SULFATE FORMATION AND ITS RELEVENCE TO ENVIRONMENTAL CONDITIONS ON EARLY MARS C. Fan[1], D. Schulze-Makuch[1] and H. Xie[2], [1]Dept. of Geology, Washington State University (cfan1@wsu.edu), [2]Dept. of Earth and Environmental Sciences, University of Texas at San Antonio.

Introduction: A variety of sulfates, hydrated phyllosilicates, and iron oxides were detected by OMEGA/MEX, TES/MGS and the Mars Rovers Opportunity and Spirit. These observations provide fresh insights into Martian surface processes at a specific time of Martian geological history. We suggest a mechanism of formation of sulfates and associated minerals based on the occurrence of sulfates on Mars, the conservation of mass, and the solubility of sulfates. We draw conclusions about the role of water in regard to Martian surface process and its implication for Martian life.

Background and Discussion: Kieserite ($MgSO_4 \cdot H_2O$) and epsomite ($MgSO_4 \cdot 7H_2O$), gypsum ($CaSO_4.2H_2O$) or bassanite ($2CaSO_4 \cdot H_2O$), and copiapite [$Fe^{2+}Fe_4^{3+}(SO_4)_6(OH)_2 \cdot 20H_2O$] or halotrichite [$Fe^{2+}Al_2(SO_4)_4 \cdot 22H_2O$], and likely halite (NaCl) have been detected through hyperspectral images in numerous areas of Mars by the ESA OMEGA team [1] [2] [3]. Jarosite [$KFe_3(SO_4)_2(OH)_6$] and the iron oxide hematite (Fe_2O_3) were identified through TES/MGS and the Opportunity rover [4]. The layered sulfate deposits on Mars as revealed from MOC images and the HRSC/MEX camera [1] [2] indicate that they were formed by precipitation in acidic brine as evaporites. The mechanism is consistent with the formation of sulfates essentially occurring on Earth, and is difficult to be interpreted otherwise.

Precipitation of sulfates from brine is controlled by the contents of cation and anion solutes, the solubility of their aqueous complexes, and temperature, pressure and pH value. Sulfates deposits accumulate when sulfates are oversaturated and the solution condenses due to evaporation of water or the influx of solutes. Solubility of sulfates is the main factor determining the sequence of different sulfate deposits given relatively constant thermodynamic conditions. Different sulfates have different solubility, which increases from magnesium-, calcium-, iron- to aluminum sulfates; the main sulfates detected on Mars until now.

Metal cations are likely derived from a thick mantle of phyllosilicate deposits of weathered basaltic crust. Abundant deposits of phyllosilicates and other hydrated minerals were detected on Mars, and are overlain by volcanic lava flows [5] [6]. The dominant sulfates detected are consistent with the major components of altered mafic igneous rocks, which are Mg, Fe Ca, Al and Na [7]. Anions are presumed to be brought up by fluids associated with volcanic activities such as near Tharsis Montes, and are thought to be dominated by SO_4^{2-}, but Cl^- and others anions can not be ruled out. A very thin CO_2-dominated atmosphere may have contributed some CO_2 to the initial solution, but HCO_3^- and CO_3^{2-} are likely negligible.

Several lines of evidence indicate that the fluid brought up by the volcanic activity between the "phyllosian" and "theiikian" era made some relatively isolated water bodies very hot and acidic dissolving weathered and unweathered basaltic crust. As water evaporated into space and temperatures decreased, major metal ions and sulfates became more and more enriched and finally became oversaturated. Magnesium sulfates such as kieserite and epsomite started to precipitate first due to their lower solubility in respect to other sulfates. Calcium sulfates such as gypsum precipitated following kieserite and overlying it, which is indicated by sulfate-rich layered deposit at Juventae Chasma, Valles Marineris [1]. Iron sulfates and aluminum sulfates precipitated when magnesium and calcium were almost fully consumed in the brine. Finally, a majority of sulfate ions had likely been consumed at this time, thus any remaining iron was deposited in form of oxides (the so-called "blueberries" detected in Meridiani Planum). Halite likely precipitated at this time when chlorine was relatively concentrated in solution due to the depletion of sulfate ions. The precipitation of sulfates overlapped with transient boundaries.

Conclusion: The sequence of sulfate formation suggests that the Martian surface was warm and spotted with standing bodies of liquid water during a span of time in Martian early history. Acidic hot water bodies may be associated with the origin and persistence of life on Earth. If so, the sites on Mars with confirmed sulfate deposits are promising targets for the exploration of Martian life.

References: [1] Bibring J.P. et al. (2005) Science, 307, 1576–1581. [2] Gendrin A. et al. (2005) Science, 307, 1587–1591. [3] Langevin Y. et al. (2005) Science, 307, 1584–1586. [4] Klingelhofer G. et al. (2004) Science, 306 1740-1745. [5] Poulet F. et al. (2005) Nature, 438, 623–627. [6] Bibring J.P. et al. (2005) Science, 312, 400–404. [7] Mustard J.F. et al. (2005) Science, 307, 1594-1597.