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Crust-atmosphere coupling and carbon sequestration on palaeo-Mars

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The modern surface of Mars displays evidence for past liquid water flows, with mounds and polygons in the Chryse-Acidalia region possibly indicating large bodies of ancient standing liquid [1]. For liquid water to be stable at the planet's surface, temperatures of >273.2K and a saturation water vapour pressure of >6.1 mbar are required [2]. To achieve such conditions, atmospheric pressures >1 bar CO_2 have been hypothesised during the late Noachian/early Hesperian period (i.e. $\sim$1.4-3.0 Ga [3]). Mars' currently thin (6 mbar) atmosphere poses the question of the fate of the hypothesised multi-bar CO_2 atmosphere. Estimates for $\sim$270 mbar lost to space [4], with $\sim$5 mbar at the poles [5], leaves a minimum 750 mbar unaccounted for.

The nakhlite martian meteorites display clear evidence of low water to rock (W/R) ratio isochemical silicate mineral carbonation [6]. Such carbonation processes can also be observed in basic terrestrial rock exposures, such as the Leka ophiolite, Norway [7].

Hydration and carbonation of silicate rocks is an important negative feedback process in the terrestrial carbon cycle. Significant atmospheric CO_2 removal via silicate weathering partly balances the volcanic CO_2 output. Peridotite contains >40% olivine, which can hydrate to form quartz, magnesite and serpentine and these reactions may be followed by carbon sequestration, forming highly alkaline travertine springs (pH>11), which have been observed in terrestrial ophiolites worldwide.

Carbonation is exothermic, with the total fully carbonated solid products possessing 44% greater mass than the reactants [8]. This causes cracking [9], exposing fresh reactant surfaces, although this can be offset by expansion causing reduced porosity [10]. The raised temperatures increase reaction rates, and a positive feedback mechanism of sustained carbonation can develop.

The crust of Mars is composed of similarly basic minerals, mostly basalt on the surface [11]. By investigating carbonated terrestrial analogues a deeper understanding of Martian crust-atmosphere dynamics can be achieved, possibly accounting for the loss of an early >1bar CO_2 atmosphere.

This research will conduct detailed petrographic observational analysis of terrestrial carbonation from collected samples of the Leka ophiolite, Norway, comparing the results with data available for Martian meteorites. It will the conduct chambered carbonation experiments on terrestrial ophiolite samples using a variety of mineralogical compositions under incrementally increased CO_2 pressures, repeating with increasing ratios of CO_2/SO_2 mixtures. The results of objectives 1 and 2 will be synthesised to create a quantitative Martian CO_2 model with variable parameters of atmospheric compositions, pressures and crustal compositions. By analysing carbon sequestration processes at differing scales and environments, carbonation rates and total silicate carbonation volumes under palaeo-martian atmospheric and mineralogical conditions can be estimated. Further mineralogical evidence to validate the model will be sought using the Curiosity Rover's Mars Science Laboratory, and collaborating with industrial partners, a new rock polishing tool will be designed, built and tested for planned use on future rovers.

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