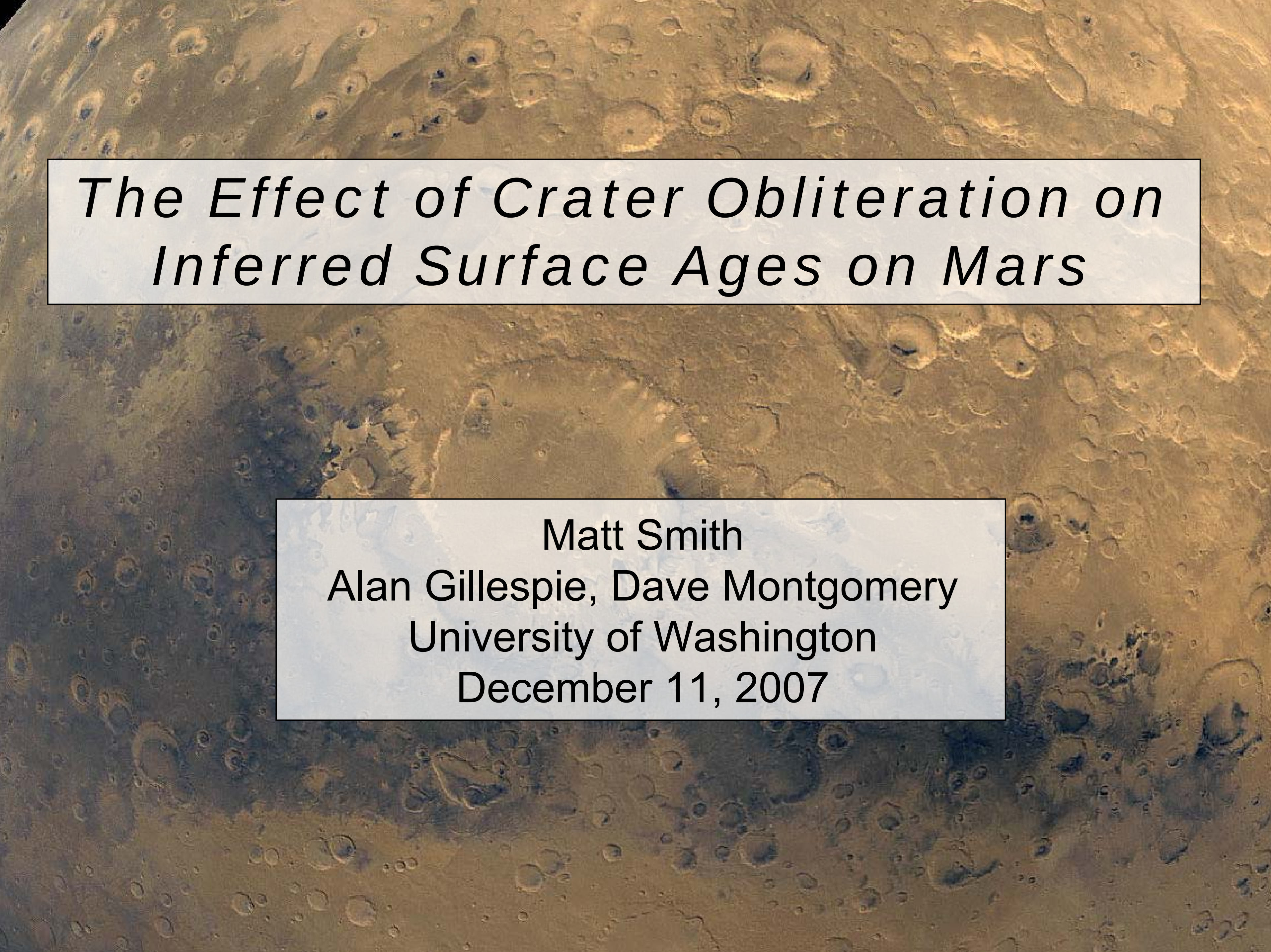


The Effect of Crater Obliteration on Inferred Surface Ages on Mars

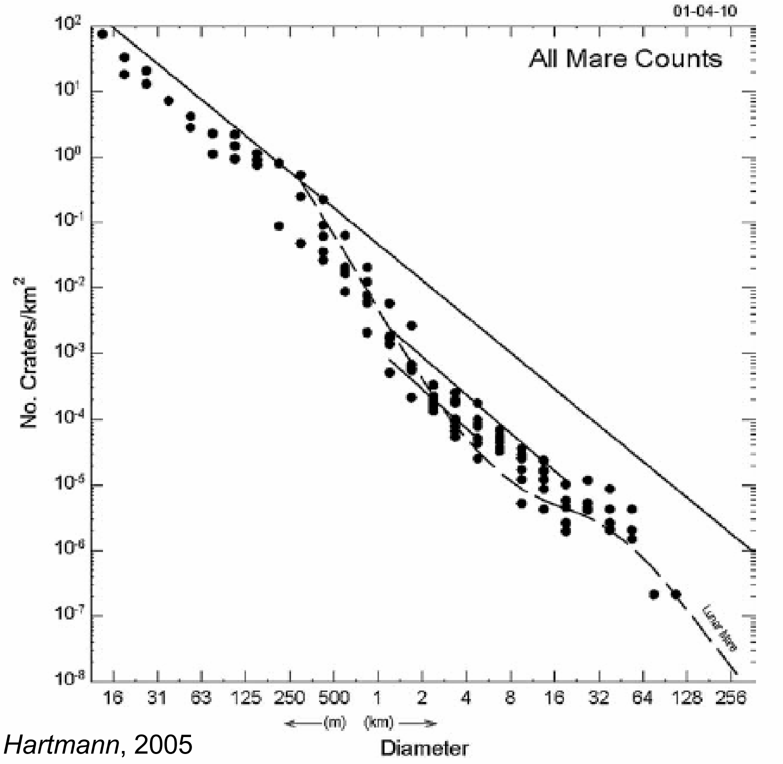
Matt Smith
Alan Gillespie, Dave Montgomery
University of Washington
December 11, 2007

Overview

- Background of crater counting and obliteration
- Overview of model
- Model validation
- Results

Background

Lunar crater counts, correlated with radiometrically dated samples (and extrapolated to other bodies) remain the only quantitative tool to determine planetary surface ages



Hartmann, 2005

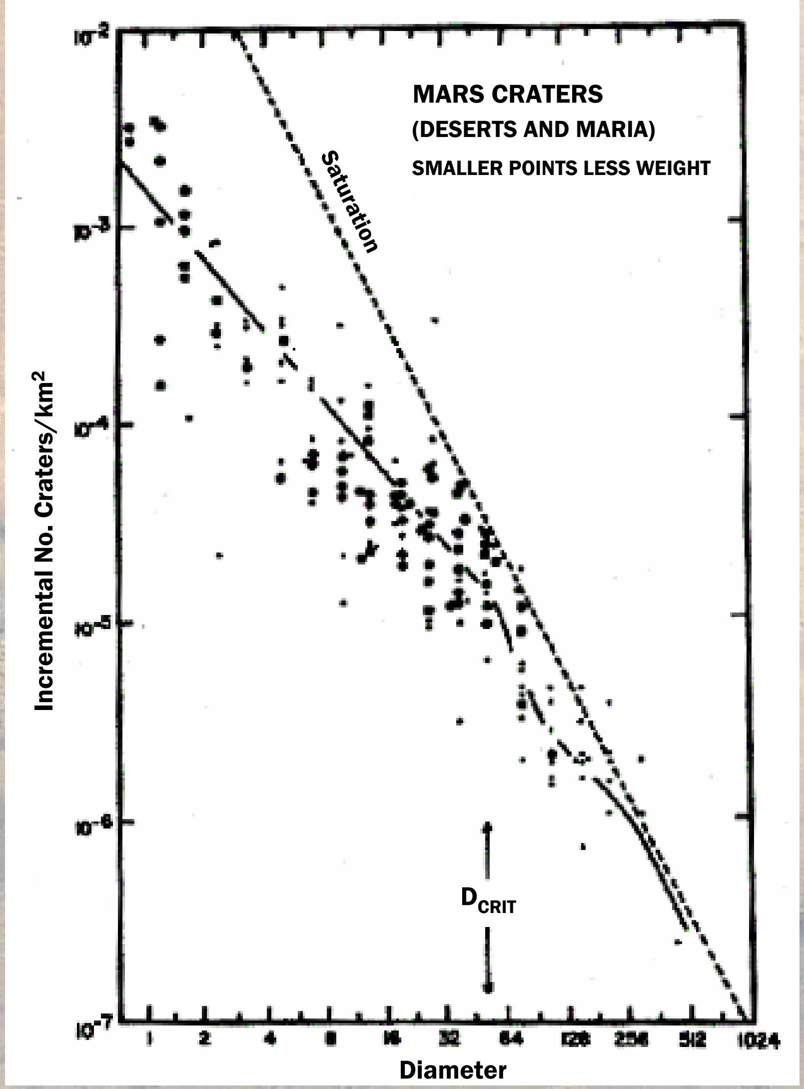
Photo credit: NASA

Unlike on the Moon, the martian atmosphere has the power to erode and deposit material, obliterating smaller craters

Previous Work

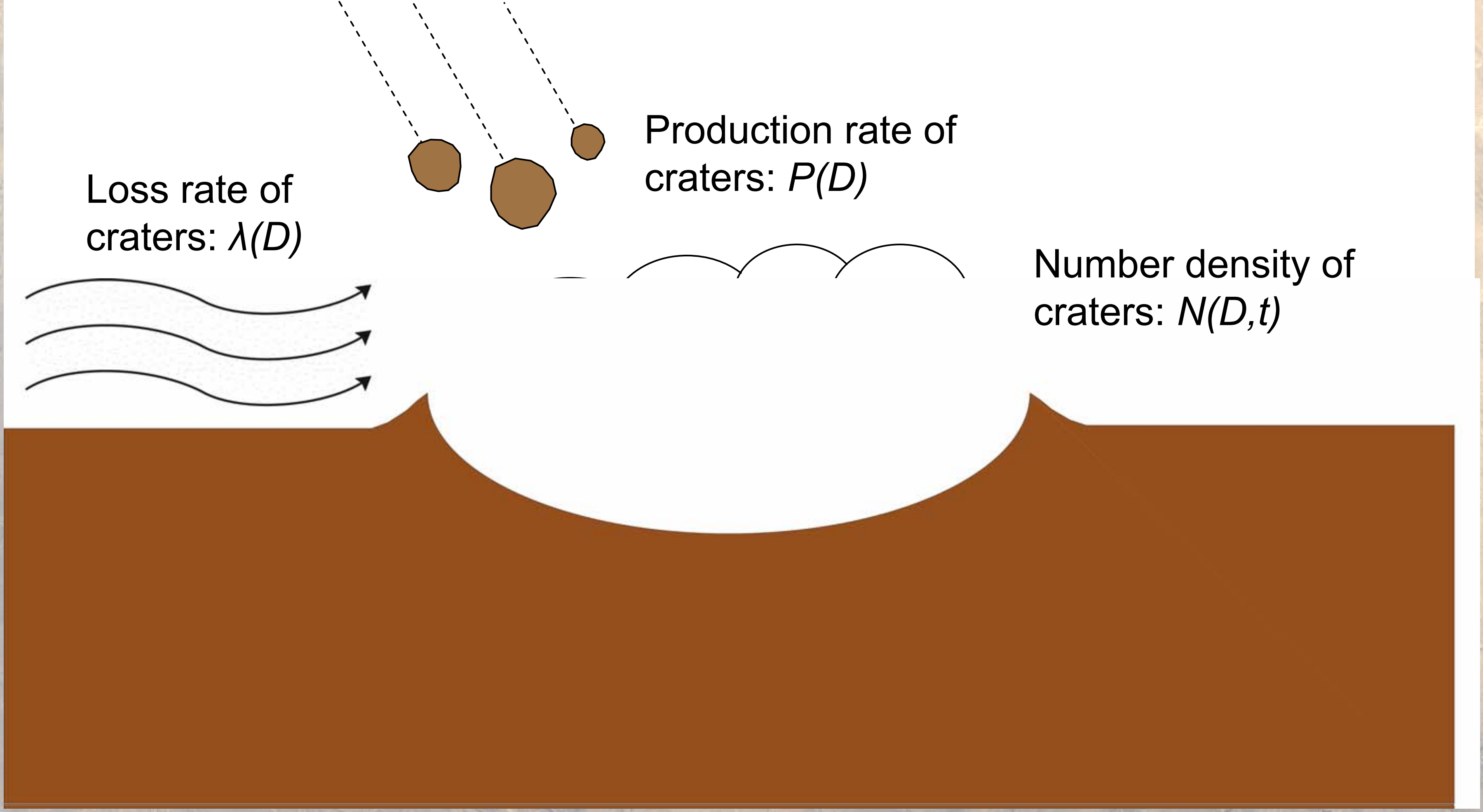
- Loss of small craters relative to lunar-derived isochons has been modeled by *Hartmann* (1971), *Chapman et al.* (1969), and observed by many others

- However, the effect of obliteration remains:
    - not commonly acknowledged in recent crater counting studies
    - poorly quantified (not tied to rates of erosion and deposition)



Hartmann, 1971

Simple Quantitative Model

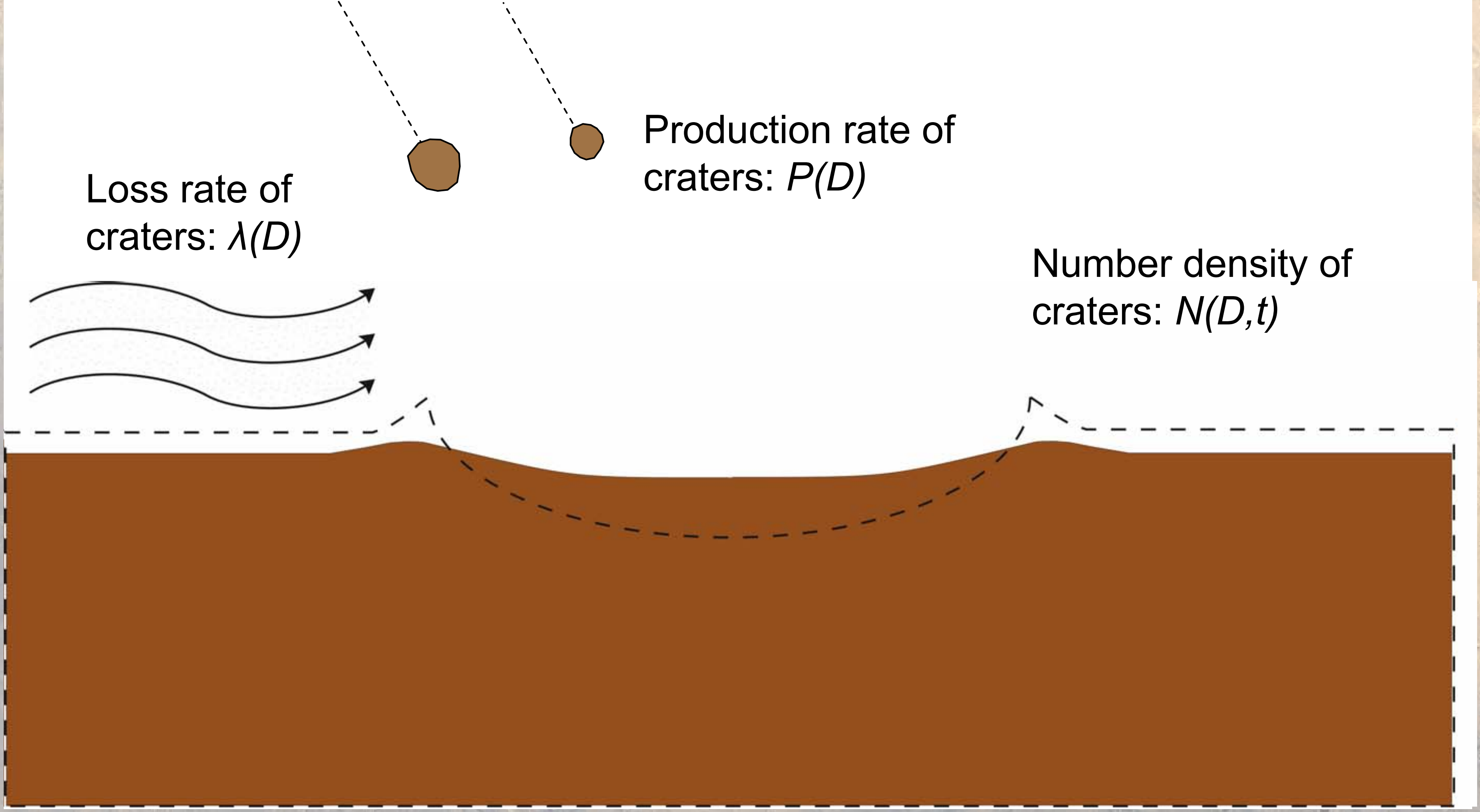


Loss rate of craters: *λ(D)*

Production rate of craters: *P(D)*

Number density of craters: *N(D,t)*

Simple Quantitative Model



Production rate of craters: *P(D)*

Loss rate of craters: *λ(D)*

Number density of craters: *N(D,t)*

Simple Quantitative Model

Apply these inputs to a formula to describe constant production and loss:

$$N(D,t) = \frac{P(D)}{\lambda(D)}(1 - \mathrm{e}^{-\lambda(D)t})$$

Model Inputs

P(D) – Production rate derived from Hartmann Production Function (HPF) (2005)

λ(D) = Loss time for a crater of diameter *D* as a function of *β* (= combined rates of erosion and deposition)

Assumptions

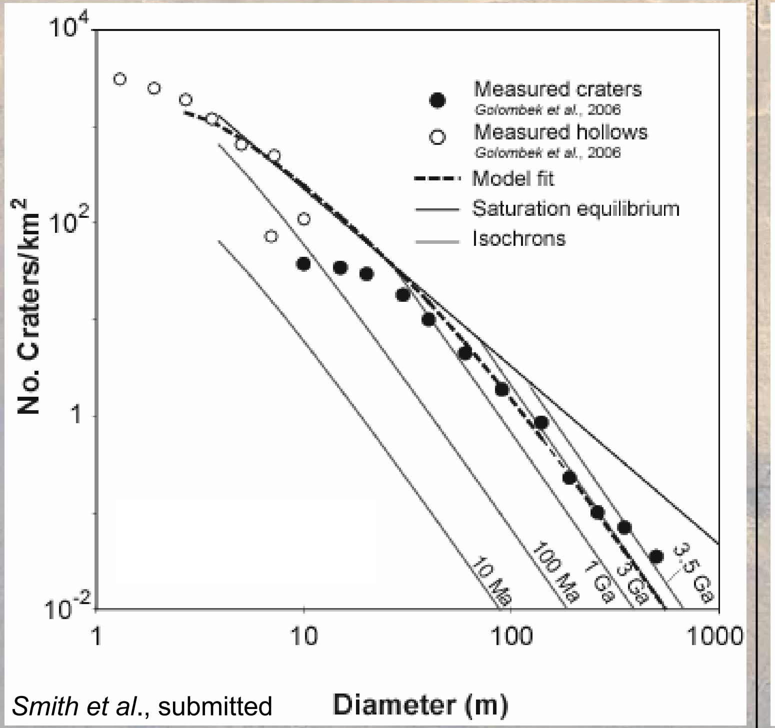
- Crater loss occurs as shown (through ground lowering and infilling)
- Once crater depth is reduced to zero, crater is invisible to detection
- Constant production rate for last 3.5 Ga
- Proportion of secondaries assumed from modeling work of *McEwen et al.* (2005)

Testing the Model

- Test model against calculated measurements of erosion rates at MER landing sites (*Golombek et al*., 2006)
  - Erosion rates were converted to β by assuming that the volume of eroded material is locally deposited over crater area (an assumption made by *Golombek et al*.)
- Model is fit using nonlinear regression to independent crater counts to derive β

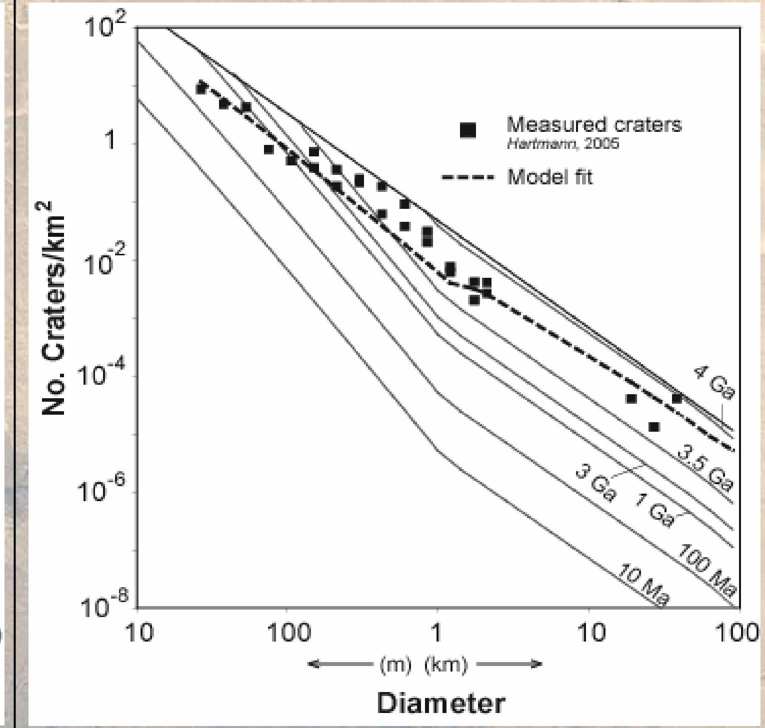
Testing the Model

Spirit



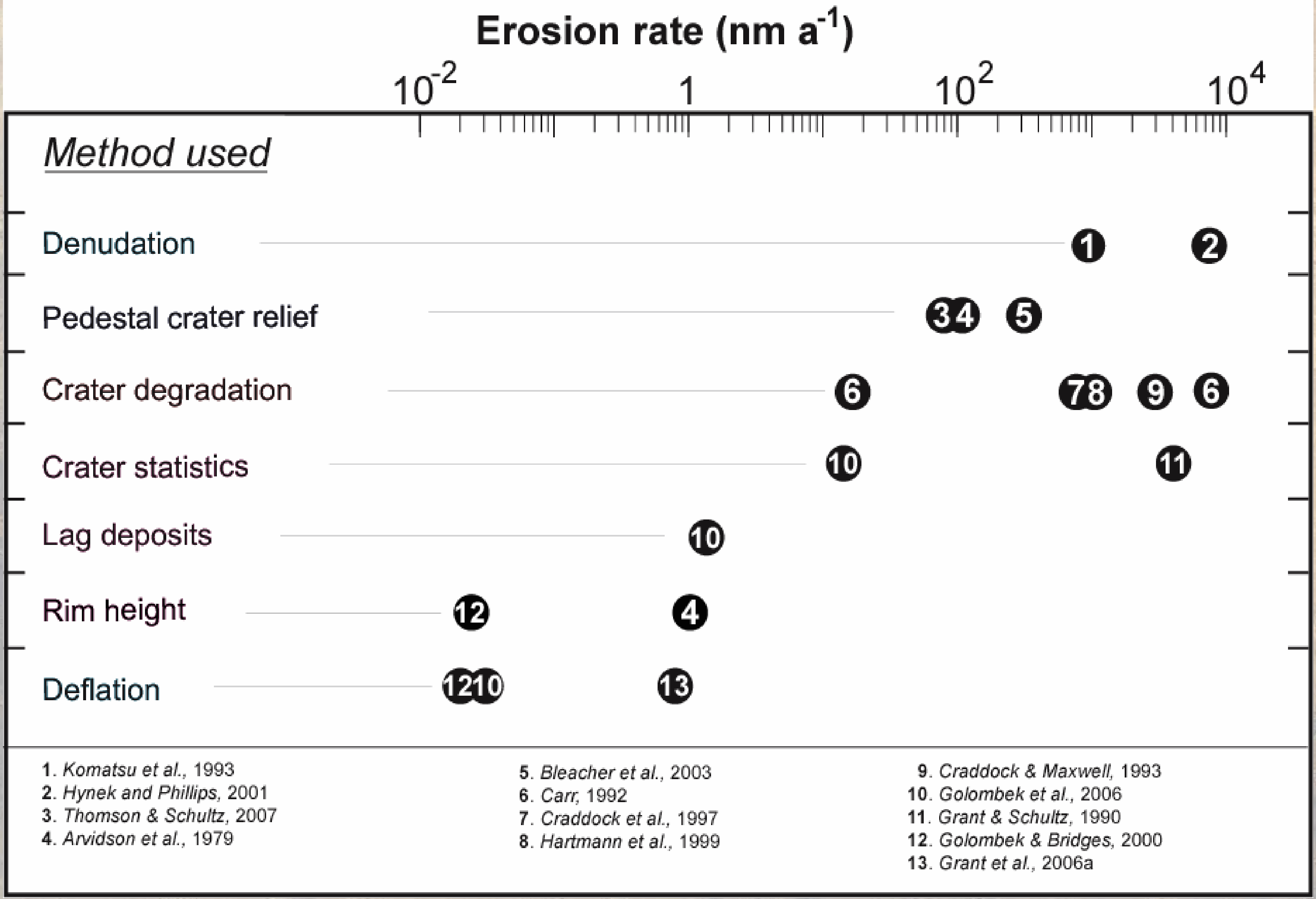
Smith et al., submitted

Opportunity



Calculated β (*Golombek et al.*, 2006)	0.02 - 5.03 nm a^{-1}	13.5 - 108.1 nm a^{-1}
Model-fit β	4.72 ± 2.58 nm a^{-1}	27.2 ± 6.0 nm a^{-1}

Martian Erosion Rates

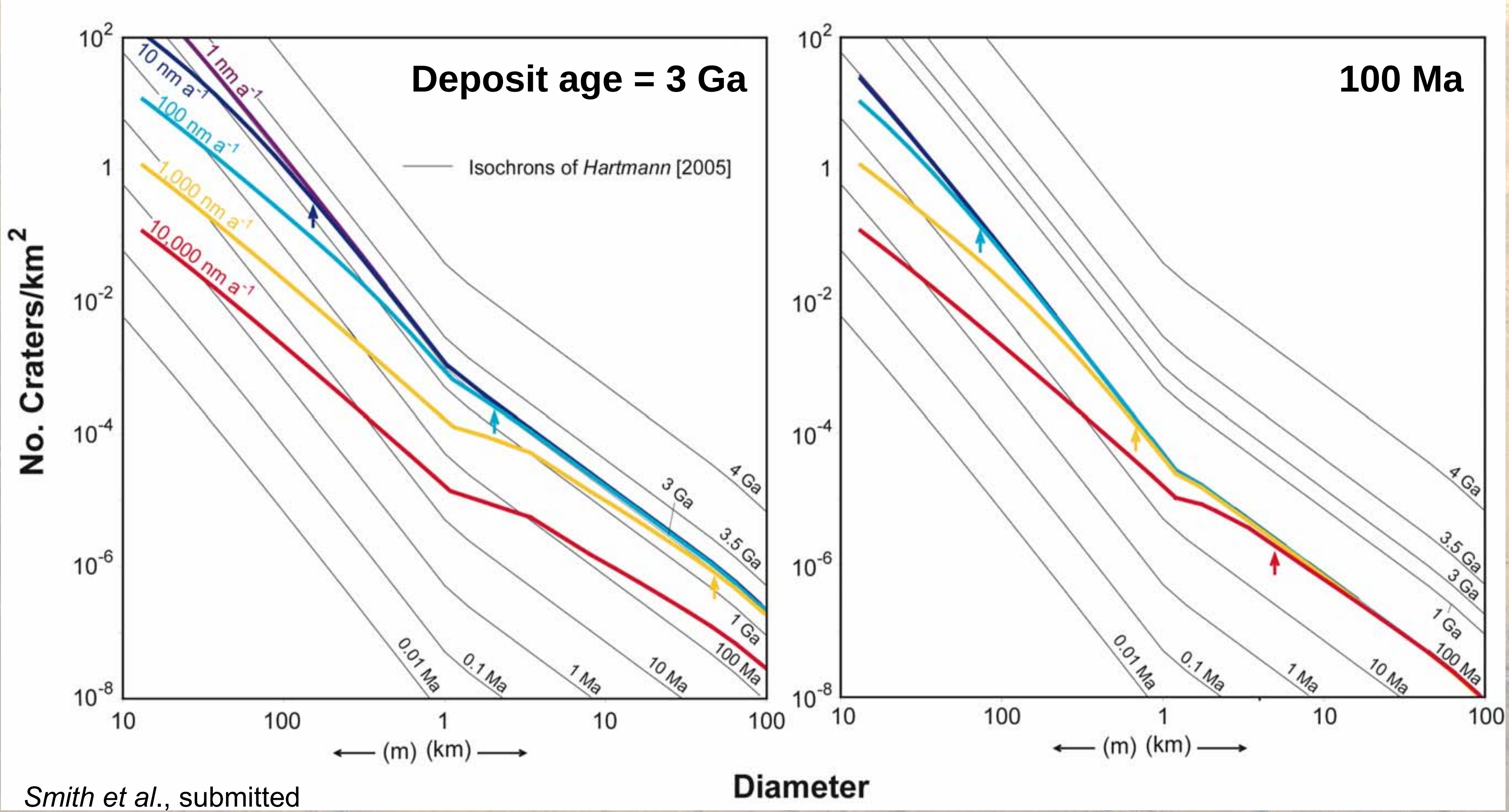


1. *Komatsu et al.*, 1993
2. *Hynek and Phillips*, 2001
3. *Thomson & Schultz*, 2007
4. *Arvidson et al.*, 1979
5. *Bleacher et al.*, 2003
6. *Carr*, 1992
7. *Craddock et al.*, 1997
8. *Hartmann et al.*, 1999
9. *Craddock & Maxwell*, 1993
10. *Golombek et al.*, 2006
11. *Grant & Schultz*, 1990
12. *Golombek & Bridges*, 2000
13. *Grant et al.*, 2006a

Model Results

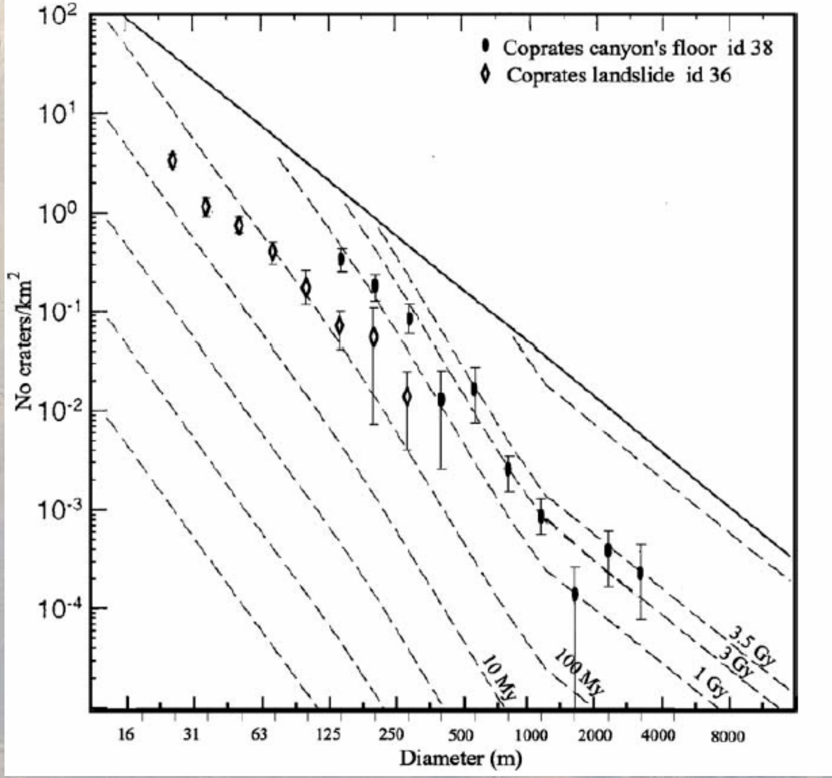
Modeled effect of obliteration (*β)* on crater curves

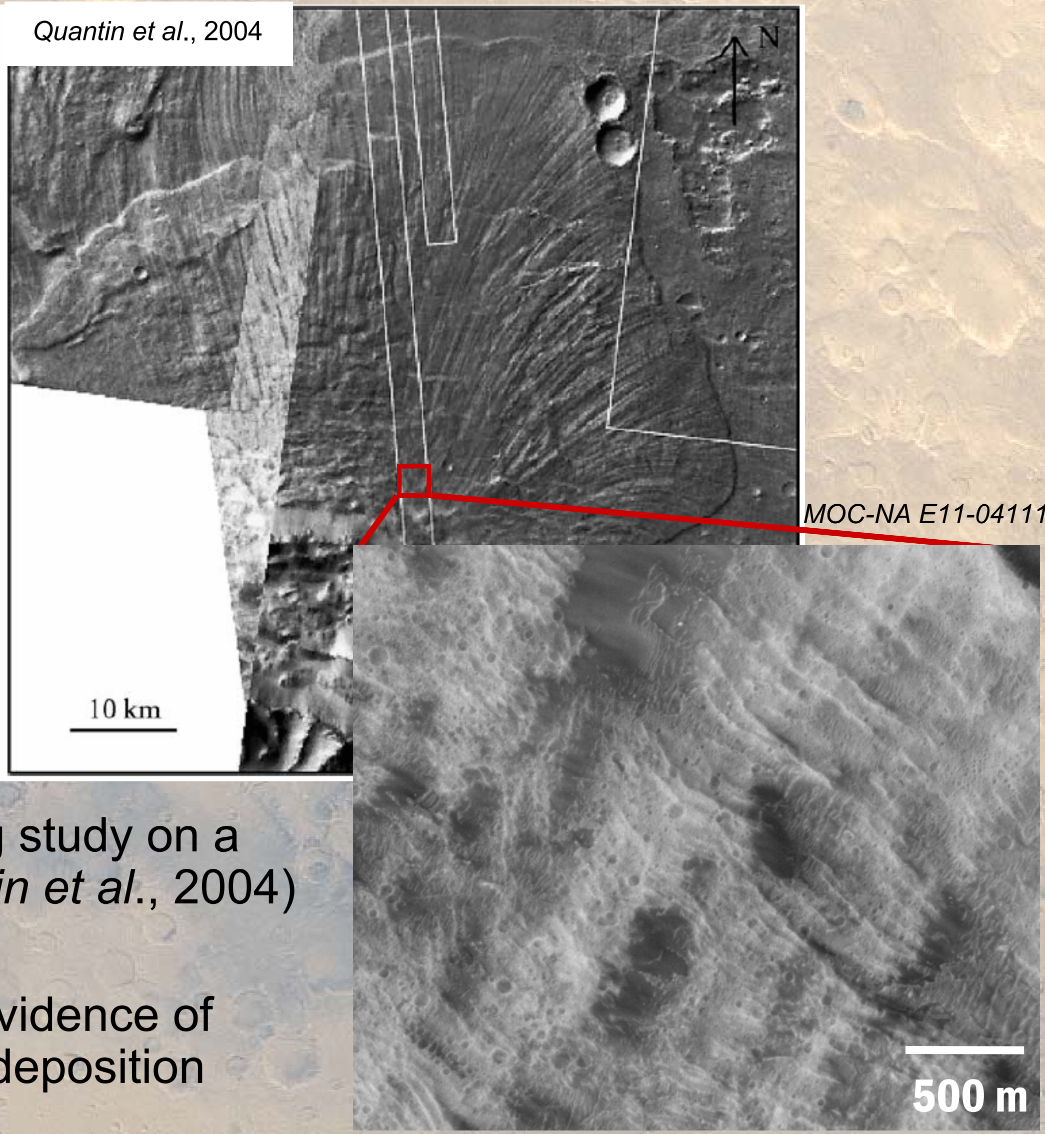
Roll-off of crater-abundance curves at small diameters for surfaces of different ages



Smith et al., submitted

Model Results

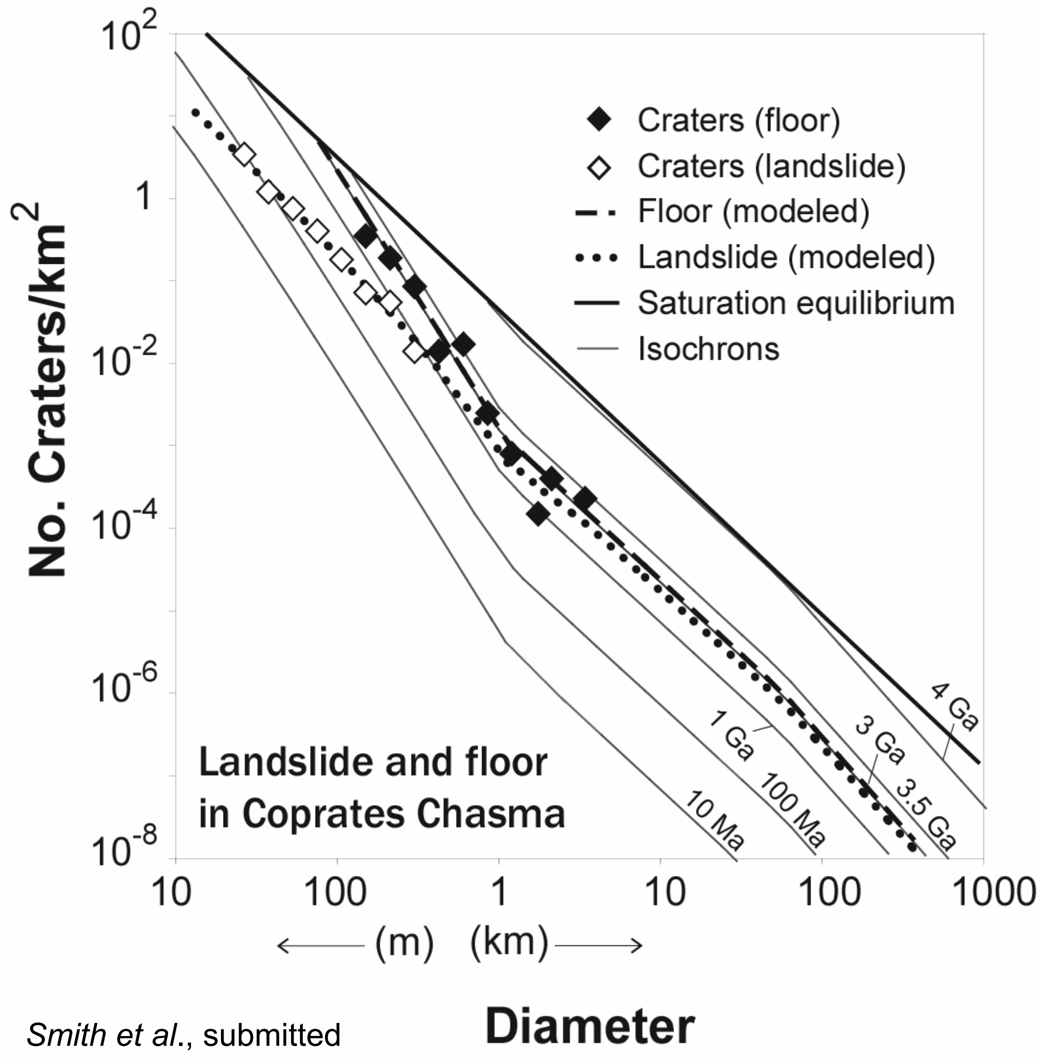



Quantin et al., 2004

MOC-NA E11-04111

- We reevaluated one crater-counting study on a Coprates Chasma landslide (*Quantin et al*., 2004)
- Calculated age = 400 Ma
- 30 m-relief flow lines are given as evidence of minimal surface modification since deposition

Model Results



Smith et al., submitted

Age (*Quantin et al.*, 2004)
= ***400 Ma***

<u>Model Fit</u>

$\beta = 54 \pm 37 \text{ nm a}^{-1}$

(Opportunity Rover →
$\beta = 13.5 – 108.1 \text{ nm a}^{-1}$)

Model age = ***~3 Ga***

Conclusions

- For low obliteration rates (<10 nm a^{-1}), depositional surfaces of all ages may be reliably dated, even if only small craters are counted
- For moderate to high oblit. rates (>50 nm a^{-1}), ages determined from counts of only small craters can lead to falsely low ages
- The reevaluation of a previous study demonstrates that even moderate erosion rates can significantly affect crater-count ages

Effect of secondary craters

- Secondary craters may constitute a large fraction of small craters on Mars (*McEwen et al*., 2005)
- HPF, which our model is based upon, includes both secondaries *and* primaries (*Hartmann*, 2005 & 2007), though:
  - the distribution of secondaries may be spatially heterogeneous, with large populations near large primary impacts and associated rays
  - a martian impact may produce more secondaries than a lunar one
- Both effects would locally <u>increase</u> populations of small craters and our model-derived values for obliteration (β) may be taken as minima

Model Inputs

$$P(D) = 0.29 \begin{cases} \dfrac{0.0035(0.13\ln(D) + 0.83)}{d^{3.3}} & D > 0.001 \text{ and } D < 1.4 \\ 10^{-1.8\log(D) - 2.59} & D \geq 1.4 \text{ and } D \leq 48.1 \\ 10^{-2.2\log(D) - 1.89} & D > 48.1 \end{cases}$$

For known input crater population (primary or secondary)

$$\lambda(D) = \frac{\beta}{1000\xi}; \quad \xi = \begin{cases} 0.2 \cdot D_p \text{ or } 0.1 \cdot D_s & D < 5.8 \\ 0.42 \cdot \ln(D) - 0.01 & D \geq 5.8 \end{cases}$$

$$N(D,t) = \frac{1000\xi P(D)}{\beta}\left(1 - e^{-\beta t/(1000\xi)}\right);$$

$$\xi = \begin{cases} 0.2 \cdot D_p & D < 5.8 \\ 0.42 \cdot \ln(D) - 0.01 & D \geq 5.8 \end{cases}$$

For unknown crater population (mixed primaries/secondaries)

$$\lambda(D) = \frac{\psi\beta}{1000\xi}$$

$$\psi = \begin{cases} 1 + \prod_s & D < 1.2 \\ 0 & D \geq 1.2 \end{cases}; \quad \xi = \begin{cases} 0.2D & D < 5.8 \\ 0.42\ln(D) - 0.01 & D \geq 5.8 \end{cases}$$

$$N = \frac{1000}{\psi\beta} P(D)\xi\left(1 - e^{-\frac{\psi\beta t}{1000\xi}}\right)$$

Derivation of model formula

$$\frac{dN}{dt} = P - \lambda \cdot N$$

$$\frac{dN}{dt} = P\left(1 - \frac{\lambda}{P} \cdot N\right)$$

$$\frac{dN}{\left(1 - \frac{\lambda}{P} \cdot N\right)} = P \cdot dt$$

$$\int \frac{\left(-\frac{P}{\lambda} \cdot d\Gamma\right)}{\Gamma} = \int P \cdot dt \ ;$$

$$\Gamma = 1 - \frac{\lambda}{P} \cdot N \ , \ d\Gamma = -\frac{\lambda}{P} \cdot dN$$

$$-\frac{P}{\lambda} \cdot ln(\Gamma) = P \cdot t$$

$$ln\left(1 - \frac{\lambda}{P} \cdot N\right) = -\lambda \cdot t$$

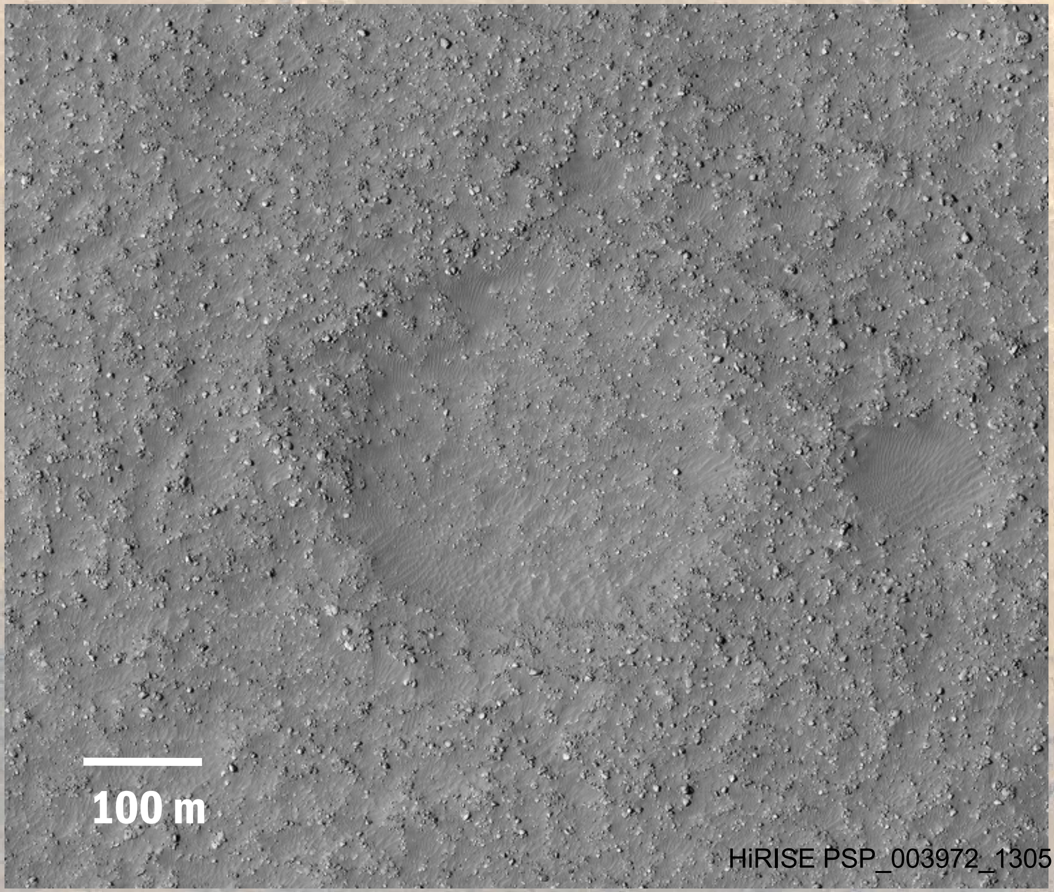
$$e^{-\lambda \cdot t} = 1 - \frac{\lambda}{P} \cdot N$$

$$N = \frac{P}{\lambda} \cdot \left(1 - e^{-\lambda \cdot t}\right)$$

Crater degradation

Mid-Latitude Crater in Noachis Terra (14.5E, 49.2S)

- Crater floor fills with wind-blown fines and boulders falling from rim
- Rim and ejecta blanket are largely lost to erosion
- Crater rim becomes dissected and rounded as material sheds onto floor

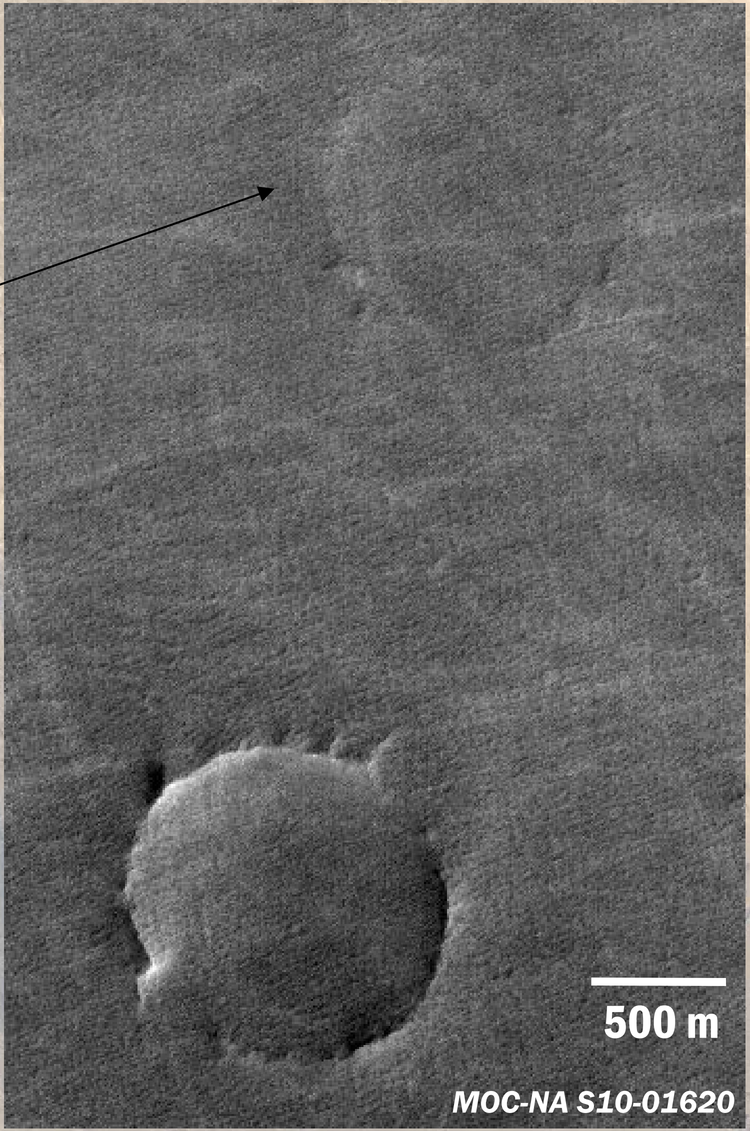


HiRISE PSP_003972_1305

Crater degradation

Syria Planum (269W, 32.47S)

Crater near detection limit has no visible contrast with surrounding material



MOC-NA S10-01620

Crater degradation

Protei Regio (south of Capri Chasma) (53.85W, 19.34S)

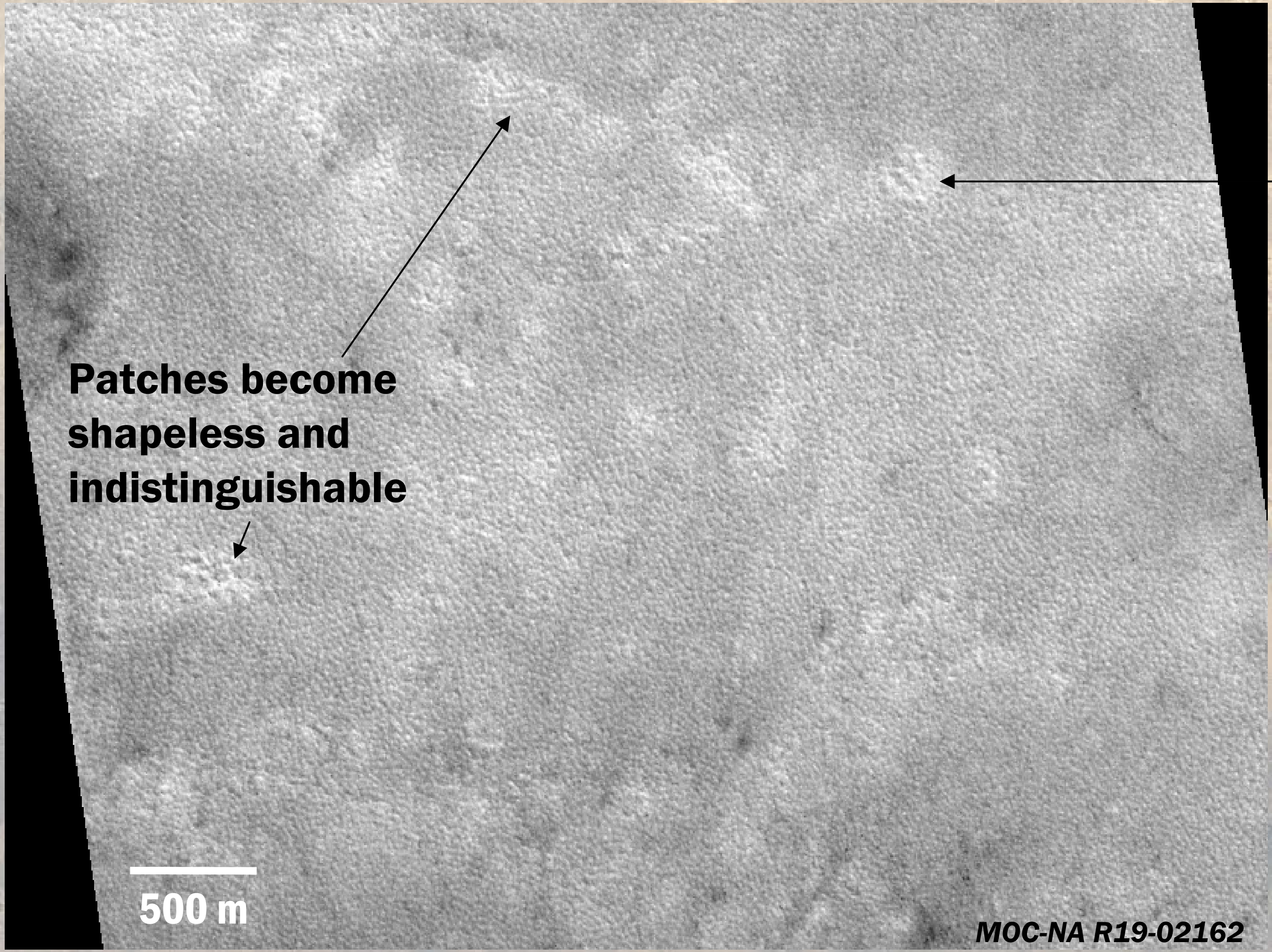
Craters in varying degrees of degradation; no circular forms without topographic expression

Crater degradation

MOC2-962

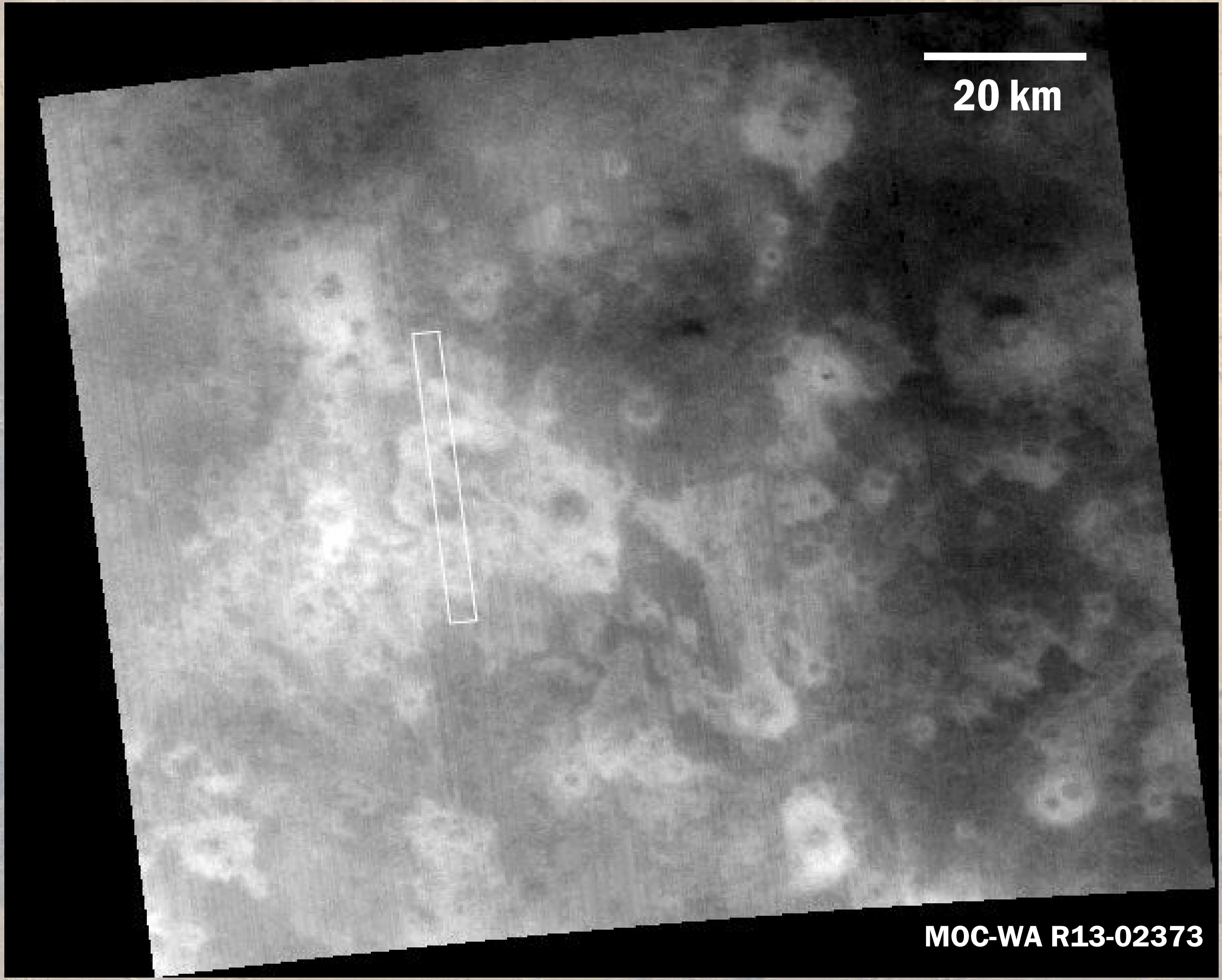
Pedestal Craters

Crater degradation

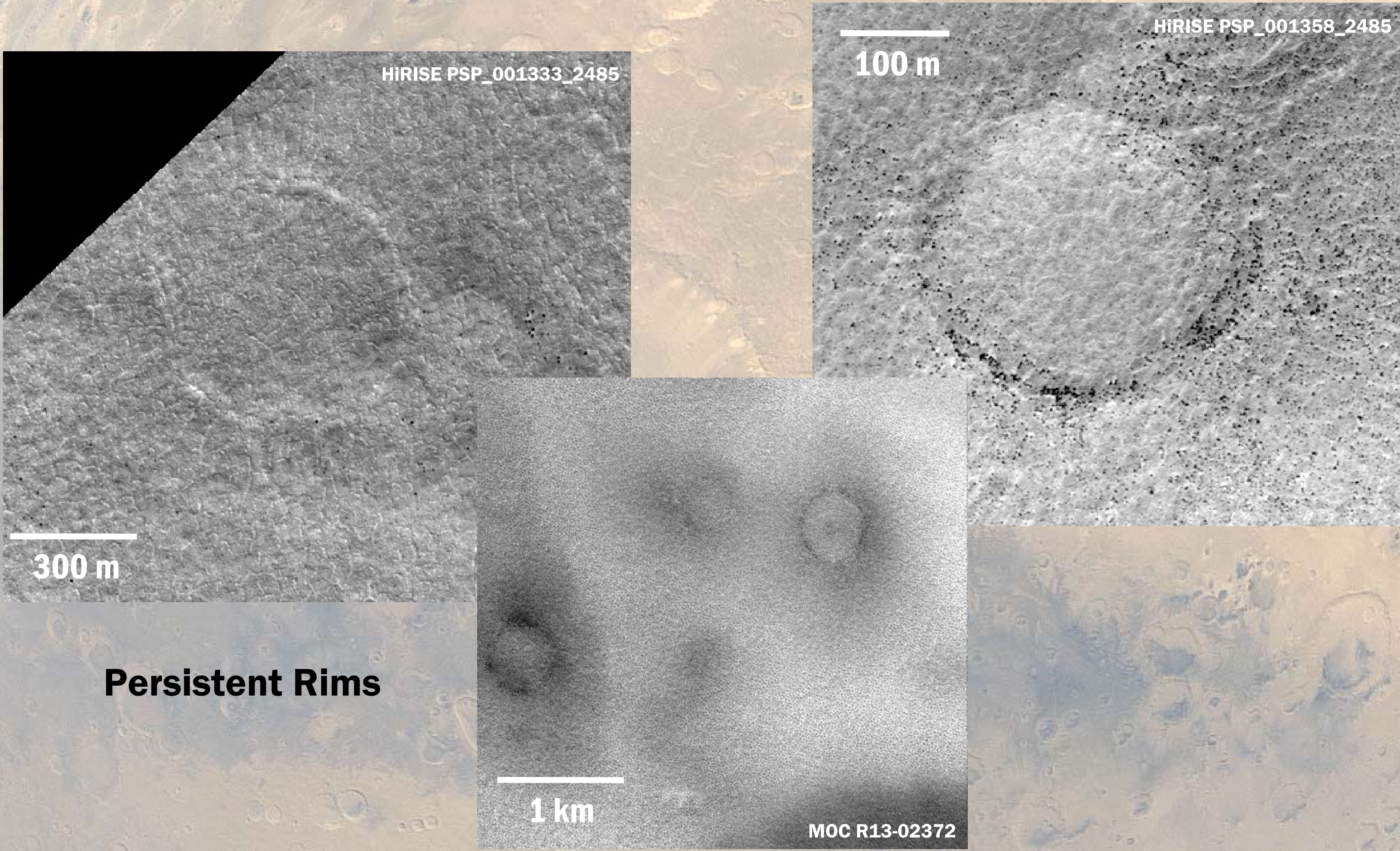


Northern Plains (246.96W, 61.5N)

Crater degradation



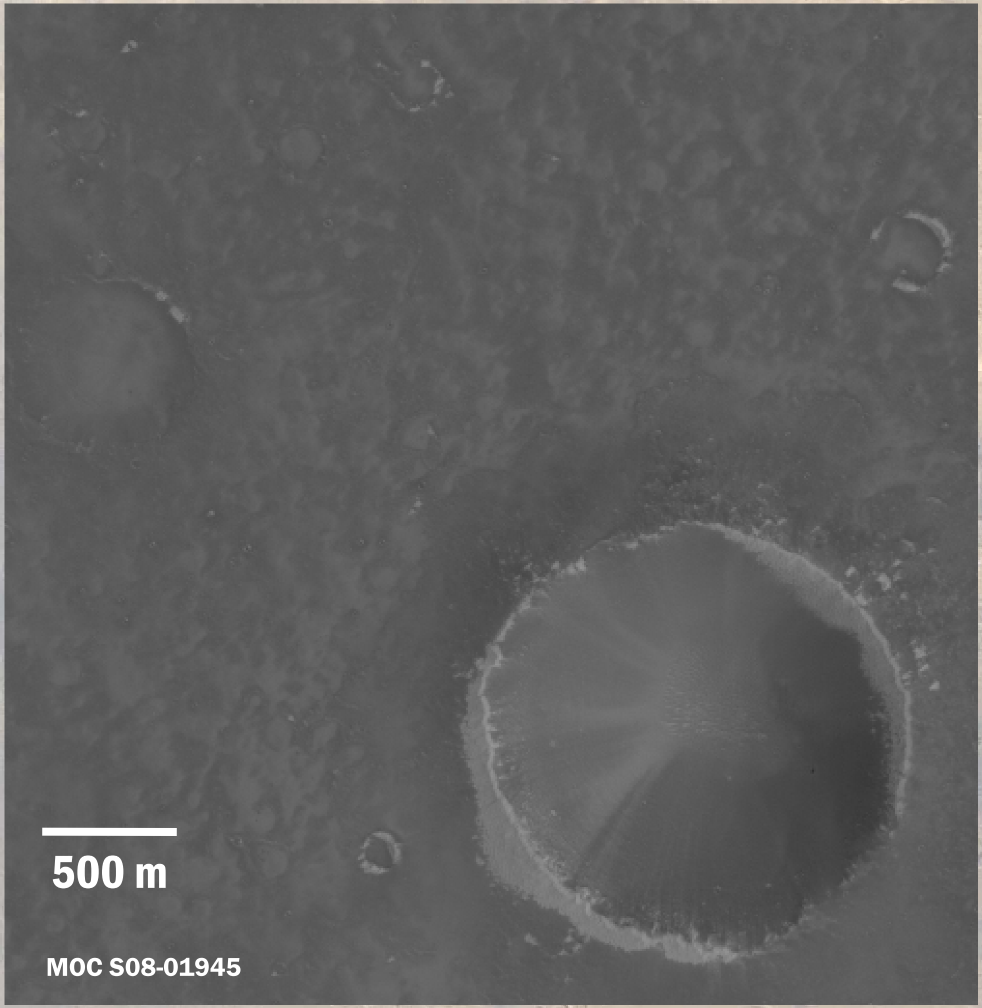
Crater degradation



Persistent Rims

Crater degradation

S of Noctis Labyrinthus (95.57W, 15.44S)



- Crater rim composition is visibly different and emphasizes craters for identification
- Degradation removes light-colored rim and lessens contrast
- Light-colored rim rock combines to make a lighter crater fill
- Some vaguely circular light – toned patches in plains, but mostly irregular and difficult to count

Production rate assumption

- Constant production rate
  - Positive factor of error 1.6
  - Falls within error of HPF (Factor of 2-3 introduced by R_{bolide})