

Aqueous alteration of basalts: Earth, Moon, and Mars

DOUGLAS W. MING

NASA Johnson Space Center, ARES, Mail Code KX,
Houston, TX 77058, USA (douglas.w.ming@nasa.gov)

The geologic processes responsible for aqueous alteration of basaltic materials on Mars are modeled beginning with our knowledge of analog processes on Earth, i.e., characterization of elemental and mineralogical compositions of terrestrial environments where the alteration and weathering pathways related to aqueous activity are better understood. A key ingredient to successful modeling of aqueous processes on Mars is identification of phases that have formed by those processes. The purpose of this paper is to describe what is known about the elemental and mineralogical composition of aqueous alteration products of basaltic materials on Mars and their implications for specific aqueous environments based upon our knowledge of terrestrial systems. Although aqueous alteration has not occurred on the Moon, it is crucial to understand the behaviors of basaltic materials exposed to aqueous environments in support of human exploration to the Moon over the next two decades.

Several methods or indices have been used to evaluate the extent of basalt alteration/weathering based upon measurements made at Mars by the Mars Exploration Rover (MER) Mössbauer and Alpha Particle X-Ray Spectrometers. The Mineralogical Alteration Index (MAI) is based upon the percentage of total Fe (Fe_T) present as Fe^{3+} in alteration products (Morris *et al.*, 2006). A second method is the evaluation of compositional trends to determine the extent to which elements have been removed from the host rock and the likely formation of secondary phases (Nesbitt and Young, 1992; Ming *et al.*, 2007). Most of the basalts that have been altered by aqueous processes at the two MER landing sites in Gusev crater and on Meridiani Planum have *not* undergone extensive leaching in an open hydrolytic system with the exception of an outcrop in the Columbia Hills. The extent of aqueous alteration however ranges from relatively unaltered to pervasively altered materials.

Several experimental studies have focused upon the aqueous alteration of lunar materials and simulants (e.g., Keller and Huang, 1971; Eick *et al.*, 1996). Lunar basalts are void of water and highly reduced, hence, these materials are initially very reactive when exposed to water under oxidizing conditions.

References

- Eick M.J., *et al.* (1996) *GCA*, **60**, 157-170.
 Keller, W.D., & W.H. Huang (1971) *Proc. Lunar Sci. Conf. II*, p. 973-981.
 Ming, D.W., *et al.* (2007) In *The Martian Surface: Composition, Mineralogy, and Physical Properties* (J.F. Bell III, ed.), Cambridge University Press.
 Morris, R.V., *et al.*, (2006) *J. Geophys. Res.*, **111**, E02S13, doi:10.1029/2005JE002584.
 Nesbitt, H.W., & Wilson, R.E. (1992) *Am. J. Sci.*, **292**, 740-777.

Crystal Water on Mars: Insights from the Mars Exploration Rovers

D.W. MING¹, B.C. CLARK², R.V. MORRIS¹ AND THE
ATHENA SCIENCE TEAM

¹NASA Johnson Space Center, Mail Code KX, Houston, TX
77058, USA. (douglas.w.ming@nasa.gov)

²Lockheed Martin Space Systems, POB 179, MS S-8000,
Denver, CO 80201, USA

The purpose of this paper is to constrain the total water contents from crystal H_2O and OH in several materials analyzed by the Mars Exploration Rovers (MER). Crystal H_2O is part of the unit cell and cannot be removed without changing the structure. Minerals that contain only OH in their structures are anhydrous minerals containing hydroxyls, although they are formed as a product of aqueous activity and will decompose with evolution of H_2O when heated.

The crystal water and OH contents of a bulk material at the MER landing sites can be estimated from mineralogical composition, which is determined by a combination of Fe-mineralogy obtained by the Mossbauer Spectrometer and mineral abundances based upon the chemical composition determined by the Alpha Particle X-ray Spectrometer.

Jarosite, along with Ca- and Mg-sulfates, have been suggested as the sulfur-bearing phases in Meridiani Planum outcrop. Models of various hydration states of Fe-, Ca-, and Mg-sulfates and other possible secondary phases suggest that 6 to 22 wt.% of the outcrop may occur as crystal H_2O and/or OH (Clark *et al.*, 2005). This estimate of water is consistent with measurements from the Odyssey orbiter, where 7 % H_2O -equivalent H was measured down to a depth of approximately 1 m for the region (Feldman *et al.*, 2004).

The Peace outcrop material, which is composed of basaltic sands cemented by Mg- and Ca-sulfates, exhibited the highest water content (1.2 to 6.9 wt.% H_2O) of rocks and outcrops encountered on the northwestern flank of Husband Hill in Gusev crater (Ming *et al.*, 2006, 2007). Paso Robles soil on Husband Hill contains Fe^{3+} , Mg-, Ca-bearing and other sulfates, Ca-phosphates, and other secondary phases (Ming *et al.*, 2006). The water content derived from these materials ranges from 2.4 to 16.9 wt.% (Ming *et al.*, 2007).

Unfortunately, the MER Athena instrument payload has not identified the secondary aluminosilicates in outcrops, rocks, and soils at the two landing sites. Therefore, it is likely that the total water constraints listed above are higher than suggested if hydrated secondary aluminosilicates are present.

References

- Clark, B.C., *et al.* (2005) *Earth Planet. Sci. Lett.*, **240**, 73-94.
 Feldman, W.C., *et al.*, (2004) *J. Geophys. Res.*, **109**, E09006, doi:10.1029/2003JE002160.
 Ming, D.W., *et al.* (2006) *J. Geophys. Res.*, **111**, E02S12, doi:10.1029/2005JE002560.
 Ming, D.W., *et al.* (2007, *in press*) In *The Martian Surface: Composition, Mineralogy, and Physical Properties* (J.F. Bell III, ed.), Cambridge University Press.