Slopes along Apollo EVAs: Astronaut experience as input for future mission planning

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Introduction

The topography of a landing region is a critical factor in the operational safety and planning of human extravehicular activities (EVAs). Therefore, the analysis of digital terrain models (DTMs) and derived slope maps (Fig. 1) is employed to propose EVA paths with minimal slopes and elevation discrepancies. Furthermore, technical constraints pertaining to the utilization and operation of equipment and tools, as well as astronauts mobility also impact EVA design. It is also important to consider the observational, physiological, and psychological experiences and constraints of astronauts for planning successful EVAs.

Data and Method

This study examined the reports of Apollo astronauts as well as audio and video recordings with the objective of ascertaining the experience and performance of the astronauts in relation to the topography and slopes encountered during their EVAs (Fig. 2). For this purpose, we analyzed the topographic profiles derived from the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) to assess elevations and slopes along the traverses of the Apollo landing sites, utilizing a 2-meter/pixel Digital Terrain Model (DTM) (Fig.3) [1,2].

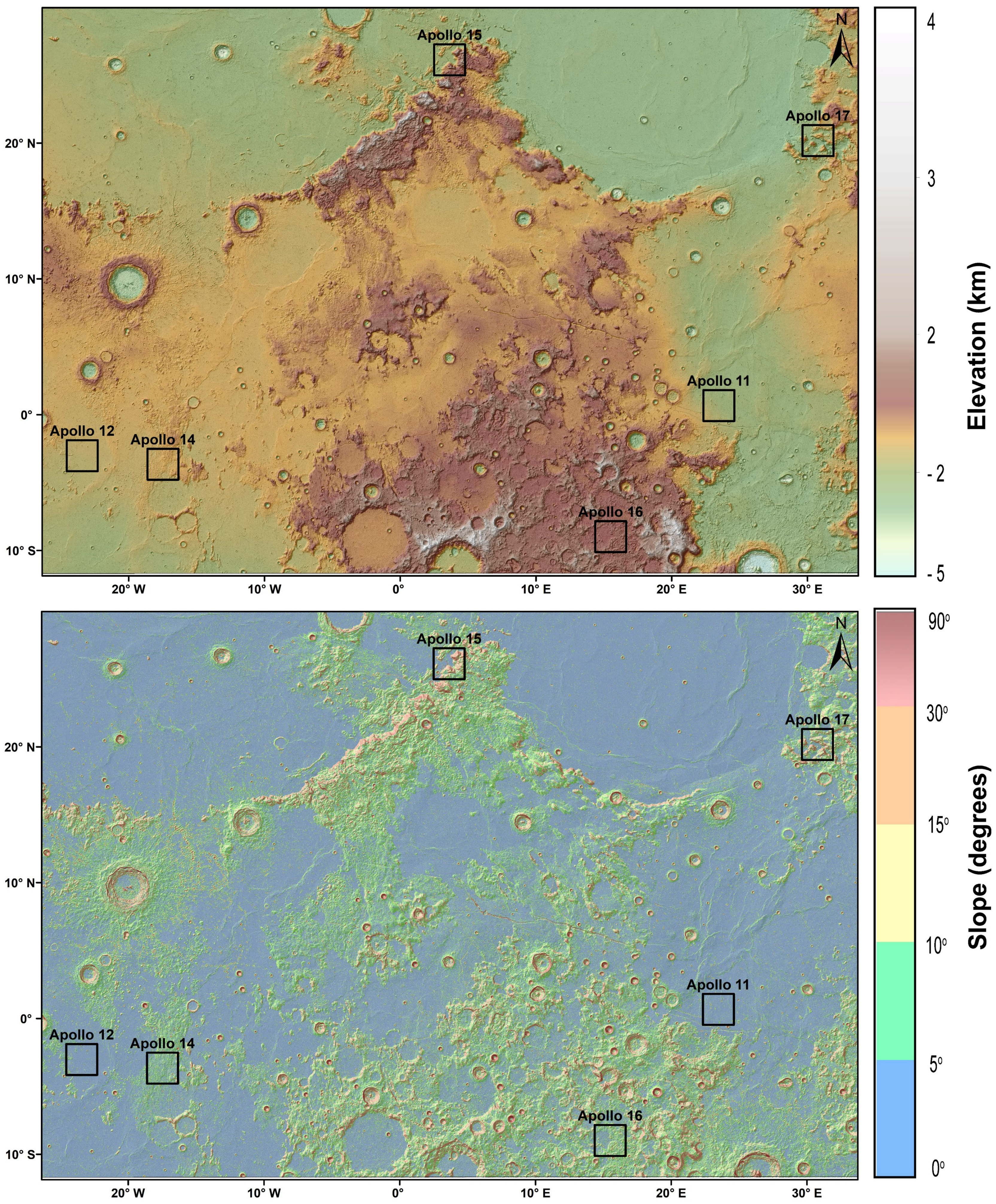

Figure 1 (above): The locations of the six Apollo landing sites are illustrated in the upper panel, which depicts the LRO-LOLA/Kaguya merged DEM (60 m/pixel), and in the lower panel, which displays the derived slope map.

During the Apollo 15 mission, Scott provided a commentary at station 2, *"Soft stuff. **Hard to work on the slope**, **hard to move on the slope**, as we point out even more definitively later on … because it's so soft and steep. So, we're getting tuned into it. And, as you note, there's **a lot of puffing**."*

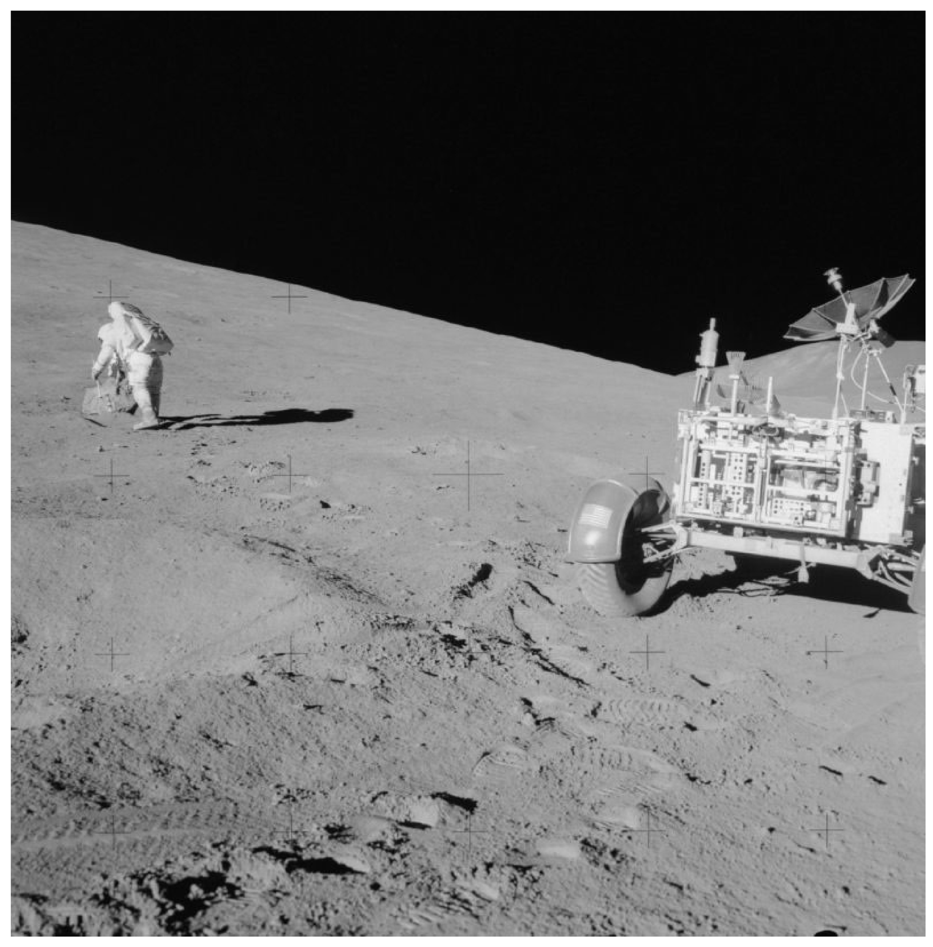

Figure 2 (right): Photo AS15-85-11437HR was captured during the EVA1 of Apollo 15. The image depicts Dave Scott examining the station 2 boulder while the rover is situated on an incline of ~13 degrees in the foreground.

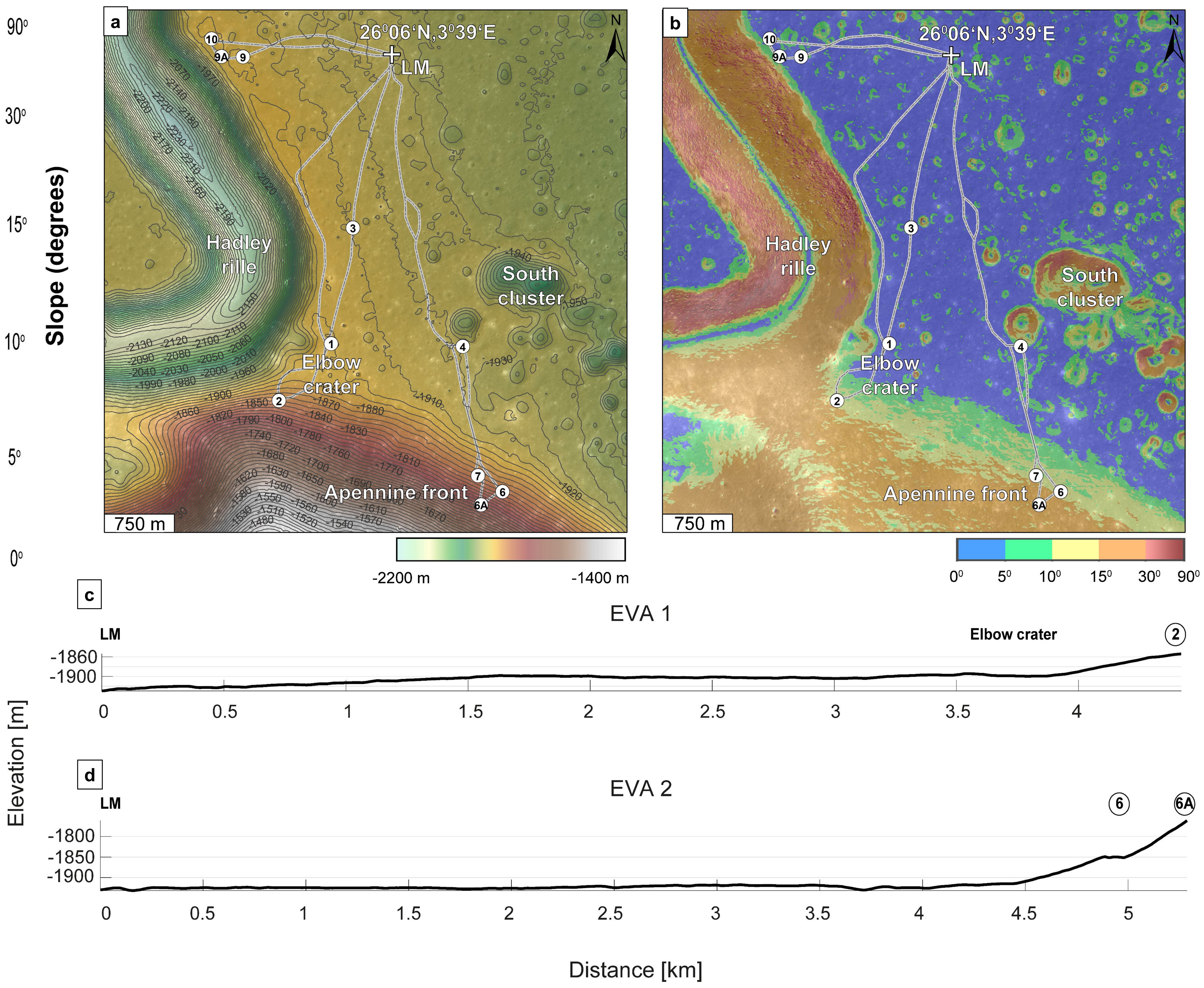

Figure 3 (above): (a) Apollo 15 traverse (gray line) shown on LRO NAC derived (left) 10 m contour DEM and (b) slope map. (c) Profile showing the change in elevation along EVA 1 (LM to station 2 along the Hadley Rill) and (d) EVA 2 (LM to station 6A). Stations (encircled) are shown on the traverse and above their location on the profiles

Discussion

Perception of Distance:

- The Apollo astronauts had difficulty judging distance and size due to a lack of reference objects [3,4].
- Astronauts' perceptions are strongly influenced by lighting conditions. For example, shadows appear longer and terrain appears more rugged in low sun angles, which are common during lunar morning landings [5].

Perception of Slopes:

- Slopes of less than 25° are considered accessible by CLSE [6], but detailed data from the Apollo missions provide specific guidelines for use under both terrestrial and lunar conditions.
- Lighting conditions can exaggerate slope steepness, such as boulders casting long shadows. Similarly, the Apollo 16 astronauts overestimated a crater slope as 60° when it was less than 30°.
- The Moon's soft regolith makes walking uphill a challenge. However, the low gravity (1/6th of Earth's) reduces the risk of sliding downhill.
- Restricted mobility due to equipment made traversing the slope difficult, resulting in longer traverse times.
- The Lunar Roving Vehicle (Apollo 15, 16, 17) was instrumental in the exploration of greater distances and steeper slopes.

Future Missions Planning:

Artemis Landing Sites:

- Chosen on ridges and crater rims in the South Pole region
- Offer good visibility of Earth and access to permanently shadowed regions (PSRs) [7] that may contain volatile-rich materials
- Exhibit more complex terrain than previous missions, likely requiring extended time at each site to complete tasks.
- Feature significant elevation differences of approximately 3400 m, compared to the 150 m climbed during Apollo missions

It is of utmost importance to prioritize safety measures [6] and to learn from past successful missions in order to optimize success.

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