Source and Implications of Large Lunar Basin-Forming Objects

H.H. Schmitt

March 2000

UWFDM-1121

Presented at the 31st Lunar and Planetary Science Conference, Houston TX, 13-17 March 2000.

FUSION TECHNOLOGY INSTITUTE

UNIVERSITY OF WISCONSIN

MADISON WISCONSIN

Source and Implications of Large Lunar Basin-Forming Objects

H. H. Schmitt[1]

Fusion Technology Institute
Department of Engineering Physics
University of Wisconsin-Madison
1500 Engineering Drive
Madison, WI 53706

March 2000

UWFDM-1121

Presented at the 31st Lunar and Planetary Science Conference, Houston TX, 13–17 March 2000, abstract #1821.

---

[1]P.O. Box 90730, Albuquerque, NM, 87199; schmitt@engr.wisc.edu

Introduction: Major events in lunar history have long been usefully put into a time-stratigraphic formulation [1]. On the other hand, the geological character of major lunar features makes possible a descriptive formulation [2] that is remarkably consistent with the time-stratigraphic system and may enable broader multidisciplinary discussions of lunar and planetary evolution. The following is an updated general outline of such a perspective [3], the "Apollo Model 2000:"

- Stage 1: Beginning (Pre-Nectarian) – 4.57 b.y. before present
- Stage 2: Magma Ocean (Pre-Nectarian) – 4.57 - 4.2(?) b.y.
- Stage 3: Cratered Highlands (Pre-Nectarian) – 4.4(?) - 4.2(?) b.y.
- Stage 4: Large Basins –(Pre-Nectarian - Lower Imbrium) – 4.3(?) - 3.8 b.y.
  - Stage 4A: Old Large Basins and Crustal Strengthening (Pre-Nectarian) – 4.3(?) - 3.92 b.y.
  - Stage 4B: Young Large Basins (Nectarian - Lower Imbrium) – 3.92 - 3.80 b.y.
- Stage 5: Basaltic Maria (Upper Imbrium, primarily) – 4.3(?) - 1.0(?)
- Stage 6: Mature Surface (Upper Imbrium, Copernican and Eratosthenian) – 3.80 b.y. - Present.

This descriptive formulation and supporting details bring to light the discontinuity in the style of cratering that occurred between the major portions of the Cratered Highlands and Basaltic Maria Stages, or between about 4.2 and 3.8 b.y. ago. During this approximately 400 m.y. period, about 50 recognizable circular basins over 300km [4,5] in diameter were created in the lunar highlands previously saturated with craters less than 70km in diameter. Each of these basin-forming events removed and redistributed a 10-30km section of the mega-breccia present at the top of the lunar crust. The source of these basin-forming impactors has not been identified, but these impactors contrast sharply in number and effects with the obviously smaller and far more numerous bodies that resulted in the preceding saturation cratering of the Cratered Highlands. They also may be distinct from the two extremely large objects that formed the earlier Procellarum and South Pole-Aitken basins [4,3].

Background: The extreme cratering intensity that characterized the Cratered Highland Stage of lunar evolution had waned significantly before most large basins formed by extremely large and energetic impact events [4]. The relatively good preservation of concentric ring structures and of some features in the surrounding ejecta blankets supports this conclusion. Preservation of many of the characteristic features of the majority of large basins contrasts sharply with the vagueness or absence of similar features related to the two very large basins, Procellarum and South Pole-Aitken, that appear to have formed during the Cratered Highland Stage [6]. These two earlier large basins may indicate that many more such early basins, possibly about 14 [7], formed during that stage only to be destroyed by the combined effects of later basin forming events and the overall, very high cratering rate during the Cratered Highlands Stage. Although little direct evidence of such "cryptic basins" yet exists, and analyses of the uniformity of anorthosite distribution in the highlands suggest few actually formed that would have excavated deeper, more mafic crust [8], the previous existence of at least some cannot be ruled out. (One such cryptic basin may encompass the roughly 2000-km diameter far side region that includes the basins Mendeleev, Moscoviense, and Freundlich-Sharonov. This region may have a crustal thickness 20-30 km less than surrounding highlands [9].) There is little doubt, however, that large crater-forming events continued for several hundred million years after the intense background impacts of the Cratered Highland Stage (and presumably of the preceding Magma Ocean Stage) had largely ceased. Thus, a strong presumption can be made that a source of objects discrete from that causing the earlier bombardment was responsible for most large basins in the period between 4.2 and 3.8 billion years. This later discrete source supplied fewer, more energetic objects (more massive and/or higher velocities) than the source responsible for about 400 million years of intense, post-accretion lunar impacts.

Source of Large Basin Impactors: Four possible sources for the impactors of the Large Basin Stage appear plausible at this time. They are: 1) the proto-Kuiper-Edgeworth Belt of cometary objects with their injection into the inner solar system as the result of orbital resonance with Neptune [10, 11]; 2) the injection of Oort Cloud cometary objects at rates greater than during the last 3.8 b.y. due to a passing stellar body [12]; 3) large, proto-moons of the Earth, swept up by the Moon during and after capture [13]; and 4) the Jupiter-induced breakup of the planetesimal precursor of the Main Belt Asteroids with injection of fragments into Mars and Earth-crossing orbits by orbital resonance with Jupiter [14].

Of the above possibilities, the initial breakup of the original Main Belt planetesimal and subsequent resonance interaction of asteroids with Jupiter would appear to be the best present choice as a discrete impactor source [15]. Modeling studies suggest that interactions between Neptune and the Kuiper-Edgeworth Belt objects probably would be completed over time-frames of about 10 million years, although time-frames on the order of 100's of millions of years may be involved in the formation of the Belt itself [16]. An Oort Cloud source is currently unconstrained by modeling studies but seems likely to have continued to supply similar objects off and on indefinitely, given its postulated large total mass. Assimilation of proto-moons of the Earth, if any existed, probably would have involved objects with low kinetic energy relative to a co-orbiting Moon, would have occurred over a shorter interval of time, and does not explain evidence for similar basin-forming periods on Mars and Mercury. At this stage of knowledge, however, it does not appear that any of these possibilities can be totally discarded, pending definitive modeling studies. Conversely, future studies of plausible interactions of the gas giants with the Kuiper-Edgeworth Belt, and of passing stellar neighbors with the Oort Cloud, might include the hypothetical constraint of large basin formation on the inner planets between about 4.2 and 3.8 billion years ago.

Planetary Implications: The probability that other terrestrial planets were subject to 400 m.y. of basin forming events should be considered relative to their pre-3.8 b.y. history. For example, consideration of protolith alternatives related to the greater than 4 billion year old zircons in gneisses of the Slave Province of Canada [17] should include this concurrent period of impact basin formation. At about 4.2 b.y., when such basins began forming in deeply pulverized and vitrified crust, some of the significant materials in a water-rich, rapidly weathering planetary surface environment would be clays, carbonates, nitrogen and phosphorous compounds, and chondritic and cometary organic compounds. Indigenous, more complex organic compounds, possibly formed on clay mineral templates [18,19], may have been created as a consequence of interactions between these materials and a continuous supply of heat energy. On the one hand, the basin-forming events probably prevented the survival of replicating life forms until about 3.8 b.y. when such events of global reach ceased. On the other hand, the resulting large basins may have contained the proto-oceans necessary for the final transition from complex organic compounds to replicating life. Maybe not coincidentally, 3.8 b.y. also is the age of terrestrial rocks in which the earliest isotopic evidence of biological activity has been found [20].

References: [1] Wilhelms, D. E., (1987) *The Geologic History of the Moon,* USGS Professional Paper 1348, p 17-23. [2] Schmitt, H. H., (1991) *Am. Min. 76,* 773-784. [3] Schmitt, H. H. (1999) *Workshop on New Views of the Moon II,* LPI 980, pp. 56-58. [4] Wilhelms, D. E., (1987) *The Geologic History of the Moon,* USGS Professional Paper 1348, 1987, pp 57-82. [5] Spudis, P. D., (1994) in Dressler, B. O., and co-workers, *Large Meteorite Impacts and Planetary Evolution,* GSA Special Paper 293, pp. 1-10. [6] Schmitt, H.H., (2000) *LPSC 31*, Abstract. [7] Wilhelms, D. E., (1987) *The Geologic History of the Moon,* USGS Professional Paper 1348, 1987, p 157. [8] Peterson, C.A., and co-workers (1999) *LPSC 30*, Abstract #1624. [9] Compare Konopliv, A. S., and co-workers (1998) *Science*, 281,1998, figure 1, p 1477 with Wieczorek, M. A., and R. J. Phillips (1998) *Jour. Geophys.*, 103, 1998, Plate 2. [10] Morbidelli, A., (1998) *Science*, 280, p. 2071-2073. [11] Murray, N., and M. Holman, (1999) *Science*, 283, pp 1877-1881. [12] Fernandez, J. A. (1999) in P. R. Weissman and co-workers, Eds, *Encyclopedia of the Solar System*, Academic Press, San Diego, 1999, pp 554-556. [13] Alfven, H. and Arrhenius, G. (1972) *The Moon,* 5, pp 210-225. [14] Cassen, P., and D. S. Woolum (1999) in P. R. Weissman and co-workers, eds., *Encyclopedia of the Solar System*, Academic Press, San Diego, p. 38. [15] Schmitt, H. H. (1999) GSA Annual Meeting Abstracts, p. A-44. [16] Davis, D.R., and co-workers (1999) *LPSC 30*, Abstract #1624. [17] Bleeker, W., and Davis, W. J. (1999) *Canadian Jour. Earth Sci.*36, pp. 1033-1042. [18] Ferris, J.P., 1996, Nature, May 2, reported in Science News, 149, p. 278 [19] Mahler, B. J., and co-workers (1998) *Geology,* 26, pp. 831-834. [20] Mojzsis, S. J., and co-workers, (1996) *Nature*, 384, p 55.