**Modeling the Moon's topographic features.** C. J. Byrne, Image Again, 39 Brandywine Way, Middletown, NJ, 07748, charles.byrne@verizon.net.

**Introduction:** The conventional explanation for the origin of the Earth's Moon is that a Mars-sized body struck Earth with a glancing impact, vaporizing material from the impactor and the Earth's crust. The vapor cloud orbited Earth, condensed, and aggregated into the Moon in the form of a magma ocean. The magma cooled and separated into a core, mantle, and crust, with a thin layer of "incompatible elements" between the mantle and crust.

After this event, the Moon would have been a symmetrical layered body (an ellipsoid due to its rotational moment). This abstract presents a model of the Moon's surface as it was formed during its subsequent history.

The model includes all large features (those that are more than 200 km in size) that have formed the current topography of the Moon. The models are based on the Kaguya Digital Elevation Maps at 1 º (Fig.1) and 1/16 º resolution.

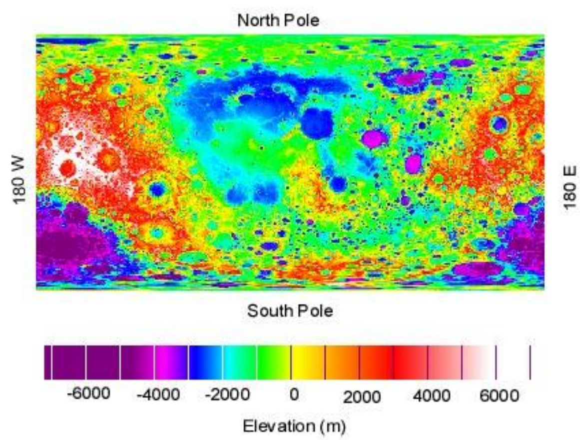


**Fig. 1:** Geometric projection (a graph of latitude and longitude showing the current topography of the Moon in false color, based on the Kaguya 1 º DEM [1]. Note the far side bulge, impacted by the SPA, slopes down to the relatively flat near side with an arced depression in and near Oceanus Procellarum. The standard deviation of the topography is 2306 m

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Many familiar features were modeled, but additional features have been discovered in the process of successive approximations to the current topography.

**Initial Giant Impacts:** Very early, starting at 4.34 billion years ago, there were three giant impacts, modeled here as the Near Side Megabasin (NSM) [2, 3], the South Pole-Aitken Basin (SPA), and the St. John-Telius Basin (STJ). The STJ (my working name) was discovered by comparing the NSM and SPA models with the current topography. Each of these features has a transient cavity formed by a horizontally-expanding shock wave, its ejecta, and a melt column extending into the mantle, forming ultimately a flat crust inside of the transient cavity, as recently revealed by simulations [5, 6]. These impacts appear to have occurred in a short interval, before the level crust of the NSM had fully solidified. After the giant impacts (and completion of subsequent isostatic compensation), the Moon's surface appeared as shown in Fig. 2. Because of the interactions between the NSM and SPA, the parameters of these giants were not found individually, but were adjusted to minimize the standard deviation of the difference between the composite (superimposed) model and the current topography [3]. The SJT was modeled from the current topography at 1/16 º resolution, adjusting for the shape of its target surface [3].

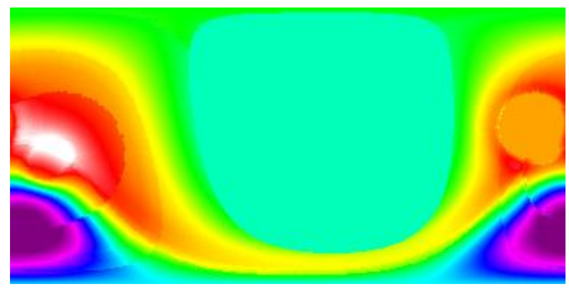

**Fig. 2:** The Moon after impacts by the NSM, SPA, and SJT events. The NSM formed the sloped sides of the transient cavity (blue to yellow: this cavity covered more than half of the Moon), the flat floor of the collapsed melt column (blue: nearly all of the near side), and with its ejecta, the far side bulge (orange to white). The SPA cavity (blue to purple) impacted the far side bulge. The SJT (orange, flat floor)) also impacted the far side bulge between the eastern limb and the 180º meridian. Subtraction of this model from the current topography results in a DEM with a residual standard deviation of 1355 km, compared with that of the current topography, 2306 m. Therefore, these three events account for 65% of the variance of the Moon's topography.

**Impacts after the period of giant impacts:** Fig. 3 shows models of the large impact features that have been formed after the giant impacts of Fig. 2.

These basins were modeled using a radial profiling technique [7], based on the Kaguya 1/16 º DEM. The models, following an extension of the Maxwell Z-model [4], show the cavities, ejecta fields, fill, and inner rings of the features. Filling by mare or ejecta is not shown in Fig. 3 but fill is added in Fig. 5. The extension of the Maxwell Z-model [3] concerns the depth-to-diameter ratios of large impact features. The original model predicts a constant d/D ratio.The extension recognizes that isostatic compensation and diversion of shock wave energy from ejection to phase changes produces observed features that are progressively shallow with size. Therefore the depth of the apparent cavity and ejecta has been inferred from cavity slope (above fill) and rim height. Some traditional basins have not been modeled because clear evidence of their impact nature could not be confirmed and a few features were added as revealed by residual maps as the modeling process developed.

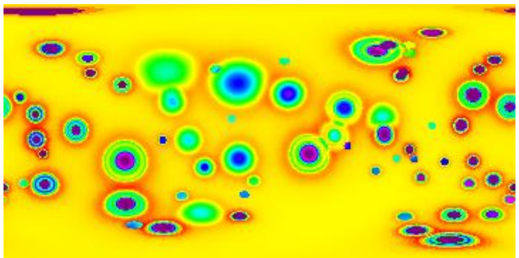

**Fig. 3:** Models of large impact features (all such features with apparent diameters more than 200 km) that have occurred after the giant basin events.

**Deposits and depressions:** After modeling the familiar impact features, the residual topography included four positive features and two negative features (Fig. 4). These are tentatively interpreted as subsonic deposits, perhaps formed by eject from the giant impacts (Fig. 2) which escaped from the Moon, stayed within the Earth-Moon system, and then partially returned to the Moon. The total volume of these four deposits is only about 27% of the volume ejected from giant basins: presumably the remaining 73% either fell to Earth or escaped the Earth-Moon system. These events occurred shortly after the giant impacts, probably before the Necterian period. The current topography in Fig. 1 clearly shows that the Nectaris Basin impacted the central deposit, the remainder of which formed the highest part of the near side central highlands.

**Fig. 4:** Models of four positive features (probably deposits) and two negative features (probably subsidence in maria).

The two negative features in Fig. 4 are the large arced depression in and near Oceanus Procellarum and an additional much smaller depression in northwestern Mare Tranquillitatis. The cause of the larger depression is tentatively identified as depletion of a large reservoir of melted mantle that erupted into Mare Nubium, Mare Humorum, Oceanus Procellarum, Mare Imbrium, and Mare Frigoris, nearly or completely submerging some basins. The depression is partly due to contraction during cooling, partly due to isostatic compensation of the heavy basalt, and probably also due to collapse of the fractured crust [8] into the depleted lava reservoir. The surface of Mare Imbrium can be seen in Fig. 1 to slope to the North, into the depression: the amount of slope is greater than in any other mare, suggesting that some collapse occurred after hardening of Mare Imbrium.

The depression in northwestern Mare Tranquillitatis is very interesting. It appears that a pool of lava there flowed south, breached and partly destroyed the northwestern rim of the Nectaris Basin, and nearly filled its cavity. The consequent loss of lava appears to have caused the depression.

**Composite Model:** After combining all of the models described previously, in the appropriate order and including the fills within the impact cavities, the resulting composite model is shown in Fig. 5. This residual includes imperfections of the models and the variance of all the features that were not modeled (those smaller than 200 km).

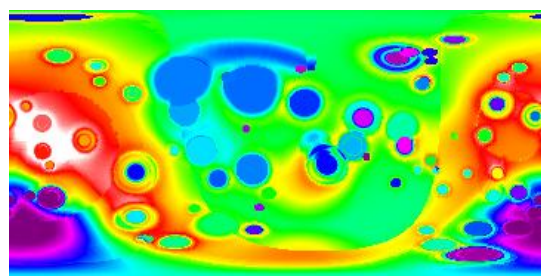

**Fig. 5**: The composite model, to be compared with the map of the current topography of Fig. 1. The residual difference has a standard deviation of 1143 m, a variance of only 25% of that of the current topography. This residual includes both imperfections of the models and the contribution of the features less than 200 m in size, of which very few have been modeled.

## References:

[1]http://www.kaguya.jaxa.jp/en/science/LALT/The_lunar_topographic_data_e.htm, 2009 [2] Byrne, C.J., The Near Side Megabasin of the Moon, LPSC 2006, Abstract 1930. [3] Byrne, C. J., 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). [4] Housen, K. R., Schmidt, R. M., and Holsapple, K. A., Crater ejecta scaling laws: fundamental forms based on dimensional analysis, JGR, 88 (B3), 1983: p. 2485-2499. [5] Ivanov, B.A., Lunar impact basins – numerical modeling, LPSC 2007, Abstract 2003. [6] Stewart, S.T, Impact basin formation: the mantle excavation paradox resolved, LPSC 2011, Abstract 1633. [7] Byrne, C.J., Radial profiles of lunar basins, LPSC 2006, Abstract 1900. [8] Schultz and Crawford, Origin of nearside structural and geochemical anomalies on the Moon, GSA Special Paper 477, 2011.