GEOCHEMICAL AND ISOTOPIC SYSTEMATICS OF THE YOUNGEST DATED LUNAR IGNEOUS ROCK, NORTHWEST AFRICA 773

L. E. Borg[1], C. K. Shearer[1], Y. Asmerom[2], and J. J. Papike[1], [1]Institute of Meteoritics University of New Mexico, Albuquerque, NM 87131 USA; [2]Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque NM 87131.

Introduction: Many lunar samples are strongly enriched in potassium (K), rare earth elements (REE), and phosphorous (P). This KREEP geochemical signature is interpreted to indicate the involvement of late-stage liquids derived from the crystallization of a magma ocean in the petrogenesis of KREEP-rich samples. Most KREEP-rich samples, including Mg-suite, alkali suite rocks, as well as KREEP-basalts, have ages greater than 3.8 Ga. This has led to the hypothesis that KREEP magmatism was confined to the earliest periods of lunar history. Below we present Rb-Sr and Sm-Nd isotopic evidence that an olivine-rich clast in the lunar meteorite Northwest Africa 773 (NWA773) is not only the youngest lunar sample yet dated, but has the largest KREEP geochemical signature.

Petrology and geochemistry of NWA 773: Northwest Africa 773 is a brecciated lunar meteorite containing a large igneous clast. This clast is interpreted to be an olivine-gabbro cumulate and contains 48-66% olivine, 19-27% pigeonite, 8-16% plagioclase, 5-11% augite, ~2% orthopyroxene, trace – 2% K-feldspar, and trace amounts of ilmenite, merrillite, troilite, Cr-spinel, Fe-Ni metal, and calcite [1-4]. The Mg#'s of mafic phases in NWA773 are relatively high (68-77), indicating that the parental magma has not undergone large amounts of fractional crystallization [1]. Jolliff et al. [1] have also demonstrated that the olivine-rich clast, like KREEP, has an elevated LREE/HREE ratio.

Analytical Techniques: A 100 mg aliquot of the olivine gabbro clast from NWA773 was obtained from M. Grady at the Natural History Museum, London. The sample was washed and sonicated in four-times quartz distilled water, followed by 0.5M acetic acid. The sample was crushed and sieved at 100-200 and 200-325 mesh. Mineral separations were begun using heavy liquids on both size fractions. Plagioclase floated in 2.85 g/cm^3, whereas the mafic minerals sank. Hand-picking was used to separate pyroxene (brown) and olivine (green) mineral grains, as well as to purify the plagioclase fraction. Individual mineral fractions were then leached in 1N HCl for 10 minutes in a sonicator prior to digestion. Chemical separations and isotope ratio measurements were done at the Radiogenic Isotope Laboratory, University of New Mexico, following standard silicate dissolution procedures and involved cation chromatography using a combination of HCl and methalactic acids. Isotopic ratios were measured on a Micromass Sector 54 multi-collector thermal ionization mass spectrometer.

Sm-Nd Isochron Plot: The Sm-Nd isochron diagram of mineral and whole rock fractions from NWA773 yields an age of 2.865 ± 0.031 Ga and an initial ε_{Nd} of -7.84 ± 0.22. (Fig. 1). This age is concordant with the Ar-Ar age determined by [6] indicating that NWA773 has not undergone significant thermal metamorphism. NWA773 is the youngest lunar sample dated (Fig. 2). The youngest crystallization age previously determined for a lunar sample is ~3.1 Ga [7], whereas the youngest crystallization of a KREEP-rich sample (15382) reported previously was 3.83 ± 0.02 Ga [8]. The 2.865 Ga crystallization age of NWA 773, therefore extends the range of dated lunar samples by 250 Ma, and the period of KREEP-magmatism by 1 Ga.

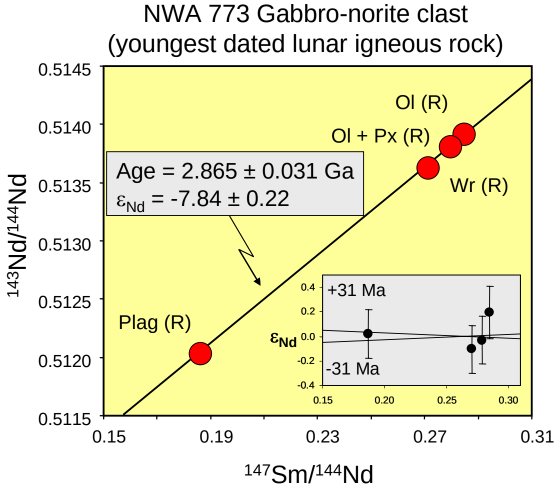

Figure 1. Sm-Nd isochron plot of NWA773 whole rock and mineral fractions. The age is calculated using the Isoplot program of Ken Ludwig [5]. The MSWD = 0.92. Nd normalization is ^{146}Nd/^{144}Nd = 0.7219. R = residues.

The Rb-Sr isochron is highly disturbed as a result of terrestrial weathering. Nevertheless, an initial ^{87}Sr/^{86}Sr ratio of 0.703568 ± 0.000032 can be estimated from the plagioclase mineral fraction assuming a crystallization age of 2.865 Ga (Fig. 3). This initial Sr isotopic composition indicates that NWA773 is derived from a source region with an extremely high ^{87}Rb/^{86}Sr ratio of 0.07, assuming the source region formed at 4.56 Ga.

Figure 4 is an age versus initial Nd isotopic composition plot. It demonstrates that NWA773 is derived from a source region with a ^{147}Sm/^{144}Nd ratio of ~0.16. By comparison to other KREEP-rich samples plotted on Figure 4 it is apparent that NWA773 is derived from the

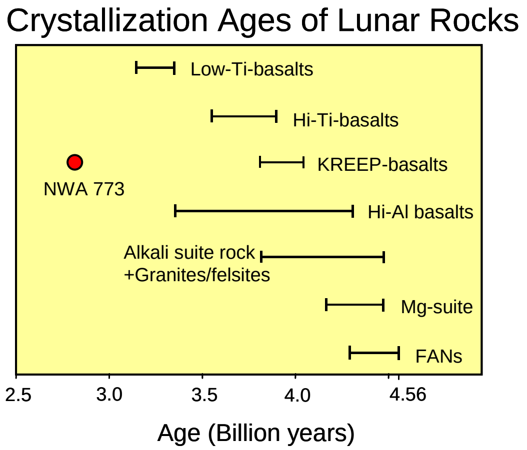

Figure 2. Crystallization ages of lunar igneous rock.

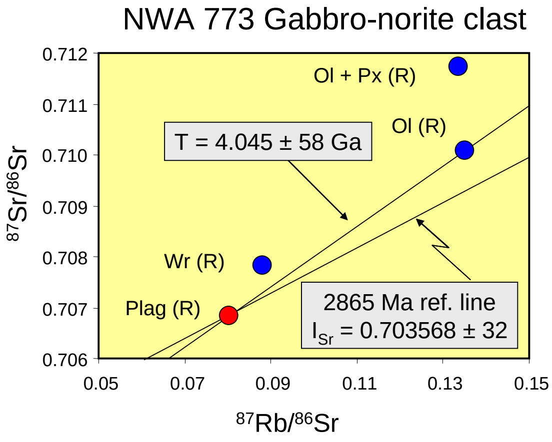

Figure 3. Rb-Sr diagram used to estimate the initial Sr isotopic composition of NWA773 to be 0.703568 ± 32.

most LREE-enriched source region of any lunar sample for which Sm-Nd isotopic analyses have been completed. This observation is consistent with the calculation of Jolliff et al. [1] in which they demonstrated that the parental magma of NWA773 has a higher LREE/HREE ratio than estimates of KREEP.

An outstanding question regarding KREEP magmatism is when the KREEP-rich component was added to the magma. On one hand it could be present in the source region during melting, whereas on the other hand, it could be assimilated by mafic melts derived from the mantle as they rise to the surface. These possibilities are modeled (Fig. 5) with mixing relationships between (1) KREEP and green glass (lower curve), and (2) KREEP and green glass/10 (upper curve). The former model is representative of assimilation of KREEP by a primitive lunar melt, whereas the latter model represents mixing between KREEP and a primitive, green glass source, estimated to have 10 times lower incompatible element abundances than the green glass. The $^{87}Rb/^{86}Sr$ ratios of KREEP-rich sources and parental magmas derived from these sources are calculated from the measured initial Sr isotopic compositions and are represented by the shaded area in Figure 5. These models demonstrate that in order to produce the $^{87}Rb/^{86}Sr$ ratio of NWA773, 22% KREEP must be assimilated by a green glass parental magma, whereas only 2% KREEP must be added to the green glass source region to produce the required $^{87}Rb/^{86}Sr$ ratio. The smaller proportion of KREEP required by the source mixing model is more consistent with the relatively low Fe content and high Mg#'s of the phases in NWA773. This is because KREEP is expected to have a relatively high Fe content [9].

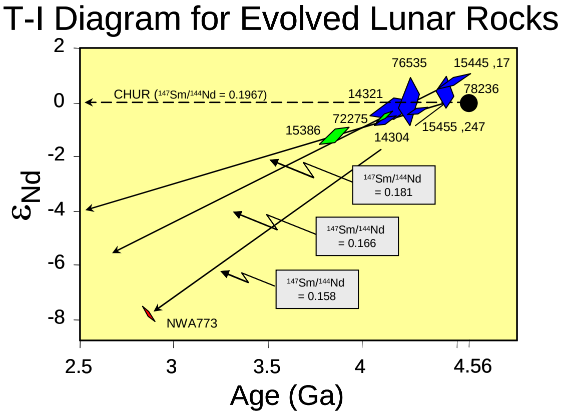

Figure 4. Age - initial ε_{Nd} plot of evolved lunar rocks.

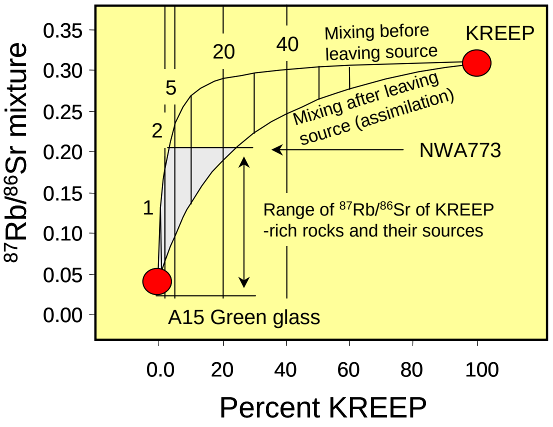

Figure 5. KREEP- green glass mixing models.

References: [1] Jolliff et al., (2003) *GCA* **67,** 4857-4879. [2] Fagan et al. (2003) *MAPS* **38,** 529-554. [3] Grossman & Zipfel (2001) *MAPS* **36,** A300. [4] Bridges et al. (2002) *MAPS* **37,** A24. [5] Ludwig (2001) Berkeley Geochronology Special Publication 1a. [6] Frenandez et al. (2003) *MAPS* **38,** 555-564. [7] Nyquist et al. (1977) *Proc. 8th LPSC* 1383-1415. [8] Papanastassiou et al. (1976) *Proc. 7th LPSC* 2035-2054. [9] Warren (1988) *Proc. 18th LPSC* 233-241.