FLUID COMPOSITION AND MINERAL REACTIONS AT YELLOWKNIFE BAY, MARS. J. C. Bridges[1], S. P. Schwenzer[2], R. Leveille[3], F. Westall[4], A. Ollila[5], R. Wiens[6], N. Mangold[7], G. Berger[8] and A. C. McAdam[9] [1] Space Research Centre, University of Leicester, UK, j.bridges@le.ac.uk, [2] Dept. of Physical Sciences, Open University, Milton Keynes, UK, [3] Canadian Space Agency, St-Hubert, QC, [4] Centre de Biophysique Moléculaire, CNRS, 45071 Orléans Cedex 2, France, [5] Dept. of Earth and Planetary Sciences, Institute of Meteoritics, University of New Mexico, USA, [6] International Space and Response Division, Los Alamos National Laboratory, NM 87544, USA, [7] Laboratoire Planétologie et Géodynamique de Nantes, LPGN/CNRS and Université de Nantes, France, [8] IRAP, Obs. Midi-Pyrénées, 31400 Toulouse, France. [9] NASA Goddard Space Flight Center Greenbelt, MD 20771, USA.

Introduction and Aims of this Study: The *Curiosity* rover of *Mars Science Laboratory* (MSL) has identified and analysed, for the first time on Mars, a set of mudstones with nodules and Mg-rich veining, recording a history of deposition within a fluvio-lacustrine environment followed by low temperature alteration [1,2]. The composition and mineralogical information preserved in the Gale Crater sediments provide a unique opportunity to determine the evolving composition of the fluid associated with the sediment's diagenesis and the nature of its interaction with the surrounding rocks. In this study we constrain water/rock ratios, temperature, pH, composition and salinity of the diagenetic fluid. In particular we model the likely alteration of olivine and amorphous, allophane-like material within Sheepbed mudstone to produce the observed phyllosilicates and Fe oxides.

Methods: We use the composition of Gale rocks and Mg-rich veins determined by ChemCam [3-5], APXS [6-8] and CheMin [9,10,11]. For thermochemical modelling of fluid-rock reactions we apply the code CHIM-XPT [12]. We tested two different types of starting fluids: 'Adapted Water' (AW) [13] and 'Gale Portage Water oxidised' (GPWox, a dilute fluid resulting from reaction with Portage, i.e. a local brine) [14] in order to cover a realistic range of conditions. Water/Rock is a progress variable with very limited rock dissolution at the high W/R end, see [15]. In the runs shown in Figs. 2,3 amphiboles, pyroxenes and garnets are excluded. We report alteration assemblages for 3 representative host compositions: Jake_M, Ekwir_brushed and Portage soil, and compare them to XRD results [8,9]. The Sheepbed mudstone contains 22% (John Klein drillhole), to 18% (Cumberland drillhole) Fe-smectite and a 13 Å spacing in the latter sample, which may be from partially chloritised smectite. These are part of a basaltic, Fe-sulfide-bearing mineral assemblage, that also contains substantial amorphous, allophane-like material 28-31% [9]. The Portage soil contained no crystalline phyllosilicates and 27% amorphous material [10].

Results: We have perfomed over 139 runs spanning 10-300 °C and including different starting rock compositions, mineral mixes and starting fluid compositions.

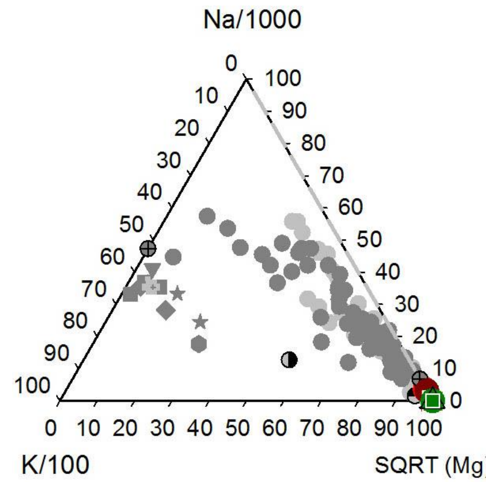

Figure 1. Na-K-Mg ternary plot of Gale Diagenetic Fluid. Coloured symbols are the brine accompanying the alteration (this study and [14]). Note that AW and GPWox results at 10, 50 and 150 °C coincide (yellow, green and red symbols). Martian comparison: Lafayette fluids (half circles, W/R 100 to 1 [15]). Terrestrial comparisons: Deccan trap fluids (light grey circles; [16]), Icelandic geothemal waters (dark grey circles; [17]), various geothermal waters worldwide from [18] (all non-circle shaped grey symbols), saline lakes (dotted circles [19,20]), Kenyan Rift Valley water (crossed grey circle [21]). Units g/l.

Whole Rock Alteration. The basaltic compositions of Portage soil and Ekwir_brushed mudstone, when reacted with AW at 10-50 ^{o}C, and at W/R of 1000-100, pH 6.0 to 10.2 (10 °C) and 5.2 to 6.9 at 50 °C produce mineral assemblages – Fe smectite (nontronite), chlorite, Fe oxide – that most closely match the chlorite-smectite, sulfide and magnetite bearing assemblage identified in the Sheepbed mudstone by CheMin [9]. The alkaline composition Jake_M [7] is not a likely source for the secondary mineralogy as neither kaolinite nor serpentine and zeolites are present in the secondary assemblage but they are formed in the modelling. High temperature, hydrothermal mineral assemblages ≥150 ^{o}C, derived from either basaltic or alkaline rocks, in the Gale Crater rim, and transported as detrital grains into the Sheepbed mudstone, are also unlikely to be major constituents in the Sheepbed mudstones, as this material would include kaolinite.

The fluid compositions in equilibrium with the secondary minerals at W/R of 100 are shown in Fig. 1 for both AW and GPWox starting fluids. At W/R = 100, the system is rock-dominated, but ionic strength is still moderate. The Na and K contents of the Gale brines are generally low compared to the Mg (and Fe) concentrations. In a terrestrial environment, this is a feature of fresh water, and the lowest Na contents in the Deccan Trap waters usually correspond to the lowest salinities [16]. The fluids in equilibrium with the observed mineralogy fall at the highest Mg/(Na+K) endmember. They are in that respect similar to the fluids modelled from a Lafayette martian meteorite starting composition (with AW) [15]. This demonstrates the juvenile nature of the Gale fluid that precipitated the observed clay minerals. The overall salinity of the fluid during the diagenesis was ≤3500 mg/kg.

Mineral Alteration. The results of modelling mineral assemblages are shown in Figs. 2 and 3. Fig. 2 shows that where dissolution predominantly affects amorphous material (70%), with 20% olivine, 10 % whole rock, then Fe-rich smectite (nontronite), chlorite and Fe oxides are produced. Magnetite is precipitated at lower W/R. In Fig. 3 by contrast, where the dissolution favours olivine (70%) with 20% amorphous material, serpentine is the dominant phyllosilicate, with <15% nontronite and chlorite. These results suggest it is not just olivine that reacts to form the phyllosilicates identifed in Yellowknife Bay but that amorphous material is critical in these reactions.

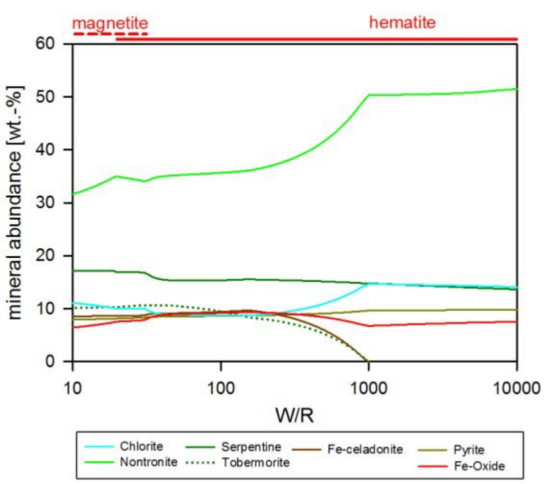

Figure 2. 70% amorphous, 20% olivine, 10% whole rock at 10 ^{o}C, reacted with GPWox starting fluid.

Conclusions: The phyllosilicate and magnetite-bearing assemblage in the Sheepbed Mudstone of Gale Crater formed during diagenesis from a fluid that was juvenile, alkali-poor, brackish, Cl, Fe, Mg-rich, neutral to alkaline at W/R 100-1000, 10-50 ^{o}C. Detrital amorphous material, and to a lesser extent olivine, were the 2 major components that contributed to the mineralogy described by [2,9] through selective dissolution.

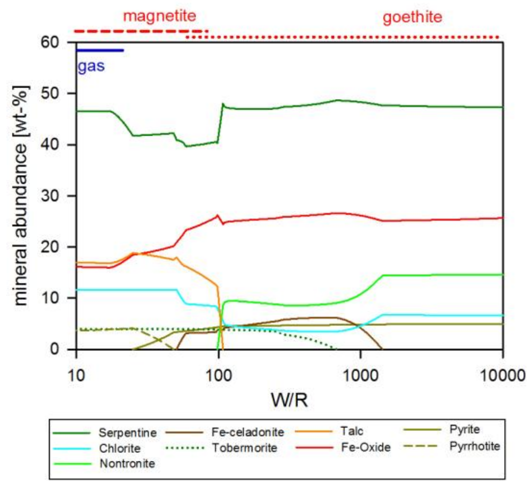

Figure 3. 70% olivine, 20% amorphous, 10% whole rock at 10 ^{o}C, reacted with GPWox starting fluid. Note gas production, which is dominated by ~90 % H_2. Methane is predicted, too, and might be possible in the presence of magnetite despite kinetic problems [22].

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