UNDERSTANDING LUNAR REGOLITH NOBLE GAS BUDGETS: ENABLING SCIENCE FROM THE ESA PROSPECT PACKAGE.

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Introduction: Future missions to the Moon including the forthcoming Roscosmos Luna-27 south polar lander, aim to investigate potential resources and volatiles budgets at the lunar surface. The PROSPECT package is an ESA contribution to Luna 27, which provides the capability to drill into the sub surface of the Moon to ~ 1 m depth, and collect regolith samples [1]. The samples will be transferred to a miniature chemistry laboratory (called ProsPA) and analysed for their volatile content and isotopic signature [2]. The aim of PROSPECT is to define the surface budget of lunar volatile species (including water, nitrogen, carbon, oxygen and the noble gases) and understand the sources of those volatiles – key lunar science objectives [3] - and to assess the *in situ* resource utilisation potential of the Moon for future lunar and planetary robotic and human exploration efforts [4-7].

Aims: Other presentations at this conference will discuss the importance of different aspects of the PROSPECT User Group activities. Here, we focus on a discussion of the science enabled by potential ProsPA measurements of noble gases trapped within the lunar regolith, and outline our current efforts to produce a database of previously reported noble gas measurements from lunar regolith samples.

Science from lunar regolith noble gases: Apollo, Luna and lunar meteorite regolith samples offer a diverse collection of material that includes all the dominant rock types on the Moon [8]. The noble gas budgets of regolith can help decipher the regolith evolution and crustal modification processes that occur on a planetary surface. Including mechanism which can help to determine: i) the regolith history and turnover rates (exposure age, burial depth and the surface exposure – maturity) of samples from different periods of lunar history [e.g., 9]; ii) evolution of the solar wind [10-11]; iii) understanding bombardment rates and delivery of meteoritic material to the Moon at different times [e.g., 12-13].

PROSPECT Activities: For PROSPECT, several questions are critical in assessing the extent to which the extraction and analysis of noble gases is feasible:

Understanding the potential sources of volatiles: What are the end-member noble gas contributors to the different lunar regolith that may be sampled by PROSPECT? For example, lunar polar regolith environments may include mineral and glass fragments that contain a wide range of different contributions [14-15] including radiogenic derived, implanted solar wind, cosmogenically produced, and absorbed lunar atmosphere. Polar ices and cold environments may also be key sink sites [16-17] for exogenously (e.g., 'planetary' signature) added components from volatile rich asteroids and/or comets [18-19].

Extraction and analysis planning: (1) Temperature of gas release: At what temperatures are the different components liberated from a regolith sample during extraction of the lunar surface and heating? Noble gases, and other volatiles, will be liberated from the extracted sample initially through sublimation and then through different heating cycles (continual or stepped) in a furnace [2]. Planetary mission traditionally have limitations on sample gas extraction methods; for example, the maximum temperature oven systems on robotic landers/rover can achieve are usually in the range of 1000°C [e.g., 20-21]. The full extraction of all noble gases generally occurs during complete sample melting (>1200°C). The volume correlated cosmogenic and radiogenic components are typically released at high (>1000°C) temperatures. Whereas, surface-correlated solar components generally dominate the lower temperatures. The behavior of noble gases trapped in lunar polar ice reservoirs is poorly understood, although the super cold temperature (-233°C) of water ice expected at the polar regions has the potential to trap noble gases [23-24].Therefore, it is important to understand at what temperatures noble gases are released from a regolith-like sample and, in the case of limited oven temperatures, the extent to which noble gases can be analysed to produce scientifically useful results if a sample is not completely melted. Such science aims including understanding the: (i) *Cosmogenic component* of lunar regoliths to enable corrections and determination of hydrogen and nitrogen isotopes [e.g., 13, 24]. Noble gases are notably important for understanding the cosmic ray exposure history of lunar samples (as a function of sample chemistry, shielding depth and nuclide production rate). (ii) *Regolith antiquity:* Argon isotopes (relationship of 'parentless' ^{40}Ar to solar wind derived ^{36}Ar) can provide an indicator of the timing of regolith closure from solar wind interaction, helping to constrain the time of past impactors [12, 22] and delivery of water ice to the lunar poles from these volatile-rich impactors.

Sample mass: We also need to understand how potential sample masses planned for the PROSPECT gas release experiment ~10 mg relate to previously determined lunar sample data to identify and understand limitations and potential problems that may occur on the Moon during analysis (e.g., instrumental detections limits, saturation of instrument, blank and memory effects) and plan for different gas preparation approaches.

Lunar Regolith Noble Gas Database: To address both instrument and mission science drivers for noble gas analysis on PROSPECT and future planetary missions, we are developing a database of existing literature data for lunar regolith samples (soils, regolith breccias, sub-surface drill cores and lunar meteorites).

The database so far includes data for over 200 different samples from ~40 refereed published papers. Data recorded includes: literature source reference, sample name and type, analysed masses, noble gas isotope concentrations (He, Ne, Ar, Kr, Xe) and uncertainties, and temperature of the gas release. We also report the calculated radiogenic, trapped and cosmogenic components of each measurement as reported in the original paper. We have not undertaken any data quality or filtering of the original reported data. We welcome authors to contact us to contribute their data (including historic Apollo and Luna mission era unpublished datasets).

Results: The database highlights knowledge gaps within the Apollo and lunar meteorite noble gas dataset. Many of the Apollo 12, 14, 15 and 17 soils have limited published noble gas budgets, and the similar is true for Apollo breccias from the Apollo 12 and 14 sites and many of the lunar meteorites. Fortunately, plentiful data has been published from the Apollo 16 regolith and soil sample set, which is most similar in feldspathic composition to the nature of the south polar 'highlands' landing site Luna 27 will be sampling.

Within the noble gas data there are huge variations (e.g., ^{36}Ar, <0.05 to ~1300 × 10^{-6} cm^3.STP/g: Figure 1) in noble gas concentrations from mission to mission as well as from different igneous rock types collected from within an Apollo landing sites. The available data for the lunar regolith shows that the majority of samples are dominated by a trapped ("solar") component (Figure 2) (as a result of their large surface/volume ratio and long surface exposure). Whereas, lunar meteorites show more of a range in trapped and cosmogenic components, likely from the varying depths they are excavated from.

Summary: Noble gas records of lunar rocks provide us with a vital tool for understanding the delivery of volatiles to the lunar surface and in most cases provide the only temporal constraints on samples analysed. Our aim is to use the database and temperature release profiles to provide an insight into the requirements for higher temperature (>1000°C) gas extraction methods on planetary missions. The database will provide a framework of the noble gas inventory of previously sampled lunar regolith that can be used and compared with future missions to the Moon.

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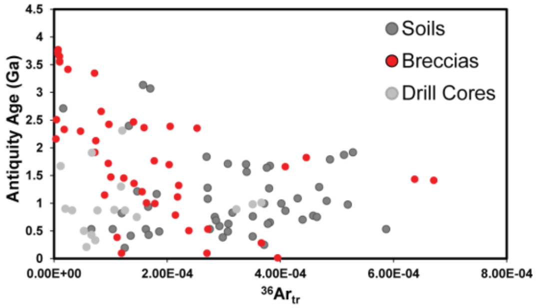

Figure 1. ^{36}Ar$_{tr}$ (solar wind component, in cm^3.STP/g) verses. Antiquity age (calculated using the bulk rock (^{40}Ar/^{36}Ar)$_{tr}$ and equation 2 of [12]) for Apollo regolith samples.

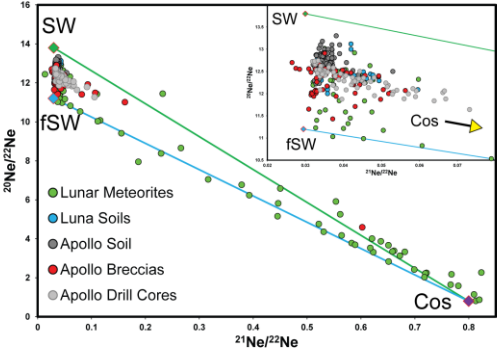

Figure 2. ^{21}Ne/^{22}Ne vs. ^{20}Ne/^{22}Ne for >250 neon literature data points for Apollo soil, regolith breccias and drill cores. The cosmogenic (Cos) and solar end-members (SW – solar wind and fSW – fractionated solar wind) are also shown on the graph. Inset graph is a close up of the solar dominated region including ~200 of the data points.