Enhanced groundwater flow on and below Vera Rubin ridge, the Murray Formation, Gale Crater: Evidence from thermochemical modeling

Conference or Workshop Item

ENHANCED GROUNDWATER FLOW ON AND BELOW VERA RUBIN RIDGE, THE MURRAY FORMATION, GALE CRATER: EVIDENCE FROM THERMOCHEMICAL MODELING. S.M.R. Turner[1], S.P. Schwenzer[1], J.C. Bridges[2], E.B. Rampe[3], C.C. Bedford[3,4,5], C.N. Achilles[6], A. McAdam[6], N. Mangold[7], L.J. Hicks[2], J. Parnell[8], T. Kirnbauer[9], A.A. Fraeman[10], and M.H. Reed[11]. [1]AstrobiologyOU, School of Environment, Earth and Ecosystem Sciences, The Open University, UK, (stuart.turner@open.ac.uk). [2]Space Research Centre, School of Physics and Astronomy, University of Leicester, UK. [3]NASA Johnson Space Center, USA. [4]School of Physical Sciences, The Open University, UK. [5]Lunar and Planetary Institute, USRA, USA. [6]NASA Goddard Space Flight Center, USA. [7]Laboratoire de Planétologie et Géodynamique, UMR6112 CNRS, Université de Nantes, Université Angers, France. [8]School of Geosciences, University of Aberdeen, UK. [9]TH Georg Agricola, Bochum, Germany. [10]Jet Propulsion Laboratory, California Institute of Technology, USA. [11]Department of Earth Sciences, University of Oregon, USA.

Introduction: NASA's Mars Science Laboratory *Curiosity* rover has been exploring Vera Rubin ridge (VRR), part of the Murray formation in Gale crater, Mars, between sol 1809 and 2302. Evidence for Fe-oxides and phyllosilicates in mineralogical and geochemical data for this region was returned by *Curiosity* [1-5]. We applied thermochemical modeling to constrain the formation conditions of the phyllosilicate-hematite assemblage identified on and below VRR. Average alteration compositions for the Murray formation on and below VRR were derived using CheMin and APXS data. These compositions were reacted with Gale Portage Water (GPW) between 25–100 °C and for 10% and 50% Fe^{3+}/Fe_{tot} of the host rock [6]. Here we summarize models run at 50 °C and 10% Fe^{3+}/Fe_{tot} for alteration compositions derived from Murray host rock compositions.

Modeling: CHIM-XPT is a program for computing multicomponent heterogeneous chemical equilibria in aqueous-mineral-gas systems [7], and was previously used in fluid-rock interaction studies for Gale crater [8-12]. Each step calculates equilibrium between a user-defined fluid and dissolved rock, meaning that each step can be interpreted independently. The water/rock ratio (W/R) in CHIM-XPT is the ratio of incoming fluid to reacted rock. Here, the models focus on 1–100,000 W/R.

The Starting Fluid. GPW was selected as the starting fluid, and has previously been used in thermochemical modeling studies [9,10,12]. GPW was derived from equilibrium mediation between a brine and rocks of the Gale area [9]. The solution is initially oxidizing (all S species as SO_4^{2-}), and the redox in the fluid is controlled by the SO_4^{2-}/HS^- pair. The redox of the system throughout each model is dependent on the Fe^{3+}/Fe_{tot} ratio of the host rock.

The Starting Rock. The composition of the alteration component in the Murray formation on and below VRR, along with an overall alteration composition, was derived by combining data returned by APXS and CheMin for the drill holes: Oudam (drilled on sol 1361), Marimba (sol 1422), Quela (sol 1464), Sebina (sol 1495), Stoer (sol 2136), Highfield (sol 2223), and Rock Hall (sol 2261) [13]. Using crystal chemistries derived for the magmatic minerals and mineral abundances determined using CheMin data, compositional oxide wt.% contributions from the magmatic phases were subtracted from the bulk APXS measurements. Ca-sulfate contributions were also excluded as these formed during late diagenesis [10,14].

Results: Thermochemical modeling was carried out for the temperature range 25–100 °C [6]. Here we compare model results for alteration compositions derived for VRR (Fig. 1) and below VRR (Fig. 2).

Figs. 1 and 2 show >10 wt.% hematite precipitating for ≥10,000 W/R for both alteration compositions at 50 °C and 10% Fe^{3+}/Fe_{tot}.

Comparing summed clay mineral / hematite ratios (C/H) at 100, 1,000 and 10,000 W/R in the models in Figs. 1 and 2 with C/H from CheMin data suggests that the models at 10,000 W/R are comparable to *Curiosity* observations [6]. For 10% Fe^{3+}/Fe_{tot} these C/H values are 1.2 and 3.0 for on and below VRR, respectively. C/H values change to 1.2 and 1.7 for 50% Fe^{3+}/Fe_{tot}. Comparable C/H values extracted from CheMin data are 1.9 ± 0.7 and 2.4 ± 0.3 for on and below VRR, respectively. When summing all Fe-oxides the value for VRR changes to 0.8 ± 0.3 due to akaganeite in Rock Hall.

Discussion: The models presented here and by [6] indicate potential formation conditions for the clay mineral-hematite assemblage in the Murray formation on and below VRR. To assess the comparability with previous modeling and Curiosity observations, the phyllosilicate chemical composition was summed for 10,000, 1,000 and 100 W/R models and shown on a ternary plot in Fig. 3. Fig. 3 shows the modeled phyllosilicates at 10,000 W/R are close to Sheepbed unit model saponite [9], with the models trending towards nontronite compositions at 1,000 and 100 W/R [6].

Note that we assume the akaganeite and jarosite detected by CheMin in the Murray formation to be the result of later alteration where Fe was remobilized from the modeled mineral assemblages [6].

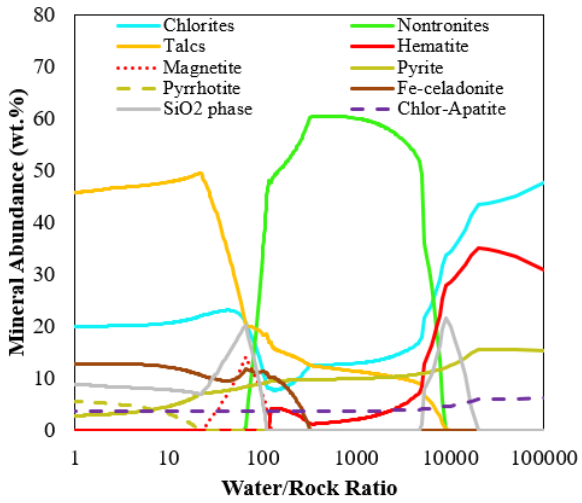

Fig. 1: CHIM-XPT thermochemical model for the VRR Murray alteration composition reacted with GPW. The model was run at 50 °C and 0.1 Fe^{3+}/Fe_{tot}.

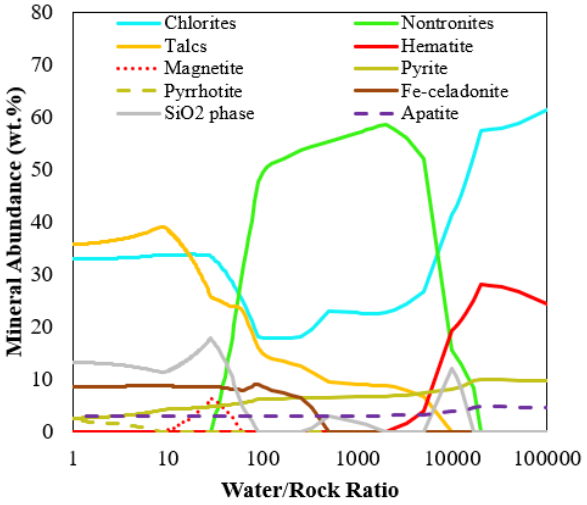

Fig. 2: CHIM-XPT thermochemical model for the pre-VRR Murray alteration composition reacted with GPW. The model was run at 50 °C and 0.1 Fe^{3+}/Fe_{tot}.

Conclusions: Results presented here and by [6] show how derived alteration compositions for the Murray formation can be reacted with a dilute brine (GPW) to produce an alteration mineral assemblage comparable with the clay mineral-hematite assemblage observed in the Murray formation on and below VRR. Results presented in this abstract focus on models run at 50 °C, however additional models show that temperatures can extend to 100 °C, with pH ranging between 7.9 and 9.3 at ~10,000 W/R [6]. This modeling suggests that the alteration mineral assemblage observed in the Murray formation is due to enhanced groundwater flow through this part of the Gale sedimentary sequence, compared to previous observations and modeling in the Bradbury group at Yellowknife bay [9].

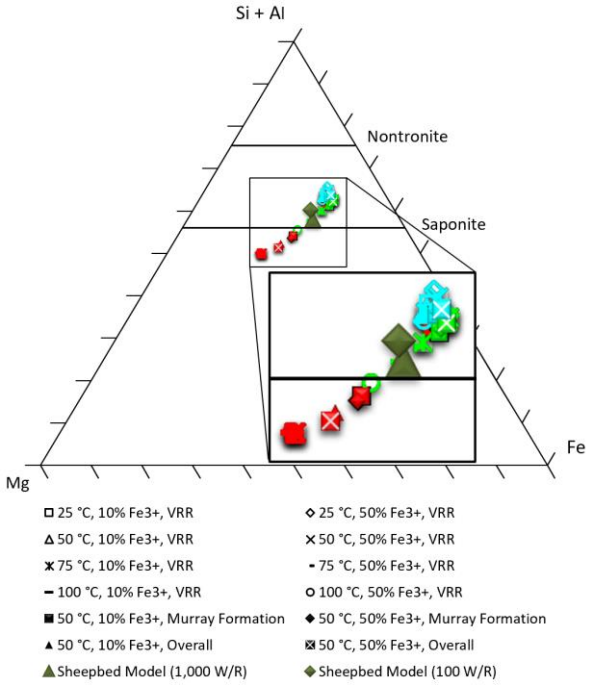

Fig. 3: Mg-Si+Al-Fe_{tot} at. ternary plot. Results at 10,000 (red), 1,000 (green) and 100 (blue) W/R from the thermochemical models in this abstract and in [6] are plotted with some additional data from other sources for comparison. CHIM-XPT results for the Sheepbed unit from [9] at 100 and 1,000 W/R are shown for comparison.

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