HiRISE OBSERVATIONS OF SMALL IMPACT CRATERS ON MARS. A.S. McEwen[1], J.A. Grant[2], L.L. Tornabene[1], S. Byrne[1], K.E. Herkenhoff[3], N.T. Bridges[4], and the HiRISE team. [1]University of Arizona, Department of Planetary Sciences, Tucson, AZ, 85721 (email: mcewen@lpl.arizona.edu); [2]CEPS/Smithsonian, Washington DC; [3]USGS, Flagstaff AZ; [4]JPL, Pasadena CA.

Introduction: The origins of small (<500 m diameter) impact craters and how to use them as constraints on chronology has been the subject of ongoing debates. One view is that they are mostly primaries and can be used to date terrains to great precision [1, 2], another view is that they are often dominated by distant secondaries and possess limited utility for chronology [3, 4], and a third view is that the crater origin doesn't influence order-of-magnitude chronology [5]. The High Resolution Imaging Science Experiment (HiRISE) is sampling the Martian surface at 25-32 cm/pixel scale [6] and providing much new data relevant to this discussion.

New Observations: HiRISE has acquired hundreds of images enabling orbital detection of craters smaller than 10 m diameter and definition of new details on the morphology of larger craters. First impressions from these data are striking. Craters smaller than 10 m diameter are rare over many areas of Mars, much less abundant than would be expected if the cratering was lunar-like. However, such small craters are present in huge numbers and high densities in association with rayed craters such as Zunil, Zumba, Gratteri, and others [7]. A rough estimate from HiRISE image PSP_1564_1520 is that Zumba (3.3 km) produced a total of 10^7 secondaries from 1-10 m diameter. Asteroidal material strikes the Martian atmosphere at v ~10 km/s and may fragment into small pieces that can quickly ablate or produce a tight cluster of very small craters that are easily erased by eolian processes [8, 9]. High-velocity impact ejecta fragments also re-impact the atmosphere but at v < 5 km/s, and the great majority impact at lower velocities. Likelihood of breakup from atmospheric impact is proportional to v^2, so formation of small secondaries should be much less impeded by the atmosphere than primaries.

HiRISE Observations of Very Recent Small Primary Craters: Malin et al. [10] reported discovery of 20 very recent (2-8 yr old) dark spots that correspond to small impact craters plus associated ejecta and blast zones. The potentially new craters range from 10-36 m diameter with one outlier at 148 m. 19 other new dark spots did not correspond to impact craters, or correspond to craters known to exist prior to the darkening. The authors assumed that the darkening of 20 spots was caused by the actual impact events, and presented high-resolution before-and-after MOC images for two of the craters. An alternative hypothesis for most of the other 38 dark spots is that the darkening was due to winds removing a thin layer of dust, a Martian process that has been known for decades [11]. An analogy would be the wind gusts that removed dust from the solar panels of the Spirit rover in 2004. The rover darkened, and subsequent high-resolution images show a rover that looks pristine at the scale of the image, but that doesn't mean that a new rover was emplaced at the time of the darkening. Results from the MER landing sites indicate crater formation often disrupts surfaces in equilibrium with on going processes and provides an inventory of fine-grained material sensitive to geologically rapid redistribution (into craters and other depressions) leading to a return to a stable surface [12]. For relatively young craters surrounded by some of these accessible fines, threshold events triggering eolian transport could lead to ejection of dust and a rapid darkening of the surface around a young, but not necessarily newly formed crater.

At the time of writing this abstract HiRISE has imaged only one of these new dark spots (PSP_2039_1545), corresponding to the largest of the craters at 148 m diameter. The image shows eolian ripples in the crater floor, wind tails behind ejecta blocks, and dust devil tracks over the ejecta, so clearly there has been eolian activity that could trigger removal of a thin layer of dust since the formation of this crater. This provides proof-of-concept that darkening associated with a crater doesn't require that the actual crater formation caused the darkening. However, there was already reason to doubt that this particular crater was as young as the others, based on its size and lack of blast-zone albedo patterns [13]. Another interesting result is that this 148-m crater produced $>10^4$ resolvable (1-10 m) secondary craters.

It was argued [10] that the new small craters must be primaries rather than a set of secondaries from a new primary because the dark spots formed at different times. If not all of the craters formed when the darkening occurred, this argument still holds because of the two craters with before-and-after images that could resolve the actual craters and from a simple probability argument. There is not an obvious new primary candidate near the new dark spots, so it would have to be a distant primary. Given the sizevelocity relation [4, 8] the distant primary would need to be at least 10 km diameter, but only ~1 of these should form on Mars per 10^6 yrs [14], so the probability that one formed in the past decade is ~1 in 10^5. Also, such a large new crater would be obvious from comparison of Viking images to multiple newer datasets.

While awaiting HiRISE images of the other very recent craters, let's assume that the derived cratering rate is correct within an order of magnitude for primaries over the past decade. It is uncertain, however, whether this rate is also a good estimate of the primary cratering rate over the 10^4-10^9 yr timeframes relevant to dating geologically recent terrains on Mars. Moreover, there is another constraint that must be considered: the set of relatively large (10-30 km) Martian primary craters that produced up to 10^9 secondaries [15] yet have very few craters superimposed over their floors or continuous ejecta blankets [3, 4]. Clearly any superimposed craters can't be older than the secondaries and are unlikely to have been preferentially erased by eolian processes. Also, small-scale primary morphologies of the crater have not been erased. Constraints on the ages of these craters can be based on either the superimposed small craters or the statistics of the craters themselves, using the same widely-used production functions [1, 5]. The result is that the few superimposed small craters point to ages 10^2 to 10^3 times younger than from the larger craters themselves. Or a better way to state this is that the probability these craters could be so young, if we believe the production functions for large craters, is 1 in 10^2-10^3.

What hypotheses can satisfy both a high primary cratering rate over the past decade and the constraint from small craters on large well-preserved craters? One possibility is that the production functions are 10^2-10^3 times too low for the large craters, but this is disproven by what we know about lunar cratering and asteroid dynamics. Another possibility is that the cratering rate from small primaries is not constant over time, and has been unusually high over the past decade. There is evidence for spikes in the primary cratering rate from dating of lunar impact spherules [16,17]. A third possibility is that either the new craters of [10] and/or the small craters on larger craters of [3] have been misinterpreted; certainly both types of observations are in need of more analysis and scrutiny.

Erosion of Craters in Light-Toned Layered Deposits: The small numbers of small craters on most of the LTLDs, some of which must be billions of years old based on the stratigraphy, has been considered puzzling [e.g., 10]. One possible resolution is if the long-term primary cratering rate is much lower than believed based on lunar studies [3]. Another at least partial explanation is offered from HiRISE observations: the craters preferentially erode. In other words, the LTLDs develop a hardened rind and/or streamlined shapes that minimize wind erosion, but when the deposits are broken into blocks either by mass wasting or cratering, these blocks are then subject to rapid erosion and removal by the wind. A similar process is observed in weakly indurated terrestrial loess deposits [18]. HiRISE images support this idea in the morphologic sequence of crater erosion and removal. This is the opposite of pedestal craters in which the surrounding terrain preferentially erodes.

In summary, it is clear that continued orbital monitoring of Mars, including high-resolution samples, can provide key information about impact processes and implications for chronology.

References: [1] Neukum, G. et al. (2004) Nature 432, 971; [2] Ivanov, B. (2006) Icarus 183, 504; [3] McEwen et al. (2005) Icarus 176, 351; [4] McEwen, A.S. and Bierhaus, E.B. (2006) AREPS 34, 535. [5] Hartmann, W.K. (2005) Icarus 174, 294. [6] McEwen A.S. et al. (2007) *JGR*, in press. [7] Tornabene, L.L. et al. (2006) JGR 111, CiteID E10006. [8] Melosh, H.J. (1989) Impact Cratering, Oxford. [9] Chappelow, J.E. and Sharpton V.L. (2005) Icarus 178, 40. [10] Malin, M.C. et al. (2006) Science 314, 1573. [11] Sagan, C. and Pollack, J.B. (1969) Nature 223, 791. [12] Grant J.A. et al. (2006) JGR 111 doi:10.1029/2006JE002465. [13] Materials posted at msss.com. [14] Ivanov, B.A. (2001) Space Sci. Rev. 96, 87. [15] Preblich, B. et al., JGR in press. [16] Culler, T.S. et al. (2000) Science 287, 1785. [17] Levine, J. et al. (2004) AGU fall meeting #SH51B-0272. [18] Pye, K. (1987) Aeolian Dust and Dust Deposits : London, Academic Press, 334 p.