ORAL PRESENTATIONS

Mars 2020 Perseverance: exploring Jezero crater and preparing for Mars Sample Return

***Keyron Hickman-Lewis*[1]**

1Birkbeck, University of London

Since landing in February 2021, the NASA Mars 2020 Perseverance rover has explored several regions of Jezero crater, including the crater floor, delta front, upper fan and crater margin, identifying diverse geological units. Crucially, it has collected a suite of samples representative of these units intended for Mars Sample Return in the near future (Herd et al., 2025). Samples collected across the crater floor include basalt and olivine cumulate reflecting distinct igneous processes (Simon et al., 2023). At the delta front and upper fan, sedimentary samples including sandstones and siltstones have the potential to shed light on the palaeoenvironmental conditions of Lake Jezero (Stack et al., 2024); based on studies of analogous Precambrian terrestrial sedimentary rocks, these may also contain minor amounts of organic materials (Hickman-Lewis et al., 2025). At the crater margin, we have identified several units with high biosignature preservation potential, for example silica-cemented carbonate represented by the Comet Geyser sample and organic-bearing mudstones with apparent reduction spots represented by the Sapphire Canyon sample. The latter includes the first unambiguous spatially constrained organic detection on Mars (Hurowitz et al., 2025). The samples collected by Perseverance have the potential to answer multidisciplinary questions of fundamental importance to the planetary science community, with implications for geology, geochronology, geochemistry, Mars' planetary evolution through the Noachian and, particularly in the case of Sapphire Canyon, astrobiology.

[1] Herd, C.D.K., et al., 2025. PNAS 122, e2404255121. [2] Hickman-Lewis, K., et al., 2025. Nature Communications 16, 2726. [3] Hurowitz, J.A., et al., 2025. Nature 645, 332–340. [4] Simon, J.I., et al., 2023. JGR Planets 128, e2022JE007474. [5] Stack, K.M., et al., 2024. JGR Planets 129 e2023JE008187.

A mountain of evidence for a habitable environment: Curiosity's ascent of Mount Sharp.

***Steven G. Banham**[1], MSL Science Team*

1Imperial College London

The Mars Science Laboratory rover, Curiosity, has been climbing Mount Sharp in Gale crater for 4732 Sols, and has gained 892 m in elevation – the equivalent hight of the mountains Great Gable or Cadair Idris. During this ascent, the scientists have gathered compelling evidence that shortly after crater formation, a habitable environment existed within its bounds, before over a protracted period, habitability diminished during the Hesperian global climate change event.

The lower part of the stratigraphic succession records persistent lakes fed by fluvial systems originating from the crater rim. As the rivers entered the lake, they released plumes of sediment and assorted nutrients into the water column to be distributed across the lakebed – recorded as the Murray formation. Geochemical and mineralogical assessments indicate that environmental conditions preserved in the strata during this timeframe would have sustained life, if it were present.

After traversing the phyllosilicate unit, the rover began the steep ascent across the orbitally-defined sulphate-bearing unit. As Curiosity climbed those strata, it witnessed distinct changes in the stratigraphy, recording a progressive drying of the palaeoenvironment preserved in the crater. The rover identified a gradual change from humid conditions containing a record of perennial lakes, to isolated ephemeral lakes, and onto desolate deserts. During this ascent, interstratification of aeolian strata became more common, including sand sheets, dune strata and deflation scours. However, despite this general aridification, the succession is still punctuated by episodes of abundant water: the Amapari ripple bed for example, records a brief shallow lake: a veritable oasis, free of ice.

This presentation will showcase the changes recorded by the rover during its ascent of Mount Sharp, to understand how habitability was impacted by climate change.

Seeing Red with CaSSIS: Shocked Plagioclase in the Martian Highlands

Joseph McNeil[1], *P.M. Grindrod*[1], *L.L. Tornabene*[2], *V.T. Bickel*[3], *J. Cuadros*[1], *R.B. Stabbins*[1], *M.R. Patel*[4], *A. Sokołowska*[5], *C. Bill*[5]

1Natural History Museum, London
2Western University, Canada
3University of Bern, Switzerland
4Open University, UK
5Imperial College London, UK

The Colour and Stereo Surface Imaging System (CaSSIS) has acquired over 38,000 images of Mars since 2018, revealing numerous red-toned outcrops (RTOs) across the southern highlands. These visually distinct deposits are widespread but poorly understood in origin and composition. Here, we present the first global investigation of RTOs using CaSSIS, HiRISE, and CRISM data, combining high-resolution imaging with multi- and hyperspectral analysis.

A convolutional neural network, trained on ~30 manually identified RTOs, was applied to the entire CaSSIS dataset, yielding 2,232 detections. After manual verification, 923 were confirmed as ‘probable’ or ‘likely’ RTOs. They occur predominantly within Noachian terrains, and are particularly common surrounding the large impact basins of Hellas and Argyre, as well as in the walls of Valles Marineris, and around Nili Fossae. Most RTOs appear as blocky outcrops or diffuse deposits within crater ejecta, suggesting a relationship with impact processes. Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectra of these outcrops show a subtle, yet broad 1.25 μm absorption consistent with partially shocked Fe-plagioclase feldspar (maskelynite), which forms in hypervelocity impact events.

Taken together, these observations suggest that RTOs represent excavated and shock-metamorphosed fragments of a plagioclase-bearing lower crust that pervaded the southern highlands, which was exhumed by ancient basin-forming impacts and reworked through martian geologic time by impact gardening. These findings provide new evidence for a feldspathic lower crust on Mars and link its exposure to the earliest basin-forming events, offering a rare window into pre-Noachian crustal composition and evolution history.

Martian quakes and structure: UK contributions from InSight

Anna Catherine Horleston[1], *J.C.E. Irving[1], N. Bowles[2], S. Calcutt[2], C. Charalambous[3], G. Collins[3], D. Kim[3], R. Myhill[1], W.T. Pike[3], N.A. Teanby[1], J. Temple[2], T. Warren[2], J. Wookey[1]*

1University of Bristol
2University of Oxford
3Imperial College London

InSight was the first mission to place a seismometer on another planet. The UK had key roles in instrument development and delivery, mission leadership, and in scientific discoveries spanning from Mars' surface to its core.

With the deployment of SEIS – including the UK delivered short period (SP) instruments – to the surface, the InSight mission showed the variety of seismic sources present on Mars. The Marsquake Service (MQS, co-led by Anna Horleston) catalogued seismic sources from super-high frequency events close to the lander, most likely caused by local cracking, to tectonic events located on the opposite side of the planet (Dahmen et al., 2020, Horleston et al., 2022). Many marsquakes were located to the Cerberus Fossae region – an area of extensive surface faulting resulting from the most recent known volcanism on Mars, hinting at a potential sub-surface upwelling in this area.

Other quakes were linked to known meteorite impacts using low- and high-resolution (MARCI, CTX, HiRISE) optical satellite imagery (Garcia et al., 2022, Posiolova et al., 2022). The marsquakes and impacts detected by MQS were used to develop the first seismically-informed structural models of Mars from its core (Irving et al., 2023) to mantle (Huang et al., 2022) and crust (Kim et al., 2022). Charalambous et al. (2024) linked an impact in the Cerberus Fossae region to a known marsquake, and Charalambous et al. (2025) revealed fine-scale heterogeneity in the Martian mantle; both results will inform future investigations. The impact rate, estimated from the seismic record (Zenhäusern & Wójcicka et al., 2024), will provide input for hazard models relevant to future missions to Mars.

Throughout the active mission (2018-2022) and during post-mission review the UK has been at the forefront of the seismic data processing and analysis greatly advancing our understanding of the structure of Mars.

Seismic evidence for a highly heterogeneous martian mantle

***Constantinos Charalambous*[1]**, *W. Thomas Pike*[1], *Doyeon Kim*[2], *Henri Samuel*[3], *Benjamin Fernando*[4,5], *Carys Bill*[1,6], *Philippe Lognonné*[3], *W. Bruce Banerdt*[7]

1Department of Electrical and Electronic Engineering, Imperial College London, London, UK
2Department of Earth Science and Engineering, Imperial College London, London, UK)
3Université Paris Cité Institut de Physique du Globe de Paris, CNRS, Paris, France
4Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, USA
5Department of Physics, University of Oxford, Oxford, UK
6 Department of Earth Sciences, University of Oxford, Oxford, UK
7Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

A planet's interior is a time capsule, preserving clues to its early history. We report the discovery of kilometer-scale heterogeneities throughout Mars' mantle, detected seismically through pronounced wavefront distortion of energy arriving

from deeply probing marsquakes. these heterogeneities, likely remnants of the planet's formation, imply a mantle that has

undergone limited mixing driven by sluggish convection. their size and survival constrain Mars' poorly known mantle rheology, indicating a high viscosity of 10^21.3 to 10^21.9 pascal-seconds and low temperature dependence, with an effective activation energy of 70 to 90 kilojoules per mole, suggesting a mantle deforming by dislocation creep. the limited mixing, coupled with ubiquitous, scale-invariant heterogeneities, reflects a highly disordered mantle, characteristic of the more primitive interior evolution of a single-plate planet, contrasting sharply with the tectonically active Earth.

Reference: Constantinos Charalambous et al., Seismic evidence for a highly heterogeneous martian mantle. Science 389,899-903 (2025). DOI:10.1126/science.adk4292

Understanding the formation and evolution of bodies in our Solar System through analysis of extra-terrestrial samples: The UK Cosmochemistry Network

***Katherine Joy*[1]*,** *Sara Russell[2], Jamie Gilmour[1], Mahesh Anand[3], Luke Daly[4]*

1University of Manchester
2Natural History Museum
3The Open University
4University of Glasgow

The UK Cosmochemistry Network: We are a consortium of the UK's leading specialists in the laboratory-based analysis of extraterrestrial material. We use a wide range of laboratory analytical techniques and approaches to analyse samples from different planetary bodies, the solar wind, and planetary analogue environments. Multi-scale analysis of extraterrestrial materials, down to atomic resolution provides insights into nucleosynthesis and stellar evolution, astrophysical environments (including the protoplanetary disk), Solar System dynamics, planetary evolution and the prebiotic processes that led to the origin of life. Investment in a new UKCAN is needed to equip the UK with a comprehensive suite of state-of-the-art laboratory instrumentation supported by specialist staff for the purpose of analysing (and collecting, preparing and curating) extraterrestrial materials, including samples returned from the Moon, Mars and other bodies by missions, and meteorite collections.

Non-destructive mineralogy and petrology of Bennu samples using correlated imaging and diffraction at Diamond Light Source

Helena Bates*[1]*, *Ashley King*[1]*, Paul Schofield*[1]*, Liam Perera*[2]

1Natural History Museum
2DLS

Determining the mineralogy and processing history of samples returned by NASA's OSIRIS-REx spacecraft from asteroid Bennu is critical for our understanding of the evolution of volatile-rich asteroids. Bennu offers a unique opportunity to investigate samples that are likely not represented widely in our meteorite collection, and that have geological context from remote observations made by the spacecraft when in Bennu orbit. However, analytical methods tend to be partially to completely destructive, including the loss of material when creating polished sections for microscopy and the loss of spatial context when powdering samples. This is a serious consideration when investigating valuable samples such as meteorites and particularly material returned from asteroids.

To address these concerns, we utilized the K11 Dual Imaging and Diffraction (DIAD) beamline at Diamond Light Source to probe the interior of a Bennu sample, a technique which relates micro-computed tomography (micro-CT) with X-ray diffraction (XRD) tomography. XRD is a powerful technique used widely in meteoritics which enables the identification of mineral phases and determination of their structure. The advantage of this work is that we are able to directly correlate diffraction data with images of the interior of the Bennu particle without subsampling and avoiding any destructive preparations.

Our aim was to attempt to understand more about the aqueous alteration of a Bennu particle by looking at the microstructure and the composition of mineral phases using entirely non-destructive techniques. We have been able to reconstruct peaks associated with individual minerals including magnetite, olivine and sulfide to create maps across the interior of the Bennu sample, showing the distribution and spatial variation of phases. Ultimately, insights gained from this analysis will offer crucial knowledge on asteroid evolution whilst preserving these incredibly precious samples.

Using Radiogenic Isotopes as Tools for Deciphering the Chronology of Lunar Volcanic Rocks

***John Pernet-Fisher*[1]** , *R. Tartèse*[1] ; *J. Snape*[1] ; *F. Boschetty*[1] ; *F. S. Anderson*[2]; *S. E. Braden*[2]; *K. H. Joy*[1]

1University of Manchester
2SwRI

Volcanism is arguably the single most critical ingredient in shaping the evolution of rocky bodies. As such, it is vital that we correctly interpret the dates of rocks that we measure either in the lab or remotely by crater counting. Radiogenic isotope analysis is a key tool for unpicking crystallisation ages from subsequent geological processes such as impact processing within the crust.

We report in situ Rb-Sr and Pb isotope data for a suite of lunar granitoids. Understanding the formation of felsic melts on the Moon has long been hampered due to their rarity and small size in sample collections; typically occurring as clasts in breccias and soils. Our results indicate that Rb-Sr and Pb-isotope systematics recorded by Si-K glass, plagioclase, and K-feldspar reflect impact resetting events, likely linked to the formation of the Imbrium basin at 3.92 Ga. In contrast, zircon U-Pb isotope dates provide the most robust constraints for granitoid formation ages, indicating ages as old as ~4.32 Ga. This has implications for assessing the feasibility of the leading model of felsic melt generation on the Moon (basaltic underplating).

The Rb-Sr isotope system can also be used to understand the crystallisation ages of basaltic rocks. The DIMPLE (Dating an Irregular Mare Patch with a Lunar Explorer) payload, selected under the NASA PRISM program, will fly to the irregular mare patch Ina. Ina is striking due to its very young (33 Ma) crater counting age. It is currently unclear how lunar volcanism could have persisted into the geologically recent past. An alternative hypothesis contends that IMPs are in fact ancient (~3.2 Ga) but are comprised of materials that cannot sustain crater-forms over geologic time. The DIMPLE payload will directly measure the age of surface materials using the Rb-Sr isotope chronometer, providing critical constraints on the longevity of lunar volcanism.

Néma 001, a diorite with affinities to the acapulcoite-lodranite clan

***Romain Tartese*[1]**

1University of Manchester

Primitive achondrites have roughly bulk chondritic compositions and are characterised by granoblastic texture evidencing high-temperature metamorphism and low degrees of partial melting. They provide us with a crucial snapshot into the transition from unmelted chondritic material to differentiated achondrites. The acapulcoite and lodranite meteorites are primitive achondrites that originated from a common parent body. Acapulcoites are fine-grained rocks that experienced very low degrees of partial melting (ca. <1 to 5%). Lodranites have larger grain sizes and experienced higher degrees of partial melting (~5-20%). Uniquely, we have a sample of their chondritic precursor in the meteorite collection, the type 4 chondrite Grove Mountains (GRV) 020043. Mineralogical studies also indicate that silicate melts were extracted from lodranite precursors, as represented by gabbroic clasts in Lewis Cliff 86220 acapulcoite-lodranite, and the pyroxene-plagioclase coarse-grained Frontier Mountain (FRO) 93001 meteorite.

Néma 001 is a coarse-grained igneous meteorite composed of mm to cm-sized crystals of ortho- and clinopyroxene, plagioclase, and olivine, with a bulk andesitic composition. Its bulk oxygen isotope composition is undistinguishable from that of the acapulcoites-lodranites, suggesting they may originate from the same asteroidal parent body. This is supported by their similar olivine Fe/Mn ratios. Petrological modelling suggests that Néma 001 could represent silicate melts formed by ~15% partial melting of a chondritic precursor similar to GRV 020043.

With the addition of Néma 001, we now have a comprehensive suite of samples from the acapulcoite-lodranite parent body, including chondritic material (GRV 020043), residues from ~1-20% partial melting (acapulcoites-lodranites), and variably differentiated igneous rocks such as FRO 93001 and Néma 001. This unique suite of samples is key to further investigate melting and differentiation processes of asteroids, and supports the existence of partially differentiated planetesimals.

Building Habitable Worlds: What Zinc Isotopes in Meteorites Reveal about Volatile Delivery to Earth and Mars

Rayssa Martins[1,2]*, Elin M. Morton*[2] *; Yihang Huang*[2] *; Helen M. Williams*[1]*; Mark Rehkämper*[2]

1University of Cambridge
2Imperial College London

Volatile elements are essential for planetary habitability and for the emergence of life. However, their low condensation temperatures mean these elements can be easily lost through evaporation and other processes during Solar System formation. Constraining the origin of these elements is therefore fundamental to understanding how habitable planets form.

To investigate this, we measured nucleosynthetic isotope anomalies of the volatile element zinc (Zn) in a range of Solar System materials. By characterizing these small isotopic variations, we can identify the materials that supplied Zn to Earth and Mars, and address two key questions about the origin of volatiles on these planets.

First, was Zn sourced from locally formed materials, or was it delivered by carbonaceous bodies that originated beyond Jupiter? The latter are volatile-rich materials formed in the colder outer regions of the Solar System, and have long been proposed as suppliers of terrestrial volatiles. However, both Earth and Mars accreted only small amounts of them, raising questions about whether volatiles were primarily inherited from local sources or delivered from afar.

Second, what were the relative roles of primitive and differentiated planetesimals in delivering volatiles? Differentiated bodies undergo melting and can lose volatiles during magmatic processes, whereas primitive planetesimals largely retain theirs. If the latter are required to build up enough volatiles to form a habitable planet, then the preservation and incorporation of such materials becomes a critical and potentially limiting step in the formation of habitable planets.

Our Zn isotope results for Earth, Mars, and meteorites from diverse regions of the Solar System provide direct constraints on these questions, offering new insights into how volatiles were supplied during planetary accretion and into the conditions required to build planets like our own.

Metastable hydrate of sodium chloride: A new mineralogical indicator of rapid freezing of brines at icy worlds

***Rachael Hamp**[1]*, *Mark Fox-Powell[1], Christoph Salzmann[2], Zachary Amato[1,3], Milz Beaumont [2], Hannah Chinnery[1], Peter Fawdon[1], Thomas Headen[3], Paul Henry[3], Liam Perera[4], Stephen Thompson[4]*

1The Open University
2University College London
3ISIS
4Diamond Light Source

Sodium Chloride (NaCl) is one the most common salts in the Solar System and has been detected on the surface of several icy worlds, including Europa, Enceladus, Ceres and Ganymede. The presence of NaCl on the surface of these icy worlds has provided evidence for a salty subsurface ocean underneath the icy exterior, which has been transported to the surface. Areas where ocean water has reached the surface could provide information on the subsurface ocean chemistry and potential habitability. We will present the discovery of a new metastable dihydrate of NaCl that is formed through rapid freezing at ambient pressure. This is the first hydrate of NaCl to be discovered at ambient pressure in over 200 years. The dihydrate is structurally related to hydrohalite (the only hydrate of NaCl previously known to form at ambient pressure), with a proposed crystal structure comprised of a 3 × 1 × 3 supercell of the hydrohalite unit cell. The cooling rates used to produce the metastable NaCl hydrate may be comparable to the rates experienced during rapid emplacement of ocean material onto the surfaces of icy worlds. Our results show that this metastable hydrate remains stable below ~190K and therefore could be present and stable on the surface of icy worlds in the outer Solar System where the surface temperatures are ≤100 K. The identification of this metastable NaCl dihydrate on the surfaces of icy could indicate regions of recent activity where subsurface brine has frozen rapidly. These areas should be high priority targets for upcoming planetary missions such as ESAs JUICE and NASAs Europa Clipper. Because of the widespread use of NaCl in industry, the discovery of this material may have implications beyond planetary science, for example in the chemical and food production industries.

Miniature laboratory experiments on salt-water solutions under high-pressure and low-temperature conditions representative of icy moon interiors.

Ines Collings[1], *Baptiste Journaux*[2], *Anna Pakhomova*[3], *Tiziana Boffa Ballaran*[4]

1Natural History Museum
2University of Washington
3European Synchrotron Radiation Facility
4Bayerisches Geoinstitut

The icy moons of Jupiter and Saturn, such as Europa, Ganymede, Callisto, and Enceladus, are expected to host saltwater oceans beneath their icy crusts, raising the intriguing possibility of habitability in these water-rich environments. The distribution and compositions of salts, both dissolved in the oceans and present in solid form as hydrates, are key factors in shaping the internal structures and evolutionary pathways of these icy worlds. Constraining the compositions of salts and salt hydrates detected on icy moon surfaces provides critical insights into the geochemistry of the subsurface oceans and interior processes [1]. Salt-water interactions under the high-pressure, low-temperature conditions characteristic of icy moon interiors give rise to a diverse range of hydrated salt structures that are not always accessible through temperature variations alone [2]. However, relatively few experimental studies have investigated the combined effects of pressure and temperature on these systems.

Here we characterise the binary salt-water systems of NaCl [2], KCl, MgCl2, and CaCl2 under high-pressure, low-temperature conditions (0–2 GPa; 300–150 K) using in situ single-crystal synchrotron X-ray diffraction and cryogenic diamond-anvil cell experiments to constrain the mineralogy, density, and bulk modulus of the chloride salts in icy moon interiors. This miniature simplified laboratory analogue of icy moon internal hydrospheres helps constrain internal phases and properties. Our high-pressure structural database will also aid in identifying high-pressure salt hydrates that have been transported from the internal hydrosphere to the surface.

1. Dalton, J. B. et al. Chemical Composition of Icy Satellite Surfaces. Space Sci Rev 153, 113–154 (2010).

2. Journaux, B. et al. On the identification of hyperhydrated sodium chloride hydrates, stable at icy moon conditions. PNAS 120, e2217125120 (2023).

Serpentinisation-driven liberation of bioessential phosphite (P(III)) on Europa: an analogue study.

Claire Cousins[1], Abu S. Baidya[1], Joanna Kalita[1], Eva E. Stüeken[1], and Nicholas Mappin[2]

1Unviersity of St Andrews
2Cambourne School of Mines

As one of the "ocean worlds" in our solar system, Europa has the potential to offer habitable conditions for life [1]. Phosphorous (P) is one of the six essential elements for life (CHNOPS), and therefore a key habitability constraint, but its abundance and speciation in Europa's subsurface ocean is unknown. On Earth, P reservoirs are dominated by the poorly soluble phosphate (P(V)) mineral apatite. However, olivine and other silicates have been proposed as alternative P reservoirs for extraterrestrial ocean environments, where lattice-bound phosphate substituting for SiO4 can be reduced to the more soluble phosphite (P(III)) via magmatic processes or via serpentinisation of ultramafic and mafic lithologies [2]. While present at lower abundances, phosphite has significantly greater solubility and reactivity, and hence bioavailability, than phosphate [3]. Similarly, while ultramafic and mafic rocks possess low bulk phosphorous contents, their anticipated lithological dominance in differentiated icy moons means serpentinisation represents a feasible mechanism for delivery of P to subsurface oceans.

Following the methods of [3] and using loss of ignition (LOI) as a proxy for water/rock ratios and hence degree of serpentinisation, we investigated P speciation in variably serpentinised harzburgitic, picritic and mafic lithologies from the Troodos ophiolite, Cyprus. Preliminary data reveal variable but ubiquitous phosphite in both mantle and crustal lithologies (P(III)/P(V) ≤0.01 to 0.45). In variably serpentinised harzburgites, increasing P(III)/P(V) correlated with LOI implies reduction of phosphate to phosphite or preferential release of magmatic phosphite, while a decrease in P(III)/P(V) above 15 % LOI may suggest an upper limit to the water/rock ratios permissive for this reaction during serpentinisation. Ongoing analyses will expand this dataset and further resolve petrological variables affecting P(III)/P(V).

[1] Vance et al. (2023), Space Science Reviews 219, 81. [2] Pasek et al. (2022), GCA 336, 332-340. [3] Baidya et al. (2024), Communications Earth & Environment 5(1), 491.

Two end-member analogue sites for depositional paleoenvironments and biosignature preservation at Oxia Planum

***Grace C. Nielson**[1], Claire R. Cousins[1], Eva E. Stüeken[1], Matt Gunn[2], Peter Grindrod [3], Harry Marsh[2], Jack Langston[2], Saskia Hagen-Fellowes[3], Leanne Staddon[1], Gordon R. Osinski[4], Anthony R. Prave[1]*

1University of St Andrews
2Aberystwyth University
3Natural History Museum
4University of Western Ontario

ESA's ExoMars Rover Rosalind Franklin is set to land at Oxia Planum in 2030. The Noachian terrain in the landing ellipse shows evidence of a potentially long-lived aqueous paleoenvironment in a deltaic to fluvio-lacustrine setting. It hosts widespread layered Fe/Mg phyllosilicate-bearing deposits, which are consistent with subaqueous sedimentation and pre-, syn-, or post-depositional alteration. On Earth, fluvio-lacustrine environments have moderate to high preservation potential for organic matter, due to rapid sedimentation and subsequent burial. As a result, these are also some of the environments that, over the course of Earth history, have preserved biosignatures on billion-year timescales. To optimize biosignature detection and paleoenvironmental reconstructions in Martian fluvio-lacustrine strata, we evaluate two terrestrial sites that can be regarded as end-member analogues for the clay bearing deposits at Oxia Planum. The first is the 1.0 - 1.1 Ga fluviolacustrine and estuarine sedimentary rocks package of the Clachtoll and Diabaig formations in northwest Scotland. These units have preserved evidence of past life in the form of microbially induced sedimentary structures, which represent microbial mats that colonized sedimentary surfaces. However, these rocks, like most Proterozoic sedimentary units, are compositionally distinct from typically mafic and Fe/Mg-clay bearing Martian sedimentary rocks, and do not include any significant amorphous fraction. To resolve this, we also investigated the much younger (~12 Ka) mafic mudstones and siltstones of the Emstrulon paleolake in southern Iceland, which comprise basaltic minerals, smectite clays, glasses, and amorphous, poorly crystalline secondary phases. Taken together, these sites provide field laboratories for proxy calibration and in turn for understanding the processes that may have occurred at Oxia Planum during a warmer wetter Noachian.

Biosignature Stability under Simulated Martian Conditions: Implications for sample analysis by the Rosalind Franklin Rover

Louisa J Preston*[1,2]*, *Charles H. Minns*[1]*, Ifigeneia Rousouli*[1]*, Connor J. Ballard*[1] *and Lewis R. Dartnell*[3]

1Mullard Space Science Laboratory, UCL
2Natural History Museum, London
3University of Westminster

The 2028 ESA/NASA Rosalind Franklin Rover will search for signs of past and present life in the shallow subsurface of Mars. It is crucial to understand how minerals and any biosignatures uncovered and brought to the surface during these sampling activities, or inadvertently exposed during modes of rover operation and movement, might be altered and subsequently identified under today's Martian conditions. This preliminary study explored the effects of cryodessication, induced by the sub-zero, near-vacuum conditions on the Martian surface, on Ca-sulphate, the SOPHIA Mars soil simulant and an Antarctic microbial mat collected during the Scott Antarctic Expedition. Powdered samples were analysed via Fourier Transform Infra-Red (FTIR) and Visible-Near-Infrared (Vis-NIR) spectroscopy, frozen, and then placed in a lyophilizer maintained at -63.4 °C with a vacuum of 1.182 mbar for 1 hour and 72 hours. After 1 hour, Mars-like sublimation processes were not fully completed within the three Mars analogue samples yet helped to increase the spectral intensity of the mineralogical, hydration, and organic features within the samples. After 72 hours exposure, hydration- and organic-induced spectral bands began to decrease in intensity and detectability, with some features now removed. Understanding how sampling activities and subsequent environmental exposure affects the mineralogical and organic content of samples, and how to spectrally identify these features using rover instrumentation, is vital in assessing the reliability of the data uncovered, the differences between the subsurface and surface environments at Oxia Planum, and therefore the environmental and biological interpretations made.

Science objectives and status of the EnVision Mission to Venus

***Philippa Jane Mason*[1]*, EnVision Science Study Team, VenSAR Team, and ESA EnVision Study Team*

1Imperial College London

EnVision is ESA's Medium-class mission to Venus, in partnership with NASA which provides the Synthetic Aperture Radar (SAR) payload, and its launch is scheduled for 2031. The main scientific aim is a holistic view of the planet, from its core to its upper atmosphere, studying the planet's history, activity and climate. EnVision aims at understanding the nature and current state of Venus' geological evolution and its relation-nship with the atmosphere. EnVision's science goals are: to characterize the events that generated its surace features, and the geodynamic framework that controls the planet's release of internal heat; to search for evidence of ongoing geological activity; to characterize the interactions between the planet and atmosphere; and to search for evidence of liquid water in Venus' past.

These science objectives will be addressed through data delivered by its instruments, which are provided by European and US research institutes and space agencies. The VenSAR S-band SAR will perform targeted surface imaging and dual-polarimetric imaging, passive radiometry and altimetry. A high frequency Subsurface Radar Sounder (SRS) will penetrate Venus' upper crust to detect material boundaries and interfaces. Three spectrometers, VenSpec-U, VenSpec-H and VenSpec-M, operating in the UV and Near and Short-Wave InfraRed, will map trace gases, including volcanic gas plumes above and below the clouds, as well as map surface material emissivity and composition. The Radio Science Experiment (RSE) will exploit the spacecraft Telemetry Tracking and Command (TT&C, Ka-/X band) system, to observe the planet's gravity field and to sound the structure and composition of the middle atmosphere and the cloud layer using radio occultation. The mission science teams will adopt an open data policy, with public release of the scientific data after validation.

In this presentation, the top-level scientific objectives, mission status and that of our own supporting investigations will be briefly presented.

Multi-wavelength Polarimetric Radar Analysis of Lava Flows at Askja, Iceland: A Venus Analogue Study

***Nikol Davidova*[1], ***Philippa Mason*[1]*, Richard Ghail*[2]*, Alberto Moreira*[3] *, Gerard Gallardo i Peres*[1]

1Imperial College London
2Royal Holloway, University of London
3German Aerospace Center - DLR

This study presents comprehensive multi-parameter radar analysis of the Askja volcanic area, Iceland, serving as a Venus analogue for advancing planetary radar interpretation.

Research Objectives

Venus' surface is dominated by volcanic terrain and understanding what changes the new missions may 'see' requires analysis of radar signatures at barren, volcanic terrains on Earth. The Askja volcanic area provides an ideal natural laboratory - basaltic composition, diverse flows (historical to 7100-year-old), minimal vegetation cover, and accessibility for validation. Can we differentiate lava flow types, ages, and processes using radar backscatter?

Methodology

Multi-wavelength radar data includes high-resolution F-SAR (2m) at X- (3.1 cm), S- (9.4 cm), and L-band (23.8 cm) with full polarimetry [1]. Flow units are mapped using S-band HH imagery, stratigraphic relationships, and field data.

Key Findings

Backscatter curves show a strong decrease with increasing incidence angle (10-15 dB from 10° to 80°). S-band HH analysis reveals systematic age-dependent changes: youngest flows (1961) show highest backscatter (-7.9 dB), oldest (7100 years) show lowest (-16.8 dB) - approximately 10 dB decrease over 6000 years due to weathering and mantling. The relationship is non-linear, with rapid initial decrease over 2000 years, then gradual homogenisation. The age-backscatter correlation is visible across all bands.

L-band provides highest dynamic range for flow differentiation. Co-polarized channels (HH, VV) yield similar values indicating lack of vegetation. HV polarization shows the greatest brightness and texture variations and is most suited to flow discrimination.

Polarimetric analysis successfully differentiates flow morphologies: high HH and HH/HV ratios indicate smooth pāhoehoe and mantled surfaces producing specular reflections, while high HV indicates rough a'ā flows producing diffuse scattering.

Implications

Multi-parameter radar enables flow morphology and age discrimination through wavelength-scale roughness analysis. Results provide validated frameworks for interpreting volcanic terrains on Venus supporting upcoming missions.

Reference:

[1] German Aerospace Center (2023). F-SAR multifrequency polarimetric data.

Determining Impact Angle from the Spatial Distribution of Shock Metamorphism: A Case Study of the Gosses Bluff (Tnorala) Impact Structure, Australia

***Auriol Rae*[1]**, *Eloise E. Matthews*[2], *Thomas Kenkmann*[3], *Nicholas E. Timms*[4], *Aaron J. Cavosie*[4], *Marian B. Holness*[2]

1University of Edinburgh
2University of Cambridge
3Albert-Ludwigs Universität Freiburg
4Curtin University

Impact angle is a key parameter controlling the impact cratering process, affecting crater morphology, ejecta patterns, shock pressures, and the volumes of melt and vapour produced — all of which have major implications for planetary surface evolution and the environmental effects of an impact. The majority of planetary impacts occur at oblique angles, yet constraining impact angle and direction in eroded terrestrial craters remains challenging.

In this study, we investigate the potential of asymmetries in shock metamorphism to act as a quantitative constraint on the direction and angle of impact at the Gosses Bluff structure in Northern Territory, Australia. We measured the frequency of specific orientations of planar deformation features in quartz from samples around the central uplift and compared the spatial asymmetries in observed peak shock conditions with predictions from new three-dimensional numerical impact simulations of the formation of the Gosses Bluff structure. This comparison indicates formation by an impact along an approximately north-to-south trajectory at an angle of 52° ± 10°. Alongside a trend of an increase in shock pressure recorded by down-range target rocks, we also observe a marked increase in shock metamorphism in the cross-range direction at Gosses Bluff. We attribute this pattern to the movement of faults in the central uplift during crater modification, displacing and dissecting the originally smooth distribution of shock metamorphism. This study provides new guidance for identifying and quantifying oblique impacts in the rock record, applicable to a large range of impact angles and crater sizes, and offers a framework for interpreting the geological signatures of oblique impacts across the Solar System.

Rays and secondary craters of the Tycho impact event revealed through deep learning

Giulia Magnarini*[1]*, *Peter Grindrod*[1]*, Riccardo La Grassa*[2]*, Adriano Tullo*[2]*, CristinaRe*[2]*, Gabriele Cremonese*[2]

1 Natural History Museum London
2 INAF-Astronomical Observatory Padua

The rays of Tycho crater are prominent features of the lunar nearside. Rays and clusters of secondary craters from Tycho have been mapped as far as Taurus Littrow Valley (TLV), the Apollo 17 landing site, more than 2000 km from the impact crater. It has been suggested that some Tycho ejecta hit the summit of the South Massif and triggered the Light Mantle avalanche in TLV.

Using a bespoke application of YOLOLens, a state-of-the-art deep learning model specifically optimized for high-resolution crater detection, to Kaguya images, we generated a dataset of ~6.8 million craters > 88 m in diameter within a quadrangle region that extends from Tycho to beyond the Apollo 17 landing site. We then used a cluster analysis method to identify clustered craters, thus potential secondary craters.

We generated density maps of the clustered craters population and identified ray segments associated with Tycho crater. Our results highlight the existence of several distal clusters that belong to the Tycho ray system that were not previously identified. We also suggest that additional non-radial clusters are plausible products of Tycho's projectiles ejected with angles ~74°-75°.

Moreover, according to our results, the youngest Light Mantle landslide unit in Taurus-Littrow Valley, the Apollo 17 landing site, occurred after the Tycho impact event. However, we cannot exclude that earlier mass-movements were triggered by the impact of Tycho ejecta that formed a cluster on the summit of the South Massif.

An important observation of this work is that potentially secondary craters from Tycho may represent ~60% of the craters < 200 m.

Exploring structures within the Caloris Basin

Christopher Brooks[1], *Prof. D. Rothery*[1], *Dr. P. Fawdon*[1], *Dr. J. Wright*[1,2]

1The Open University
2University of Leicester

The Caloris Basin is the largest well-preserved impact basin on Mercury. The rim region is spectrally and morphologically complex, hosting unusual landforms of uncertain origin. This complexity has left important questions, such as how to define the rim, unresolved. These questions are, in turn, tied to the key questions regarding the processes affecting Caloris's formation, about 3.9 billion years ago, and extensive modification since. Addressing these will improve our understanding of different states of the basin formation process, modification of the basin after formation and the broader evolution of Mercury's surface.

We have begun examining features found around the rim of the basin and present our conclusions thus far. Our initial search began with a re-examination of potential ghost craters; impact sites degraded and/or buried, leaving either a few fragments or an outline. Previous work has been unable to confirm the presence of any ghost craters (Ernst et al., 2015), whose discovery would confirm a significant time interval between basin-formation and flooding of its floor by lavas. We identified our best (48.3°N, 168°E) and second-best (23.7°N, 178.3°W) candidates located just inside the rim of Caloris, where both have rim segments that form a part of the boundary of the larger Caloris basin. We applied geoscience techniques, using improved topographic and gravity datasets taken from the MESSENGER mission to establish if our candidates are truly ghost craters. While the current data is inconclusive, these remain our best candidates for further investigation with data from the BepiColombo mission.

The Fluvial History of Hadriacus Cavi

Adam Losekoot[1], *Matthew Balme[1], Angela L. Coe[1], Peter Fawdon[1]*

1The Open University

The Hadriacus Cavi are an ~50km long chain of up to 700 m deep depressions, located near the rim of Hellas Basin, a 2300 km wide and 9 km deep impact basin in Mars' southern highlands (Smith et al., 1999). The Cavi record sequences of alternating light and dark layers that together are at least 100s of meters thick (Skinner at al., 2021). Some of these strata contain channel-forms interpreted to be fluvial, but it is unknown how widespread these are, or whether they occur at multiple points within the stratigraphy. Investigating these unknowns will shed light onto the fluvial history of early Mars and the possibility of a past ocean in Hellas basin (Wilson et al., 2007).

We are using CTX (6m/pixel), HiRISE (25-50 cm/pixel) and CaSSIS (colour; ~4m/pixel) orbital images and Digital Elevation Models in a GIS-based approach. We are identifying fluvial structures in these data and noting how these relate to the wider sedimentary succession in the Cavi. We will search for distinct packages and repeating patterns of strata with the intent of tracing these across the region. We will measure dimensions of fluvial deposits, internal structures, and dip directions to help us interpret how these early rivers relate to the Hellas basin and the surrounding region.

We have identified extensive fluvial channel deposits within the Cavi. These extend laterally across the Cavi. We note at least two types of deposit: i) flat-topped, curved-bottom features which we interpret as channel deposits (Skinner et al., 2021); ii) Lateral series of sloping layers truncated by flat surfaces at the top and bottom which we interpret as lateral accretion surfaces recording channel migration. If multiple packages of fluvial channels are present, it would indicate that there may have been multiple periods of fluvial conditions during the early-middle Noachian.

Microbial activity and biosignature preservation amongst alkaline hot springs at Lake Magadi, Kenya

Amy Quinton*[1,2]*, *Dr Anne D. Jungblut*[2] *and Dr Keyron Hickman Lewis*[1]

1Birbeck, University of London
2Natural History Museum

Located in the East African Rift Valley, Lake Magadi is an alkaline, hypersaline lake recharged by a network of hot springs, thought to have been active for several hundred thousand years. Such environments have been identified as suitable analogues for hydrothermal environments on the Archean Earth, and on other bodies in our Solar System, such as Mars, Europa and Enceladus. Multiple environmental stressors in this habitat, including high pH, temperatures, and metal concentrations place it among the most poly-extreme habitats on earth, where little life is found except on the microbial scale. However, the functional diversity and metabolic capabilities that enable microbial survival in this habitat are understudied, providing an untapped resource of palaeoecologically and biotechnologically relevant adaptations. We will employ shotgun metagenomics to characterise microbial taxa richness, metabolic pathways and the genomic-basis for adaptation to multiple extremes. This will contribute to the development of hypotheses concerning the adaptation strategies microbial life may require to survive on other bodies in our solar system with evidence of hydrothermal activity. Furthermore, the Magadi basin is geologically unique, possessing outcrops of magadiite, a hydrothermally influenced siliceous mineral phase. Preliminary studies have revealed the presence of thermally immature organic matter within these deposits, which we plan to investigate in more detail for records of ancient microbial life. Elemental composition, mineralogy and microstructures will be investigated using a range of spectroscopic and microscopic techniques, and compared between samples of a range of ages, and present microbial communities, to reveal which biomolecules and relics of biomass survive diagenesis in a hydrothermal environment. Silica-rich deposits analogous to those found in terrestrial hydrothermal environments on Earth have been identified on Mars, thus this information has the potential to inform not only the interpretation of biosignatures in rocks from the early Earth, but also the detection of biosignatures in samples brought to Earth by future Mars sample return missions, providing an insight into biogeochemical signatures diagnostic of putative ancient microbial communities.

Numerical Modelling of the Moon's South Pole – Aitken Basin Formation

***Carys Bill*[1], *G.S. Collins*[1], *T.M. Davison*[1]**

1Imperial College London

The ~2500 km diameter South Pole–Aitken (SPA) Basin is the largest and oldest known impact crater on our Moon. Its formation dramatically influenced the Moon's interior and surface evolution, creating an exciting destination for several upcoming lunar missions such as Artemis, Chang'e 7 and the Farside Seismic Suite.

Numerical simulations of the formation of the SPA Basin are conducted using iSALE-3D that consider a range of impactor sizes, speeds, angles and target thermal profiles. We constrain possible impact scenarios by comparing simulated crustal thickness profiles, and elongation of the crater planform, to the observed basin.

For cold-target (10 K/km) scenarios, a narrow annulus of thickened crust is observed outside the inner basin and the mantle is exposed in the centre. A broader, less thick annulus is produced in the hotter (30–50 K/km) scenarios and a weakened crust rafts inwards to re-cover the mantle. This is more consistent with observations and indicates that a warmer weaker crust and earlier formation time are required to form the SPA.

Crust- and mantle-derived simulated ejecta is emplaced surrounding the basin predominantly in the downrange direction. The trajectory of the impact and therefore the actual location of this ejected material on the Moon remains uncertain. Ongoing work involves modelling the effect of a pre-impact crustal and thermal dichotomy in the target to help constrain the impact direction and the fate of ejected mantle rocks.

Alteration of 2:1 clay minerals in brine: Implications for sediments on Mars

Elshan Abdullayev[1], *Paul Schroeder[1], Elvin Alizade[2], Sakina Asgarova[3], Narinj Taghiyeva[4], Maxim Rudmin[5]*

1Department of Geology, University of Georgia, USA
2Department of Petroleum Engineering, Khazar University, Azerbaijan),
3Department of Chemistry and Chemical Engineering, Khazar University, Azerbaijan
4Division of Chemistry, Azerbaijan State Oil and Industry University, French-Azerbaijani University, Azerbaijan
5Department of Geology, Tomsk Polytechnic University, Russia

Clay minerals play a key role in the preservation of organic molecules in sediments that can be sign of life on Mars (1). Therefore, investigating their stability is important, as the destabilization of minerals can result in the decomposition of the organic molecules. The aim of this research was to investigate the impact of magnesium-rich sulphate brines, which are widespread on Mars, on 2:1 dioctahedral clay minerals such as montmorillonite and glauconite.

We carried out batch experiments to study the interactions of montmorillonite and glauconite separately with a simulated brine (1 M $MgCl_2$, 0.5 M Na_2SO_4, and 0.5 M $CaCl_2$) at a pH of approximately 8.0, which is favourable for formation trioctahedral clay minerals that common on Mars (2), at a temperature of 75 °C to accelerate chemical reactions in the aqueous environment. The experiment continued for 9 weeks. XRD analyses of the samples after 3 weeks showed that montmorillonite and glauconite had completely disappeared, and new peaks were observed in both experiments. In the using NEWMOD2 to simulate interstratified clay layer types, peaks at 8.37Å and8.42 corresponded to serpentine-talc mixed-layered minerals. In addition, we identified the presence of alunite in the experiment with montmorillonite and jarosite in the experiment with glauconite. The peaks corresponding to both alunite and jarosite, at approximately 6.0 Å, overlap with bassanite. At weeks 6 and 9, the peaks had not disappeared, suggesting that they are stable in such a brine environment.

References: 1. Summons, R. E. et al. Astrobiology 11, 157–181 (2011). 2. Bristow, T. F. & Milliken, R. E. Clays Clay Miner 59, 339–358 (2011).

Cracks in the Map: Unresolved Topographic Anomalies on Venus from Magellan Altimetry Data

Gerard Gallardo i Peres*[1]*, *isardSAT S.L.*

1Imperial College London

The most recent, highest-resolution, global estimate of the topography of Venus is the Global Topographic Data Record (GTDR), a gridded representation of the altimetry data from the Magellan radar space mission (1990-1992). This product is the topographic reference for geological, geomorphological and atmospheric studies of Venus, amongst others, as well as the baseline for the software being developed for planned space missions to the planet such as EnVision.

However, the GTDR is impaired by an occasional pattern; a series of visually striking topographic “pits,” often referred to as spuriously low values, which in many cases might be generating false topographic signatures. These have not been in-depth studied or classified for more than 30 years, until now: in a recent publication on JGR Planets, we have derived global maps of these anomalies, and found that up to 2.865% of the original product is impaired by them. They are not uniformly distributed but rather concentrate around rift systems and summit areas at low latitudes; this can have the effect of biasing analysis of these areas towards depth overestimation and cross-section distortion, with potential implications for our current geological understanding of the planet.

In this work, we address the inconsistencies of the GTDR dataset and our methodology to locate the anomalies across the planet. We discuss the various implications this has for Venus science and future mission planning operations, and elaborate on our vision for reprocessing the Magellan altimetry dataset.

PROSPECT- a miniaturised geochemistry lab for exploring lunar surface volatiles in situ

***James Mortimer*[1], *Feargus Abernethy[1], Simeon Barber[1], Pete Landsberg[1], Mark Leese[1], Andrew Morse[1], Hannah Chinnery[1], Simon Sheridan[1], Alexander Verchovsky[1], Neil Murray[2], Fred Goesmann[3], Chris Howe[4], Tom Morse[4], Amy Briggs[5], Philipp Reiss[6], Christian Panza[7], Roland Trautner[8], David Heather[8]*

1The Open University
2Dynamic Imaging Analytics Ltd
3Max Planck Institute for Solar System Research
4RAL Space
5Airbus Defence and Space
6Technical University of Munich
7Leonardo S.p.A
8ESA ESTEC

The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is being developed by the European Space Agency (ESA) to support international lunar surface exploration missions. It comprises a drilling element (ProSEED – PROSPECT Sample Excavation and Extraction Drill, developed by Leonardo S.p.A., Italy) and a Sample Processing and Analysis element – ProSPA (being developed by The Open University, UK). PROSPECT will investigate volatiles and other resources from the perspectives of both science (e.g. nature, abundance, distribution of lunar volatiles) and of exploration (e.g. availability and extractability of materials for use as resources).

The first flight of the PROSPECT package will be an ESA contribution to NASA's CLPS programme, and will visit the southern hemisphere of the Moon in late 2027/early 2028.

ProSPA has two physical units with a combined mass of just 13 kg – (1) a Solids Inlet System (SIS) comprising a series of single-use sample ovens on a rotary carousel together with a sample imager, and (2) a miniature (37 x 27 x 13 cm) chemical analysis laboratory incorporating two mass spectrometers and associated sample and reference gas processing and control systems.

ProSPA will operate in 4 different 'science' modes, with a preprogrammed sequence of operations: 1) Background Exosphere (to 'sniff' all the different volatile gases present in the tenuous lunar exosphere around the lander); 2) Evolved Gas Analysis (where a soil sample is heated at a constant rate of 6°C/min and the volatiles released are measured in real-time, preserving original speciation); 3) Isotopic composition (of C, N, H, O, and noble gases, collected as aliquots at chosen temperature steps, under combustion or pyrolysis conditions); and 4) In-Situ Resource Utilisation demonstration (a lunar soil is heated in the presence of hydrogen gas, reducing metal oxides present to form water for use as a resource).

New Magnitude Scaling and Source Characterization of Marsquakes

Jung-Hun Song[1], *Doyeon Kim*[1], *Victor Tsai*[2], *Folarin Kolawole*[3], *Philippe Lognonné*[4], *Marouchka Froment*[5]

1Department of Earth Science and Engineering, Imperial College London),
2Department of Earth, Environmental and Planetary Sciences, Brown University
3Department of Earth and Environmental Sciences, Columbia University
4Institut de Physique du Globe de Paris, Université Paris Cité
5Norwegian Seismic Array

The InSight mission has revolutionized our understanding of Mars' interior, revealing key seismic discontinuities associated with the crust, mantle, and core. However, most studies to date have focused on structural inferences, while the source properties of Marsquakes remain comparatively underexplored. A key example is the largest event recorded, S1222a, whose magnitude (Mw ≈ 4.7)—estimated using a recalibrated terrestrial magnitude scale—differs by about 0.5 Mw from results obtained through waveform inversion of body and surface waves. This discrepancy corresponds to roughly a fivefold difference in seismic moment, suggesting a systematic bias in current Marsquake magnitude estimates. In addition, focal mechanism determinations have so far been limited, focusing mainly on regional events from the Cerberus Fossae area and S1222a. Here, we present a new, independent Marsquake catalog that includes both magnitude and focal mechanism solutions, extending beyond the existing catalogs produced by the Marsquake Service. The catalog also incorporates impact-related source parameters to account for seismic signals generated by meteorite impacts. We revisit the magnitude scaling laws applied to InSight data using the latest Martian velocity and attenuation models, and validate these findings by comparing magnitudes derived from the revised scaling relations with independently obtained waveform-based moment tensor and impact source parameter solutions. We discuss the implications of these results for regional to global tectonic processes and the broader seismic character of Mars, emphasizing the need to recalibrate source scaling relations and to establish a consistent, physically grounded magnitude framework for future planetary seismological studies.

Classifying Iron Meteorites: A Machine Learning Approach

***Louis-Alexandre Lobanov*[1,2]*,** *Hilary Downes*[1,2]

1Birckbeck, University of London
2Natural History Museum London

Iron meteorites are of extreme scientific interest as they represent the remnants of planetesimals destroyed in the early solar system. They provide an opportunity to study physical specimens of the cores of these planetesimals, enabling research into planetary differentiation and formation processes. Critical to this is understanding how many planetesimal cores are represented in the over 1400 iron meteorites known, as well as their genetic relationships. The chemical classification has to date been carried out manually on 2D graphs. Machine learning can provide a method for classifying iron meteorites that enhances the speed, transparency and reproducibility of the classification while reducing bias.

A database of 2,501 analyses of iron meteorites was built starting from the UCLA Cosmochemistry Database and expanding to include 61 publications spanning 1967-2023. These cover 935 iron meteorites or roughly two-thirds of iron meteorites. Cluster analysis is a form of unsupervised machine learning that partitions data into groups based on finding a mode in which the data points in a cluster are as alike as possible and the clusters are as different from each other as possible.

Building on the results of the previous element model and work on classifying ungrouped meteorites, seven different element combinations were run in the model ranging from 5 to 10 different elements. The results of this suggest 29 meteorites currently classed as ungrouped that are marked as being related to an existing group.

Cluster analysis presents a new method for the classification of iron meteorites. This model has enormous potential for the future of iron meteorite classification, fast and reproducible as well as scalable and adaptable to different element combinations. Its applications include verifying the classifications of existing meteorites and assisting in the classification of ungrouped iron meteorites and even in discovering new groups.

The Enfys InfraRed Spectrometer for the ExoMars Rosalind Franklin rover

Matt Gunn[1], *Claire Cousins*[2], *Peter Grindrod*[3], *Enfys Instrument Team*[1,4,5]

1Aberystwyth University
2University of St Andrews
3Natural History Museum
4Mullard Space Science Labs, University College London
5RAL Space

The Enfys infrared spectrometer is a UK development to restore the remote sensing capabilities to the ExoMars Rosalind Franklin rover, following the removal of Roscosmos ISEM instrument in 2022. Enfys has been developed at pace to meet the revised mission schedule, drawing heritage from PanCam and expertise from UK institutions and industry. In a little under 3 years since inception, the first Enfys prototype has now been assembled, characterised and calibrated, and will be installed on the Amalia Ground Test Model rover in Turin in the near future.

An overview of the Enfys project will be presented, along with instrument design and performance figures and some initial test measurements.

I would rove 500 miles: Long Range Rover Investigations on Mars

***Matt Balme*[1]*,** *C. Vye-Brown[2], D. A. Rothery[1], C. J. Jordan[2], J. Davis[3]*

1The Open University
2British Geological Survey
3Imperial College London

Mars is a compelling target to study terrestrial planet surface evolution; the same variety of environments found on early Earth are likely to have also been present on early Mars (Yingst et al., 2020; MEPAG Decadal Survey White paper, https://mepag.jpl.nasa.gov/reports.cfm?expand=decadal). Furthermore, unlike the Earth, Mars has an accessible rock record that spans its entire history. Hence, if a Mars Rover mission can ‘cover enough ground’ Mars’ environments can be studied in detail in both space and time.

We discuss the development of a “Long-Range Rover Investigation” (LoRRI) concept for Mars. With high levels of autonomy, LoRRI would perform long traverses of 100s to 1000 km, determining fundamental geological characteristics of the rocks and units it encounters and to date key horizons in the stratigraphy. LoRRI would exploit the proposed ESA Mars electric propulsion transfer stage (“EP Tug”) architecture (see https://europeanspaceflight.com/esa-to-begin-work-on-mars-transfer-vehicle-mission-concept/) in the 2030s.

By documenting extents, thicknesses, lithology, structure and contacts. LoRRI will redefine our understanding of local and global stratigraphy. LoRRi would explore many locations, from the most ancient to more recent, documenting large-scale transitions from potentially habitable environments shaped by water to younger regions where the rocks were laid down in colder and/or more arid environments. environments. To build a stratigraphy, geologic contacts would be crossed and re-crossed at widely separated locations. Repeating or spatially-limited stratigraphic transitions could be targeted, to explore cyclicity or episodic variations in environment. Combining such a rover with new instrumentation to perform in-situ radiometric dating would allow a quantitative chronology to be added to the stratigraphy.

Here we present plausible locations for such a mission, including traverses, topographic profiles, and locations of key scientific targets, and aim to discuss the technological/programmatic requirements with the community.

The application of orbital and rover observations of fluvial and lacustrine environments to the 2028 ExoMars Rosalind Franklin Rover in Oxia Planum.

***Nisha Gor*[1]**, *Matthew Balme*[1], *and Peter Fawdon*[1]

1The Open University

Exploration with Mars rovers has allowed us to confidently identify and investigate in detail fluvial and lacustrine settings on Mars that were first only hypothesised from orbital data [1]. Identifying the characteristics of fluvial and lake deposits from orbital data is important because it allows those locations with the highest biosignatures preservation potential to be prioritized for future rover missions searching for evidence of past life on Mars. For example, in the 2028 ExoMars Rosalind Franklin Rover mission to Oxia Planum, understanding the fluvial and lacustrine environments feature heavily in interpretation of the landing sites geological history [2,3]. These locations will be key to the mission objective: reconstructing past environmental conditions and understanding the history of water activity and habitability [4].

To prepare for this mission we use NASA's Rover's Analyst notebook [5] to collate images taken along the traverses of NASA's Mars Exploration Rovers (MER), Mars Science Laboratory (MSL) and Mars 2020 missions and explore the geological evidence for lacustrine environments and their stratigraphic contacts. Examples include contacts such as the Sheepbed–Gillespie contact at Yellowknife Bay [MSL; 6] erosional unconformities such as the Murray-Stimson contact [7] and the Jura-Knockfarril Hill [MSL; 8] as well as lake-bed deposits found at Wildcat Ridge [Mars 2020; 9]. We then compare this rover data to orbital remote sensing data (CTX, HRSC, HiRISE and CaSSIS) of those same contacts and their pre-mission interpretations.

This analysis of how the context of fluvial and lacustrine geological units can be identified from orbit is then used to identify locations in Oxia Planum that have the potential to host lacustrine deposits. We then collate and examine those examples that occur within the landing ellipse patterns of the 2028 launch opportunities. These provide exciting target locales that could be explored during the upcoming Rosalind Franklin mission [10].

References: [1] R. M. E. Williams et al. (2013), Science 340,1068-1072 [2] Vago et al. (2024), LPI Contributions 3007 [3] Grotzinger, J. P., et al. (2014), Science, 343(6169) [4] Golombek, M. P., et al. (2012), Space Sci. Rev, 170 [5] NASA's Planetary Data System, 2025 [6] J. P. Grotzinger et al. (2014), Science 343 [7] J. P. Grotzinger et al. (2015), Science350 [8] Fedo, C. M. et al. (2022), JGR Planets, 127 [9] Witze, A., (2022). Nature, 609(7929) [10] Fawdon, P. et al. (2021), Journal of Maps, 17(2).

Geological maps as a tool for planetary exploration and the geological mapping of the ExoMars rover landing site in Oxia Planum

***Peter Fawdon*[1]**, *Csilla Orgel[2],and The ExoMars Rover Science Operations Working Group (Macro) mapping team*

1The Open University
2ESA

Geological mapping is a key tool in the exploration of our natural history. In terrestrial geoscience maps tell us about the surface and subsurface (stratigraphic) distribution of rock types, how they have been deformed and, though various dating, how the events that created these rocks are distributed over time. These geological histories are built on field data, much of which was collected in the 19th century or earlier with supplementary analytical investigations data adding detail to our understanding more recently.

Planetary science however is still in the exploration phase, but with a converse paradigm of exploration scale: whereas on Earth we built up our understanding by connecting disparate outcrops to understand global stratigraphic patterns, in planetary science we are presented with the global scale patterns in remote sensing data, but we have very sparce knowledge about the actual rocks that make up the surface: Where terrestrial maps show us how are answers fit together, planetary maps show us where the unanswered questions are and are thus key to guiding our ongoing exploration.

Oxia Planum is the selected landing site for the ExoMars Rosalind Franklin (RF) Mission, launching in 2028 which will search for evidence of life and characterize the geochemical environment in the subsurface by analysing samples for analysis from as deep as 2 m.

In preparation for this mission ESA, a program of high resolution morphostratigraphic mapping and analysis has been conducted to provide context for in-situ sample analysis and to serve as an input into strategic planning for rover operations.

We present the high-resolution geological map of the landing site in Oxia Planum (Fawdon et al., 2024), an overview of hypotheses relevant to key events in Oxia Planum's geological history and discus how future RF observations will impact these questions and our wider understanding of Mars.

Anatomy of a Breakup: High-Resolution Study of a New Crater Cluster on Mars

Peter Grindrod*[1]*, *Gareth Collins*[2]*, Sarah Sutton*[3]*, Matthew Chojnacki*[3]*, Joseph McNeil*[1]*, Ingrid Daubar* [4]

1Natural History Museum, UK
2Imperial College London, UK
3University of Arizona, USA
4Brown University, USA

The majority of the >1200 new impact craters identified on Mars consist of clusters created by the atmospheric breakup of a primary meteoroid. These crater clusters provide an opportunity to investigate entry and fragmentation in the thin martian atmosphere. Here we report on the discovery of a new crater cluster on Mars, located ~16 km from the InSight lander, making it the closest new impact event discovered to date. The cluster was first identified in a new CaSSIS image by the presence of a ~100 x 150 m blast zone. Combined with a CTX image, we have a temporal resolution that rules out cluster formation while the InSight mission was still active, with the event occurring between 18 October 2024 and 15 April 2025. However, for the first time for any new impact on Mars, we have HiRISE (stereo and colour) images taken before and after the event. We georeferenced and orthorectified all HiRISE images using two separate stereo Digital Terrain Models, to allow for an unprecedented identification of all new impact features. We identify 78 new craters in this cluster, with a maximum crater size of 3.4 m, an effective diameter of 19.6 m, and a dispersion of 139.4 m. We will present results on the multispectral analysis of the effects of this crater cluster using both CaSSIS and HiRISE instruments, and fragmentation models to determine the breakup conditions for this event.

Reflections from Earth: L-Band Radar Studies of Lunar South Pole Analogues

***Poppy McVann*[1]**, *Richard Ghail*[1], *Connor Knight*[1], *Philippa Mason*[2], *Gerard Gallardo i Peres*[2]

1Royal Holloway, University of London
2Imperial College London

The study of terrestrial analogues can provide insight into the processes that shape planetary surfaces. In the last half-decade many different sites have been selected for astronaut training, developing exploration strategies, and understanding the geology of the terrains we share with other planets. The Lunar South Pole is a region characterised by extensive cratering, complex topography, and numerous permanently shadowed regions (PSRs). ISRO's Chandrayaan-2 DFSAR and JAXA's ALOS PALSAR, both operating in L-band, enable comparative analysis of Lunar polar and terrestrial radar backscatter imagery to better understand surface and subsurface properties.

Four analogue locations are identified on the basis of their morphological characteristics:

Turpan, Xinjiang, China: The steep topographic transition of this region from rocky, mountainous highs of 3.8km, to the fine-grained sandy desert with an elevation in the tens of metres serves as an analogue to study the dramatic topography around some of the Artemis III landing sites, such as the De Gerlache-Kocher Massif. Alluvial fans descending from the mountain front are comparable with mass-wasting features observed on some crater walls.

McMurdo Dry Valleys, Antarctica: A well-established Martian analogue, the Dry Valleys also serve as a valuable Lunar analogue, being the driest and coldest desert on Earth with very little surface ice. Analysis of ALOS PALSAR data enables investigation of radar interactions with permafrost-bearing soils, providing insight into subsurface conditions similar to those anticipated at the Lunar poles.

Haughton Impact Crater, Nunavut, Canada: A well-preserved impact structure within a polar desert environment, comparable in size to many Lunar craters. Its ground-ice features, >100 m thick crater-fill impact melt rocks, and ejecta remnants are good analogues for South Polar crater morphology.

Tenoumer Crater, Mauritania: The rim of this crater is well preserved and sharp, and the crater bowl itself is infilled with 200-300m of unconsolidated postimpact sediment.

Sample analysis using the PanCam Training Model

Rebecca Warrilow[1], *Connor Ballard*[1]; *Louisa J. Preston*[1] ; *Andrew Coates*[1]

1MSSL, University College London

The PanCam instrument onboard the Rosalind Franklin rover (scheduled for launch in 2028) is designed to provide high-resolution, multispectral imaging to support geological and mineralogical investigations on the Martian surface. The PanCam Training Model (TM) is a functional replica of the flight instrument that includes a single operational wide-angle camera equipped with a modified filter wheel containing all 11 geology-specific spectral filters, enabling the acquisition of multispectral datasets that closely replicate expected rover observations on Mars. In this study, we present some of the first sample analyses conducted using the PanCam TM in a laboratory setting to capture calibrated image sequences of two terrestrial rock analogues. The first is a hydromagnesite deposit from Lake Salda, Turkey - an analogue sample for the Mg-carbonate deposits detected by Perseverance in Jezero crater. The second is a polymict lithic ‘Bunte’ breccia from the Nördlinger Ries impact structure, Germany. Data processing and spectral analysis were performed using the PanCam Operations Toolkit (PCOT) to generate reflectance spectra. These results demonstrate the capability of the PanCam TM instrument to support data analysis and assist geological interpretations for a variety of Martian surface materials that the Rosalind Franklin rover may traverse in Oxia Planum.

The future exploration of the Venus

***Richard Ghail*[1]**, *Philippa Mason*[2]

1Royal Holloway University of London
2Imperial College London

The ‘decade of Venus’ is coming: within the next 5 years, several missions will be making their way to our closest planetary neighbour. Why the sudden interest in what has been described as Earth’s ‘evil twin’? And what is in it for Britain? Many factors have converged to cause this change in fortunes but Britain has been influential in making it happen, particularly through EnVision, and we should exploit the opportunities it brings. The UK-led (Imperial, Oxford and Royal Holloway) EnVision proposal was unique in anticipating a complex, active planet that would be best understood with an holistic approach and a cooperative community of atmospheric, surface, and interior scientists.

That vision of Venus as Earth-like was enhanced by the discovery of many Earth-sized exoplanets, bringing in a fresh community of astronomers keen to understand the ‘exoplanet in our backyard’. The spirit of cooperation extended beyond Europe and EnVision, allowing synergies with NASA’s DAVINCI probe and VERITAS, and the development of India’s Venus Orbiter Mission (unofficially Shukrayaan), supported by the UK Space Agency’s Bilateral Science programme.

Our understanding of Venus has transformed in the last decade: the simple story of a geologically static world shaped by global volcanic catastrophe is replaced by a recognition that its geological complexity is driven by ongoing tectonic and volcanic activity that sustains a diverse and dynamic atmospheric chemistry. Just as we are discovering how sensitive and fragile Earth’s systems might be, we also begin to recognise that Venus may once have been more benign, and might be our first example of a self-sterilized habitable world.

Our knowledge of Venus is about to change in the way the first decade of Mars exploration changed our understanding of the red planet. This is a golden opportunity for UK science and engineering, and we must prepare for it.

Late deformation and hydrofracturing of the Bright Angel formation, Jezero crater, Mars.

***Robert Barnes**[1], A. Jones, S. Gupta[1], B. Horgan[2], G. Paar[3], K. Stack[4], B. Garczynski[5], A. Klidaras[2], A. Broz[2], B. Wogsland , J. Bell, J. Maki[4], P. Russell[6] .J.I. Simon[7], S.E. Hamran[8], D. Paige[6], J. Hurowitz[9], C. Traxler[10], H.[10], M. Jones[11], C. Schrank[11], N. Randazzo[12] , Uni Arting[13], K. Farley[4]*

1Imperial College London, UK
2Purdue University, USA
3Joanneum Research, Austria
4JPL-Caltech, USA
5Western Washington Uni., USA
6UCLA, USA
7JSC, USA
8University of Oslo, Norway
9Stony Brooke University, USA
10VRVis GmbH, Austria
11QUT, Australia
12University of Alberta, Canada
13Jardfeingi Faroe Isles

The Bright Angel formation in western Neretva Vallis, Jezero crater, Mars, preserves a complex record of post-emplacement deformation and fluid activity. Using Mastcam-Z stereo mosaics and 3D digital outcrop models (DOMs), we mapped bedding geometries and fracture networks across multiple outcrops to reconstruct the structural evolution of this fine-grained, phyllosilicate-rich unit. Our analysis reveals a broad synclinal geometry with steep dips at the northern contact with the Margin Unit, exceeding typical Martian angles of repose. These dips are interpreted as the result of contractional folding, pre-dating vein emplacement.

Fracture mapping identifies five vein sets with distinct orientations and mineralization styles. Centrally sutured layer cross-cutting veins are observed throughout, and strike E-W overall, with an orthogonal set which abuts against and cross-cuts the earlier fractures. Layer-parallel veins in steeply dipping strata at Cheyava Falls are interpreted as the youngest generation formed under stress conditions favouring propagation along bedding planes. In contrast, Walhalla Glades hosts cross-cutting and polygonal veins in shallowly dipping beds, suggesting localized stress field variation or a strong influence of anisotropy. Cross-cutting relationships and paleostress inversion support a multi-phase deformation history involving folding which pre-dates ~3 phases of fluid migration that resulted in parallel en-echelon tensile fracturing and mineralisation on planes parallel to primary lamination dip where it was >~40°. Corridors of anastomosing vein systems are common where stratal dips are <40° and these sets are observed to strike overall parallel to the unit contact. Additional diagenetic activity is present in the form of bands of nodular concretions and exhumation-related open fracturing.

These findings refine the structural model of Bright Angel and provide critical context for interpreting the Sapphire Canyon sample, a key target for Mars Sample Return. The interplay between stratigraphy, stress evolution, and fluid pathways has implications for biosignature preservation and basin-scale tectonics.

Rainbow Vision across the Reality Spectrum: Preparing for Planetary Surface Spectral Sensing across Theoretical, Computational, Laboratory and Field Simulations in the UK and Beyond

Roger Stabbins[1], *P. Grindrod[1], M. Gunn[2], S. Hagan-Fellows (Natural History Museum), S. Motaghian[1], E. Allender[3], H. Marsh[4], B. Whiteside[5], C. Cousins[3], S. Kameda[6], A. Coates[5]*

1 Natural History Museum, London
2 Department of Physics, Aberystwyth University
3 School of Earth & Environmental Science, University of St. Andrews
4 Department of Physics, Aberystwyth University
5 Mullard Space Science Laboratory, University College London
6 Department of Physics, Rikkyo University

Reflectance spectroscopy and spectral imaging are key methods for planetary exploration, as efficient means to collect dense datasets on the distribution of materials across a planetary surface. The UK leads the spectral imager PanCam and the infrared spectrometer Enfys for the upcoming ESA ExoMars Rover Mission, and plays key roles in the development and operation of spectrometers and imagers across a range of present and upcoming missions. Here we showcase a suite of tools and methods that support verification and validation activities for the development of spectrometers and spectral imagers at the levels of an ideal model (theoretical), a virtual implementation (computational), a controlled reality (laboratory), and natural reality (field). We review theoretical models of PanCam and Enfys and their software implementations, and describe how they have been used to simulate data collection, investigate instrument sensitivity at the raw data and science product levels, and investigate on-board closed-loop algorithms, such as auto-exposure. We showcase how we have extended these computational methods into efficient tools for the exploration of generic high-dimensional spectral data, and how the knowledge developed through these projects have supported controlled laboratory testing of instrument performance, feeding into curation campaigns of extraterrestrial samples returned by spacecraft. The tools and expertise developed have initiated new international collaborations, namely involvement with the development of the OROCHI spectral imager for the Japanese-led Martian Moons Exploration mission. We highlight how foundational theoretical, computational and laboratory studies of these instruments and associated experiments have informed field campaigns by spinning-out quick-look rapid analysis software to support quantitative analyses on tactical time scales. Finally, we consider the future role of concerted theoretical, computational, laboratory and field studies in various stages of instrument development, from component selection and design optimisation through to data acquisition and analysis.

Biology of Biosignature Detection: Integrating Life Sciences and Planetary Exploration

Scott Perl[1], *Charles Cockell[2], Woodward Fischer[3], and the Biology of Biosignature Detection Science Team*

1UCLA Earth, Planetary and Space Sciences
2University of Edinburgh
3California Institute of Technology

Our astrobiology mission design, focuses on advancing the biological foundations required to interpret and identify biosignatures across planetary environments. This mission-driven effort bridges molecular biology, planetary science, and systems engineering to refine how life detection is conceptualized, measured, and validated beyond Earth. Our science team goals is to address key challenges in linking biological processes to detectable signals under diverse geochemical and physical conditions—ranging from Earth's extreme environments to analog sites representative of Mars, Europa, and Enceladus. We have developed a unified biosignature science framework that we will employ to our future life-detection lander payload to the Martian subsurface. By merging laboratory experimentation, field analog studies, and mission simulations, the program strengthens our capability to interpret signs of life with biological and geochemical fidelity. Ultimately, this work advances comparative planetology as a tool for understanding habitability and lays the groundwork for robust biosignature detection strategies that can withstand the complexity and ambiguity inherent to searching for life beyond Earth.

A Novel Unsupervised Change Detection Method for Inter-Mission SAR images

Yao Gao[1], *Gerard Gallardo i Peres*[1]; *Shubham Awasthi*[1]; *Nikol Davidova*[1]; *Richard Ghail*[2]; *Philippa J. Mason*[1]

1Department of Earth Science & Engineering, Imperial College London
2Department of Earth Sciences, Royal Holloway, University of London

Detecting geological changes on Venus is a key objective for comparing Magellan Synthetic Aperture Radar (SAR) images with those from upcoming missions like EnVision and VERITAS. However, inter-mission comparisons face challenges due to differences in radar system configurations, such as resolution and frequency. Traditional change detection methods often fail to accurately model these disparities, resulting in poor threshold selection and unreliable results. In this work, we propose a novel unsupervised change detection algorithm for single-channel SAR intensity images. Based on the Kittler-Illingworth (KI) minimum-error thresholding framework, we integrate the generalized beta prime distribution (GB2) to achieve change detection between SAR images with different resolutions. The GB2 extends classical Gamma-ratio models by capturing differences in Equivalent Number of Looks (ENL) and offers excellent fitting performance for ratio images. Under the GB2 assumption, a modified KI criterion function is derived to minimize classification errors. To address class imbalance, an entropy-weighted average maximum likelihood estimation method is proposed to estimate the GB2 parameters for changed and unchanged classes. This approach dynamically boosts minority class likelihood contributions, ensuring robust fitting even when the quantities of the two classes are extremely imbalanced. Algorithm performance is evaluated through simulations and real inter-mission SAR data. Simulations are conducted between Magellan cycle 1 and cycle 3 images, with simulated change regions added. Further validation uses pre- and post-eruption observations of the Holuhraun lava flows in Iceland from Sentinel-1 and Radarsat-1. Our results demonstrate that the proposed method is a useful tool to achieve reliable change detection in inter-mission SAR images with different resolutions.