Origin of the Northern Lowlands of Mars in a Single String-of-Pearls Impact. Nick Hoffman, School of Earth Sciences, University of Melbourne, Parkville, Australia 3010. nhoffman@unimelb.edu.au

Introduction: It has long been recognized that the Northern Lowlands of Mars were formed very early in the history of the observed planetary surface [1-3] and may well be the earliest geologic event that is still visible today [4]. Models of the formation process have included early asymmetric convection, whether in a magma ocean or by slower plate-style tectonics [5, 6]. Alternatively, one or more giant basin-forming impacts may have formed the crustal dichotomy by excavation of originally uniform crust [2].

To date, it has been deemed improbable that an impact origin can explain the detailed shape of the crustal dichotomy, since it is far from circular and would require multiple impacts to generate the detailed shape of the boundary. Statistically, random impacts are highly unlikely to have only struck one hemisphere of Mars.

One impact model has not received attention to date, yet holds the key to simultaneous explaining the coincidental location of multiple impacts.

A "String-of-Pearls" impactor, similar to comet Shoemaker-Levy 9, impacting about 40 degrees from the spin axis of Palaeo-Mars would carve a series of overlapping impact basins, distributed around a small circle. These overlapping impact basins would define a composite basin with a scalloped and irregular margin, essentially identical to the observed crustal dichotomy on Mars.

Endogenic Models: In asymmetric convective models, the formation of the thicker southern highlands crust is a consequence of the asymmetry of convection, with "clots" and "islands" of crust being swept southward and accumulating while the northern plains did not form permanent crust till slightly later in Mars' cooling history. While this is a perfectly reasonable scenario, it is not the only one able to explain the configuration of the northern lowlands.

String-of-Pearls impacts: The impact of 20+ fragments of comet Shoemaker-Levy 9 into Jupiter over a seven-day period in July 1994 received considerable attention as a new class of impacts in the Solar System. The path of the fragments essentially intersected Jupiter as a fixed stream of particles, while Jupiter rotated beneath the stream. A series of impact scars was generated in Jupiter's atmosphere which persisted for some time and formed a small circle at around 45 degrees latitude.

The potential for catastrophic multiple impacts on the Terrestrial planets was recognized, with several astroblemes spread across the target, rather than a single concentrated impact. In terms of impact risk, this would be a more dangerous scenario with impact damage spread in a belt around the target. Accordingly, considerable work has been done on String-of-Pearls impact risk in the modern Solar System

However, little attention has been paid to a similar scenario in the early Solar System, when larger basin-forming impacts were common. A basin-scale String of Pearls impact would leave distinctive impact scars on the target which could persist to the present day. A recent study of Mars [7] showed that most of the major impact basins of mars lie on a single great circle. This is persuasively argued not to be a String of Pearls impact, but instead the record of the decay of a series of captured satellites equating to a fragmented 700 km+ asteroid or planetismal. Nonetheless, the study focuses attention on what a string-of pearls impact would be like, if the impactors were of basin-forming scale.

Mars Polar Wander. There is ample evidence that Mars has experienced extreme true polar wander through geologic time, with numerous palaeoequators and paleopoles. Evolving mass imbalances such as Tharsis have led to migration of the spin axis relative to the lithosphere by over 70 degrees, and probably multiple times. One can plausible pick almost any rotation axis for a hypothetical early Mars. It is perhaps a coincidence that the Northern Plains are approximately centred on the modern spin axis. Nonetheless, it is convenient to consider a spin axis reasonably close to the modern pole for the model of string-of pearls impact into the Northern Plains.

The Northern Plains impact: If a small-scale string of Pearls impactor hit the northern hemisphere of Mars, a belt of impact craters would be distributed in a small circle around the target latitude, as Mars rotated beneath the impact stream. These craters would be of random sizes, according to the fragment size, and would wrap multiple times around the planet at that latitude.

If the size of the fragments was considerably larger, then at least some of the impact sites would be of basin-scale. A scarred belt would be developed around the planet at the target latitude.

If the scale of the fragments was sufficient, and the impact close enough to the spin axis, then the damage zone would form a composite impact basin straddling the pole, with an irregular scalloped margin formed by the overlapping impact basins. This is the scenario where a planet like Mars can acquire an irregular-shaped impact basin straddling much of one hemisphere – a scenario which is highly unlikely through independent random impacts but is actually quite probable through a String-of-Pearls impact.

Scale of the impactor(s): We can calibrate the scale of the impacts required to excavate the observed Northern Plains. To do this with a single impact requires a body of the order of 300 km in diameter to generate the 6000 km diameter northern plains. This single impact model, as noted, fails to generate the scalloped margin of the northern plains in any credible scenario. Additionally, the magnitude of such an event may remelt the entire crust of Mars and destroy the evidence of its arrival.

However, if 3-5 separate impactors, each less than half this diameter were to collide in a String-of-Pearls event on a small circle between about 35 degrees and 40 degrees in latitude, their individual impact basins would overlap across the pole, and form a single composite basin with a scalloped margin (Figure 1). This small-circle impact chain includes several recognized impact basins, as well as more speculative basins beneath northern Tharsis. All of these impacts are approximately coeval with each other and the crustal dichotomy at 4.12 Ga [8]. The subtle differences in preservation of the various basins may reflect their detailed chronology within the String-of-Pearls impact sequence, with first-formed basins being more degraded by ejecta from later ones in the series.

The pre-fragmentation size of the impactors would be about half the size and mass of the single unfragmented impactor, so the risk of global re-melt is lessened, and the geometry resulting from the impact is much more similar to that observed for the Northern Lowlands of Mars.

Summary: This model is highly speculative but nonetheless offers a way to explain the observed northern lowlands of Mars as essentially a single multiple impact basin, formed in a geologic instant, but stretching over a period of a few days in real time. If supported by further work, this adds another spectacular chapter to the assembly of the Terrestrial Planets, and helps us better understand the evolution of Mars and some of the paradoxes of a non-plate tectonic planet with an apparent "ocean" basin.

References: [1] Wise D. U. et al. (1979) *JGR 84*, 7934-7939. [2] Wilhelmes D. E. and Squyres S. W. (1984) *Nature 309*, 138-140. [3] Frey H. V. and Schultz R. A. (1988) *GRL 15*, 229-232. [4] Frey H. V. et al. (2002) *GRL 29*, 10.1029/2001GL013832. [5] Sleep N. H. (1994) *JGR 99*, 2955-2968. [6] Fairen A. G. and Dohm J. M. (2003) *Icarus 168*, 277-284. [7] Arkani-Hamed J. (2005) *JGR Planets in Press* 2004JE002343 [8] Nimmo F. and Tanaka K. (2005) *Annual. Rev. Earth. Planet. Sci. 33*. 3.1-3.29. doi 10.1146/annurev.earth.33.092203.122637

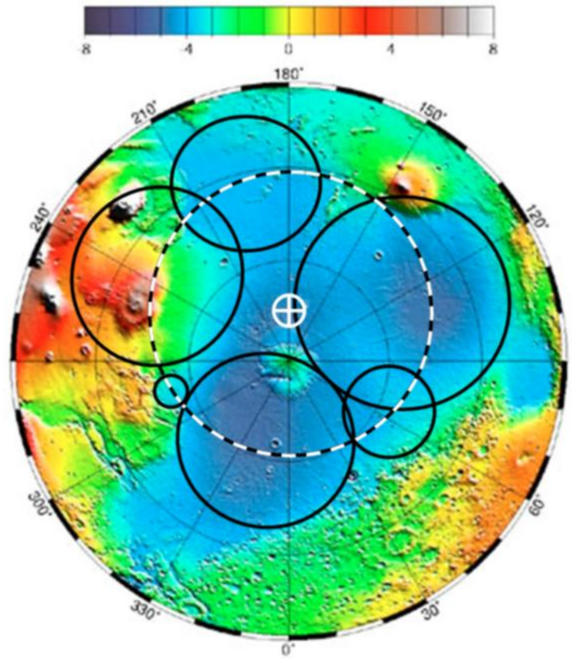

Figure 1: Hypothetical small-circle impact "daisy" responsible for the northern lowlands of Mars. Individual impact basins (black circles) overlap to create an irregular lowland basin complex. Impact centres are distributed on a small circle (dashed) at ~40 degrees latitude from the palaeopole (White Cross at ~N75 E180). The absence of residual highlands near the polecap itself is due to either complete overlap of the impact basins, or to later subsidence due to crustal flexure as the northern basins filled with several km of material. Topography from MOLA team at NASA GSFC.