IDENTIFYING THE LUNAR SOURCE CRATERS OF THE NORTHWEST AFRICA 773 CLAN METEORITES USING THE SPECTRAL DATA FROM THE KAGUYA MULTIBAND IMAGER Mingyu Tian[1], Zilong Wang [1,2], Jianqi Qin[1,3], Wei Tian[1]. [1] School of Earth and Space Sciences, Peking University, Beijing 100871, China [tmy101@stu.pku.edu.cn], [2] Key Laboratory of Paleomagnetism and Tectonic Reconstruction of MNR, Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100871, China. [3]Institue of Remote Sensing and Geographical Information System, Beijing, 100871, China.

Introduction: Lunar meteorites have been used for decades to provide detailed structural and chemical insights into the geological history of the Moon. However, identifying the exact lunar source craters for the meteorites remained a complex challenge due to the vast and varied lunar landscapes. In recent years, it has been demonstrated that the source regions can be identified by comparing the chemical composition of the meteorites with the spectral data of the lunar surface [1,2].

The Northwest Africa (NWA) 773 clan comprises a group of lunar meteorites, including 16 distinct stones that feature four different lithologies: regolith breccia, olivine gabbro, ferro-gabbro, and olivine basalt, with a young radiometric age of ~2.9-3.1 Ga [3]. A previous study [2] suggested that Le Verrier D is a potential source crater for this clan. However, the spatial resolution of the remote sensing data employed in that study, namely the Global Elemental Maps from the Lunar Prospector gamma-ray spectrometer, was relatively low, with a pixel size of 60km×60km. Moreover, the mineral-abundance data were not incorporated, which limited the secondary validation of the proposed source regions based on the modal abundance of the meteorites [2].

The recent establishment of high-spatial-resolution oxide and mineral abundance datasets from the Kaguya Multiband Imager (MI) allows for more precise identification of the potential source regions [4, 5]. In this study, we identified two updated potential source craters for the NWA 773 clan by integrating this high-resolution spectral data with estimates of the age and diameter of the source craters. This study leverages state-of-the-art datasets to enhance our understanding of the lunar surface and the provenances of specific meteorite samples.

Methods: We employed oxide-content and mineral-abundance data from the Kaguya MI [4, 5] to identify potential source craters for the NWA 773 clan meteorites. The oxide-content and the mineral-abundance data have a resolution of ~59 m/pixel and ~62 m/pixel, and cover latitude ranges of $\pm$65° and $\pm$50°, respectively. The regions beyond the $\pm$50° latitude were thus excluded from the subsequent analysis. The mineral model abundance and chemical composition of the NWA 773 clan were sourced from a previous study [6]. We then compared the oxide-content and mineral-abundance data of the NWA 773 clan with the corresponding spectral datasets using ArcGIS. By establishing and applying reasonable matching thresholds for each parameter, we identified regions that matched all criteria as potential source craters for the meteorite clan.

To determine the threshold values for the source-crater matching, we initially assumed that the sample is composed entirely of olivine gabbro to obtain one boundary value. The other boundary was set by considering the sample as entirely breccia. We then adjusted these initial values by adding three times the reported measurement error. Given that the Kaguya MI data include only four mineral types (olivine, clinopyroxene, orthopyroxene, and plagioclase), we calculated the normalized modal abundance of the four minerals of the NWA 773 clan. For elemental thresholds, we focused on FeO and TiO_2 for the matching, which is consistent with the configuration of [2]. Consequently, the matching threshold values for minerals were set as follows: olivine (18-57 vol.%), plagioclase (9.8-28.1 vol.%), clinopyroxene (22.8-61.4 vol.%), and orthopyroxene (0-23 vol.%). The thresholds for oxides were set as: FeO (18.9-21.4 wt.%) and TiO_2 (0.4-2 wt.%).

Additionally, given that the radiometric age of the NWA 773 clan samples is ~2.9-3.1 Ga, the age of the source region should be consistent with or younger than this age. Thus, we utilized crater-size frequency distribution (CSFD) measurements to further refine the search for the source crater.

Table 1. Possible source craters of the NWA 773 clan.

	1	2	3
Name	-	Borel	Deseilligny
Location	$57°14'W$ $0°20'S$	$26°25'E$ $22°22'N$	$20°34'E$ $21°7'N$
Diameter (km)	5.5	4.7	6.0
Terrain	Oceanus Procellarum	Mare Serenitatis	Mare Serenitatis
CSFD age (Ga)	$2.91^{+0.30}_{-0.53}$	$2.91^{+0.09}_{-0.10}$	$3.17^{+0.04}_{-0.05}$

Results and Discussion: Applying the established thresholds for mineral and oxide contents, along with crater size and age considerations, led to the identification of three lunar craters as potential source regions for the NWA 773 clan meteorites (Table 1).

Following the analysis framework of [2], it is proposed that the NWA 773 clan meteorites underwent two distinct shock events. The first impact event is believed to have caused the excavation and subsequent exposure of the meteorites on the lunar surface, while the second event is thought to have resulted in their ejection and eventual arrival on Earth. This two-stage impact process necessitates that the source craters meet specific diameter criteria: the crater from the first event should be larger than 5 km, and the crater from the second event should be no smaller than 0.849 km. Based on these requirements, only Crater 1 and 3 from Table 1 fulfill the diameter constraint. Remote sensing images from Kaguya terrain camera of these craters are presented in Figure 1.

Our results deviate from those deduced in [2], particularly regarding the proposed Le Verrier D crater located in the northern part of Mare Imbrium. The discrepancy in location – approximately 1027 km from the nearest source crater identified in our study – suggests limitations in the earlier 1°×1° spectral datasets [1,2]. Those datasets may lack the necessary precision for accurate source-crater matching of meteorites, especially considering the small size of meteorite samples and their representation of a very limited lunar surface area. Furthermore, when incorporating other major oxides (e.g., CaO, MgO, Al_2O_3) from the MI datasets into the source-crater matching process, no region completely aligns with the lithology and composition of the NWA 773 clan meteorites without significantly relaxing the threshold criteria. This finding emphasizes the importance of ensuring that meteorite samples are representative of the lunar surface regions from which they originate. Additionally, improving the spatial resolution and fitting accuracy of spectral datasets and selecting appropriate thresholds are crucial for successful source crater identification.

Given these challenges and the current findings, it is clear that further research and refinement are needed to fully establish and validate the source-crater matching method. Future efforts should focus on enhancing the precision of spectral datasets and refining the methodology for aligning meteorite compositions with potential lunar source regions. This continued work is essential for advancing our understanding of the origins of lunar meteorites, the history of lunar impacts, and the broader geological context of the Moon's surface. Such advancements are not only critical for academic research but could also have practical implications for future lunar exploration missions and studies.

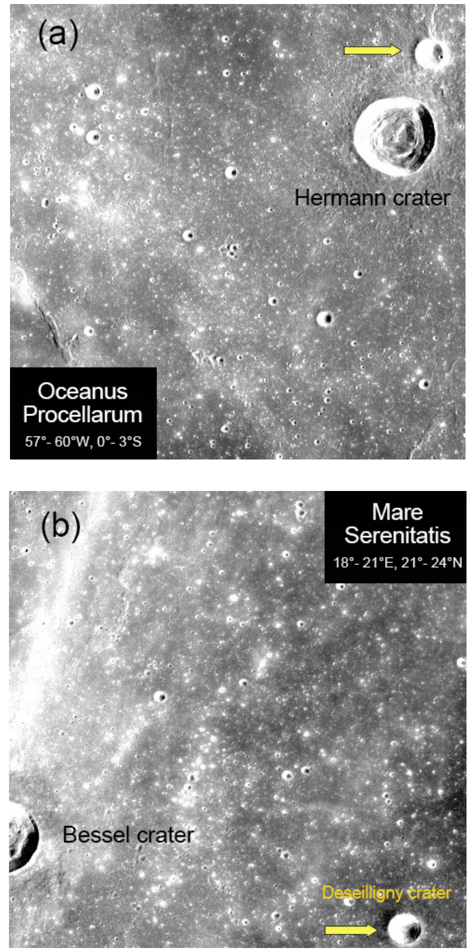

Figure 1. Optical images from Kaguya terrain camera; (a). image of Crater 1; (b). image of Crater 3

Acknowledgments: The authors thank the Planetary Data System (PDS) for documenting the Kaguya Terrain Camera data.

References: [1] Calzada-Diaz A. et al. (2015) *Meteoritics & Planet. Sci.* 50, 214-228. [2] Nagaoka H. et al. (2021) *Icarus* 370, 114690. [3] Merle R. E. et al. (2020) *Meteoritics & Planet. Sci.* 55, 1808-1832. [4] Lemelin M. et al. (2019) *Planet. & Space Sci.* 165, 230-243. [5] Zhang L. et al. (2023) *Icarus* 397, 115505. [6] Fagan, T. J., et al. (2003) *Meteoritics & Planet. Sci.* 38, 529-554.