THE EUROPEAN SPACE AGENCY EXPLORATION SAMPLE ANALOGUE COLLECTION (ESA^{2}C) AND CURATION FACILITY – PRESENT AND FUTURE.

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Introduction: Since 2014, the Natural History Museum (NHM) has been the prime contractor to the European Space Agency (ESA) for defining and initiating the development of an Exploration Sample Analogue Collection and Curation Facility in support of the Human & Robotic Exploration mission preparation programme. The ESA Exploration Sample Analogue Collection (ESA^{2}C) will support the ongoing or future technology development activities that are required for human and robotic exploration of Mars, Phobos, Deimos, C-Type Asteroids and the Moon. The long-term goal of this work is to produce a useful and useable resource for engineers and scientists developing technologies for ESA missions and for appropriately qualified international users as well.

Sample Analogue Collection: The 'Mission Statement' of the ESA^{2}C is *"..to maintain, develop and manage a collection of materials, which recreate the physical and/or chemical properties of different Solar System target bodies of interest. The ESA^{2}C is designed to be available to appropriate investigators relating to any sanctioned project developing technologies or scientific payload in support of human & robotic exploration of the Solar System"*.

The complex mission architectures and diverse target bodies of interest means that a variety of different analogue materials are required to test all systems that come into contact with the target body, whether these be part of the spacecraft system, such as landing and/or roving systems (e.g. wheels), sample collection systems (e.g. drills or scoops) or scientific payload. The analogue materials must replicate as far as possible the expected 'geological' environment of the target body in terms of both physical/mechanical properties and chemical/mineralogical properties.

In addition to ensuring that the samples as accurately as possible represent the physical and chemical properties of the target bodies of interest, it is important to select materials that can be readily obtained both now and in the future, in enough volume that will ensure a sustainable collection. As is the case for the existing NASA lunar and martian analogues (JSC-1A and JSC-Mars-1) [1] we have selected samples that are available from commercial suppliers to mitigate the risk of materials becoming unavailable and to ensure large quantities can be sourced if necessary. Additionally, as our chosen suppliers provide materials to a number of industries we are confident in the quality control procedures in operation during material production, which should allow for good reproducibility in sample properties over time.

Samples selected include a variety of aggregates from the olivine-rich basalts from the Upper Lava Formation of the Paleogene Antrim Lava Group of Northern Ireland and clay samples from Cyprus, Spain and Senegal. During 2016 and 2017 we carried out a detailed characterisation of the analogue samples' physical and chemical properties [2,3]: *Chemical properties:* Whole-rock chemistry – major, minor and trace element analyses by ICP-AES and ICP-MS. Mineralogy – analytical SEM, EPMA and XRD (whole-rock). *Physical and mechanical properties:* Particle Size Distribution (PSD) (aggregate and granular samples) – sieving. Grain Size and Morphology – SEM, X-ray micro-CT and visual inspection. Density and porosity (all samples) – mass-volume measurement and helium pycnometry, X-ray micro-CT. Shear strength (aggregate, granular and powder samples) – shear box apparatus. Compressive and tensile strength (rock samples) – UCS testing and Brazilian indirect tensile method. Examples of the sub-samples produced for this characterisation work are shown in Figure 1.

As part of ongoing work, further samples have been acquired for the ESA^{2}C – anorthosite from a Norwegian quarry, basaltic sand and basaltic/ hyaloclastite collected from the Askja Region in Iceland and volcaniclastic/sedimentary/clay masonry unit (CMU) analogues that will be used for system level testing of the ExoMars crushing station. We are also in the process of characterising three Lunar simulants: EAC-1, Zybek NU-LHT-2M and USGS NU-LHT-2M (reported in an accompanying abstract [4]) in support of the ESA Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) mission; the Martian analogue JSC Mars-1; and 36 samples collected during Mars Utah Rover Field Investigation (MURFI) [5,6]. Some of these analogues are contained in the ESA^{2}C as voucher specimens which are defined as *representative of any sample (from a study, a field test, a laboratory test or any other relevant source) and have been deemed worthy of retention within the Collection*.

Figure 1. Examples of the sub-sample types within the ESA^{2}C.

ESA Sample Analogue Curation Facility: This unique venture will build on ESA's Human & Robotic Exploration mission preparation programme by establishing methodologies and protocols/procedures for curating the ESA^{2}C, as well as defining and validating the distribution mechanisms and information exchange protocols for the analogue materials. The overarching role of the Sample Analogue Curation Facility (SACF) is to:- *Curate ESA^{2}C samples and those identified and acquired for the Collection and associated data pertaining to those samples; make samples available for study and provide access to relevant data pertaining to those samples; carry out fundamental physical and chemical properties testing in the SACF (or testing via appropriately qualified external laboratories).*

Underpinning much of the SACF development work is the creation of the ESA^{2}C Collections Management System (CMS) and database of acquired anayaltical data (Figure 2).

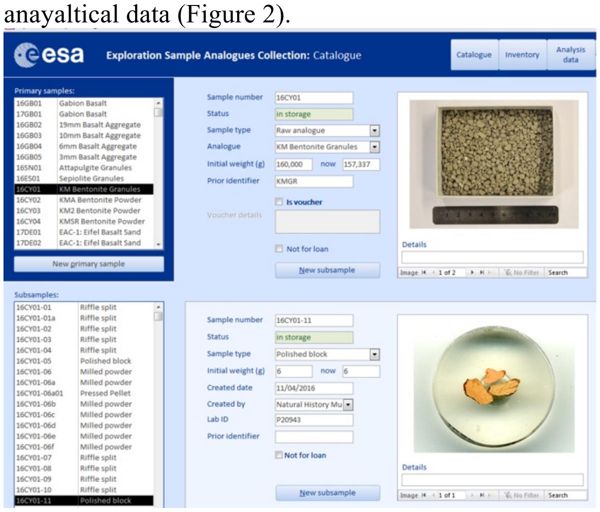

Figure 2: Screen shot of a portion of the ESA^{2}C database interface.

The CMS is primarily a curatorial tool for the Collection Curator to manage the core curatorial sample management functions of an actively used collection. These include the recording and management of incoming (new) samples to the Collection, samples being worked on within the SACF and the loan and return of samples and associated data to external partners. These curatorial functions have been designed to meet minimum national and international standards for collections.

All analogues in the ESA^{2}C (including voucher specimens) will undergo *fundamental properties characterisation* using procured (or outsourced) equipment in the SACF laboratory, which include the following: *Mineralogical and Chemical Properties:* X-ray diffraction (XRD) – bulk mineralogy; SEM – mineral chemistry by point analysis of dominant phases; X-ray fluorescence (XRF) – minor and trace element identification and quantification; fourier-transform infrared (FTIR) and raman – chemical/molecular bonding and fingerprinting. *Physical and mechanical properties:* soil PSD – sieving and laser particle analysis (latter outsourced); soil grain size and morphology – SEM and visual inspection; soil bulk density and rock dry density – mass-volume measurements; rock and soil particle density (for porosity) – gas pycnometry; soil shear strength (outsourced) – direct shearbox; rock UCS (outsourced) – uniaxial/unconfined compression. To date, tests have been carried out at the NHM or the University of Portsmouth, however, some equipment has been procured for the SACF: helium pycnometer, sieves, bulk density measures, digital calipers. Equipment pending procurement for the above characterisation work include rock crushing and milling equipment, a binocular microscope, benchtop XRD, raman and FTIR; a table-top SEM and a handheld XRF.

Future Opportunities: The facility will formally open on the Harwell campus (UK) beginning of Q3 2018. Some level of operation is however already insured by NHM and at present specimens from the ESA^{2}C are being used by engineers and scientists in the United Kingdom, Hungary and the US to support planetary research, related technology developments and testing activities for a variety of missions and mission architectures. The global distribution of planetary analogue material which has been well characterised, i.e. has known fundamental physical/mechanical and chemical/mineralogical properties, provides a vital resource for scientists and engineers to carry out comparative and collaborative investigations into the vast sector of space exploration. The ESA Sample Analogue Curation Facility hopes to spearhead and centralise access to these resources for many years to come.

References: [1] NASA website – https://isru.msfc.nasa.gov/simulantdev.html (2016). [2] Manick K. et al. (2017) *LPSC XLVIII*, Abstract #1220. [3] Manick K. et al. (2017) *LPSC XLVIII*, Abstract #1222. [4] Manick, K. et al. (2018) *LPSC XLIX*, Abstract #1411. [5] Beaty, D. W. et al. (2017) *LPSC XLVIII*, Abstract #2750. [6] Hipkin, V. J et al. (2017) *LPSC XLVIII*, Abstract #2709.

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