Planetary and Space Science 131 (2016) 119–127

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Microstructures, mineral chemistry, noble gases and nitrogen in the recent fall, Bhuka iron (IAB) meteorite

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ARTICLE INFO

Article history:
Received 13 May 2016
Received in revised form
6 August 2016
Accepted 12 August 2016
Available online 26 August 2016

Keywords:
IAB iron
Silicate inclusion
Graphite inclusion
Noble gases
Nitrogen
Exposure age

ABSTRACT

We report some chemical, petrological and isotopic studies of the Bhuka iron meteorite that fell in Rajasthan, India in 2005. Numerous silicate and graphite inclusions are visible on the surface of the hand specimen. In the polished and etched surface studied, irregular patches of graphite are found as the most dominant inclusion and commonly associated with pure corundum (95 wt% Al_2O_3), spinel, feldspar and Si-rich phases. Apart from typical lamellar intergrowth with kamacite (i.e. the Widmänstatten pattern), taenites are also commonly found to occur as a rim of the graphite inclusions. P-rich (up to 10 wt%) taenites are also found locally within the recrystallised kamacite matrix. Based on mineralogy, texture and bulk composition, Bhuka resembles the low-Ni IAB subgroup (ungrouped). Noble gas isotope studies suggest He, Ne and Ar are mostly of cosmogenic origin, while Kr and Xe are a mixture of cosmogenic, radiogenic and trapped components. A pre-atmospheric radius of 10 ± 1 cm and a cosmic ray exposure age of 346 ± 52 Ma are derived based on depth dependant $(^{3}He/^{4}He)_c$ and $^{38}Ar_c$ respectively, as per the production systematics of cosmogenic noble gas isotopes (Ammon et al., 2009). Cosmogenic ^{83}Kr and ^{126}Xe yield production rates of 12 and 0.335 (in 10^{-15}ccSTP/g Ma) for ^{83}Kr and ^{126}Xe respectively. Presence of trapped Kr and Xe, with $(^{84}Kr/^{132}Xe)_t = 2$ and radiogenic $^{129}Xe = 120 \times 10^{-12}$ ccSTP/g are due to presence of graphite/silicate inclusions in the analysed sample. Over ~150% excess $^{131}Xe_c$ than expected from spallation suggests contribution from (n,γ) reactions from Ba from inclusions and suggests irradiation of pre-atmospheric object in a larger body, indicative of complex irradiation. Trapped N of 24 ppm, with $\delta^{15}N = -10.7 \pm 0.8$‰ observed in Bhuka, is heavier than the range observed hither to in IAB irons.

1. Introduction

Iron meteorites are generally considered as the cores of differentiated planetesimals. They have been chemically classified into 4 major groups I–IV, based on the abundances of moderately volatile siderophile elements Ga and Ge, and further divided into 14 clusters with alphabets A to G attached to these Roman numerals (see Goldstein et al. (2009) and references therein). Also, based on their formation mechanism irons are broadly classified as magmatic (formed as metallic cores of differentiated objects, and mostly devoid of silicate inclusions) and non magmatic (formed either by segregation from a local melt pool and/or catastrophic impact breakup and reassembly of partially molten chondritic objects, and contain silicate inclusions) groups (Wasson and Kallemeyn, 2002, Benedix et al., 2000). A new iron meteorite fall/find needs to be classified first to realise its importance for further studies. While chemical and microstructure studies will help in classification, inferring the shock and thermal process, noble gas and nitrogen isotopic studies will help in understanding the interplanetary journey of the meteoroid, as well as providing clues to the formation and evolution history of the parent body.

On 25th June 2005 at 23:08 h (IST), a single piece of Bhuka iron with a total weight of 2420 g fell in Bhuka village (25°41′N/72°00′E), Barmer district, Rajasthan, India (Fig. 1a and b). First report of the fall was earlier described by Shrivastava et al. (2005), however, the morphology, micro textures, phase compositions, chemical classification and metallography of this particular iron were not described in detail. Moreover, the presence of silicate inclusions as reported in the preliminary study also urges for detailed petrological and mineralogical examination and importantly the chemical classification of the Bhuka iron.

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http://dx.doi.org/10.1016/j.pss.2016.08.007

Noble gases in iron meteorites are mostly dominated by in situ produced components (cosmogenic, radiogenic and fission components), but indigenous trapped components, either of Q (a primordial noble gas component of solar nebular origin, see

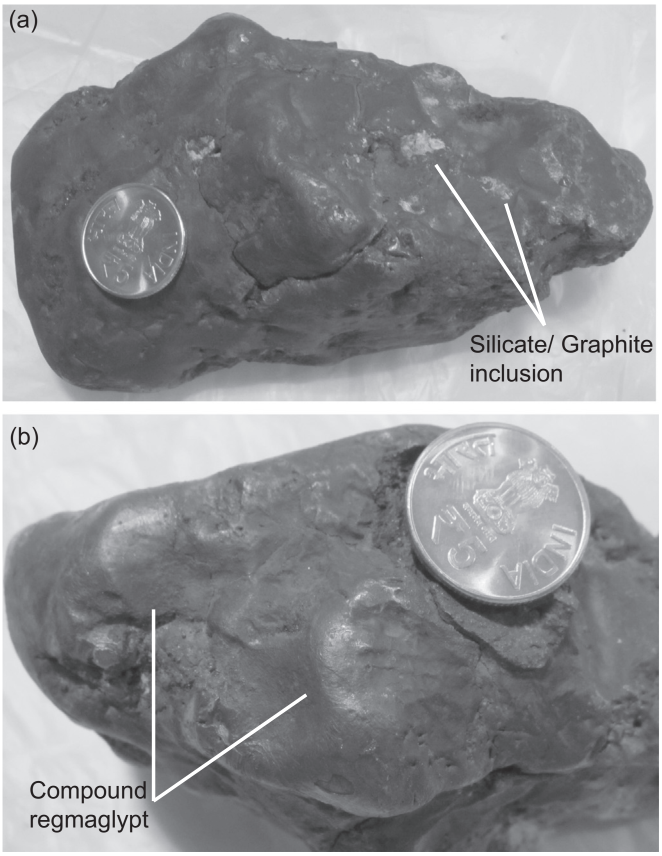

Fig. 1. a Hand Specimen of Bhuka iron with several inclusions. Diameter of coin is 2.2 cm. b. Enlarged view of complex regmaglypt.

Busemann et al., 2000) composition or occasionally of HL (a trapped noble gas component of interstellar origin, found in interstellar diamonds, see Ott (2014)) composition are observed in inclusion bearing non magmatic irons (Alexander and Manuel, 1968; Bogard et al., 1971; Murty and Marti, 1987; Mathew and Begemann 1995; Maruoka et al. 2001; Matsuda et al. 1996, 2005; Nishimura et al., 2008). The isotopic and elemental ratios among the various noble gas components are distinctly different. In Fig. 2, the ranges in compositions of some isotopic and elemental ratios of noble gases that are relevant to meteorites are shown, with respect to the compositions in Earth's atmosphere. The differences range from several percentage to several orders of magnitude, which allows their easy recognition and decoupling. While the trapped components will help in understanding the formation process of iron meteorites, the in situ produced components aid in understanding the evolution and breakup events of their parent bodies. Cosmogenic noble gases in particular will help in deriving the meteoroid size and its interplanetary sojourn (Ammon et al., 2009). The production of cosmogenic nuclides in a meteorite sample is dependant on the position of the sample (depth in the meteoroid) and the radius of the meteoroid, in addition to the abundances of target elements (Voshage and Feldmann, 1979; Ammon et al., 2008, 2009, 2011). Cosmogenic He, Ne and Ar production in iron meteorites are mostly dependant on the major elements Fe, Ni, while cosmogenic Ne production is also very sensitive to the abundance of minor elements S and P (Ammon et al., 2008). On the other hand, the production of Kr and Xe in irons is dependant on the trace element abundances of Mo, Ru, Rh, Pd (for Kr) and Ta, W, Re, Ir and Pt (for Xe) (Munk, 1967).

Trapped N has been studied in most iron meteorite types and it ranges in abundance from less than a ppm to several tens of ppm, with isotopic composition ranging from −100‰ to +155‰ and often shows a clustering for each iron group (Prombo and Clayton, 1993, Franchi et al., 1993, Murty and Marti 1994, Mathew et al. 2000). Acid residues of iron meteorites, mostly made up of graphite, schreibersite and refractory silicates are found to be enriched in N (Murty et al., 1983). A comparison of the isotopic composition of irons with that from metal of chondrites has been

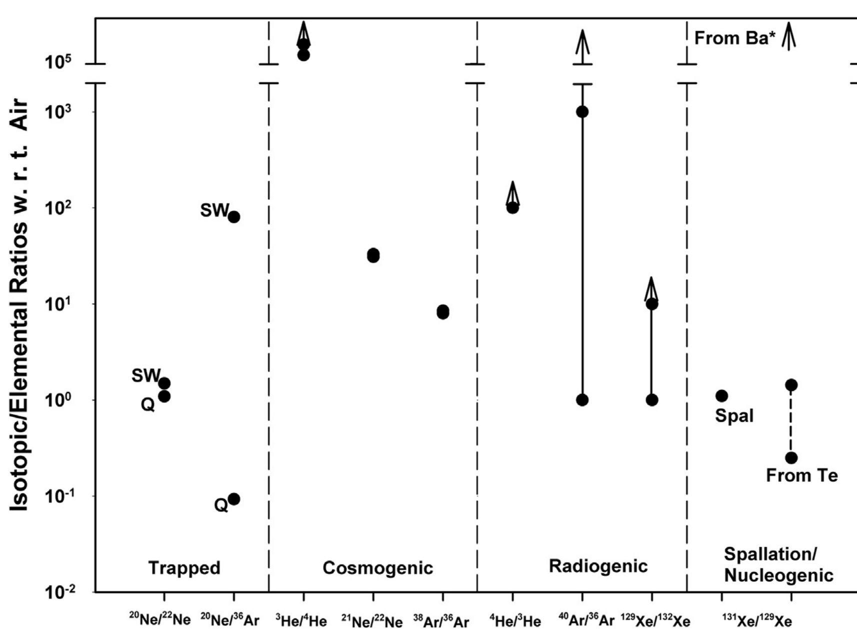

Fig. 2. Noble gas isotopic and elemental ratios of some components of relevance for iron meteorites, normalised to corresponding ratios in Earth's atmosphere are shown. The wide variation among various components facilitates their easy recognition and decomposition to individual components, to infer the formation and evolution history of the parent body of the meteorite. Data sources: Munk (1967), Ozima and Podosek (2002), Ott (2014), Busemann et al. (2000), Browne and Berman (1973), Hohenberg et al. (1981). *Nucleogenic ^{131}Xe produced from ^{130}Ba is monoisotopic anomaly.