CONSTRAINTS ON THE AGE OF STICKNEY CRATER AND ASSOCIATED FEATURES ON PHOBOS.

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Introduction: The age of Stickney Crater (~11 km diameter) on Phobos has been computed as 3.66 or 4.3 Gyrs by Schmedeman et al., (2013) [1] using the size/frequency distribution of craters. The two age estimates, 3.66 and 4.3 Gyr, are due to alternate scenarios that are used to predict the flux of impactors at Phobos [1].

The Stickney impact crater has a series of areally associated features that might be used to set limits on the age of Stickney *if* they were produced as a consequence of the impact. These areally associated features include 1) grooves that cover most of Phobos [2,3], 2) blocks interpreted to be ejecta that are proximal to Stickney [4], 3) continuous ejecta deposits [2], and 4) "blue" terrain that is observed on the Stickney crater rim and floor [5] [Fig. 1].

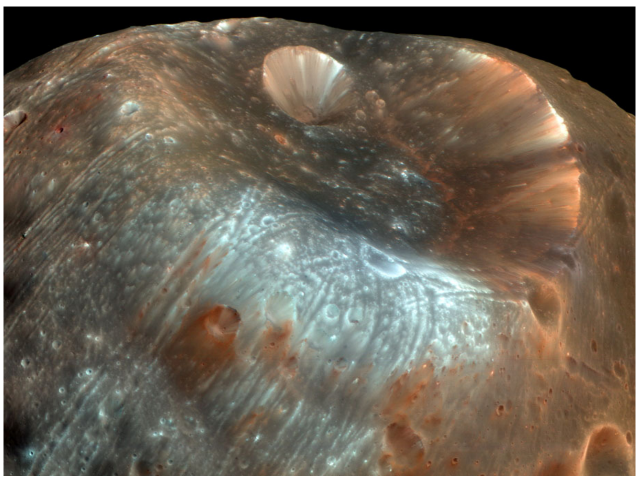

Fig. 1. Stickney crater and its eastern rim. Stretched color HiRISE image PSP 007769 9010 IRB. Note the complex interrelated geology.

Under this assumption, the age of Stickney sets limits on the ages of associated features that it produced, and the age of the Stickney impact may be dated by modeling the system that produced the associated features. If it turns out that an associated feature is unlikely to survive from the computed age of Stickney to the present day, then 1) the associated feature was produced by a younger independent process, or 2) the Stickney impact is younger than previously computed.

A clear example of a potential mismatch in age-dating is the problem of ejecta blocks that according to Thomas, et al., (2000) [4] are the product of the Stickney impact. Blocks that are observed near Stickney appear to be proximally related; however, Basilevsky et al., (2013) [5] suggest that boulder survival times on Phobos are substantially less than the 3.66/4.3 Gyrs estimated for the age of Stickney by Schmedeman et al. [1]. Consequentially, Stickney is either a much younger crater than previously thought, or the blocks that are observed proximally to the Stickney rim have a separate and younger genesis.

Similar problems appear likely when comparing the age of Stickney to other associated features. The blue regolith unit [Fig. 1] may not be as old as the 3.66/4.3 Gyrs date [1] for Stickney due to expected effects from space weathering processes [7]. Groove features also appear to be younger than Stickney [1], yet the apparent age of the grooves may be younger than Stickney by only hours, and may appear to have an older age due to alteration by secondary impacts from Stickney that arrived only days later from martian orbits [8]. Furthermore, the process by which ejecta from Phobos globally and uniformly accumulates onto Phobos after a sequence of secondary and tertiary re-impacts [8] is likely to alter the interpretation of all surface features on Phobos in ways that may be inconsistent with extrapolated lunar age-dating analogs.

Because the Stickney impact would have produced an overlapping sequence of contemporaneous events and processes, it is likely that the age of Stickney and its associated features can only be adequately unraveled by modeling the entire impact process as a single system and then observing the sequence of events within that system in order to assess the consequences of each associated process on all other associated processes.

Method: In order to systematically assess the age of Stickney Crater and associated features and units, we model the gravitational fields of Phobos and Mars and the orbital revolution and rotation of Phobos as it orbits Mars. In the model, impact ejecta from Stickney is launched from the crater rim and the flight trajectories are observed for their interactions with Phobos. The model tracks the flight of simulated ejecta blocks, including boulders that may produce grooves by bouncing and rolling along the surface of Phobos [9] [Fig. 2]. The model further accounts for secondary impacts and follows the flight of simulated secondary ejecta until follow-on ejection velocities are no longer sufficient to escape the gravitation of Phobos. We report on our initial results below.

We initially assume that associated features of Stickney are a consequence of the Stickney impact. The model is run at a range of orbital altitudes of Phobos that correspond to the altitude of Phobos during its geological history. If no orbital altitude accounts for all geological features that are typically associated with the Stickney impact (i.e., grooves, ejecta blocks, and blue terrain), then the orbit that best matches Phobos as it is observed in the present day is used to date the impact system.

Predictions and Discussion: In Ramsley and Head (2013) [8] we conclude that >95% of ejecta from Phobos intersects and eventually accumulates on Phobos. The Stickney impact in its present day longitude is situated such that ejecta from the west rim would disproportionately escape from the martian gravitational system. Nonetheless, >90% of Stickney ejecta would accumulate on Phobos during a process that begins immediately after the impact and gradually diminishes over thousands of years as ejecta intersects Phobos from martian orbits. Rather than a one-time event, the Stickney Crater impact began an extended process where earlier ejecta deposits are reworked by the arrival of later deposits.

The impact system is mainly driven by the distribution of ejecta velocities and the size/frequency distribution of ejecta blocks. Fig. 2 shows the fate of 100 m blocks that are launched from Stickney with an initial velocity of 8 m/sec. The dominant processes that control the fate of these blocks is the gravitation of Mars and the rotational period of Phobos. Although the model does not yet track the fate of blocks that re-impact onto Phobos, it is clear in Fig. 2 that low-velocity (8 m/sec) ejecta follows the trail of large grooves that radiate from the east rim of Stickney.

Nearly all of the ejecta from Stickney enters orbits around Mars and the distribution of Stickney ejecta that accumulates on Phobos is governed by the sequence of re-impacts of the ejecta from martian orbits. Re-impacts continue to produce new ejecta until the residual velocity is sufficiently low to permit capture by the gravity of Phobos [8]. We compute that two or more impacts are required for larger blocks to become captured by Phobos, and consequently it is likely that many boulders that are observed near the Stickney rim [4] arrived as fragmented secondary ejecta from impacts on the opposite side of Phobos [8].

Parallel grooves from rolling boulders may be produced from large blocks that are directed by gravitational forces generally to the east [e.g., 9] [Fig. 1,2]. Solitary grooves are more likely the consequence of a solitary ejecta block that returns to Phobos from a nearby martian orbit. Returning boulders accumulate on Phobos, however they are subject to destruction from solar system projectiles [6] and may not be found in large numbers, given sufficient residence time [6].

Nearly all of the ejecta from the Stickney impact re-impacts onto Phobos within seven crater radii of Stickney at velocities up to 4 km/s. As a consequence, the crater size/frequency distribution that is associated with Stickney may include a surplus of rounded secondary crater impacts that are indistinguishable from solar system impactor flux. Significant numbers of additional secondary impacts from the Stickney impact could result in a higher crater count and an older date for Stickney than if the same impact took place on the Moon. Therefore, age-dating of the Stickney impact is likely to produce an older date than dates that are computed using a lunar analog that is corrected by the expected projectile flux in the vicinity of Mars.

Conclusion: The geology that is associated with the Stickney Crater impact appears to be produced by an event where multiple overlapping and interrelated processes strongly influence the subsequent morphology of all associated features. Only by modeling the Stickney impact as a complete contemporaneous system is it possible to work out the age of Stickney and the nature of related impact processes.

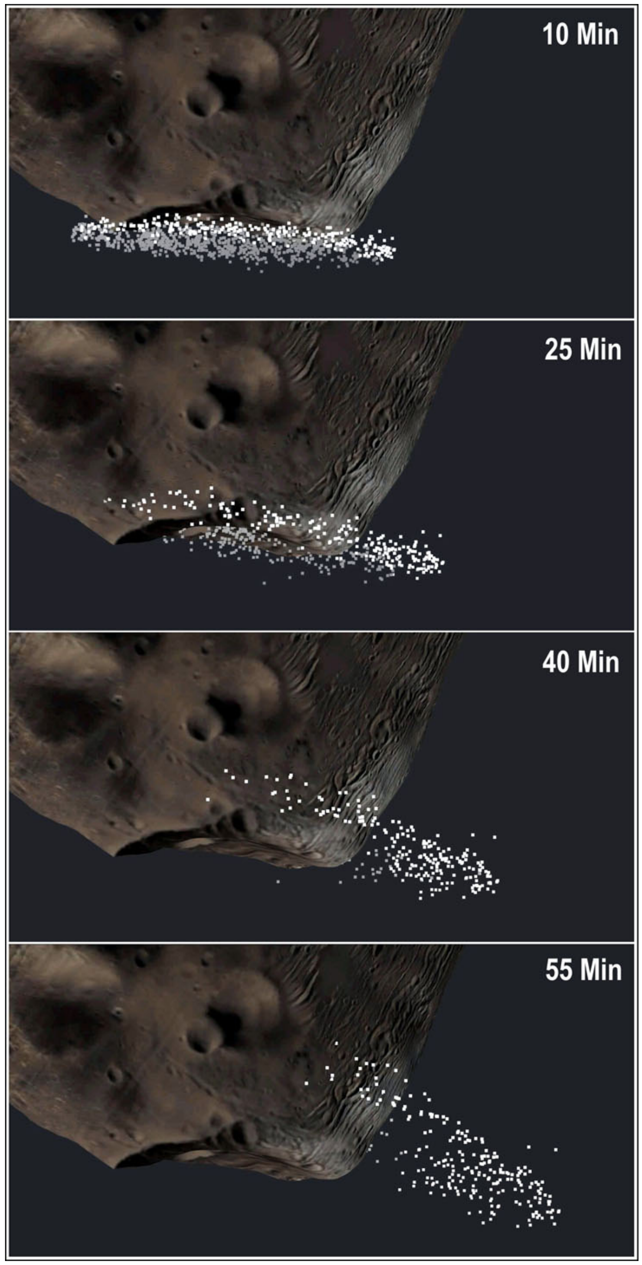

Fig. 2. Parallel grooves that radiate from the eastern rim of Stickney crater align to the flow of 8 m/sec ejecta blocks from the Stickney impact, strongly suggesting that the scoured terrain and grooves to the east of Stickney Crater were produced by Stickney ejecta outflow [Modeled in Blender software].

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