THE CASE FOR A LUNAR SAMPLE RETURN MISSION: LICHTENBERG CRATER. D.B. McAlpin, J.I. Nuñez, A.R. Griffin, S.B. Porter, M.S. Robinson, School of Earth and Space Exploration, Arizona State University, PO Box 871404, Tempe, AZ 85287-1404 (david.mcalpin@asu.edu).

Introduction: The Oceanus Procellarum region of the Moon contains what are believed to be the youngest lunar mare deposits [1,2,3,4]. To date however, no samples of these deposits have been returned for radiometric dating, so their precise age, and a well-constrained date for the end of lunar volcanism remains elusive. Understanding the age of lunar mare deposits is key to understanding the evolution of the Moon and its internal structure. Lichtenberg Crater presents a diverse geologic setting that may hold the answer to this and other critical questions, including the age of the Lichtenberg impact, composition of pre-mare crust in the Procellarum KREEP terrane, the composition of two separate, and lithologically distinct mare deposits, and the related implications on our understanding of lunar crustal evolution. We propose to address these questions by sending a robotic rover to the Lichtenberg Crater vicinity to select pertinent samples and return them to Earth for dating and other investigations.

Background: Lichtenberg Crater (31.8º N, 67.7º W) is located within Oceanus Procellarum, on the far northwestern limb of the Moon as viewed from Earth. Its diameter is ~20km, with a depth of ~1.2km, and is thought to be Erastothenian in age. To its east is a large, flat plain of young basalts, rich in FeO and TiO_2, believed to be among the youngest basalts on the Moon [1,2,3,4]. To the north and west, older basalts, slightly less mafic and lower in titanium, underlie the younger basalt plain [3]. The crater itself is the source of an extensive ejecta blanket whose highly reflective rays extend more than 100 km from the crater's rim, and consist of an underlying layer of low-FeO, anorthosite-rich rock, similar in composition to the nearby highlands [1,4,6].

	TiO_2 (%wt / σ)	*FeO (%wt / σ)*
P9 Basalts	9.2 / 0.4	18.7 / .2
Feldspathic ejecta	2.3 / .4	13.1 / .3
P53 Basalts	3.2 / .2	17.5 / .1

Table 1: *Average TiO_2 and FeO content of major lithologic units, shown with standard deviation of the applicable measurement field [5].*

Given its distinctive rays, Lichtenberg was originally mapped as Copernican in age [4]. Subsequent research show that its rays reflect composition, not maturity, [1,7], while an age as much as 1.68 b.y. has been suggested by Hiesinger et al. [2].

Analysis: We used multi-spectral images from Clementine's UV/VIS camera to examine the Lichtenberg area as a 3-band color composite image (Fig. 1) and in false-color ratio data sensitive to the absorption range of FeO and TiO_2 . We also subjected the 3-band composite image to iterative cluster analysis, and produced a generalized lithologic sketch map, which we overlaid against a high-resolution Lunar Orbiter image (Fig. 2) to clarify key geologic relations.

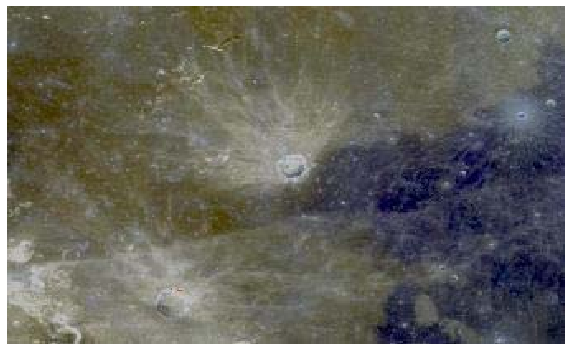

Fig. 1: *North is at top in this Clementine UV/VIS color composite image (1000nm, 900nm, 415nm) of Lichtenberg Crater. Young, dark P53 mare are visible to the right, while lighter, older, brown basalts (P9) occupy the north, south, and west. Lichtenberg, at center, is ~20km across.*

In these images, a low-albedo basalt is observed to embay Lichtenberg Crater from the east. This relationship was previously interpreted as a post-impact flow that overlies the crater's ejecta blanket on its south and east flanks [3,8,9]. Crater morphology similarly suggests that an older basalt (mapped by [2] as unit P9) was present on impact, overlying a felsic pre-mare crust now exposed as Lichtenberg's rays. After impact the younger lava (designated P53 by [2]) pooled on the crater's east side, overlying the south and east ejecta rays.

We suggest, alternatively, that the P53 basalt east of Lichtenberg Crater may not overlie its ray pattern at all. Herrick and Forsberg-Taylor found that oblique lunar impacts greater than ~15º but less than ~45º produce an asymmetric ejecta blanket down-range of impact while leaving an essentially round crater [10]. We suggest that Lichtenberg was created by an oblique impact, traveling on a SE to NW trajectory. The oblique impact created a downrange ejecta blanket, surrounded by an uplifted area of P9 basalts. Following impact, the subsequent P53 basalts were stopped by the uplifted P9 terrane (Fig. 2).

These spatial relations result in three units (P9 and P53 mare units, as well as the ejecta apron of feldspathic) within the same proximate area. This close proximity presents the opportunity to easily sample all three units and thus definitively date these major lunar events, and to analyze the geochemistry and mineralogy of at least three distinct lithologic units with one rover.

Technical approach: We propose a robotic sample return mission to Lichtenberg Crater to traverse and sample both the P9 and P53 mare deposits, as well as the feldspathic ejecta apron. The required rover is of the Mars Exploration Rover (MER) class, carrying cameras for navigation and analysis, as well as instruments for sample identification, analysis of elemental composition, sample collection and storage, and self-calibration. Following its sample collection traverse, the rover will rendezvous with an ascent stage that returns the samples to Earth. After return-vehicle egress from the lunar surface, the rover continues robotic exploration. If the rover were equipped with an RTG it could continue long-range robotic operations for five years or more. In this case the rover could explore and collect an additional suite of samples from a large number of sites to cache or deliver to a human outpost for a future return to Earth.

Each phase of the mission, from launch to sample return, is achievable with existing propulsion systems and proven technologies that minimize risk, cost, and development time. We anticipate a sample return payload of 2 to 10 kg collected over a nominal mission duration of 90 days.

Conclusion: A Mobile Lunar Sample Return (MLSR) mission can fill a languishing niche in Solar System exploration by enabling a focused and affordable high scientific value robotic sample return. Our proposed MLSR mission returns a sample enabling derivation of accurate age date for the terminal stage of lunar volcanism. We propose to accomplish this key science objective by sending a robotic roving vehicle to Lichtenberg Crater to select pertinent samples and to return those samples to Earth for age dating and other investigations. Additionally, MLSR will sample a second older compositionally distinct mare unit, and pre-mare feldspathic crust. These diverse samples will provide the means to clarify our understanding of lunar thermal history and the evolution of the crust and mantle. The development of MLSR systems and methodology for sample selection and return could be applied to future Mars sample return missions.

References: [**1**] Hawke, B.R. *et al*., (2004) *Icarus*, 170, 1-16. [**2**] Hiesinger, H. *et al*. (2003) JGR 108, 5065. [**3**] Schultz, P.H. and Spudis, P.D. (1983) *Nature*, 302, 233-236. [**4**] Wilhelms, D.E. (1987) *USGS Prof. Paper 1348*. [**5**] Lucey, P.G. *et al*. (2000) JGR 105, 20297-20305. [**6**] McEwen, A.S. et al. (1994) *Science*, 266, 1858-1861. [**7**] Grier, J.A., *et al*. (2007) LPS XXX Abstract #1910. [**8**] Schultz, P.H., (1976) *Moon Morphology*, Univ. TX Press, 626pp. [**9**] Allen, C.C., (1977) *Phys. Earth Planet. Inter*. 15, 179–188. [**10**] Herrick, R.R., and Forsberg-Taylor, N.K. (2003) *MAPS*, 38, 11, 1551-1578.

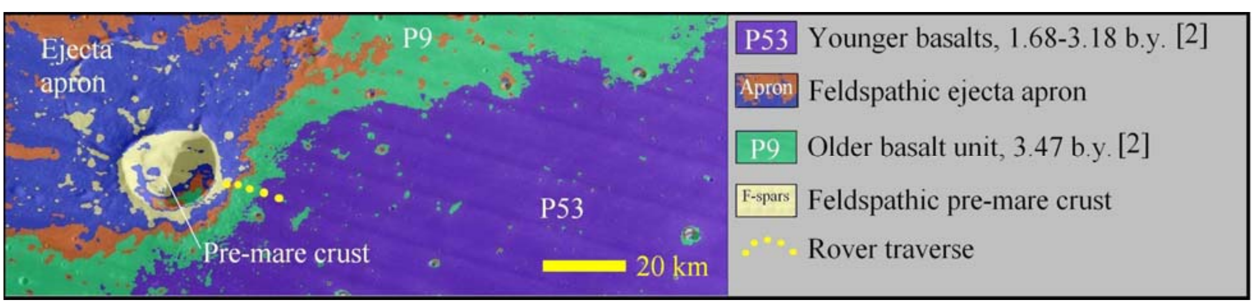

Fig. 2: *Cluster analysis of Lichtenberg Crater, derived from Clementine's UV/VIS (1000nm, 900nnm, 415nm) clarifies general lithologic boundaries, and is shown as an overlay against a Lunar Orbiter image. The uplifted P9 basalts (shown just southeast of the crater) allow collection of P53 basalts, P9 basalts, and feldspathic ejecta material, within a short traverse (less than 20km), as shown in yellow.*