**Introduction:** Impact melt deposits occur on the floors, walls and rims of lunar impact craters and basins [1, 2] and there is a range of field and experimental evidence that proportionally more melt is produced as a function of increasing crater size [3, 4]. Hydrocode models predict that basin-scale impacts will produce huge quantities of impact melt [5, 6]. The nature of impact melt formation and evolution in lunar basins is uncertain, however, due to post-basin flooding and modification by mare volcanic deposits, and obscuration of the basin interior [7] where the majority of melt resides [1, 2]. The Orientale basin [8-11], only partly flooded with mare, offers a unique opportunity to assess the nature of impact melt deposits and address questions concerning their volume, thickness, mode of emplacement, cooling and possible differentiation. A major unknown is the thickness of impact melt sheets in lunar basins. Earlier we applied simple cooling theory and utilized topography data to estimate the thickness of the melt sheet on the floor of the Orientale basin [12].

**Impact Melt in the Orientale Basin: Morphology and Topography of the Maunder Formation:** The Maunder Formation lies inside the Outer Rook ring and consists of two facies, both of which have historically been interpreted as impact melt [2, 7-9]. The outer corrugated or fractured facies drapes the inner plateau and peaks of the Inner Rook Ring protrude through this facies. The inner plains facies is smooth and occupies the basin floor, exposed from place to place through the thin mare fill [11, 12]. The smooth facies occurs inside the inner depression and is characterized by marginal normal faults (down to the basin interior) and a series of large fractures and polygonal cracks. Most workers interpret the corrugated facies as being impact melt mixed with breccia clasts, and the smooth facies as a more pure impact melt [8-10]. M³ data on the mineralogy of the Maunder Formation [13] indicate that the upper surface of the plains facies is largely anorthositic in nature. M³ [13,17] and Kaguya [14] data on the Orientale region have detected no evidence for the presence of subcrustal mafic mantle material in the Orientale basin deposits. Crustal thickness below the center of the Orientale basin is estimated to be ~10 km [15]. LOLA data reveal the altimetry of the basin in detail and show that the inner depression lies at an average elevation of about 2 km below the corrugated facies that occupies the Inner Rook plateau [17].

**Analysis of Nature of Subsidence and Implications for Thickness of Melt Sheet:** On the basis of LOLA altimetry [6] of the floor of Orientale, the prominent topography of the interior is seen to be composed of the Inner Rook plateau, and the inner depression, separated abruptly by the margin of the inner depression. Among the sources of immediate post-basin-collapse topography is general thermal equilibration of heat: 1) imparted to the substrate by the impact [18], of which impact melt is a significant part, and 2) caused by uplift of deep lithospheric isotherms during collapse, both of which are predicted to lead to thermal subsidence [18]. Deconvolution of this combined topographic signal requires further theoretical and modeling assessments; here, because the thickness of the melt sheet is so poorly known, we assume as an endmember that all of the observed topographic subsidence [12] is due to cooling of the melt sheet. Analysis of the broad topography shows that the inner depression is separated from the Inner Rook plateau by an average by ~2 km (Fig. 1) and we adopt this as representing the regional thermal subsidence. In summary, on the basis of LOLA topography and basic cooling models [12], we interpret the melt sheet to have had a maximum thickness of ~20-25 km.

**Morphology and Morphometry of the Maunder Formation:** Our goal in this analysis is to characterize the nature and evolution of impact basin melt sheets in order to assess their volumes, modes of emplacement, cooling and petrogenetic evolution. How were they emplaced? What do the different facies mean? How deep are they? How long did it take them to cool? How did they evolve as they cooled? What was the nature of their cooling behavior? What is their mineralogy and stratigraphy? Did differentiation or equilibrium crystallization [23,24] take place? How are they related to mascons? How sensitive is their evolution to lunar thermal evolution? What can knowledge of these questions tell us about the immediate post-basin formation crust-mantle configuration? Here we report on results from the first phase of our analysis: the surface morphology, morphometry, stratigraphy and sequence of major events in the evolution of the Maunder Formation, the Orientale basin impact melt sheets. We specifically describe four elements of the smooth facies of the Maunder Formation.
(Fig. 1): 1) Inner ring bounding scarp: This scarp is located at the edge of the inner ring depression along the western border, drops 2.8 km over a lateral distance of only ~12 km (Fig. 1a) and distinctly separates the fissured facies from the smooth facies of the basin interior; its two distinct back-tilted scarps suggest listric normal faults. Interpretation: This scarp marks the location of the major thickness variation between the thin and more rapidly cooling Maunder fissured facies and the much thicker smooth facies of the more slowly cooling interior basin. Its abrupt drop and magnitude provide evidence for the thickness of the melt sea [12]. 2) Hummocky floor topography: This hummocky texture (Fig. 1b) is in contrast to the generally smooth character of the basin floor; the texture is composed of small mounds and hummocks, short linear ridges and fissured troughs. Topographic relief is typically 100-200 m, but can be locally up to ~500 m. Interpretation: On the basis of surface morphology, we tentatively interpret this terrain as remnants of a quenched crust that contained floating elements of impact breccia fragments. 3) Floor massifs: These features consist of central mountains rising hundreds of meters above a relatively flat irregularly shaped plateau (Fig. 1c,d); plateau widths are of the order 10-20 km, with steep marginal scarps that rise up to 300-500 m above the surrounding smooth plains. Interpretation: These features are interpreted as “rockbergs” in which km-scale excavated crustal fragments float in the impact melt sea, cool their surroundings, and then fracture at the edge of the cooled plateau as the adjacent hotter melt continues to solidify and subside. 4) Marginal transitional deformed terrain: This distinctive terrain (Fig. 1e), located between the steep scarp (Fig 1a) and the smooth plains with floor massifs (Fig. 1c,d), represents a more transitional boundary between the fissured and smooth Maunder facies, with a 2.3 km high, ~30 km wide transition representing more of a draping of the cooling melt sheet rather than a distinctive scarp. The smooth parts of the melt sheet are highly fractured with some parts separated by scarps of ~700 m relief. Portions of the melt sheet tilt toward the interior indicating preferential subsidence toward the melt sheet interior. Interpretation: We interpret these terrains as transitional between the fissured facies and the smooth facies; in contrast to faulting of the cooling melt sheet at the abrupt scarp (Fig. 1a), these manifest the more substantial central melt sea cooling by faulting, fracturing and tilting of the margins of the cooling and thickening melt boundary layer.

Conclusions: These observations and stratigraphic relationships help to confirm an impact melt origin for the Maunder Formation and provide initial quantitative data on the cooling history of the Orientale melt sheet [12].


Figure 1. Orientale Maunder Formation surface structure and topography. Kaguya TCOrtho_MAP image and LOLA and TC merged DEM (SLDEM2015, [21]).