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Simulated real-time lunar volatiles prospecting with a rover-borne neutron spectrometer

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Abstract

In situ resource utilization (ISRU) may one day enable long duration lunar missions. But the efficacy of such an approach greatly depends on (1) physical and chemical makeup of the resource, and (2) the logistical cost of exploiting the resource. Establishing these key strategic factors requires prospecting: the capability of locating and characterizing potential resources. There is already considerable evidence from orbital and impact missions that the lunar poles harbor plausibly rich reservoirs of volatiles. The next step is to land on the Moon and assess the nature, “ore-grade”, and extractability of water ice and other materials. In support of this next step, a mission simulation was carried out on the island of Hawai’i in July of 2012. A robotic rover, provided by the Canadian Space Agency, carried several NASA ISRU-supporting instruments in a field test to address how such a mission might be carried out. This exercise was meant to test the ability to (a) locate and characterize volatiles, (b) acquire subsurface samples in a volatile-rich location, and (c) analyze the form and composition of the volatiles to determine their utility. This paper describes the successful demonstration of neutron spectroscopy as a prospecting and decision support system to locate and evaluate potential ISRU targets in the field exercise.
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Keywords: Moon; Volatiles; Rover; Neutron spectroscopy

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1. Introduction

1.1. Lunar ISRU and a mission simulation

The Moon’s polar regions clearly harbor a variety of volatiles. Several independent lines of evidence from Lunar Prospector (LP), the Lunar Reconnaissance Orbiter (LRO), and especially the Lunar CRater Observation and Sensing Satellite (LCROSS) impact mission point to the strong likelihood of cold trapped water ice and other species (cf. Feldman et al., 1998, 2000; Colaprete et al., 2010). Taken together, the evidence suggests that there are locations where water ice, at least, is present in sufficient abundance to warrant investigating its use for ISRU. There are extensive areas where surface and subsurface temperatures are sufficiently low to preserve water ice for over 1 Ga (Paige et al., 2010). However, not all these potential cold traps host similar abundances. Evidence of surface frosts is found in several permanently shaded craters at the south pole, but not all (Gladstone et al., 2012). Some

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but not all of these features have volumetrically significant hydrogen abundance (assumed to be in the form of water ice). Such a heterogeneous distribution of volatiles over hundreds of kilometers has been difficult to explain – why should equally effective cold traps not retain similar reservoirs of volatiles? Whatever the cause, such lateral heterogeneity may exist down to small scales, plausibly down to meters and tens of meters (Hurley et al., 2012).

Simply sampling in a cold, dark location at the Moon's poles does not assure finding significant, useful concentrations of volatiles. Surface mobility will be required to discover, map, characterize and in effect assay the "grade" of volatile deposits. Ease of extraction versus ore concentration and total volume is the trade. Therefore, a robotic mission to seek out and explore the volatile reservoirs of the Moon's polar region must be mobile and carry tools that permit the sensitive detection of surface frosts (in shadowed areas) and volumetrically significant bodies of hydrogenous materials.

As described by Sanders and Larson (2015) and Heldmann et al. (2015), the mission approach is unique and unlike rover operations on Mars, because operations are intended to be carried out in real time. This would be the case for a lunar polar rover mission with limited sunlight and power access. Based on current knowledge, the physical nature, distribution and chemical state of lunar polar volatiles at a given site are poorly known – in order to react to and capitalize on new discoveries and surprises, real-time operations must include mission operators, systems specialists and scientists. The decision as to when and where to interrupt a traverse for the risky, time-consuming and energetically expensive activity of sample acquisition and volatile processing involves more than engineering factors – real time data from the prospecting instruments are key. A major goal of the 2012 mission simulation included understanding what works, and what does not, in the area of supervised robotic prospecting and operations team decision-making.

Here we describe a field exercise in which the National Aeronautics and Space Administration (NASA) and the Canadian Space Agency (CSA) jointly developed, integrated and operated a lunar polar rover and prospecting/processing payload (see Sanders and Larson, 2015). This mission simulation had the goals of (1) locating near subsurface volatiles and assessing their ore quality in real time, (2) excavating and analyzing samples of volatile-bearing subsurface materials, (3) demonstrating the form, extractability and usefulness of the materials. The rover, provided by CSA, was the Artemis Jr. platform (for a description of the rover and its subsystems, as well as its performance in the 2012 exercise, see Cristello et al. (2013)). Instrumentation for prospecting and sample analysis was part of the Kennedy Space Center-managed integrated Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE) payload.

RESOLVE is a rover-based payload that includes several key instruments: (1) a neutron spectrometer subsystem (NSS) for assessing the volumetric abundance of hydrogen (including water) in the subsurface over which the rover is driving; (2) a near-infrared volatile spectrometer subsystem (NIRVSS) that senses surface hydration and mineralogy; (3) a drilling system (DESTIN, developed by NORCAT and provided by CSA) to auger and collect core samples down to one meter below the surface; (4) an Oxygen and Volatile Extraction Node (OVEN), that accepts samples from the drill system, seals and heats them, and conveys gaseous volatiles to (5) the Lunar Advanced Volatile Analysis (LAVA) subsystem, a gas chromatograph/mass spectrometer that analyzes water and other volatiles released from the heated samples. LAVA also incorporates a near-IR spectrometer in its surge tank (NIRST), which views the gaseous volatiles in the tank and provides additional assessment capability to the system.

As described by Heldmann et al. (2015), the primary prospecting instrumentation were the NIRVSS and NSS. Roush et al. (2015) describe the NIRVSS system, while the details of NSS can be found in Elphic et al. (2008). NIRVSS measures the reflectance spectrum over ~1.2–2.4 μm, from surface materials below the rover, as illuminated by a constant intensity lamp. NSS consists of two helium-3 gas proportional counter tubes that are sensitive to thermal and epithermal neutrons, the intensity of which correlates with bulk hydrogen in the soils. Both instruments were nearly collocated on the rover, and were run continuously while the rover was in operation. NIRVSS also included the Drill Operations Camera (DOC), which imaged the NIRVSS field-of-view and the auger and coring drill tools while in operation. In addition, forward-viewing navigation cameras returned imagery of the site, and a very wide-angle downward-viewing camera imaged the surface immediately below the rover.

The RESOLVE neutron spectrometer is similar to instruments flown on orbital missions including Lunar Prospector, Mars Odyssey, MESSENGER to Mercury, Dawn at Vesta, and aboard the Lunar Reconnaissance Orbiter (Feldman et al., 1999, 2002; Goldsten et al., 2007; Prettyman et al., 2011; Mitrofanov et al., 2010). A rover-borne neutron spectrometer can provide immediate measurements of the local hydrogen concentrations, allowing real-time monitoring and decision-making (Elphic et al., 2008). As the rover encounters volumetrically important hydrogen-bearing volatile deposits, NSS provides information that enables operators to halt the traverse and carry out more detailed characterization of the resource prospect. For this field test, the NSS resolution scale was a spot 25–30 cm in diameter, centered below the instrument.

The purpose of this paper is primarily to document the execution of the RESOLVE Hawai'i 2012 resource prospecting traverse plans, focusing on the NSS performance in detecting resource prospects and serving as a decision support tool. We also discuss the overall success of this prospecting approach with a view to how a similar technique may be used in a lunar polar rover mission to search for volatiles.