EXPLORING MARTIAN IMPACT CRATERS: WHY THEY ARE IMPORTANT FOR THE SEARCH FOR LIFE.

S. P. Schwenzer[1,7], O. Abramov[2], C. C. Allen[3], S. Clifford[1], J. Filiberto[1,4], D. A. Kring[1], J Lasue[1,5], P. J. McGovern[1], H. E. Newsom[6], A.H. Treiman[1], D. T. Vaniman[5], R. C. Wiens[5], A. Wittmann[1]. [1]Lunar and Planetary Institute, Houston TX 77058, USA; *clifford@lpi.usra.edu*; *kring@lpi.usra.edu*; *lasue@lpi.usra.edu*; *mcgovern@lpi.usra.edu*; *treiman@lpi.usra.edu*; *wittmann@lpi.usra.edu*. [2]University of Colorado, Boulder, CO 80309, USA; *Oleg.Abramov@Colorado.edu*. [3]Johnson Space Center, Houston, TX, 77058, USA; *carlton.c.allen@nasa.gov*. [4]Rice University, Houston Texas 77005, USA; *Justin.Filiberto@rice.edu*. [5]Los Alamos National Laboratory, Los Alamos, NM 87545, USA, *vaniman@lanl.gov*; *rwiens@lanl.gov*. [6]University of New Mexico, Albuquerque NM 87131, USA; *newsom@unm.edu*. [7]The Open University, Earth and Environmental Sciences, Walton Hall, Milton Keynes, MK7 6AA, UK; *s.p.schwenzer@open.ac.uk*.

Summary: Fluvial features and evidence for aqueous alteration indicate that Mars was wet, at least partially and/or periodically, in the Noachian. Also, impact cratering appears to have been the dominant geological process [1] during that epoch. Thus, investigation of Noachian craters will further our understanding of this geologic process, its effects on the water-bearing Martian crust, and any life that may have been present at the time. Impact events disturbed and heated the water- and/or ice-bearing crust, likely initiated long-lived hydrothermal systems [2-4], and formed crater lakes [5], creating environments suitable for life [6]. Thus, Noachian impact craters are particularly important exploration targets because they provide a window into warm, water-rich environments of the past which were possibly conducive to life. In addition to the presence of lake deposits, assessment of the presence of hydrothermal deposits in the walls, floors and uplifts of craters is important in the search for life on Mars.

Impact craters are also important for astrobiological exploration in other ways. For example, smaller craters can be used as natural excavation pits, and so can provide information and samples that would otherwise be inaccessible (e.g., [7]). In addition, larger (> ~75 km) craters can excavate material from a potentially habitable region, even on present-day Mars, located beneath a >5-km deep cryosphere.

Hydrologic aspects: For habitable conditions, one key aspect is the availability of water. Valley networks [e.g., 8], rampart craters [9], and hydrous minerals [e.g., 10,11] are the most important evidence for a water rich environment and crust in the Noachian. If the early Noachian did start out warm and wet, theoretical models of atmospheric evolution suggest that such conditions did not persist beyond the end of heavy bombardment [8,12]. With the transition to a colder climate, a freezing front developed in the planet's crust, creating a growing cold-trap for both atmospheric and subsurface H_2O – a region known as the cryosphere. Models show that the depth of the present-day cryosphere may vary from 0-9 km near the equator to as much as ~10-22 km near the poles [13,14]. Below the cryosphere, a briny aquifer may persist, which may provide a hydraulic connection between long-lived geothermal environments associated with volcanoes, igneous intrusions, and episodic impacts.

Post-impact mineralogy: Models of the post-impact cooling of large impact craters [4] indicate that the temperature of the central region of a 100-km diameter crater is initially up to 900 °C, melting ice and extracting water from minerals. With time, a hydrothermal system evolves that shows the most intense and longest activity between 300 and 100 °C. Temperatures decline with the isotherms moving inwards and downwards over about 300,000 years [4]. The change in temperature and water flow disturbs the thermochemical state of the pre-impact stratigraphy, causing alteration minerals to form. The main hydrous silicates expected to form from Martian rock chemistry at intermediate (150 °C) temperatures are chlorite, smectite (Mg-nontronite) and serpentine [15]. All the above results are obtained from models, but are also supported by observations at terrestrial craters.

Ground truth on Earth and Mars: On Earth, there are a few large impact structures that have been studied for their post-impact alteration. Two prominent examples are Sudbury and Chicxulub, for which post-impact hydrothermal hydrology was calculated using the same model that was applied to the Martian case [16,17]. Mineralogical information for both craters comes from detailed investigations (e.g., Chicxulub [18-20], and Sudbury [21]). In both cases, diverse hydrothermal mineral assemblages are observed that display successions from high to lower temperatures. Transferring this knowledge to Mars is not straightforward at this point in exploration, because the information obtained from Mars is not at the same level of detail as that for the Earth. However, several discoveries of hydrous silicates, especially nontronite and chlorite in central peaks and terrace zones of complex Noachian craters on Mars point to the potential of finding fossil hydrothermal systems and their alteration products in those craters. Currently, the best examples come from a ~40 km diameter crater in Nili Fossae (17°N, 72°E), which exposes a plagioclase-pyroxene rock containing ~15% smectite and ~20% pumpellyite [22], a 25 km crater west of Nili Fossae (20°N, 66°E), where analcime and chlorite/smectite have been found in the central uplift [11], and a ~60 km diameter crater in Cimmeria Terra (32°S, 141°E), where chlorite and either Al-clay or another hydrous silicate have been detected in the central uplift [23].

Impact craters and life: All craters with phyllosilicates in their central peaks are in Noachian terrains, when water was more abundant and the impact frequency was also very high during the Late Heavy Bombardment (e.g., [24]). The largest impacts may have sterilized Mars' surface, as is inferred for Earth (e.g., [25]). However, at the same time, these impacts may have created an abundance of surface and subsurface habitats. For example, impact crater lakes (e.g., [5,26,27,28]), and impact-induced hydrothermal systems (e.g., [2,29]), driven by impact-deposited heat, may have provided an incubator for organisms able to thrive in hot subsurface hydrothermal fluids [30,31]. Furthermore, while post-impact hydrothermal systems in different craters were independent from each other, connection of the individual sites to a regional or global deep aquifer may be critical for the emergence of life, especially if the surface is very cold.

Exploring impact craters for biomarkers: The Martian crust appears to be lithologically and structurally complex, based on our orbital views of chasms and impact-excavated strata. These impact-excavated strata would allow a lander access to deep-seated rocks, far deeper than any realistic proposed drill system. The excavation depth of a crater is approximately one tenth of the transient crater diameter [32], or approximately one fifteenth to one twentieth of the final crater diamter. Thus, craters as small as 75 km in diameter can excavate material from a depth of 5 kilometers; this is deep enough to access subsurface aquifers, such as might contain signs of current or ancient biological activity.

Gale crater and MSL. To illustrate the value of impact craters, one can consider the ~150 km Gale crater in Elysium Planitia (4.49°S, 137.42°E), one of the proposed landing sites for Mars Science Laboratory (MSL). Gale has a complex history that starts with the impact and its aftermath, and is followed by sedimentation and erosion, including one or more crater lakes [26,33,34]. Small craters pepper all zones of the crater, including its ejecta, terraces, floor and central peak; together, these craters must expose pre-impact target rocks, impact deposits, and post-impact sediments [13]. At Gale, the suite of instruments on the MSL could investigate any or all of these types of craters and the materials they have ejected. Those instruments include the Mars Descent Imager to map the projected driving path upon landing, and the imaging and analysis suite on MSL's mast, which can operate from a distance. Finally, small craters and their ejecta can be targets for detailed chemical and mineralogical analysis. Each site will most likely display a variety of rocks. For example, a crater punched into crater floor material could have excavated lake sediments and melt sheet material.

In conclusion, each small crater at Gale will provide multiple strata that could have preserved evidence for hydrothermal and aqueous activity, fossil habitats and their potential inhabitants. Discoveries made at these individual sites would in turn improve our understanding of impact craters as potential windows into past habitable environments, as well as Mars as a geologic, hydrologic, and potentially ecologic system.

References: [1] Hartmann W.K., Neukum G. (2001) *Space Sci. Rev.,* 96, 165–194. [2] Newsom H.E. (1980) *Icarus,* 44, 207–216. [3] Newsom H.E. et al. (2001) *Astrobiology* 1, 71–88. [4] Abramov O., Kring D.A. (2005) *J. Geophys. Res. 110,* doi: 10.1029/2005JE002453. [5] Newsom H.E. et al. (1996) *J. Geophys. Res.*, 101, 14,951–14,955. [6] Kring D.A. (2000) *GSA today 10(8)*, 1–7. [7] Moore H.J. (1977) *J. Research U.S. Geol. Survey*, 5 (6), 719–733. [8] Carr M.H. (1999) *J. Geophys. Res.* 104, 21897-21909. [9] Reiss D. et al. (2006) *MAPS* 41, 1437–1452. [10] Bibring J.-P. et al. (2005) *Science* 307, 1576–1581. [11] Ehlmann B. L. et al. (2009) *J. Geophys. Res.* 114, doi: 10.1029/2009JE003339. [12] Haberle R. M. et al. (1994) *Icarus* 109, 102–120. [13] Schwenzer, S.P. et al., in prep. for Icarus by the authors of this abstract. [14] Clifford et al. (2009) J. Geophys. Res., in press. [15] Schwenzer S.P., Kring. D.A. (2009) *Geology* 37, 1091–1094 [16] Abramov O., Kring D.A. (2004) *J. Geophys. Res.,* 109, doi: 10.1029/2003JE002213. [17] Abramov O., Kring D.A. (2007) *MAPS*, 42, 93–112. [18] Hecht L.et al. (2004) *MAPS,* 39: 1169–1186. [19] Zürcher L., Kring D.A. (2004) *MAPS*, 39: 1199–1221. [20] Zurcher L.et al. (2005) In: Kenkmann T. et al. Large Meteorite Impacts III, GSA Special Paper 384: 223–238 [21] Ames D.E.et al. (2006) In: C. Cockellet al. Biological Processes Associated with Impact Events, p. 55–100 [22] Poulet F. et al. (2008) *Icarus* 195, 106–130. [23] Wray J.J. et al. (2009) *Geology* 37, 1043–1046. [24] Strom R.G. et al. (2005) *Science* 309, 1847–1849. [25] Sleep N.H., Zahnle K. (1998) *J. Geophys. Res.* 103, 28529–28544. [26] Cabrol N.A. et al. (1999) *Icarus* 139, 235–245. [27] Newsom, H.E. in prep., In: Cabrol, N. (ed.): Lakes on Mars, in preparation; Cambridge Press. [28] Lindsay J. & Brasier M. (2006) Astrobiology 6, 348-363. [29] Zahnle K.J., Sleep N.H. (1997) In: Comets and the Origin and Evolution of Life, p. 175–208. [30] Maher K.A., Stevenson D.J. (1988) *Nature* 331, 612–614. [31] Chyba C.F. (1993) *Geochim. Cosmochim. Acta* 57, 3351–3358. [32] Melosh, H.J. (1989) Oxford University Press, 245 pp. [33] Malin M.C., Edgett, K.S. (2000) *Science* 290, 1927–1937. [34] Milliken, R.E. et al. (2009) *LPSC* XL, #1479.