STARTING A EUROPEAN SPACE AGENCY SAMPLE ANALOGUE COLLECTION (ESA^{2}C) AND CURATION FACILITY FOR EXPLORATION MISSIONS. C. L. Smith[1], K. Manick[1], L. Duvet[2] and H. Schroeven-Deceuninck[2], [1]Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK c.l.smith@nhm.ac.uk. [2]ESA ECSAT, Fermi Avenue, Harwell Campus, Didcot, Oxfordshire, OX11 0XD, UK.

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 a Sample Analogue Collection and supporting Curation Facility in support of the Robotic Exploration mission preparation programme. The ESA Sample Analogue Collection (ESA^{2}C, pronounced "ESA square C) will support the on-going 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.

Analogue Requirements Definition: 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. Defining a set of well-characterised analogue materials, with both appropriate geotechnical and chemical properties, which could potentially be used as part of an 'end-to-end' methodological approach for testing, evaluation and verification of requirements during mission development would be highly advantageous. A detailed literature review on the current state-of-the-art knowledge of the compositions of the various target bodies of interest was carried out and also a two day, expert stakeholder workshop comprising planetary scientists and engineers was held to determine the main requirements to satisfy all the needs for planning and developing exploration missions. Figure 1 shows a simple flow chart identifying the main mission architecture elements that are relevant to any exploration mission and identifying the broad categories of analogues required for testing and verifying different engineering and payload technologies.

Analogue Samples Definition: 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. This is particularly relevant for materials that will be used in large scale engineering testing, for example to produce a 'Mars Yard' or similar environment, where tens to hundreds of tons of material can be used. As is the case for the existing NASA lunar and martian analogues (JSC-1A and JSC-Mars-1A) [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 e.g. construction, large-scale civil engineering projects, 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. Table 1 shows a summary of the materials selected as being suitable for inclusion in the ESA^{2}C.

Analogue Characterization and Verification: During 2016 we carried out a detailed characterization of the analogue samples' physical and chemical properties using a variety of different analytical techniques. The key characteristics measured and techniques used are:

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 properties:

- Grain size and shape – sieving and visual inspection, X-ray micro-CT.
- Bulk density and porosity – mass-volume measurement and helium pycnometry, X-ray micro-CT.
- Shear strength (aggregate and powder samples) – shear box apparatus.
- Compressive and tensile strength – UCS testing and Brazilian indirect tensile method.

The results of the chemical/mineralogical analyses and the physical properties testing are provided in more detail in accompanying abstracts at this meeting [2,3].

Sample Analogue Curation Facility: This unique venture will build on the 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. Underpinning the work will be the development of the ESA^{2}C database that will be undertaken by the NHM in the coming year. Samples will be available to suitable qualified PIs within the next year and we welcome requests for information on the samples we have already acquired and characterized.

Acquisition of further analogue samples:

As part of ongoing work, additional samples to those shown in Table 1 were acquired for the ESA^{2}C. Anorthosite blocks were acquired from a Norwegian quarry and basaltic sand/gravel and basaltic/hyaloclastite blocks were collected from the Askja Region of the Vatnajökull National Park in Iceland. These analogues have not yet been characterized and will be the subject of the next round of test work. Additionally, sample mixtures will be made up using the characterized clays and basalts for varying grain sizes and clay:basalt ratios to better replicate the Phobos/Deimos/C-Type Asteroids and martian regoliths. We have also acquired a variety of samples from a recent field campaign to Utah and we will continue to seek sources of new materials for potential acquisition and subsequent characterization to enhance the initial Collection. A critical part of our work is to actively collaborate with our colleagues in the space mission engineering and planetary sciences communities to ensure that the ESA^{2}C is a relevant and practical resource for technology development.

References:

[1] https://isru.msfc.nasa.gov/simulantdev.html. [2] Manick K. et al. (2017) 48th Lunar and Planetary Science Conference. [3] Manick et al. (2017) 48th Lunar and Planetary Science Conference.

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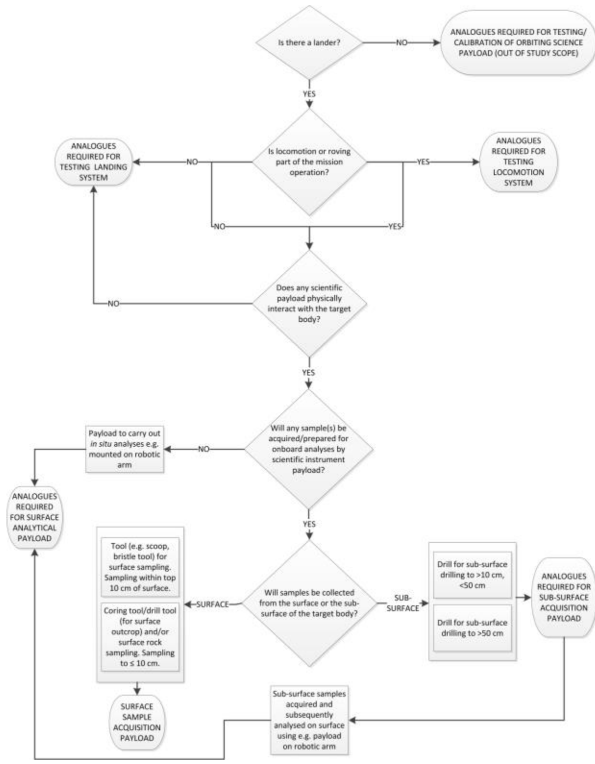

Figure 1. Simple flow diagram showing an overview of mission architectures/operations applicable to Solar System robotic exploration missions and where analogue samples would be applicable for technology testing.

Analogue Material Type		Physical Description	Relevant Target Body	Mineralogy
Basalt	Basalt Rock	150-200 mm gabion stone	Mars, Moon	Feldspar ($Ab_{35-46}Or_{1-2}An_{52-64}$) Olivine ($Fo_{54-60}$) Pyroxene ($En_{36-39}Wo_{44-46}Fs_{16-18}$) Ilmenite
	Basalt Aggre-gre-gate	19 mm, 10 mm, 6 mm and 3 mm and down (dust)	Mars, Moon	
Clay Granules	Sepio-lite	Granular materials up to ~10 mm in size	Mars, Mars' moons, C-type asteroids	Palygorskite-sepiolite group with smectite component (>95%). Minor calcite, dolomite, quartz, mica (<5%)
	Atta-pulgite			Palygorskite-sepiolite group with smectite component (>90%). Minor Ca plagio-clase, calcite, dolomite (<10%)
	KM Gran-ules			Smectite group minerals (>90%). Minor quartz, calcite, mica, chlorite (kaolinite?) (<10%).
Clay powders	KMA	Very fine grained with 75 % <75 µm size	Mars, Mars' moons, C-type asteroids	Smectite-group minerals (>95%). Minor quartz, feld-spar, calcite, magnetite (<5%)
	KM2			Smectite group minerals (>95%). Minor quartz, calcite, dolomite feldspar, magnetite
	KMSR			Smectite group minerals (>90%). Minor quartz, calcite, mica, feldspar, chlorite (<10%).

Table 1. Summary of samples forming the initial ESA^{2}C.