ESA'S PROSPECT PACKAGE FOR EXPLORATION OF LUNAR RESOURCES: INVESTIGATION DOMAINS E. Sefton-Nash[1*], J. D. Carpenter[1], R. Fisackerly[1], R. Trautner[1], the ESA Lunar Exploration Team, the PROSPECT User Group and the PROSPECT Industrial Team. 1. ESA/ESTEC, Keplerlaan 1, 2201 AZ, Noordwijk, The Netherlands (e.sefton-nash@cosmos.esa.int).

Introduction: The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is a payload in development by ESA for application at the lunar surface as part of international lunar exploration missions.

As part of ESA's European Exploration Envelope Programme (E3P) [1] PROSPECT is part of contributions to the Russian-led Luna-Resource Lander (Luna 27) mission, which aims at exploring for the first time the South polar region of the Moon, performing an assessment of volatile inventory in near surface regolith, and an analysis to determine the abundance and origin of any volatiles discovered. Furthermore, E3P dictates that PROSPECT will build-up a European lunar exploration user community to exploit the engineering and scientific data, and the other benefits generated during the project.

Establishing the utilization potential of resources found in-situ on the Moon may be key to enabling sustainable exploration and lunar habitability in the future. The purpose of PROSPECT is to support the identification of potential resources, to assess the utilization potential of those resources at a given location and to provide information to help establish the broader distribution. PROSPECT will also perform investigations into resource extraction methodologies that maybe applied at larger scales in the future and provide data with important implications for fundamental scientific investigations on the Moon. To achieve these objectives PROSPECT is required to:

- Extract samples from depths of at least 1m.
- Extract water, oxygen and other chemicals of interest in the context of resources.
- Identify the chemical species extracted.
- Quantify the abundances of these species.
- Characterize isotopes such that the origins and emplacement processes can be established.

In the lunar polar regions PROSPECT is able to target water ice. At all locations on the Moon PROSPECT is able to extract solar wind implanted volatiles from the regolith through heating and aims to extract oxygen and other chemicals of interest as resources from minerals by a variety of techniques.

Drilling and sampling: ProSEED is the PROSPECT Sample Excavation and Extraction Drill. Once at the required depth, a tool acquires small samples, whilst preserving their temperature below limits set to ensure volatile preservation. ProSEED then delivers samples either to the Luna 27 robotic arm for passing on to Russian analytical instruments, or to the ProSPA Solids Inlet System (SIS).

ProSEED will include sensors and equipment for making measurements of sample temperature, subsurface permittivity and recording images of the sampling operations. It will also acquire a comprehensive set of engineering data from integrated sensors that will support analysis of subsurface soil properties and engineering parameters.

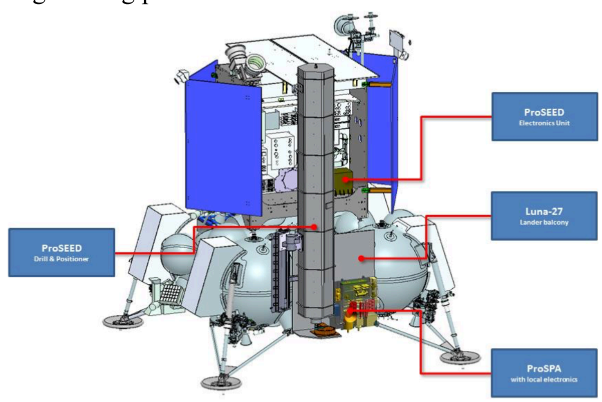

Figure 1: ProSEED and ProSPA Elements of PROSPECT on board the Luna 27 platform.

Chemical extraction and volatile analysis: The functions of ProSPA are distributed across two physical units: 1) The SIS comprises a series of single-use sample ovens (with heritage from ExoMars [2]) 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 ancillary and control systems [3].

Various heating profiles may be applied to the ovens for the purposes of addressing different science and ISRU objectives. Heating in vacuum extracts ices and solar wind implanted volatiles, and pyrolyses some volatiles from minerals. Reacting gasses may also be introduced to the ovens to extract additional chemistry of interest, including combustion with oxygen [4] and reduction using hydrogen and methane [5]. Volatiles released during a heating profile are passed to the ProSPA chemical laboratory for analysis. The laboratory comprises an ion trap device for analytical mass spectrometry (2 - 200 AMU), as well as a magnetic sector instrument for analysis of stable isotopes (D/H, δ13C, δ15N, δ18O) [3]. Measurements of Ar, Kr and Xe are also expected to be possible [6].

Associated ancillary and control systems comprise gas handling and processing components, including open/closed valves, metering valves, micro-reactors, pressure sensors and reference materials.

Investigation Domains: PROSPECT has objectives that lie firmly within lunar exploration and science: in-situ planetary geology, and analysis of samples and volatiles, but there exist a number of expertise domains, some related to specific hardware elements, in which scientific contributions must be focussed in order to realise these objectives:

1. Drilling, Geotechnics and Sample Handling: Data will be returned from the ProSEED drill system that can be used to derive regolith physical properties. Sample behaviour during handling, as evidenced by relevant sensors (e.g. imagers) may also be relevant information sources. The focus of this investigation domain is therefore firmly targeted at retrieving and analysing mechanical and other relevant physical properties of lunar regolith at the landing site, to provide both context to the other measurements made and to support development of future exploration systems that also target lunar polar landing sites.

2. Imaging, Surface Modelling and Spectral Analysis: The PROSPECT payload has two cameras: 1) a drill camera to image the landing and drill site in several spectral bands, monitor drilling operations as well as robotic sample transfer operations to ProSPA's SIS and the Russian robotic arm, and 2) a sample imager that will provide multi-spectral images and allow generation of depth-maps of sample deposit surfaces after they have been deposited in ovens.

Investigations using data from the sample camera will focus on sample properties that may be derived using spectral and morphological data retrieved from images obtained in various bandpasses [7]. Data from the drill camera will also provide contextual information regarding the drill work area, boreholes and drill cuttings, as well as the landing site, allowing interpretation of local geology and local morphology/illumination conditions.

3. Permittivity: The ProSEED drill rod is planned to accommodate a permittivity sensor, which allows determination of the electrical permittivity of materials in contact with the sensor electrode, via a comparison of the electrode current measured for air/vacuum and for contact with the material of interest. Permittivity measurements of borehole materials at specific drill rotation azimuth and depth will be made during drilling operations, at periodic measurement intervals during which the drill will be stopped and non-rotating.

This will allow reconstruction of permittivity properties as a function of borehole depth and azimuth, leading to retrieval of profiles of H_2O content and other relevant geologic properties.

4. Thermal Environment and Volatile Loss: The ProSEED drill design includes a set of temperature sensors which provide information on sample temperature as well as mechanism temperatures. Together with engineering data on the energy used in the drilling and sampling process, the temperature data will allow the modelling of the thermal environment, and - most importantly - support the modelling and quantification of volatile losses and possible isotopic fractionation during sublimation [8], during the sampling and sample transfer processes.

5. ProSPA Sample Analysis: Volatiles released during oven heating, and optionally following reaction with reference gases, are passed to the ProSPA chemical laboratory for analysis. Volatiles could originate from ices, chemisorbed volatiles, cosmogenic volatiles, and implanted solar wind. This area of investigation focusses on analysis of the chemical composition and abundance of volatiles (using gas pressure determination and ion trap mass spectrometry) as well as isotopic analysis (using magnetic sector mass spectrometry) [3].

6. ProSPA ISRU: During ProSPA's ISRU experiment operation mode an oven may be heated to temperatures of up to 1000°C and fed with H_2 or CH_4 in order to reduce the molecules in the regolith and extract oxygen. These experiments are intended to provide an in-situ reference for terrestrial investigations into oxygen extraction processes that could be applied in future ISRU plants at the lunar surface. PROSPECT's ISRU science investigation will therefore require expertise in mineralogy and sample processing, to quantify the resource potential of lunar regolith with respect to future human and robotic missions.

References: [1] Houdou, B. and Carpenter, J. (2017), European Lunar Symposium [2] Schulte W. et al. (2010), Proceeding of i-SAIRAS. [3] Wright I.P. et al. (2012) Planetary and space science, 74, 1, p. 254 - 263. [5] Schwandt et al., (2012) Planetary and space science, 74, 1, 49-56. [3] Barber, S. J. et al. (2017), LPSC 48, Abs. 2171. [7] Schmitz, N. and Donaldson-Hanna, K. (2017), LPSC 48, Abs. 1904. [6] Curran, N. M., et al. (2017), LPSC 48, Abs. 2243. [8] Mortimer, J., et al. (2017), LPSC 48, Abs. 1945.