DISCOVERY OF A LARGE RAYED CRATER ON MARS: IMPLICATIONS FOR RECENT VOLCANIC AND FLUVIAL ACTIVITY AND THE ORIGIN OF MARTIAN METEORITES. A. McEwen[1], E. Turtle[1], D. Burr[1], M. Milazzo[1], P. Lanagan[1], P. Christensen[2], J. Boyce[3] and the THEMIS science team. [1]LPL, University of Arizona, Tucson, AZ 85721, [2]Arizona State University, Tempe, AZ, [3]HIGP, University of Hawai'i.

Introduction: Recent impact craters on the Moon, Mercury, and icy Galilean satellites have produced bright rays extending hundreds or thousands of kilometers from the crater rims. A large rayed crater has never previously been seen on Mars, and it has been assumed that the active aeolian environment would quickly remove the ephemeral ray material [1]. Here we report the discovery of a 10-km diameter crater in the young volcanic plains of Cerberus (SE Elysium Planitia) with rays (apparent in THEMIS IR mosaics) extending more than 800 km.

The rays are associated with ~10^5 to 10^7 secondary craters ranging from 15 to 100 m in diameter. This quantity of secondary craters, if typical, suggests that most small craters seen in NA-MOC images are secondaries. About 75% of the craters superimposed over Athabasca Valles [2] originated from this single impact event. Attempts to date very young surfaces from the density of small craters are limited by the fact that secondary cratering is highly clustered in space and time, increasing the uncertainties by a factor of 30 or more.

The 10-km Cerberus crater may be the youngest crater on Mars of this size class, perhaps < 10^6 yrs old [3]. The presence of flow ejecta suggests that ground ice was present at depths of a few hundred meters even in very recent times at this equatorial location. Mars meteorite EET79001 (basaltic glass) has an ejection age of less than 1 Ma [4] and could have originated from this crater.

Observations by MOC: Small (15-100 m) bright-rayed craters on Mars [5] have been extremely puzzling. They appear very fresh and well-preserved, with bright ejecta and fine rays extending up to distances of ~10 crater diameters. They are strongly clustered both locally and globally (most are in the Cerberus region). The crater rims are generally circular, but those imaged at the highest resolution appear more angular and unusually shallow (for primary craters). Some of them consist of very tight clusters of craters. They range in size from the limits of MOC resolution (~10 m diameter) up to ~100 m; a few are slightly larger. It is very difficult to map out the distribution of these craters from the sparse NA-MOC coverage.

Observations by THEMIS: THEMIS IR images (day and night) have revealed exquisite detail in well-preserved impact craters [6]. There are strong variations in thermal inertia (TI) and albedo, apparent from early morning and late afternoon temperatures and visible images. The fresh craters typically have 3 facies: (1) very high-TI, low-albedo crater rims and interiors; (2) moderate-/high-TI and moderate-albedo continuous ejecta, and (3) low-TI and high-albedo outer ejecta and fine rays. The high-TI, low-albedo material is rocky, as expected from lunar and terrestrial craters. The low-TI ejecta facies appears unique to Mars. The TI and albedo of this material is similar to that of the ubiquitous Martian dust, but may be lightly sintered.

Daytime and nighttime THEMIS mosaics of the Athabasca Valles region were acquired and assembled to support the study of this region as a candidate landing site for MER. The nighttime mosaic revealed roughly east-west trending streaks of cold material superimposed over diverse terrains. Small bright (warm) spots could be resolved in some cold streaks. Comparison to MOC images revealed a 1:1 correspondence between these streaks and the small bright-ejecta craters. These are like crater rays composed of clusters and streaks of secondary craters, much like those observed near the Apollo 17 landing site on the Moon from rays of Tycho.

A larger-scale nighttime IR mosaic of the Cerberus region was assembled and showed a regional pattern to the cold streaks: they radiate from a position ~400 km southeast of Athabasca Valles. THEMIS daytime IR images revealed a fresh 10-km crater at this central location (7.7° N, 166° W), surrounded by swarms, radial streaks, and clusters of secondary craters. A THEMIS visible image at 18 m/pixel shows this primary crater to be pristine, with no superimposed craters; it includes flow ejecta.

This crater does not have obvious chains of irregular secondary craters within a few crater diameters of the rim, which is considered the typical pattern for secondary crater fields [1]. The great majority of the resolved craters formed from blocks thrown 10 to 80 crater diameters, impacting with velocities sufficient to produce circular craters. Nevertheless there is a strong radial pattern pointing to this crater as the source.

Crater Counts: We counted small craters over 4 regions of the channel floor of Athabasca Valles, and put each crater into one of 3 categories: (1) those with the TI/albedo facies described above for recent craters and clearly associated with rays radial to the Cerberus primary, (2) those that do not have the recent facies, and (3) those that have the recent facies but are not clearly part of rays. We interpret (1) as likely secondaries from the Cerberus primary, (2) as craters not associated with this event, and (3) as uncertain. 73% of the 380 craters we counted fall into category (1), 20% fall in (2), and 7% in (3). We conclude that ~70% to 80% of the craters superimposed over Athabasca Valles originated from this single impact event.

The area counted covers 200 km^2, 0.01% of the area of a circle with 800 km radius (the approximate extent of well-defined rays). If this is typical of the density of secondary craters within this circular area, then there should be a total of 2 x 10^6 secondary craters ~15-100 m in diameter produced by this event. We selected 4 images that are distributed over Athabasca Valles without regard to the positions of rays, but crater counts over just 0.01% of the region must be considered an order-of-magnitude estimate at best. Probably there are at least 10^5 and no more than 10^7 15-100 m secondary craters produced by this event.

Is this Physically Plausible? Can a 10-km primary crater on Mars create 10^6 craters 15-100 m in diameter up to 800 km from the source? An ejection velocity of at least 1.8 km/s is required to travel 800 km, well within the 5 km/s escape velocity exceeded by the Martian meteorites. Spalls exceeding the escape velocity should be abundant for craters as small as 3 km in young basaltic terrains [4], and the existence of abundant distant secondary craters is implied by the work of Head et al. [4]. The mean Athabasca crater diameter of 30 m can be produced by a block of ~5 m diameter at typical velocities. 10^6 such blocks require a volume of 0.125 km^3, about 0.4% of the volume of material excavated by the primary (~30 km^3). Secondary fragment volumes range from 0.2% to 7.5% of the primary crater excavation in Table 6.1 of Melosh [1], although these estimates exclude distant secondaries.

Crater Age Dating of Young Surfaces: Hartmann [7] has published model isochrons for Mars down to 16 m diameter, and several studies [2, 8] have used this model along with crater counts, concluding that there are lava flows and flood channels with very young ages, probably less than 10 Ma. What are the uncertainties in these estimates due to the nonuniformities of secondary cratering in space and time? The Cerberus plains include extensive individual lava flows (large areas at a constant age) that we have mapped from MOLA shaded relief images. MOC image M13-01528 crosses both heavily and lightly cratered regions on one well-defined lava flow; crater densities differ by a factor of 17 over areas with significant numbers of craters (>100) and give model ages ranging from ~300 Ma to ~10 Ma. We conclude from this simple test that the age uncertainty here is at least a factor of 30, independent of counting statistics. Note that few of these craters would be eliminated as "obvious secondaries" by the criteria of previous workers [7, 9]. Nonetheless, the majority of these small craters appear to be secondaries from the recent 10-km Cerberus crater as they are strongly concentrated in radial streaks and chains of clusters.

The Cerberus crater may be the youngest crater on Mars of this size class (≥10 km diameter). We expect ~1 such crater to form per 10^6 yrs [3]. Athabasca Valles and the youngest lavas in the Cerberus region are older than this crater, which could be only 0.5 Ma or younger, and they are probably younger than the ~300 Ma discussed above. Tighter constraints may be possible following detailed mapping of the large young craters and their secondary fields, but the errors will always be larger than those based on the assumption that each small crater is an independent event.

Are Small Craters on Mars Mainly Primaries or Secondaries? Three hypotheses for the paucity of small primary craters over Athabasca Valles are:

(1) The atmosphere screens out small primary bodies much more effectively than secondaries. The differences in velocity (5-30 km/s for primaries, <5 km/s for secondaries) will preferentially screen out primaries below a certain size, but that size may be well below a meter and have no effect on craters resolved in MOC images [10].

(2) There has not been enough time for many primaries to accumulate because both Athabasca Valles and the 10 km Cerberus crater are so recent. This idea could work in this special case, but if ~10^6 secondaries that are 0.1% to 1% of the diameter of the primary is typical, then secondaries must dominate over primaries on Mars (and probably on the Moon and Mercury as well). However, the Cerberus crater excavated some of the youngest and presumably most competent lavas on Mars, ideal conditions for creating abundant spalls and distant secondary craters [4].

(3) The steep "secondary branch" in the size-frequency distribution for craters smaller than ~1 km on the Moon and Mars may in fact be due to the abundance of secondary craters, as originally proposed by Shoemaker [11]. Neukum and colleagues [e.g., 9] have argued that the steep branch is due to primary craters, but the issue of how to distinguish primaries from distant secondaries has not been fully resolved. The Moon is too heavily cratered to make this distinction, except for basin secondaries, which indeed dominate over primaries smaller than 20 km on Imbrium ejecta [12]. The youthful surface of Europa provides a clean slate; nearly all craters smaller than 1 km may be secondaries [13]. Mars also has very young terrains and our work appears to confirm the suggestion of Bierhaus et al. [13] that the number of secondary craters produced may be much higher in general than previously assumed.

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