# CLEMENTINE LASER ALTIMETRY AND MULTI-RING BASINS ON THE MOON

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Altimetry from the Clementine mission allows us to study the distribution and configuration of multi-ring basins on the Moon. In addition to confirming the presence of basins previously mapped from photogeologic evidence alone, the altimetry image shows several depressions that may represent basins that had not been recognized. Both relatively shallow (1-2 km deep) and deep (5-7 km) basins occur on the Moon; there is no correlation between a basin's depth and relative age. The large topographic depression associated with Oceanus Procellarum is only partly circular. A Procellarum trough defined by the 0 km contour appears to be elongate and irregular, suggesting an origin either by internal processes or by a coalescence of multiple, overlapping impact basins, rather than a single large basin-forming impact.

Among other important products, the Clementine mission has provided our first global topographic map of the Moon [1,2]. Although at low resolution (about 200 km; [2]), this map allows us to evaluate the presence and configuration of the long-wavelength topographic features of the lunar crust. One of the principal features of the Moon at this scale are the largest impact craters, the multi-ring basins (generally defined as impact craters greater than 300 km in diameter, regardless of presently expressed morphology; [3,4]). Basins are of primary importance in the excavation and redistribution of crustal materials and serve as the loci for the accumulation of extruded lavas on the Moon and understanding their distribution and configuration is important in order to reconstruct the basin-forming impact [4].

One of the most interesting early discoveries in the Clementine altimetry was the expression of large amounts of relief in association with some of the oldest, most degraded impact basins [5]. Basins such as Mendel-Rydberg, a nearly obliterated ancient basin (600 km diameter, 5 km deep) south of Orientale, displays nearly as much relief as the "pristine" Orientale basin (900 km diameter; 7 km depth). The Fecunditatis basin, an obscure quasi-circular feature south of Mare Crisium [3], displays considerable topographic prominence, including an average relief of about 5 km. However, not all of the ancient basins are so deep, as the Mutus-Vlacq basin [3], south of Nectaris, is clearly visible in the altimetry [5], but is only 1 to 1.5 km deep. Other basins that appear ill-defined in the altimetry, yet clearly are present as regional depressions include the Australe, Tranquillitatis, and Marginis basins [3]. Imbrium, one of the most prominent basins on the Moon and a major stratigraphic marker on the lunar near side[3], is extremely subdued on the topographic image; this cannot be due entirely to mare fill, as the visible terra islands that make up the Imbrium rim are not topographically prominent. Another unusual expression of topography for a basin is that of the degraded Lomonosov-Fleming basin [3,6]. This feature appears as a quasi-circular, smooth plateau of nearly constant elevation about 500 km across. Such an expression is likely caused by infilling of the basin with ancient mare basalts that were then covered by highland plains and re-exposed as the ejecta of dark halo impact craters [7,8]. Such an interpretation is supported by the mafic signature of the plains in this region in the Clementine global color image [9].

That both relatively deep and shallow basins exist on the Moon is not surprising; what is remarkable is that there is no correlation between basin depth and geologic age. On the basis of crater densities [3], Coulomb-Sarton is one of the oldest lunar basins, yet at 5 km depth [5], it is also one of the deepest. In contrast, Imbrium, the youngest basin on the Moon but one, is vague and subdued. Apparently, basin depth is more dependent on local conditions (e.g., crustal thickness, lithospheric conditions at the time of impact) than on relative age.

The Clementine altimetry image shows several depressions that are likely to be previously unrecognized basins. As previously discussed [5], a large depression east of the Moscoviense basin at 25°N, 165°E, appears to be a newly delineated basin, about 300 km across and 4-5 km deep; morphological evidence for this feature is very weak. Two depressions north of this feature that are elongate in the north-south direction may also be degraded basins, but their occurrence near the central far side and the fact that north-south artifacts exist in the altimetry data cast doubt on their validity as basins. Other regional depressions that appear to be previously unrecognized basins occur near the crater Darwin (20°S, 70°W; basin about

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300 km diameter), eastern Mare Frigoris (55°N, 30°W; basin about 700 km across), west of Atlas (45°N, 55°E; basin about 350 km across), and east of Mare Humboldtianum (60°N, 130°E; basin about 400 km diameter).

A controversy of long-standing is the existence of the Procellarum basin, an alleged 3200 km diameter impact feature. This basin has been held to be responsible for a variety of phenomena, including regional compositions, volcanic patterns, and tectonic and topographic features [3,10]. The global topographic map shows the Procellarum region as a major depression (Fig. 1), the smooth fill of the mare averaging about -3 km elevation [2]. Moreover, the western shoreline of Procellarum (from about 60°N to 10°S) is remarkably circular, having an average curvature of a 3000 km diameter circle. However, the central highlands forms a peninsula that extends finger-like into the putative basin (about 5 o'clock on Fig.1); average elevations on this terra island exceed elevations outside the proposed basin rim crest, a relation not seen in any other basin. Moreover, a supposed low south of Copernicus is actually an elevated plateau; if the Insularum basin [3] exists, it must be completely filled. A trace of the 0 km reference contour on the front side of the Moon outlines the western rim of Procellarum, but also defines a horseshoe-shaped depression that encompasses most of the northern hemisphere of the lunar near side, running from Procellarum through Imbrium, Frigoris, Serenitatis, and into Nectaris (see Fig. 2a of [2]). This fact, coupled with topographic [2] and photogeological [11] evidence for multiple, overlapping basins within the Procellarum trough, suggests that Procellarum, while a "basin" in the structural-topographic sense, is probably not the site of a single, ancient impact structure.

**References** [1] Nozette S. *et al.*, 1994, *Science* **266**, 1835. [2] Zuber M.T. *et al.*, 1994, *Science* **266**, 1839. [3] Wilhelms D.E., 1987, *USGS Prof. Paper* **1348**, 302 pp. [4] Spudis P.D., 1993, *Geology of Multi-ring Impact Basins*, Cambridge Univ. Press, 263 pp. [5] Spudis P.D. *et al.*, 1994, *Science* **266**, 1848. [6] Wilhelms D. and El-Baz F., 1977, USGS Map I-948. [7] Schultz P.H. and Spudis P.D., 1979, *Proc. Lunar Planet. Sci.* **10**, 2899. [8] Schultz P.H. and Spudis P.D., 1982, *Nature* **302**, 233. [9] Lucey P.G. *et al.*, 1994, *Science* **266**, 1855. [10] Whitaker E.A., 1981, *Proc. Lunar Planet. Sci.* **12A**, 105. [11] DeHon R., 1979, *Proc. Lunar Planet. Sci.* **10**, 2935.

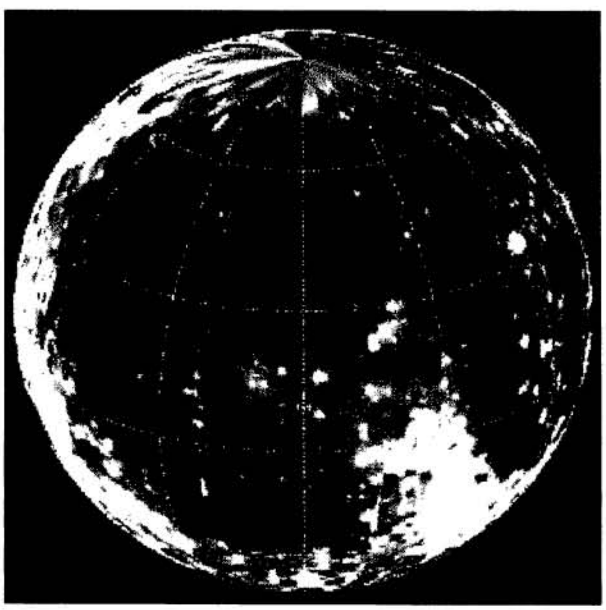

Figure 1. Stereographic projection of the Clementine altimetry, centered on 25° N, 17°W (center of the proposed Procellarum basin [3]). Imbrium is the prominent basin near the center; note the continuation of the Procellarum low through Frigoris to the northwest towards Humboldtianum (2 o'clock).