PhD projects: The Nature of Magmatic Carbon on Mars

This studentship is based at the University of St Andrews in partnership with the University of Edinburgh, the Open University, and the Geophysical Laboratory (Carnegie Institution of Washington, USA).

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**Key Words**
1. Carbon Geochemistry
2. Martian Magmatism
3. Experimental Petrology

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Funding eligibility: Fully-funded by the UK Space Agency for 3.5 years (available to all EU nationals)
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To Apply, click here
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**Overview**

**Introduction**

Differentiating between the possible source(s) for biologically-significant carbonaceous compounds in the Martian lithosphere and atmosphere is not straightforward because the chemistry of a planet’s atmosphere is an archive of surface and subsurface processes, inclusive of volcanism, weathering, meteoritic influx, and biological processes. For example, methane (CH₄) has been observed in the Martian atmosphere, but the origin(s) of these emissions are enigmatic. Several hypotheses are open to examination including [i] an extant subsurface biosphere, [ii] hydrothermal activity, [iii] the melting of clathrates or [iv] present-day (non-eruptive) magmatism (Formisano et al., 2004; Mumma et al., 2009; Webster et al., 2014; 2018). Recent insights show that sedimentary rocks on Mars can store reduced organic carbon on billion-year timescales (Eigenbrode et al., 2018), and the source domain for Martian basalts are known to contain both solid macro-molecular carbon and gaseous organic carbon components (CH₄; Blamey et al., 2015). Importantly, macro-molecular carbon co-occurs in association with high-temperature magmatic minerals, and this requires that they are sourced directly from the Martian interior (Steele et al., 2012). Ergo, a reduced carbon component present during Martian magmatism could be a primary source of recently observed CH₄ in the Martian atmosphere (Webster et al., 2018). **Addressing this possibility is fundamental to the ExoMars programme, and establishes the focus of this fully-funded PhD project.**

**Primary Objectives**

The main aim of this PhD studentship is to test the hypothesis that gaseous methane in the Martian atmosphere and solid macro-molecular carbon in Martian basalts can be the product of Martian magmatism. To achieve this, we will address three key objectives:

[1] What carbonaceous gases does magmatism release into the Martian atmosphere?

[2] Is macro-molecular carbon in Martian basalts the result of Martian magmatism or secondary alteration in the Martian lithosphere?

[3] What is the equilibrium carbon isotope value of magmatic carbon on Mars?

**Approach**

To address these questions, a PhD student will execute an integrated experimental and theoretical research programme to investigate the nature of magmatic carbon on Mars (as shown in Fig. 1a). This project will also contribute fundamental data necessary for interpreting and constraining the speciation of abiogenic carbon on Mars as determined from geochemical data obtained from the ExoMars rover, including providing context for its life-detection experiments.
We will replicate the conditions thought to be representative of Martian magma chambers to gain understanding of the speciation of carbon during differentiation of magma in the Martian lithosphere. Then we can examine the nature of carbonaceous gases that should be degassed and detected by the Nadir and Occultation for Mars Discovery (NOMAD) instrument on the Trace Gas Orbiter (TGO) which is making measurements of the Martian atmosphere (today).

Work Package 1 (WP1): Magmatic Carbon (years 1-2): One cannot accurately model stable isotope data without knowledge of the bonding environments within a given system. Therefore, the aim of the first work package is to provide the required experimental constraints to enable precise thermodynamic modelling of the speciation of solid and gaseous magmatic carbon under pressure, temperature, and chemical conditions applicable to Martian magma chambers (Fig.1). These data will provide essential information on the fraction of carbonaceous gases (CO$_2$/CH$_4$) released into the Martian atmosphere, alongside determining which carbonaceous phases (MMC/graphite/hydrocarbons) will be emplaced into Mars’ crust. Piston cylinder presses at St Andrews and Edinburgh will be employed to simulate the conditions of melting and magma chamber crystallisation on Mars (between 0.5-1.0 GPa and 800-1600°C). The texture of all run products, their redox state and phase assemblage (petrology) and the speciation of gaseous carbon in the fluids/gases and silicate melt will be determined in situ on quenched run products using Raman and infrared absorption spectroscopy followed by scanning electron microscopy and electron microprobe analysis (available at St Andrews, OU, Carnegie, and Edinburgh). The speciation of solid carbon in these samples will be mapped using the state-of-the-art custom built confocal micro-Raman spectroscopy facility at the Geophysical Laboratory using the method detailed in Steele et al., (2012).

Work Package 2 (WP2): Isotope Fractionation (years 2-3): On Earth, magmatic carbon is characterised by $\delta^{13}$C values of -5 ± 2‰ (see Mikhail et al., 2014). However, magmatic carbon on Mars is characterised by $\delta^{13}$C values < -20‰ (Grady & Wright, 2003). Isotopically-speaking, one can empirically state that mantle carbon from Earth ≠ mantle carbon from Mars. Importantly, life on Earth shows a preference for the lighter isotope ($^{12}$C vs $^{13}$C) because C-H bonds require less energy, and Martian magmatic $\delta^{13}$C values of < -20‰ overlap with biogenic $\delta^{13}$C values on Earth. Ergo, to accurately interpret Martian atmospheric $\delta^{13}$C data one must fully understand the isotopic nature of magmatic carbon on Mars (Stevens et al., 2017 & this study). Following the synthesis protocol of WP1, we will produce carbon-oversaturated experiments across redox conditions designed to generate samples whereby the carbon is present as dissolved carbon in a silicate glass and gaseous carbon exsolved from the melt. Gaseous carbon will be extracted via vacuum crushing, and the dissolved carbon by heating of crushed glass in vacuum (both attached online to a Thermo MAT253 isotope ratio mass spectrometer at St Andrews). We will then generate curves for carbon isotope fraction factors vs temperature for different carbonaceous systems (gaseous CH$_4$ or CO$_2$ in equilibrium with dissolved CO$_2^{2-}$ or C$^0$).

**Methodology**

The student will utilise several analytical methodologies at the host and partner institutions, listed below:

- Piston cylinder and 1-atm gas-mixing experiments (St Andrews, Edinburgh, Geophysical Laboratory)
- Stable isotope analysis (University of St Andrews)
- u-Raman spectroscopy (Geophysical Laboratory)
Training & Skills

Training Opportunities: Along with the specialist training provided by the supervisory team, the student will attend external training workshops such as the experimental petrology workshop at the Bayerisches Geoinstitut (Germany), and micro-analytical technique workshop at the University of Bristol (UK). The opportunity to engage in demonstrating (St Andrews) will also be available. The student will attend the UK Aurora meetings, the Geochemistry Groups UK-based Research in Progress meeting, and at least 2 international meetings (e.g. LPSC, Goldschmidt), to gain experience in presentation, public speaking and professional networking; essential skills for a career in either academia or industry.

Research Environment: The student will be enrolled at St Andrews as a member of the postgraduate-only college of St Leonards. Therefore, besides the bustling postgraduate and postdoc community the School of Earth and Environmental Science, the student will instantly become part of an eclectic and wider community inclusive of membership in the Centre for Exoplanet Sciences. For the School, the research foci are diverse with a strong emphasis on isotope geochemistry, atmosphere evolution, and petrology. Alongside the research experience and supervision at the host institution the student will benefit from experiencing the research environment of the three partner institutions and co-supervision from leaders in the fields of experimental petrology (Dr Bromiley), spectroscopy (Dr Steele), and planetary exploration (Dr Patel). These collaborations provide the opportunity for international experience in the USA at the Carnegie Institution of Washington working with Dr Steele (Co-I on active NASA and ESA missions including instruments on the Mars Science Laboratory on the MSL Rover and the Philae Lander). Finally, the student will also be working alongside Dr Patel (Open University, UK) who is Co-PI for NOMAD and is involved with present-day planetary exploration (ExoMars TGO). In summary, this project provides state-of-the-art training associated with exciting research that is helping to define the cutting edge of planetary science.

References & Further Reading

Blamey et al. 2015. Evidence for methane in Martian meteorites. Nature Communications. doi:10.1038/ncomms8399


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