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Interlayer trapping of noble gases in insoluble organic matter of primitive meteorites

Yves Marrocchi[a,*], Sylvie Derenne[b], Bernard Marty[a,c], François Robert[d]

[a]*Centre de Recherches Pétrographiques et Géochimiques, CNRS UPR 2300, 15 rue Notre-Dame des Pauvres, BP20, 54501 Vandoeuvre lès Nancy Cedex, France*
[b]*Laboratoire de Chimie Bioorganique et Organique Physique, UMR CNRS 7573, Ecole Nationale Supérieure de Chimie de Paris, 11 rue Pierre et Marie Curie, 75231 Paris Cedex 05, France*
[c]*Ecole Nationale Supérieure de Géologie, Rue du Doyen Roubault, BP 40, 54501 Vandoeuvre-Lès-Nancy Cedex, France*
[d]*Laboratroire de Minéralogie, FRE CNRS 32, Museum National d'Histoire Naturelle, 61 rue Buffon, 75005 Paris, France*

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Abstract

Noble gases in primitive meteorites are trapped in a residue left after demineralization of bulk meteorite by HF and HCl. Most of the primordial Ar, Kr and Xe and small amounts of He and Ne are removed by oxidation of this acid-resistant residue, e.g. with HNO_3. These gases, referred as P1, are trapped in a poorly characterized, presumably organic, phase labeled phase Q. In order to understand the siting of P1 noble gases, we have performed a solvation experiment on insoluble organic matter of Orgueil (CI). Pyridine was used because it presents an important swelling ratio of about 2 potentially able to change considerably the structure of phase Q without affecting the crystalline structure of nanodiamonds, chromite, spinel and metal alloys present in acid residue.

Heavy noble gases are largely lost upon pyridine treatment at room temperature. However, the elemental pattern of the remaining Ar, Kr and Xe is not different from that of the starting acid residue, showing similar losses of all the heavy noble gases during solvation. Xenon stepwise heating data and deconvolution of different components based on isotopic ratios show that Xe-P1 is mainly affected by loss (≈60%), following by Xe-P3 (≈25%) and Xe-HL (≈12%). The xenon release is maximum at temperatures ≤1300 °C (≈70–80%) whereas only 23% is lost at 1600 °C and no further loss occurs at 2100 °C. These results suggest the existence of at least two substructures in phase Q, with Xe-P1 being trapped preferentially in the less retentive phase. As macromolecular organic matter is the only phase of acid residue sensitive to solvation, this study demonstrates the organic nature of phase Q. The behavior of heavy noble gases

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* Corresponding author. Present address: Laboratory for Space Sciences and the Physics Department, Washington University, 1 Brookings Drive, St. Louis, MO 63130-4849, USA.
E-mail address: ym@physics.wustl.edu (Y. Marrocchi).

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upon pyridine solvation supports interlayer trapping of these elements, probably within organic layers of aromatic moieties linked by short aliphatic chains.

Keywords: insoluble organic matter; solvation; pyridine; P1 noble gases; phase Q; interlayer trapping

1. Introduction

Noble gases trapped in primitive meteorites constitute an exceptional set of cosmochemical tracers for understanding the origin and processing of planetary bodies. However, they are mainly hosted by a phase whose precise characterization has resisted decades of investigation. Meteoritic noble gases are mainly hosted by two carbon-rich phases that survive HF/HCl attack of bulk meteorites: nanodiamonds and an enigmatic carbonaceous phase referred to as phase Q [1–6]. Nanodiamonds contain the majority of primordial He and Ne, as well as the so-called Xe-HL, Xe-P3 and Xe-P6 components, and present Te and Pd isotopic anomalies interpreted as due to nucleosynthetic processes in supernovae [6–12]. However, the fact that average C and N isotopic ratios are solar has led some authors to propose that nanodiamonds were formed in the solar system [13]. Phase Q is the carrier of “normal” primordial Ar, Kr and Xe, as revealed by HNO_3 oxidation of HF/HCl residues [1]. Noble gases trapped in phase Q, referred hereafter as P1 following the nomenclature proposed by Huss et al. [7–10], are present in all chondritic classes and probably also in ureilites [14]. Elemental and isotopic compositions of P1 noble gas from different types of meteorites present remarkable similarities [15–17]. These similarities may result from a common process that has shaped the characteristics of P1 noble gases in the early solar system or in the interstellar medium. However, the nature of phase Q and the mechanism(s) at the origin of the trapping of noble gases remain poorly understood. Several mechanisms for trapping P1 noble gases in phase Q have been advocated: adsorption [18–21], active capture [22], condensation [23], diffusion [21], ion implantation onto presolar diamonds [24], but none of these can reproduce all the characteristics of P1 noble gases [18–24]. The most widely adopted model is the “labyrinth” hypothesis in which previously adsorbed noble gases diffuse through a complex network of micropores toward the interior of carbonaceous grains [19].

P1 noble gases are readily released from HF/HCl residues by chemical oxidation (HNO_3) [1,10]. Because HNO_3 etching induces little mass loss of the HF/HCl residue but triggers important degassing of noble gases, it has been proposed that P1 noble gases are located at, or very close to, the surface of carbonaceous grains [19–21]. However, stepped combustion experiments of acid residues have revealed that some carbon, nitrogen, and P1 noble

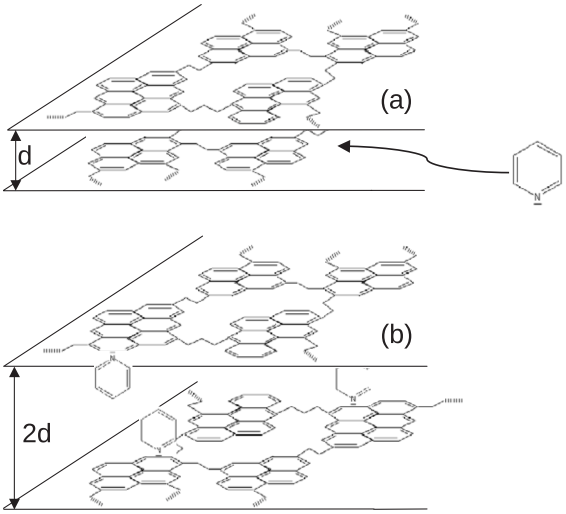

Fig. 1. (a) Schematic view of the insoluble organic matter of primitive meteorites with aromatic moieties linked by short aliphatic chains [30,31]. Pyridine, the solvent used in this study, is also represented. It presents an aromatic structure and a non-bonding electron pair. (b) The introduction of pyridine in acid residue induces solvation process and considerable change in the structure of the macromolecular network. Pyridine makes for the electron-rich sites; probably delocalized π-electron of the aromatic rings, and generates weak interactions with macromolecular network. These interactions induce the swelling of the macromolecular network by a factor of 2 in the case of pyridine.