KALAHARI 009 AND NORTH EAST AFRICA 003: YOUNG (<2.5 GA) LUNAR MARE BASALTS

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During the past seven years, the lunar sample collection has been supplemented with about 48 meteorites from the Moon. Eight of the nine mare basalt meteorites have been dated and five of these have crystallization ages between 2.5-3.0 Ga (includes results from this study) significantly younger than the ma-jority of Apollo and Luna basalts (Fig. 1), The younger ages, most of which were obtained by Ar-Ar dating, cannot simply be explained by Ar loss because Ar-Ar ages are resistant to minor-moderate shock events. For example, the Ar-Ar age of 2.91 ± 0.02 for NWA 773 [1] is indistinguishable from the Sm-Nd isochron age of 2.865 ± 0.031 Ga [2]. The younger ages are evidence that the basaltic meteorites sampled different areas of the Moon from the Luna and Apollo basalts. The formation ages and chemical composition of lunar meteorites, represents the most promising means to identify plausible source areas within a lunar mare. Here we present formation ages for two young lunar meteorites and consider their possible source regions.

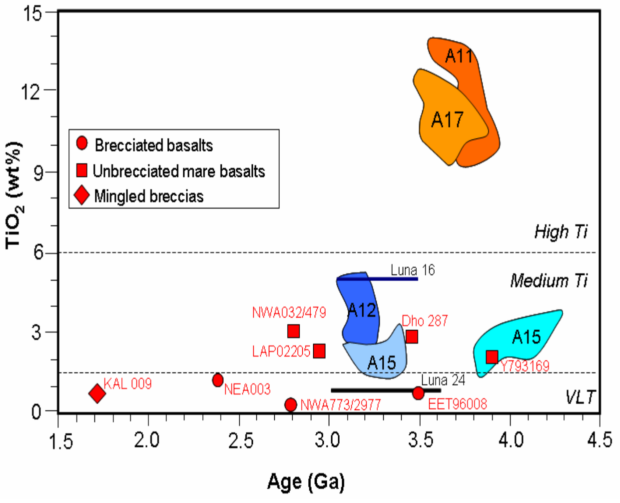

Fig. 1 TiO_2 vs Age of lunar basalt meteorites and Apollo and Luna basalts (modified after [3] Kal009 and NEA003 this study).

Kalahari 009 (Kal 009) was found in the Kalahari desert, in Botswana [5] and is compatible with a VLT lunar mare basalt. It is a mingled breccia consisting of fragments of basaltic lithologies embedded in a fine-grained matrix. The basaltic clasts have a coarse-grained subophitic texture. Clasts and matrix display the same composition. The mineralogy comprises pyroxene and plagioclase, with lesser olivine, and accessory ilmenite, chromite, troilite, ulvöspinel, and Fe,Ni metal with about 0.6 wt% Ni. Pyroxene grains are zoned with compositions of pigeonite and augite (En_{14-46} Fs_{42-76} Wo_{7-44}) and display exsolution lamellae at the scale of <5 µm. On a Mn vs. Fe plot the pyroxenes plot along the lunar fractionation line. Kal 009 contains the lowest Th abundance of all mare samples. Kal 009 is significantly shocked, suggesting pressures of at least 15–20 GPa [4] according to the calibration scheme of [5] for ordinary chondrites (S4). Terrestrial alteration occurs along veins containing with up to 4.3 wt% K_2O.

Ar-Ar stepped heating experiments were carried-out on a bulk sample, and basaltic (coarse-grained) and brecciated (fine-grained) components separated from the bulk sample. Only a minor amount of trapped lunar Ar was released from the samples but a significant amount of terrestrial atmospheric Ar was released, particularly at low to intermediate temperatures (300-700ºC). An atmospheric origin was determined on the basis of ^{40}Ar/^{36}Ar ratios of 285-320 that are close to the air value of 295.5. At intermediate temperatures a significant ^{39}Ar release occurred, again associated with atmosphere-like ^{40}Ar/^{36}Ar ratios, of effectively zero age. This is assumed to be Ar release from secondary K-rich minerals present in alteration veins. The Ar-Ar spectrum for all three samples of Kalahari 009 (Fig. 2) shows considerable variation in apparent age between 1.4-2.6 Ga for steps >50% ^{39}Ar release. At least some of this variation can be attributed to subtle changes in the relative amounts of terrestrial, radiogenic and minor trapped lunar Ar components that cannot be adequately resolved using the present data set. However, it is likely that the contribution of terrestrial Ar diminishes at high temperature. Both the brecciated sample and the bulk have one or two steps giving apparent ages of 2.5 Ga but these ages are significantly reduced (<1.5 Ga) if a correction is applied for atmospheric Ar based upon the release of ^{36}Ar. Summing the Ar released above 700ºC leads to apparent ages: bulk 1.70 ± 0.04 Ga (all errors are 2σ); basalt 1.51 ± 0.10 Ga; and brecciated material 2.03 ± 0.14 Ga Given the problems with atmospheric Ar contamination outlined above, it is unlikely that the differences between these samples are significant, and we take the age of the bulk material as being the best estimate for the crystallisation age of Kalahari 009. However, this age should be considered a maximum age at present because it does not account for any trapped Ar. For example, if it is assumed that all the ^{36}Ar released above 700ºC from the bulk has an atmospheric origin then the integrated age reduces to 1.21 ± 0.05 Ga.

For the bulk sample a cosmic-ray exposure age of 25 ± 9 Ma is obtained at 1100ºC when most of the cosmogenic Ar was released.

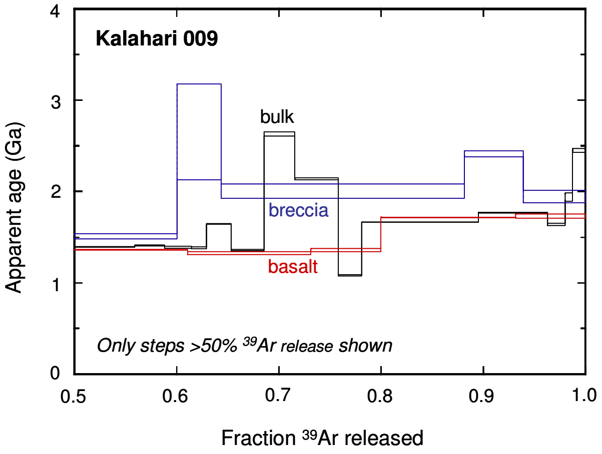

Fig. 2 Ar-Ar age spectrum for Kalahari 009 (1σ errors).

North East Africa 003 (NEA 003) is an unbrecciated coarse-grained low-Ti olivine-rich basalt [6] recovered from northern Libya in the wadi Zam Zam area. The mineralogy, petrography and bulk chemis-try have been described [6], and is summarised here. The weathering grade is low, calcite and gypsum veinlets are present. The rock has a porphyritic tex-ture of olivine (Fo73-19), zoned pyroxene (En5-71Wo6-38) and plagioclase (An84-92), (Fig. 1). Areas of late-stage mesostasis are comprised of silica, Fe-rich pyroxene and pyroxferroite, plagioclase, ilmenite, troilite and apatite, and are enriched in K. Opaque phases include chromite, Ti-rich chromite, ulvöspinel, ilmenite, troilite and trace Fe-Ni metal. Shock veins and impact melt pockets occur throughout the sam-ple. The bulk composition suggests that it is previ-ously unsampled basalt; MgO is the highest and TiO2 content is the lowest among lunar unbrecciated ba-saltic meteorites [7]. NEA 003 has the lowest and flattest chondrite-normalised REE pattern among all known mare basalt meteorites. The Th content in NEA003 is 0.43 ppm.

The Ar-Ar age spectrum for NEA003 is shown in (Fig. 3). Unlike Kal 009, this meteorite contains negligible trapped Ar (air or solar). Apparent ages show a progressive increase to 2.74 Ga at 950ºC. Thereafter apparent ages decrease to approximately 2 Ga. This decrease is accompanied by a progressive increase in Ca/K values reflecting the changing influence of Ar release from plagioclase to pyroxene with increasing temperature. Thus, the age spectrum can be interpreted in terms of recoil of ^{39}Ar from the plagioclase into pyroxene and the age of NEA 003 is calculated by integrating Ar released over interval 900-1500ºC. The age determined is 2.38 ± 0.04 Ga and corresponds to 81% of ^{39}Ar release. The exposure age for this meteorite, based upon cosmogenic Ar release, is 17 9 ± 5 Ma

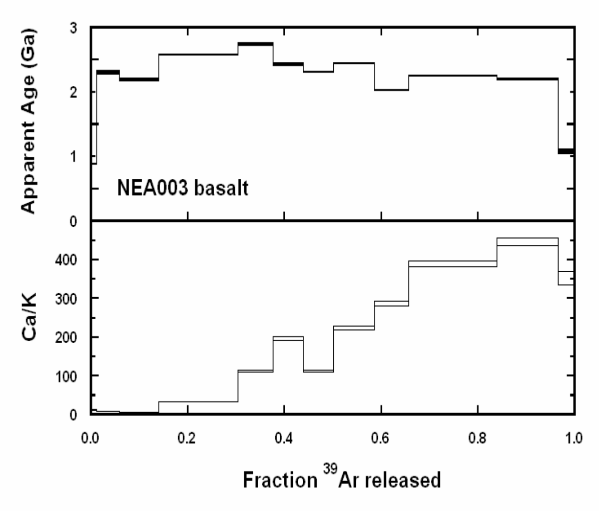

Fig.3 Ar-Ar apparent age and Ca/K spectra for NEA003.

Potential lunar source areas Kal 009 and NEA 003 are the two youngest lunar basaltic meteorites available for study. Integrating the age and composition of Kal 009 with crater counting ages by [8,9] and chemical maps by [10,11], and in particular its low Th content the likely source area for Kalahari 009 is very far from the Procellarum KREEP Terrain, further than the source for the Luna 24 basalts (0.2 ppm). It is reasonable to suggest that Kalahari 009 is a mare basalt from the farside. Possible flows with similar ages to NEA 003 were dated, based on crater counts, within Mare Serenitatis and Oceanus Procellarum.

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