Introduction: The Moon’s South Pole-Aitken (SPA) Basin is the largest and oldest feature on the lunar surface [1-3]. This basin records a massive impact event which played a significant role in the Moon’s formation and may have produced an impact melt sea [4,5]. The SPA impact event produced enough energy to excavate the lunar mantle [3], yet spectral data reveals the occurrence of olivine in only a few locations [6], including the peak ring of Schrödinger crater and the central peak of Zeeman crater (Fig. 1), both of which lie at the southern floor of the SPA.

Figure 1: Topographic map of the SPA in km showing locations of craters in this study (black circles) with superimposed locations of spectrally-detected olivine (white dots) and pyroxene (red dots) reported by [6] and mineralogical regions outlined in [3].

Two prevailing mechanisms have been proposed to explain the anomalously feldspathic mineralogy of the SPA. In the first, the SPA stratigraphy formed as an impact melt sea differentiated into distinct layers of norite, pyroxenite, and dunite, with norite comprising the uppermost 12.5 km [7,12]. Modelling of Orientale basin suggests another mechanism, wherein the energy from the basin-forming impactor melts adjacent lunar crust which then flows into the basin, masking the underlying excavated ultramafic material [13].

This work investigates the origin of one particular topographic feature: a massif on the northwest rim of Zeeman crater that towers as much as 8 km above the crater floor. The origin, characteristics, and formation of this feature—and its significance in the broader context of the SPA basin—have been largely unexplored before now.

Spectral data guides further study, but is alone insufficient to address questions surrounding the origin of Zeeman’s massif, where olivine has not been detect-
Discussion: The grain density expected for pure anorthosite is 2.75 g cm\(^{-3}\), 2.95 g cm\(^{-3}\) for norite, 3.20 g cm\(^{-3}\) for pyroxenite, and 3.25 g cm\(^{-3}\) for dunite [12]. Taking the grain density for pure anorthosite (2.75 g cm\(^{-3}\)), we can place an upper bound of 42% on the volume fraction of ultramafic mineralogy in the massif. The basin interior has a slightly higher grain density, reflecting a greater abundance of ultramafic mineralogy consistent with spectral detections of olivine. Feature 5a yields the lowest density value in this study, consistent with pure anorthosite, yet lies hundreds of km from the proposed SPA exterior boundary.

Conclusions: We infer the impact melt sea hypothesis based on slightly higher average grain densities across the crater rims, consistent with an overlying noritic residuum. The crustal melt inflow hypothesis favors a lower density, feldspathic composition consistent with lunar highland anorthosite, but does not rule out the possibility for compositional mixing. Changes in density across these features highlights the complexity of the SPA. The effects of later crustal mixing from impact bombardment, or uncorrected variations in porosity may account for the variations we observe here.

What formed the anomalously high massif on Zeeman crater? While crater rims are typically elevated, this massif is too tall to have been formed solely by the Zeeman crater impact event. Density values eliminate the possibility of excavated mantle material, suggesting instead that the massif is autochthonous, comprised of the same material as the SPA floor. Alternatively, this massif may be a block of crust ejected during the SPA or another large impact, which became lodged in the SPA floor, prior to the Zeeman impact. In this case, a lower density, would be anticipated [10].

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