THE EVOLUTION OF THE LUNAR CRUST I. A MULTI-PERSPECTIVE APPROACH TO UNDERSTANDING THE ORIGIN OF FAN AND MG-SUITE LITHOLOGIES AT THE LUNA 20 LANDING SITE. C. K. Shearer1,2,3, S.B. Simon1, N. Petro4, D. Moriarty4,6, J.J. Papke1,2, and F.S. Joyce1, 1Institute of Meteoritics, USA. 2Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, 3Lunar and Planetary Institute, Houston TX 77058; 4NASA Goddard Space Flight Center, Greenbelt, MD 20771; 5University of Maryland, College Park, MD. cshearer@unm.edu

Introduction: Basin rims are well-known to expose deep-seated lithologies at the lunar surface [1-5]. A large array of remote sensing studies of the Crisium region based on Earth-based spectral data [1,6], Clementine UV-VIS data [2], and Chandrayaan-1 M3 and Spectral Profiler [7-9] provide important constraints on the composition of the rings of Crisium and variability in the crust in that area. These data indicate an abundance of olivine (Fo80-85) along the rim of the Crisium Basin that has been attributed to excavation from the upper mantle-lower crust, igneous intrusions, or impact melt sheets (Fig. 1) [7-10]. The Luna 20 mission returned samples from the noritic Hilly and Furrowed Terrain [11] associated with the Crisium basin-forming event (Fig. 1). Here, we examine the crystalline lithologies returned by the Luna 20 mission and integrate orbital and sample data to gain additional insights into the composition and origin of the crust surrounding the Crisium basin. Is the material from (a) magmatic intrusions emplaced in the crust (Mg-suite, FANS); (b) the lunar mantle; or (c) crystallization of impact melt sheets following the Crisium impact event?

Analytical Approach: Thin sections of sieved material (250-500 µm) collected from the Luna 20 site and allocated to NASA were examined and integrated with data collected during consortium studies in 1973 [13]. We collected backscattered electron (BSE) images, quantitative EDS analyses and X-ray maps with a TESCAN Lyra3 SEM. After imaging and analysis of all lithic fragments, we focused on crystalline lithologies and conducted further chemical and modal mineralogy analyses.

Results: The fragments observed in this suite of samples include crystalline lithologies, breccias, impact melt breccias, impact melts, basalts, and individual minerals. Our focus for this initial examination was the crystalline rocks which appeared to be clast-free and products of crystallization from a melt. These fine- to medium-grained (<100 µm) lithologies include spinel troctolites, troctolites, norites, gabbro-olivines, and gabbros. No ultramafic lithologies (e.g., dunites) were observed. In addition to these fine-grained fragments, there are coarse-grained plagioclase fragments (>250 µm) associated with much smaller mafic grains, predominantly pyroxene. BSE images of examples of different mineralologies and textures are shown in Figure 2. Pyroxenes in all these assemblages did not exhibit exsolution lamellae greater than 2-3 µm in width (Fig. 2E). Earlier x-ray examination of pyroxene from Luna 20 samples indicated sub-micron lamellae of varying degrees of complexity [e.g. 14].

Modal abundances of phases of these lithologies are shown in Figure 3A. These are compared with approximate modal mineralogy calculated from orbital data near the Crisium rim [10] (Figure 3B).

Mineral chemistries are plotted on a traditional mafic silicate (Mg#) versus plagioclase (An) diagram (Figure 4). These lithologies fall within the Mg-suite and the ferroan anorthosite (FAN) fields. All the lithologies defined by coarse-grained plagioclase are in the FAN field. These plot at the more Mg-rich end of the FAN field defined by Apollo samples. Spinel (stricto sensu) occurs predominantly in the spinel troctolites, although observed in other assemblages [15]. The spinel compositions are summarized by [15].

Discussion: It has been proposed that lunar mantle material was excavated by the Crisium event. There is limited evidence for this from the Luna 20 samples. Dunites are rare and Mg-rich olivine bearing-assemblages appear to be derived from the shallow crust. It is puzzling that the suite examined here consists of spinel-bearing lithologies which have been interpreted as representing deep crustal lithologies (30-40 km) [e.g., 16], and numerous lithologies with fine-
pyroxene exsolution lamellae, suggestive of rapid cooling in shallow crustal environments. However, [17,18] provided alternative interpretations of spinel in mafic rocks representing shallow crystallization.

Do these crystalline lithologies that seemingly crystallized in the shallow crust represent Mg-suite-FAN plutonic suites, or crystallization products of an impact melt sheet associated with the Crisium impact event? Modeling the crystallization sequence of large impact melt sheets on the Moon [e.g., 19,20] produces abundant norites and ultramafic cumulates that appear not to match the lithologies represented by the present samples. Perhaps this difference is a product of the proportions and composition of crustal-mantle lithologies that were melted. However [19,20] used a variety of starting compositions in their modeling. Another problem with the interpretation that these lithologies represent cumulates from a Crisium melt sheet is the chronology established for these rocks by Ar-Ar ages [15 and ref. within]. These data suggest crystallization ages that pre-date the Crisium event and fall within the range of ages for the Mg-suite. Although multiple chronometers would better define the crystallization history, we are left with the conclusion that these lithic fragments represent pre-Crisium episodes of shallowly emplaced Mg-suite magmas and FAN magmatism related to primordial differentiation.

Fig. 2. BSE images of lithologies from Luna 20. A. troctolite. B. spinel troctolite. C. norite, D. gabbro. E & F. FAN.

Fig. 3. Modal mineralogy determined from A. Luna 20 samples; and B. remotely collected measurements [10].

Fig. 4. Mg# versus An for lithologies from Luna 20.


Acknowledgments: This work was funded by NASA LDAP grant 80NSSC19K1099 to CKS and NP.