APOLLO 16 LUNAR MODULE ASCENT STAGE IMPACT. J. Meador[1] and P. J. Stooke[2], [1]Independent researcher, Mountain View, CA. [2]Department of Geography and Institute for Earth and Space Exploration, University of Western Ontario, London, Ontario, Canada N6A 5C2, pjstooke@uwo.ca.

Introduction: The Apollo 16 Lunar Module Ascent Stage (LMAS) *Orion* was abandoned in low lunar orbit after a successful rendezvous and docking with the Command/Service Module *Casper*. The Apollo 12, 14, 15 and 17 ascent stages were crashed after use to provide a seismic signal, but control of the *Orion* LMAS was lost before an impact could be commanded. It was long assumed to have crashed at an unknown location within months of the landing. As with recent work on earlier Apollo missions **[1]**, we have used simulations to try to understand in greater detail what eventually happened to the Apollo 16 LMAS, and the results are reported here.

Prediction: The LMAS was left in a roughly circular 110 km orbit inclined 10.55° to the lunar equator. GRAIL gravity data and LRO LOLA topography make orbit evolution and impact modelling far more accurate than was possible at the time of Apollo.

One of us (JM) performed the analysis and identified a broad impact region extending from 74° E to 125° E and 8.8° N to 10.2° N. Within this region the impact site would necessarily be on higher terrain facing the incoming spacecraft, which was travelling east to west (retrograde) and would therefore strike an east-facing slope. The orbit destabilizes rapidly in late May 1972 and predictions all suggest an impact between 28 May and 2 June on an east-facing slope in Figure 1. The Apollo 16 subsatellite PFS-1, released into an identical orbit, was tracked to an impact on 29 May in the same area.

Seismic Data: The LMAS had a mass of 2350 kg and struck the surface at 1.68 km/sec, creating a seismic signal which the Apollo seismometers could have detected. Dr. Yosio Nakamura examined the Apollo seismic record from around the expected time of impact and identified a single seismic event on 29 May 1972, the only one in the period of interest. The timing suggested by the seismic record enables us to focus the randomized trials on impacts with the right time, narrowing the range of impact locations. The impact longitude was also found to be sensitive to the LMAS orbital inclination at release, which can be estimated from the Metric Camera pointing data. With this constraint a candidate region was found that satisfied all criteria. The LMAS probably struck the surface within 0.05° (1500 m) of 10.05° N, 104.30° E (Figure 2), at 21:14 UTC on 29 May 1972. Details of this analysis may be found at https://snoopy.rogertwank.net/

Image search: With this location in mind one of us (PS) conducted a search of images to locate the impact site. The Chang'e 1 impact site was identified because a surface marking matching expectations (downrange fan of ejecta emanating from a plausible impact structure) was found in an LRO NAC image but was not visible in a pre-impact Apollo 16 Panoramic Camera image **[2]**. The SMART-1 **[3]** and Apollo 12 LMAS **[4]** impact sites were found because features with the expected characteristics were found very close to the predicted location despite there being no high resolution pre-impact images of the site.

The predicted Apollo 16 LMAS impact site is on the edge of Apollo 16 panoramic camera coverage and probably falls within image AS16-P-5046. Unfortunately several factors make it unlikely that a pre-impact image of the site can be found. The predicted site is at the very end of the long panoramic camera image where oblique viewing reduces effective resolution, and the illumination is low oblique and west to east (late afternoon lighting), casting long shadows over the east-facing slope. These are the worst possible conditions for comparison with a post-impact image. Most likely the site will only be seen on NAC images.

An extensive search of NAC images of the impact area using the shadow-cancelling method described in **[4]** (morning and afternoon illumination images merged to cancel shadows and emphasize albedo markings) produced a plausible candidate for the impact at 9.99° N, 104.26° E. The Apollo 12, 14 and 15 LMAS impact sites are known (14 and 15 not yet published) and all show elongated trough-like depressions on the order of 30 m long and 5 m wide, and albedo markings extending downrange and laterally from the trough. The Apollo 16 candidate is similar (Figure 3), but we lack any image resolution better than 98 cm/pixel or a minimum-phase image. The images show a bright streak about 20 m long and a faint fan of bright ejecta extending downrange. It most closely resembles the SMART-1 impact site **[3]**. Any topographic trough is oriented east-west and we lack cross-trough illumination to show morphology clearly.

References: [1] Meador, J., 2021. *Plan. Space Sci.* 205:105304. [2] Stooke, P. J., 2019. *Icarus*, 319:334-336. [3] Stooke, P. J., *Icarus*, 321:112-115. [4] Stooke, P. J. and Marcus, M., 2019. *Icarus* 331:98-102.

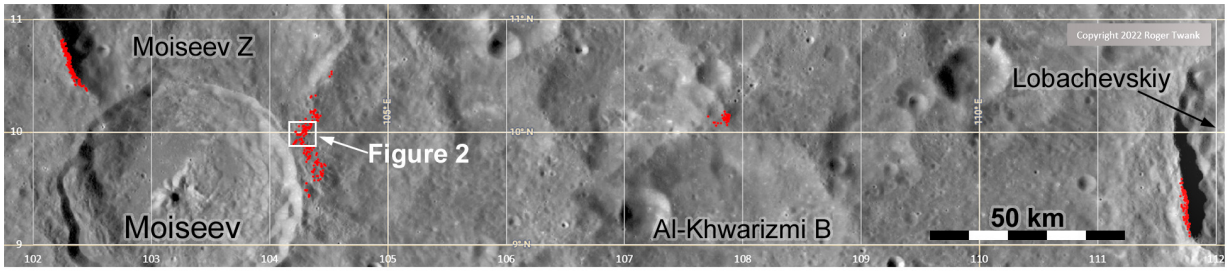

Figure 1. Simulated impact locations constrained by GRAIL gravity and the LOLA DEM.

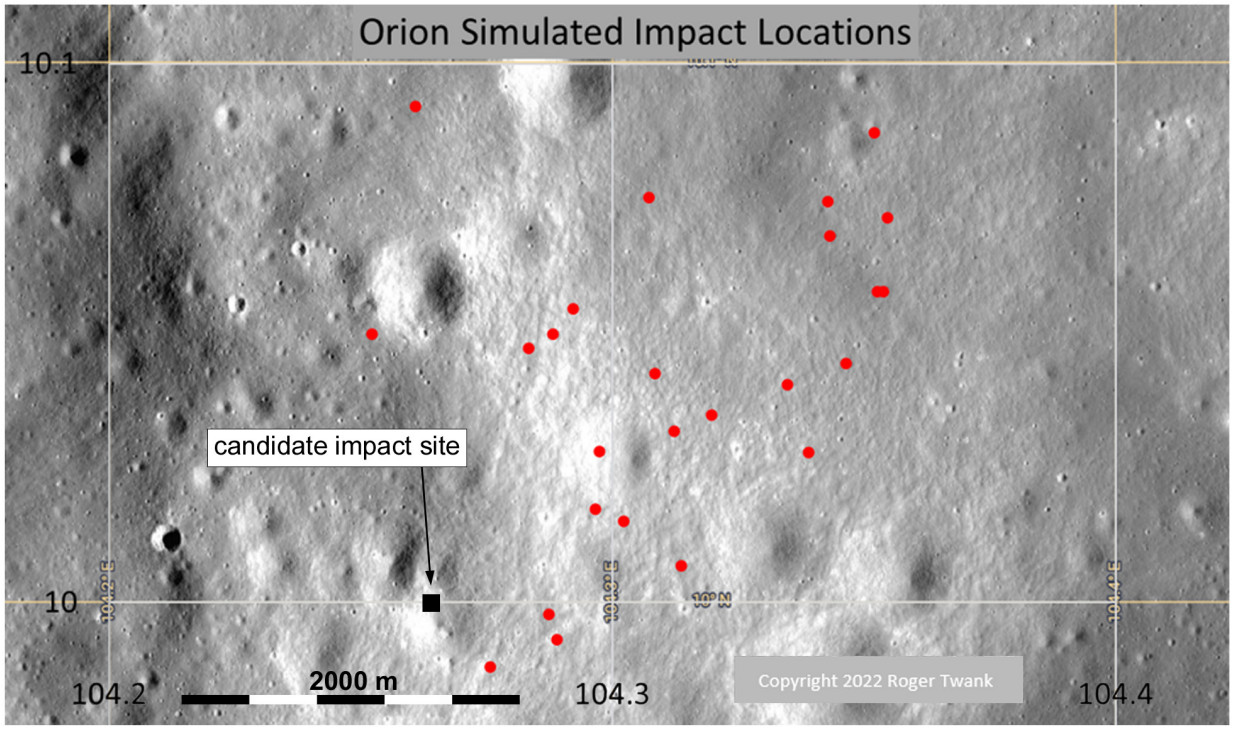

Figure 2. Predicted impact points further constrained by impact time and orbit inclination.

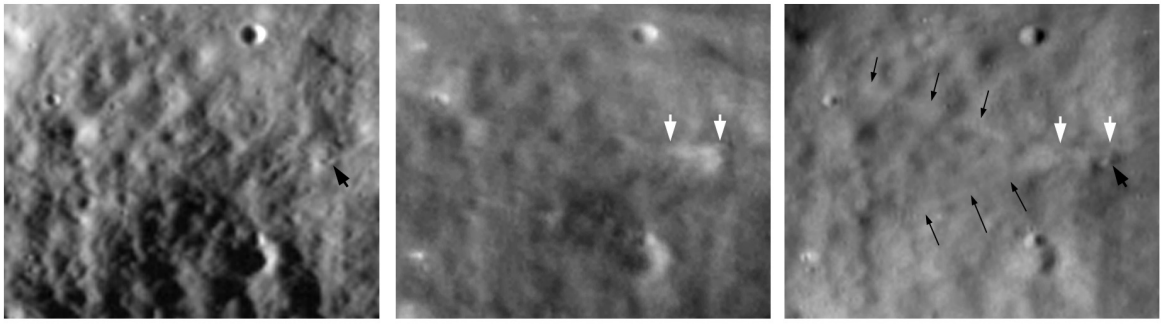

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Figure 3. LROC NAC images of the candidate impact site. Scale: 100 m top to bottom. Black arrow: small E-W trough. White arrows: bright streak. Small arrows: ejecta fan.