Genetic Geological Modelling for Lunar Resources: West Tranquillitatis Ilmenite Deposit.

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Introduction: On Earth, genetic models are commonly employed to explain the origin of mineral economic deposits, playing a critical role in estimating the tonnage, grade, and quality of mineral resources. In contrast, there has been no development of geological genetic models for lunar resources thus far. Although the absence of samples poses a challenge, it is possible to use available remote sensing data, combined with recent models lunar volcanic eruption, presents an opportunity to make initial approximations of lunar deposits from an economic lunar geology perspective.

Ilmenite lunar deposit: Ilmenite ($FeTiO_2$) is the most abundant oxide mineral on lunar rocks, occurring in mare basalts. It is a mineral of interest for the extraction of oxygen, specially using hydrogen reduction methods [1]. Also, ilmenite's crystal structure is favorable for retaining solar-wind-implanted gases like H or ^3He. Enrichments ni TiO_2 were first observed in Apollo 11 samples. Subsequent orbital measurements confirmed TiO_2 concentrations exceeding 8 wt.% with maximums surpassing 10 wt.% in the region's northwestern part (Figure 1).

Deposit characterizations: In this project, we aim to explore the potential of lunar regolith as a resource, as it is the first material to be excavated due to its accessible and unconsolidated nature. Specifically, we are focusing on three key characteristics of the regolith: (1) Possible parent material, (2) regolith maturation and, (3) regolith depth.

Possible parent material: It was believed that coherent solid basalt served as the parent material for mare regolith development. However, more recent research on lunar volcanic eruptions has revealed that the the starting conditions for regolith formation can vary greatly depending on factors such as eruption style, initial volatile content, total dike volumes, vent configuration, and magma discharge rate [3,4]. These variations in the original protolith have significant implications for subsequent development, maturation, and regional variability of regolith deposits, resulting in a diverse array of deposits with comparable remotely detected TiO2 content but differing mineral modes, thickness, surface features, and internal structures.

Regolith maturation plays a critical role in determining its mineral composition. As the regolith matures, the number of agglutinates and impact glasses within it increases. Consequently, while the overall chemical composition of the deposit may remain relatively constant, the mineralogy can experience significant changes [5].

Regolith depth is a crucial determinant in evaluating the quantity of material that will be obtainable for subsequent excavation and processing.

Methodology: To characterize the deposit several aspects are being considered.

(1) Morphology features as the surficial expression of the style and duration of the eruption and thus, of the deposit bedrock. Presented here.
(2) Regional average of regolith depth using crater morphology methods and crater counting techniques [6]
(3) Creation of 3D geological models using geological modelling software (eg. Leapfrog™). and geostatistics methods to estimate grades and tonnages.

Datasets:

- Imaging data from LROC WAC and NAC (100 and 0.5 m/px, respectively), and Selene's Terrain Camera (10 m/px).
- SLDEM, (Selene-LOLA coregistred DEM; 512 m/deg, vertical accuracy 4-5 m) LOLA and Selene [7].
- OMAT maturity index derived from Clementine's UVVIS dataset (∼ 140 m/px) [8].
- M3 datasets (70 m/px) [9].
- Gravity maps from GRAIL mission [10].

West Tranquillitatis Ilmenite eruption style: The deposit is located to the Northwestern side of mare Tranquillitatis (Figure 1). It exhibits an irregular shape with the higher concentrations of TiO_2 found in its interior.

The volcanic freatures observed are indicative of the phase of eruptive activity which it was formed. In the case of this deposit is noticeable that most of the irregular mare patches (IMP) are situated within or close to areas showing these higher concentrations in the interior of the deposit. The presence of IMPs suggest the region was formed in the declining phase of dike emplacement reaching different depths within the cooling of the lunar crust [3, 11]. Shallow dikes may have formed the domes observed within the region and depth dikes may form the grabens observed, whereas dikes that have remained trapped close to the surface, may have accumulated and have local magmatic foam extrusions [11].

There are fewer IMPs and domes present in regions of the deposit with lower TiO_2 content. Here predominates long lava flows that are indicative of a hawaiian eruptive style [3].

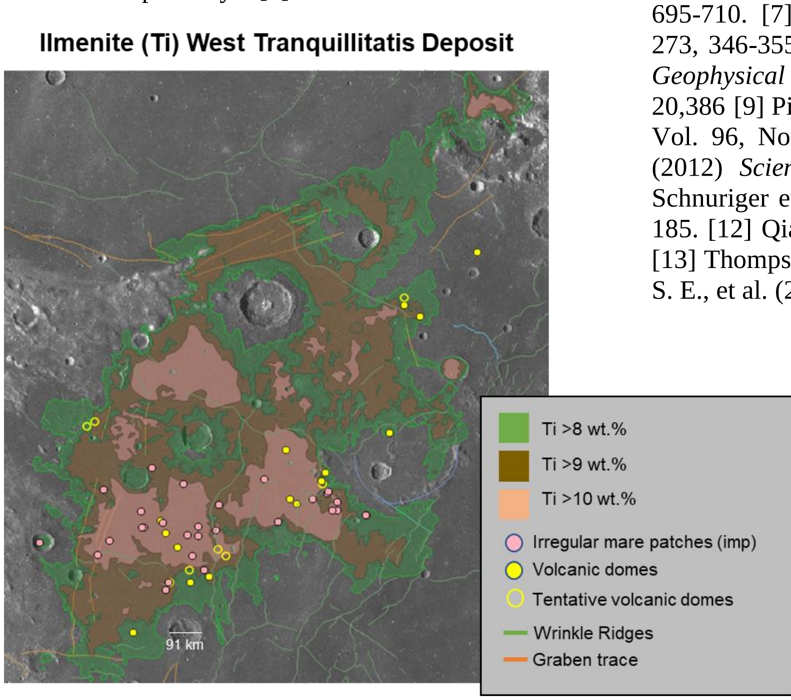

Figure 1 : Ilmenite geomorphology deposit map. Ti content from LROC/WAC-derived Ti maps. Domes generated using data from [12]. Wrinkle Ridges from [13]. Graben Traces from the Unified Geologic Map of the Moon (2020) and Irregular mare patches extracted from [14]. Base map LROC/WAC image. North to the top.

Conclusion: In summary, the region is not homogeneous, it exhibits a diversity of volcanic features and materials that have likely impacted regolith development. It is possible then than materials within the region have different grain-sizes distributions. During this project, connections between the original protolith and the regolith formation are being investigated to provide insights into those lateral regional variations.

Finally, geological modelling will be conducted to do a first estimation of grades and tonnages expected depending of the regolith regional variability. This has important implications for an hypotetic development of a mine as well as for the subsequent beneficiation and oxygen extraction processes.

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