THE SOUDAN MINE, MINNESOTA: A HYDROCHEMICAL ANALOG FOR RIMSTONE DAMS ON THE MARTIAN SURFACE. E. Calvin Alexander, Jr.[1], Scott C. Alexander[1], Andri E. Hanson[1], Steven M. Pinta[1], Penelope J. Boston[2], Jeffrey A. Gralnick[3]. [1]Univ. of Minnesota (Dept. of Geology & Geophysics, 310 Pillsbury Dr. SE, Minneapolis, MN 55455; alexa001@umn.edu, alexa017@umn.edu, hans1949@umn.edu, pint0034@umn.edu), New Mexico Tech (Earth & Environmental Sciences Dept., NM Institute of Mining & Technology, 801 Leroy Place, Socorro, NM 87801; pboston@nmt.edu), [3]Univ. of Minnesota. (Dept. of Microbiology, BioTechnology Institute, 356 Gortner Laboratory, 1479 Gortner Ave., St. Paul, MN 55108; gralnick@umn.edu).

Introduction: Evidence of running, liquid water solutions on Mars has become steadily more detailed and compelling since the first flyby mission photos in the 1960s. Although many of the water-related features are ancient, Mars Orbiter Camera (MOS) have document geologically recent gullies at many places on the Martian surface [1]. Recently, repeated MOS photos [2] document evidence of liquid water flows "since August 1999". Data from the Mars Exploration Rovers [3] document a variety of sedimentary mineral deposits including abundant jarosite.

Actively flowing water at Martian surface temperature and pressure probably requires high concentrations of dissolved salts. Eutectic $CaCl_2$ brines, such as the brines in the Don Juan Pond, Antarctica have been proposed possible analogs for Martin subsurface waters [4]. Such brines are ubiquitous in terrestrial shield rocks [5] and seem to be one end point in the geochemical evolution of crustal brines.

Rimstone Dams on Mars: Fig.1 shows a subframe from a MOS high resolution image that shows gullies in a crater wall in the southern hemisphere of Mars. At the base of a regolith slope below the gullies there is a sinuous feature that surrounds a smooth area on its upslope side (circled in red in Fig. 1). The working hypothesis of this abstract is that the circled feature is a rimstone dam which was produced by the ponding of a liquid on the Martian surface. Similar features can be seen in several of the gullies images.

Rimstone dams occur in a variety of surface and subsurface environments on Earth. Rimstone dams form via an elegant self-leveling mechanism in which the ponded water deposits material as it thins flowing over the low point in the pools edge [7]. The low point builds upward until it is no longer the lowest outlet at which point the flow (and deposition) moves to the new low point. Terrestrial rimstone dams form at scales from millimeters to kilometers and the largest are larger than the feature in Fig. 1.

$CaCl_2$ Brines in the Soudan Mine, MN: Seepage water on the deepest, 710m below surface, level of the Soudan Iron Mine are Ca-Na-Mg/Cl solutions about twice as salty as sea water [8] similar to brines widely distributed in old terrestrial continental rocks [5]. The major cations are Ca (~60%), Na (~30%) and Mg (~10%) on an equivalent basis, with Cl as the dominant anion. The Cl/Br ratio of 180 indicates these are residual solutions. The solutions are anoxic and contain 150 ppm Fe and 10 ppm Mn.

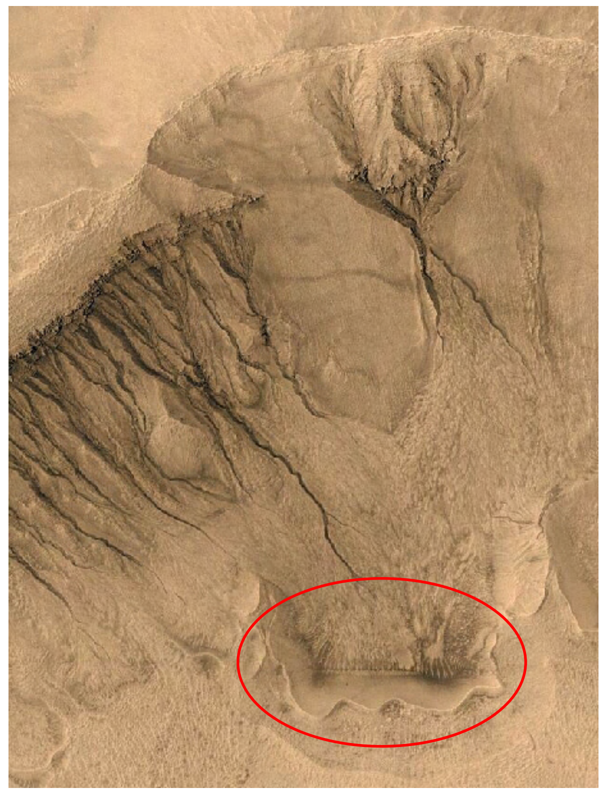

Fig. 1. A rimstone dam (circled in red) associated with gullies in crater at 39.0°S, 166.1°W on Mars [6]. The long dimension of the dam is about 400m.

When the seep waters reach the oxygenated mine drift tunnels the soluble ferrous Fe begins to oxidize precipitating a wide variety of brightly colored secondary deposits. These deposits represent the interface between anoxic and oxic waters. Fig. 2 shows one such deposit. The smooth surfaces across the middle of the image are rimstone pools about a meter wide and a few centimeters high. The mineralogy of the deposits is currently being determined but initial XRD and SEM work has identified abundant jarosite in several of the deposits. Jarosite is being deposited from waters

Fig. 2. Diamond drill hole #963. Iron rich deposits on the 27th level of the Soudan Mine. The view is about 4 m high by 3 m wide.

that contain only about 50 ppm sulfate. The Soudan Mine brines are an environment in which jarosite is deposited from concentrated chloride solutions containing low sulfate concentrations.

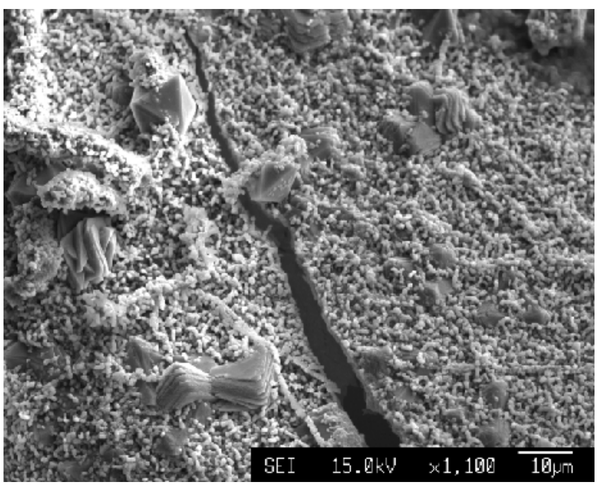

Fig. 3. SEM photo of jarosite crystals precipitating from $CaCl_2$ brines in the Soudan Mine. SEM image by M.N. Spilde and P.J. Boston.

Microbiology: The Soudan $CaCl_2$ brines are teaming with microbes. The very high chemical and redox gradients present in this environment are a rich environment for microbial life. Fig. 3 is an SEM image of a Soudan biofilm similar to orange deposits in the lower part of Fig. 2. The large angular objects are jarosite crystals. The filaments and small dots are various kinds of bacteria.

Pyrosequencing [9] has documented very different microbial populations living in the anoxic and oxic waters only centimeters apart and is a start on the documentation of this biological system. Additional microbiological characterizations are underway.

Implications for Mars: The Martian gullies are one part (visible to orbital photography) of liquid flow systems that intersect the Martian surface in places. The curvilinear rimstone dams appear to be a second, consistent part of the flow systems.

Concentrated $CaCl_2$ brines are plausible candidates for a fluid phase on the Martian surface. $CaCl_2$ brines have very low freezing points, reduce the equilibrium partial pressures of water vapor and can deposit rimstone dams. Other plausible fluid-phase candidates include formate and acetate salts, which also exhibit large freezing point depressions.

The formation of jarosite in the Soudan Mine calcium chloride brines (with modest sulfate contents) illustrates the fallacy of assuming that hydrous sulfate minerals on the Martin surface require that the parent waters were necessarily sulfate rich. For example, on Earth gypsum precipitates from chloride-rich brines with modest sulfate contents.

The Martin surface may represent an interface between two radically different environments: a highly oxidizing surface and a strongly reducing subsurface. That interface may be only slightly thicker than the depth range of the analytical instruments current deployed on the Martian surface.

References: [1] Malin M.C. and Edgett K.S. (2000) *Science, 288*, 2330-2335. [2] Malin M.C. *et al.* (2006) *Science, 314,* 1573-1577. [3] Squyres et al. (2006) Science, 313, 1403-1407. [4] Burt D.M. et al. (2002) *LPS XXXIII*, Abstract # 1240. [5] Frape S.K. and Fritz P. (1987) *Geol. Soc. Canada Special Paper 33*, 19-38; Douglas M. *et al.* (2000) *J. Hydrology*, 235, 88-103. [6] Edgett K.S. and Malin M.C., MSSS, MGS MOC Release No. MOC2-320, 7 October 2002. [7] Hill, C. and Forti, P. (1997) *Cave Minerals of the World, 2nd ed.*, 92-94 and references therein. [8] Alexander E.C., Jr. *et al.* (2005) abstract, NC GSA Meeting, Minneapolis, MN, 19-20 May 2005. [9] Edwards *et al.* (2006) *BioMed Central Genomics 2006, 7*, 1-13.