

14th Early Career scientists' Annual Meeting



UK

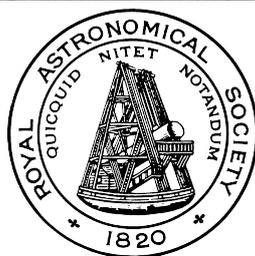
Planetary Forum

23rd January 2017 - The University of Manchester

Comet 67P from 16 km (Rosetta-ESA)

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The UK Planetary Forum

<http://ukplanetaryforum.org> | ukpf@hotmail.co.uk

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The UK Planetary Forum (UKPF) was founded in 1996 as a representative body of the planetary science community. Its main aim is to promote planetary research in the UK among scientists and the public. UKPF is affiliated with the Royal Astronomical Society (RAS).

The UKPF maintains a website and mailing list through which announcements, news and opportunities are posted. There are over 440 members of the UKPF from institutions across the UK and the worldwide community of planetary scientists. The list also includes research council and media representatives. We are keen to develop innovative activities to promote planetary science in the UK and welcome suggestions and ideas from all of our members.

How to Join

We urge all members of the planetary science community to join the UKPF. Email your name and research details to the address above, or contact one of the committee members directly.

UKPF Committee

Natalie Curran (The University of Manchester | natalie.curran@postgrad.manchester.ac.uk)

Alex Clarke (The University of Manchester | alex.clarke-2@manchester.ac.uk)

Penny Wozniakiewicz (The University of Kent | P.J.Wozniakiewicz@kent.ac.uk)

Science Nuggets

In an effort to further address our aim of promoting planetary science in the UK, the UKPF will be introducing 'Science Nuggets' to our website (www.ukplanetaryforum.org) in early 2017. A Science Nugget consists of a single powerpoint slide that highlights the main findings of a recent paper or collaborative research effort (within the ~last two years) conducted in the UK, and gives relevant links to this research (e.g. to the paper and source of funding). The UKPF will advertise these Science Nuggets through monthly emails, postings on our facebook page and twitter posts. These Science Nuggets will therefore represent a great opportunity for you, as members of the UK planetary community, to publicise and raise the profile of your research and papers.

Science Nuggets should be submitted to the UKPF via email to ukpf@hotmail.co.uk using the template on the website above.

Acknowledgements

We would like to thank Gemma Coleman, Lynn Davies and staff at the University of Manchester for this help organising this conference. We are indebted to the Royal Astronomical Society, The University of Manchester and Isotopx for the funds to run this meeting and refreshments and to help keep the meeting a free event. Finally we would like to thank The University of Manchester for hosting us this year.

Travel

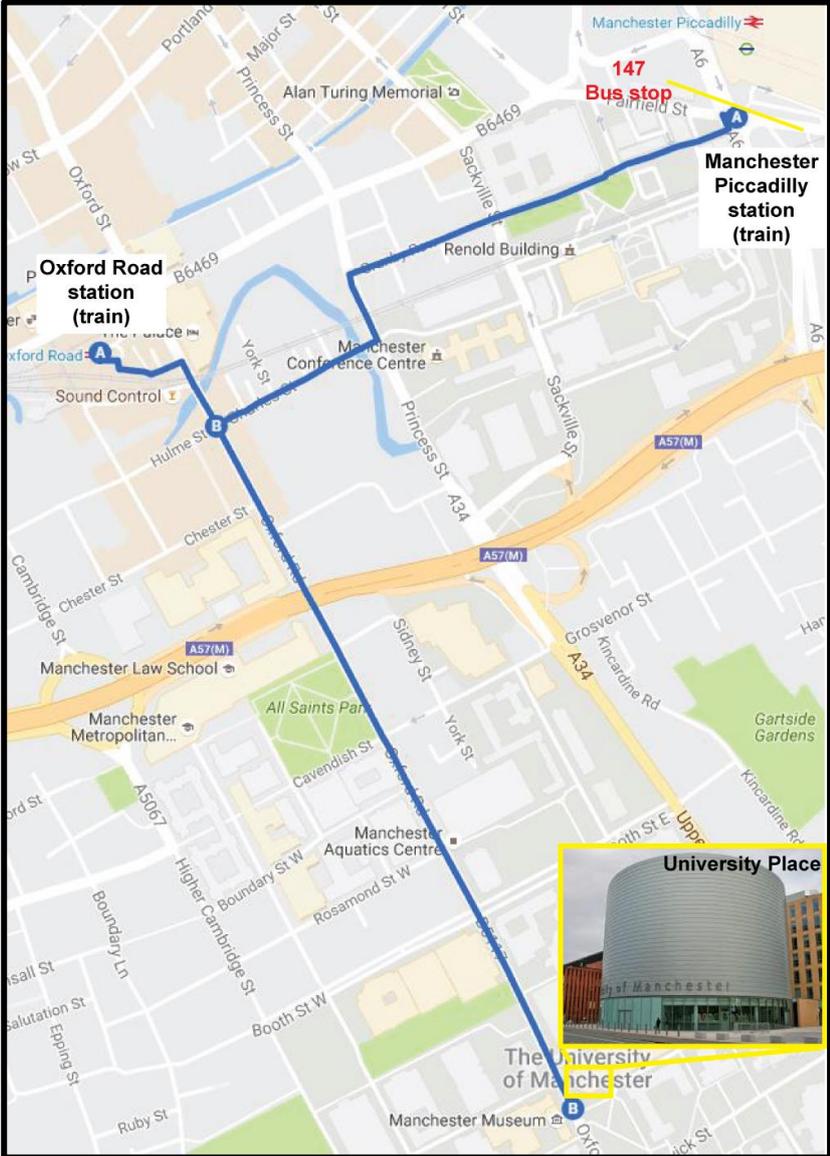
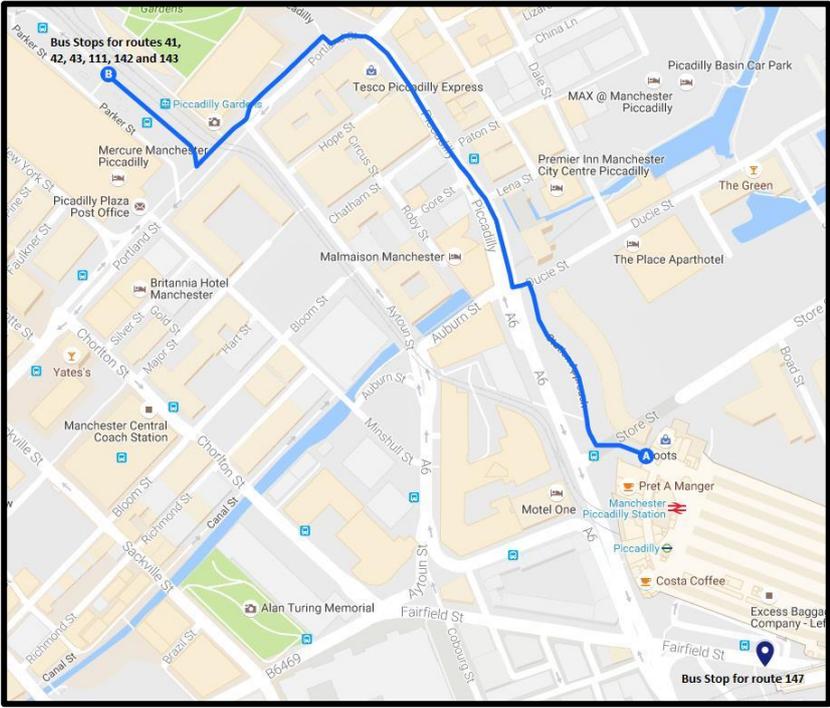
Rail: Manchester Piccadilly station has direct links to most cities around the UK, and is around a 20 minute walk from the conference venue. Manchester Oxford Road station is closer (around a 10 minute walk), but has fewer direct services, so you may have to change at Piccadilly. From either station, you can reach the conference venue by taxi, bus, or on foot.

Taxi: A taxi rank can be found outside both Manchester Piccadilly and Manchester Oxford Road railway stations. A taxi from either of these stations will cost £5-7, and take around 5 minutes.

Bus: Manchester Museum is served by many bus routes, which have regular services. The 147 departs from outside Manchester Piccadilly station (see map below), and takes around 10 minutes to reach the conference venue. Most other bus services depart from Piccadilly Gardens, around a 5 minute walk from Manchester Piccadilly station (see map below). From here, you can take the 41, 42, 43, 111, 142 or 143 to Manchester Museum, with most journeys taking around 10 minutes.

The Conference will take place in University Place, theatre A with poster session in the Ground Floor Drum Foyer. University Place is directly across the road from the Manchester Museum. The University of Manchester Visitors Centre is also located in University Place:

The Visitors Centre
The University of Manchester
Oxford Road
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M13 9PL
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Email: visitorscentre@manchester.ac.uk



UK Planetary Forum 14th Early Career Planetary Scientists' Meeting

- 09:30 Registration
- 09:50 Welcome Address
- 10:00 **Keynote: Professor Tim O'Brien** (Professor of Astrophysics and Associate Director of Jodrell Bank Centre for Astrophysics, The University of Manchester)
Title TBC
- 10:30 Thomas Wilson (UCL)
Herschel/SPIRE observations of water production rates and ortho-to-para ratios in comets.
- 10:45 Thomas Lawton (The University of Manchester)
Determining cometary noble gases with closed-system stepped etching.
- 11:00 Natasha Almeida (Natural History Museum)
Utilising the meteorite collection at the Natural History Museum.
- 11:15 Tea/Coffee
- 11:45 **Keynote: Dr Romain Tartèse** (Natural History Museum Paris)
Abundance and origin of water and volatiles in the Moon.
- 12:15 Hannah Sargeant (The Open University)
Resource extraction at the lunar south pole.
- 12:30 James Mortimer (The Open University)
D/H fractionation during sublimation of water ice at low temperatures into a vacuum.
- 12:45 Samantha Bell (The University of Manchester)
Crystal storage and transfer in lunar magmatic systems.
- 13:00 Louise Alexander (Birkbeck)
Examining the history of the solar system preserved in the lunar regolith.
- 13:15 Lunch
- 14:15 **Keynote: Professor Andrew Coates** (Professor of Physics, UCL)
What next for UK planetary science? ExoMars, JUICE, BepiColombo and beyond.
- 14:45 Roger Stabbins (UCL)
Multispectral imaging with the ExoMars 2020 panoramic camera instrument.
- 15:00 Frances Butcher (The Open University)
Evidence for recent melting of glaciers on Mars.
- 15:15 Alfiah Putri (UCL)
Observing changes in the south polar residual cap with CTX-HRSC images.
- 15:30 Tea/Coffee
- 16:00 Nicola Mari (University of Glasgow)
Using wide-ranging meteorite ages and Os-isotope to provide new insight into the mantle evolution of Mars.

- 16:15 Aimee Smith (University of Glasgow)
Apatite in Martian meteorites NWA 7034 and NWA 8159.
- 16:30 Jack Piercy (University of Leicester)
Olivine alteration of shergottite Northwest Africa 10416.
- 16:45 Jack Wright (The Open University)
Volcanic shields on Mercury identified at last?
- 17:00 Poster Session
- 18:00 Close

Poster Session

- 1 Helena Bates (Natural History Museum)
Dhofar 2046- a thermally altered CM chondrite?
- 2 Hannah Chinnery (The Open University)
Volatile deposition in the Martian regolith.
- 3 Benjamin Farrant (The University of Manchester)
Volatile components and impact melt processing in the early solar system.
- 4 Leon Hicks (University of Leicester)
A 2-D model of the nakhlite parent rocks.
- 5 Jane MacArthur (University of Leicester)
A clastic meteorite from Mars: petrological and textural insights into Martian regolith processes.
- 6 Christopher Malliband (The Open University)
Preliminary results of 1:3 million geological mapping of the Mercury quadrangle H-10 (Derain).
- 7 Dayl Martin (The University of Manchester)
Micro-FTIR spectroscopy of Apollo 14, 15 and 16 regolith samples.
- 8 Francesca McDonald (The University of Manchester)
Halogen abundances in the lunar mantle: developing an understanding of volatiles of the Earth-Moon system.
- 9 Paul Streeter (The Open University)
Investigating the role of advection processes in improved Martian dust assimilation techniques for ExoMars.
- 10 Aaron Wilson (Imperial College London)
Simulation of the atmospheric entry of micrometeorites through the Martian atmosphere.

HERSCHEL/SPIRE OBSERVATIONS OF WATER PRODUCTION RATES AND ORTHO-TO-PARA RATIOS IN COMETS

Thomas G. Wilson¹, Jonathan M. C. Rawlings², and Bruce M. Swinyard³. ¹University College London. ²University College London. ³University College London.
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Introduction: Water is the main constituent of cometary comae, and multi-band sub-millilitre spectroscopy of fundamental rotational water lines is an important tool in studying the physical properties of comae.

Observations and Data Analysis: *Herschel*/SPIRE spectroscopic observations of three Jupiter-family comets and one Oort-cloud comet were analysed to study several fundamental rotational ortho- and para-water transitions. Cometary comae synthetic line profiles were produced using the RAT4COM radiative transfer model[1] that includes excitation by collisions with water and electrons, and by solar infrared radiation. Using a least-square fitting method water ortho-to-para ratios were determined and used to derive water production rates.

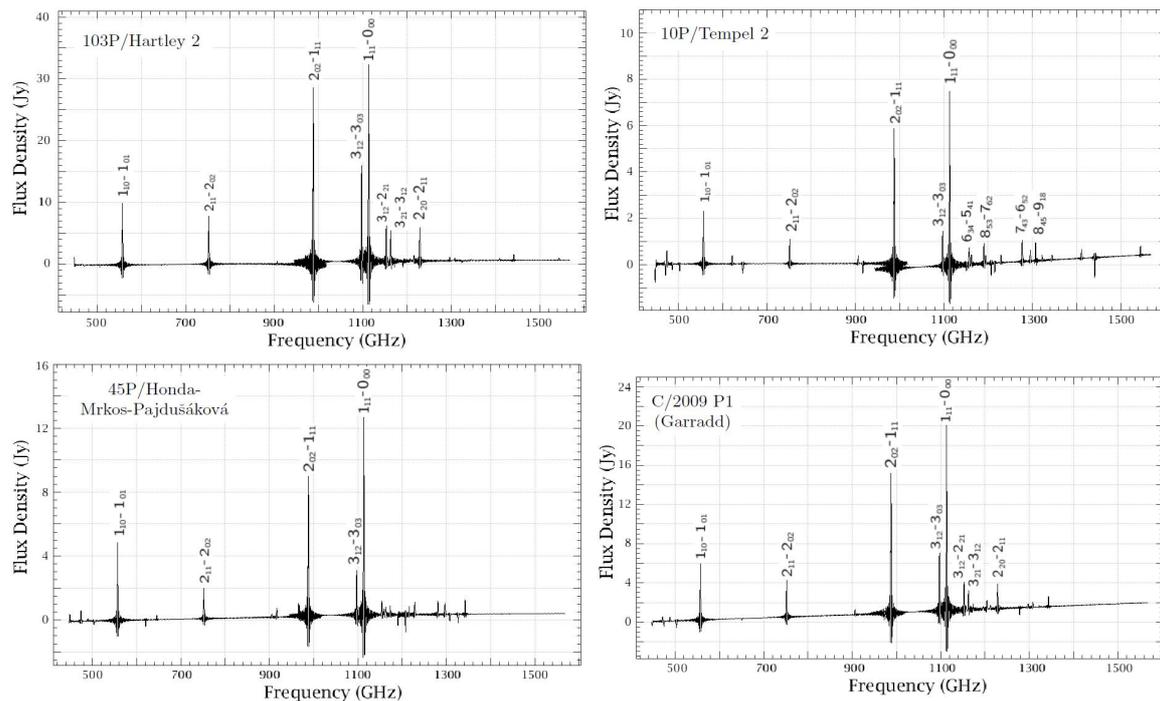


Fig. 1. On-nucleus spectra of obtained with *Herschel*/SPIRE showing the observed fundamental rotational water lines.

Results: Three of the comets in the study have an ortho-to-para ratio considerably lower than the statistical equilibrium value of 3, however the values agree with the ortho-to-ratios of 1P/Halley and C/2001 A2 (LINEAR), and the protoplanetary disk TW Hydrae. Recent laboratory studies have shown that ortho-to-para ratio variation could be due to gas phase nuclear-spin conversion in cometary comae[2] rather than prior to freeze out during cometary formation as was previously thought[3]. Further observations at a range of nucleocentric distances could help constrain cometary comae nuclear-spin conversion.

For all comets in the study the water production rates agree with previous work and decrease with increasing nucleocentric distance in general. This could potentially be due to a coma temperature profile, additional water source, or ortho-to-para ratio variation in the comae, or model inaccuracies.

References: [1] Bensch F., Bergin E. A., 2004, *ApJ*, 615, 531. [2] Hama T., Kouchi A., Watanabe N., 2016, *Science*, 351, 65. [3] Mumma M. J., Weaver H. A., Larson H. P., 1987, *A&A*, 187, 419.

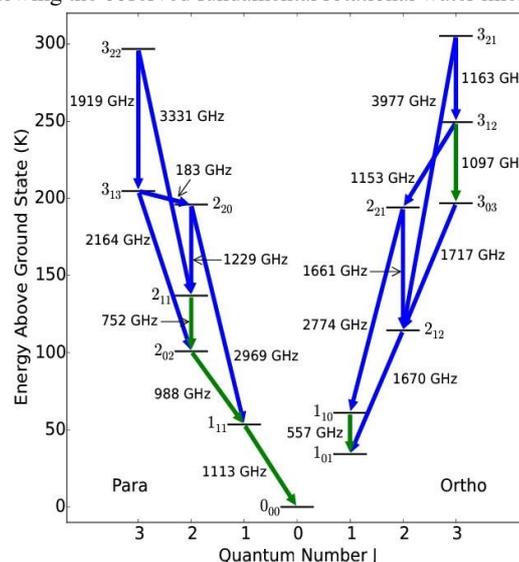


Fig. 2. Ortho- and para-water transitions in the RAT4COM radiative transfer model; unobserved (blue) and observed in all SPIRE detectors (green).

Determining Cometary Noble Gases with Closed-System Stepped Etching

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²IGP, ETH Zurich, Switzerland. E-mail: Thomas.Lawton@postgrad.manchester.ac.uk.

Samples returned from comet Wild 2 are some of the most primitive solar system materials available on Earth, and may contain a record of significant ancient reservoirs of heavy noble gases. Comets could have played an important role in the transportation of volatiles, prebiotic molecules, and the formation of planetary atmospheres in the early solar system [1]. Characterising the Kr and Xe contained in cometary refractories and ices will elucidate these processes, improve models of the formation of the terrestrial atmosphere, and increase our understanding of cometary evolution. NASA's Stardust mission captured and returned cometary refractories and noble gases from comet Wild 2 for laboratory analyses [2]. However, the highly porous aerogel used by Stardust to capture samples contains high concentrations of atmospheric noble gases. Distinguishing extraterrestrial noble gas components from this terrestrial atmospheric contamination using the typical stepped heating approach of noble gas spectrometry is difficult [3]. We avoid this contamination by employing a closed-system stepped etching (CSSE) sample extraction technique [4] to sequentially etch the different materials contained in Stardust samples, releasing each discrete noble gas component individually. To separate components associated with aerogel from silicates and organics, we are conducting stepwise etching with HF followed by HNO₃ [5]; xenon isotopic analysis will be made with the RELAX mass spectrometer [6]. We will validate the technique using a Stardust analogue comprising aerogel, a lunar regolith breccia (PCA02007) and organic residue from Vigarano (CV3); samples with close compositional resemblances to actual Stardust samples, each with distinct xenon isotopic signatures. We have determined baseline compositions and concentrations for PCA02007 and the Vigarano residue using stepped heating and RELAX, we now plan to etch the analogue. In parallel, we are developing an instrument capable of tandem Xe/Kr analysis by combining the resonance ionization processes of RELAX and RIMSKI [7] in one ion source, this instrument will provide simultaneous elemental and isotopic measurements of both noble gases.

References

- [1] Owen T. and Bar-Nun A. 1995. *Icarus*. 116:215-226. [2] Brownlee D. et al. 2006. *Science*. 314:1711-1716. [3] Mohapatra R. K. et al. 2013. Abstract #2201. 44th LPSC. [4] Wieler R. et al. 1986. *GeCA*. 50:1997-2017. [5] O'Mara A. et al. 2014. Abstract #5288. 77th MetSoc. [6] Gilmour J. D. et al. 1994. *Reviews of Scientific Instruments*. 65:617-625. [7] Strashnov I. et al. 2011. *JAAS*. 26:1763-1772.

UTILISING THE METEORITE COLLECTION AT THE NATURAL HISTORY MUSEUM.

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The Natural History Museum first acquired meteorites in 1802, following the purchase of three recent falls by the then President of the Royal Society, Sir Joseph Banks. Since then, the collection has increased to 4877 acquisitions, denoted by their accession or 'BM.' number. The Museum hosts approximately 700 of the 1150 known falls, including all known martian falls – Chassigny, Shergotty, Nakhla, Zagami and Tissint. The type of specimen ranges from fully crusted stones, slabs, and fragments, to prepared powders, thin sections and polished blocks. We also hold collections of tektites and impactites from a variety of terrestrial locations. In the past five years, over 1100 samples have been sent out across 305 loans.

Responsible use of this collection is a collaborative effort of curators and researchers; therefore, I will cover the process for requesting and borrowing specimens, as well as your responsibilities regarding storing, using and returning any materials. With the continuing development of new analytical techniques, providing detailed information of sampling requirements and instrument capabilities is imperative for our decision-making in sample allocation, especially with respect to rare specimens such as SNCs. As one of the oldest collections in the world, the NHM provides a well-documented history and stable housing of specimens, however, the effects of sample storage practices and materials used in preparation on certain techniques may be best identified by external researchers, and thus we would like to promote open dialogue.

M. H. Hey described the greatest challenge of collections care, the 'Curator's Dilemma' [1], as "two diametrically opposed duties: on the one hand, he [the curator] must make material available for research and study, and on the other, he must preserve the material in his care for enjoyment and study by future generations". We implore researchers to assist us by clearly providing accurate information to enable us to balance these duties efficiently and fairly. We are also open to collaborative research projects and can offer expertise in the imaging and analysis of extraterrestrial material. Furthermore, with the increasing trend towards digitization, we are working towards effective storage and dissemination of diverse analytical datasets, including EDX element maps [2] and micro-CT scans.



Figure 1: The Waterhouse building of the Natural History Museum in wide-angle. Opened in 1881, the building is clad in a terracotta façade with ornate carvings of both extinct (east wing) and extant (west wing) flora and fauna. Photo by David Iliif. License: CC-BY-SA 3.0

References: [1] Hey, M. H. 1969. *Meteoritics*, 4:253-255. [2] Kearsley, A. T., Smith, C. L., Spratt, J., Benedix, G. K., Hunt, A., Russell, S. S., & Gounelle, M. 2011. *Meteoritics and Planetary Science*, 74, A5280. [3] Smith C. L. & Welzenbach L. C. 2006. *Meteoritics & Planetary Science*, 41, A164. [4] Cassey, D. J., Smith, D. A., & Smith, C. L. 2011. *Meteoritics and Planetary Science*, 74, A5334

ABUNDANCE AND ORIGIN OF WATER AND VOLATILES IN THE MOON.

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A paradigm shift has recently occurred in our knowledge and understanding of water in the lunar interior. This has transpired principally through continued analysis of returned lunar samples and found on Earth as meteorites using modern analytical instrumentation. While these recent studies have undoubtedly measured indigenous water in lunar samples, they have also highlighted our current limitations and some future challenges that need to be overcome in order to fully understand the origin, distribution and evolution of water in the lunar interior. These sample-based outcomes, combined with the unambiguous detection of water-ice on the surface of the Moon through instruments flown on a number of orbiting spacecraft missions, indicate that the Moon is not an anhydrous planetary body as previously believed.

New observations and measurements support the possibility of a wet lunar interior and the presence of distinct reservoirs of water on the lunar surface. Furthermore, an approach combining measurements of water abundance in lunar samples and its hydrogen isotopic composition has proved to be of vital importance to fingerprint and elucidate processes and source(s) involved in giving rise to the lunar water inventory. A number of sources are likely to have contributed to the water inventory of the Moon ranging from primordial water to meteorite-derived water-ice through to the water formed during the reaction of solar wind hydrogen with the lunar soil. Perhaps two of the most striking findings from these recent studies are the revelation that at least some portions of the lunar interior are as water-rich as some Mid-Ocean Ridge Basalt source regions on Earth and that the water in the Earth and the Moon probably share a common origin. Finally, studies of other volatile elements such as chlorine have also yielded key results, which help placing constraints on large scale processes that affected important reservoirs such as the lunar magma ocean. During this presentation, we will review the developments that have taken place over the past decade in this field of lunar volatiles, and the exciting challenges that lie ahead of us.

RESOURCE EXTRACTION AT THE LUNAR SOUTH POLE

H. Sargeant¹, F. Abernethy¹, I. Wright¹, S. Barber¹, M. Anand¹, S. Sheridan¹ and A. Morse¹. ¹ School of Physical Sciences, The Open University, Walton Hall, Milton Keynes, UK. E-mail: Hannah.sargeant@open.ac.uk

Introduction: To establish a permanent human presence elsewhere in the Solar System it has become apparent that skills and technologies must first be advanced closer to home. The next step for human exploration in space will therefore begin with a return to the Moon, where In-Situ Resource Utilisation (ISRU) will be crucial in creating an environment independent of the Earth's resources. Numerous reviews have highlighted the resources available on the Moon [1-3], so to further this work we have completed a comprehensive study to directly compare each available resource. The aim of our study is to determine the resources most suitable for extraction. The results will be used to focus efforts on the extraction techniques required to obtain the selected resources. If the extraction techniques are viable they can be applied to future lunar prospecting instruments such as ProSPA [4], currently being developed at the Open University.

The resources being considered for extraction are those identified by Crawford [1] with the addition of other resources highlighted as having potential uses. To determine those worth focusing on, we conducted a lunar resource trade-off study which considers the energy required to extract the resource; the complexity of the extraction process; applications of the resource; and useful by-products of extraction. When considering each of these categories the results indicate that frozen water is the most suitable resource to extract by the utilisation of the thermal gas release process. The ProSPA instrument should be capable of releasing frozen water and other volatiles from the lunar soil through thermal gas release due to similar process heritage. Resource extraction from the Lunar south pole on the Ptolemy [5] and MOMA instruments [6]. The resources of next importance are trapped water and oxygen which can be extracted by reducing ilmenite with hydrogen. It was therefore decided that ilmenite reduction would be considered for further investigation in order to determine whether it is a feasible resource extraction process for the potential use on ProSPA and future ISRU experiments.

The ilmenite reduction reaction is now being trialed in the laboratory using a breadboard model of the ProSPA instrument. By modelling the reaction rate and gas flow within the system it is possible to optimise the design to produce the desired products. The trade-off analysis and the latest design of the breadboard model will be discussed along with potential avenues of future work.

References: [1] Crawford I. A. 2015. *Progress in Physical Geography*. 39:137-167. [2] Schunk D. et al. 2007. *The Moon: Resources, Future Development and Settlement*. [3] Lewis J. S. et al. 1993. In *Resources of Near-Earth Space*. P. 3-14. [4] Carpenter J. et al. 2014. *Annual Meeting of the Lunar Exploration Analysis Group*. [5] Wright I. et al. 2007. *Space Science Reviews* 128(1-4):363-381. [6] Arevalo R. et al. 2015. *IEEE Aerospace Conference*.

D/H FRACTIONATION DURING SUBLIMATION OF WATER ICE AT LOW TEMPERATURES INTO A VACUUM.

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Introduction: The work outlined here was carried out within the framework of ESA's PROSPECT programme, which will provide both a sample drill and miniaturised mass spectrometer system for flight on-board the planned Russian Luna-27 mission to the lunar south pole. There, it aims to collect samples of regolith, containing water ice and other volatiles, and to make isotopic and abundance measurements to fingerprint the source(s) of these volatile species. However, it is necessary to first consider how any localised temperature increases during sample acquisition activities may result in water ice loss via sublimation and thus isotopic modification of the remaining residual ice. To attempt to address these concerns, a suite of sublimation experiments were conducted at the Laboratoire de Géologie de Lyon during the summer of 2016, where a method for performing such experiments was already established [1]. The results of this work will help to inform model-ing which will extrapolate the data down to lunar-relevant conditions.

Experimental Procedure: For all experiments, the same starting water reservoir was used, and its composition remeasured alongside each batch of samples to take into account any isotopic evolution over time within the starting water reservoir. A 0.5 mL aliquot of water was measured out from the reservoir flask of starting water (doubly-distilled Rhône river water, with an initial δD value of -75.69 ‰) using a micropipette, transferred into a small PyrexTM glass round-bottomed vessel for weighing (using a balance accurate to ± 0.0001 mg), and then introduced into the vacuum system. Before exposing the water aliquot to vacuum, the water inside the round-bottomed vessel was frozen using a bath of liquid nitrogen (LN). Once frozen, the vessel was opened to the vacuum line and pumped down to the appropriate pressure. Then, the vacuum line was isolated from the pumps and the temperature-controlled cryogenic trap (TCCT) was cooled (again with an external bath of LN), ready for the transfer of the water aliquot. Water transfer into the TCCT was facilitated by the use of a hand-held heat gun. After water transfer was complete (monitored by watching the pressure of the vacuum line fall as water vapour was trapped down into the TCCT), the vacuum line was again opened to the pumps to ensure full removal of all untrapped vapour from the system. After approximately ten minutes, the line was again isolated from the pumps and the system was ready for sublimation to begin.

Temperatures of sublimation were controlled by use of a thermal resistance heating wire coiled around the sample tube inside the TCCT, balancing out the cooling effect of an external bath of liquid nitrogen, and with efficient heat transmission ensured by an envelope of helium gas between the LN bath and the heating coil/sample tube (Fig. 1). Temperatures were monitored in real-time by use of a thermocouple positioned at the lowest point of the TCCT. Once the de-sired temperature was reached, the temperature was able to be held at this value, accurate to within ± 2 °C of the target temperature.

During sublimation, a separate pre-weighed empty PyrexTM vessel with a glass valve was cooled using a bath of LN, for trapping of any water vapour released during sublimation (the 'sublimate'). This process was repeated after sublimation by heating up the TCCT to 30 °C and collecting all of the residual ice as vapour in a third pre-weighed empty PyrexTM vessel. Amounts of sublimate and residue were then calculated by re-weighing the now-full valved collection vessels and subtracting their empty weights.

Finally, both sublimate and residue water fractions were transferred into small (1 μ L) glass vials using separate syringes, stored in an oven at 60 °C between uses, and sealed with metal caps containing septa, ready for isotopic analysis. Samples were loaded into an autosampler and analysed for D/H using a chromium-based reactor tube installed in a EuroEA3028-HT elemental analyser, connected to an IsoPrime isotope ratio mass spectrometer.

Results: Until ~35 % of water ice was lost to the vapour phase, the isotopic composition of both the sublimate and residue samples remained relatively constant; sublimate samples were only slightly enriched in H compared to the initial water ice composition, with residue samples correspondingly enriched in D. For both sublimate and residue samples, measured isotopic values fell within ± 5 ‰ of the initial ice composition. After 35 % sublimation, the fractionation trend reversed, with a significant enrichment in D for sublimate samples and an enrichment in H for residue samples. These results imply that at least around 1/3 of the starting water ice can be lost before any significant fractionation of the residual ice occurs, at both -75 °C and -100 °C. Further, no significant increase in the rate of sublimation was observed when temperature was kept constant and the pressure of the vacuum system was reduced from 10^{-3} to 10^{-5} mbar, and thus the fractionation behavior at both pressures was almost identical.

Further Considerations: Although these results are reproducible using the same sublimation set-up and vacuum line volume, different vacuum lines with a different ratio of heated glass to cooled traps may produce slightly different results (i.e. a vacuum line with a more efficient water vapour removal set-up may enable meaningful sublimation experiments past ~30-40 % sublimation at -75 °C etc. by preventing the retardation of further sublimation through the presence of already-sublimed water vapour in the line). Also, the sublimation behaviour of a water ice sample will depend on many factors, such as ice geometry and thickness, as well as how it is heated (i.e. from all sides, or just from the top surface?). Therefore, care should be taken when applying these results to other scenarios. Introducing water and fine dust particles into any vacuum system is hazardous; perhaps a better solution would be to use much larger grain sizes initially, and then scale the results from these tests to scenarios where larger surface area samples are used.

Acknowledgements: This work was funded by the European Space Agency in support of the PROSPECT lunar exploration package. The initial direction of the study was informed by the PROSPECT User Group.

Reference: [1] Lecuyer C. et al. (2017) *Icarus*, 285, 1-7.

CRYSTAL STORAGE AND TRANSFER IN LUNAR MAGMATIC SYSTEMS.

S. K. Bell¹, M. E. Hartley¹, K. H. Joy¹ and J. F. Pernet-Fisher¹. ¹School of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK. E-mail: samantha.bell@manchester.ac.uk.

Introduction: Mare basalts sampled by the Apollo missions show a range of chemical and petrological characteristics, as well as variable crystallisation histories ^[1]. Such properties are a reflection of both diversity within the lunar mantle source ^[2,3] and differences in magmatic histories and eruption processes ^[4]. At the Apollo 15 landing site, located on the eastern edge of Mare Imbrium (26.13222° N latitude, 3.63386° E longitude), two suites of mare basalts with similar eruption ages have been identified based on differences in whole-rock major element abundances ^[5]. The quartz-normative samples (which are thought to have erupted at ~3.35 Ga) and the olivine-normative samples (which are thought to have erupted at ~3.25 Ga), have caused some controversy due to their uncertain petrogenetic relationship. Current theories suggest that the quartz-normative group experienced a multi-stage cooling history with crystallisation occurring within magma chambers of the mid-to-lower crust, during ascent to the lunar surface and within lava flows ^[6]. Conversely, the olivine-normative group shows that crystallisation predominantly occurred after eruption in lava flows on the lunar surface, ± minor crystallisation at low-pressures in near-surface magma chambers ^[6,7,8]. This project aims to use quantitative petrology and mineral chemistry techniques on crystals within the two suites of Apollo 15 mare basalts to enable further analysis and interpretation of the processes that took place during magma storage and eruption.

Methods: Textural characteristics and mineral compositions of thin sections from both the quartz-normative and olivine-normative groups will be identified using a combination of back-scattered electron (BSE) images, element maps and electron microprobe (EPMA) data. Magma ascent rates and crystal residence times will be calculated using diffusion modelling in zoned crystals. Crystal size distributions of plagioclase and olivine crystals will also be calculated in order to identify signatures of fractional crystallisation and/or crystal accumulation within the two sample suites. QEMSCAN ESEM mapping methods will be utilised in order to automate crystal size distribution calculations.

Expected Outcomes: The three key problems aimed to be addressed by the end of the project are: (1) Do lunar magmas propagate rapidly up to the surface or do they stall and crystallise in magma chambers within the lunar crust? (2) Is crustal material assimilated during ascent? (3) Is there evidence of crystal mush formation, disaggregation and crystal entrainment? The project will initially be focused on samples from the Apollo 15 mission, with further plans to analyse other mare basalts, such as those collected on the Apollo 12 mission. The answers to these key questions will allow for a greater understanding of lunar magmatic plumbing systems and how eruption styles vary in different regions across the Moon through time.

References: [1] Neal C. R. and Taylor L. A. 1992. *Geochimica et Cosmochimica Acta*. 56: 2177-2211. [2] Snyder G. A. et al. 1990. Workshop on mare basalt petrogenesis. LPI. pp. 43-44. [3] Hallis L. J. et al. 2010. *Geochimica et Cosmochimica Acta*. 74: 6885-6899. [4] Wilson L. and Head J. W. 2016. *Icarus*. 000: 1-30. [5] Chappell B. W. and Green D. H. 1973. *EPSL*. 18: 237-246. [6] Schnare D. W. et al. 2008. *Geochimica et Cosmochimica Acta*. 72: 2556-2572. [7] Ryder G. and Steele A. 1988. 18th LPSC. pp. 273-282. [8] Ryder G. and Schuraytz B.C. 2001. *JGR*. 106: 1435-145.

Examining the History of the Solar System Preserved in the Lunar Regolith.

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Introduction: The lunar surface has been directly exposed to space since its formation ~ 4.5 billion years ago. During this time the Solar System has been subjected to a wide range of galactic environments as it orbits the Galaxy and passes through the spiral arms and star-forming regions. The lunar surface may therefore preserve a record of enhanced galactic cosmic ray (GCR) fluxes as a result of supernova explosions and associated supernova remnants occurring in close proximity to the Solar System during these orbits [1,2]. In addition, changes in Solar activity could also be preserved in the lunar surface as a result of Solar Energetic Particle (SEP) fluxes. This has important implications for the development of life on Earth [3,4].

Methods and application: We are measuring concentrations of Argon, Neon and Helium isotopes produced by GCR and SEP interaction with the lunar surface in order to examine variations in these fluxes through time. In addition to measuring isotopes in lunar samples, we are also conducting a thorough literature review to test hypotheses that enhanced activity is preserved in the lunar regolith and to examine whether signatures of long exposure can be separated from spikes in the lunar record.

Importance for future missions: Results from this project will be used to develop criteria for selecting future lunar samples which may be able to provide a detailed galactic record, providing that they are extracted from different dateable horizons. Accessing such samples will require an infrastructure capable of drilling into the sub-surface and returning a diverse range of samples to the Earth for analysis.

References: [1] Crawford and Joy (2014) *Phil. Trans. R. Soc. A* 372. [2] Wieler, R. (2002) *Rev. Mineral. Geochem.*, 47, 125-170. [3] Crawford, I.A. et al. (2010) *Earth, Moon and Planets*, 107, 75-85. [4] Airapetian, V.S. et al. (2016) *Nature Geosci.* 9, 452.

WHAT NEXT FOR UK PLANETARY SCIENCE? ExoMars, JUICE, BepiColombo AND BEYOND.

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Introduction: Space missions provide much of the impetus for planetary science worldwide, and the UK is no exception. In addition, ground based work experimental work and theory/simulations also provide excellent opportunities for planetary science research. In this talk we will discuss recent, present and future space mission opportunities for the UK planetary science community. Recent and current missions include Cassini-Huygens, Rosetta, Mars Express and Venus Express, future missions include ExoMars 2016 and 2020, JUICE and BepiColombo, and there are a number of relevant opportunities in the ESA (M5) and NASA (Discovery and New Frontiers) competitions as well as with other agencies. Several of these missions, and later possibilities beyond these, provide excellent career opportunities for the UK planetary scientists of the future.

MULTISPECTRAL IMAGING WITH THE EXOMARS 2020 PANORAMIC CAMERA INSTRUMENT.

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Introduction: The ESA - Roscosmos ExoMars 2020 Rover has the primary objective of detecting extinct or extant life on Mars, by subsurface sampling at unprecedented depths (up to 2m). The panoramic camera instrument, PanCam [1], will provide the context of the rover's local environment, using a combination of stereo, multispectral, and high resolution imaging techniques. Here, progress is reported on an investigation into the multispectral imaging capabilities of PanCam, with regards to the inference of surface composition, and atmospheric studies.

PanCam: PanCam is mast mounted on a Pan-Tilt Unit at 2m above the surface, with complete 360° x 180° panoramic coverage. Two fixed focus Wide Angle Cameras (WACs) give 50cm-baseline multi-view stereo vision, with 38.3°x38.3° FoV. A High Resolution Camera is positioned right-of-centre, with variable focus and 4.88°x4.88° FoV. A 1Mpix CMOS detector is used for each camera, sensitive across visible and near-infrared wavelengths (VNIR, 440-1000nm). 22 filters are distributed in 11-slot filter wheels between the WACs, consisting of 2xRGB broadband, 12 narrowband geology, and 4 low transmission solar filter sets. The geology filters have been selected to highlight spectral features of hydrated minerals of astrobiological significance, in particular phyllosilicates and sulphates, and also ferric and ferrous oxides [2]. However, these spectral features are subtle, and real measurement scenarios are subject to perturbing environmental factors such as illumination conditions, scene geometry, and surface textures. Confidence in identification is further limited by the VNIR and 12-band constraints of the camera system. In spite of these challenges, field trials using a representative PanCam Emulator have demonstrated the filter set's ability to detect the presence of hydrated minerals, identifying zeolite veins and phyllosilicates within substrates [3].

Composition Identification: Identifying specific minerals with multispectral imaging is an ill-posed inverse problem. Before attempting to regularise the inversion process with priors such as spectral mineral databases, a model of the forward process is required, covering the illumination, surface scattering, and detection processes. A parametric model allows for synthetic PanCam images to be generated of specified properties, such that the outputs of information extraction algorithms can be compared against the defined input conditions.

The PanCam Instrument Model: A hyperspectral simulation of the photon detection process has been constructed, considering the transport of light through the camera optics, the silicon detector, and on to representation as a digital image, following the Photon Transfer technique [4]. In addition to the role of generating synthetic PanCam images of virtual scenes, this simulation allows the performance of PanCam to be predicted, prior to the instrument calibration campaign. The off-axis spectral response of the narrowband filters has been included in the model, such that the variation of the central wavelength of detection across the field of view can be incorporated into later image analysis. The model has been tested under simulated ideal illumination conditions of uniform white light, representative of an integrating sphere. The next step is to replace this illumination with scattering from simple surface compositions, and to increase simulation detail and complexity towards representative scenes of candidate rover environments.

References: [1] Coates A. J. et al. 2017. *Astrobiology*. In Press. [2] Cousins C. R. et al. 2012. *Planet. Space Sci.* 71:80-100. [3] Harris J. K. et al, 2015, *Icarus*. 252:284-300. [4] Janesick J. R. et al. 1987. *Op. Eng.* 26(10):972-980.

EVIDENCE FOR RECENT MELTING OF GLACIERS ON MARS. F.E.G. Butcher¹, C. Gallagher^{2,3}, N.S. Arnold⁴, M.R. Balme¹, S.J. Conway⁵, S.R. Lewis¹, A. Hagermann¹. ¹School of Physical Sciences, The Open University, UK (frances.butcher@open.ac.uk), ²UCD School of Geography, University College Dublin, Ireland, ³UCD Earth Institute, University College Dublin, Ireland ⁴Scott Polar Research Institute, University of Cambridge, UK, ⁵CNRS, LPG Nantes, France.

Introduction: Diagnostic evidence for past melting of putative debris-covered glaciers (DCGs) in Mars' mid-latitudes [e.g. 1-2] is extremely rare. As such, it is widely believed that these DCGs have been perennially frozen to their beds in cold-based thermal regimes [e.g. 3] since their formation ~40 Ma to 1 Ga [4-8]. We challenge this paradigm. We identify a sinuous ridge emerging from a DCG in the broad rift zone NE of the Tharsis volcanic province. We interpret this ridge as an esker formed by deposition of sediment within a subglacial meltwater conduit. This is only the second esker-like ridge to be identified in association with a mid-latitude DCG [9]. Significantly, both candidate eskers are located within graben. Graben are topographic troughs formed by crustal extension and are commonly associated with an elevated geothermal heat flux [e.g. 10].

Methods: We produced a geomorphic map (Fig 1a) of the graben in NE Tharsis using a basemap comprising Context Camera images (CTX, 6 m/pix) [11], integrated with day/night infrared (IR) Thermal Emission Imaging System (THEMIS) images [12].

Results: We propose that the sinuous ridge is an esker because: (1) longitudinal transitions in its cross-sectional morphology (Fig 1b) are strikingly similar to those of terrestrial eskers as they cross topographic undulations [e.g. 13], (2) its plan-view morphometrics are similar to typical terrestrial eskers [e.g. 14], and (3) its progressive exhumation from the DCG tongue implies a subglacial origin.

Landsystem model: We propose that the candidate esker could represent a transient phase of wet-based glaciation within an otherwise cold-based glacial regime. Under this model, a cold thermal regime at glacial maximum precluded large-scale reworking of the glacier-proximal floor such that terminal moraines ('knobbly' ridges, Fig 1a) were poorly-developed. A distinct THEMIS high thermal inertia anomaly (possible bedrock [15]) in the area confined by the 'knobbly' ridges is consistent with a lack of glacial modification beyond them. During deglaciation, atmospheric warming supplemented enhanced geothermal heat flux within the graben, increasing basal temperatures and permitting transient basal melting and meltwater routing along a subglacial conduit in the south, forming the candidate esker. Meltwater permitted more efficient basal erosion and supplied sediment to a well-developed moraine-like transverse ridge complex at the terminus of the eastern DCG. The DCG transitioned back to a cold-based regime and stagnated as thinning raised the melting point of the basal ice. The esker was subsequently exhumed by down-wasting of the DCG.

Conclusions: Eskers are diagnostic of glacial melting and challenge the paradigm that martian DCGs have never produced meltwater. Two observations of candidate eskers within glaciated mid-latitude graben on Mars [this study, 9], where positive geothermal heat anomalies might be expected, are (thus-far) unique in the mid-latitudes of Mars. A paucity of meltwater morphologies associated with DCGs elsewhere in Mars' mid-latitudes implies that atmospheric warming was insufficient for widespread basal melting. Elevated geothermal heat flux (e.g. in graben) may have been a pre-requisite for basal melting. This has implications for the search for recent life on Mars, as it helps constrain the likely regions of recent meltwater production within protected subglacial environments. As eskers are exposed relicts of subglacial drainage systems they are accessible to landed missions without the high-risk requirement to drill through remnant decametre-thick, debris-mantled ice.

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References: [1] Head, J.W. et al. 2010. *Earth Planet. Sci. Lett.* 294:306-320. [2] Levy, J.S. et al. 2014. *J. Geophys. Res. Planets.* 119: 2188-2196. [3] Marchant, D.R., and Head, J.W. 2007. *Icarus.* 192:187-222. [4] Baker, D.M.H. et al. 2010. *Icarus.* 207:186-209. [5] Hartmann, W.K. et al. 2014. *Icarus.* 228:96-120. [6] Levy, J.S. et al. 2007. *J. Geophys. Res. Planets.* 112: E08004. [7] Berman, D.C., et al. 2012. *LPSC XLIII.* Abstract #1593. [8] Baker, D.M.H. and Head, J.W. 2015. *Icarus.* 260:269-288. [9] Gallagher, C., and Balme, M.R. 2015. *Earth Planet. Sci. Lett.* 431:96-109. [10] Meixner, J. et al. 2016 *J. Struct. Geol.* 82:1-15. [11] Malin, M.C. et al. 2007, *J. Geophys. Res. Planets.* 112 (E5):E05S04. [12] Christensen, P.R. et al. 2004, *Space Sci. Rev.* 110:85-130. [13] Shreve, R.L. 1985. *Geol. Soc. Am. Bull.* 96:639-646. [14] Storrar, R.D. et al. 2014. *Quat. Sci. Rev.* 105:1-25. [15] Putzig, N.E. and Mellon, M.T. 2007. *Icarus.* 191:68-94.

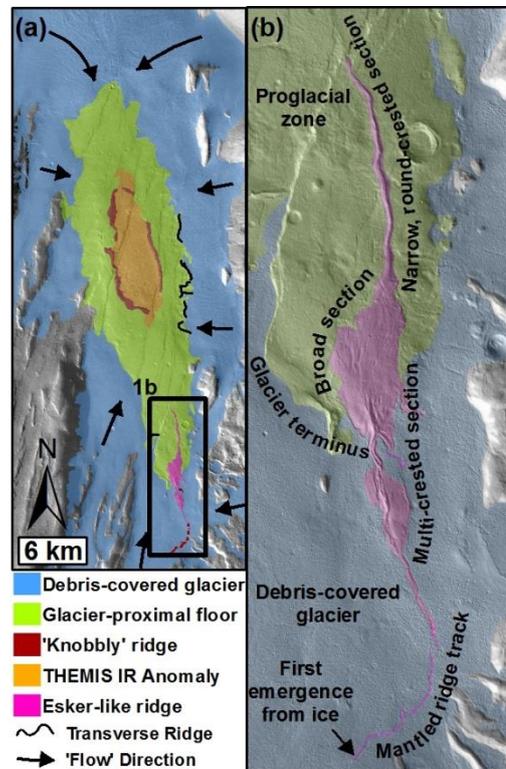


Figure 1: (a) Key geomorphic units from our mapping (b) The candidate esker with esker-like morphological subsections labelled. Extent shown in (a). CTX base image P18_008168_2279_008168.

OBSERVING CHANGES IN THE SOUTH POLAR RESIDUAL CAP WITH CTX-HRSC

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Introduction: The south polar region of Mars is interesting because of the existence of a Carbon Dioxide ice layer which persists even into the summer, different from the water ice layer over the north polar region which sublimates into the atmosphere each Martian spring. This residual ice layer is aptly named the Mars South Polar Residual Cap (SPRC). Although most of the surface remains unchanged, there are some changes identified, with exotic names such as spiders[1], so-called Swiss cheese terrains[2], and layers seen on the edges of the ice cap [3].

Broadening coverage for research: Research on changes on Mars are usually done using images taken by the same instrument. Using multi-instrument images from different instruments (multi-instrument) increases the probability of detecting changes both temporally and spatially from a period of 5 MYs to 10 MYs, and if necessary to also use Viking images from 20 MYs prior to the present day (MY 33). To reach this objective, we need to co-register multi-instrument images and correct them all to a global reference system as images from different instruments are not well co-registered between each other. Terrain relief induced geometric distortions need to be corrected as well.

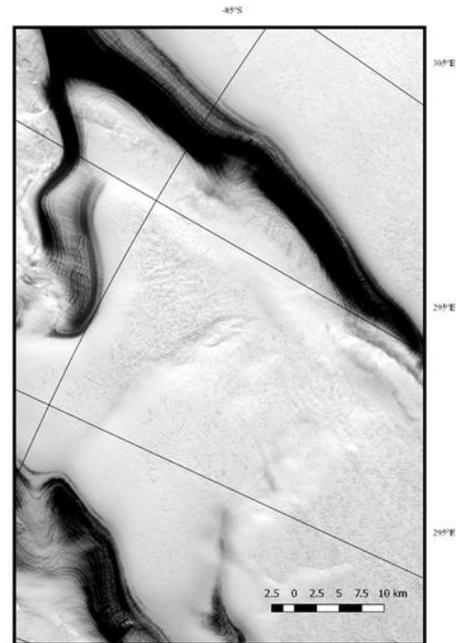
Terrain Correction: Terrain correction can be performed by orthorectifying images to base Digital Terrain Models. The current Digital Terrain Model we have for Mars is MOLA DTM [4]. Although its near-polar orbit means that the resolution is better around the poles than in the equator (112 m/pixel), the DTM has problems in that area around the pole, where the majority of the Residual Cap is located, as this is not covered by MOLA points. We have produced Digital Terrain Models [5] from HRSC [6] images using a method proposed by Kim and Muller [7] with the Gotcha (Gruen-Otto-Chau) algorithm [8] on a VICAR-based pipeline developed by DLR (German Aerospace Agency) [9] for areas around the south polar region to address these problems. In this study we discuss the process to produce the Digital Terrain Model and the resulting products.

Observation: To coregister other high-resolution images with HRSC images, we need to find other high-resolution images overlapping with certain HRSC orthorectified images, in this study we are using CTX images. Different with other areas on Mars whose surface pretty much remains unchanged, because of the diurnal cycle of the ice cap [10], care is needed to be given to obtain overlapping CTX images with similar surface conditions, by looking at solar longitude information. By grouping HRSC images and overlapping high-resolution images by their solar longitude, we can observe the South Polar Residual Cap without the effect of the diurnal cycle. On the other hand, research into the effects of the diurnal cycle over the South Polar Residual Cap can be done by analysing images with different solar longitude values in the same Martian year.

Summary: We will show results over the Mars polar caps, especially the Mars South Polar Residual Cap (SPRC), 3D models generated over the SPRC along with changes at the edges of SPRC, because of the growth and recession of the ice cap.

References: [1] Piqueux, S. et al. 2003. *J. Geophys. Res.* 108, 5084. [2] Titus, T. N., et al. 2004. *Lunar Planet. Sci.* XXXV 35, 2005. [3] Milkovich, S.M. and Plaut, J.J., 2008. *J. Geophys. Res. E Planets* 113. [4] Seidelmann, P. K., et al. 2002. *Celest. Mech. Dyn. Astron.* 82,83–111. [5] Putri, A. R. D. et al. 2016. *Mars Polar 2016*. [6] Neukum, G. et al. 2004. *Mars Express: The Scientific Payload*. [7] Kim, J.-R. and J.-P. Muller. 2009. *PSS* vol. 57, pp. 2095–2112. [8] Shin, D. and J.-P. Muller. 2012. *Pattern Recognition*, 45(10), 3795–3809. [9] Scholten, F. et al. 2005. *Photogramm. Eng. Remote Sens.* 71, 1143–1152. [10] Titus, T. M. 2016. *Mars Polar 2016*, 6041

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Figure 1 South Polar Residual Cap Ice Layers Observed in HRSC Images

Using wide-ranging meteorite ages and Os-isotope to provide new insight into the mantle evolution of Mars

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Introduction: The only available rock samples from Mars are represented by the Martian meteorites, roughly divided into shergottites (basalts), nakhlites (clinopyroxenites), and chassignites (olivine cumulates), with some exception. Crystallization ages of these mantle-derived rocks are different, from around 4.4 Ga to a few hundred Ma, and this relatively long range could be the key to understanding how the mantle of Mars evolved during its geological history. Osmium isotopes and highly siderophile elements (HSE) are very useful in revealing magmatic processes and the evolution of planetary mantles. In particular, the long lived ¹⁸⁷Re-¹⁸⁷Os isotope system and HSE can be used to answer still open questions about the evolution of the Martian mantle: Mars has similar HSE behaviour to Earth's basaltic magmas, and both Earth and Mars have mantle HSE abundances in chondritic relative proportions (and similar concentration) to Earth [1]. Martian meteorite Re-Os systematics have been investigated by previous authors, and suggest either both the existence of two chemically different mantle reservoirs [2], or a single mantle reservoir affected by crustal contamination [3].

Objectives:

Volatile element evolution of the Mantle. This study will focus on Tissint, an olivine-phyric shergottite (age of 596±23 Ma [4]), NWA 8159, an augite basalt (age of 2.3±0.5 Ga [5]), and the unique Martian volcanic breccia NWA 7034 (with a range of age within 4.44 Ga to 170 Ma [6]) to constrain the volatile element composition of the Martian mantle over time. In particular, amphibole in shergottites could be a strong indicator of mantle volatile contents (Fig. 1). Amphibole differs in composition among Martian meteorites. In the nakhlites and chassignites Cl-rich amphibole is probably the product of interaction between eruption processes and surficial/subsurface fluids [7], while in shergottites it is more likely to derive from the mantle [8].

Os-isotope and HSE. Previous authors [2,3] only analysed Os-isotopes in the shergottites (with just one nakhlite). Our work will focus on Re-Os systematics of nakhlites (Nakhla, Lafayette, Miller Range) in order to definitively understand if mixing of distinct mantle sources and/or crustal contamination occurred. Moreover, prior studies focus on bulk-rock powders for which textural information is lost while we aim to sample mineralogically specific areas via micro-coring techniques prior to destructive analyses. Characterizing HSE behaviour during nakhlite formation will highlight any late-stage disturbance to HSEs and/or Re-Os isotopes by impactor contamination and/or planetary alterations and constrain possible open-system HSE contributions resulting from crustal assimilation.

High-pressure experiments. In addition to the analytical aspects of this project, we also aim to investigate Martian samples from an experimental point of view by using natural or synthetic materials for high-pressure and high-temperature experiments, to better interpret the textural and analytical data. This will allow for the quantification of processes of magma accumulation in crustal storage regions, and to determine whether mixing and equilibration with other magmas occurred (e.g. a debated argument for Tissint [9]).

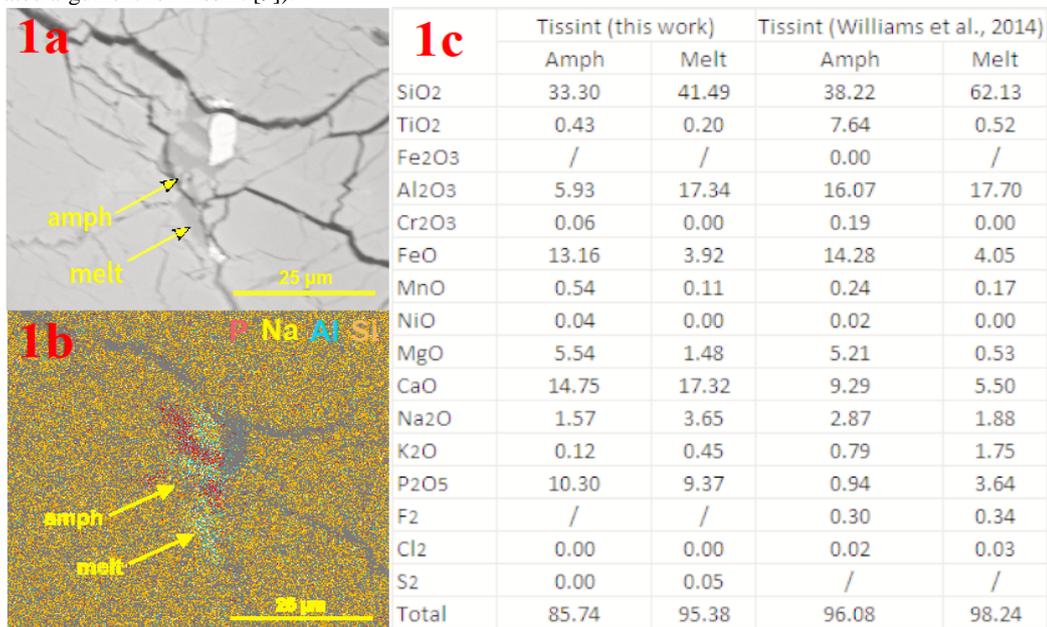


Fig. 1 – (1a) Backscattered electrons image of a 6-7 μm long amphibole (amph) in a melt inclusion in Tissint; (1b) P, Na, Al, and Si elemental map of the amphibole, surrounded by merrillite (red areas) and glass; (1c) Major elements composition of both the amphibole and the surrounding melt with the previously analyzed amphibole in Tissint [8] for comparison.

References: [1] Birck J. L., Allegre C. J., 1994. *EPSL*, 124: 139-48. [2] Brandon A. D. et al., 2000. *Geochim. Cosmochim. Acta.*, 64: 4083-4095. [3] Brandon A. D. et al., 2012. *Geochim. Cosmochim. Acta.*, 76: 206-235. [4] Brennecka G. A. et al., 2013. *44th LPSC*. [5] Simon J. I. et al., 2014. *77th MetSoc*. [6] Nyquist L. E. et al., 2016. *Met. & Pl. Sci.*, 51: 483-498. [7] McCubbin F. M. et al., 2013. *Met. & Pl. Sci.*, 48: 819-853. [8] Williams K. B. et al., 2014. *45th LPSC*. [9] Brennecka G. A. et al., 2014. *Met. & Pl. Sci.*, 49: 412-418.

APATITE IN MARTIAN METEORITES NWA 7034 AND NWA 8159.

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Introduction: Measurements of the volatile abundances at the Martian surface (e.g. H₂O, Cl, CO₂, CH₄) are a priority for the latest generation of Martian rovers (Curiosity) due to the astrobiological importance of these compounds. Rovers however, are limited to surface exploration, and therefore tell us little about the volatile content of the Martian interior. However, the Martian meteorites that have been identified on Earth are predominantly basaltic and the volatile contents of primary igneous minerals within these Martian basalts can indicate the volatile content of the source regions at depth in the Martian interior.

NWA 7034 and NWA 8159: Until recently, it was thought that ALH 84001 (orthopyroxene) was the only Martian meteorite that did not fit within the SNC categories for Martian meteorites. However, the discovery of NWA 7034 and pairings, as well as NWA 8159, has expanded the diversity of the Martian meteorites beyond the common SNC types [1]. Martian meteorite NWA 7034 is a polymict basaltic breccia formed via impact melting and welding of an area of Martian regolithic soil (Fig. 1). It contains numerous apatite grains within various lithological clasts as well as free apatite grains within the matrix from many differing sites on Mars. This unique meteorite is water rich compared to other SNC meteorites, with ~600 ppm of extraterrestrial H₂O released during stepped heating [1]. NWA 7034 has crystallisation ages up to 4 Ga, with a Rb-Sr age of 2.089 ± 0.0081 Ga [1] and an age of 4.42-4.46 for zircon grains within the meteorite [2]. NWA 8159 is a newly classified fine grained, augite basaltic Martian meteorite, with small (<10 µm) apatite grains in its matrix. NWA 8159 has a unique crystallisation age of 2.3 ± 0.5 Ga (Sm-Nd) [3].

Martian Apatite: Apatite (Ca₅(PO₄)₃(F, Cl, OH)) is the major volatile bearing phase in Martian meteorites and is the main host for phosphorus (P) in extraterrestrial rocks [4], [5], [6]. It is a major sink for the volatile elements: fluorine (F), chlorine (Cl) and water (OH) during Martian volcanism and therefore the ratio of these three elements in apatite can indicate their abundances in the parental melt. On average, Martian apatites contain little OH and have a Cl: F: OH ratio of ~ 5:3:2 (Fig. 2) [7], [8]. Apatites in both NWA 7034 and NWA 8159 present an opportunity to measure the F, Cl and OH ratio and therefore the source region of their Martian parental melts. However, NWA 7034 may present a rare opportunity to measure these volatile elements of numerous Martian parental melts within one meteorite sample due to the clastic nature of this meteorite.

D/H ratio: Mars and Earth may have had similar D/H ratios during their formation, but due to the preferential loss of hydrogen (relative to the heavier hydrogen isotope deuterium) in the upper Martian atmosphere the current Martian atmosphere is deuterium enriched [9], [10]. Hydrogen isotope studies of both NWA 7034 and NWA 8159 will enable me to track the source of water (e.g., Martian mantle, crustal sedimentary contamination, or groundwater/ice) within these meteorites that crystallised at a different time and location on Mars. NWA 7034 was hydrothermally altered at ~1.5 Ga [11]. Therefore, if it is discovered that the deuterium to hydrogen (D/H) ratio is the same in all of the apatites present within this meteorite then this value will represent the D/H ratio of Mars' surface water and atmosphere at 1.5Ga. This can then be compared to measurements of the current D/H ratio of Mars (Curiosity Rover data), as well as surface measurements from ancient mudstones (Curiosity data) and other meteorites to give us a picture of the D/H ratio of Martian atmosphere over time. This information will in turn allow for calculations of the rate of Martian atmospheric stripping.

Methods: Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray analysis (EDX) conducted at the ISSAC Facility, University of Glasgow will be used to characterise the fluorine, chlorine and water content of both NWA 7034 and NWA 8159 to determine their volatile content and possibly their Martian source regions. The Cameca ims 1280 ion-microprobe, within the NASA-funded W. M. Keck Cosmochemistry Laboratory, University of Hawaii will be used to collect hydrogen isotope data from both NWA 7034 and NWA 8159 to determine the source of water within these two meteorites

References: [1] Agee C. B. 2013. *Science*. 339:780-785. [2] Lin Y. T. et al. 2016. #6248 *79th Met. Soc.* [3] Kayzar T. M. 2015. #2357 *46th LPSC*. [4] McCubbin F. M. et al. 2015. *Am. Min.* 100: 1790-1802. [5] Howarth G. H. et al. 2015. *Geochim. Cosmochim. Acta*. 166: 234-248. [6] Greenwood J. P. et al. 2003. *Geochim. Cosmochim. Acta*. 67: 2289-2298. [7] Filiberto J. and Treiman A. H. 2009. *Geology*. 37: 1087-1090. [8] McCubbin F. M. and Nekvasil H. 2008. *Am. Min.* 93: 676-684. [9] Villanueva G. L. et al. 2015. *Science*. 348: 218-221. [10] Watson L. L. et al. 1994. *Science*. 265: 86-90. [11] McCubbin F.

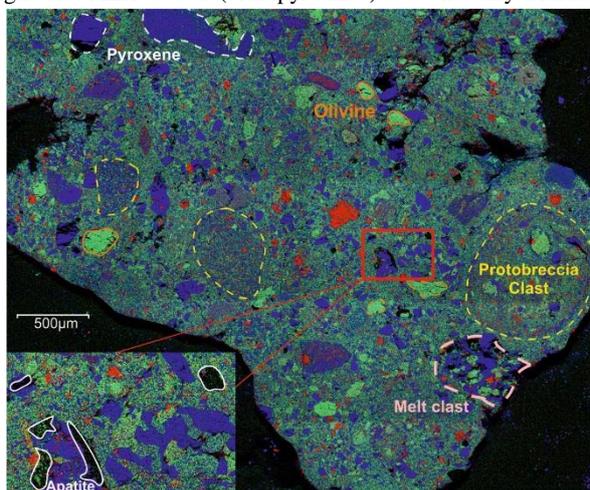


Figure 1: SEM image of NWA 7034 with overlain false colour elemental map.

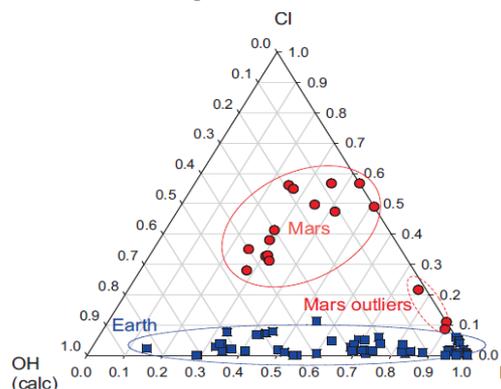


Figure 2: Cl, F and OH in Martian meteorite and terrestrial apatite. Martian apatites tend to be Cl-rich and OH- poor (data from [7]). Outliers represent terrestrial contamination.

M. et al. 2016. *JGR*. 121: 2120-2149.

Olivine Alteration of Shergottite Northwest Africa 10416.

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Introduction: Studying secondary alteration phases in martian meteorites, allow us to form hypotheses regarding martian water-rock reaction processes [1]. The initial step in these studies is to identify whether the secondary alteration phases are terrestrial or martian. Northwest Africa (NWA) 10416 is an olivine-phyric martian Shergottite with olivine grains that show orange-brown altered cores and clear unaltered rims (Fig. 1). We have performed microanalysis of these olivine grains by various techniques in order to help test whether the olivine core alteration is terrestrial or not; the results of which we present here.

Methods: A thin section was initially characterised through Back Scattered Electron (BSE) imagery and Energy Dispersive X-ray fluorescence (EDX) spectroscopy, using an Environmental Scanning Electron Microscope (ESEM) XL-30. Fe-K X-ray Absorption Spectroscopy (XAS) was carried out using the I-18 microfocuss spectroscopy beamline at the *Diamond* synchrotron, UK. Measurements were taken from 6900 eV to 7500 eV.

Olivine: Comprises ~15% of the analysed thin section. These grains are ~1 mm size and consist of orange central zones, dark brown outer bands and clear, unaltered olivine in the outer margins of the larger grains (Fig. 1). There are also smaller groundmass olivine grains. The olivine grain shown in Figure 1 clearly displays a large fracture cutting and displacing half of it. It is notable that the orange-brown colouration is also displaced; the significance of this is discussed below.

The large phenocrysts show chemical variation consistent with igneous zonation. The grains have Mg-rich olivine cores, $\text{Fo}_{78}\text{Fa}_{22}$, and rims of almost equal Mg and Fe content olivine, $\text{Fo}_{52}\text{Fa}_{48}$.

X-ray Absorption Analysis: XAS measurements were taken on the sample in order to gather information about the oxidation state across the altered olivine grain and the nature of fluid alteration (Fig. 2). Higher resolution measurements of 0.1 eV increments were taken across the XANES region (7100-7125 eV), because the best indication of oxidation is present in the pre-edge features and the absorption edge position.

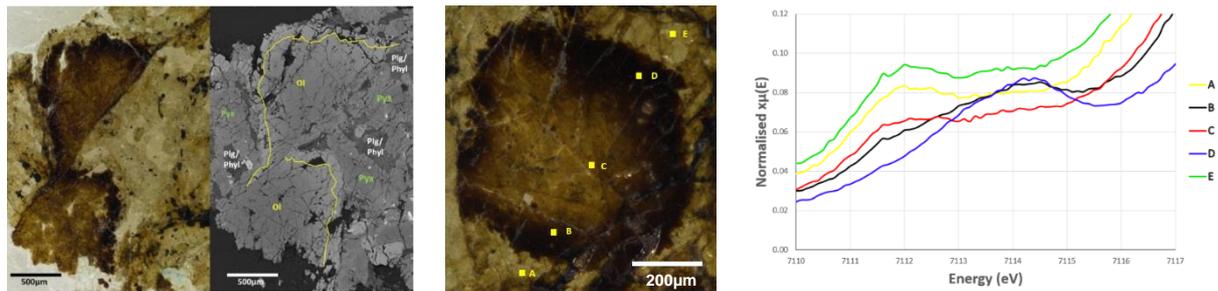


Figure 1 (left) – Optical and BSE image comparison of a fractured olivine grain in NWA 10416. Altered core - clear rim boundary shown as yellow line. Minerals labelled: olivine (yellow), pyroxene (green) and plagioclase with phyllosilicate alteration (white).

Figure 2 (middle) – Optical image showing locations corresponding to XAS data shown in Figure 3. Points A and E are within the olivine grains clear rim, whereas points B and D lie within the cores brown boundary and C in its orange core.

Figure 3 (right) – XAS data of pre-edge region and initial part of the absorption edge. Lines A, B, C, D and E correspond to XAS sites shown in Figure 2.

Figure 3 shows a definite oxidation variation across the sites indicated in Figure 2. The pre-edge features of B and D (brown boundary of olivine core) differ from A, C and E which also suggests some compositional variation. The initial section of the absorption edge (and the entire edge) shows the following order from highest absorption energy to lowest, and therefore highest oxidation state to lowest; D, B, C, A, E.

Discussion: Previous studies [2,3] suggested that the olivine alteration is pre-terrestrial due to serrated boundaries between the olivine grains and groundmass, as well as an overlap in composition of the clear rims and clear groundmass olivine when compared to the altered olivine cores. However, oxygen isotope analysis [4] suggests an ‘overprinting by terrestrial alteration’ in the cores of the olivine grains, meaning the secondary alteration, that caused the orange-brown colouration, might have been caused on Earth.

Our XAS data indicates an oxidation trend across the olivine grain, which in turn could indicate a reaction front at the core-rim boundary. It has been observed that Fo-olivine is more susceptible to alteration over its Fa counterpart under oxidizing conditions when subject to low-temperature surface fluids [5]. This can explain why we only see the alteration within the Mg-rich olivine cores.

One possible model to explain the alteration pattern is that the parent rock underwent igneous zonation as it cooled quickly, creating the olivines’ Mg-rich cores and rims of almost equal Mg, Fe. Martian shock effects caused veins and fracturing of the compositionally zoned olivines. During its time in Northwest Africa, groundwater exploited the fractures and altered the olivine in a way that was controlled by the pre-existing, igneous compositional zonation.

References: [1] Changela H. G. and Bridges J. C. (2011) *Meteoritics & Planet. Sci.*, 45, Nr 12, 1847–1867. [2] Herd C. D. K. et al. (2016) *LPS XLVII*, Abstract #2527. [3] Vaci Z. (2016) *LPS XLVII*, Abstract #2538. [4] Ziegler K. (2016) GSA, Paper #49-5. [5] Hausrath E. M. and Brantley S. L. (2010) *JGR*, 115, 2156–2202.

VOLCANIC SHIELDS ON MERCURY IDENTIFIED AT LAST?

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Introduction: Small (<50 km across) shield volcanoes are known on Earth [1], the Moon [2], Mars [3] and Venus [4], but previous identifications of these features on Mercury [5] have been reevaluated [6]. Until now, only low-lying volcanic craters formed by putative explosive eruptions have been positively identified on Mercury [6]. We have found two new candidate small shields at the edges of impact basins using orbital data from NASA's M_{ER}cury Surface, Space E_Nvironment, G_Eochemistry, and Ranging (MESSENGER) spacecraft. We introduce the better-evidenced candidate here (Fig. 1).

Observations: The candidate shield is a positive relief feature situated within a ~120 km diameter impact basin (Fig. 1A). Smooth plains material covers the basin floor. The positive relief feature appears roughly circular in map view and has a diameter of ~6 km (Fig. 1B). Shadow length calculations return a height of ~600 m and an average slope of ~20°. The bowl-shaped summit depression has a shallower appearance than craters of similar diameter nearby. The northern flank of the feature has a separate depression running from the peak to the base. The superposition relationship between the northern flank depression and the summit depression is equivocal in all available NAC images. The summit has a red spectral anomaly, similar to those of putative pyroclastic deposits elsewhere on Mercury [5] (Fig. 1C). Local impact craters have blue ejecta.

Interpretation: Basins, such as the one shown here, have complex morphologies and should have either central peaks or peak-rings [7]. Our positive relief feature could be an element of this basin's peak-ring (though it is farther from the centre of the basin than would be predicted [7]) with a central superposing impact crater. If this is the case, it is difficult to explain why this element of the peak-ring is present but the remainder is deeply buried with no surface expression. An impact origin for the summit depression is inconsistent with the red spectral anomaly, also. Local impact craters of a similar diameter to the summit depression exhume blue material, requiring a deeper source for the red material. Furthermore, the shape of the summit depression appears shallower than local impact craters. We suggest the smooth plains were emplaced by a volcanic eruption within the basin, burying the peak-ring. The positive relief feature was built as a late-stage volcanic edifice. The depression on the northern flank was formed by subsequent small impacts. Before the extinction of the volcano, at least one deep-sourced [8], explosive eruption occurred, creating the red spot (a pyroclastic deposit, [5]). The relatively undegraded state of the host basin suggests a Mansurian age (~3.5-1.0 Ga) for its formation [9], providing an upper bound on the age of the volcanic edifice.

Conclusions: The apparent paucity of volcanic edifices could be ascribed to the very low molten viscosities of materials matching the surface composition of Mercury [10] or their implied high effusion rates [11]. Our results show that, at least under certain circumstances, eruptions on Mercury could build volcanic edifices. If more candidate shields are found by searching similar settings, then shield building on Mercury may be characteristic of late-stage, post-impact volcanism. Confirmed shields will be important science targets for the upcoming BepiColombo mission to Mercury [12].

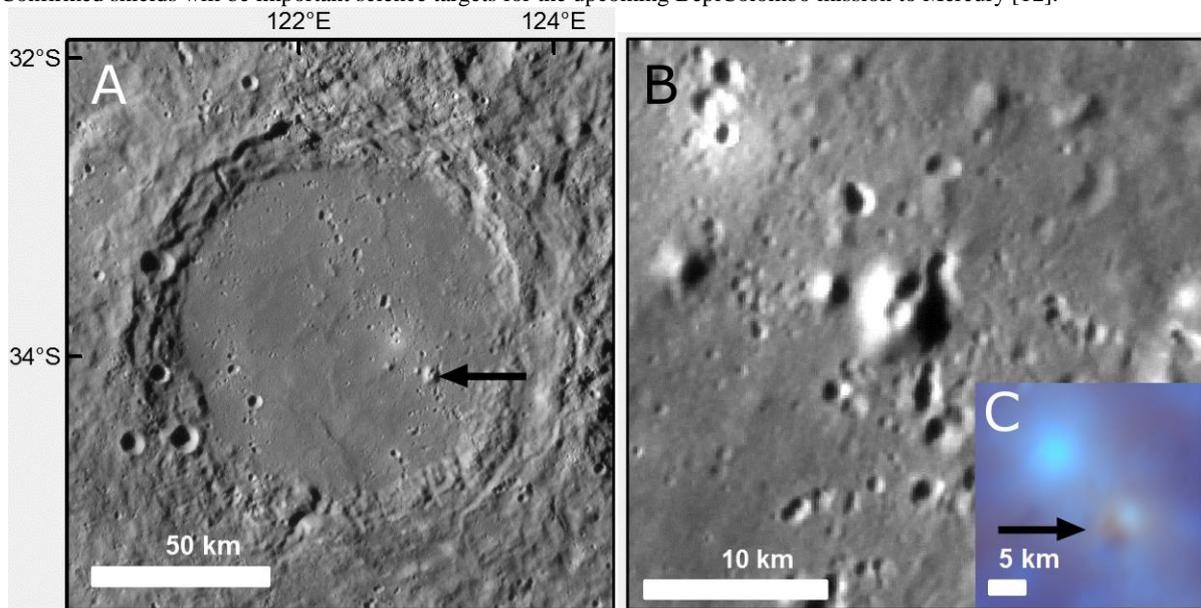


Fig. 1. **A** – The unnamed impact basin hosting the candidate volcanic edifice (black arrow) (123°02'14" E, 34°07'40" S). **B** – The best view of the edifice (MESSENGER NAC image EN1015774526M, ~136 m/pix). **C** – Enhanced colour mosaic of the host impact basin. The black arrow indicates the red spot associated with the candidate volcanic edifice. Immediately to the north-west of the red spot, bright crater ejecta can be seen from a nearby young impact. This demonstrates that small, local impacts exhume blue material from shallow depths. The red material must have a different, non-impact source.

References: [1] Swanson D. A. 1973. *GSA Bull.* 84:615-626. [2] Head J. W. and Gifford A. 1980. *The moon and planets.* 22:235-258. [3] Hauber E. et al. 2009. *JVGR.* 185:69-95. [4] Ivanov M. A. and Head J. W. 2004. *J. Geophys. Res. Planets.* 109:E10. [5] Head J. W. et al. 2008. *Science.* 321:69-72. [6] Rothery D. A. et al. 2014. *Earth Planet. Sci. Lett.* 385:59-67. [7] Pike R. J. 1988. *Mercury.* 165-273. [8] Thomas R. J. et al. 2015. *Earth Planet. Sci Lett.* 431:164-172. [9] Kinczyk M. J. et al. 2016. Abstract #1573. 47th LPSC. [10] Stockstill-Cahill K. R. et al. 2012. *J. Geophys. Res. Planets.* 117:E12. [11] Byrne P. K. et al. 2013. *JGR: Planets.* 118:1303-1322. [12] Rothery D. A. et al. 2010. *Planet. Space Sci.* 58:21-39.

Dhofar 2046 – A Thermally Altered CM Chondrite?

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Introduction: The Dhofar (Dho) 2046 meteorite was found in 2011 and recently classified as an anomalous CM2 chondrite [1]. It consists of chondrules and silicate fragments set within a fine-grained Fe-rich matrix but has an O isotopic composition that is significantly heavier ($\delta^{17}\text{O} = 7.78\%$, $\delta^{18}\text{O} = 19.93\%$) than typical CM chondrites. One process predicted to shift the O isotopes of CM chondrites to heavier values is thermal metamorphism [2]. There are now >20 known thermally altered CM chondrites and these are likely good analogues for materials that will be returned by the Hayabusa-2 and OSIRIS-REx missions. X-ray diffraction (XRD) is a useful tool for identifying thermally altered CM chondrites because heating causes dehydration of phyllosilicates, resulting in the collapse of the phyllosilicate structure and a lack of coherent diffraction [3]. Here, we present a preliminary XRD investigation of Dho 2046.

Experimental: A 50 mg chip of Dho 2046 was powdered using an agate mortar and pestle and packed into an aluminium sample well. XRD patterns were then collected from the rotating sample for 16 hours using an INEL X-ray diffractometer with Cu $K\alpha_1$ radiation.

Results & Discussion: The main diffraction peaks identified in the Dho 2046 pattern are from olivine (Fo_{70}) and Fe-sulphides. Peaks at $\sim 12^\circ$, $\sim 19^\circ$ and $\sim 24^\circ$ (2θ Cu $K\alpha_1$) attributed to phyllosilicates in CM chondrites are not observed. We therefore suggest that Dho 2046 is a thermally metamorphosed CM chondrite.

The XRD pattern of Dho 2046 is very similar to several other thermally altered CM chondrites (e.g. B-7904, PCA 02010 and PCA 02012) that we, and other groups, have studied [4, 5]. The broadness of the olivine peaks in these meteorites indicates that it is fine grained and/or poorly crystalline, which is consistent with recrystallization from phyllosilicates at temperatures $>500^\circ\text{C}$. Such high temperatures on the CM parent body(ies) were probably short-lived and generated by either impacts or solar radiation [2–5]. We estimate the maximum temperature experienced by Dho 2046 to be $>750^\circ\text{C}$.

References: [1] Met. Bulletin #105. (2016) [2] Tonui E. K. et al. (2014) *Geochim. Cosmochim. Acta* 126, 284–306. [3] King A. J. et al. (2015) *Geochim. Cosmochim. Acta* 165, 148–160. [4] King A. J. et al. (2015) *Meteoritics & Planetary Science* 50:A5212. [5] Nakamura T. (2005) *J. Mineral. Petrol. Sci.* 100, 260–272.

Volatile Deposition in the Martian Regolith.

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Introduction: The carbon dioxide condensation-sublimation cycle is a dominant climatic process on Mars and is currently the subject of much investigation. Recent discoveries include a widespread low-latitude diurnal carbon dioxide frost cycle^[1] using observations made by the Mars Climate Sounder on board the Mars Reconnaissance Orbiter. This is much more widespread than previously thought, and has some important implications. Piqueux et al. (2016) suggest that this frost cycle could be preventing soil induration, and thus could help maintain a source of dust. For this to occur, subsurface carbon dioxide ice must form in addition to the surface frosts observed by the MCS, as this would result in mechanical weathering analogous to the freeze-thaw process experienced on Earth with water ice.

Methodology: In order to model carbon dioxide ice deposition in the subsurface at a given time and location, subsurface temperature profiles and carbon dioxide condensation curves must first be calculated. This has been done on a 20° latitude by 20° longitude grid at four times of year (Spring Equinox, Summer Solstice, Autumn Equinox, and Winter Solstice).

Modelled temperature and atmospheric pressure data from the Mars Climate Database^[3, 4] is used for these calculations, which inherently considers location specific variables, such as elevation.

By combining the temperature profiles (an example of which is shown in Figure 1) with the calculated condensation curves, the location, depth and time of active carbon dioxide condensation can be determined. This has been repeated for each of the each of the specified times of year (example shown in Figure 2), and for each location on the a 20° latitude by 20° longitude grid. These results have then been brought together and plotted as contour maps of carbon dioxide ice incidence for each specified time of year.

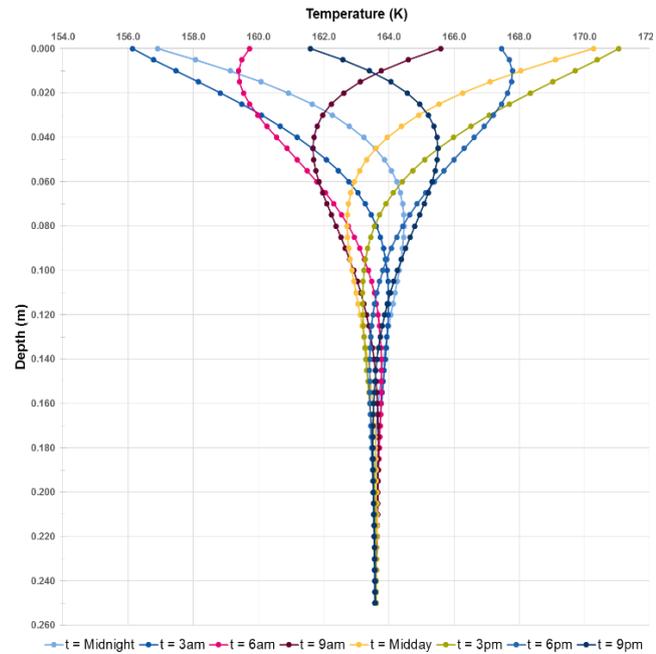


Figure 1. Example of a calculated subsurface temperature profile over one daily cycle at the Phoenix Lander site.

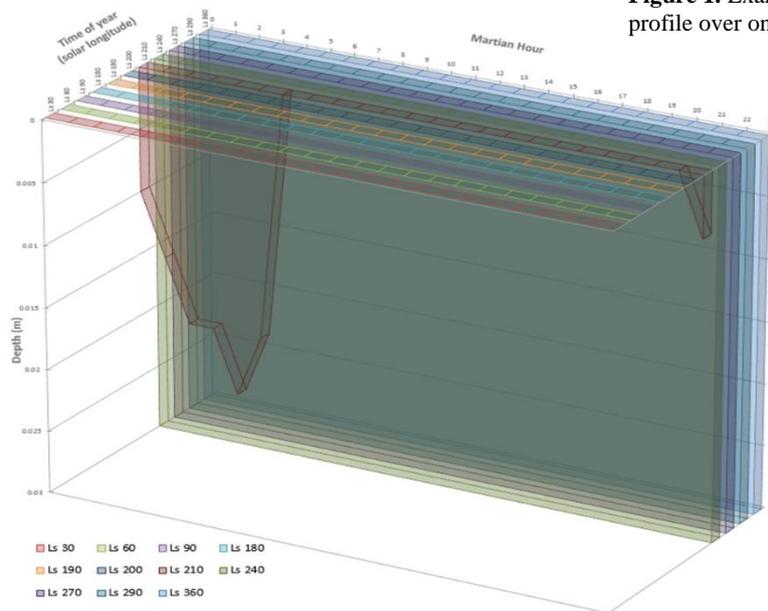


Figure 2. Example of a daily cycle of CO₂ ice deposition at the Phoenix Lander site. This is calculated at intervals of 30° of solar longitude for one Martian year. This illustrates the variability of CO₂ ice content of the shallow subsurface (calculated for the uppermost 3 cm of regolith).

References: [1] Piqueux, S. et al. (2016) Discovery of a widespread low-latitude diurnal CO₂ frost cycle on Mars. *Journal of Geophysical Research: Planets*. [2] Hagermann, A. (2005) Planetary Heat Flow Measurements. *Philos Trans A Math Phys Eng Sci*. [3] Forget, F., et al. (1999) Improved general circulation models of the Martian atmosphere from the surface to above 80 km. *Journal of Geophysical Research*. [4] Millour, E., et al. (2015) The Mars Climate Database (MCD version 5.2). *EPSC Abstracts*, Vol. 10. [5] Cornwall, M. A. (2014) Estimating Planetary Heat Flow from a Shallow Subsurface Heat Flow Measurement. [6] Christensen et al. (2001) The Mars Global Surveyor Thermal Emission Spectrometer experiment: Investigation description and surface science results, *J. Geophys. Res.* Vol. 106. [7] Grott, et al. (2007) Thermal structure of Martian Soil and the Measurability of the Planetary Heat Flow. *J. Geophys. Res.* Vol. 112.

VOLATILE COMPONENTS AND IMPACT MELT PROCESSING IN THE EARLY SOLAR SYSTEM

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Introduction: Ordinary chondrites are the largest group of meteorites found on Earth and as such are categorized in many ways according to their petrologic type, level of thermal equilibration and the weathering they have experienced while at the Earth's surface. They are also categorized by their shock stage according to a classification scheme devised by Stöffler et al [1] which splits shock levels into the increasing stages S1-S6. In stages S3-S6 shock melting may occur which can manifest as melt veins, pockets or dykes [1]. Some of these impact melts are vesiculated implying volatile loss from the melt phase [2]. This study is designed to investigate this volatile loss by measuring halogen and noble gas abundances in impact melted and unmelted fragments of shocked ordinary chondrites with an aim of examining what effect impact melting had on the volatile inventories of these meteorites. Noble gas mass spectrometry will be utilized alongside scanning electron microscopy and electron probe micro-analysis.

Impact Melting: Most impacts on ordinary chondrite parent bodies occurred early in their history when impact rates were much higher [2] and these are recorded in the Ordinary Chondrite record. Impacts incurring a pressure above ~15GPa caused melting [1] and produced variable impact melt products such as metal-troilite mixtures, vugs and larger impact melt areas and pockets [3]. These larger impact melt areas are often vesiculated implying volatile loss which compliments the commonly held belief that impact melting on chondrite parent bodies causes halogen and noble gas depletions [3]. Many authors typically state volatile loss and vaporisation as the cause of formation for the vesicles without stating which volatiles have been lost and to what extent [4]. However, some authors do attribute vesicle formation to sulfur vaporisation during the breakdown of metal-sulfide phases during the melting [2] as vesicles are often found associated and in contact with such phases [2,5]. The aim of this project is to better understand this volatile loss and if possible identify which elements are being volatilised and in what quantities. Ordinary chondrites of particular interest are Chico [4] and Chelyabinsk [6] as both contain vesiculated impact melt and adjacent portions of unmelted material which allows for direct comparison and identification of changes in volatile abundances.

Halogens: The halogens are useful volatiles to examine because they are also important tracers of thermal and aqueous processes in the early solar system. Understanding how halogens were affected by impact processing could help us to understand how the volatile budget changed in the early inner solar system, how these changes affected aqueous processes on parent bodies and how this translated into planetary halogen abundances. For example, halogens in Chondrites are typically locked within apatites. The suggestion that F-Cl rich apatites are associated with regolith breccias could mean that a large amount of volatile loss may have occurred if halogens are found to commonly degas during impact melting [7]. This could explain the volatile element depletions of the terrestrial planets compared to CI carbonaceous chondrite [7]. Halogens will be investigated utilising the Thermo Scientific Argus VI mass spectrometer at the University of Manchester to obtain possible Ar-Ar ages as well as halogen (Cl, Br, I) abundances on irradiated samples utilising the neutron irradiation noble gas mass spectrometric technique [8].

Noble Gases: Noble gases are also useful to examine as they are also important tracers of thermal and aqueous processes in the early solar system. A connection between volatile depletion and noble gas abundance is clear as there is a correlation between volatile element loss in ordinary chondrites and the loss of fragile noble gas carriers [9]. A correlation between shock level and radiogenic ⁴⁰Ar and solar ⁴He in Chondrites has also been identified [10] and impact events often cause partial degassing of ⁴⁰Ar in ordinary chondrites [4]. However, little work has been done looking at how the heavier noble gases (Kr, Xe) are affected during impact melting and volatilization. This project will aim to investigate the effects of impact degassing on noble gas abundances in addition to the more about halogen complement of ordinary chondrite material. Of particular interest will be Xenon. In addition to heavy noble gases elemental ratios, we will attempt to discern any isotopic fractionation during impact processing and potentially whether differences phases / noble gas carriers are more susceptible to impact degassing than others. Noble gases will be investigated utilising the Thermo Helix multicollector mass spectrometer and the VG 5400, both at the University of Manchester, in order to determine He, Ne, Ar, Kr, and Xe noble gas abundances and isotope ratios.

References: [1] Stöffler D. et al. 1991. *Geochemica*. 55:3845-3867. [2] Bendix G. K. et al. 2008. *Geochemica*. 72:2417-2428. [3] Rubin A. E. 1985. *Reviews of Geophysics*. 23:277-300. [4] Bogard D. D. et al. 1995. *Geochemica*. 59:1383-1399. [5] Kring D. A. et al. 1996. *JGR*. 101:29353-29371. [6] Righter K. et al. 2015. *Meteoritics*. 50:1790-1819. [7] Jones R. et al. 2016. *American Mineralogist*. 101:2452-2467 [8] Ruzié-Hamilton L. et al. 2016. *Chemical Geology*. 437:77-87. [9] Wieler R. et al. 2006. *MESS II*. Eds. Laurretta D. S. and McSween H. Y. 499-521. [10] Schultz L. and Stöffler D. 1993. 56th MetSoc. pp 432.

A 2-D MODEL OF THE NAKHLITE PARENT ROCKS

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Introduction: The nakhlite meteorites are basaltic clinopyroxenite rocks formed in a thick basic-ultrabasic lava flow or shallow sill intrusion [1] with a common age of 1.3 Ga [2]. Similar petrologic and isotopic characteristics mean that it is usually regarded that the nakhlites all originated from a single magmatic formation. However, with minor variations in mesostasis abundance and varying chemical compositions in the olivine and pyroxene rims, they are considered to have each experienced subtly different thermal histories suggesting variable depths in formation [3,4,5]. This nakhlite pile ranges from a crystallisation depth of 1-2 m from the surface with MIL 090030/032/136 and NWA 5790, followed with increasing depth by NWA 817, MIL 03346, Y 000593 paired with Y 000749, GV along with Nakhla, and to the bottom with Lafayette and NWA 998 at a burial depth of >30 m.

A unique feature of the nakhlites is the presence of hydrothermal veining [6,7,8] which likely formed ≤ 670 Ma in the mid-to late-Amazonian epoch [9,10], consisting predominantly of siderite, ferric saponite and Al-rich ferric serpentine, amorphous silicate gel of saponitic composition, and halite and sulphates [7,8,11,12]. An impact-induced event may have been responsible for the hydrothermal system and secondary alteration, with heated fluids percolating upwards from buried H₂O-CO₂ ice and through the newly fractured nakhlite igneous mass [7].

Analysing the variation in chemical composition, in particular Mg# (=Mg100/(Mg+Fe)), the Fe/Si (wt%) ratio, and ferric (Fe³⁺/ΣFe) content [7,8], and assessing the extent of the secondary alteration, we propose a profile for the nakhlites, in terms of the burial depth [5] and distance from the hydrothermal source.

Discussion: Beginning with partial dissolution of the surrounding ol-clinopyroxenites by warm (150 ≤ T ≤ 200 °C) CO₂-rich fluids of pH 6–8 and a water:rock ratio (W/R) of ≤300 [12], the initial fluid migrated through the nakhlite pile from Lafayette closest to the hydrothermal source, through GV to Nakhla. This is shown by the deposits of sideritic carbonates, becoming less Ca-rich and more Mg-rich. The fluids exhausted its HCO₃⁻ content, and did not reach farther than Nakhla, although a minor abundance of siderite was reported in Y-000593 [13], but an accurate mineralogical composition has not been obtained.

As the fluids cooled (>50 °C) at pH 9 and a low W/R of 6, the Ca-siderite began to corrode Lafayette with crystalline ferric saponite precipitated within the olivine fractures, and ferric serpentine in mesostasis fractures. Following this, a rapid cooling of the remaining fluids formed amorphous gels in the centre of the veins, of similar composition to the phyllosilicates [7,8].

The hydrothermal fluids had also flowed beyond Nakhla and into the rest of the other nakhlites, where they also rapidly cooled depositing predominantly amorphous Fe-silicate gel [7,8]. The composition of clay and gel fractionated as the fluids migrated through the nakhlites away from the heat and fluid source. The variation in composition trend is a decrease in Mg# (ranging Mg#=41 to 13), and an increase in Fe/Si (1.1-1.5). The variation also included a decrease in oxidation from the highly ferric (Fe³⁺/ΣFe =1.0) deposits in Lafayette and down to a ferric-ferrous ratio as low as Fe³⁺/ΣFe =0.4 in MIL 03346. The nakhlite NWA 5790 formed in the upper regions of the pile with the highest abundance of mesostasis (33.6%) and the extensive chemical zoning in the augite and olivine grains [5], and with a lack of secondary alteration present it is suggested to have been beyond the influence of the hydrothermal event.

Additionally, the new nakhlite NWA 10659 (a pair of NWA 10153 [14,15]) has a mesostasis abundance and chemical compositions that suggest a burial depth of ~1-7 m, with NWA 817 and MIL 03346 above it, and Y-00593 and Nakhla below [16]. Analysis of the limited secondary alteration found chemical compositions of Mg#=13.1 and Fe/Si=1.1 in the olivine fractures with a low ferric content of Fe³⁺/ΣFe=0.4, similar to MIL 03346, suggesting the NWA 10659 sample is likely the farthest of the altered nakhlite samples from the fluid source.

Spaceborne detections of Amazonian carbonates and phyllosilicates are sparse rather than large-scale [17,18], but if such formations occurred only in brief localised events, such as suggested for the nakhlites, then this is to be expected.

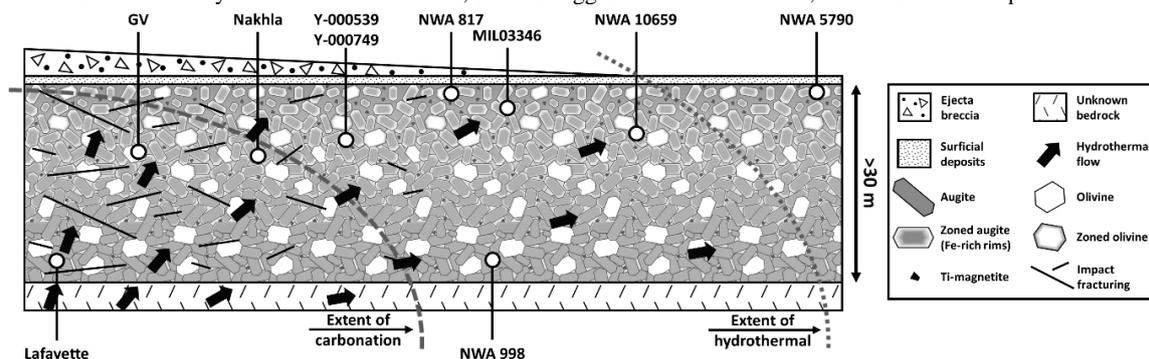


Figure 1: A 2-D profile of the >30 m deep nakhlite formation (not to scale).

References: [1] Treiman A. H. et al. 1993. *Meteoritics*. 28:86-97. [2] Nyquist L. E. et al. 2001. Ages and Geologic Histories of Martian Meteorites. *Space Sci. Ser.* 96:105-164. [3] Mikouchi T. et al. 2003. *Antarct. Meteorit. Res.* 16:34-57. [4] Mikouchi T. et al. 2006. Abstract #1865. *LPSC XXXVII*. [5] Mikouchi T. et al. 2012. Abstract #2363. *LPSC XLIII*. [6] Gooding J. L. et al. 1991. *Meteoritics* 326:135-143. [7] Changela H. G. and Bridges J. C. 2011. *MAPS* 45:1847-1867. [8] Hicks L. J. et al. 2014. *GCA* 136:194-210. [9] Swindle T. D. et al. 2000. *MAPS* 35:107-115. [10] Shih C. Y. et al. 1998. Abstract #1145. *LPSC XXIX*. [11] Bridges J. C. and Grady M. M. 2000. *EPSL* 176:267-279. [12] Bridges J. C. and Schwenzer S. P. 2012. *EPSL* 359-360:117-123. [13] Grady M. M. et al. 2007. Abstract #1826. *LPSC XXXVIII*. [14] Mikouchi T. et al. 2016. Abstract #6369. *79th MAPS Meeting*. [15] Irving A. J. et al. 2015. Abstract #5251. *78th MAPS Meeting*. [16] Hicks L. J. et al. 2016. Abstract #6421. *79th MAPS Meeting*. [17] Ehlmann B. L. and Edwards C. S. 2014. *Annu. Rev. Earth Pl. Sc.* 42:291-315. [18] Turner S. M. R. et al. 2016. *JGR: Planets* 121:608-625.

A CLASTIC METEORITE FROM MARS: PETROLOGICAL AND TEXTURAL INSIGHTS INTO MARTIAN REGOLITH PROCESSES

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Introduction: The first clastic meteorites from Mars [1,2] provide a unique opportunity to study the processing and oxidation history at a Martian impact site. Formed in an impact ejecta blanket from precursor magmatic assemblages, it is possible that hydrothermal systems could have caused further alteration to it [3,4]. It contains zircons of 4.4 Ga (U-Pb) [5] and the whole rock ages of 2.1 Ga (Rb-Sr) [1] and 1.5 Ga (U-Pb) [6] are associated with impact regolith processes. The rocks were ejected from Mars by another impact ~5 Ma ago [7] and found in 2012. Our study combines mineralogical work [8,9] with the textures and compares it with terrestrial pyroclastic material and impact ejecta.

Methods: Three polished sections from the main mass of NWA 8114 were examined with an SEM and electron probe microanalyser (EPMA) for initial elemental analyses. The focused ion beam (FIB) sections for transmission electron microscope (TEM) analysis were taken from different specifically chosen clasts of NWA 8114.

Beamlines at the *Diamond Light Source* synchrotron were used: I-18 for X-ray absorption near edge structure (XANES) analyses [10] and X-ray diffraction (XRD), and B-22 for Fourier Transform Infrared (FTIR) spectroscopy. Fe-K XANES, XRD and FTIR were carried out at sample points on a representative variety of clasts, as well as XANES 5 μm resolution and FTIR 8 cm^{-1} resolution maps.

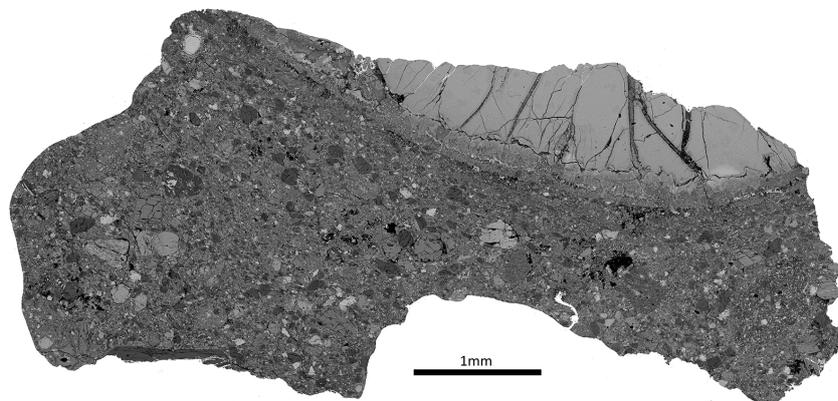


Fig. 1: Backscattered electron image of NWA 8114.

Results and Discussion: Figures 1 and 2 show the range of mineralogy, sizes, shapes and textures. Some pyroxene clasts ($\text{Wo}_{2}\text{En}_{65-72}\text{Fs}_{26-33}$) have a porous texture and feldspar border, some have exsolution lamellae varying in width, indicating a crystallisation temperature above 900°C. FIB-TEM has shown others ($\text{Wo}_{12-18}\text{En}_{31-34}\text{Fe}_{47-56}$) to be more oxidised and show partial breakdown to iron oxide and aluminium silicate, an anhydrous high temperature reaction [8]. Cryptoperthite alkaline feldspar $\text{Ab}_{8-20}\text{Or}_{80-92}$ and plagioclase An_{24-43} indicate more than one magmatic source and slow cooling. Feldspar-rich veins ($\text{An}_{20-43}\text{Ab}_{55-71}\text{Or}_{0-16}$) show evidence of subsequent regolith melting. The presence of goethite, identified with synchrotron FTIR and XRD, requires low temperature rock/water interaction [9]. Given that two veins of terrestrial Ca carbonate cross-cut the goethite, and the D/H isotope analyses support the martian origin of the hydrated phases [1], the goethite was most likely formed on Mars. This indicates the presence of a fluid in the regolith as it slowly cooled on Mars.

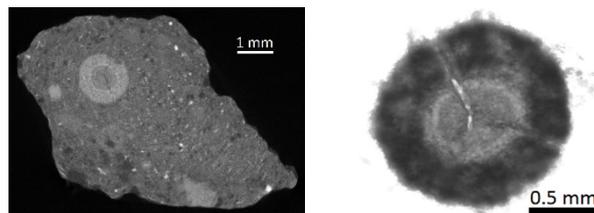


Fig. 2: CT-scan images showing a spherical accretionary pellet-like structure in NWA 8114

The impact ejecta blanket where this breccia formed may have resulted from fallout from an impact plume [6] or an impact-generated current [10] with similarities to a pyroclastic density current. The meteorite material is poorly sorted, and accretionary rims (shown in Fig.1 and Fig.2 above) are similar to those found in ignimbrites which would favour an impactoclastic density current emplacement mechanism [11]. Many impact craters on Mars show evidence for flow mechanisms [12], particularly craters featuring double layer ejecta, which have been shown to be common on Mars as more high resolution images are obtained [12]. Incorporation of volatiles in the subsurface together with impact energy is thought to be the main driver for formation of these ejecta morphologies [12].

References: [1] Agee C.B. et al. 2013, *Science* 339, 780-785. [2] Santos A. et al. 2014, *GCA* 157, 56-85. [3] Gattacceca J. et al. 2014, *GRL* 41, 4859-4864. [4] Liu Y. et al. 2016, *47th LPSC Abstract* #1127. [5] Humayun M. et al. 2013, *Nature* 503, 513-516. [6] McCubbin F.M. et al. 2016, *JGR*, 121, 2120-2149. [7] Cartwright J.A. et al. 2014, *EPSL*, 400, 77-87. [8] MacArthur J.L. et al. 2015, *46th LPSC Abstract* #2295. [9] MacArthur J.L. et al. 2016, *MAPS*, #6020. [10] Wittman A. et al. 2015, *MAPS*, 50, 2, 326-253. [11] Branney M.J. & Brown R.J. 2011, *Journal of Geology* 119 275-292. [12] Barlow N.G. 2015, *Geological Society of America Special Paper* 518, 31-63.

PRELIMINARY RESULTS OF 1:3 MILLION GEOLOGICAL MAPPING OF THE MERCURY QUADRANGLE H-10 (DERAIN). C. C. Malliband¹, D. A. Rothery¹, M. R. Balme¹ and S. J. Conway² ¹School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK ²LPG Nantes–UMR CNRS 6112, Université de Nantes, France. E-mail: chris.malliband@open.ac.uk

Introduction: MESSENGER heralded a new era in our geological understanding of Mercury as a dynamic planet. Geological mapping of surface features is essential in understanding both local and global geology. To this end, we have started mapping the H-10 (Derain) quadrangle to publish at 1:3 million scale to the same standards as other new MESSENGER mapping [1,2,3,4,5,]. This will allow integration into a global geological map [6]. H-10 quadrangle is in the equatorial band of Mercury, located between 0°–72°E and 22N°–22°S (Fig. 1). It was not imaged by Mariner 10; therefore this MESSENGER-based work is the first high resolution geological mapping of the quadrangle.

Features: H-10 contains a wide variety of features. Very few of these have been studied in any detail. We show here some features of particular note.

Ancient Basins: H-10 contains two highly degraded basins identified by [7], where they are listed as B30 and B36. Basin B30 shows clearly in topography, but is otherwise obscure and is probably pre-Tolstojan in age. Its diameter is 1390 km [7], making it the second largest basin on Mercury. At the SE basin edge, the boundary is marked by a lobate scarp. B36 is a 730km diameter ancient basin. It is of Tolstojan or Calorian age, given degradation of crater overlying the basin and its margin. B36 is much more obvious on the MDIS mosaic than B30.

Picasso: Picasso is a 120 km diameter crater centred at 50.21° E, 3.44° N. Its crater degradation class places it at Tolstojan age, but it has an apparently younger plains unit occupying its floor.

Picasso contains a set of arcuate red pits. This set of pits appears to be located around the trace of the mostly buried peak ring. Enhanced colour shows more intense red colour at the northern end of the chain. This may suggest that the pits were active sequentially, from south to north. It also contains quasi-radial, curvilinear, features that form steps in the topography. The steps seem to link sectors of a degraded lobate scarp that can be seen outside the crater, to the east and to the west, and are probably evidence of unusual localization of strain.

Derain: Derain contains extensive areas of red pits, which have partially coalesced into a larger pit. Hollows are present on the crater floor [8]. This is the only set of hollows previously identified in B36. As hollows are thought to be formed by volatile loss [8, 9], it is likely that a volatile phase underlies Derain. This phase may not be present elsewhere in B36, or Derain crater may be unique in encouraging currently visible hollow forming processes. Derain has also excavated a large amount of low reflectance material, principally towards the north and west.

References: [1] Galluzzi V. et al, (2016), J. Maps, 12, Sup1, 227-238 [2] Mancinelli P. et al, (2016), J. Maps, 12, Sup1, 190-202. [3] Wright J. et. al, (2016) LPSC 47, 2067. [4] Guzzetta L. et al. (2016) XIII Congresso Nazionale di Scienze Planetarie [5] Rothery D A. et. al, (2017) LPSC 48, 1406 [6] Galluzzi V. et. al, (2016) LPSC 47, 2119, [7] Fassett C. I. et. al. (2012) JGR, 117. [8] Thomas R. J. et. al. (2014) Icarus, 229, 221–235. [9] Blewitt D. T. et. al. (2016) JGR: Planets, 121, 9.

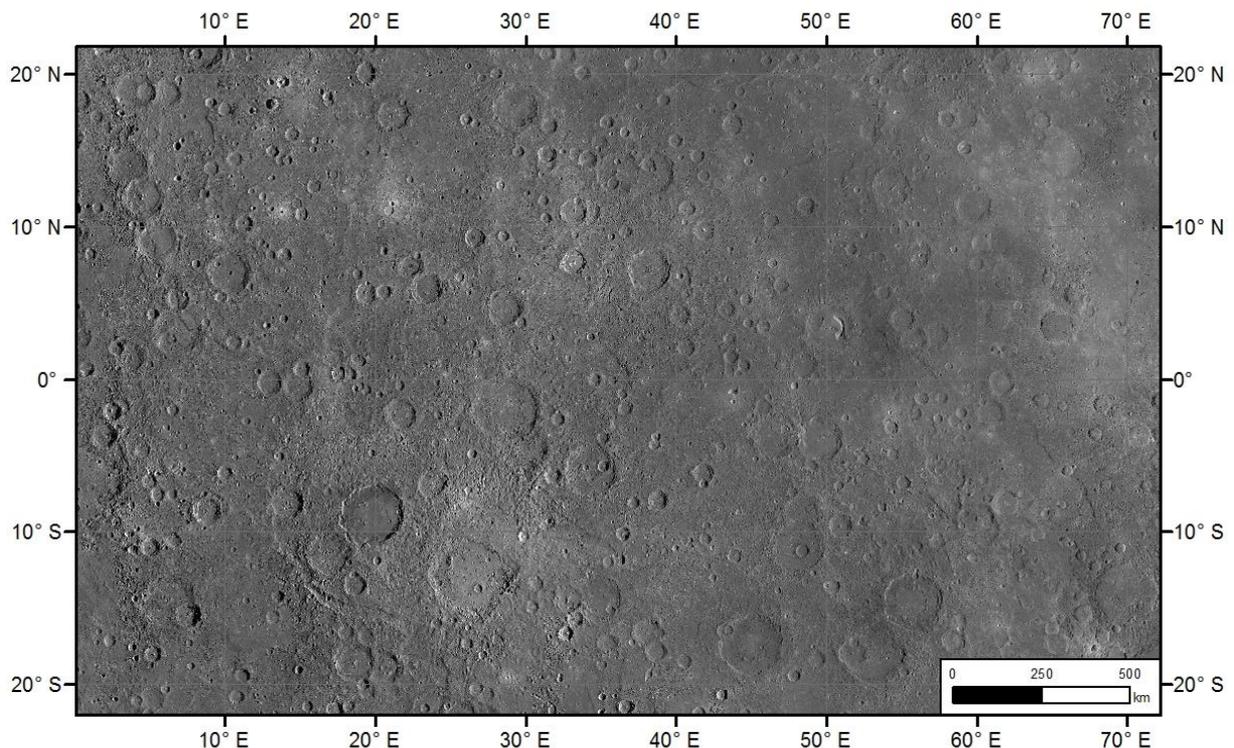


Figure 1: Quadrangle H-10 (Derain). Locations of Figures 2, 3 and 4 are shown. Basemap is MESSENGER 166m mosaic

MICRO-FTIR SPECTROSCOPY OF APOLLO 14, 15, AND 16 REGOLITH SAMPLES.

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Introduction: Apollo soils 14259,672, 15401,147, and 67481,96 were collected from a range of lunar geological settings: mare volcanics (A14 and A15) and feldspathic highland crust (A14 and A16). The samples have a range of space weathering ‘maturities’ (a measure of the amount of time spent at the lunar surface [1-4]), ranging from highly immature (e.g., little surface exposure: 15401) to mature (e.g., extended surface exposure: 14259). Spectroscopic analysis of such samples allows for characterisation of their key chemical, physical, and mineralogical properties. Quantification of these properties, alongside development of the analysis and processing techniques, are vital for comparison with both current and future remote sensing datasets in order to further investigate the chemical and physical properties of planetary surface materials [5].

Methods: Prior to spectral analysis, the Apollo regolith samples were sieved into 5 size fractions: 0-25, 25-63, 63-125, 125-250, and >250 μm using stainless steel sieves and a fine brush (to minimise the loss of fine/electrostatically charged material). Following this, Fourier-Transform InfraRed (FTIR) spectroscopy was used to investigate the aforementioned properties of the three Apollo regolith samples, using a mid-infrared wavelength range of 3-15 μm (4000-650 cm^{-1}) both in Manchester and Münster. Sample preparation involved the filling of an aluminium sample cup with sample material and flattening of the surface via scraping across the top of the sample cup with a spatula.

Analyses in Manchester: Each size fraction and bulk fraction of each regolith sample was analysed using a Spotlight-400 FTIR spectrometer with attached mapping unit, whereby a 4.5×4.5 mm area of the surface of each sample was mapped at high resolution (25 μm pixel size, 2 scans per pixel). This resulted in 32000 spectra per sample that were averaged to obtain a single representative mid-infrared spectrum per size fraction of each sample. Individual spectra from each map were analysed to identify the phases present in the samples (mineral, glass, and agglutinate phases) and create a database of Apollo mineral and glassy/amorphous regolith components.

Analyses in Münster: A Bruker 70v Vertex spectrometer was used in Münster to obtain mid-infrared spectral measurements of the regolith samples. This instrument uses a broad mid-infrared beam (~ 1 cm) with a large number of scans (512) to obtain an average spectrum of a powder.

Spectral Analysis: Band positions and %Reflectance values were collected for the phases present in each regolith sample using a least-squares algorithm, resulting in low peak position (0.1 cm^{-1}) and %Reflectance (0.5 %R) uncertainties. %Reflectance values varied across each map and between maps due to the heterogeneous nature of the sample surfaces at the micron scale. As such, ratios of %Reflectance values of two specific bands were calculated in order to compare the varying physical properties of the samples and negate the varying %Reflectance values due to sample surface topography. The band ratio 932 / 1942 cm^{-1} decreases with increasing sample maturity and the band ratio 932 / 1145 cm^{-1} decreases with increasing crystallinity of a sample (that is, the relative proportion of crystalline to glassy/amorphous material).

Results: Each of the bulk sample spectra of the three regolith samples display unique properties. The spectrum of 67481,96 (A16) show strong diagnostic mineral bands (between 1200 and 900 cm^{-1}) and a strong transparency feature around 825 cm^{-1} , indicating a high proportion of crystalline material and the smallest size fraction respectively. This is in contrast to 14259,672 (A14), which shows a broad, flat spectrum with few resolvable diagnostic mineral bands, indicating little crystalline material present. The bulk spectrum of 15401,147 (A15) has a broad peak between 1125 and 900 cm^{-1} , with few of the diagnostic mineral bands present, indicating a high proportion of glassy material in this sample.

Band Ratios: The bulk regolith samples have 932 / 1942 cm^{-1} ratios of 0.124 (A15), 0.119 (A16), and 0.085 (A14) which, when compared to their measured I_{ν}/FeO maturity values of 3, 31, and 85 respectively, show a linear trend of decreasing band ratio value with increasing maturity. An inverse trend is also present in the band ratio 932 / 1145 cm^{-1} when compared to the crystallinity of the samples. The bulk regolith spectra suggest A16 is highly crystalline, A14 is partly crystalline, and A15 is highly glassy/amorphous; their 932 / 1145 cm^{-1} band ratio values of 2.49, 3.70, and 8.11 respectively reflect the differences in proportions of crystalline and glassy/amorphous material well.

Discussion: The main advantage of using a mid-infrared band ratio to estimate the maturity of a lunar sample is the non-destructive nature of this technique. Previous estimations of maturity have required multiple analyses, some of which destroy the fraction of sample being analysed (i.e., noble gas measurements) [6]. Although the estimated maturity values using FTIR methods can vary by up to 15 units from the measured I_{ν}/FeO maturity value, it is accurate enough to classify the sample as either highly mature, mature, immature, or highly immature, providing key information about the sample’s formation environment. More samples with varying maturities are required to further test the reliability of this band ratio and more accurately determine the trend between the 932 / 1942 cm^{-1} band ratio and maturity. This band ratio may be useful for existing remote sensing datasets and future missions to airless bodies, such as the upcoming BepiColombo mission to Mercury (on-board which will fly the mid-infrared spectrometer MERTIS) [7].

Conclusions: Three Apollo regolith samples have been analysed using FTIR spectroscopy techniques, resulting in the establishment of a new method for non-destructive analysis of the maturity of lunar samples. Crystallinity has also been found to vary with a specific band ratio, though this has yet to be quantified. Average grain size and composition can also be estimated from bulk sample FTIR spectra, with the new FTIR powder analysis technique allowing for individual phases in a powder to also be identified. These techniques may prove useful for future remote sensing datasets of airless planetary bodies. Future work includes analysis of peak areas, development of an algorithm to automatically identify specific minerals given their spectrum, and measurements of the regolith samples with higher numbers of scans.

References: [1] Meyer C. 2011. Lunar Sample Compendium (online). [2] Morris R. V. 1978. *Proc. 9th Lunar Sci. Conf.* 2287-2297. [3] Heiken G. H. 1975. *Rev. Geophys. Space Phys.* 567-587. [4] Heiken G. H. et al. 1973. *Proc. Lunar Sci. Conf.* 251-266. [5] Hapke B. 1984. *Icarus.* 59. [6] Signer P. et al. 1977. *Proc. 8th Lunar Sci. Conf.* 3657-3683. [7] Hiesinger H. et al. 2010. *PSS.* 58:144-165.

HALOGEN ABUNDANCES IN THE LUNAR MANTLE: DEVELOPING AN UNDERSTANDING OF VOLATILES OF THE EARTH-MOON SYSTEM.

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Volatile elements play a key role in terrestrial planetary evolution having control on mantle dynamics and magma evolution, e.g. through influencing melt viscosity, solidus temperatures, and rheology [1]. However, relatively little is still known about the origin and abundance of volatile elements in the inner Solar System.

The Moon lacks an atmosphere, surface water, crustal recycling and has experienced a comparatively simple mantle evolution relative to the Earth. Lunar samples are old >3Ga and unaltered and therefore may provide a window on early terrestrial-lunar volatile composition. Some recent SIMS studies of lunar volcanic glass beads and apatite grains suggest that the lunar mantle may contain water in abundances comparable to present day MORB [2-5]. This may mean volatiles were retained following the purported moon-impact forming event, or that later addition of volatiles occurred prior to mantle closure. In contrast, a dry lunar mantle is argued for on the basis of Cl-isotope studies on lunar volcanic glasses [e.g. 6].

The heavy halogens (Cl, Br and I) are an important group of volatile elements that are incompatible and controlled by fluid mobility, and are not strongly affected by fractional crystallisation or partial melting processes. This makes the halogens a useful tool for tracing other volatile elements, magma source regions, degassing processes and the movement of hydrous fluids [7]. On Earth, halogens are recycled by subduction processes making it difficult to determine the primary composition of the terrestrial mantle, however, potentially important insights can be gained on the Earth-Moon halogen and volatile signatures by determining halogens in samples from the primitive lunar mantle.

Seven olivine-rich mare volcanic basalts were chosen from a range of Apollo missions (11, 12, 14 and 15). The samples were selected as representative of partial melts that vary in both age (~4.2 and 3.2 Ga) and mantle source depth (variation in chemistry, e.g. Ti- and Al-content). Olivine-hosted melt inclusions are preserved in some samples, which are a good target for analysis of pre-eruptive mantle volatiles.

Whole-rock fragments and olivine separates (~2-6 mg) of each sample underwent neutron irradiation to convert the constituent heavy halogens Cl, Br and I into their respective noble gas isotopes. Noble gases (Ar, Kr and Xe) were released in a single fusion step with a CO₂ laser. Neutron-produced noble gas isotopes from halogens were measured using an Argus VI mass spectrometer. Reduction of noble gas data to halogen abundances follows the method of [8] with the added complication of correcting for spallogenic noble gas isotopes produced at the lunar surface. The full correction procedure is being developed and indications are that the samples contain resolvable amounts of Cl, Br and I.

References: [1] Filiberto J. and Treiman A. H. 2009. *Chem. Geol.* 263:60-68. [2] Saal, A. E. et al. 2008. *Nature. Lett.* 454:192-195. [3] Hauri, E. H. et al. 2001. *Science*, 333:213-215. [4] Tartèse, R. et al. 2013. *GCA*, 122:58-74. [5] Barnes, J. J. et al. 2013. *Chem. Geol.* 337-38:48-55. [6] Sharp, Z. D. et al. 2010. *Science*, 329:1050-53. [7] Pyle D. M. and Mather T. A. 2009. *Chem. Geol.* 263:110-121. [8] Ruzié-Hamilton L. et al. 2016. *Chem. Geol.* 437:77-87.

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INVESTIGATING THE ROLE OF ADVECTION PROCESSES IN IMPROVED MARTIAN DUST ASSIMILATION TECHNIQUES FOR EXOMARS.

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Introduction: Mineral dust is a crucial component of Mars' weather and climate system, playing a role comparable in importance to that of water in Earth's atmosphere. Dust in the atmosphere absorbs radiation from the sun, heating the atmosphere and cooling the surface, in the process affecting the global circulation. Martian dust storms can last for weeks and attain global scale, causing significant temperature variations [1]. Understanding Martian dust is thus vital for planning future robotic and manned missions to Mars.

Data assimilation is a method for combining observational data with a numerical model to improve and constrain the model and obtain the best representation [2]. The Open University uses a Mars Global Circulation Model (MGCM) developed by the Laboratoire de Météorologie Dynamique and adapted by the University of Oxford and the Open University [3] and a data assimilation technique adapted from the Met Office's Analysis Correction scheme [4]. By using data assimilation to integrate spatio-temporally irregular and limited observations into an MGCM, a complete, self-consistent atmospheric state can be obtained, including important atmospheric variables not measured in the observations such as zonal and meridional wind.

Current data assimilation techniques have yielded valuable results, even with simplistic assumptions about factors such as vertical dust distribution [5] and how to represent dust advection within the assimilation scheme [6] [7]. However, recent detection of detached dust layers in the upper atmosphere [8] have cast doubts on the prescribed vertical distributions, while work on assimilating vertical profile data from the Mars Climate Sounder (MCS) with full dust transport enabled has reproduced these layers [9].

Proposed work: Future work will aim to further improve advection in the Open University assimilation scheme, for example by investigating how best to couple interactions between dust distribution and winds in the model. This work will be tested and validated with existing dust observations. The intention is to subsequently use these improved schemes on forthcoming observations from the ExoMars Trace Gas Orbiter (TGO), which will offer vertical dust distribution profiles at unprecedented resolution.

References:

[1] R. Haberle et al., *Icarus*, (1982). doi:10.1016/0019-1035(82)90129-4. [2] W. Lahoz et al., *Data Assimilation*, Springer, (2010). [3] Forget et al., *J. Geophys. Res.*, (1999). Doi: 10.1029/1999JE001025. [4] A. Lorenc et al., *Q.J.R. Meteorol. Soc.*, (1991). doi:10.1002/qj.49711749704. [5] B. Conrath et al., *Icarus*, (1975). doi:10.1016/0019-1035(75)90156-6. [6] S. Lewis et al., *Icarus*, (2007). doi:10.1016/j.icarus.2007.08.009. [7] L. Montabone et al., *Icarus*, (2015). doi:10.1016/j.icarus.2014.12.034. [8] Heavens et al., *J. Geophys. Res. Planet.*, (2014). doi:10.1002/2014JE004619. [9] T. Ruan, DPhil thesis, (2015).

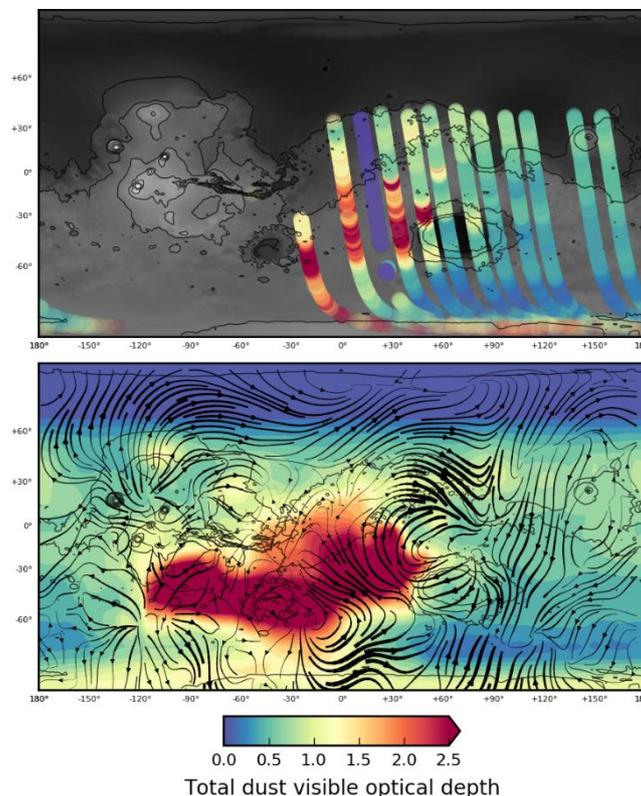


Figure 1: Top: Thermal Emission Spectrometer (TES) visible dust optical depth measurements over a period of ~ 1.4 sols at $L_s = \sim 320$. Bottom: MGCM wind and total dust visible optical depth output with TES data assimilated over the same period.

SIMULATION OF THE ATMOSPHERIC ENTRY OF MICROMETEORITES THROUGH THE MARTIAN ATMOSPHERE.

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Introduction: The main source of extraterrestrial material accreted by the Earth is micrometeorites with approximately 20-40Kt estimated to be accreted by the Earth annually [1]. In the past, several attempts have been made to model the atmospheric entry of micrometeorites (MMs) through the Earth's atmosphere [2, 3, 4]. These models predict that most particles experience peak temperatures high enough to cause significant melting and this is reflected in MMs found on the Earth's surface with 70-90% of particles >50 μ m in radius being melted [5]. This study uses a new model based on that of Love & Brownlee (1991) to examine the effects of atmospheric entry heating for particles falling through the Terrestrial and Martian atmosphere.

Method: Simulations of 4300 particles with radii ranging from 10-500 μ m and entry angles ranging from 5-90° were ran for both entry conditions on the Earth and on Mars. The particles are assumed to have an ordinary chondrite like composition and an average density of 3gcm⁻³ [4]. The entry velocity was taken to be the minimum entry velocity for both planets, 11.2kms⁻¹ and 5.0kms⁻¹ respectively.

Results: Initial results indicate a positive correlation between peak temperature and starting particle radius for both the Earth and Mars. However, this correlation reverses for particles with entry angles below ~8° on Earth and ~14° on Mars.

Peak Temperature: Assuming a solidus temperature for the particle of 1573K [4] these simulations show that ~11% of particles on Earth remain below this solidus temperature and therefore remain unmelted. However, ~92% of the MMs incident on Mars remain below this temperature. Particles as small as 30 μ m reach this temperature on Earth whereas a particle's initial radius must be >390 μ m on Mars for it to reach 1573K.

Mass Loss: It can also be seen that the proportion of mass lost by particles falling on Earth is significantly higher than that of Mars. For particles falling to Earth, approximately 86% lose more than half their original mass and the maximum loss is 96.8% for a 500 μ m particle. However, on Mars the largest mass loss of all particles was ~9.1% for a 500 μ m particle and ~66% of the particles falling on Mars lost <1% of their original mass.

Discussion: Particles entering below 8° on Earth and 14° on Mars are interpreted to have grazing incidents, a process in which an incident MM enters the planet's atmosphere at a low enough angle as to not collide with the surface, but instead is slowed by the planet's atmosphere, exits the atmosphere and eventually re-enters assuming exit velocity was below escape velocity. The reason why this occurs at higher entry angles on Mars compared to the Earth is attributed to the lower acceleration due to gravity and the smaller size of Mars. The smaller acceleration due to gravity will affect the trajectory of the particle less than on Earth and the smaller size results in a shorter length of atmosphere in which a particle can be slowed down, resulting in a smaller velocity loss. This allows particles entering at low angles to escape the atmosphere before being slowed significantly enough for full capture. However, the reason larger particles that skip reach lower peak temperatures is still uncertain.

The majority of particles will have entry angles above this grazing incident angle and for those it is clear that a much higher proportion survives without melting on Mars compared to Earth. These particles also survive at much larger initial radii. These larger unmelted particles could provide samples of MM parent bodies which are not seen on Earth due to the significant melting and mass loss seen in terrestrial MMs.

Although [6] calculated the annual micrometeorite flux on Mars to be only ~17% of that on Earth, due to the much higher survival rate of MMs falling through the martian atmosphere it is reasonable to assume that there should be a high quantity of MMs present on the surface of Mars. As the sedimentation rates on Mars are thought to be much slower than on Earth [5], it is also possible to say that the martian soil could contain a large proportion of MMs.

Conclusion: These simulations clearly show a much higher survival rate for MMs on Mars than on Earth. Large quantities of MMs could have built up on the martian surface and may also provide samples of MM parent bodies not yet studied. Future martian rover missions could incorporate instruments capable of finding and studying MMs on the surface with the hope of gaining a wider understanding of the population of meteorite parent bodies.

References: [1] Love, S. G and Brownlee, D. E. 1993. *Science*. 262: 550-553. [2] Love, S. G and Brownlee, D. E. 1991. *Icarus*. 89: 26-43. [3] Campbell-Brown, M. D. & Koschny, D. 2004. *A&A*. 418: 751-758. [4] Genge, M. J. 2016. *MAPS*. 51: 1063-1081. [5] Genge, M. J. *et al.* 2008. *MAPS*. 43: 497-515. [6] Flynn, G. J and McKay, D. S. 1990. *JGR*. 95: 14497-14509.