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Context of Robotic Lander, Rover, and Sample Return Sites on the Moon: Imaging with LROC

J. B. Plescia (1), M. S. Robinson (2), T. Murphy (3), B. Jolliff (4), and S. Lawrence (2)
(1) Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20723 USA (jeffrey.plescia@jhuapl.edu), (2) School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 USA, (3) Department of Physics, University of California, San Diego, La Jolla, CA 92023 USA, (4) Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130 USA.

Abstract

The locations of the robotic vehicles landed on the lunar surface during the 1960's and 1970's have been located with the LRO LROC images. Locating the landing sites allows the observations and returned samples to be placed in appropriate geologic context.

1. Introduction

The United States and the Soviet Union sent a number of robotic spacecraft to the Moon during the 1960's and 1970's to collect information prior to human missions, to explore the surface, and to return samples to the Earth. Determining the locations of the landed missions is particularly important in order to allow the observations and returned samples to be placed in the appropriate geologic context. Using the LRO LROC imaging system [1] each of the Surveyor, Luna sample return, and Lunokhod rover sites have been repeatedly imaged and each of the spacecraft successfully located. The current values for the positions of the spacecraft are listed in Table I. These updated coordinates represent a considerable increase in precision for many of the locations [2,3,4,5].

2. Luna 17 / Lunokhod 1

Luna 17, which carried Lunokhod (Луноход) 1 was launched on 10 November 1970 and landed on 17 November in northwest Mare Imbrium south of Promontory Heraclides [6,7]. The landing was successful and the rover was deployed. Over the next 322 days the rover traversed 10540 m across the Imbrian-aged mare lavas of the area.

One of the key experiments carried by the rover was a laser retroreflector for lunar geodesy. Laser reflections were obtained by the Soviets and French in 1971 during the mission until September 1971 (about two weeks before last contact with the rover). As returns were no longer received it was assumed that the rover was parked in an orientation such that the reflector did not permit laser returns.

Figure 1. Upper frame shows the Luna 17 lander and rover tracks. Lower frame shows the Lunokhod 1 rover. LROC frame M127159138L.

However, using the coordinated provide by the LROC instrument team, the rover was recovered on 22 April 2010 using the Apache Point Observatory Lunar Laser Ranging Operation (APOLLO) in New Mexico by one of us (Tom Murphy). Subsequently it was been reacquired multiple times to provide very precise location coordinates.

Reacquiring the laser return from Lunokhod 1 is important not only to determine the rover's position, but for lunar geodynamics and tests of general relatively. The Lunokhod 1 rover is located in the northwest quadrant of the Moon. Now combined with the retroreflectors from the Apollo program and Lunokhod 2 (near the Moon's eastern limb) a wider reflector array can be used.

3. Luna 24

Luna 24 was launched on 9 August 1976 toward Mare Crisium on the eastern limb of the Moon. The vehicle landed on 18 August and lifted off for the Earth with on 19 August with about 170 g of sample [8.9]. The returned samples were not what had been expected based on interpretations of the remote sensing data at the time. The samples had been expected to be relatively mature and high TiO_2. However, the returned sample was immature, contained numerous lithic fragments and had low TiO_2 content. More recent analysis by Jeff Gillis indicates that the observed TiO_2 is consistent with the spectral signature of mare units.

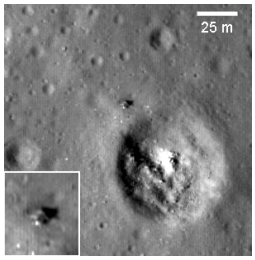

Figure 2. Luna 24 sample return landing site. The descent stage of the spacecraft rests just outside the rim of a 61 m diameter. Inset has expanded image of the spacecraft. LROC image M119449091RE.

The reason for the difference between the expected and observed sample character is resolved by locating the lander. Luna 24 landed on the continuous ejecta of a 61 m diameter crater (Figure 2) a few meters from the rim. Subsurface material was excavated and deposited it on the rim where it was sampled by Luna 24. The Luna 24 core contained several layer and the ejecta blanket may have been penetrated allowing for recovery of more typical Crisium surface material.

4. Summary and Conclusions

Observations of the landing sites of various lunar robotic spacecraft provides the geologic context that is necessary to interpret the observations and the returned samples. Considerable uncertainty of the scale of kilometers existed in the positions of many of these spacecraft. Now the absolute locations are knows to a precision of a few hundred meters. More importantly, the detailed geology of the landing sites can be resolved.

References: **[1]** Robinson, M. S., et al., Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview. *Space Sci. Rev.* **150**, 81-124 doi 10.1007/s111214-010-9634-2 (2010). **[2]** Dickey, J. et al. Lunar Laser Ranging: A Continuing Legacy of the Apollo Program, *Science* **265**, 482-490 (1994). **[3]** Williams, J. G., et al., DE412 Lunar Orbit: Physical Librations, and Surface Coordinates. Jet Propulsion Laboratory, Interoffice Memorandum IOM 335-JW, DB, WF-20080314-001 (2008). **[4]** Davies, M. E., & Colvin, T. R. Lunar coordinates in the regions of the Apollo landers. *J. Geophys. Res.* **105**, 20277-20280 (2000). **[5]** Roncoli, R. B. Lunar Constants and Models Document, Jet Propulsion Laboratory Document D-32296 (2005). **[6]** Akademiya Nauk SSSR, Predvizhnaya Laboratoriya na Lune, Lunochod-1, Izdatel'stvo Nauka, Moskva, 128 pp. (in Russian) (1971). **[7]** Florensky, K, P., et al., V. Peredvizhnaya Laboratoriya na Lune, Lunochod-1, Izddatel'stvo Nauka, Moskva, pp. 96-115 (in Russian) (1971). **[8]** Florensky, C. P., et al., Luna 24: Geologic setting of landing site and characteristics of sample core (preliminary data). *Proc. Lunar Sci. Conf. 8th* 3257-3279 (1977). **[9]** Butler, P. & Morrison, D. A. Geology of the Luna 24 landing site. *Proc. Lunar Sci. Conf. 8th* 3281-3301 (1977).

Table 1: LROC Derived Spacecraft Coordinates

Mission	Latitude (°)	Longitude (°E)
Luna 17	38.3282±0.001	325.002±0.002
Lunokhod 1[a]	38.3158±0.001	324.995±0.002
Lunokhod 1[b]	38.3154	324.9920
Luna 21	26.0027±0.006	30.4078±0.005
Lunokhod 2[c]	25.8324±0.002	30.9196±0.006
Lunokhod 2[d]	25.8323	30.9222
Luna 20	3.7868±0.001	56.6245±0.001
Luna 23	12.6667±0.001	62.1510±0.001
Luna 24	12.7140±0.002	62.2130±0.001
Surveyor 1	-2.4741±0.003	316.6609±0.000
Surveyor 3	-3.0145±0.001	336.5819±0.001
Surveyor 5	1.4607±0.004	23.1947±0.002
Surveyor 6	0.4734	358.5726

Uncertainties are the standard deviations of various measurements of positions from different LROC frames. a: LROC position; b: APOLLO data; c: LROC position; d: LLR data.