Bhawad LL6 chondrite: Chemistry, petrology, noble gases, nuclear tracks, and cosmogenic radionuclides

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Abstract—Chemical and mineral analysis of the Bhawad chondrite, which fell in Rajasthan in 2002, suggest that this stone belongs to LL6 group of chondrites. Based on helium, neon, and argon isotopes, it has a cosmic ray exposure age of 16.3 Ma. The track density in the olivines shows a narrow range of 1.7–6.8 × 10^6/cm^2. The 22Na/26Al ratio of 1.13 is about 25% lower than the solar cycle average value of about 1.5, but is consistent with irradiation of the meteoroid to modulated galactic cosmic ray fluxes as expected for a fall around the solar maximum. The cosmogenic records indicate a pre-atmospheric radius of about 7.5 cm. Based on U/Th-4He and K-40Ar, the gas retention ages are low (about 1.1 Ga), indicating a major thermal event or shock event that lead to the complete loss of radiogenic 4He and 40Ar and the partial loss of radiogenic 129Xe and fission Xe from 244Pu.

INTRODUCTION

A small, fully crusted stone weighing about 678 g fell at Bhawad village (26°30′30″N, 73°06′55″E) in the district of Jodhpur, Rajasthan, India on June 6, 2002, at 18:00 h IST. The fall, which was witnessed by one woman, was described by Paliwal et al. (2002). Petrographic studies carried out by Paliwal et al. (2002) indicate that the meteorite belongs to metamorphic grade 6. To classify the meteorite, they carried out Mössbauer studies, but these results are ambiguous, since they concluded that it belongs to either L or LL class. We have therefore carried out a detailed chemical analysis of this meteorite, analyzing it for cosmogenic effects, e.g., radionuclides, tracks, and rare gases.

MACROSCOPIC AND MICROSCOPIC STUDIES

The stone has a well-developed fusion crust and regmaglypts formed due to atmospheric transit (Fig. 1). The fusion crust is dull black with sub-millimeter thickness. One corner of the stone has a broken appearance, and a thin fusion crust on this face suggests that the stone might have broken in the atmosphere shortly before its fall (Fig. 1). The meteorite was examined for its texture and mineralogy using optical and scanning electron microscopes (Fig. 2a). A variety of large (500 to 1000 μm) chondrules are present, but are rare and poorly preserved with ill-defined rims, sometimes recrystallized and partially replaced by matrix, as shown in Fig. 2. The meteorite shows a higher class of metamorphism from the melt flow patterns of feldspathic composition.

Chondrules, made up of mostly pyroxene, olivine, and troilite, have relict texture, corroded boundaries that are occasionally merged with the matrix (Fig. 2b), indicating the high degree of metamorphism suffered by the meteorite. A large feldspathic chondrule with degraded rim is shown in Fig. 2c. One of the chondrules shows the presence of plagioclase feldspar and has refractory inclusions such as spinel and calcium-aluminum rich phases (Fig. 2d). In one such inclusion, the energy dispersive X-ray analysis showed the presence of Cr, Al, Fe, Ti, Mg, and Ca, in decreasing order of abundances. All these observations suggest that the Bhawad meteorite belongs to petrologic class 6.

MINERAL CHEMISTRY

The olivine and pyroxene grains were analyzed in the polished thin section using the electron probe microscopy analyzer (EPMA) at the National Geophysical Research Institute (NGRI), Hyderabad, India. The results are given in Table 1. The olivine contains ~28 mol% fayalite and the