Ar-Ar studies of two lunar mare rocks: LAP02205 and EET96008

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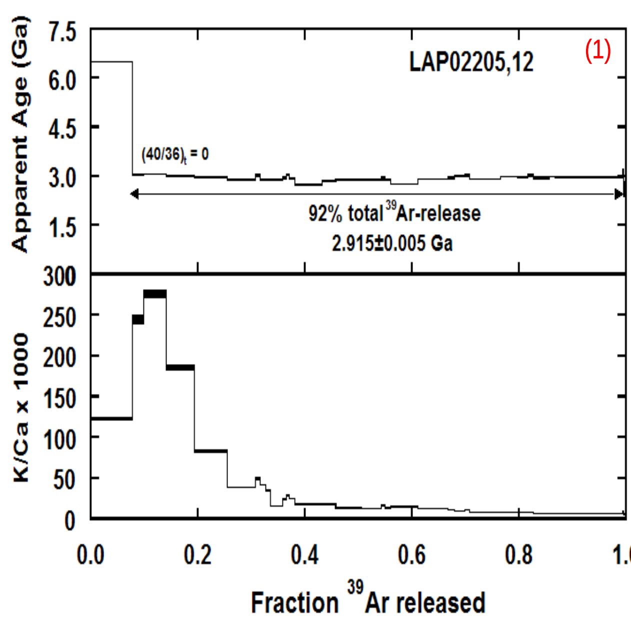
Introduction: Since 1999, the lunar sample collection has been supplemented with about 50 meteorites from the Moon. Many of these stones are paired, and the total number of different lunar meteorites in the present collection is 37. Of these 37, five are lunar mare basalts, which represents ~14% of the lunar meteorite collection. Considering that the maria represent ~17% of the lunar surface, the lunar mare basalts are a good representative of the lunar maria. When major and trace element composition of these lunar mare basalt meteorites are compared with mare basalts collected by the Apollo and Luna missions, it is clear that the basaltic meteorites represent basalt flows different from those the missions do. In the present work, we present new chemical and Ar-Ar age data for two lunar mare basalt meteorites LAP02205,12 and EET96008,45.

Method: Prior to irradiation, meteorites LAP (2.36 mg) and EET (4.42 mg) were each split into two approximately equal halves: one for bulk IR-laser step heating, and the other was used for sample characterization using SEM and EMPA. The latter portion was then used for UV-laser spot analyses on individual minerals in an attempt to determine the crystallisation age and timing of any shock events experienced by the meteorites. Each of the fragments contained differing proportions of plagioclase and pyroxene, thus providing the possibility of extracting different geologic events from the Ar-release pattern at different temperatures during step heating. Further Ar-Ar analyses are currently being carried out on the fragments obtained from the meteorites sections.

Samples LAP02205,12 This sample is a low-Ti lunar mare basalt, showing a coarse-grained subophitic texture [1-7]. The mineral composition of the section we have studied is dominated by relatively large crystals of plagioclase (100-600 μm) and pyroxene (100-500 μm). Previous work [1-7] has also indicated the presence of minor olivines. The plagioclase crystals are elongated subhedral to anhedral, the An content varies from 89 to 93, slightly higher than that reported by [7] but within range to that reported by [2], with K contents of 500 to >1000 ppm. The pyroxenes are anhedral showing magmatic zoning with a core richer in Mg than the rim (typical core has 8.5 wt% Mg and typical rim has 0.4 wt% Mg). The K content in pyroxenes is about 10 times lower to that of plagioclases suggesting that most of the ^{39}Ar release will be released from the plagioclase. Maskelynite was found adjacent to an area of mesostasis and has a K content similar to that of plagioclase. Present wthin the mesostasis area are pure silica veins, FeSi, FeS, together with ilmenite (<5 μm) and glass with a chemical composition between that of plagioclase and pyroxene. The plagioclase crystals are highly fractured by shock disturbance. The pyroxenes do not present such shock features, although [1,2 & 7] report undulatory to mosaic extinction in pyroxene, and [7] suggest that LAP has experienced shock related pressures of <30 to >75 GPa.

EET96008,45 This sample is a fragmented breccia dominated by basaltic phases and minor highland material and other clasts [8,9]. Warren and Ulff-Møller [10] suggested that the mare component of this meteorite originated either as a shallow intrusion or as an unusually deep-ponded flow. The section used for the Ar-Ar studies comprised two main regions: (1) having brecciated appearance, and (2) a gabbroic texture comprised mainly of plagioclase (~400 μm) and pyroxene (~400 μm), but also minor olivines. The large pyroxene crystals show exsolution lamellae superposed by shock related cracks. These lamellae are atypical for mare basalts [10]. The mare component of this meteorite show textural, mineral and geochemical similarities to low-Ti and VLT basalts [9&10]. The K concentration of plagioclase varies from 100-900 ppm, and pyroxene between 0-100 ppm, so that during Ar-Ar step heating experiments, ^{39}Ar release will be exected to be dominated by plagioclase. U-Pb isochron ages of 3.53±0.27 Ga for apattite and 3.52±0.10 Ga for whitlockite were reported previously for this meteorite {9}. This meteorite has an ejection depth of 540-600 g/cm^2 from the lunar surface, a Moon-Earth transfer time of <<10 ky, and terrestrial age 80 ± 30 ky [11].

Ar-Ar Results: LAP02205 The Ar-Ar age spectrum and K/Ca results for LAP are shown in Fig. 1. The spectrum is relatively straightforward to interpret: the initial step, corresponding to ~8% of the ^{39}Ar shows a high apparent age (~6.49 Ga) and has no geological significance, and is mostly due to surface related Ar. The following 28% of the ^{39}Ar release is marked by a relatively high K/Ca values. Comparing with EMPA K/Ca, the likely origin of this release is a combination of phases such as K-rich glass and plagioclase. The remaining ~92% give fairly consistent apparent ages between 2.864±0.016 and 3.056±0.011 Ga with an integrated age of 2.915±0.010 Ga. Both of these ages are within error similar to those determined by Sm-Nd, Rb-Sr and Ar-Ar by [12], and the Pb-Pb age reported by [13].

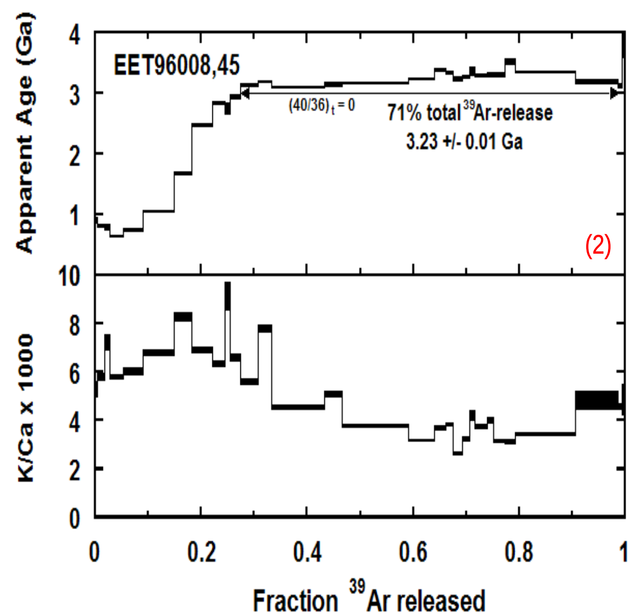


An interesting result obtained during the UV-laser ablation experiments was in the region of the glassy mesostasis where a range in ages was 1.71 to 2.32 Ga with an average of 2.18±0.12 Ga, which may be that of the formation of the [14] reported Re-Os systematics of LAP to be disturbed at ~10 Ma, however the much younger event did not disturb the Ar systematics. Considering the fractured appearance of the plagioclase and pyroxene in this sample, and the suggestion by [7] that this basalt was subjected to pressures of <30 to >75 GPa, remains the question whether the 2.915 Ga age represents to the crystallisation of a second flow of LAP as suggested by [12] or due to an impact event that may have disturbed the K-Ar system and reset the clock to a younger age. Based on experiments to study the shock-effects and the K-Ar system, [15] concluded that shock pressures up to 52.5 GPa do not disturb the K-Ar clock, instead to reset the K-Ar system on a non-molten material, it is necessary an extensive period at high temperatures. Bogard et al. [16] conducted shock experiments over a large interval from 29 to 70 GPa, which overlaps the pressures suggested for LAP [7]. These authors concluded that Ar loss can be due to extensive grain fracturing and heating during shock, and that large scale gas loss in shocked, but unmelted samples requires that materials reside for prolonged periods of time at elevated temperatures in a relatively hot impact formation, either inside or outside the crater cavity. This prolonged heating environment could occur during extrusion of an overlying lava flow [12]. Also we note that the age of 2.92 Ga for LAP is similar to that obtained for two other lunar basalt meteorites NWA032 (2.80 Ga) and for NWA773 (2.91 Ga) [17].

EET96008 The age spectrum for EET96008 is shown in Fig. 2. The initial 28% of ^{39}Ar release gives relatively young apparent ages (0.63 to 2.93 Ga) indicating Ar loss from the low-temperature sites. The lowest apparent age obtained is 630 ± 9 Ma perhaps representing the timing of an impact event that caused this Ar loss. This region of the spectrum is also characterised by a high K content as indicated by the relatively high K/Ca values (Fig. 2). For the remaining 72% of ^{39}Ar release an age of 3.22±0.01 Ga is determined (3.09±0.02 to 3.77±0.20). This age is slightly lower than the U-Pb isochrons of 3.53±0.27 Ga and 3.52±0.10 Ga obtained for apatite and whitlockite respectively [9].

Cosmic Ray Exposure (CRE)-ages LAP02205 contained negligible trapped Ar and yields a CRE age from Ar released at high temperature of ~64 Ma (using a production rate of 1.086 x 10^{-8} cm^3 g^{-1} Ca Ma^{-1} based on the chemical composition of LAP02205 and production rates of [18]). This exposure age is comparable with the CRE age determined for the cumulate portion of NWA 773 of ~73 Ma [17]. For the basalt EET96008, the total $^{38}Ar/^{36}Ar$ of this meteorite is ~1.44 which is just slightly lower than the cosmogenic value of ~1.54 possibly indicating presence of minor trapped Ar components. The total CRE-age calculated from the ^{38}Ar released at a production rate 1.032 x 10^{-8} cm^3 g^{-1} Ca Ma^{-1} is approximately 15 Ma. This age diverges from those suggested by [19] corresponding to a "recent exposure on the Moon" at 26 Ma and an "early exposure on the Moon" ≤9 Ma.

Summary Both LAP02205 and EET96008 show petrographic similarities to previous investigations works [1-7, 9, 10]. The Ar-Ar age of 2.915±0.010 Ga obtained for LAP is indistinguishable from that reported earlier [12&13] and the CRE-age is ~64 Ma. Both ages are similar to those obtained for NWA773 [17]. Ar-Ar analysis of EET96008 shows evidence for Ar disturbance occurring 630 Ma ago. The age obtained for the intermediate and high temperature steps of 3.22±0.01Ga is similar to the age obtained for the U-Pb isochron of phosphates [9]. This age is similar to that calculated to be the age of the flow where the Luna 24 lander collected samples [20]. Considering the low-Ti and low-Fe composition of EET, Mare Crisium maybe a good candidate as the source region on the lunar surface from where EET was excavated. A source region for LAP02205 is the NW region of the Oceanus Procellarum.



Refs.: **[1]** Joy et al (2004), LPSC 35th, abst.#1545. **[2]** Joliff et al. (2004), LPSC 35th, abst.#1438. **[3]** Mikouchi et al (2004) LPSC 35th, abst.#1548. **[4]** Korotev et al (2004) LPSC 35th, abst.#1416. **[5]** Righter et al (2004) LPSC 35th, abst.#1667. **[6]** Anand et al (2004) LPSC 35th, abst.#1626. **[7]** Zeigler et al (2005) MAPS 40, 1703-1722. **[8]** Mikouchi (1999) LPSC 30th, abst.#1558. **[9]** Anand et al (2003) GCA, 67, 3499-3518. **[10]**arren and Ulff-Møller (1999) LPSC30th, abst.#1450. **[11]** Nishiizumi et al (1999) LPSC30th, abst.#1980. **[12]** Nyquist et al. (2005) LPSC 36th I, abst# 1374. **[13]** Anand et al. (2006) GCA 70, 246-264. **[14]** Day et al. (2005) LPSC 36th abst.# 1424. **[15]** Jeßberger & Ostertag (1982), GCA 46, 1465-1471. [16] Bogard et al. (1987), GCA 51, 2035-2044**[17]** Fernandes et al. (2003) MAPS 38, 555-564. **[18]** Eugster&Michel (1995), GCA 59, 177-199. **[19]** Eugster et al. (2000) MAPS 35, 1177-1181. **[20]** Fernandes&Burgess (2005) GCA69,4919-4934.