RECENT AQUEOUS ENVIRONMENTS IN IMPACT CRATERS AND THE ASTROBIOLOGICAL EXPLORATION OF MARS.

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Introduction: Fresh gullies and debris aprons raise the question of the existence of aqueous environments on Mars in recent geological times and their astrobiological implications. Three cases of such environments are surveyed at MOC high-resolution in the *E-Gorgonum*, *Newton* and *Hale* craters. Their regional settings suggest that the mechanisms of aquifer destabilization, flow discharge, and gully formation in these three cases result from local geological triggers that can include impact cratering, and tectonic processes rather than climate or insolation factor. We take as a working hypothesis that life appeared on Mars in ancient geological times, managed to survive underground either in dormant or active state, and that biomolecules could be preserved in the subsurface. We assess the known environmental constraints for life and what type of potential habitats are provided in these three craters by sudden aquifer discharges using comparison with terrestrial analogs and their associated microbial communities. These environments include: the release of water on a dry crater floor in E-Gorgonum and the possibility for microorganisms and preserved biomolecules to be flushed out and mixed in with the sediment exposed at the surface; the evidence of a recent and prolonged lacustrine episode in the Newton crater with analogy to Antarctic Dry Valley lakes; and the exposure on the floor of Hale. Finally, we envision current impact cratering as a factor to destabilize aquifers on Mars today, thus generating new temporary environments. We analyze the implications of impacts of different sizes for two geological types of rock units that could harbor traces of life. As a result, we compare the potential and limitations of astrobiological exploration of crater floors, rims and ejecta on future missions to Mars.

1- East-Gorgonum*:* 37.4°S/36.50°W- Potential triggers of gully formation are located North and Northeast of the E-Gorgonum crater. The morphology of the gullies and crater shows that the drainage occurred in a dry crater floor. Two impact craters of 3 and 4 km in diameter and similar state of preservation are located respectively 8 and 18 km from E-Gorgonum. The energy delivered by impacts of this magnitude is sufficient to fracture and fluidize the frozen aquifer and put it underpressure. The direction of shock-wave propagation in the subsurface toward E-Gorgonum crater corresponds to the location of the gullies on the North and Northeast inner slopes. The drainage of the West slope can be explained by the presence of a fault that also provides an emergence level and drainage outlet for a fluidized aquifer. Both the orientation and the preservation of the gullies are consistent with this scenario, the only assumption being that the two craters were formed at the same time or within a very short interval. Their similar pristine morphology supports this assumption. Because the two craters are of relatively small diameters, potential hydrothermal processes sustained by the lenses of melt material would be reduced within a maximum of a few tens of thousands of years (Melosh 1996). Such contribution cannot be assessed currently as the available data does not include TES spectra. The discharge of shallow seepage channels into a dry crater would result in rapid evaporation and accumulation of evaporitic salts, possibly containing biomolecules and cells (if any) interspersed amongst salt crystals. To survive with functional integrity, flushed-out cellular structures and biomolecules would need to be halotolerant and would require the support of water-replacement molecules such as trehalose to sustain the tertiary structure of proteins (Potts 1994). Salts, lithosol crystals and the desiccated state would protect both biomolecules and cells so that evaporite aprons might be a potential source of biological material flushed from buried strata, but without any subsequent growth on the surface.

2- Newton- Located at 41.1°S, 159.8°W and nearly 550 km southeast of E-Gorgonum crater, the drainage of the a 7-km crater in the Newton crater basin may have an origin similar to the previous case but with a more complex ponding history. We found converging evidence for the presence in a recent past of a small ~7-km^2 lake at the bottom of the crater. The height of the northern layered lacustrine platform is consistent with the volumes of water suggested by Malin and Edgett (2000). The presence of the lake was likely related to the drainage of the gullies, although their final morphology is consistent with discharge on a dry floor. This apparent contradiction is explained if the lake had already receded towards the center of the crater floor when the last discharges occurred. Considering the volume of water implied, it would take between 5-10 years to freeze solid at a freezing rate of 5-10m/yr (Carr 1996). Sublimation rates are likely to be low because of the low temperatures on the surface of the ice, and because of the logarithmic dependence of the vapor pressure of water on temperature (Carr 1996). Assuming an ice sublimation rate of 0.01-0.1 cm yr^{-1} (Carr 1990), and no recharge, it would take between $5 \cdot 10^4$ to $5 \cdot 10^5$ years for the frozen lake to completely disappear. The long duration of water in Newton Crater would result in a typical ice-covered lake habitat as described for Epoch II of the McKay Mars hydrology model and analogous lakes in the Dry Valleys of Antarctica (McKay 1997, Wynn-Williams 1999). These present-day ice-capped often hypersaline lakes permit the penetration of solar radiation through the ice-cap and water column to warm the dense bottom water and sediments by trapping thermal energy. This enables shade-adapted halotolerant cyanobacteria to form a variety of stromatolitic communities (Wharton et al. 1994). Given time, these communities which can be over a meter thick could have developed in lakes such as Newton Crater on Mars (Wharton et al. 1995). However, they would have required and element of UV protection because the clarity of ice and the non-turbulent water column permits significant penetration of UV radiation to the lake bottom (Vincent et al. 1998). Nevertheless, on gradual desiccation, the ice-cap and water would have dissipated to leave an evaporite-encrusted stromatolitic lake bed containing the residues of photosynthetic bacteria and cyanobacteria and their fossil pigments (Overmann et al. 1993).

3- Hale Crater- 35.95°S and 36.78°W- the exposure on the floor of Hale crater of material from a regional subsurface which is likely to have retained traces of one of the oldest and largest martian bodies of water recognized to date (Parker et al., 2000) in the Argyre basin. We show how the waters of the Argyre sea (~3.8 Ga ago) were likely to have been hydrothermal and how the subsequent formation of the 150-km Hale on the outermost northern ring of Argyre generated more hydrothermal pumping. This potentially accounts for the anomalously high-location of the springs on the craters crests today with respect to the rest of the regional subsurface distribution.

4- Current and future impact cratering and the potential for generation of current environments for life. Impact craters provide favorable conditions in recent to current Mars for the development of temporary aqueous environments where traces of diversified ancient microbial communities could have been exposed in debris aprons, or dormant microorganisms re-activated following the generation of lakes, ponds and hydrothermal processes resulting from impacts. They also provide an access to deeper materials from ancient geological times that can contain fossil records by exposing them in their ejecta. Although recommended, the exploration of the ejecta is subjected to serious physical and dynamical contraints. To illustrate these constraints, we chose the cases of a salt and a carbonate as generic examples of biocompatible environments. However, these constraints must be reevaluated for each type of geological material in landing areas, as the Hugoniot Elastic Limit (HEL) can vary considerably from one material to another, often within similar mineralogical families. This reevaluation requires a good knowledge of the mineralogy of martian rocks and must be acquired at high-spectral resolution in potential landing sites. We must be aware that unshocked to lightly shocked rocks can be ejected at great distances from their point of origin by spalling processes and may be completely disconnected in time and geological history from the site where they are observed, potentially obscuring the reconstruction its geological and biological history.

6- Conclusion - We envisioned that geological triggers and regional setting could explain the formation of gullies *at least in the three cases surveyed*. Like the insolation hypothesis, the geophysical hypothesis also presents a set of paradoxes and a series of strong and weak arguments that will be discussed. For instance, the location of the gullies *always* between 30 and 70 degree of latitude in both hemispheres is a consistent trend. However, we do not believe that the geographic factor necessarily supports the past climate hypothesis more than the geological trigger hypothesis. If the gullies were generated during a former and more favorable climate period, they could be millions of years old. If geological events are responsible, they could still be forming today. The age of the gullies has implications for the potential preservation of traces of paleolife or even the survival of extant life. Not surprisingly, the latitudinal distribution of the gullies corresponds to the latitudes where the highest content of volatile is observed on Mars (Mouginis-Mark 1979, Kuzmin et al. 1988, Barlow 1988, Costard 1988). This zone is also where water/ice would be the more stable at shallower depth in the subsurface in current conditions (Paige 1992, Carr 1996). Therefore, assuming that two identical bolides would hit the surface of Mars today on similar geological material, one in the equatorial region of Mars and one in the highest latitudes, the latter would be more likely to destabilize a volatile-rich aquifer and generate a flow, while the former would also generate shock waves and quakes but in a desiccated substratum, which would not result in gully formation. The energy delivered by the impact could explain by itself the fracturation and fluidization of the aquifer and its emergence without the need to invoke additional heating from insolation. The orientation on the other hand seems to be a more complex argument that could be used to support the hypothesis of the gullies formed during an ancient favorable climate cycle. The solar thermal input provides an elegant way to explain why the gullies all show the same pristine morphology. The disadvantage is that, unless the hypersalinity of brines in the outflows is a major factor, its possible dependence on more favorable obliquity could push back their formation to hundreds of thousands or even millions of years in the past. This is at variance with their pristine morphology. Ice -or salt- cementation and/or a slow erosion rate could be advocated to defend a relative old age for the gullies. For instance, from the survival of craters at the VL-1 landing site, Arvidson et al. (1979) estimated that the erosion rates could not be more than $10^{-2}\mu$m yr^{-1}. Carr (1992) estimated that the total loss of internal relief in craters did not exceed 60 m during the past 3.8 Gyr, giving an erosion rate of $2 \cdot 10^{-2}\mu$m yr^{-1}. If the gullies are 10^6 years old, the total erosion should be of 1cm, therefore barely perceptible. If we pursue this argument, we could even consider that the gullies could be one billion years old and have only lost 10 m of their internal relief. While a very valid argument (assuming a constant rate of erosion through time), other observations recorded by MGS suggest that the gullies are not that old and could be recent or even current. Neither model (geological or solar) provides a completely satisfying explanation for the (possible) apparent lack of older gullies (Malin and Edgett 2000), although it must be considered that the high-resolution of MOC does not give total global coverage and evidence could yet be found If there really are actually no older gullies, this evidence could support either model. For instance, a one-time drainage associated to geological processes in regions of volatile-rich subsurface could explain the lack of older gullies locally. Although it can be argued that geological processes have been going on since the beginning of Mars history, only the younger gullies may have avoided erosion. A similar argument can be presented for seasonal changes and climate cycles. If the process is seasonal, varied stages of gully degradations should theoretically been observed. However, if the estimates of martian erosion rates are correct, and if all these features are less than 100 million years old, the removal of material would be insignificant and gullies separated in age by 1, 10, 100 or 1000 years in the same valley wall might be adjacent on orbital images without our being able to discriminate between them. The major flaw in this model is that it ignores deposition associated with slope movements, avalanches, destabilization and creep. It assumes immobile slopes, while MOC images have shown many evidence to the contrary. If the gullies were old, they should be partially filled with material, which is not the case.