**Geology of the Moscoviense Basin: Implications for the character of the highland crust.** K.G. Thaisen[1], L.A. Taylor[1], J.W. Head[2], C.M. Pieters[2], P.J. Isaacson[2], G.Y. Kramer[3], T.B. McCord[3], M. Staid[4], and N.E. Petro[5] [1]Planetary Geosciences Institute, Dept. Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA (kthaisen@utk.edu), [2]Dept. of Geological Sciences, Brown University, Providence, RI 02912, USA, [3]Bear Fight Center 22 Fiddler's Rd, P.O. Box 667, Winthrop, WA 98862, USA, [4]Planetary Science Institute, Tucson, AZ 85719 USA, [5]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA.

**Introduction:** It is generally accepted that the Moon was largely molten to depths of 400-500 km [1] during its early evolution. With slow cooling, this Lunar Magma Ocean (LMO) crystallized to form the early crust and upper mantle [2]. It is reasoned [3] that this LMO fractionally crystallized in a sequence of minerals beginning with olivine, which was followed by orthopyroxene and then by clinopyroxene. These minerals settled to form bottom-up layering of the upper mantle in a fashion similar to layered-igneous intrusions on Earth (e.g., Stillwater Complex, Duluth Gabbro Complex, Skaergaard Intrusion).

After approximately 70% of the magma ocean had undergone crystallization, plagioclase began to crystallize from the remaining melt. The lower density of the plagioclase crystals, relative to the more Fe-rich LMO residual melt, resulted in the plagioclase being buoyant and floating upward towards the surface of the Moon, where it coalesced to form the Ferroan Anorthositic crust (FAN) [2]. Between the FAN crust and the upper mantle, the remaining magma ocean melt continued to differentiate, crystallize and finally formed the K, REE, and P rich (KREEP), incompatible-rich lithology, termed *urKREEP* by [1], containing the residual components of the liquid. The high concentrations of U and Th in this urKREEP provided a portion of the heat for further magmatism.

It has been hypothesized that a second stage of lunar magmatic activity occurred along with and shortly after the FAN crust developed, and involved massive serial magmatism at the upper mantle-FAN boundary, with intrusions of highly feldspathic magmas melting, assimilating, and replacing much of the FANs with hi-Mg suite rocks [4]. This was closely followed by more Fe-enriched gabbo-norite rocks and more alkali-rich lithologies [4]. It is believed that all of this took place during the first 100-200 Ma after the formation of the Moon [4].

Petrologic studies of Apollo and Luna samples have provided these invaluable insights into the complex nature of nearside lunar crustal materials. However, all of the Apollo and Luna samples that were collected represented material that was part of the regolith and not from outcrops of bedrock. Compared to the significant basin-forming episodes, which have so significantly modified the surface of the lunar nearside, the feldspathic highland terrain (FHT) [5] of the farside northern hemisphere, consists of what may represent *relatively* undisturbed highland crust. A few farside impact basins have exposed cross-sections of the original products of the LMO and early crustal magmatism. The Moscoviense Basin (Fig. 1) is one of these basins.

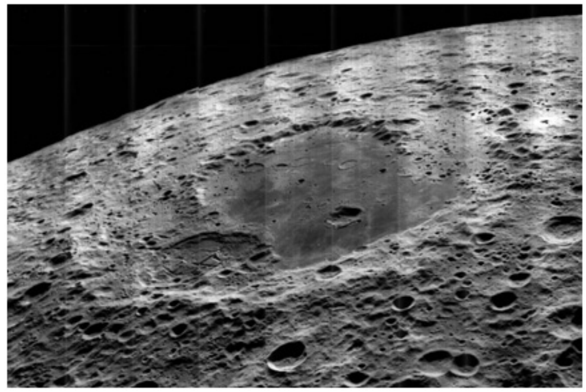

**Figure 1. Lunar Orbiter Mosaic of the Moscoviense Basin on the farside of the Moon. (Image Courtesy of NASA)**

**Datasets:** The Moon Mineralogy Mapper ($M^3$), a NASA-funded reflectance spectrometer onboard the Indian Chandrayaan-1 spacecraft, collected images across the Moscoviense Basin. Each of these images was taken in the global mapping mode and has a spatial resolution of ~140 meters/pixel across a ~40 kilometer swath. Reflectance data were collected across 85 spectral channels between 430-3000 nm at a resolution of 20–40 nm. A digital elevation model (DEM) produced from the lunar laser altimeter onboard the Japanese Kaguya orbiter [6] has a resolution of 16 pixels/degree and accuracy ±5 meters. Combining the high-spatial and spectral-resolution datasets from the $M^3$, a digital elevation model, and high-spatial resolution imagery, such as those from the Chandrayaan Terrain Mapping Camera, and/or from the Kaguya or Lunar Reconnaissance Orbiter missions, provides a means of evaluating the geologic processes associated with the basin.

**Moscoviense Basin:** The Moscoviense Basin has been reported as having the thinnest crust on the Moon [7]; a truly surprising discovery. This basin resulted from a major impact during the Nectarian Period (3.85-3.92 Ga) [8], and experienced subsequent mare volcanism during the Upper Imbrian Epoch (3.2-3.8 Ga) [9,10,11] and possibly even as recent as 1.1-3.2 Ga [11,12]. It is approximately 640 km across, and its floor is ~8 km below the surrounding rim (Fig. 2). The inner peak-ring is represented by a half ring of approximately 105 km radius, which stands 2-3 km above the basin floor and is open to the northeast. The middle ring, which represents the original crater rim, has a radius of approximately 215 km and is nearly continuous around the basin. The outer ring, which formed during the late stages of basin formation as the crust collapsed into the crater, can be identified approximately 320 km from the center of the basin and forms the outer ring; similar to the Oriental Basin as described by [13]. The surrounding rim is generally higher to the west and south, with corresponding steeper slopes into the basin than to the north and east, which contain lower rims, gentler slopes, and distinct slump blocks. Much of the floor of the basin has been filled by mare basalts of varying compositions [e.g., 10, 11] and occupies a roughly rectangular depression that trends southwest to northeast.

The geologic setting of the Moscoviense basin provides a cross-section through what may be *a relatively undisturbed primitive highlands crust*, as well as windows into the lunar mantle in the form of the several types of mare basalts. The highly feldspathic character of the basin and its surroundings as measured by M3 is characterized along with several small areas of unusual compositions (OOS: orthopyroxene, olivine, spinel) along the western peak ring [14, 15]. Current models [16] and terrestrial studies [17] suggest that deep-seated material from below the basin floor has undergone a combination of uplifting, folding, and faulting, which results in the formation of a peak-ring. The OOS [15] within the peak-ring may represent isolated exposures of different units within a larger layered intrusive body (Fig. 2), outcrops from several smaller intrusive bodies, ejecta from another impact event, or fragments from an asteroid that survived an impact with the moon and has subsequently been incorporated into the regolith. For the OOS rock types of [15], we envision an indigenous formation scenario that resulted from secondary magmas of the lower crust and upper mantle intruding into and incorporating large quantities of FAN that has increasing magnesium content toward the surface causing the composition to evolve from an iron-rich to a magnesium-rich melt. As the magma in these intrusions began to cool; small-scale LMO-like scenarios repeated themselves, time and again, forming compositionally distinct layered units.

In the three component system of Anorthite (Plag), Olivine (Ol), and $SiO_2$; stable phases of Spinel (Sp) + Ol + Pyroxene (PX), + Plag + $SiO_2$ all exist [18]. Once the secondary magma(s) began to assimilate and fractionally crystallize within the FAN country-rock, layered units of Sp + Plag, Sp + Ol, Plag + Sp + Ol, Ol + Plag, Ol + PX, Ol + PX+ Plag, or PX + Plag could form as a result of *crystal settling* within the magma chamber (i.e. too dense to float) [19]. These spectral signatures may represent exposures of secondary magmatic processes that penetrated into the feldspathic crust, which resulted in the formation of the Mg-Suite rocks, as well as new rock types such as that detailed by [14, 15]. Despite the compositional variability seen within the peak-ring by $M^3$, the surface expression in high-resolution imagery is not always obvious.

**Summary:** The combination of $M^3$ spectral imagery, high-resolution imagery, and the new surface topography produced by JAXA provide significant tools that can contribute to our understanding of lunar geology and igneous processes. Study of the Moscoviense Basin may provide our first glimpse of in-place material from the interior of the FHT crust, provide insights into secondary magmatic process of the early moon, and identify layered igneous intrusions on the Moon.

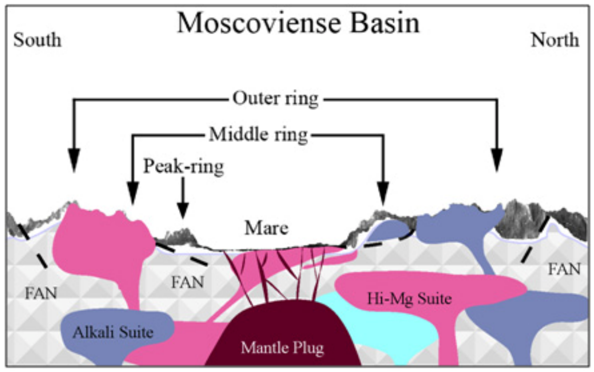


**Figure 2. Profile view of the Moscoviense Basin. Hypothetical locations of secondary magmatic intrusions guided by $M^3$ imagery. The surface is represented by Kaguya DEM that crosses the basin from south to north. The peak-ring is absent to the north, but middle and outer rings are apparent. Vertical exaggeration is 10x, distance between outer-rings is ~640 km, and elevation change is ~8 km.**

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