AAPG Search and Discovery Article #90172 © CSPG/CSEG/CWLS GeoConvention 2010, Calgary, Alberta, Canada, May 10-14, 2010

Chronologic Surface: A New Method for Dating Martian Landforms

Radu Dan Capitan
Centre for Planetary Sciences and Exploration, The University of Western Ontario, London Ontario, Canada
rcapitan@uwo.ca

Gordon R. Osinski

Centre for Planetary Sciences and Exploration, The University of Western Ontario, London Ontario, Canada
gosinski@uwo.ca

and

Marco Van de Wiel

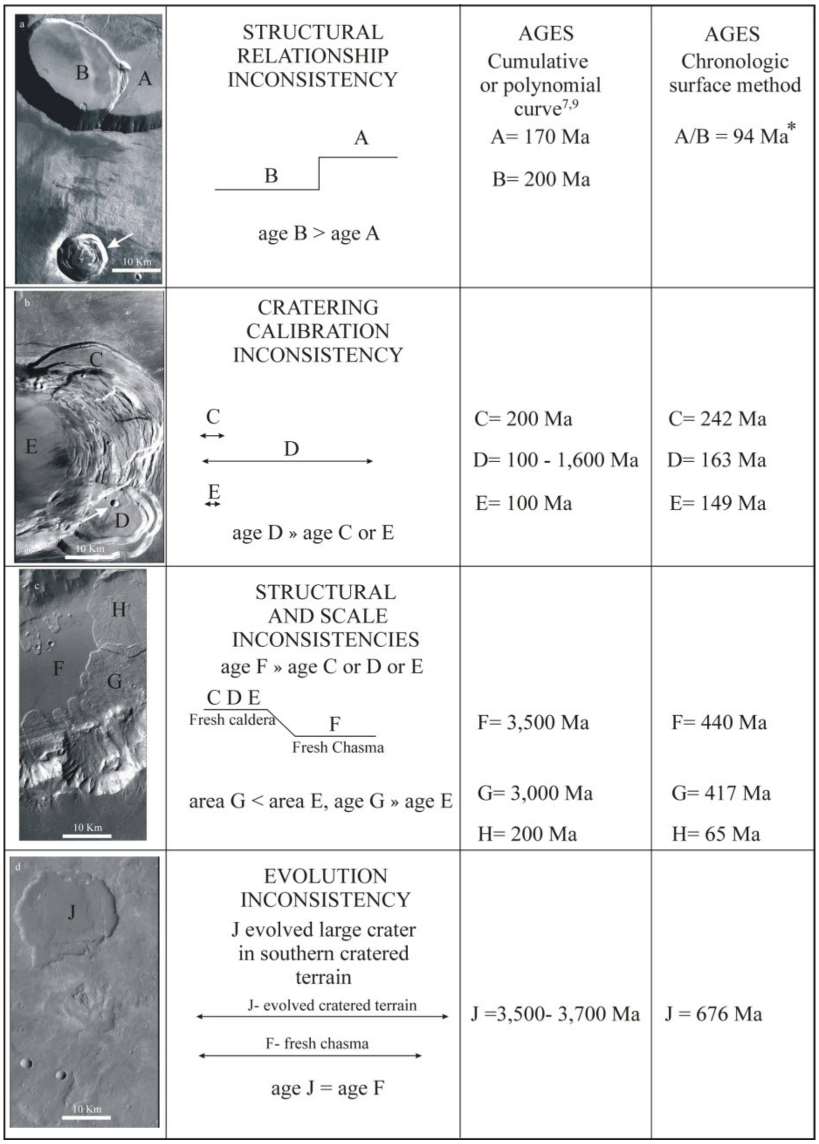
Department of Geography, The University of Western Ontario, London Ontario, Canada
mvandew3@uwo.ca

Summary

One of the most fundamental requirements for our understanding of planetary bodies is the ability to date geological surfaces or events. Except for small areas of the Moon – where *in situ* samples were collected during the Apollo and Luna missions – dating of planetary surfaces relies on crater counting. However, absolute dating of the Martian surface using crater counting techniques results in large uncertainties particularly when it is applied to small areas. This is due mainly to the difficulty to translate the lunar dating system to the Martian counterpart. Here, we show that ages can be determined using crater morphometrical characteristics and their accumulation on landforms- the chronologic surface technique. Our new method assumes that each crater has a spatial and temporal contribution to the determination of ages and, therefore, as craters accumulate and age, they describe a continuous evolution of the Martian surface up to present-day. We suggest that this technique provides a more accurate determination of the age of surfaces on Mars and, as such, has the potential to provide a new framework upon which interpretations of Mars' past geological and environmental history can be revisited.

Introduction

Several examples of the difficulty in assigning absolute ages to different areas of the Martian surface are presented in the literature[1,2]. Absolute age determinations for Mars are more difficult to determine than on the Moon, due to differences between the cratering rates between the two bodies[3], the difficulty of tracing homogenous geological sequences that are used as counting areas[4], and the lack of samples or meteorites from known geological deposits[5]. Major issues in dating the Martian surface are presented in Figure 1.



a	STRUCTURAL RELATIONSHIP INCONSISTENCY A B age B > age A	AGES Cumulative or polynomial curve[7,9] A= 170 Ma B= 200 Ma	AGES Chronologic surface method A/B = 94 Ma*
b	CRATERING CALIBRATION INCONSISTENCY C D E age D » age C or E	C= 200 Ma D= 100 - 1,600 Ma E= 100 Ma	C= 242 Ma D= 163 Ma E= 149 Ma
c	STRUCTURAL AND SCALE INCONSISTENCIES age F » age C or D or E C D E Fresh caldera F Fresh Chasma area G < area E, age G » age E	F= 3,500 Ma G= 3,000 Ma H= 200 Ma	F= 440 Ma G= 417 Ma H= 65 Ma
d	EVOLUTION INCONSISTENCY J evolved large crater in southern cratered terrain J- evolved cratered terrain F- fresh chasma age J = age F	J =3,500- 3,700 Ma	J = 676 Ma

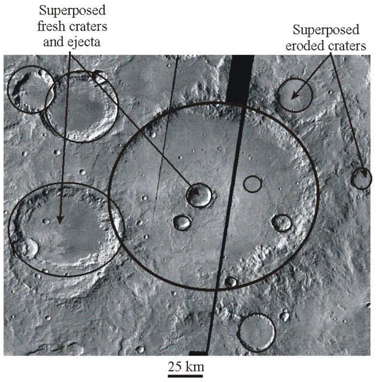
Figure 1 Dating Martian surface results and related inconsistencies (a) Olympus Mons calderas dated using Neukum's polynomial curves (CTX image P07_003621_1980 P10_005032_1980 (b) Ascraeus Mons calderas dated using Neukum's polynomial curve (CTX image P01_001378_1914) (c) landslides on Ganges chasma using Hartmann's crater production function (CTX image P01_001389_1719) (d) intercrater depression in northern Gorgonum area using Hartmann's crater production function and Tanaka's geologic map (CTX image B06_011903_1466). * Data not available at HRSC resolution for Olympus Mons caldera. Age for both calderas is calculated at MOLA resolution. Last column represents ages calculated using the present chronologic surface method.

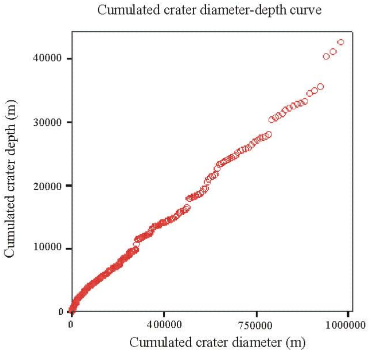
Theory and/or Method

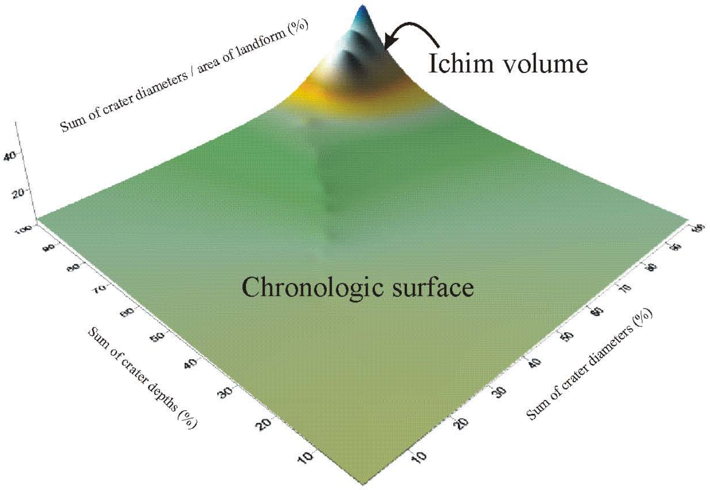
Considering that the four major issues of Martian age calculation presented in this presentation have major consequences for the evaluation of time, we proceeded to assess age as a relationship between crater accumulation and evolution "imprints". Our new method implies that age can be reconstructed from the spatial manifestation of cratering events relative to a finite area of crater accumulation, combined with evolution signature imprinted in the aspect of craters (i.e., crater diameter to crater depth relationship). The result is a three-dimensional space in which all three variables that describe evolution are considered: craters' magnitudes, craters' depths and craters' areal accumulation (see Box 1).

Box 1. Chronologic surface calculation and age evaluation

Visualization of chronologic surface is shown below. Within a landform area craters accumulate and evolve (THEMIS mosaic image). The first component of the method is represented by the relationship between crater diameters and depths (graph).







The sum of crater diameters represents the total magnitude of the cratering events (x axis). The sum of crater depths reflects the morphologic work to shape craters from the moment of their formation (y axis). The sum of craters diameter and depths are plotted from 100% (the beginning of the cratering events) to less than 1 (the most recent event recorded in the Martian topography). The second component of the method refers to the spatial accumulation of the cratering events within a landform area. Each crater that superposes on the Martian surface creates a space of crater manifestation[6]. Each impact event recorded on x-y axes is displaced into the 3rd dimension (z axis) with a percent of crater areal coverage within the landform area. Consequently, the space of crater accumulation evolves continually and increases with each impact with the combined signature of crater diameter and depth. The surface of this 3D relationship, referred to here as the chronologic surface integrates the geomorphic work of creating and shaping craters into an areal expression of crater manifestation, thereby describing the evolution of the cratering events (within a confined area of a landform). Thus, in geomorphic terms, the evolution is described as:

Evolution = Sum of crater magnitudes x Sum of geomorphic work x Areal coverage x Scale factor [1]

The volume underneath the chronologic surface increases accordingly with each crater signature (Ichim volume). This volume is calculated relative to the x-y base that represents no cratering events and beginning of cratering evolution following the formula:

$$\text{Ichim volume} = \sum_{Kx=1}^{100} D \times \sum_{Ky=1}^{100} h \times \int_{Kz=1}^{n} \frac{\Pi R^2}{A_L} dz \times \sqrt{\bar{x}^2+\bar{y}^2+\bar{z}^2} \quad [2]$$

Calibration of the volume is necessary to evaluate the age of different landforms. The calibration is achieved by applying the method to the Hellas impact basin which is the oldest unambiguously preserved crater on Mars[10]. Therefore,

Age landform = Age Hellas x (Ichim volume feature / Ichim volume Hellas) [3]

Examples

We applied the method to the same areas presented in Figure 1, and to regional scale morphologies in southern hemisphere in Atlantis and Gorgonum area[6]. The new method of age evaluation enables a high resolution dating of surface terrains at a regional scale of analysis. Comparison between the chrono-stratigraphic[8] and chronologic surface dating reveals significant differences in age evaluation (Figure 4 b and c). In the first case, the evolution of stratigraphic structures is seen only within late Noachian- early Hesperian eras. The new method of dating suggests that there was a continuous evolution of the planetary surface in this region that propagates throughout the entire Martian history (Figure 2).

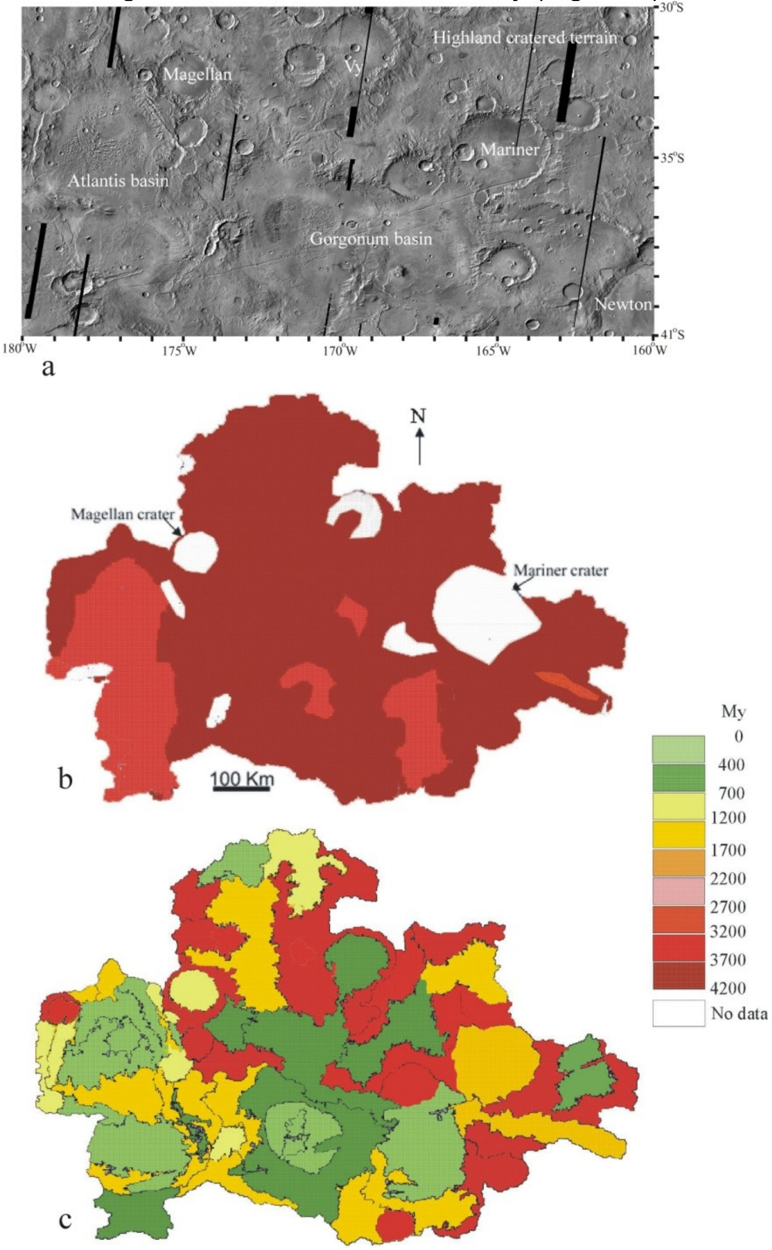


Figure 2. (a) Location of Atlantis and Gorgonum basins (b) Ages derived for chrono-stratigraphic deposits (after the geologic map of Scott and Tanaka 1986) vs. ages derived by using the chronologic surface method in Gorgonum and Atlantis basins (c).

Conclusions

The proposed method of age determination does not make reference to the lunar counterpart because of the evolution differences between the two planetary bodies. Ages of the Martian surfaces refer to specific descriptors of the Martian craters that have direct implications on their evolution. An important consequence is that the method describes a more recent evolution of the upper part of highland cratered terrains in Atlantis and Gorgonum area. We present these cases of dating the southern highlands and volcanic provinces to demonstrate the potential implications of this new age dating technique for the entire Martian surface. We also note that this method is an initial step in refining the ages of more extended surface morphologies on Mars.

Acknowledgements

The Ichim surface is named in honor of my former Professor of Geomorphology from “Alexandru Ioan Cuza” University, who suffered a brain stroke in 1996 and died in 2007. Professor Ionita Ichim supervised my research in cuesta geomorphology and had been my mentor during my bachelor thesis preparation.

Thank you for accepting an abstract to the GeoCanada2010 Convention.

References

1. Malin, M. C., Edgett, K. S., Posiolova, L., McColley, V., Shawn, M. Dobrea, N., Eldar, Z. 2006. Present-day impact cratering rate and contemporary gully activity on Mars. *Science*, **314**. DOI: 10.1126/science.1135156.

2. Hartmann, W. K. 2005. Martian cratering 8: Isochron refinement and the chronology of Mars. *Icarus*, **174**, pp. 294-320.

3. Ivanov, B. A. 2001. Mars/Moon cratering rate ratio estimates, *Space Science Reviews,* **96**, 1-4, DOI 10.1023/A:1011941121102, pp. 87-104.

4. Wilhelms, D. E. Geologic mapping., in Planetary Mapping, ed. by R Greeley and R. M. Batson, New York Cambridge Univ. Press., pp. 208-260, 1990.

5. Head J.W., Greeley R., Golombek M.P., Hartmann W.K., Hauber E., Jaumann R., P. Masson P., Neukum G., Nyquist L.E. and Carr M.H. 2001. Geological processes and Evolution, *Space Science Reviews,* **96, pp.** 263-292.

6. Capitan, Radu-Dan. 2009. Planetary morphology study of landforms in Gorgonum and Atlantis basins, Mars., London, Ontario : Ph.D. Thesis, Faculty of Graduate and Postgraduate Studies, University of Western Ontario

7. Neukum G., et al. 2004. Recent and episodic volcanic and glacial activity on Mars revealed by the High Resolution Stereo Camera. *Nature*, **432**, pp.971-979.

8. Scott, D. H. and Tanaka, K. L. 1986. Geologic map of the western equatorial region of Mars, U.S. Geol. Surv. Misc. Invest. Ser. Map, I-1802-A, 1:15,000,000.

9. Quantin C., Allemand P., Mangold N., Delacourt C. Ages of Valles Marineris (Mars) landslides and implications for canyon history, *Icarus,* **172,** 555-572, 2004

10. Frey H.V. 2006. Impact constraints on, and a chronology for, major events in early Mars history, *J. Geophys. Res.* **111**, E08S91, doi:10.1029/2005JE002449.