DEPTH AND DIFFERENTIATION OF THE ORIENTALE MELT LAKE. W. M. Vaughan[1], J. W. Head[1], P. C. Hess[1], L. Wilson[2], G. A. Neumann[3], D. E. Smith[4], and M. T. Zuber[4]. [1]Department of Geological Sciences, Brown University, Providence, RI 02912, USA, Will_Vaughan@brown.edu. [2]Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK. [3]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771. [4]Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139.

Introduction: Impact melt emplacement and evolution in lunar multi-ring basins is poorly understood since impact melt deposits in basins are generally buried by mare basalt fill and obscured by subsequent impact cratering. The relatively young Orientale basin [1-3], which is only partially flooded with mare basalt [4-5], opens a rare window into basin-scale impact melts.

We describe the geology of impact melt-related facies in Orientale and suggest that the central depression of Orientale may represent a solidified impact melt lake that vertically subsided shortly after basin formation due to solidification and cooling [6]. We use Lunar Orbiter Laser Altimeter (LOLA) data to measure the depth (~1.75 km) and diameter (~350 km) of this central depression. If all the observed subsidence of the central depression is due to solidification and cooling, the melt lake should be ~12.5-16 km deep, far more voluminous (~10^6 km^3) than the largest known differentiated igneous intrusions on Earth [7-8]. We investigate the possibility that the Orientale melt lake has differentiated and model 1) the bulk composition of the melt lake, 2) the operation of melt mixing in the melt lake, and 3) the chemical evolution of the resulting liquids on the An-Fo-Qz ternary in order to predict the lithologies that might be present in the solidified Orientale melt lake. Finally, we consider the possible significance of these lithologies.

Geology of melt-related facies in Orientale: The topography of the Orientale basin is shown in Figure 1. The Inner Rook Ring, at a radius of 480 km from the basin's center, and the Outer Rook Ring, at a radius of 620 km, are interpreted respectively as the peak ring [9] and an approximation of the rim crest of the transient cavity prior to cavity collapse [1, 10]. Models of impact melt production suggest that most melt is formed in a hemispherical or spherical melt cavity interior to the peak ring [11]. Assuming that only a small proportion of melt is completely ejected by the collapse of the melt cavity during crater modification [12], most impact melt should remain interior to the Outer Rook Ring [12-13].

In fact, the Maunder Formation, which lies inside the Outer Rook Ring, comprises two facies which have been interpreted as impact-melt related [1-2, 14-15]. A smooth inner plains facies, exposed through thin mare fill [5, 16] and interpreted as a pure impact melt sheet [1-3], occupies the central depression of the Orientale basin. Near the edges of the central depression, wrinkles, fractures, and polygonal cracks are apparent in the smooth facies and overlying mare. About 175 km from the center of the Orientale basin, the topography abruptly rises ~1.75 km from the central depression along a series of marginal normal faults to a corrugated, rough fissured facies. This corrugated facies is interpreted as clast-rich impact melt draping the Inner Rook Ring peaks [1-3].

Depth of the Orientale melt lake: What caused the substantial (~1.75 km) vertical subsidence of the Orientale basin's central depression? One possibility is that the vertical subsidence of the smooth facies is related to thermal stresses resulting from impact-generated heat and uplift of crustal isotherms [17]. This model predicts gentle radial vertical subsidence. However, new, high-resolution LOLA altimetry [18] shows that the vertical subsidence of the central depression is abrupt: along the west edge of the depression, the topography drops ~2 km over a radial distance of ~20 km. The model of [17] cannot fully explain this abrupt vertical subsidence. The fractures of the smooth inner plains facies bear resemblance to the deformed surfaces of terrestrial lava lakes [19]; if the smooth facies is an impact melt sheet, these fractures could result from lateral shrinkage upon solidification and cooling. The vertical subsidence of the central depression could similarly result from solidification and cooling of the impact melt sheet [6]. This constrains the depth of the impact melt sheet: a body of hot magma emplaced on the lunar surface should undergo ~11-14% vertical subsidence [6] upon solidification and cooling. ~1.75 km average vertical subsidence is observed (Fig. 1), implying the melt sheet is up to ~12.5-16 km deep.

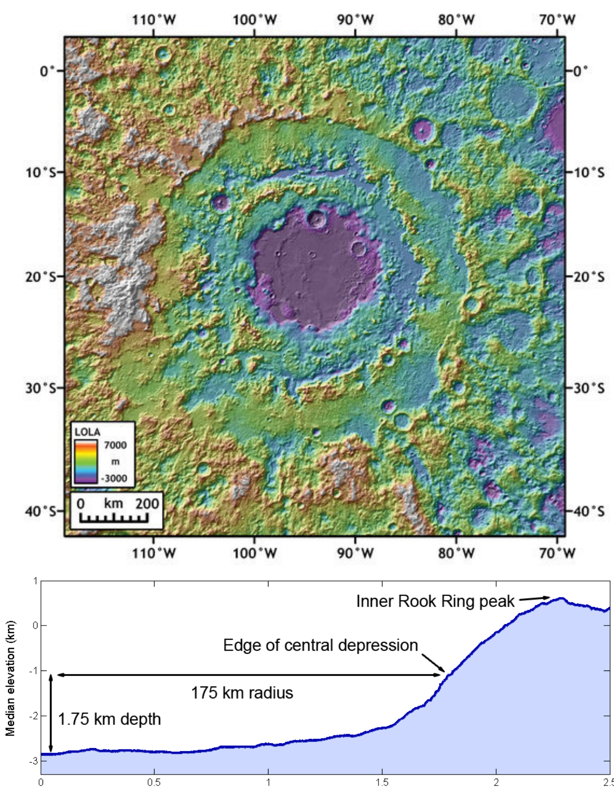


Figure 1. Topographic map (top) and average radial topographic profile (bottom) of the Orientale basin.

Differentiation of the Orientale melt lake: The Orientale melt sheet (which, volumetrically, may be better described as a lake) is ~350 km in diameter and may be up to ~12.5-16 km deep, implying a volume of ~10^6 km^3, far greater than the largest differentiated igneous intrusions known on Earth [7-8]. Could the Orientale melt sheet have differentiated? Previous work [20] has argued that impact melt sheets do not differentiate since 1) few or no differentiated impact melt sheets are known on Earth, 2) impact "melt" sheets are better described as magmas carrying cold clasts, assimilation of which rapidly depresses liquid temperature. However, mounting evidence suggests that several large terrestrial impact melt sheets have differentiated (namely, the Sudbury Igneous Complex [21-22], Manicouagan [23], and Norokweng [24]). Also, the volume of shock melt produced by an Orientale-size impact is so enormous [11] that huge clast-free volumes seem likely to exist. We therefore develop a simple model to predict the lithologies that might crystallize from the Orientale melt lake and other solidified multi-ring basin impact lakes based on 1) the bulk composition of the melt lake, 2) the operation of melt mixing in the melt lake, and 3) the chemical evolution of the resulting liquids on the An-Fo-Qz ternary.

Bulk composition of the melt lake. We model the lunar crust as a planar layer of anorthosite ~26.9 km thick overlying an anorthositic norite layer extending to a depth of 52.0 km based on the dual-layered crustal thickness model presented in [25]. The anorthosite layer has a density of 2.82 g/cm^3 and a composition of 86 wt. % anorthite, 10.5 wt. % enstatite, and 3.5 wt. % forsterite; the anorthositic norite layer has a density of 3.04 g/cm^3 and a composition of 60 wt. % anorthite, 30 wt. % enstatite, and 10 wt. % forsterite. These compositions are highly approximate; the modal anorthosite is based on [25] and the modal mafic minerals are calculated based on a 3:1 enstatite:forsterite proportion by weight.

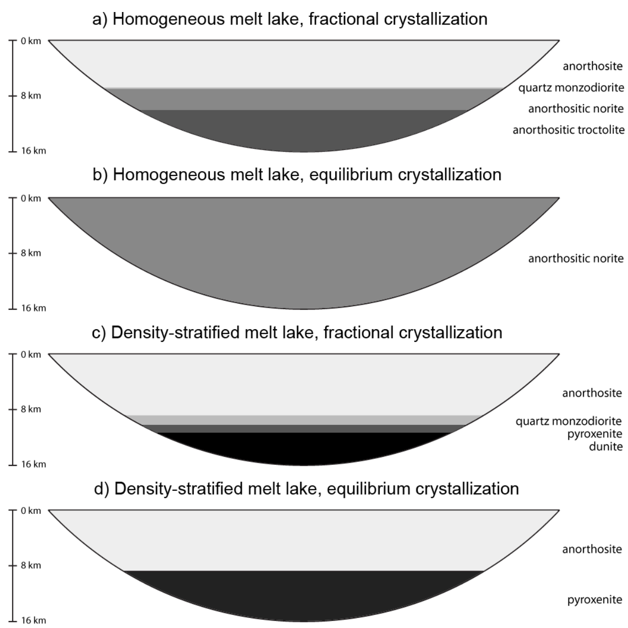
The melt cavity has a complex geometry [11] which we approximate as a hemisphere with its largest cross section coincident with the top of the anorthosite crustal layer. M^3 [16] and Kaguya [26] spectra of the Orientale region detect no evidence for the presence of subcrustal mafic mantle material in Orientale basin deposits, so we assume that the Orientale impact did not sample the upper mantle. Therefore, we choose the radius of our modeled melt cavity to be 50 km, slightly less than the thickness of the far side crust [25]. The mass of each layer melted was calculated as the product of the volume of the melt cavity hemisphere intersecting the anorthosite and anorthositic norite layers and the density of these layers.

Melt mixing. Impact melt is vigorously mixed and may therefore be homogenous; i.e., the composition of any small volume of melt will be identical to the bulk composition of the melt lake. However, even a well-mixed melt lake may not be homogenous [22]: impact-melted liquids with very different viscosities may be effectively immiscible on short timescales and stratify according to density contrasts. In the Orientale melt lake, viscous anorthosite liquid and fluid mafic liquid could be effectively immiscible and separate by density to produce anorthosite liquid overlying dense mafic, pyroxenitic liquid.

Igneous differentiation. We treat igneous differentiation of the homogenous melt lake on the well-known An-Fo-Qz ternary phase diagram at 1 atm (since lunar crustal pressures are low). Impact melt has an initial temperature well above the liquidus at 1400 °C. Upon crystallization, the processes of crystal settling and convection operate to fractionate and mix crystals and liquid. We consider homogenous and density-stratified liquids operated upon by fractional crystallization and equilibrium crystallization to bound the resulting lithologies (Fig. 2).

Implications. Three puzzles in lunar petrology are young anorthosites [27], the provenance of Mg-suite rocks [28], and the provenance of Mg-spinel lithologies [29]. Young anorthosites could have crystallized from melt sheets. Mg-suite norites and troctolites could form in melt sheets, although their distinctive geochemical signature [28] would be hard to explain. Mg-spinel lithologies could form from mixing of anorthosite and olivine-rich mantle liquids. We continue to investigate remotely-sensed data and the lunar sample suite in order to identify possible impact melt differentiates.

Figure 2. Model differentiated melt lake lithologies.



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