**CHARACTERISTICS, AFFINITIES AND AGES OF VOLCANIC DEPOSITS ASSOCIATED WITH THE ORIENTALE BASIN FROM CHANDRAYAAN-1 MOON MINERALOGY MAPPER ($M^3$) DATA: MARE STRATIGRAPHY.**

J. Whitten[1], J. Head[1], M. Staid[2], C. Pieters[1], J. Mustard[1], L. Taylor[3], T. McCord[4], P. Isaacson[1], R. Klima[1], J. Nettles[1], and the M3 Team. [1]Brown Univ., Providence RI 02912; [2]PSI, Tucson AZ; [3]Univ. Tenn., Knoxville TN 37996; [4]BFC, Winthrop, WA; (Jennifer_Whitten@brown.edu).

**Introduction:** The Orientale basin located on the western limb of the moon, is one of the youngest multi-ring basins on the lunar surface, dating to the beginning of the Upper Imbrian period at ~3.84 Ga [1]. Unlike the other large lunar multi-ring basins Orientale is well preserved, being only partially filled with mare, which makes it very important for the study of basin formation processes [2-4]. The Orientale basin is ~900 km in diameter and covers an area of ~700,000 $km^2$ [2]. Understanding the characteristics of each feature within the basin including their age, mineralogy and morphology will assist in deciphering the basin forming processes.

Within the basin there are many volcanic deposits, those in the center of the basin itself and others within the different rings. The largest of these mare deposits is Mare Orientale in the center of the basin. It covers an area of 47,000 $km^2$ and is ~1 km deep [2]. Lacus Veris, lying between the Inner Rook and Outer Rook rings, is composed of five large mare ponds and several smaller scattered ponds oriented in an arcuate belt. Similar in situation is Lacus Autumni, positioned between the Outer Rook and Cordillera rings [5,6]. These three main mare deposits have many volcanic features that are indicative of the eruption style, such as sinuous rilles and small shield volcanoes [5]. Other volcanic deposits in the basin include dark mantle deposits, such as the dark ring centered on the Outer Rook ring to the southwest [7], flooding on the floors of younger impact craters [6], and as cryptomaria [4].

**Ages and Stratigraphy:** Previous compositional studies of mare in the Orientale basin have reported subtle differences in the titanium content [4, 9,8]. Using Galileo Sold Sate Imaging (SSI) 0.41/0.56 µm spectral reflectance ratio images Greeley et al. [4] found that units in Mare Orientale are medium-high-Ti basalt soils (3-7 wt % $TiO_2$), with lower titanium signatures in the northeast and west-central mare. Lacus Veris containes a medium-high-Ti basalt soil and Lacus Autumni has medium-high-Ti basalt soil in the north and medium-Ti basalt soils (<4 wt % $TiO_2$) in the south. It is possible that contamination from Orientale basin (highland) materials could be influencing the compositions observed [4, 8-9].

Based on these findings the compositional differences were used to define stratigraphic relations within Mare Orientale, Lacus Veris and Lacus Autumni, which were then dated using Lunar Orbiter photographs and crater-size frequency distribution curves. These data represent one of the first theories about the mineralogic and morphologic evolution of the Orientale basin (Fig. 1). The oldest mare was emplaced in south-central Mare Orientale at ~3.70 Ga, followed by the emplacement of maria in western and southeastern Mare Orientale at ~3.45 Ga. Moving outside the basin center, Lacus Veris has an average model age of ~3.50 Ga and, further still, Lacus Autumni is the youngest deposit with an age of ~2.85 Ga [4]. Even younger ages have been reported for central Lacus Veris at ~2.59 and ~2.29 Ga [8-9]. Based on these findings mare volcanism in Orientale has been estimated to last between 0.85-1.50 Ga [4,8], beginning only ~100 Ma after basin formation. Despite this long span of volcanic activity, the mare has a very narrow range of compositions compared to the nearside mare. This could indicate multiple eruptions from a heterogeneous source or multiple sources with subtle compositional differences [4].

**New Discoveries with $M^3$ Data:** A mosaic of images encompassing the whole of Orientale basin at ~155m/pixel (reflected light and thermal emission) from the Moon Mineralogy Mapper ($M^3$) was utilized to characterize and define the stratigraphy of volcanic deposits in the basin and to build upon the work of previous studies of volcanism in Orientale. Crater ages were obtained for parts of Mare Orientale, the Maunder Formation and mare ponds in the laci using the methods of [10] (Fig. 2). The average age of the melt sheet material (Maunder Formation) is ~3.69 Ga while the average age for the mare is ~3.59 Ga. Ages were calculated for the five main ponds in Lacus Veris identified on the basis of mare morphology and produce an age range of 3.69 to 3.20 Ga. The three ponds of Lacus Autumni range in age from 3.47 Ga for the northernmost pond to 2.43 Ga for the southernmost pond. The time of impact for Maunder and Kopff craters were calculated as well. The mare floor of Kopff was calculated at 3.36 Ga and it's ejecta is 3.63 Ga, lending support to the idea that Kopff might have been produced by impact into molten melt sheet material [11]. Maunder ejecta gives an age of 2.88 Ga. This younger age is supported by the superposition of Maunder ejecta on Kopff crater.

Previous studies have concentrated on the mare patches Lacus Veris and Lacus Autumni, confined to the northeastern part of Orientale basin. However, with the increased spatial and spectral resolution of $M^3$ several more mare deposits have been identified to the west and south of the basin (Fig. 2). The first pond is very small, only 34 $km^2$, and located along the inside of the Cordillera ring (Fig. 3). The two largest ponds (Fig. 4) have been noted previously in Zond and Galileo data [9,12-13]. They have areas of 550 and 1060 $km^2$ and are located just inside and outside of the Outer Rook ring in a similar position to the ponds comprising Lacus Veris. One of the new ponds, 87 $km^2$, lies just inside some massifs in the Inner Rook ring (Fig 5). The other two new mare ponds, 80 and 95 $km^2$, lie along the scarp of the Cordillera mountain ring and mirror the situation of the ponds of Lacus Autumni (Fig 6 and 7). Despite their small size, these new deposits show that volcanism in Orientale was active over the entire region and not confined to the eastern part of the basin.

**Conclusion:** Crater ages and stratigraphic data indicate that: 1) mare filling began a few hundred million years after basin formation, followed closely by later pulses of volcanism that produced the mare ponds in Lacus Veris and lastly those in Lacus Autumni. 2) The total duration of volcanic activity in Orientale spans 0.85-1.50 Ga, but despite this lengthy duration the ponds have relatively low volumes [6]. 3) Mare eruption locations were focused along the margins of the different basin rings, especially the Outer Rook and Cordillera rings. New $M^3$ data shows that volcanism was not confined to the eastern part of the basin, but that it was in fact much more wide spread than previously believed.

**References:** [1] Wilhelms, D.E. (1987) *US Geol. Surv. Prof. Pap.*, 1348, 302. [2] Head, J.W. (1974) *The Moon*, 11, 327-356. [3] Spudis, P.D. et al. (1984) *JGR*, 89, C197-C210. [4] Greeley, R. et al. (1993) *JGR*, 98, 17,183-17,205. [5] Greeley, R. (1976) *Proc. Lunar Sci. Conf. 7th*, 2747-2759. [6] Yingst, R. A. & Head, J.W. (1997) *JGR*, 102, 10,909-10,931. [7] Head, J.W. et al. (2002) *JGR*, 107, E1. [8] Kadel, S.D. & Greeley, R. (1993) *LPSC 24* #1374. [9] Kadel, S.D. (1993) M.S., Ariz. State. [10] Neukum, G. et al. (2001) *Chron. & Evol. of Mars*, 96, 55-86. [11] Guest, J. & Greeley, R. (1977) *Geo. on the Moon*. [12] Scott, D. et al. (1977) USGS Map 1-1034. [13] Head, J.W. et al. (1993) *JGR*, 98,17149.

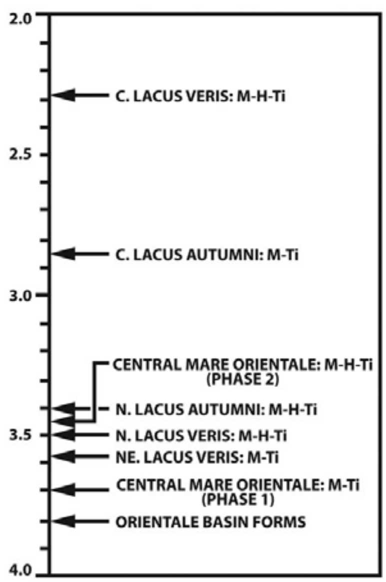


Fig. 1. Phases in the emplacement of mare deposits following the formation of the Orientale basin at 3.8 Ga (reported in Ga). From [4, 8-9].

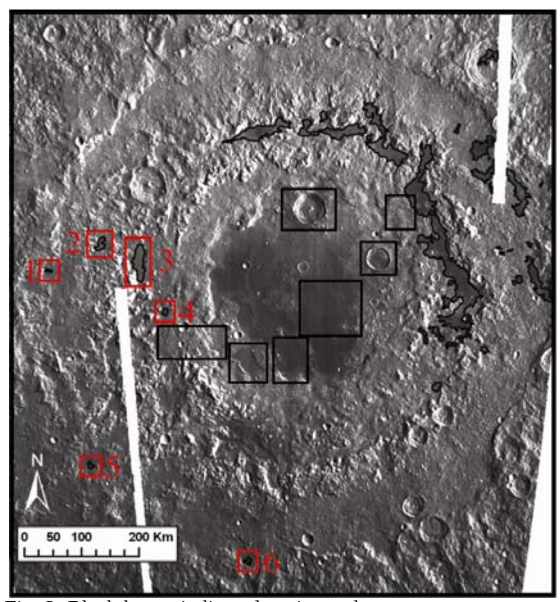


Fig. 2. Black boxes indicate locations where crater counts were conducted for Mare Orientale and the Maunder Formation. All identified mare ponds are outlined as well. Red numbered boxes indicate the newly identified mare ponds.

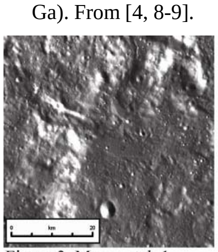

Figure 3. Mare patch 1.

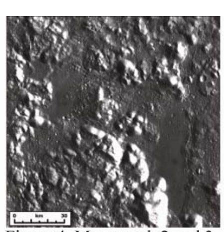

Figure 4. Mare patch 2 and 3.

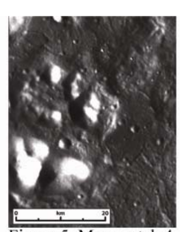

Figure 5. Mare patch 4.

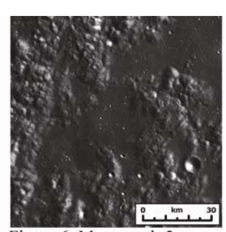

Figure 6. Mare patch 5.

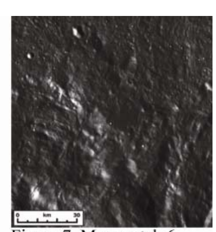

Figure 7. Mare patch 6.