FINDING LAUNCH SITES OF METEORITES USING LUNAR PROSPECTOR GAMMA-RAY SPECTROMETER DATASETS.

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Introduction: Nine lunar localities where sampled during the Apollo and Luna missions. Regolith compositions from those areas were analysed, permitting ground-truth validation for remote-sensing instruments [1-4]. However, the Apollo and Luna missions were very restricted geographically and so do not provide information about the whole Moon.

Lunar meteorites are material ejected from ramdon localities on the Moon in the last 20 million years, the vast majority in the last 10 million years [5]. They originated from small shallow impact craters (less than few km in size) and, therefore, they are sample from the upper part of the lunar surface [6,7]. Lunar meteorites are classified broadly into 3 groups: Impact melt breccias, crystalline mare basalts and regolith breccias [8-10].

Our project aims to use remote sensing datasets to locate the source regions of lunar meteorites so we can better place them into a geological context. Seconday goals are to understand the evolution of the lunar crust and mantle and shed light on the geology of the regions not sampled by the Apollo and Luna missions.

Adapting a method previously applied to lunar meteorites [11,12], we have developed a software application based on Python Programming language that matches input meteorite elemental compositions with the 2 degree per pixel (i.e., 60 km per pixel) LP-Gamma Ray Spectrometer (LP-GRS) dataset, including analytical standard deviations and errors derived from the remote-sensing instrument. The Python application is compatible with ArcGIS™ and produces a shapefile layer that allowas for convenient visualization of the results.

Apollo and Luna validation: We validated our approach by comparing the compositions of the Apollo and Luna bulk regolith samples [13-19] with the elemental abundance of FeO, TiO_2 and Th reported by LP-GRS. FeO was selected to discriminate between feldspathic and basaltic lithologies, TiO_2 allows us to distinguish different types of basalts, and Th is sensitive to KREEP-bearing materials. We do not include the Mg concentration in our approach due to the poor compositional resolution of the LP-GRS instrument for that element.

We obtain good correlations for most of the landing sites (Figure 1). However, there are small discrepancies related to the spatial resolution of the instrument: our dataset covers a region of 60 km per pixel and therefore heterogeneities in the area, and the fact that the samples were taken from a much smaller area, may affect our results. In the case of the Apollo 14 landing site, the average Th compositions are larger than those reported in the LP-GRS dataset so we did not obtain any matching results.

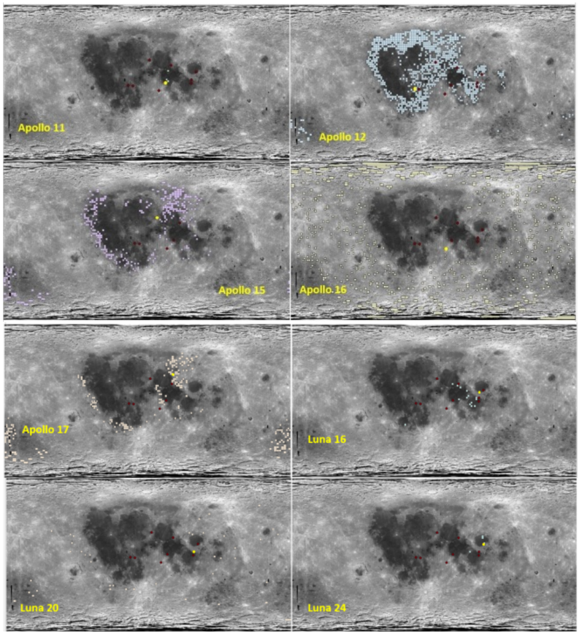

Figure 1: The coloured squares shows the results obtained during our validation exercise. Yellow points designate the landind sites points.

Lunar meteorite results: Previous work has attempted to locate the launch site of certain meteorites [8,11,12,20,21], however this is the first time that this exercise has been done in a systematic manner for all of the meteorites with reporteded bulk compositions.We create a dataset with the bulk element composition of 85 meteorites and for each of these we calculated the analytical standard deviation of averaged measurements. Some examples are described below:

Impact melt breccia. Dhofar 489 (Dho 489) is a feldspathic impact melt breccia that includes clasts of magnesian anorthosite (MAN). The low-Fe and Th content and the high-#Mg have suggested they may derive from the Anorthositic Feldspathic Highland Terrain (FHT) on the lunar central far side [22-24]. However, based on Fe, Ti and Th content, our software also returns matches on the nearside Outer FHT terrain (Figure 2a).

Crystalline basalt. LaPaz Icefield 02205 (LAP 02205) is a crystalline basalt with low Ti content [25-27]. Our results show mainly two regions as possible source regions: the Serenitatis Basin and the western area of Oceanus Procellarum (Figure 2b). Studies indicate that this meteorite crystallised at ~ 3 Ga [28] enabling us to restrict its launch site to lava flows in the western Oceanus Procellarum where lavas of this age outcrop.

Incompatible trace element (ITE)- rich mingled regolith breccia. Northwest Africa 4472 (NWA 4472) is a regolith breccia with high content on KREEP elements such as Th (up to 7 ppm) [8,12]. It is thought to be part of Imbrium ejecta deposits both from composition and age (3.92 Ga). Our approach return Mare Frigoris or the surroundings of Mons Caucasus as probably launch sites for this meteorite (Figure 2c).

Basaltic mingled regolith breccia. Calcalong Creek is a basaltic-bearing anorthositic regolith breccia [29]. Our results show that the western boundary of Oceanus Procellarum and the eastern area of Mare Frigoris should be considered as possible source regions (Figure 2d). This meteorite had been hypothesized to originate from the South Pole-Aitken impact basin [30] so our results shed doubt on this previous hypothesis.

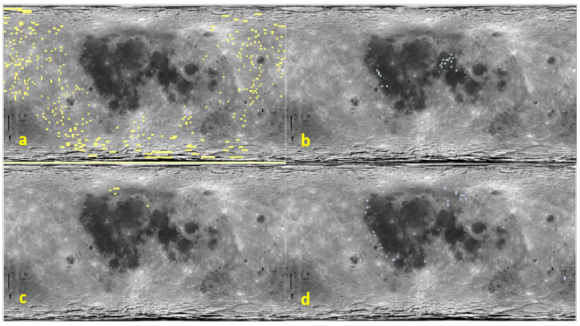

Figure 2: Image showing the places where the analytical FeO, TiO2 and Th compositions matches the regolith measurements reported by LP-GRS (coloured squares). Meteorites plotter are: a Dho 489; b LAP 02205; c NWA 4472 and d Calcalong Creek.

Discussion: Although we have successfully validate our approach against the Apollo localities, several additional factors should be taken into account: the spatial resolution and the measurement uncertainty in the remote sensing data.

The spatial resolution of the LP-GRS dataset used in this work is 2 degrees (i.e., 60 km per pixel). It was chosen due to a combination of an adequate compositional accuracy and an acceptable spatial resolution. Nonetheless, geologically, terrain varies significantly across 60 km, and samples of lunar material are collected or launched from a discrete point, which may lead to some of the small discrepancies seen in our results.

Measurement uncertainties of the LP-GRS instrument also limits the use of some elements such as Mg. Enhanced maps with minimised errors will allow us to include more elements and improve the results.

Future work: The next step will be to integrate chronology where possible, as well as explore other remote-sensing datasets for better constrain the results.

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