IMPACT MELT MINERALOGY AT LUNAR COMPLEX CRATERS: SYSTEMATICS OF MELT EMPLACEMENT AND EVOLUTION D. Dhingra, C.M. Pieters and J. W. Head Department of Geological Sciences, Brown University, 324, Brook St, Box 1846, Providence, RI 02906, USA (deepdpes@gmail.com)

Introduction: Impact cratering processes almost inevitably produce melt, the volume of which is dependent upon the impact energy, target and impactor material properties and gravity of the target planetary body [1]. Countless craters dotting the lunar surface have generated melt (by recycling the primary and secondary crustal material) that must have covered much of the Moon over geological time. Impact melt, therefore, could be regarded as the *tertiary crust* (reworked primary and secondary crust) [2]. It might also have played a role in the observed compositional diversity of the crust [e.g. 3]. However, there have been very limited studies on the mineralogy of the lunar impact melt deposits, especially using remote sensing [e.g. 4, 5].

We have been surveying impact melt deposits at lunar complex craters by focusing on their mineralogy and corresponding geological context. The purpose is to characterize impact melt mineralogy, evaluate its role in lunar crustal composition and also use the mineralogical variations as a tracer to understand the impact cratering process. Here, we report the progress of this impact melt mineralogical survey initiative.

Datasets: We have used high spectral resolution Moon Mineralogy Mapper (M^3) data [e.g. 6] for extracting mineralogy and high spatial resolution monochrome imaging data from SELENE Terrain Camera [7] and Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera [8] for understanding the local and regional geologic context.

Results and Discussion: We have initally analyzed 10 craters (20-100 km diameter) located in diverse geologic settings. The mineralogy of impact melt at these craters (Table 1) cannot be grouped into a single category. While some of these craters clearly display noticeable diversity in the melt mineralogy (e.g. Copernicus crater [9]), some differences are more subtle (e.g. Jackson crater [10]) and others are not easily detectable (e.g. Aristillus). Our work has highlighted mineralogical heterogeneity in impact melt on the Moon [e.g. 11, 12], inefficiency in melt mixing on the crater scale [e.g. 9] and a companion abstract [13] explores the mineralogical character at depth (in relation to central peak composition) by studying the spatial variations in impact melt mineralogy. There are several broad aspects that are pertinent for discussion here:

i) Impact melt is rarely found as amorphous glass: The common perception of impact melt as a geologic unit, formed in a rapid process of impact cratering, that cooled off subsequently to achieve a monotonous character is fast changing with the new datasets and analy-

No.	Crater	Location	Dia. (Km)
1	Copernicus	9.62° 339.92°	96
2	Tycho	-43.29° 348.78°	86
3	Jackson	22.04° 196.68°	71
4	Giordano Bruno	35.96° 102.89°	22
5	King	4.96° 120.49°	76
6	Aristillus	33.88° 1.20°	54
7	Eratosthenes	14.47° 348.68°	59
8	Glushko	8.11° 282.33°	40
9	Lowell	-12.96° 256.58°	63
10	Ohm	18.32° 246.22°	62

Table 1 List of initial craters analyzed in the mineralogical survey of impact melt

-sis. Most lunar samples are breccias. A few contain glass while others are completely crystalline impact melt [e.g. 5] implying very slow cooling for some of these deposits. Morphological analysis and modeling [e.g. 14] for some of the youngest melt deposits provide independent evidence of impact melt mobility with multiple generations visible and cooling time scale of several years.

Our mineralogical assessment of impact melt at various craters has shown the presence of crystal field absorptions indicating crystalline material in the melt. This may due to entrained target debris or slowly cooled melt. An example is melt deposits at crater Glushko. Various melt ponds there show weak to strongly crystalline absorption bands (Fig. 1), similar to that observed at many other craters.

ii)Impact melt may not be compositionally uniform: Earlier terrestrial studies [e.g. 15] indicated that impact melt deposits are very well mixed and therefore uniform in composition. Recent terrestrial studies [e.g. 16, 17] and our analyses at lunar complex craters [e.g. 9, 10, 11] have, however shown large scale heterogeneity prevalent in impact melt. Fig. 1 highlights different melt mineralogly at crater Glushko. The red spectrum from a melt pond on the rim (Fig. 2a) has short wavelength band positions indicating more Mg-rich pyroxenes as compared to the blue spectrum, sampled from northern crater wall (Fig. 2b) which has relatively long wavelength band positions and therefore more Fe-Ca pyroxenes. The differences are subtle but still distinct.

iii)Impact melt as a tracer of the cratering process: The normally assumed chaotic nature of impact melt still hold clues to the understanding of melt evolution as well as pre-impact target geology. Our work at Copernicus crater has shown the occurrence of a mineralogically distinct sinuous melt feature highlighting the inefficiency in melt mixing [e.g. 9]. Further work has emphasized radial variation in melt mineralogy [e.g. 18] suggesting likely limited lateral mixing compared to vertical mixing of melt.

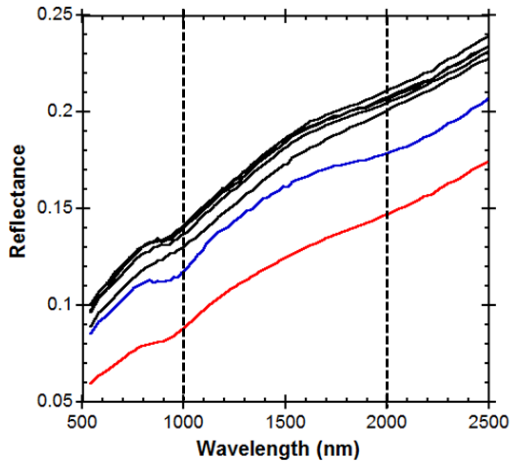

Fig. 1 Spectra of various melt deposits at crater Glushko. Black spectra represent floor melt, red spectrum is from melt pond on the northern rim (Fig. 2a) and blue spectrum is from melt pond on the northern wall (Fig. 2b)

iv) Impact melt is pervasive: With the availability of high resolution imaging data [e.g. 7, 8], it is amply clear that impact melt is much more pervasive than initially thought. Our extensive mineralogical assessment integrated with high spatial resolution imaging [e.g. 9, 10, 11, 12] coupled with many other studies [e.g. 19] have clearly highlighted the widespread occurrence of impact melt on the Moon. Accordingly, we propose impact melt deposits as the lunar *tertiary crust* [2]. The pervasive nature of impact melt has implications for deciphering the mineralogical structure of the lunar crust through studies of central peaks [e.g. 20]. Central peaks draped with impact melt (Fig. 2c) have often been observed [e.g. 11] and could potentially affect mineralogical interpretations of the deeper crustal material. Studies in this context [e.g. 21, 22] would help put better constraints on this problem.

v) Impact melt ages with time, losing its identity: There is a stark contrast between youthful impact melt morphologies at geologically young craters compared to the older craters. Since the process of cratering remains the same, the only aspect making a difference is the crater age which likely leads to a progressive degradation of such features and merging of the landscape into a continuum. But, by analogy from young craters, the older craters (including their peaks) likely had significant volume of impact melt strewn around. Establishing mineralogy of such deposits would be difficult unless it is distinct from the surroundings.

Summary: Mineralogy of impact melt, in conjunction with high spatial resolution geological context, is providing a wealth of information about their role in the evolution of lunar surface, cratering process as well as the nature of melt deposits themselves.

Acknowledgement: This research is supported by NASA SSERVI.

References:[1] Melosh H.J. (1996) *Oxford University Press*, 245p. [2] Taylor S.R. (1989) *Tectonophysics*, **161**, 147-156 [3] Pieters C.M. (1986) *Rev. Geophys., 24, 557-578* [4] Smrekar S. and C. M. Pieters. (1985) *Icarus*, **63**,*442-452*. [5] Tompkins S. and Pieters C. M. (2010) *MAPS*,.**45**, 1152-1169 [6] Pieters et al. (2009) *Curr Sci.*, **96**, 500-505 [7] Haruyama et al. (2008) *Earth, Planet, Space*, **60**, 243-256 [8] Robinson et al. (2010) *Space Sci. Rev.*, **150**, 81-124 [9] Dhingra et al. (2013) *GRL*, **40**, 1-6 [10] Dhingra et al. (2012) *NASA Lunar Sci. Forum* [11] Dhingra et al. (2011) *LEAG Meeting*, #2025 [12] Dhingra et al. (2012) *39th COSPAR Assembly*, # B0.1-0034-12 [13] Dhingra et al. (2014) *45th LPSC*, #1117 [14] Bray et al. (2010) *GRL*, **37**, L21202, doi:10.1029/2010GL044666 [15] Phinney W.C. & C.H. Simonds (1977) *Impact and Explosion cratering*, 771-790 [16] Osinski et al. (2011) *EPSL*, **310**, 167-181 [17] Lambert P. (2010) *GSA Sp. Paper*, **465**, 509-541 [18] Dhingra et al. (2013) *LMI-V Conf.*, Canada t# 3036 [19] Carter et al. (2012) *JGR*, **117**, E00H09, doi:10.1029/2011JE003911 [20] Tompkins and Pieters (1999) *MAPS*, **34**, 25-41 [21] Kuriyama et al. (2013) *44th LPSC*, # 1402 [22] Dhingra R. D. et al. (2014) *45th LPSC*, # 1754

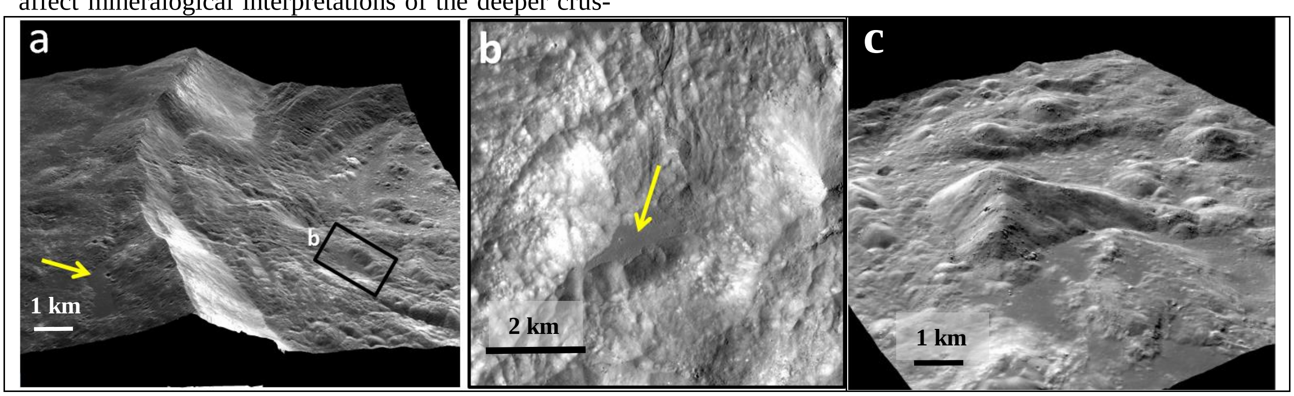

Fig. 2 Melt deposits at crater Glushko (a) Melt pond on northern rim. (b) Melt pond on northern wall. (c) Pervasive melt deposits on the floor covering local topography.