INVESTIGATION OF LUNAR METEORITES POTENTIALLY SOURCED FROM CRYPTOMARE REGIONS A. Calzada-Diaz[1], K.H.Joy[2] and I.A. Crawford[1], [1]Department of Earth and Planetary Sciences, Birkbeck College, University of London WC1E 7HX, UK [2]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, UK. (acalza01@mail.bbk.ac.uk)

Introduction: Lunar meteorites provide valuable information about the geology far from the regions sampled during the Apollo and Luna programs [1]. Thus, some of the meteorites recovered show bulk compositions not observed in the Apollo and Luna sample collection, providing key new insights to the compositional variation of the lunar crust. However, the fact that the launch location of the meteorites is unknown makes it difficult to fully interpret their geologic history.

Some meteorites have been suspected to be launched from cryptomare regions [i.e. 2]. These regions are ancient lava deposits older than 3.8 Ga that, after emplacement onto the lunar surface, have been buried by feldspathic (higher albedo) impact ejecta blankets. Cryptomare regions have been identified by the presence of impact craters that penetrate to the mare substrate creating dark haloes around them, geochemical and geophysical evidence as well as their photo-geological context [3, 4]. Recent studies estimate that cryptomare deposits cover ~ 56.34 × 10^4 km^2 of the lunar surface with an estimated lava volume of ~111.57 × 10^4 km^3 [5]. It is not unreasonable to think that some of the meteoritie collection originated from ancient lavas represented by such cryptomare materials. These lava flows are scientifically important to provide insights into the timing and duration of lunar volcanic magmatism and its thermal history.

In this study we have used elemental compositions (FeO, TiO_2, MgO and Th) and remote sensing observations from Lunar Prospector gamma-ray spectrometer (LP-GRS) to better understand the potential provenance of some of these meteorites [6-8]. For our investigation we have selected paired meteorites Kalahari 008 and 009, Northwest Africa (NWA) 5207 and 4932 and Sayh al Uhaymir (SaU) 300. These samples are breccias of basaltic (17-23% FeO, 8-12% Al_2O_3), intermediate (7-17% FeO, 13-20% Al_2O_3) and feldspathic (<7% FeO, >25% Al_2O_3) bulk composition, representing different mixtures of highland material with more mafic lithologies. Determining their potential launch location may help to understand the origin of the mafic component of these samples and, provide new insights into early lunar magmatism.

Methodology: To investigate what regions of the Moon are geochemically similar to these meteorites we have utilised geochemistry data from the Lunar Prospector gamma-ray spectrometer (LP-GRS) using the Prettyman et al. [9] calibration 2 × 2 degrees (i.e., 60 × 60 km).

We have used the software described in [8] and the FeO, TiO_2, MgO and Th measured compositions of the lunar meteorites (Table 1: [9-12]) to query the potential for an origin in a cryptomare region. In this approach laboratory analytical technique uncertainties and uncertainties derived from the remote sensing instrument have been taken into account. It is considered a compositional match between the meteorite chemistry and LP regolith footprint if the LP-GR values for all the four elements lie within two standard deviations (2σ) of the averaged sample compositions.

Results: *Kalahari 008/009.* Kalahari 008 is an anorthositic regolith breccia [10, 11] and Kalahari 009 is a basaltic fragmental breccia with a low-FeO content (~16 wt%) compared with mare basalts [12]. These meteorites are considered paired based on similar mineral compositions, the proximity of the locations where they were found and similar exposure ages [9]. Previously, we have investigated their possible cryptomare origin based on measured LP-GRS FeO, TiO_2 and Th element values [7]. In this work we have now also included MgO in our analysis (Table 1) to produce more contrained. We have obtained compositional matched for Kalahari 008 in the Mendel-Rydberg cryptomare region and Kalahari 009 shows a match in the Australe basin (Figure 1A).

Meteorite	FeO wt%	TiO_2 wt%	MgO wt%	Th ppm
Kalahari 008	4.87 ± 0.28	0.40 ± 0.16	4.53 ± 0.13	0.18 ± 0.01
Kalahari 009	16.43 ± 1.56	0.26 ± 0.05	8.24 ± 0.41	0.20 ± 0.05
NWA 5207	7.56 ± 0.69	0.61 ± 0.12	7.50 ± 0.10	0.35 ± 0.081
SaU 300	7.00 ± 0.85	0.28 ± 0.063	6.78 ± 0.93	0.50 ± 0.04
NWA 4932	8.55 ± 0.78	0.34 ± 0.07	9.15 ± 0.11	0.5 ± 0.12

Table 1: Averaged bulk meteorite composition ± the analytical 1σ standard deviation of averaged measurements used during this study [9-11].

NWA 5207. The meteorite is a feldspathic fragmental breccia. Its matrix is formed by several lithic components: troctolitic orthocumulates, noritic and trocolitic anorthosites, gabbros, basalts, impact melt clasts, breccias and green glasses [12]. The bulk rock FeO, TiO_2, MgO and Th compositions measured from these samples (Table 1) are similar to the compositions of cryptomare regions Mendel-Rydberg, Schiller-Schickard, Australe, Milne, Langemark and surroundings of Lomonosov- Fleming. It also shows similarities to areas in the interior of the Orientale basin and Tsiolkovsky crater (Figure 1B).

SaU 300 and NWA 4932. SaU 300 and NWA 4932 are both crystalline impact-melt breccias. SaU 300 and NWA 4932 have bulk rock compositions that are low in incompatible trace elements and that are at the more mafic end of the feldspathic meteorite group [12]. The samples contain low volumes of mare basalt lithics, and their mafic component is contributed from gabbroic and troctolitic clasts [12]. Both meteorites are considered to be paired with each other on the basis of similar texture and bulk composition (Table 1 and [12]). Our results show that the bulk compositions of the meteorites (Table 1) are similar to the composition of regoliths in the Australe cryptomare region (Figure 1C).

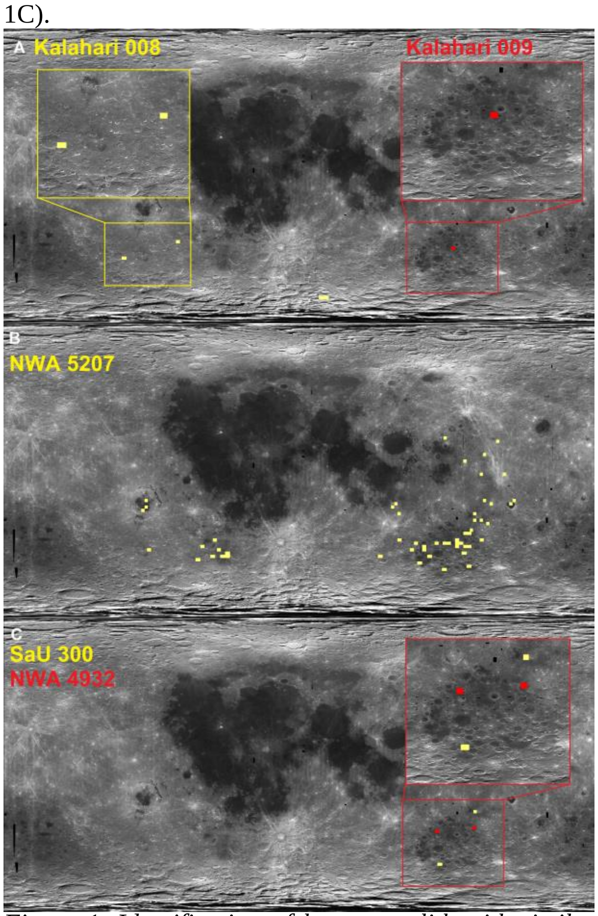

Figure 1. Identification of lunar regolith with similar FeO, TiO_2, MgO and Th compositions to (A) Kalahari 008 (yellow) and Kalahari 009 (red) (with blown up boxes for closer view), (B) NWA 5207 and (C) SaU 300 (yellow) and NWA 4932 (red) (with blown up boxes for closer view). Search locations are overlain on a Clementine mission albedo map of the Moon.

Discussion: Kalahari 008's matches are restricted to Mendel-Rydberg cryptomare region, however, paired stone Kalahari 009 shows similarities to regoliths in the Australe cryptomare region (Figure 1A). However, as this approach returns better results using regolith breccia material, we suggest that Kalahari 009 potentially represents a cryptomare sample from Mendel-Rydberg basin covered by feldspathic regolith represented by Kalahari 008 [8, 10]. A launch location in a cryptomare region for these samples is consistent with our results (Figure 1 and [8]) and with the ancient lava flow crystallisation age (>~4.35 Ga) reported for Kalahari 009 [11].

The potential source regions for NWA 5207 are mostly constrained to cryptomare regions in the eastern and western limbs of the Moon, as well as some regions in the near side (Figure 1B). All those areas show similar compositions that may indicate ancient magmatism of similar characteristics in those areas.

SaU 300 and NWA 4932 both are similar to slightly different regions within the Australe cryptomare region (Fig. 1c). Rather than representing ancient cryptomare volcanic material themselves, these samples may be the result of the impact event that created the Australe North basin [13], which hosts younger cryptomare lava flows. In this case, dating these impact melts could potentially help to investigate the age of the Australe North basin–forming event.

It is possible that the mafic component observed in NWA 5207, SaU 300 and NWA 4932 may be caused by the presence of norites, gabbronorites or troctolites of the noritic lower crust and not due to a mixture of mare basalt and feldspathic material. However, the fact that most of the results plot in cryptomare regions suggest (1) the meteorites effectively were launched from these regions, or (2) the compositions detected by the LP-GRS instrument in cryptomare areas are similar to the composition of the lower feldspathic crust.

Finally, none of the meteorites appear to have an origin within the Procellarum KREEP Terrain (all of them are ITE-poor), so their mafic component does not represent KREEP-driven magmatism. If these samples were sourced from cryptomare areas, the drivers of mantle melting may have been different in the early part of the lunar history.

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