Mid-infrared reflectance spectroscopy of calcium-aluminium-rich inclusions to identify primitive near Earth asteroids

PLANETARY SURFICIAL PROCESSES

ORAL PRESENTATIONS

Session Chairs: Beth Steer (Open University) Louise Alexander (Birkbeck, University of London), Richard Passmore (Oxford)

The Lunar Geological Record as an Archive of the Galactic Environment of the Solar System

Ian Crawford (Invited)
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One of the principal scientific reasons for wanting to resume in situ exploration of the lunar surface is to gain access to the record it contains of early Solar System history. Part of this record will pertain to the galactic environment of the Solar System, to which the Solar System, and thus the lunar surface, has been exposed for 4.5 billion years. During this time the Solar System has orbited the Galaxy approximately 20 times, and will have encountered a wide range of environments of interest to astronomers. Much of this record will also be of astrobiological interest as it will inform our understanding of the past habitability of the Earth. We argue that this galactic record (including variations in the cosmic ray flux, supernova explosions, and passages of the Solar System through dense interstellar clouds) will be best preserved in ancient, buried regolith ('palaeoregolith') deposits in the lunar near sub-surface. Locating and sampling such deposits will be an important objective of future lunar exploration activities. Robotic sampling missions may be able to access palaeoregoliths at a limited number of favourable sites (for example where buried layers are observed to outcrop in the walls of craters or rilles) and return samples to Earth for analysis. However, fully sampling the record of galactic environments preserved in lunar palaeoregolith deposits will probably require the mobility, drilling, and sample return capabilities of future human exploration.

Examining Lunar Geology Through the Study of Regolith Fines Returned by the Apollo 12 Mission

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The Apollo 12 mission landed in the Eastern region of Oceanus Procellarum (Mare Cognitum). Crater size-frequency distribution measurements by [1] indicate that some of the youngest lava flows on the Moon occur within the Oceanus Procellarum region and it is, therefore, possible that some younger, exotic fragments have been sampled by the Apollo 12 mission. Samples from this site are therefore important for exploring this possibility. Most basalts from the Apollo 12 site can be grouped into three main basaltic suites: olivine, ilmenite and pigeonite, based on their mineralogy and bulk composition [2,3,4]. An additional suite of feldspathic basalts consists of one sample only [4]. However, care needs to be taken with classification based on bulk chemical properties as the small sizes of samples allocated for research means that they may not be representative of their parent rocks [4]. We demonstrate how we can make the most of small sample sizes by examining and comparing the major, minor and trace elements in mineral phases together with mineral crystallization trends to look at differences between the samples studied and the known basalt groups in order to help identify potentially unusual or exotic samples.

Additional information: References: [1] Hiesinger, H. et.al. (2003) JGR, 108, E7. [2] James O. B. and Wright T.L. (1972) Bull. Geol. Soc. Am., 83, 2357-2382. [3] Rhodes J. M. et al. (1977) LPS IIX, 1305-1338. [4] Neal C. R. et al. (1994) Meteoritics, 29, 334-348.

On the Extended Distribution of Thorium near the Lunar Compton-Belkovich Volcanic Complex

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An anomalous excess of surface Thorium lies on the Moon's far side, between the craters Compton (103.8°E, 55.3°N) and Belkovich (90.2°E, 61.1°N). The anomaly was first detected by the Lunar Prospector Gamma Ray Spectrometer (LP-GRS), in a topographically elevated, high albedo region containing irregular depressions, cones and domes. It has thus become known as the Compton-Belkovich Volcanic Complex (CBVC). We enhance the resolution of LP-GRS thorium maps near the CBVC, via statistically robust 'pixon' image reconstruction techniques. We find that the thorium is distributed over a much larger (40-75 km) area than the (25-35 km) elevated region. Post-emplacement processes are insufficient to disperse material this far, so we conclude that the thorium must have been initially emplaced over a wide area. One possible mechanism is highly silicic, pyroclastic eruption, the products of which offer an insight into the volatile content in this region of the Moon's upper mantle at a relatively late time in its evolution.

Trends in Distribution of Small Craters in the Apollo 17 Region

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The Apollo landing sites are the best-studied planetary surfaces outside the Earth. In the last few years, we have witnessed a resurgence of lunar missions, with much of the Moon's surface now photographed to a sub-meter resolution at vary-ing observation conditions. This study is based on Narrow Angle Camera (NAC) [1] images at a spatial resolution of ~1.4 m and phase angle ~68 degrees. I carried out a census of craters down to a diameter of 5 m within a region centred on Taurus-Littrow valley, site of the Apollo 17 mission. I extended the survey to parts of the surrounding uplands for comparison. Estimating relative and absolute ages using small crater populations has proved to be a controversial issue, an approach marred by poor statistics (past low res. images) and concerns about the contribution of secondary cratering. Here we show that, buried within small-craters surveys, we may find trends worth exploring. In geological terms, the 15 Ma age model, derived from crater size distributions within shallow craters of known formation age, offers a tantalising resurfacing estimate matching the dating of a fragment in the breccia 78155 collected not far from SWP (one of the surveyed craters) of 17±1 [8].

Selecting Landing Sites for the 2018 ExoMars Rover

Peter Fawdon
The Open University

Part of the European Space Agency (ESA) 2018 ExoMars mission is a lander and rover carrying a package of instruments designed to investigate signs of life. Because of the present surface conditions and extensive resurfacing since any period of habitability in the earliest parts of martian history, the landing location of the rover is paramount to the success of its mission. The call for landing site submission was made in December 2013 with proposals submitted in February 2014. In this time a consortium of UK scientists from The Open University, Birkbeck University of London, Imperial College London, UCL Mullard Space Science Laboratory, The University of Leicester and the Natural History Museum was set up to scrutinise the martian surface within the engineering constraints and proposed a number of potential landing locations. We present the three landing sites resulting from our initial investigation Oxia Palus, Hypanis Vallis and Mawrth Vallis. We discuss the process of selecting these locations for proposals and some of the new science results which have resulted from the search. Additionally we review of all the proposed landing sites for their astrobiological potential, with respect to satisfaction of the mission science criteria and engineering constraints.

Additional information: http://www.bbc.co.uk/news/science-environment-26743089
http://www.theguardian.com/science/across-the-universe/2014/mar/26/life-mars-exomars-spacecraft-landing-site

Mercury – New Views of the Sun's Innermost Planet

David Rothery (Invited)
The Open University

Many questions remain for ESA's BepiColombo to answer ten years from now, but thanks to NASA's MESSENGER (orbiting Mercury since March 2011) we now know far more about the closest planet to the Sun than was possible from ground-based astronomy and the Mariner-10 flybys in the 1970s. Mercury is a rocky planet with a disproportionately large iron core. The outer core is molten, and dynamo processes there generate a magnetic field (unique among the terrestrial planets apart from Earth). It has a rich and dynamic exosphere. The surface is perplexingly rich in volatile elements such as S, K, Na and Cl, and there is widespread evidence of explosive volcanic eruptions (mostly more than 3 billion years ago, but extending into the past billion years) that must be driven by expanding volatiles. Such volatile abundance is hard to reconcile with models for Mercury's origin that call for much of its primordial silicate fraction to have been stripped away, possibly in a giant impact. Thermal contraction of the planet has led to widespread development of 'lobate scarps' at the surface that have taken up at least 7 km of radial contraction. The most recent macroscopic process to sculpt the surface (other than ongoing impact cratering) is the formation of 'hollows' - occurring as fields of steep-sided, flat-bottomed depressions tens of metres deep where a surface layer has been removed, seemingly by some sort of sublimation process. The volatile phase involved has not been identified.

The Fast-Evolving Surface of Pluto

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St Andrews

Pluto's surface-brightness and colour maps are seen to change on timescales as short as a year, as it presently recedes from the Sun. Using archival photometry in the submillimetre, taken in 1997 and 2012, we show that the near-sub-surface can also change substantially. An optically-dark longitude range has appeared as submillimetre-bright over this short time span. Possible alterations in the complex icy surface of the dwarf planet will be discussed. These results are complementary to the data that will be obtained in the New Horizons close flyby in 2015, where the submillimetre-varying longitudes will be almost out of view.

Chilling in Antarctica – Meteorites Weathering the Cold

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Meteorites that fall in Antarctica can reside there for up to 1 Ma before collection [1]. In this time, water can access their inside as thin films along grain boundaries, altering the mineralogy. The alteration products caused by this affects the suitability of samples for studies and captures a record of the environmental conditions in which they formed [2]. To better understand the unique processes of cold desert weathering and the chemical signatures that accompany it, this study focuses on the small scale changes caused by proximity of different mineral species to one another. For this, rim and interior thin sections from the L6 chondrite Queen Alexandra Range 94214 were studied, both texturally and chemically using a combination of optical microscopy, SEM, EMPA and LA-ICP-MS at The Open University [3]. Native Fe-Ni, and sulphide minerals are observed to weather initially, causing iron staining to radiate from the weathering minerals across large parts of the meteorite (all of the rim and 40% of the interior). This staining is a visual sign of deposits from the weathering minerals, deposited from a fluid that is likely acidic. We demonstrate how this fluid, derived from the weathering of native Fe-Ni and sulphide minerals, alters major and trace element composition within the silicates.

Additional information: [1] Benoit, P.H. and Sears, D.W.G (1999) JGR. 14159-14168. [2] Hallis, L.J. (2013) MAPS. 1-15. [3] Steer, E.D. et al. (2014) LPSC Abstract #1958.

Mid-Infrared Reflectance Spectroscopy of Calcium-Aluminium-Rich Inclusions to identify Primitive Near Earth Asteroids

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The recent availability of mid-IR spectroscopy from space telescopes has led to studies attempting to characterise the composition of near Earth asteroids (NEAs) by comparison to spectroscopic observations of meteorites in the laboratory (e.g. [1, 2]). Mid-IR of carbonaceous chondrite meteorites has also recently been in focus to identify primitive asteroids and the aqueous alteration processes occurring on them [3]. Of special interest among the components of carbonaceous

chondrites are the refractory calcium-aluminium-rich inclusions (CAIs) because they are formed very early on in the solar system. We have gathered reflectance spectra in the 2.5-16.0 μm range of the phases (spinel, olivine, melilite, pyroxene, etc.) in CAI sections of meteorites Allende (CV3.3), Vigarano (CV3.3) and Ornans (CO3.3) with a Perkin Elmer AutoIMAGE FTIR microscope, and compared them to mid-IR spectra of several NEA targets (253 Mathilde, 243 Ida, 1917 Cuyo, and the target of OSIRIS-Rex mission 101955 Bennu) of the Spitzer Space Telescope's Infrared Spectrometer (IRS [4]). Spectra from Spitzer were extracted with an optimal extraction method [5] and corrected with a near earth thermal model [6]. Reflectance spectra obtained from the CAIs were compared to spectra in the Keck/NASA RELAB database [7]. Overall, we see some features on the surfaces of the observed asteroids that may correspond to the pristine CAIs from the chondrites, though identification of these features is not easy.

Additional information: References: [1] Emery, J. P. et al. (2006) Icarus, 182, 496-512. [2] Lim, L. F. et al. (2011) Icarus, 213, 510-523. [3] Trigo-Rodriguez, J. M. et al. (2014) Mon. Not. R. Astron. Soc. 437, 227-240. [4] Houck, J. R. et al. (2004) Astron. Phy. J. Suppl. 154, 18-24. [5] Lebouteiller, V. et al. (2010) Publ. Astron. Soc. Pac., 122.888, 231-240. [6] Harris, A. W. (1998) Icarus 131, 291-301. [7] Pieters, C. M., and Hiroi, T. (2004). Lunar Planet. Sci. XXXV, # 1720.

Clast Classification in Martian Meteorite NWA7034/ NWA8114

Jane MacArthur

NWA7034 and its pair NWA8114 represent a new unique Martian basaltic breccia class. They contain ~2.1 Ga (Rb-Sr) clasts [1] and ~4.4Ga (U-Pb) zircons [2], and could have originated from a volcanic or an impact event. Agee et al. [1] reported a wide range of feldspar and pyroxene clast compositions, noting many clasts appear to have been affected by secondary processes. Santos et al. [3] found two alkaline feldspar clasts, trachyandesitic and mugearitic, suggesting greater diversity. This study investigates four types of clasts: feldspar, pyroxene, phosphate and gabbroic. A polished thin section from NWA8114 was examined using a XL30 ESEM at the University of Leicester to classify different clast types. The individual phases in each clast were analysed to give a bulk composition for each clast. Most of the feldspar clasts are plagioclase, though two were of alkaline composition with cryptoperthite intergrowth of two feldspars, which are likely to have cooled relatively slowly, as K-rich and Na-rich feldspar domains have separated, showing either over 70% albite or over 70% sanidine compositions. An iron-rich pyroxene clast, mainly pigeonite, shows a regular Ca-rich and Ca-poor exsolution intergrowth. Several phosphate clasts showed predominantly homogenous Cl-apatite. The gabbroic clasts show a range of augite, low-Ca pyroxene and plagioclase feldspar compositions. A brecciated gabbroic clast contains sub-clasts with low-Ca pyroxene, alkali-feldspar and Cl-apatite.

Additional information: References:
[1] Agee C. B. et al., Science 339, 780-785, 2013, [2] Humayun M. et al., Nature 503, 513-517, 2013, [3] Santos A. R. et al, 76th Annual Meteoritical Society Vol. 48, Issue s1, 5284, 2013