

LOCATING LANDED SPACECRAFT AND ARTIFICIAL IMPACT CRATERS IN LRO IMAGES. P. J. Stooke¹, ¹Dept. of Geography, University of Western Ontario, London, Ontario, Canada N6A5C2; pjstooke@uwo.ca.

Introduction: One goal of the 2008 Lunar Reconnaissance Orbiter is imaging previously landed or impacted hardware on the lunar surface. Reasons for doing so include scientific interpretation, mission documentation, historical interest and perhaps future preservation of historic sites. LOC resolving power should be adequate for the task, but uncertainty in targeting will make new identifications difficult.

Background: The first identification of a landed spacecraft in an orbital image was Surveyor 1 in a Lunar Orbiter 3 image [1]. Other Surveyors were located precisely by matching features in surface panoramas with orbital images, except Surveyor 5 which landed outside high resolution coverage [2]. Ranger and some Apollo impact craters were located by Ewen Whitaker in Apollo and Lunar Orbiter images [3]. Apollo LMs and areas of disturbed regolith were imaged from orbit by panoramic cameras in Apollos 15, 16 and 17 [4, 5, 6]. Apollo LM exhaust disturbed the regolith enough to form a brighter surface in which footprints and rover tracks appeared dark. Ranger 6 may now have been located in Clementine images [7]. No Soviet spacecraft were located precisely or imaged from orbit. These results provide lessons for searching for hardware or impact craters in images from LRO or future orbiters.

Landers: Landers will typically be seen as positive relief features a few pixels across, but may be difficult to distinguish from boulders. The Apollo 17 LM was imaged from orbit, but an image of a boulder was accidentally substituted for it in [6]. The Surveyor 1 identification was helped by its distinctive shadow under low sun. This may be useful in future, given suitable lighting. Confirmation in the form of identification of surrounding craters or rocks will be possible for sites with surface panoramas (Surveyor, Lunas 9, 13, 20, Lunokhod and Apollo sites).

A much bigger problem will be uncertainty in targeting. For instance, Luna 9, a target of the greatest historical significance, clearly does not lie where it is usually described, at 7.08° N, 64.37° W. This tracking position, uncertain by tens of km, lies among or very close to a range of hills up to 800 m high (from LAC shadow measurements). The Luna 9 panoramas show about 200° of horizon from south through west to north, but no prominent hills. The lander must be far enough north of the hills that they lie beneath the local horizon. A position near 8° N, 64° W (Figure 1) is

more likely [7]. Luna 13 is even less well constrained..

Impacts: Many impact craters made by orbiters at the ends of their missions, or by failed landers, will be difficult to locate because of location uncertainties. The Lunar Orbiter impact sites are uncertain by hundreds of km and would be very difficult to distinguish from natural fresh impacts. Ranger craters were located easily because their images allowed impact sites to be predicted, and two of the three imaged their impact points for comparison with later images. Apollo SIVB and LM ascent stages (except the Apollo 11 and 16 LMs) were tracked to narrow the search area, and those which fell in areas subsequently imaged were located fairly easily [3]. Some Soviet landers may be reasonably easy to locate for this reason. Hiten, the Japanese orbiter, should be located easily using earth-based tracking and observation of the impact.

One factor which helps identify artificial impacts is the distinctive nature of the ejecta. Conventionally, fresh ejecta is bright. Whitaker found that Rangers 7 and 8, the Apollo 13 and 14 SIVBs and the Apollo 14 LM ascent stage all had dark ejecta [3]. Conversely Ranger 9 showed bright ejecta in Apollo 16 images, and Ranger 6 ejecta (Figure 2) [7] may also be bright. The cause of darkening is unclear, perhaps related to release of propellants from ruptured tanks or to exotic fragments in the ejecta. This may help identification, or at least guide the search.

Conclusion: The scientific value of this work includes placing lander data in better context, refining seismic results from Apollo impacts, or planning future visits to old sites for study of old hardware, as Apollo 12 did for Surveyor 3. In some cases, Apollo sampling sites may be refined, improving the geologic context of samples. For instance, Apollo 16 station 5 is not unambiguously located [7]. Lunokhod 1 may still have value as a laser ranging target if it can be located precisely [8]. Impacts made by known masses impacting with known velocity may also contribute to regolith or impact studies. Often, though, this search will have primarily historical value. Can the site of the Luna 2 impact be located? If it is, will visual observers [7] be vindicated after years of doubt? Can Luna 9 or Surveyor 5 be located at last? Can the Apollo 15, 16 and 17 SIVB craters be found? If so, another item of documentation is added for these missions and seismic data interpretation may benefit. If in future it

is decided to confer special designations or protection on these sites [9], finding them is essential.

References: [1] Spradley, L.H. *et al.*, 1967. *Science* **157**: 681-684; [2] *Surveyor Project Final Report*, JPL TR-32-1265, 1969; [3] Whitaker, E.A., 1972, in ref. 5, pp. 29-39 to 29-45; [4] *Apollo 15 Prelim. Sci. Rep.*, NASA SP-289, 1972.; [5] *Apollo 16 Prelim. Sci. Rep.*, NASA SP-315, 1972.; [6] *Apollo 17 Prelim. Sci. Rep.*, NASA SP-330, 1973.; [7] Stooke, P.J. (work in progress) *The International Atlas of Lunar Exploration*; [8] Stooke, P.J., 2005. *LPS XXXVI*, Abstract #1194; [9] Stooke, P.J., 1988. Lunar Historical Parks (abstract), *Symp. on lunar bases and space activities in the 21st Century*, LPI cont. no. 652, p. 234.

Figure 1 (below): Luna 9 landing area from ref [7], on reprojected Lunar Orbiter image III-214-M

Figure 2 (top right): Possible Ranger 6 impact site in Clementine LWIR mosaic (on LTO map detail). Dark ejecta in LWIR is bright in visible light.

