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Geochemistry and mineralogy of a feldspathic lunar meteorite (regolith breccia), Northwest Africa 2200

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Abstract

The lunar meteorite Northwest Africa (NWA) 2200 is a regolith breccia with a ferroan feldspathic bulk composition (Al_2O_3 = 30.1 wt.%; $Mg^{\#}$ = molar 100 × Mg/(Mg + Fe) = 59.2) and low Th content (0.42 µg/g). Lithologically, NWA 2200 is a diverse mixture of lithic and glassy clasts, mineral fragments, and impact glass spherules, all embedded in a dark glassy matrix. NWA 2200 contains some feldspathic brecciated rock components (ferroan anorthositic granulitic breccia, poikiloblastic granulitic breccia, and glassy melt breccia with an intersertal texture). The bulk compositions of these brecciated components indicate they are derived from ferroan troctolitic or noritic anorthosite lithologies (bulk Al_2O_3 = 26−30 wt.%; bulk FeO/MgO > 1.0). The bulk composition of NWA 2200 is more ferroan and feldspathic than the Apollo feldspathic regolith samples and feldspathic lunar regolith meteorites, and is also more depleted in incompatible elements (e.g., rare earth elements) than Apollo 16 feldspathic regolith samples. We conclude that NWA 2200 originated from a location different to the Apollo landing sites, and may have been sourced from the ferroan KREEP-poor highlands, “KREEP” materials are enriched in such elements as potassium (K), rare earth elements (REE), phosphorus (P).

Keywords: Geochemistry; Mineralogy; Lunar meteorite; Ferroan anorthosite

1. Introduction

Numerous meteorites have recently been found and collected in the North African desert. Some of these have been categorized as being meteorites that originated from the Moon. These lunar meteorites provide information about areas of the Moon not sampled by the Apollo and Luna missions, which collected samples from a relatively small and geochemically anomalous region of the lunar surface (Warren and Kallemeyn, 1991). Therefore, lunar meteorites can be used to develop more representative geochemical datasets from which it is possible to evaluate lunar petrogenesis. In particular, it is likely that feldspathic lunar meteorites with low incompatible element

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abundances originate from the inner and outer regions of the Feldspathic Highlands Terrane (FHT). These meteorites represent a variety of lunar highlands crustal lithologies (e.g., Arai et al., 2008; Cahill et al., 2004; Joy et al., 2010; Korotev et al., 2003; Palme et al., 1991; Takeda et al., 2006; Treiman et al., 2010; Warren et al., 2005; Yamaguchi et al., 2010).

We report here the geochemistry, petrology, and mineralogy of the feldspathic lunar meteorite Northwest Africa (NWA) 2200. This stony meteorite weighing 552 g was found in Morocco (Connolly et al., 2006). Our study is the first to present a detailed examination of the bulk major and trace element composition, petrology, and mineralogy of NWA 2200, although brief descriptions of the geochemistry (Korotev et al., 2008; Nagaoka et al., 2008, 2009), and petrology and mineralogy (Kuehner et al., 2005; Nagaoka et al., 2008, 2009) have been reported elsewhere as conference abstracts. This study combines bulk chemical results obtained by neutron-induced prompt gamma ray analysis (PGA) and instrumental neutron activation analysis (INAA) with mineral descriptions and compositions determined by scanning electron microscope (SEM) and electron probe microanalyzer (EPMA), respectively. Our new geochemical and mineralogical results for NWA 2200 allow us to compare it with other feldspathic lunar meteorites and Apollo rock samples, and to infer its petrogenesis.

2. Bulk chemistry of NWA 2200

NWA 2200 is a lunar feldspathic breccia (Connolly et al., 2006). A 233 mg slice of NWA 2200 was used in this study. The sample separation procedures for NWA 2200 and analytical methods applied to each sample are presented in Fig. 1.

2.1. Neutron activation analysis

For PGA, the slice of NWA 2200 was first sealed in a thin fluorinated ethylene polyethylene film bag and irradiated for 2 h with a thermal neutron beam (flux: 1.6×10^{8} cm^{-2} s^{-1}) from the Japan Research Reactor (JRR-3M) at the Japan Atomic Energy Agency, Ibaraki, Japan. At the same time, the prompt gamma rays emitted from the sample were measured for 2 h. Elemental concentrations in the sample were determined by comparison with the response to the JB-1 standard (a geochemical reference sample issued by the Geological Survey of Japan) treated with the same procedures (Imai et al., 1995a, b; Terashima et al., 1994).

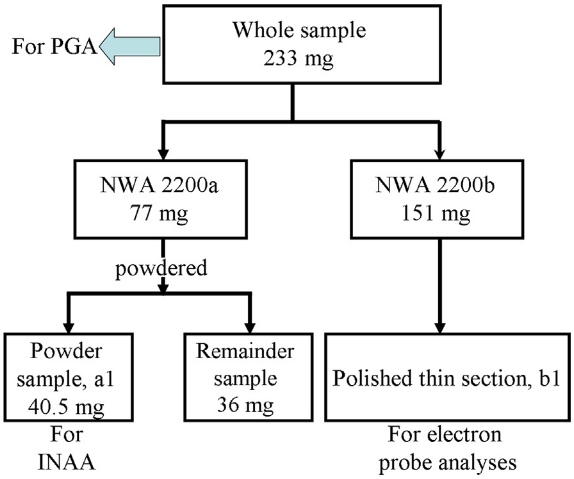

Fig. 1. Sample separation procedures for NWA 2200 and the analytical methods used for each sample.

A description of the PGA procedures can be found in Latif et al. (1999).

After a two-month cooling period, the slice of NWA 2200 was divided into two pieces for further chemical and mineralogical analyses (77 mg = NWA 2200a; 151 mg = NWA 2200b). NWA 2200a was used for chemical analysis and ground to a powder in a clean agate mortar. A 40.5 mg fraction of the powdered sample (powder sample, a1) was used for INAA, and was irradiated two times with different irradiation periods, which were adjusted in accordance with the half-lives of nuclides used for the determination of elemental concentrations. The powder sample, a1 was sealed in high-purity polyethylene bags and irradiated with thermal neutrons at the PN-3 (flux = 1.5×10^{13} cm^{-2} s^{-1}) in the Japan Research Reactor (JRR-3M) of the Japan Atomic Energy Agency for 10 s. After a few minutes of cooling after irradiation, gamma rays emitted from the sample were measured for 5 min. JB-1 was used as a reference standard.

After approximately 1 yr of cooling, the powder sample, a1 was re-irradiated for 10 min with thermal neutrons at HR-1 (flux = 9.6×10^{13} cm^{-2} s^{-1}) in the Japan Research Reactor (JRR-3M) of the Japan Atomic Energy Agency. After irradiation, gamma rays emitted from the sample were measured several times over different cooling times at the RI Research Center of Tokyo Metropolitan University, Tokyo, Japan. Both JB-1 and an Allende meteorite reference sample issued by the Smithsonian Institute (Washington DC, USA) (Jarosewich et al., 1987) were used as reference standards. Details of the INAA procedures are given in Shirai and Ebihara (2004).