Evidence for Earth-Accreting Planetesimals Intercepted by the Moon. Charles J. Byrne, Image Again, charles.byrne@verizon.net.

Introduction: The early Earth accreted from planetesimals that formed in the region of what would become the Earth's orbit. Projectiles that impacted the Moon shortly after its crust separated from the Lunar Magma Ocean may have been a subset of those late planetesimals that were intercepted by the Moon [Bottke, W. F., 2012]. Depending on the position of the Moon at the time, a planetesimal could have been intercepted as it approached Earth or, if it missed Earth, as it left Earth after having been redirected by Earth's gravity. This paper describes evidence for five lunar features that may have been caused by such ancient impacts. Three are giant basins, with flat floors formed by the tops of melt columns below them. Two earlier impacts occurred before the Moon's crust hardened and are detected only by patterns of mineral concentrations.

After the crust hardened: Planetesimals that impacted the Moon after its crust hardened would have caused basins such as the South Pole-Aitken Basin (SPA). Basins in this size range (greater than one thousand km in diameter) are called megabasins [Minton, 2012]. Recent simulations have shown that such large impacts would have produced a cylindrical column of melted and vaporized material that penetrates the crust and extends far into the mantle [Ivanov, B. A., 2007, Stewart, S. T, 2011]. The chaotic mixture is sent well above the surface, subsides into a melt column, which then cools. New minerals such as olivine and low-calcium pyroxene are formed from the mix of crust and mantle [Yamamo et al., 2010, Nakamura et al., 2012].

Before the crust hardened: Planetesimals that impacted the Moon before its crust hardened, when its shear strength was low, would not have left a permanent crater, rim, and ejecta pattern typical of a basin. However, they would have formed a melt column of mixed crust and mantle material, so the new minerals would have formed as the melt column cooled.

Mineral Patterns: Whether an impact occurred before or after the crust hardened, the olivine and low-calcium pyroxene (LCP) can be excavated by later impacts. High resolution spectroscopic observations have detected crystalline outcrops of such minerals exposed on the steep slopes of crater walls where glassy debris from small meteoroid bombardment can drop away, exposing the outcrops [Yamamo et al., 2010, Nakamura et al., 2012]. Patterns of such outcrops can reveal impacts that happened before hardening of the crust [Nakamura et al., 2012].

Melt columns: The base map for the five melt columns mapped here is from Figure 1 of [Nakamura et al., 2012], showing outcrops of olivine and low-calcium pyroxene on a background of lunar albedo.

The South-Pole-Aitken (SPA) melt column : Within the SPA crater is a circular area that probably indicates the extent of its melt column. A number of surface exposures of olivine and low calcium pyroxene (LCP) have been detected. Within this area, there is a generally low albedo, a high iron anomaly, and mare flooding the floor of several large basins and craters. The SPA melt column is the probable source of both the mare and the minerals, in a circular area centered at 48° S and 171° W with a radius of 650 km (see Figure 1). Because of the interaction between the far side bulge and the SPA, it is difficult to map the flat floor of the SPA with precision. Further, because of the oblique nature of the SPA impact, some melt column materials may have been splashed outside of the subsided melt column.

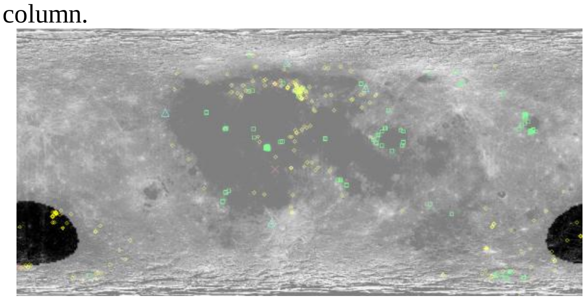

Figure 1: The area outside of the melt column of the SPA planetesimal megabsasin is covereed with a light mask. The base map is albedo. LCP outcrops (yellow squares and blue triangles, as in [Nakamura et al.) are concentrated near the SPA melt column, but also appear on the slope of its crater.

The **Near Side Megabasin (NSM) melt colulmn:** The NSM [Byrne, C. J., 2007] has a crater (centered at 10° N and 24° E with a radius of 3845 km) that extends over more than half of the Moon's surface; its rim extends beyond each pole and passes through the Orientale Basin and Tsiolkovskii (see Figure 2).

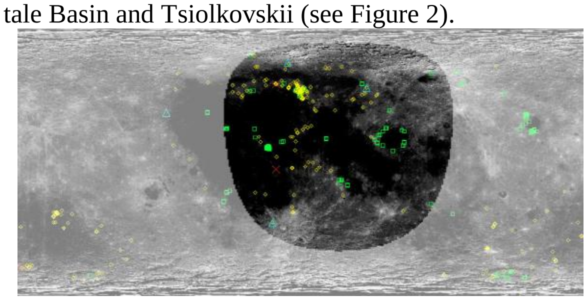

Figure 2: The area outside of the melt column of the NSM planetesimal megabasin is covered with a light mask. The light mask covers the NSM slope. The rim and ejecta field of the NSM (the far side bulge) is clear.

It has a flat floor (that is, following the geoide) that marks the top of its melt column, whose radius is 2124 km. Like SPA, most of this area is dark with a high iron anomaly and is flooded with mare. It has a large number of surface expressions of olivine and LCP. This area has been flattened by the nature of the subsided melt column, the source of its crystalline minerals.

The Chaplygin-Mandel'shtam (CM) melt column: CM's crater [Byrne, 2012] is centered at 9° N and 161° E and a flat floor 520 km in radius (see Figure 3). There are a few olivine exposures within the area of the flat floor. Its shape is determined by subtracting models of the NSM and SPA from the current topography; the melt column is inferred from its shape.

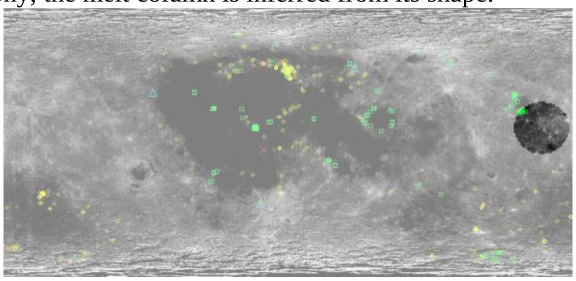

Figure 3: The area outside of the CM planetesimal melt column is covered with a light mask

Procellarum melt column: This impact feature was detected by the circular pattern of LCP outcrops [Nakamura, 2012]. It is in the general area of the older proposed Procellarum Basin [Wilhelms, 1987], whose basin shape and crater thickness were not confimed [**Neumann, 1996**]. The Procellarum Impact Feature is centered at 14° N and 19° W with a radius of 1940 km (see Figure 4). Most of the Procellarum Impact Feature, except for its far western segment in Oceanus Procellarum, is within the area of flat floor of the NSM, so that part of its area was subjected to two successive chaotic melt column events. The resultant concentration of its incompatible layer may have stimulated the massive eruptions of basalt of Oceanus Procellarum.

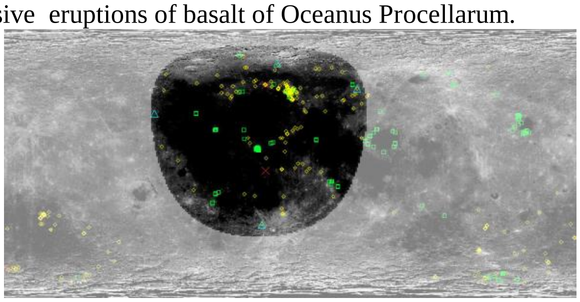

Figure 4: The area outside of the Procellarum melt column [Nakamura, 2012] is covered with a light mask.

The Australe melt column: The feature proposed here is in the region of the earlier Australe Basin, another proposed basin that could not be confirmed to have a crater, rim, ejecta field or crustal thinning. However, it is clearly a circular area, centered at 50° S and 93° E, with a radius of 550 km (see Figure 5). This area has a high iron anomaly, mare exposures, and at least one, perhaps two outcrops of olivine.

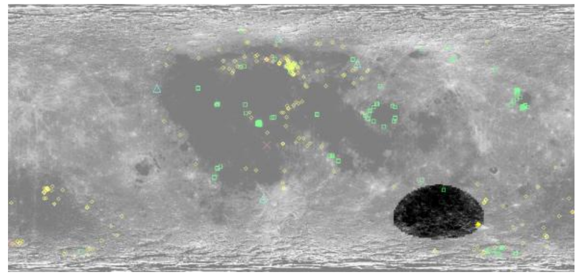

Figure 5: The area outside of the Australe melt column is covered with a light mask

Summary: Five patterns of topography and mineralogy have been identified as potential impacts of Earth-accreting planetesimals that were intercepted by the Moon after having been attracted by Earth's gravity. Estimates of the number of such impacts on Earth range from 16 to 20 times as many as on the Moon. It is unlikely that signs of such impacts would remain on either Earth or Venus, but possibly Mercury may retain signs of its incoming late planetesimals.

Figure 6 shows a plot of the cumulative number of lunar planetesimal impact features as a function of the diameters of their melt columns.

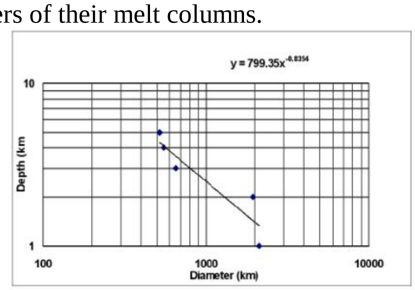

Figure 6: Count of planetesimal megabasins and iimpact features as a function of the diameter of their melt columns.

References: Bottke, W. F., 2012, The great Archean bombardment, LPSC 2012, Abstract # 4036. **Byrne, C. J., 2007,** A large basin on the near side of the Moon, Earth, Moon, and Planets, v. 101, p. 153 – 188, 2007, doi:10.1007/s11038-007-9225-8, 2007 (on line), 2008 (print). **Byrne, C. J., 2012**, Modeling the Moon's topographic features, LPSC 2012, Abstract # 1118. **Ivanov, B. A., 2007**, Lunar impact basins – numerical modeling, LPSC 2007, Abstract 2003. **Minton, D. A., et al., 2012**, The early bombardment history of Mars revealed in ancient megabasins, Workshop on the early Solar System impact bombardment II, Abstract # 4040, 2012. **Neumann, G., et al., 1996,** The lunar crust: global structure and signature of major basins, JGR 101(E7): 16,841-16,843, 1996. **Stewart, S. T, 2011,** Impact basin formation: the mantle excavation paradox resolved, LPSC 2011, Abstract 1633. **Wilhelms, D. E, 1987,** The Geologic History of the Moon, USGS Professional Paper 1348, US Gov. Printing Office, 1987.