

THE NAKHLITE HYDROTHERMAL BRINE. J. C. Bridges¹ and S. P. Schwenzer², ¹Space Research Centre, Dept. of Physics & Astronomy, University of Leicester, LE1 7RH, UK, j.bridges@le.ac.uk, ²CEPSAR, The Open University, Milton Keynes MK7 6AA, UK, s.p.schwenzer@open.ac.uk.

Introduction: Mineralogical studies have demonstrated that the nakhlite SNC meteorites have preserved the effects of water-rock interaction between a hydrothermal brine and the nakhlite parent rocks on Mars. Brittle fracturing and corrosion of olivine grains and mesostasis associated with the hydrothermal event have left veins of zoned Fe-carbonate, Fe-smectite (with minor serpentine), and an amorphous gel of smectite composition [1] (Fig. 1). In addition the fluid was trapped in fluid inclusions within the cumulus pyroxene grains, though most of these have since been split, perhaps during the impact ejection [2]. The most complete assemblage is preserved in the Lafayette meteorite, which on Mars was closest to the heat source that we envisage as an impact prior to the one which led to the ejection of the nakhlites from Mars. Final evaporation of the residual brine left soluble salts. A terrestrial overprint can be distinguished in some of the nakhlites, e.g. jarosite in Y000749 [1]. This detailed characterization now allows us to accurately determine the T, pH and composition of the martian fluid.

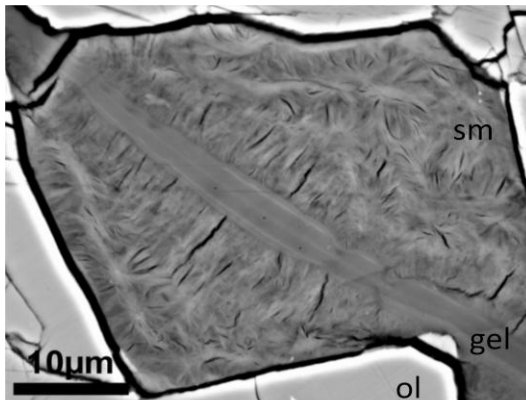


Figure 1. Fe smectite (sm) and gel, with similar composition but amorphous, within vein in olivine (ol). Lafayette nakhlite, NHM sample, BM 1958, 775.

Fluid Modelling: The formation conditions of the observed minerals during brine–host rock contact can be modelled, leading to an assessment of the hydrothermal brine. We used CHILLER [3] to calculate the species in solution, temperature, fluid salinity and pH as well as identify minerals precipitating from that brine upon cooling and evaporation.

Host rock chemistry was calculated from Lafayette whole rock and olivine [4] and Lafayette mesostasis (new SEM-EDX data) in an iterative process that allows for the observed alteration minerals to form [1]. The starting fluid was taken from fluids that discharge at Deccan Trap thermal vents [5]. Various amounts of CO₂ were added to explore the carbonate formation parameter space. CO₂ concentrations ranged from 10 (in the early, carbonate-rich part of fluid's history) to 0.1 mole/kg water. In each run calculation of the alteration assemblages starts at very high W/R and proceeds to lower W/R. W/R thereby is expressed in g/g and on the basis of 1 kg (or 55 mole) of water, which was kept constant except for the evaporation runs designed to model the final stages of the fluid's evolution. The W/R therefore reflects the amount of rock that has reacted with the fluid, which is lower than the total amount of rock in the Lafayette system. This is consistent with the observation that many parts of the rock remain fresh and unaltered.

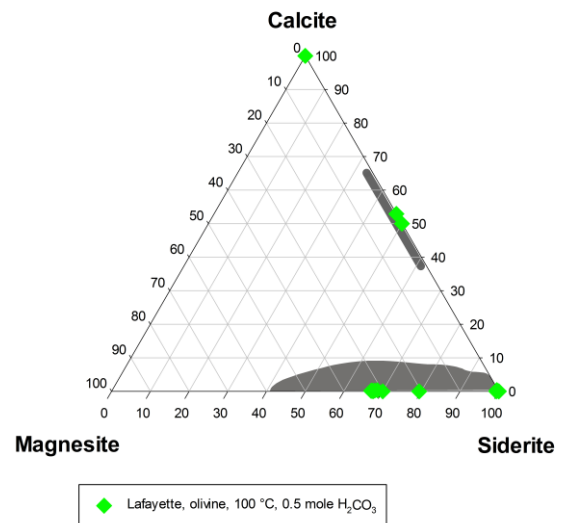


Figure 2. Carbonate composition in the nakhlite meteorites shown in grey areas [6]. Green symbols are the carbonates precipitated at W/R ~10, and 75-100 °C, pH 8 at the earliest stages of the fluid's evolution. The fluid at this point is dominated by dissolution of olivine.

Results: Our modelling results show that corroding olivine is the dominant source for cations in the early stages of the fluid's evolution, associated with Fe (Ca) carbonate growth which closely matches that of the nakhlites (Fig. 2). At this stage the W/R is approx-

imately 10, and 75–100°C, pH 8. Bulk Lafayette and mesostasis progressively become more dominant components of the fluid. With the components 70% ol, 20% bulk, 10% mesostasis and an extra albite-like component (cations Na, K, Al, and Si dissolved in the early stages but not precipitated with the carbonate), the precipitated assemblage resembles that of the silicate secondary assemblages (Fig. 3). Smectite and serpentine precipitate at 50°C, pH 9.5, and with the W/R at 5.7 the mineral compositions e.g. Mg#, Ca content are close to those in the nakhlites [1,6]. The fluid at this stage is a dilute brine, 0.06 mole/l. Final evaporation of the brine produces the soluble salts present in Nakhla.

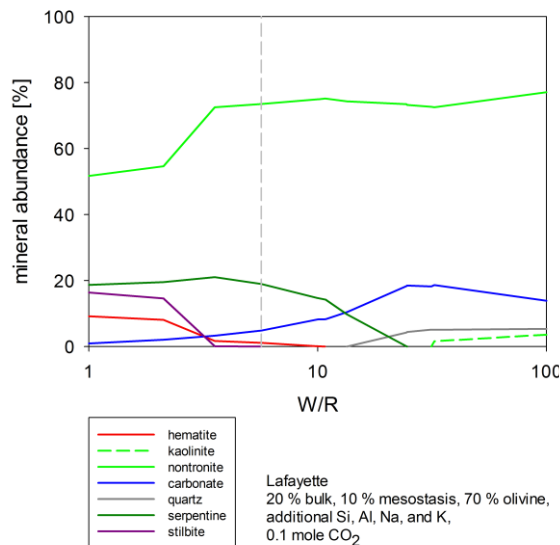


Figure 3. Silicate mineral assemblages precipitated from the modelled brine derived from a mixture of 20 % bulk Lafayette, 10 % mesostasis, and 70 % olivine and an albite-like component (Si, K, Al, Na) was added to the starting rock composition. The vertical dashed line at W/R = 5.7 is the point at which the mineral assemblage and mineral composition most closely match that of the nakhlites. W/R water rock ratio (g/g).

Discussion: The origin and evolution of the nakhlite brine resulted from the partial dissolution of parent rocks similar to Lafayette in composition. The dilute brine was initially CO₂-charged, and CO₂ concentrations decreased with carbonate precipitation. Temperatures reached 100°C and were progressively alkaline, reaching pH 9 towards the end of the hydrothermal event. At first the fluid was dominated by dissolution of olivine at W/R 10, and this corresponds to the early phase of Fe-carbonate precipitation. At 50°C the Fe smectite (with lesser serpentine in the

mesostasis alteration) appear together with minor Fe oxide. Rapid, metastable precipitation of a smectite-like composition led to precipitation of the amorphous gel found throughout the nakhlites as a late product of the hydrothermal brine. The fluid had low W/R ratios, e.g. 5.7, during smectite crystallisation consistent with our model of partial corrosion of the nakhlites over a relatively short period of time.

Further refinements of this fluid modelling will be achieved through the use of additional thermodynamic data, modelling techniques and calculation of ferric contents of the hydrothermal minerals [7]. We aim to use the results of our fluid modelling to assess the habitability of such fluids, which may be associated with impact structures [8].

References: [1] Changela H. G. & Bridges J. C. (2010) Alteration Assemblages in the Nakhlites: Variation with Depth on Mars. *MAPS*, 45, 1847–1867. [2] Bridges J. C. et al. (2000) Progressive evaporation and relict fluid inclusions in the nakhlites. *LPS XXXI*, Abstract #1590. [3] Reed M.H. & Spycher N.F. (2006) Users Guide for CHILLER. University of Oregon. [4] Treiman A.H. (2005) The nakhlite meteorites: Augite-rich igneous rocks from Mars. *Chem. Erde.*, 65, 203–270. [5] Minissale A., Vaselli O., Chandrasekharan D., Magro G., Tassi, F. & Casiglia, A. (2000) Origin and evolution of ‘intracratonic’ thermal fluids from central-western peninsular India. *Earth and Planetary Science Letters*, 181, 377–394. [6] Bridges J.C. et al. (2001) Alteration assemblages in the Martian meteorites: Implications for near-surface processes. *Space Science Reviews*, 96, 365–392. [7] Hicks L.J., Bridges J.C. and Gurman S.J. (2011) Ferric iron content of nakhlite hydrothermal minerals. *LPS LXIII* (subm.). [8] Schwenzer S. P. and Kring D. A. (2009) Impact-generated hydrothermal systems capable of forming phyllosilicates on Noachian Mars. *Geology* 37, 1091–1094. [8]