THE SEARCH FOR BIOSIGNATURES ON MARS: Using predictive geology to optimize exploration targets.

Dorothy Z. Oehler[1] and Carlton C. Allen[1]. [1]NASA-Johnson Space Center, Houston, TX 77058. dorothy.z.oehler@nasa.gov, carlton.c.allen@nasa.gov.

Summary: Predicting geologic context from satellite data is a method used on Earth for exploration in areas with limited ground truth. The method can be used to predict facies likely to contain organic-rich shales. Such shales *concentrate* and *preserve* organics and are major repositories of organic biosignatures on Earth [1]. Since current surface conditions on Mars are unfavorable for development of abundant life or for preservation of organic remains of past life, the chances are low of encountering organics in surface samples. Thus, focusing martian exploration on sites predicted to contain organic-rich shales would optimize the chances of discovering evidence of life, if it ever existed on that planet.

Introduction: A major goal of the Mars exploration program is to determine if life ever evolved on that planet. This can only be accomplished if settings are indentified in which biosignatures are present in concentrations suitable for analysis. Potential biosignatures include 1) morphologically preserved fossils, 2) stromatolites, 3) biologically influenced minerals, and 4) organic chemical biomarkers *(i.e*., organic matter in sedimentary rocks). Among these biosignature types, it has been suggested that "*the most easily detected and the least ambiguous would be accumulations of organic matter"* [2].

Significant concentrations of organic matter occur in shales in some of the oldest sedimentary successions on Earth. These shales provide biomarkers of microbial life that existed on our planet nearly 3.5 billion years ago. Similar accumulations of organic-rich shales might be expected on Mars during its early history when the planet was wetter and more conducive to development of thriving biological systems. It is these types of sediments on which the Mars exploration program should focus to optimize the chances of discovering biosignatures, if they are present [1].

Follow the water, clays, etc.: Since water is a critical requirement for life, the first phase of martian exploration was focused on a "follow the water" strategy [5]. An adjunct to that strategy has been a focus on areas with clay minerals (phyllosilicates), since clays form in the presence of water. In addition, the fact that significant amounts of dissolved organic compounds can be adsorbed within smectite clays [6] has stimulated interest in searching for clays as repositories of potential organic biosignatures from the early wet - and thus most habitable - time on Mars [7].

However, the presence of phyllosilicates does not necessarily imply associated organics. Clays can form in settings lacking organic matter. The presence of phyllosilicates also says little about the length of time that water might have been present in the environment.

And critically, clays can accumulate and persist in environments where organics (though initially present) may have been destroyed by post-depositional processes such as oxidation, radiolysis, or perhaps photocatalytic decomposition, as has recently been suggested [8]. This is a concern on Mars, where surface oxidation appears to be significant over much of the planet's surface, and oxidants such as perchlorates and possibly peroxides, have been postulated [e.g. 9-13]. While Kennedy *et al*. [6] have shown that adsorption of organic matter within smectite interlayers plays a role in organic preservation on Earth, it is not certain that comparable preservation would occur on Mars, since peroxides are stronger oxidants than terrestrial oxygen. In addition, in 2010, Shkrob *et al*. suggested that potential organics on Mars may be destroyed by photocatalytic decomposition due to reaction with particulate iron (III) oxides that are abundant in the martian surface [8]. These authors conclude that there may be "*no safe haven*" for organic compounds on the surface of Mars, since the process of photocatalytic decomposition involves small, mobile and highly reactive radicals.

Others have focused on different attributes of living systems, and there have been suggestions that Mars exploration should "follow the nitrogen" [14], "follow the energy" [15], "follow the carbon" [16], or "follow the chemistry" [17]. Each of these strategies captures important aspects of habitability or life, and each has different advantages and challenges.

However, aspects of all of the above can be incorporated within a strategy focused on predicting settings where martian life not only may have thrived, but also where its biosignatures would have been both concentrated and preserved; that is, settings where organic-rich shales would be expected.

Predictive Geology: Much is known about geologic settings in which organic-rich sediments occur. These types of sediments are source rocks for most of the oil and gas deposits on Earth. For decades, petroleum companies have studied source rock development on Earth as part of their assessment of hydrocarbon plays [18-21]. This body of knowledge can be applied beyond oil exploration, as the sedimentary processes resulting in accumulation and preservation of organic-rich shales are applicable to sediments of any age.

In general, organic-rich sediments are found in marine or lacustrine, basinal settings within distal, quiet-water facies (20, 22-25]. This is where *in-situ* living systems may have proliferated, where organic material is concentrated by transport processes, and where burial with associated muds and sometimes evaporites protects organic matter from oxidation. The processes resulting in the organic-rich sediments have occurred throughout geologic time on Earth and there are organic-rich shales known from sediments of all ages, including several examples in the early Archean with ages approaching 3.5 billion years.

A similar approach can be used for Mars [1, 26]. Since the lowland-highland dichotomy appears to have formed very early, in the pre-Noachian, and ancient rivers follow the current topographic gradient [27], present day topography can be used as first-pass guide to ancient and regional sedimentary settings. Orbital data can be used for designation of topography, river valleys, outflow channels, and catchment areas to define sediment sources and sinks. This sort of regional assessment can be fine-tuned with detailed geomorphology and mineralogy from the higher resolution spectrometers now orbiting Mars. From these types of assessments, facies can be predicted.

This approach was used in a study of thousands of mounds in Acidalia Planitia [26, 28]. Figs. 1-2 illustrate the location of sediment sources and predicted facies in sinks. The distal facies is where fine-grained, organic-rich sediments would be expected. These results provided context for interpreting the mounds as sedimentary diapirs most like terrestrial mud volcanoes.

Conclusions and Implications: Geologic facies can be predicted on Mars using satellite data. This approach can be used to optimize the search for organic biosignatures. Predictive geology also could target exploration aimed at other types of biosignatures, (*e.g.*, stromatolites or morphologically preserved microorganisms) by identifying settings most likely to have sediments in which these types of biosignatures would occur. Finally, facies prediction on Mars could be applied beyond the search for life to questions related to more general geologic inquiry (*e.g.*, best locations for hydrothermal deposits, salts, carbonates, silica, etc.).

References: [1] D.Z. Oehler, C.C. Allen (in press) *SEPM Spec. Publ*., Sedimentary Geology of Mars. [2] R.E. Summons et al. (2010) *AbSciCon*, Abs. #5256. [3] D.Z. Oehler et al. (2010) *Astrobiology 10*, 413-424. [4] D.Z. Oehler et al. (2010) *AbsiCon*, Abs. #5002. [5] G. Briggs (2000) *Meteoritics & Planet. Sci. 35*, 892-893. [6] J.J. Kennedy et al. (2002) *Science 295*, 657-660. [7] B.L. Ehlmann et al. (2008) *Nature Geoscience 1*, 355-358. [8] I.A. Shkrob et al. (2010) *Astrobiology 10*, 425-436. [9] T. Encrenaz et al. (2004) *Icarus 170*, 424-429. [10] T. Encrenaz et al. (2008) *Modeling & Observat.* Abs. #9018. [11] Ten Kate et al. (2006) *Geophys. Res. Let. 36*, L02205, doi:10.1029/ 2008GL036513. [12] J.A. Hurowitz et al. (2007) *EPSL 255*, 41-52. [13] M.H. Hecht et al. (2009) *Science 325*, 64-67. [14] D.G. Capone et al. (2006) *Science 312*, 708-709. [15] T.M. Hoehler et al. (2007) *Astrobiology 7*, 819-823. [16] NRC (2007) *An Astrobiology Strategy for the Exploration of Mars*, Natl. Acad. Press, Wash. DC, 130 p. [17] M.H. Hecht (2009) *The New Martian Chem. Wkshp*, Abs. # 8030. [18] P.A. Allen, J.R. Allen (1990) *Basin Analysis, Principles & Appl.*, 309-396. [19] H.D. Klemme, G.F. Ulmishek (1991) *AAPG Bull. 75*, 1809-1851. [20] D.L. Gautier (2005) *GSA Prog. Abs. 37*, 312, Paper #137-3. [21] A. Tommeras, U. Mann (2008) *Petrol. Geoscience 14*, 291-299. [22] J.H.S. Macquaker, C.D. Curtis (1989) *J. Geol. Soc. Lond. 146*, 271-272. [23] R.V. Tyson (1996) *Geol. Soc. Lond. Sp. Publ. 103*, 75-96. [24] H.C. Jenkyns (2007) *Lethaia 4*, 327-352. [25] K.S. Davies-Vollum, N.D. Smith (2008) *J. Sed. Res. 78*, 683-692. [26] D.Z. Oehler, C.C. Allen (2010) *1st Intl. Conf. Mars Sed. Stratig.*, Abs. #6069. [27] M.P. Golombek, R.J. Phillips (2009) in *Planetary Tectonics* (Watters & Schultz, eds), Cambr. Univ. Press, 183- 232. [28] D.Z. Oehler, C.C. Allen (2010) *Icarus 208*, 636-657. [29] H.V. Frey (2006) *JGR 111*, E08S91, doi: 10.1029/ 2005JE002449. [30] USGS (2009) Mars DVD.

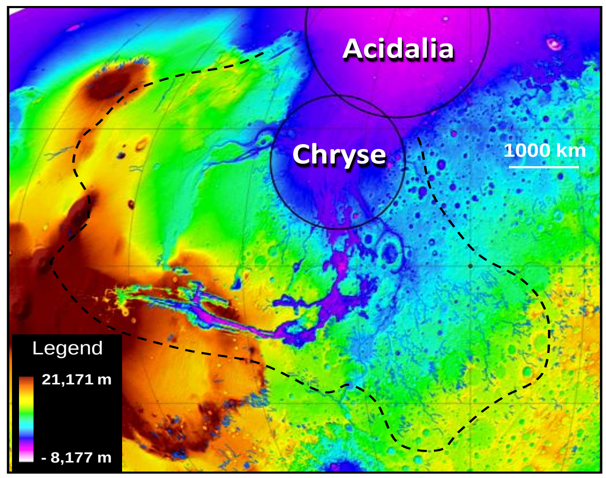

Fig. 1. Sediment sources for the Chryse-Acidalia Embayment on MOLA base. Circles mark proposed ancient impact basins [29]. Dashed line shows catchment area based on channels (thin blue lines) mapped by Carr [30] and major outflows.

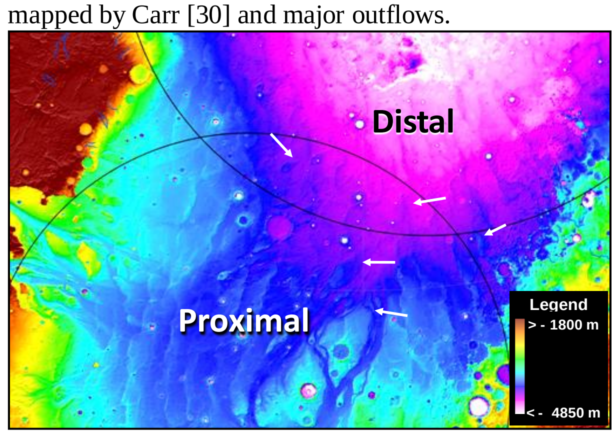

Fig. 2. General facies predicted for Chryse and Acidalia on stretched MOLA base. Arrows point to streamlined islands suggesting that water from circum-Chryse outflows continued into Acidalia.