

THE MARTIAN SOIL AS A GEOCHEMICAL SINK FOR HYDROTHERMALLY ALTERED CRUSTAL ROCKS AND MOBILE ELEMENTS: IMPLICATIONS OF EARLY MER RESULTS. H. E. Newsom, M. J. Nelson, C. K. Shearer, and D. S. Draper, University of New Mexico, Institute of Meteoritics, Dept. of Earth & Planetary Sciences, Albuquerque, NM 87131 newsom@unm.edu

Introduction: Hydrothermal and aqueous alteration can explain some of the exciting results from the MER team's analyses of the martian soil [1,2], including the major elements, mobile elements, and the nickel enrichment. Published results from the five lander missions lead to the following conclusions: 1) The soil appears to be globally mixed and basaltic with only small local variations in chemistry. Relative to martian basaltic meteorites and Gusev rocks the soils are depleted in the fluid-mobile element calcium, but only slightly enriched to somewhat depleted in iron oxide. 2) The presence of olivine in the soils based on Mössbauer data argues that the soil is only partly weathered and is more akin to a lunar regolith than a terrestrial soil [3]. 3) The presence of bromine along with sulfur and chlorine in the soils is consistent with addition of a mobile element component to the soil.

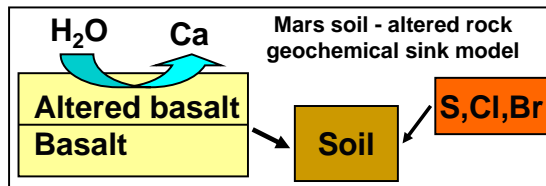


Fig. 1 Sink model for the martian soil. Alteration of the basalt is decoupled in time and space from the formation of the soil.

Geochemical sink model for the martian soil:

The MER data require the presence of unaltered material in the soil, but also imply the action of aqueous processes. For models involving in situ processing of the soil the aqueous activity would have to be global and have operated recently in Mars history to explain the geochemical differences from the basaltic protolith. Our model for the soil as a geochemical sink decouples the processes of alteration from the physical formation of the soil itself [4-6]. The model consists of the following processes: 1) Aqueous alteration of the martian crust that could have occurred at any time in the martian past. 2) Erosion by aeolian (and fluvial) processes of both altered and unaltered crust to form the bulk of the present soil material. 3) Addition of mobile elements, including S, Cl, and Br to the soil from hydrothermal fluids [5], recycled evaporates such as the material at Meridiani, and volcanic aerosols. 4) Minor additions from local sources could explain the variations seen at some sites such as the higher K_2O at the Pathfinder site. 5) High nickel abundances for the soils [1,2] that could reflect addition of a small meteoritic

component to the soil, and/or contributions of Ni from preferentially altered olivine in crustal rocks. 6) Minor local transport of water soluble phases.

The sink model avoids the contradiction between the need to have the soil undergo an episode of in situ aqueous alteration and the evidence for primitive unweathered components in the soil (e.g. olivine) by allowing the alteration to occur before the formation of the soil. This alteration could have occurred at a time or location where water was relatively abundant. Such conditions could have occurred locally more recently in Mars history, or generally at earlier times.

Hydrothermal alteration or aqueous weathering component: Our terrestrial analog studies show that hydrothermal alteration, involving impact craters and volcanism, could explain the major element trends observed in martian soil [6,7]. The homogeneity and presence of unweathered olivine in the soil makes it difficult to form the soil by a simple palagonitization model involving the in situ aqueous alteration of volcanic ash. McSween and Keil [8] showed that palagonitization can explain the major element trends, aside from the Cl and S enrichment, but the missing CaO remains a problem. They also argued that hydrothermal alteration of basalts produce alteration trends that are inconsistent with the Mars soil, but our data for altered basalts, including Lona rocks, do not have this problem [6].

We have used quantitative mass-balance mixing models to investigate possible mixtures of basaltic compositions with different types of alteration materials, including palagonite. We show that the Mars soil composition can be matched with a combination of unweathered basaltic martian meteorites, such as EETA 79001B with basaltic FeO-rich, CaO-poor alteration products (Fig. 2). The rock Bounce studied by the MER Opportunity is identical in composition to 79001B [2]. Palagonite is a possible, but not a necessary component of successful model mixtures. The hydrothermal alteration materials that form successful model mixtures are formed in low temperature, low water/rock ratio environments, and they can reproduce the required geochemical trends because they are poorer in CaO and MgO, but not in FeO compared to their respective protolith. These results argue that material altered by hydrothermal processes could be a plausible component of the soil, and that removal of CaO from the soil into some undiscovered reservoir after its formation is not required.

Mobile element component: The enrichment of Br relative to Cl in Mars soil is consistent with terrestrial hydrothermal fluid compositions. Newsom et al. [5] proposed a soil model that combined acid sulfate and neutral chloride fluids to explain the S and Cl abundances. This model also predicted an enrichment of Br in the soil, based on the Br/Cl ratios in terrestrial hydrothermal fluids, that can now be compared with martian soil (Fig. 3). The enrichment of the Br/Cl ratio relative to CI chondrites is consistent with both MER observations [1,2], and is unlikely to be a characteristic of the martian crust based on the Br/Cl ratios of basaltic martian meteorites. The Br/Cl ratios of volcanic aerosols are quite variable, but Br is more volatile than Cl, therefore contributions from volcanic aerosols with enriched Br/Cl ratios is still possible.

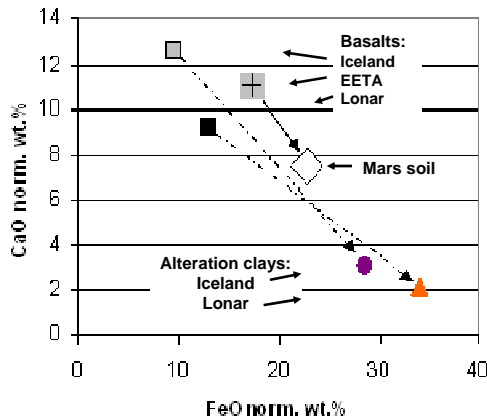


Fig. 2 Successful mixing models combine altered and unaltered basaltic compositions shown here to match the target Mars soil composition [6].

Meteoritic component?: Nickel is enriched in the martian soil compared to rock, possibly reflecting a meteoritic component. The Ni abundances in soils are ~ 450 ppm at Gusev [1], and ~770 ppm at Meridiani [2], compared to low Ni in martian meteorites and rocks (200 ppm Ni in Gusev floor rocks, 6 - 310 ppm in basaltic meteorites). Even if the Ni is largely meteoritic, this is the only measured element that would be significantly enriched compared to the abundances in the soil from other sources [4]. The amount of a meteoritic component could provide timing constraints for the formation of the soil, however there are many uncertainties, such as the meteoritic flux, and the global thickness of the soil accumulating the meteoritic debris. The enrichment of Ni in the soil, however, may not be just due to a meteoritic component. In the context of the altered rock geochemical sink model, another possibility is the preferential contribution of Ni to the soil from altered olivine in the altered rock component. Ni abundances in martian basaltic meteorite olivine ranges from 170 ppm up to 1800 ppm [9,10].

The olivine Ni content can therefore be more than ten times the rock abundances. As an example, the presence of 10% of a Ni-rich olivine component could double the Ni content of the soil. In addition, olivine is preferentially altered relative to every other phase during any weathering or hydrothermal process. (Note that the soil contains both altered material and unaltered basalt in our model, explaining the presence of unaltered olivine in the soil.) Any enrichment of Ni from an altered olivine source would reduce the possible contributions from a chondritic component, and lower any age estimates.

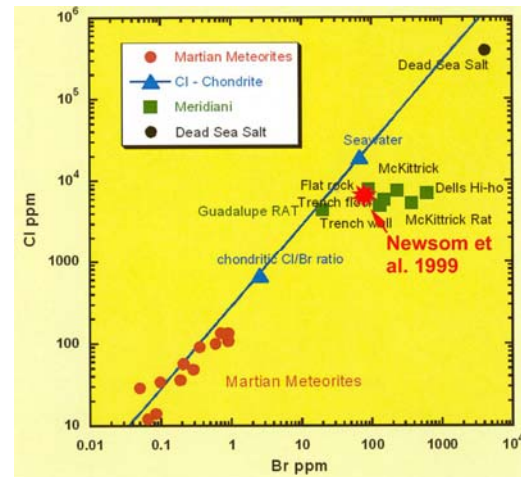


Fig. 3. Prediction of Newsom et al., [5] for the Br content of the soil based on Br/Cl ratios in hydrothermal fluids. Figure after [2].

Implications for Mars: The new data for the martian soil can be explained by an altered rock geochemical sink model. The altered rock component could have formed by aqueous or hydrothermal processes at any time in Mars history before erosion to form part of the soil. Addition of mobile elements such as Br to the soil can also be explained by a hydrothermal component. The addition of Ni from preferentially altered olivine could greatly reduce the need for a meteoritic component in the soil, implying a younger age for the soil than otherwise might be inferred.

References [1] Gellert, R. et al. (2004) *Science* 305, 829-832. [2] Rieder, R. et al. (2004), *Science* 306, 1746-1749. [3] Morris, R.V. et al. (2004) *Science* 305, 833-836. [4] Newsom, H.E. and Hagerty, J.J. (1997) *JGR* 102, 19,345 - 19,355. [5] Newsom, H. E. et al. (1999) *JGR*, 104, 8717-8728. [6] Nelson, M.J. Newsom, H.E. and Draper, D.S. (2005), *GCA* in press. [7] Hagerty, J.J., and Newsom, H.E. (2003) *Meteoritics and Planet. Sci.*, 38, 365-381. [8] McSween, H.Y. and Keil, K. (2000) *GCA* 64, 2155-2166. [9] Herd et al. (2001) *LPS XXXII* #1635. [10] C.K. Shearer, unpublished data. Partially supported by NASA P.G. & G. NAG 5-11496, and M.F.R.P. NNG04GE87G.