

CALL FOR TESTING THE THEORETICAL EFFECTS OF CLIMATE ON THE FLOW AND DISCHARGE OF GROUNDWATER ON MARS THROUGH LABORATORY EXPERIMENTS. J. M. Goldspiel U.S. Naval Research Laboratory, Code 7644, 4555 Overlook Ave. SW, Washington, DC 20375, USA (goldspiel@nrl.navy.mil).

Introduction: Early in the Mars Global Surveyor (MGS) mission, high-resolution Mars Orbiter Camera (MOC) images revealed erosion gullies in impact craters, major valleys and south polar pits (Malin and Edgett 2000). Like the small valleys seen by the Viking orbiters in the ancient southern highlands of Mars, the gullies were quickly recognized as important features with potentially major implications for the history of the martian climate.

In the case of the small valleys, the discussion of formation mechanisms mostly converges on two leading theories: erosion associated with groundwater discharge (sapping) (Sharp and Malin 1975, Pieri 1980, Howard et al. 1988) and erosion associated with precipitation and surface runoff (Craddock and Howard 2002). As has been discussed in the context of valleys on volcano slopes, sapping and surface runoff need not be mutually exclusive (Gulick and Baker 1989, 1990).

For the more recently discovered gullies, different theories for the processes responsible have been advanced as well. As with the small valleys, groundwater sapping is one of the leading theories for the formation of the gullies (Malin and Edgett 2000, Heldmann and Mellon 2004, Marquez *et al.* 2005, Heldmann *et al.* 2007). While details of the erosion process varies in the different models, most alternative explanations for the origin of these small geologic features invoke erosion through subaerial deposition of atmospheric condensates (Lee *et al.* 2001, Gilmore and Phillips 2002, Hecht 2002, Christensen 2003, Balme *et al.* 2006, Lee *et al.* 2006, Dickson *et al.* 2007).

Question of Climate Control: Because liquid water is thermodynamically unstable on the surface of Mars today given the current cold, dry and thin atmosphere, the past and present atmospheric conditions on Mars factor directly into the discussion of the small valleys and gullies. In the context of groundwater origins, however, climate is not the only consideration. If many or even most of the gullies and small valleys formed by groundwater sapping, or by mass wasting aided by groundwater seepage (Carr 1995), then geothermal heat may also have been important for the formation of these features (Gulick and Baker 1989, 1990, Gulick 1998, Goldspiel and Squyres 2000).

Important to understanding the large issues of regional hydrology and global climate history on Mars is understanding whether these features are remnants of a martian climate that was warmer in the past (Sagan et al. 1973, Pollack 1979), products of regional climate variations (Gulick and Baker 1989, 1990), or whether they were produced free from any climate control. In judging the importance of climate control, it is important to consider the thermal environments not just above the surface but below the surface as well, and to understand how the near-surface thermal environment regulates the groundwater flow and corresponding erosion mechanisms.

Groundwater Modeling: In the context of a groundwater discharge origin, the vertical location of gullies seen on valley, crater and polar pit slopes in MGS MOC images suggest that liquid water flowed within a few hundred meters of the surface (Malin and Edgett 2000, Heldmann and Mellon 2004). With the further inference of young gully ages, the images also suggest that the water flows may have occurred relatively recently (Malin and Edgett 2000 Mellon and Phillips 2001).

Previous numerical simulations of groundwater sapping indicate that the link between valley formation and a warmer early martian climate is not necessarily strong (Gulick 1998, Goldspiel

and Squyres 2000). The recent imaging and implied young age of gullies on crater walls and other slopes would seem to support the conclusion of this earlier modeling (Malin and Edgett 2000, Mellon and Phillips 2001, Malin *et al.* 2006). Preliminary results from more recent modeling that takes into account sloped sapping faces and arbitrary solar exposure azimuths come to similar conclusions (Goldspiel and Squyres 2007).

Laboratory Testing: Numerical modeling of groundwater flow constrained by orbital and surface measurements provides a convenient means to test various climate history hypotheses. Numerical modeling can also be useful in determining the locations on Mars most likely to yield the most valuable samples for return to Earth for detailed analyses. Numerical models, however, must be tested to be fully useful.

Since the original work of Darcy (1856), several laboratory and field experiments have been developed to test the accuracy and applicability of various groundwater flow models (Rowe 1960, Howard *et al.* 1988). Laboratory experiments have also been conducted to test models of evaporation under current martian conditions (Hecht 2002). These studies provide important results for validation of components of groundwater flow and discharge models.

What seems to be missing, however, are controlled experiments that simultaneously simulate groundwater flow and current environmental conditions at the surface of Mars. Laboratory experiments that can simulate both surface and subsurface environmental conditions would provide a relatively inexpensive and valuable test bed for numerical models of surface and subsurface processes, including the discharge of groundwater under conditions like those found on Mars today.

There is no substitute for direct analyses of surface and subsurface materials on Mars. Numerical models, however, will still be necessary to explore climate-related hypotheses even while in-situ analyses of martian materials hopefully become more common and more capable. The more these models can be tested against laboratory simulations of complex surface, subsurface and atmosphere interactions, the more useful these models will be.

References:

- Balme, M., N. Mangold, D. Baratoux, F. Costard, M. Gosselin, P. Masson, P. Pinet, and G. Neukum (2006) *J. Geophys. Res.* 111, E05001.
- Carr, M.H. (1995) *J. Geophys. Res.* 100, 7479-7507.
- Christensen, P.R. (2003), *Nature*, 422, 45-48.
- Craddock, R.A. and A.D. Howard (2002), *J. Geophys. Res.* 107, doi:10.1029/2001JE001505.
- Darcy, H. (1856). *Les fontaines publiques de la ville de Dijon*. Paris: Dalmont.
- Dickson, J.L., J.W. Head, and M. Kreslavsky (2007), *Icarus*, 188, 315-323.
- Gilmore, M.S. and E.L. Phillips (2002), *Geology*, 30, 1107-1110.
- Goldspiel, J.M. and S.W. Squyres (2000) *Icarus* 148, 176-192.
- Goldspiel, J.M. and S.W. Squyres (2007) *Lunar Planet. Sci.* XXXVIII, abstract 1598.
- Gulick, V.C. and V.R. Baker (1989) *Nature*. 341, 514-516.
- Gulick, V.C. and V.R. Baker (1990) *J. Geophys. Res.* 95, 14,325-14,344.
- Gulick, V.C. (1998) *J. Geophys. Res.* 103, 19,365-19,387.
- Hecht, M.H. (2002), *Icarus*, 156, 373-386.
- Heldmann, J. L. and M. T. Mellon (2004) *Icarus* 168, 285-304.
- Lee, P., C.S. Cockell, M.M. Marinova, C.P. McKay, and J.W. Rice Jr. (2001), *Lunar Planet. Sci.*, XXXII, Abstract 1809.

- Lee, P., B.J. Glass, G.R. Osinski, J. Parnell, J.W. Schutt, and C.P. McKay (2006), *Lunar Planet. Sci.*, XXXVII, Abstract 1818.
- Heldmann, J.L., E. Carlsson, H. Johansson, M.T. Mellon, and O.B. Toon (2007), *Icarus*, 188, 324-344.
- Howard, A. D., R.C. Kochel, and H.E. Holt (Eds.) (1988) NASA SP-491.
- Malin, M. C. and K. S. Edgett (2000) *Science* 288, 2330-2335.
- Malin, M.C., K.S. Edgett, L.V. Posiolova, S.M. McColley, and E.Z. Noe Dobrea (2006) *Science* 314, 1573-1577.
- Marquez, A., M.A. de Pablo, R. Oyarzun, and C. Viedma (2005), *Icarus*, 179, 398-414.
- Mellon, M. T. and R. J. Phillips (2001) *J. Geophys. Res.* 106, 23,165-23,179.
- Pieri, D. C. (1980) *Science* 210, 895-897.
- Pollack, J.B. (1979) *Icarus* 37, 479-553.
- Rowe, P.P. (1960) *J. Geophys. Res.* 65, 3419-3424.
- Sagan, C., O.B. Toon, and P.J. Gierasch (1973) *Science* 181, 1045-1049.
- Sharp, R. P. and M. C. Malin (1975) *Geol. Soc. Am. Bull.* 86, 593-609.

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