Using Terrestrial Basalts as Analogues for Extra-terrestrial Volcanism; implications for off-world construction & in-situ resource utilisation.

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Scientific Background & Rationale: The diverse surface of Mars holds the key to understanding its early differentiation and subsequent evolution and is vital in our search for potentially habitable environments elsewhere in the Solar System. Martian meteorites are, to date, the only samples of the surface currently available to science. Apart from the Martian breccias, these meteorites represent true volcanic or magmatic rocks, recording Martian volcanism from the ancient Noachian to the present Amazonian (see figure 1). Until we have direct sample return from Mars, these unique meteorites provide us with a rare opportunity to directly study the Martian crust and constrain volcanic behaviour through time [1].

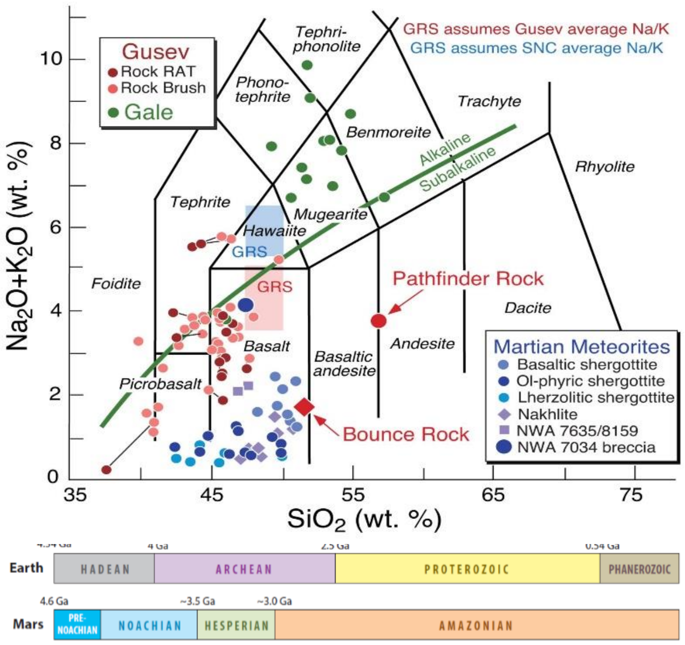

Figure 1: Total alkali-silica (TAS) diagram for Mars illustrating geochemical classification of igneous rocks on Mars from orbiter, rover, and meteorite data (top) [1]; Geological evolution of Mars timeline in comparison to Earth, where Mars' volcanism extends from the Noachian through to present day (~110 Ma), after [12].

Current international efforts to explore Mars are focussed on Mars Sample Return (MSR); high precision analysis of the sampled materials will provide answers to many of the outstanding questions concerning Mars' origin & evolutionary history. However, future Mars missions (including landers and rovers proposed within MSR) require ground-truth to assess their viability on Mars' often inhospitable surface. In-situ resource utilisation (ISRU) is a key component in the future of human exploration and the establishment of sustainable infrastructure to facilitate the future human exploration of Mars. Various projects funded by NASA with industrial partners are underway to investigate the use of local materials for the 'off-world construction' of habitats via 3D printing or additive manufacturing that could be used on airless bodies [e.g. 2], and whether regolith (unconsolidated, organic-free material on the surface of extra-terrestrial bodies) can be utilised for this purpose [3].

Analogue, or 'simulant', materials aim to replicate either the geotechnical or petrological signatures of their extra-terrestrial counterparts so that they can be used in engineering tests and/or equipment viability assessments such as within the Mars Yard at NASA Jet Propulsion Laboratory [4] without the necessity to perform destructive analysis on precious extra-terrestrial samples. These materials must also be able to withstand exposure to airless environments and endure potential bombardment from micro-meteorites or space debris if they are to be used off-world. Both ESA and NASA produce and curate simulant materials for various bodies using terrestrial rocks [5, 6], therefore interest in benchmarking simulant materials and their properties relative to "real" extra-terrestrial samples is growing. Previous investigations into planetary materials have involved microscopic and spectroscopic techniques [e.g. 7, 8] alongside scattering techniques to investigate the bulk thermal properties of these extra-terrestrial materials [9]. However, only recently are we beginning to appreciate the subtle differences between analogues and the true Lunar or Martian materials [10] that astronauts will eventually be faced with.

This project aims to ground-truth NASA & ESA analogues, alongside the identification & classification of new, terrestrial analogues that could provide a better fit to Mars' surface geology [11], enabling new research into the suitability of materials for both scientific investigation and off-world construction for the future of sustainable space exploration.

Project Aims & Objectives: This project aims to determine whether existing analogue materials are fit for purpose for off-world construction by investigating true extra-terrestrial materials, alongside the terrestrial and synthetic analogues produced by both NASA and ESA, to determine:

(a) How well the analogues geochemically match true extra-terrestrial materials.
(b) A full microstructural characterisation of Martian & analogue materials to establish strength, identify weaknesses, and investigate longevity.
(c) Whether these materials can be used as is for ISRU on extra-terrestrial surfaces, or whether other considerations need to be made for successful application in 3D printing as described in the literature.

	Year 1				Year 2				Year 3			
T1. Student induction & training in electron nanobeam techniques	■	■										
T2. SEM characterisation of Martian meteorites - chemistry & nanostructure with EDS, EBSD, and EPMA via project partners		■	■	■								
***T3.** Optional fieldwork (funding dependent) to collect orientated samples from terrestrial lava flows at an analogue site (working with local teams) and/or meteorite recovery in the Australian outback*				■	■							
T4. SEM characterisation of analogue samples - chemistry & nanostructure with EDS, EBSD (PEMC; Oxford Instruments), and EPMA via project partners				■	■	■	■					
T4. Extraction of specific crystals for 3D-EDS/EBSD, also TKD analysis, from Martian & terrestrial samples						■	■	■				
T5. Additional data collection (LA-ICP-MS) from both sample sets, Martian & terrestrial analogues with project partners for trace element determination							■	■	■			
T6. Comparison of Martian samples to terrestrial analogues, context from in-situ, orientated sampling (EBSD), potential flow identification at Mars								■	■	■	■	
***T7.** Optional placement within applications development team at Industry partner, Oxford Instruments, using own samples to help develop advanced in SEM-EDS & WDS software*										■	■	
T8. Preparation of thesis for examination										■	■	■
M1. Characterisation of Martian volcanism; EBSD determinations of flow vs settling (T2; T5)				■								
M2. Comparison of Martian volcanism to terrestrial analogues, context from in-situ, orientated sampling (T3; T4; T5)								■				
M3. Exploration of ISRU suitability of current simulants alongside newly identified analogues, compared to Martian samples (T6; T8)												■

Table 1: *Project timeline and milestones. T = task; M = milestone.*

Student Training & Opportunities: The student will join the Imperial planetary research group within ESE but work with project partners across the UK and Australia. The student will be trained in various analytical microscopy techniques; scanning electron microscopy (SEM) and analytical techniques within the SEM, used for non-destructive geochemical (Energy Dispersive Spectroscopy - EDS) or structural (Electron Backscatter Diffraction - EBSD) characterisation. Non-destructive approaches are essential for planetary geology, where samples are extra-terrestrial in origin and irreplaceable. Additional support is available via collaboration with the University of Portsmouth on their NERC-funded fs-LA-ICP-Mass Spectrometer for trace element analysis.

External Partners: Various partners have committed in-kind support to this project, including Oxford Instruments Ltd., covering costs for instrument access, software licensing, training, and development opportunities within their global headquarters.

Fieldwork: Optional fieldwork to collect new samples is within scope; terrestrial basalts from known and provisional sites including Hawaii, New Mexico, or Iceland. Extra-terrestrial samples will be recovered from the Nullarbor Plain in South Australia, in partnership with Australian colleagues.

References: [1] McSween (2015) Science [2] Yashar et al. (2021) ICES-2021-96 [3] Goulas et al. (2017) Applied Materials Today 6, 54-61 [4] Zhou et al. (2014) Journal of Field Robotics 31(1) 1410160 [5] Martin et al. (2019) LPSC L, #2663 [6] Butts et al. (2011) Advances in Space Research 47(11), 1912-1921 [7] Stephen et al. (2014) LPSC XLV #1378 [8] Stephen & Dijkstra (2015) Annual Meeting of the Meteoritical Society #1856 [9] Brand et al. (2019) LPSC L #1361 [10] Brand et al. (2020) LPSC LI #1628 [11] Willcocks et al. (2021) Annual Meeting of the Meteoritical Society #6061 [12] Wordsworth, R.D. (2016) Annual Review of Earth & Planetary Sciences. 44:1–31.

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