulation experiments (Matsuda et al., 1991).

In the chemical vapor deposition process, both diamond and graphite are produced at the same time; but under the right conditions, graphite is destroyed again in the plasma faster than the diamond, thereby enriching diamond in the product. However, slight changes only in physicochemical conditions may lead to preferential formation of graphite or amorphous carbon rather than diamond (Daulton et al., 1996; Angus and Hayman, 1988; Kruger et al., 1997). It has also been shown that under certain conditions the amorphous carbon produced by chemical vapor deposition can trap large amounts of noble gases with a fractionated elemental pattern similar to that observed for diamond from ureilites (and Q phase from primitive meteorites) (Fukunaga and Matsuda, 1997). The trapping efficiency for amorphous carbon is found to be highest among all carbon phases studied including diamond (Fukunaga and Matsuda, 1997).

Almost all the ureilites contain diamond, ALH 78019 being the only known exception. This ureilite is also the least shocked among the ureilites. No lines of diamond were detected in