LAP 02205, LAP 02224 and LAP 02226 - Lunar Mare Basaltic Meteorites. Part 2: Geochemistry and Crystallisation. K. H. Joy[1] (k.joy@ucl.ac.uk), I. A. Crawford[1], S. S. Russell[2], A. T. Kearsley[2]. [1] UCL/Birkbeck Research School of Earth Sciences, UCL, Gower Street, London, WC1E 6BT, [2]The Natural History Museum, Cromwell Road, London SW7 5BD, UK.

Introduction: In an accompanying abstract [1] we presented the petrography and mineral chemistry of the paired LAP lunar basaltic meteorites 02205 [6], 02224 and 02226. In this work we present bulk rock chemical data and parental melt crystallisation trends. The samples used for this study are the same as those discussed in [1].

Method: Major bulk major-element chemistry was attained using ICP-AES analysis on chips of LAP 02224(31) and LAP 02205(13). Other techniques used are described in [1]. Modal mineralogy was estimated using the Oxford Instruments INCA Phasemap tool. Mineral trace element concentrations were measured using a VG PlasmaQuad LA-ICP-MS.

Lunar Origin: Fe to Mn ratios in pyroxenes and olivines (Fig. 1), oxygen isotope levels in LAP 02205 of $\delta^{18}O$ of +5.6 ‰ and $\delta^{17}O$ of +2.7‰ [8] and a typical lunar anhydrous mineralogy together confirm that the meteorites are lunar in origin.

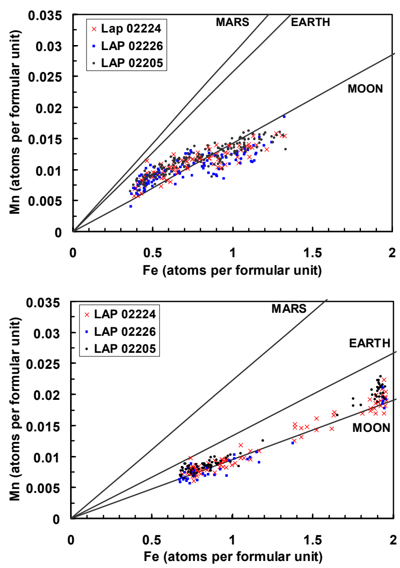

Fig. 1. Fe to Mn ratios in minerals in LAP 02205, 02224 and 02226.

Pyroxenes at top. Olivines at bottom.

Data plotted against trend lines for Mars, Earth and the Moon as quoted in [7].

Sample Description: LAP 02205, 02224 and 02226 are unbrecciated and holocrystalline lunar basalts. Their unbrecciated nature suggests that they have been excavated from depth below the level of lunar gardening. Individual minerals have shock deformation features suggesting pressures of about 15-30GPa [3, 4]. These include undulose extinction and shock deformation features in pyroxenes, mosaic extinction and the vitrification (maskelynisation) of plagioclase, and undulose extinction in olivines.

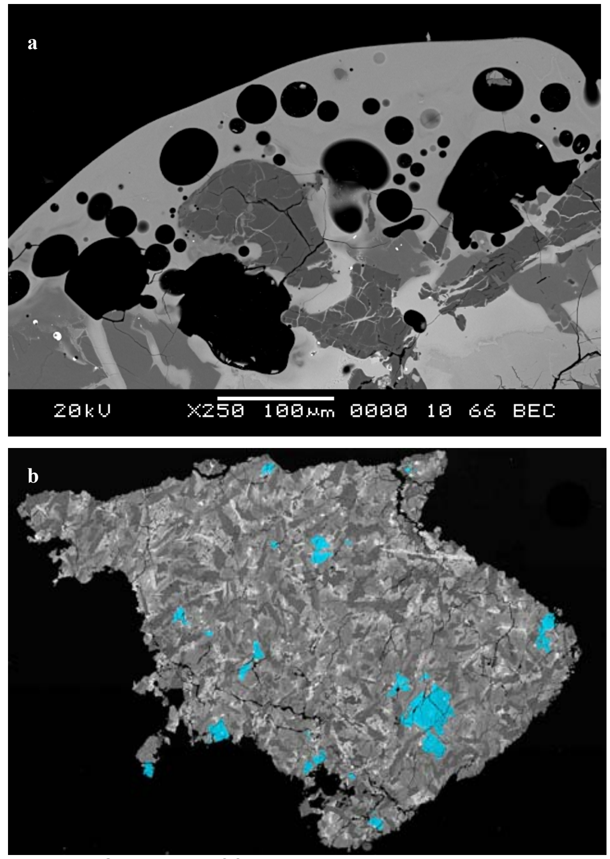

Fig. 2. (a) SEM image of fusion crust in LAP 02224. (b) Forsteritic olivine located in the whole thin section sample of LAP 02226(25) using the Oxford Instruments INCA Phasemap tool – similar phase maps were compiled for other mineral phases.

Heterogeneous melt veins of basaltic composition are seen in all three samples along with micro-faults and associated fault melt. Additionally, the section of 02224 is bound by a porous fusion crust (Fig. 2a) with a composition very similar to the melt veins although with more heterogeneity in places.

Modal Mineralogy: The technique used identified different chemical phases in montaged x-ray maps of the samples (Fig. 2b), from which representative mineral proportions could be measured. The estimated mineral content in the 02224(32) and 02226(25) sections is listed in Table 1a. The two sections have similar mineral proportions suggesting that they were crystallised from a related melt source.

Bulk-rock composition and Lunar Context: Measured using chips from LAP 02205(13) and 02224(31) (Fig. 3 and Table 1b). The meteorites can be classified in the lunar mare basalt group [2] of low-Ti, low-Al, low-K. We hypothesise that LAP 02226 is of the same class as it is mineralogically so similar (Table 1) to the other two stones.

Fig. 3. Chip of LAP 02224 (31) used for bulk chemical analysis. Plagioclase and mafic mineral phases are visible. Scale bar is 1mm.

Bulk Mg# of LAP 02205 and 02224 is very low at 31.45 and 35.16 respectively, reflecting crystallization from a much more fractionated source than most basalts in the Luna and Apollo collections [2]. The samples have very similar major element concentrations with only small differences in TiO_2, CaO, Al_2O_3, MgO and FeO. These may reflect small analysis sample volumes and heterogeneity (i.e. local clumping of ilmenite or forsteritic olivine) in patches of crystallized melt.

Trace element abundances: Pyroxene and plagioclase show complementary REE patterns (Fig. 4). REE abundances vary from 0.1 x CI in some plagioclase. HREEs to ~20 x CI in pyroxene. Melt REE concentrations were reconstructed using the values of [10] and are shown in Fig. 4.

Crystallisation: Based on mineral trace element chemistry, petrographic relationships and bulk chemistry we suggest that LAP 02205, 02224 and 02226 were formed from a related evolving basaltic source.

The evolution in melt composition can be explained if the rock included xenocrystic forsteritic olivines into a melt containing Cr-spinel and rapidly crystallized plagioclases with a skeletal texture (blue in Fig. 4). Intergranular pidgeonite (red in Fig. 4) and sub-calcic augites (black in Fig. 4) were then co-tectically crystallized with euhedral plagioclases. As the melt evolved, pyroxenes grew to have Fe-rich rims, and spinels became Ti-rich. Late extreme fractionation caused silica saturation and residual liquid immiscibility to form mesostasis areas.

Discussion: Based on petrographic similarity, mineral chemistry [1] and bulk chemistry (Table 1), lunar meteorites LAP 02205, 02224 and 02226 are probably launched paired stones that originate from what may be the same parent melt body.

As LAP 02205, 02224 and 02226 are basalts it is very likely that they were emplaced on the lunar near-side in a mare region. We plan to use remote sensing measurements from the Clementine, Lunar Prospector and SMART-1 missions and develop the technique of [5] to try and locate the possible parent mare region of these unusual lunar meteorites.

References: [1] Joy et al. (2005) LPSC *XXXVI* [2] Neal and Taylor (1992) GCA. Vol. 56. pp. 2177-2211. [3]Rubinet al (1997) GCA. Vol. 61. pp. 847-858. [4] Scott et al. (1992)GCA. Vol. 56. pp. 4281-4293. [5]Kramer et al (2004) LPSC *XXXV Abstract. 2077* [6]Joy et al (2004) LPSC *XXXV, Abstract #1545*. [7] Papike et al. (2003) American Min. Vol. 88. pp. 469-472. [8] McCoy T. et al (2003) *Antarctic Meteorite Newsletter, Vol. 26 No 2*. [9] Anders and Grevasse (1989) GCA. Vol. 53. pp. 197–214. [10] Synder et al. (1995) GCA. Vol 59 pp. 1185-1203.

(a) Modal Mineralogy

	LAP 02224	LAP 02226
Pyroxene	58.5	60.0
Plagioclase	32.1	33.0
Forsteritic Olivine	2.7	2.8
Fayalitic Olivine	0.7	0.5
Ilmenite	3.8	2.8
Cr-spinel	0.9	0.3
Silica	0.59	0.45
Other phases	1	1.1

(b) Bulk Chemistry

	LAP 02205	LAP 02224
Na_2O	0.42	0.41
MgO	5.58	6.47
Al_2O_3	10.13	9.93
SiO_2	44.53	44.57
P_2O_5	0.12	0.09
CaO	11.23	10.99
TiO_2	3.43	3.21
MnO	0.28	0.28
FeO	21.69	21.29
Total	97.52	97.33
Ba (ppm)	170	136
Cr	1958	2294
Sr	131	120
Zr	227	190

Table 1. (a)Modal mineralogy in LAP 02224(and 02226. (b) Bulk Chemistry in LAP 02205 and 02224.

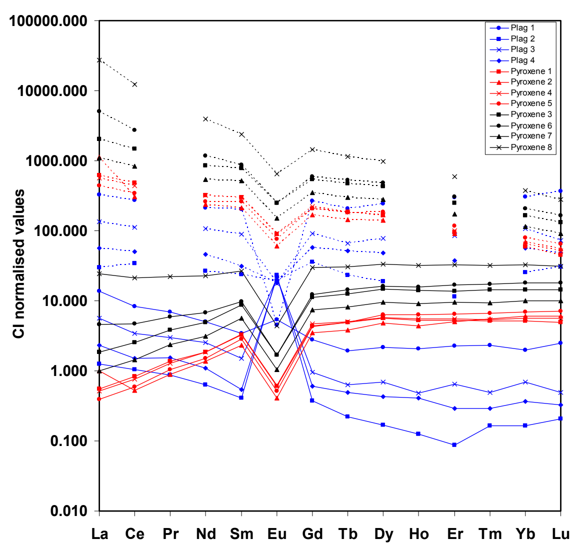

Fig. 4. REE element concentrations in mineral phases in LAP 02205 (solid lines) plotted on a CI normalised scale [9]. Calculated melt concentrations are shown in red lines.