ProSPA: The Chemical Laboratory for In-Situ Assessment of Lunar Volatile Resources within Esa's Prospect Package

Conference or Workshop Item

ProSPA: THE CHEMICAL LABORATORY FOR IN-SITU ASSESSMENT OF LUNAR VOLATILE RESOURCES WITHIN ESA's PROSPECT PACKAGE. S.J. Barber[1], J.D. Carpenter[2], F. Rizzi[3], I.P. Wright[1], F.A.J. Abernethy[1], M.R. Leese[1], G.H. Morgan[1], A.D. Morse[1], S. Sheridan[1], A. Verchovsky[1], E.K. Gibson Jr.[4], C. Howe[5], P. Reiss[6], F. Goesmann[7], G. Bianucci[8], S. Cleaver[9], R. Fisackerly[2], B. Houdou[2]. [1]The Open University, Milton Keynes, MK7 6AA, UK, [2]ESA ESTEC, The Netherlands, [3]Finmeccanica S.p.A., Italy, [4]ARES, NASA Johnson Space Center, USA, [5]RAL Space, UK, [6]Technical University of Munich, Germany, [7]Max Planck Institute for Solar System Research, Germany, [8]Media Lario Technologies, Italy, [9]Airbus Defence and Space Ltd., UK.
simeon.barber@open.ac.uk

Introduction: Establishing the utilisation potential of resources found in-situ on the Moon may be key to enabling future sustainable exploration. A Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is in development by ESA for application at the lunar surface as part of international lunar exploration missions in the coming decade, including the Russian Luna-27 mission planned for ~2021.

PROSPECT will support the identification of potential resources, assess the utilisation potential of those resources at a given location and provide information to help establish the broader distribution. PROSPECT will also perform investigations into resource extraction methodologies that may be applied at larger scales in the future and provide data with important implications for fundamental scientific investigations on the Moon.

PROSPECT comprises two main elements: a drill system named ProSEED designed to access samples from depths up to 1.2 to 2 m, and ProSPA (Figure 1), a miniature chemical laboratory for the extraction and characterisation of volatiles within those samples.

Objectives: ProSPA aims to extract, identify and quantify the volatile species present within samples extracted from up to 1.2 to 2 m depth. Isotopic characterisation will be performed such that the origins, emplacement processes and evolution of volatiles on the Moon can be established. An additional objective is to demonstrate the feasibility of extractions relevant to in-situ resource utilisation (ISRU) on the lunar surface.

Operational description: The ProSEED drill will obtain and handle samples and transfer these to the ProSPA sample oven and carousel assembly (Figure 1). The samples may be at temperatures of 120 K or lower, and must be handled carefully to avoid loss of the more volatile components. The samples are then sealed in ovens, derived with heritage from those developed for Rosetta [1] and activities performed through the German LUISE [2] programme. The samples are imaged within the oven to provide geological context and estimation of sample size, thus enabling the quantities of volatiles subsequently released to be expressed in terms of volumetric concentration in the source regolith.

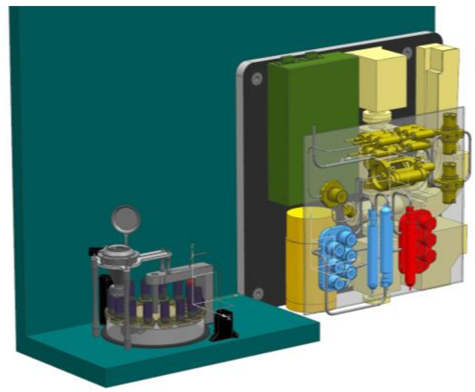


Figure 1. Conceptual representation of ProSPA. The main unit (right) containing the chemical laboratory and the electronics is housed separately from the sample ovens and carousel (left) which must be maintained cold prior to sample introduction to prevent loss of volatiles.

Samples can then be heated to temperatures as high as 1000°C or more. Heating may be performed in one of three ways (Figure 2), as described in the following.

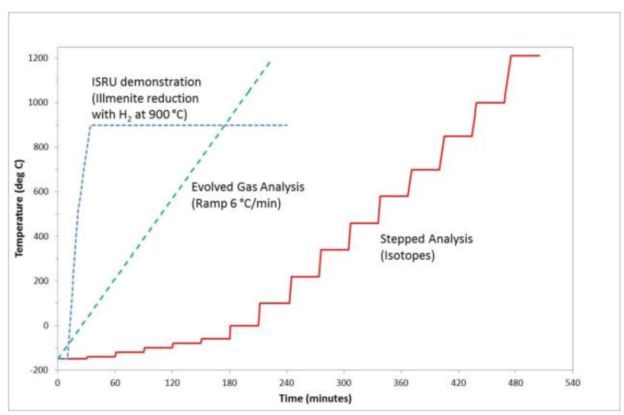


Figure 2. Indicative ProSPA sample heating profiles for extraction of volatiles. Temperature-time profiles are to be confirmed.

Evolved gas analysis ramp: By using a continuous heating ramp the evolved gases can be monitored in real time, using an ion trap mass spectrometer based upon that recently operating in the Rosetta mission [3]. This gives a qualitative measure of the composition, and provides an indication of the overall concentrations of volatiles within the sample, allowing subsequent analysis steps to be tailored accordingly. This mode is well-established as a means of detecting a range of released volatiles and the release temperature is diagnostic of the nature of the starting material in the sample (Figure 3, left). An additional goal is to detect phase changes taking place during the heating process.

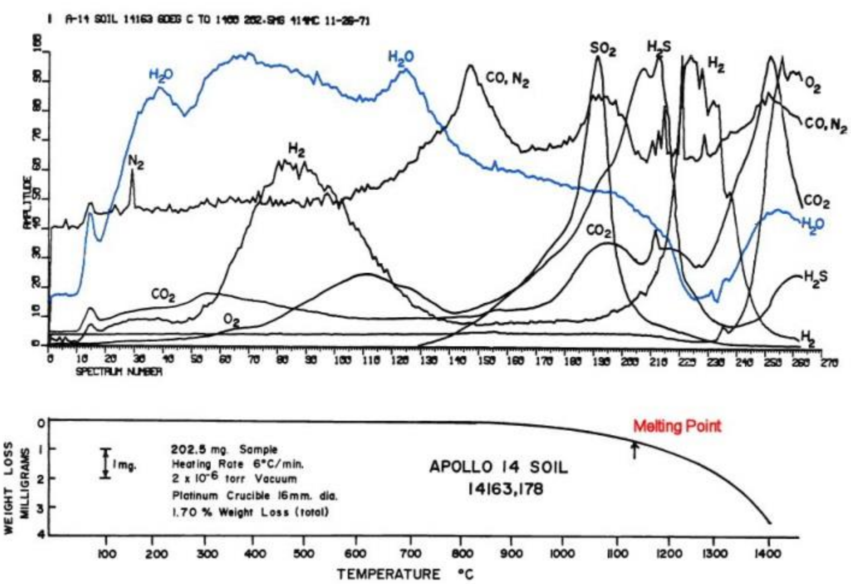
Stepped Analysis: Alternatively the heating may be undertaken in steps: in vacuum i.e. stepped pyrolysis (Figure 3, right) or in oxygen i.e. stepped combustion. The gases evolved in each step are purified or subjected to certain pre-preparations [3], before isotopic determination in a magnetic sector mass spectrometer derived from the Beagle 2 Gas Analysis Package. This utilizes on-board calibration to yield results with sufficient accuracy and precision to enable comparison with laboratory measurements on Earth of meteorites and returned samples.

ISRU Demonstrations: Reagent gases may also be introduced to the ovens to effect additional chemistry of interest, usually at a fixed reaction temperature. A number of techniques are under investigation, based on a combination of flight heritage and laboratory investigations. These include combustion with pure oxygen [4], oxidation using fluorine [5] and reduction using hydrogen and methane [6].

Challenges: The samples provided by the ProSEED drill may contain a wide range of volatiles in a variety of chemical and physical forms, and thus ProSPA is required to have wide dynamic range to determine both trace and more abundant species. In the case of a polar mission such as Luna-27, a key target species is water which may conceivably be present in concentrations that range from ppm to percent levels. In samples at an expected temperature of 120 K, the water may be present in a variety of forms, all of which should be preserved in the sample extraction and handling chain to enable their measurement by ProSPA. This is expected to require the development of an end-to-end volatile preservation model, informed by dedicated testing on representative analogues in a representative environment.

Conclusions: PROSPECT is a package for the investigation of lunar volatiles and other potential resources with potential applications for both exploration and fundamental science. The ProSPA element builds on extensive flight heritage and capabilities developed over decades by a number of groups across Europe. PROSPECT is funded by the European Space Agency.

References: [1] Finzi et al. (2007) *Space Science Reviews* 128: 281–299 [2] Reiss P. et al. (2014) *ELS*, 65-66. [3] Wright I.P. et al., (2015), *Science*, Vol. 349, Issue 6247 [4] Wright I.P. et al. (2012) *Planetary & Space Science*, 74, 1, 254-263. [5] Sebolt W. et al, (1993) in Resources of Near Earth Space, University of Arizona Press, 129. [6] Schwandt et al., (2012) *Planetary & Space Science*, 74, 1, 49-56. [7] Gibson E.K., Jr. et al. (1972) *Proc. Lunar Sci. Conf*. 2029-2040.



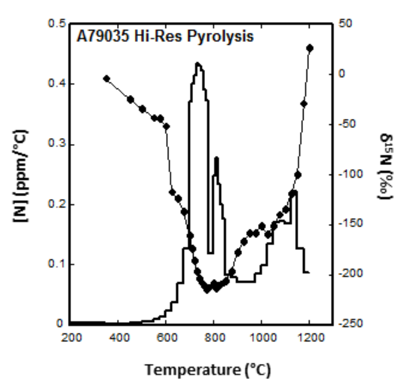


Figure 3. Left: Evolved gas release from Apollo 14 lunar soil 14163 during heating at 6°C/min from room temperature to 1400°C. [7]. Gas releases are normalized to 100% at the temperatures of greatest abundance. Right: Stepped extraction of nitrogen by pyrolysis of lunar breccia 79035. Credit: CT Pillinger