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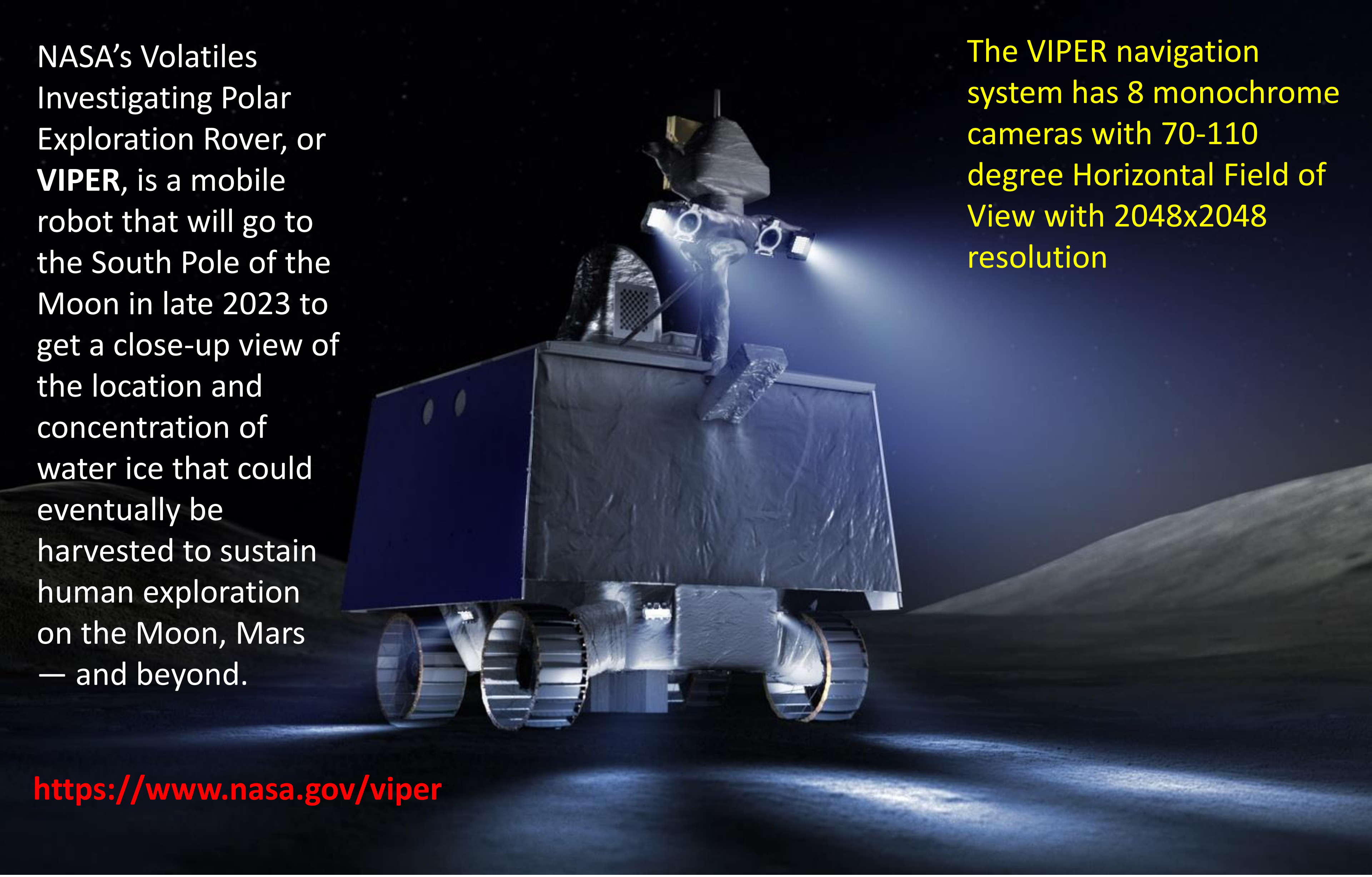
Investigation of geomorphological signatures of permafrost in the polar lunar areas with VIPER

Abstract

A study of images of the polar regions shows that small craters near the poles of the Moon are distinguished by the following features: 1. they have a smoother shape - see Fig (a); 2. patterned ground ("wrinkled skin") is often observed in and around the crater - see Figs (a,b,c); 3. outside the craters landslides and cracks are noticeable - see Fig (d); 4. layers or scarps are often visible on the inner slope - see Fig (e). These features (scarps and patterned ground) are typical for Martian craters in the permafrost zone (see Fig f), as well as for similar zones on Earth. It is hypothesized that these features of lunar craters are associated with the presence of permafrost in the polar regions of the Moon. In 2023, the VIPER rover will investigate the distribution of ice (volatile) deposits in the region of the Moon's South Pole. VIPER navigation cameras represent a unique opportunity for the geomorphological analysis of the lunar surface and the study of physical properties of regolith due to multiple key factors:

- A large number of high-quality digital images with a good resolution of the South Pole of the Moon, which is a key region for the landing of manned expeditions.
- A low position of the Sun, which generates long shadows, creates favorable conditions for object recognition algorithms.
- A presence of a rover track in the images enables VIPER wheels to be used as tools for the study of the regolith and the development of a geotechnical model of regolith in the South Pole region.

Rover navigation cameras will allow investigation of the distribution and shape of small craters and other structures along the path of the rover and test the hypothesis about geomorphological signatures of permafrost in the lunar polar areas. If a relationship between characteristics of lunar craters and the distribution of permafrost is confirmed, this will open a possibility to remotely determine the deposits of lunar ice from satellite imagery.



NASA's Volatiles Investigating Polar Exploration Rover, or **VIPER**, is a mobile robot that will go to the South Pole of the Moon in late 2023 to get a close-up view of the location and concentration of water ice that could eventually be harvested to sustain human exploration on the Moon, Mars — and beyond.

The VIPER navigation system has 8 monochrome cameras with 70-110 degree Horizontal Field of View with 2048x2048 resolution

https://www.nasa.gov/viper

The Moon's South Pole, which contains ice deposits, is essential for the landing of expeditions under the *Artemis* program. This area has not previously been visited by robots or astronauts, so the VIPER rover will be sent there to explore the underground ice.

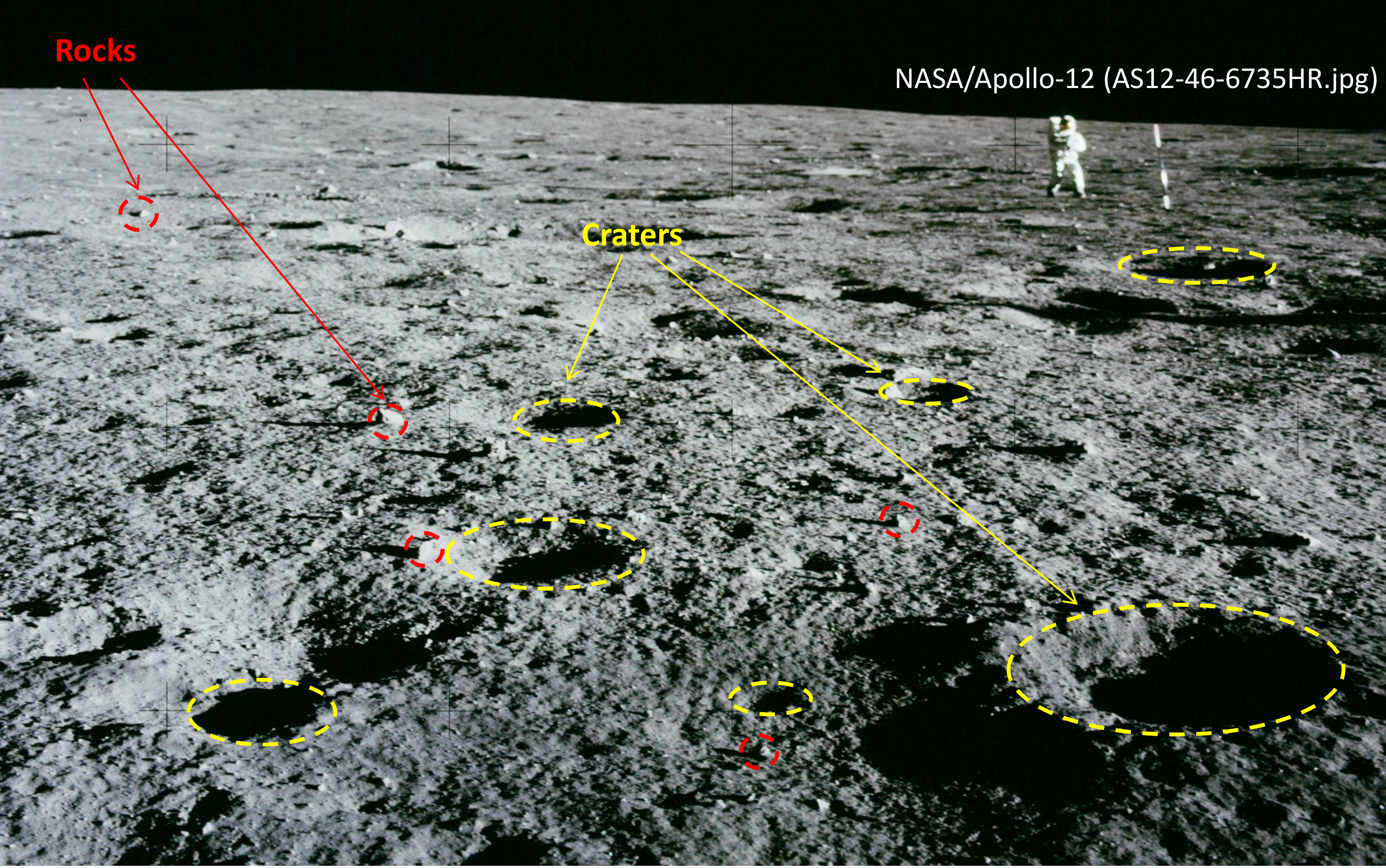


Fig. 1. The main factor determining the geomorphology of the lunar surface is impact craters. *Apollo* and *Surveyors* data show that the Moon is covered with numerous small craters (yellow ellipses) and rocks (red circles). VIPER imagery from navigation cameras enable to create a catalog of such craters and rocks.

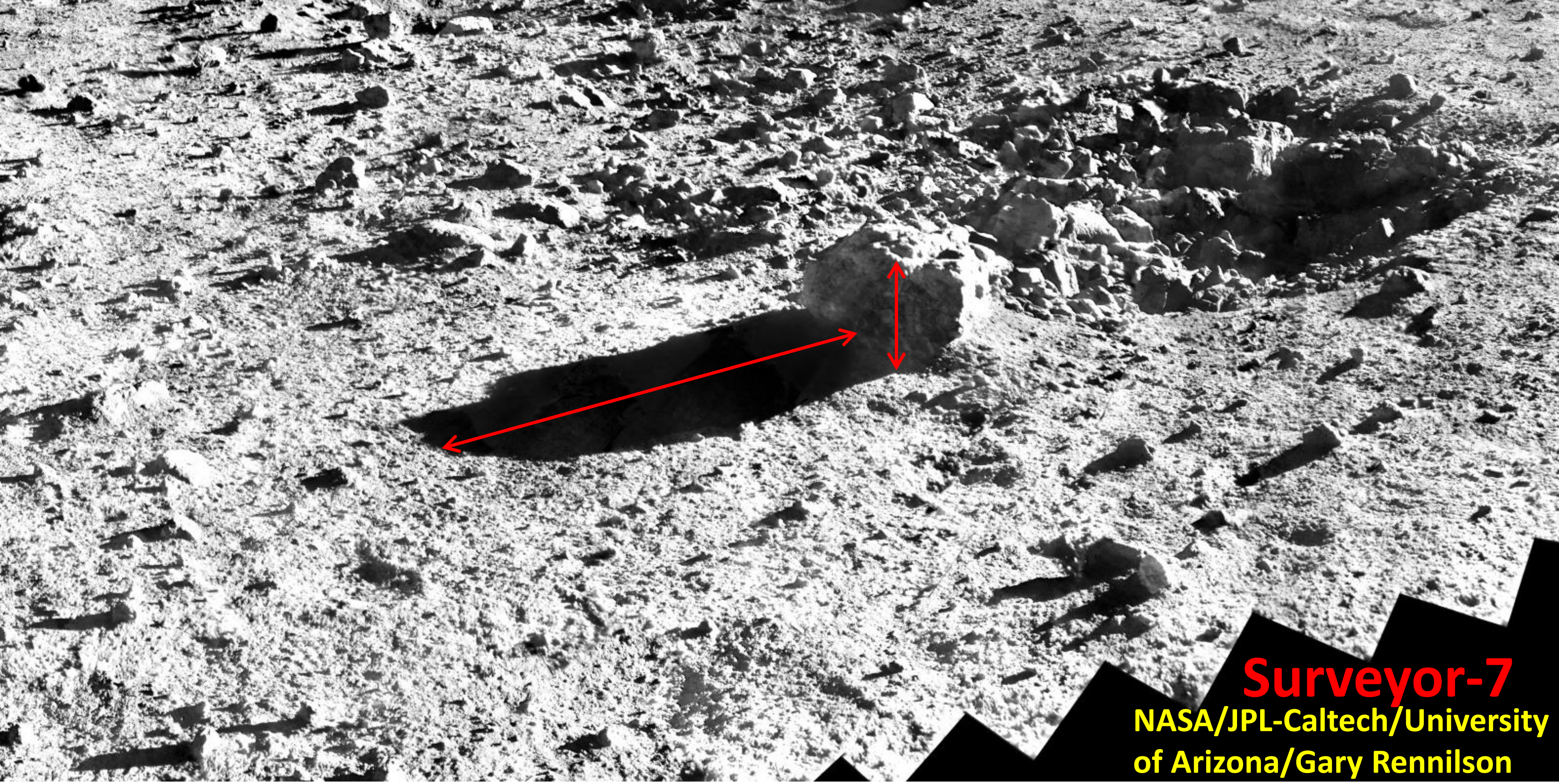


Fig. 2. Craters and rocks contain important information about the following:

1. The geological age of the area, which provides important constraints for models of the distribution of volatiles under the regolith layer in different regions of the lunar surface.

2. The lower layers of the lunar regolith, which are opened upon impact. Thus, craters represent numerous natural pits that carry valuable information about the surface layers of lunar regolith and ice.

3. A distribution of small meteorites bombarding the surface of the Moon. Even a small meteoroid with a mass of 5 kg can excavate a ~10 m crater, hurling 75 tons of lunar regolith and rock on ballistic trajectories above the Moon. An accurate assessment of the meteorite hazard on the Moon is critical for the safe implementation of the *Artemis* program (Elphic et al, 2014).

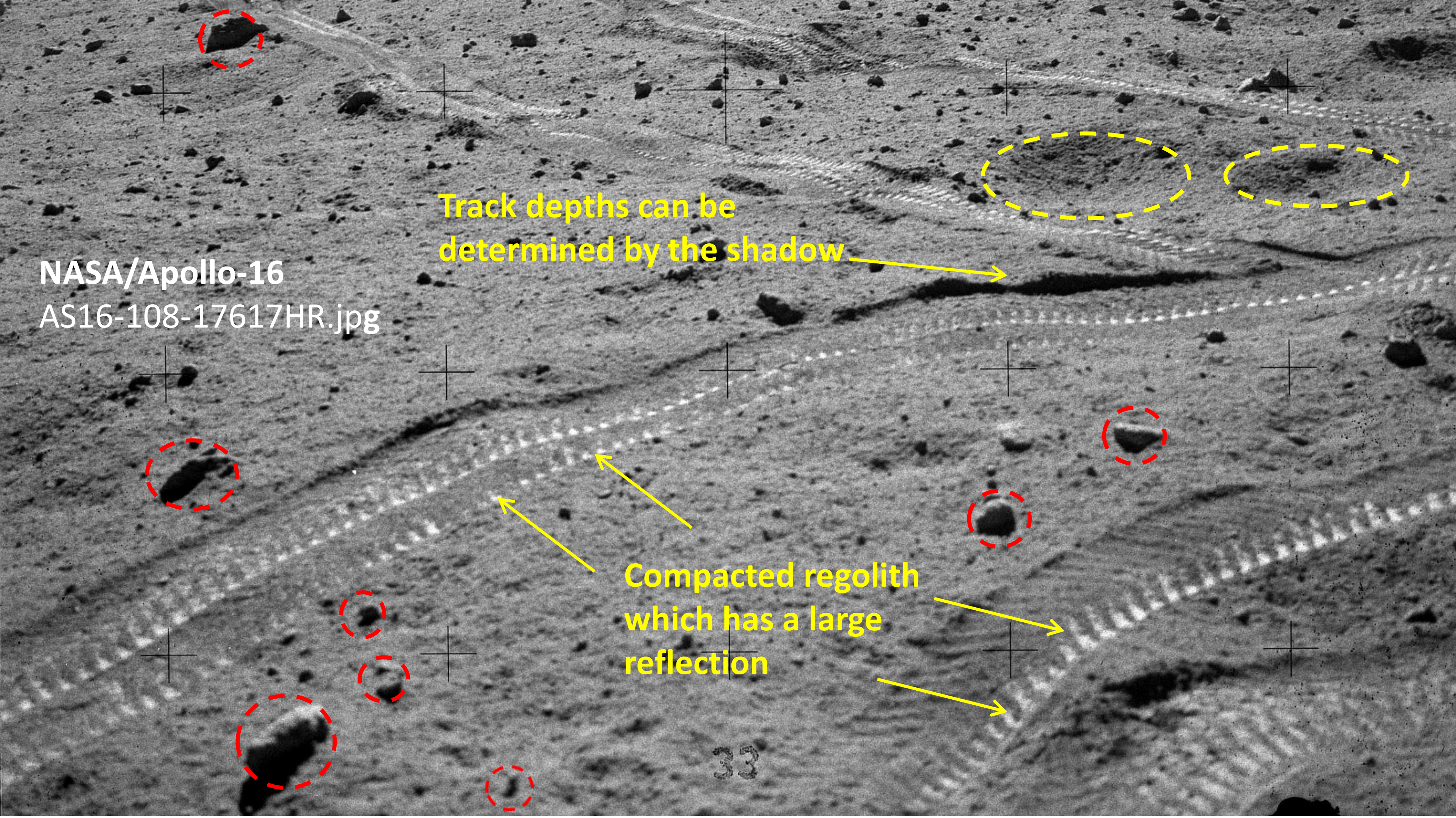


Fig. 3. The rover wheels are an important tool for probing the lunar and martian regolith. A depth of the wheel imprint and characteristics such as the darkening of the loosened regolith and an increase in the albedo of the compressed regolith (Figs. 3,4) are the key data to create a geotechnical model of the regolith, as well as a model of its optical properties.

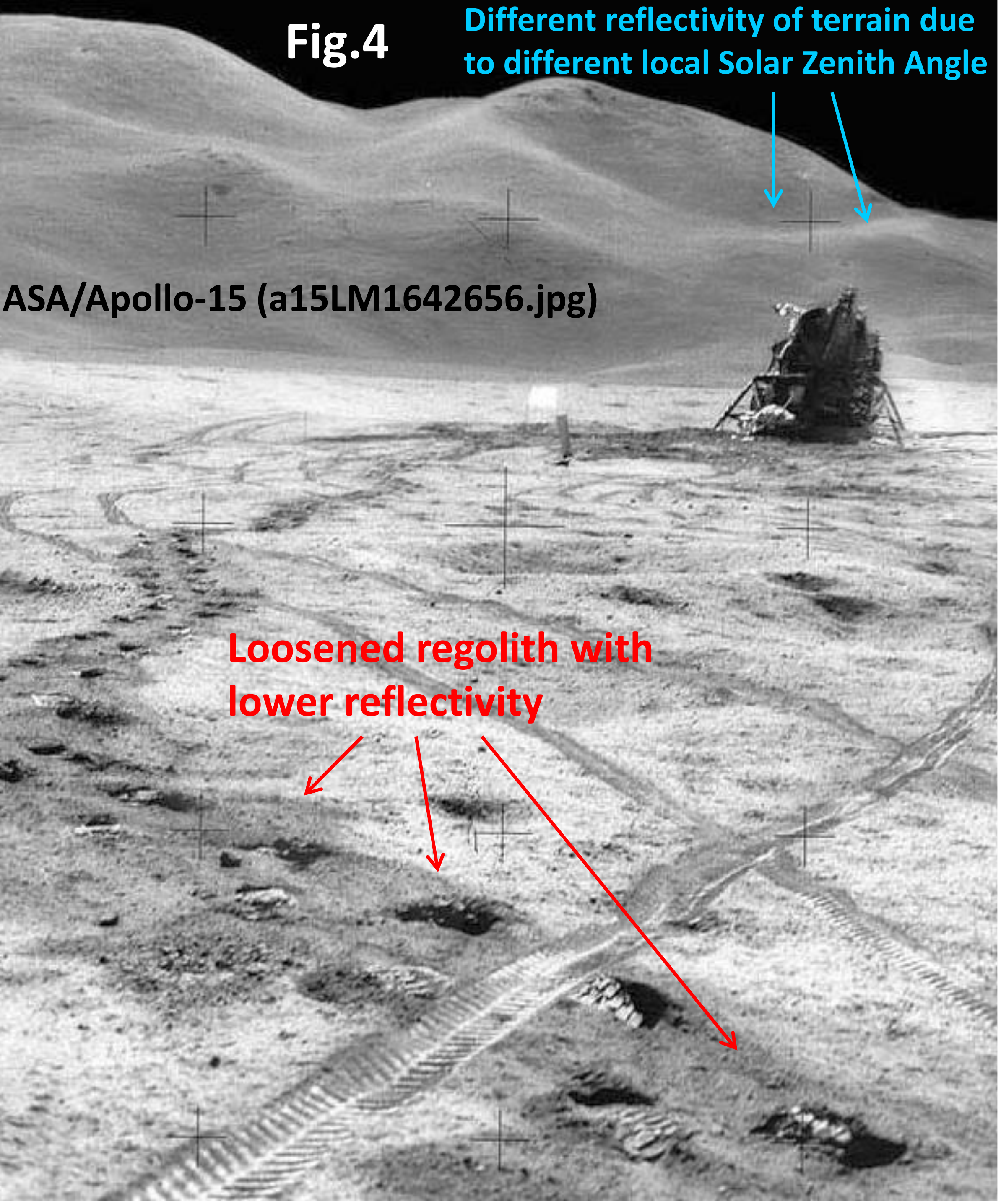


Fig.4
Different reflectivity of terrain due to different local Solar Zenith Angle
ASA/Apollo-15 (a15LM1642656.jpg)
Loosened regolith with lower reflectivity


Mars
NASA's
Curiosity
02/09/2014
PIA17944_Mcam-SOL538-WB.jpg

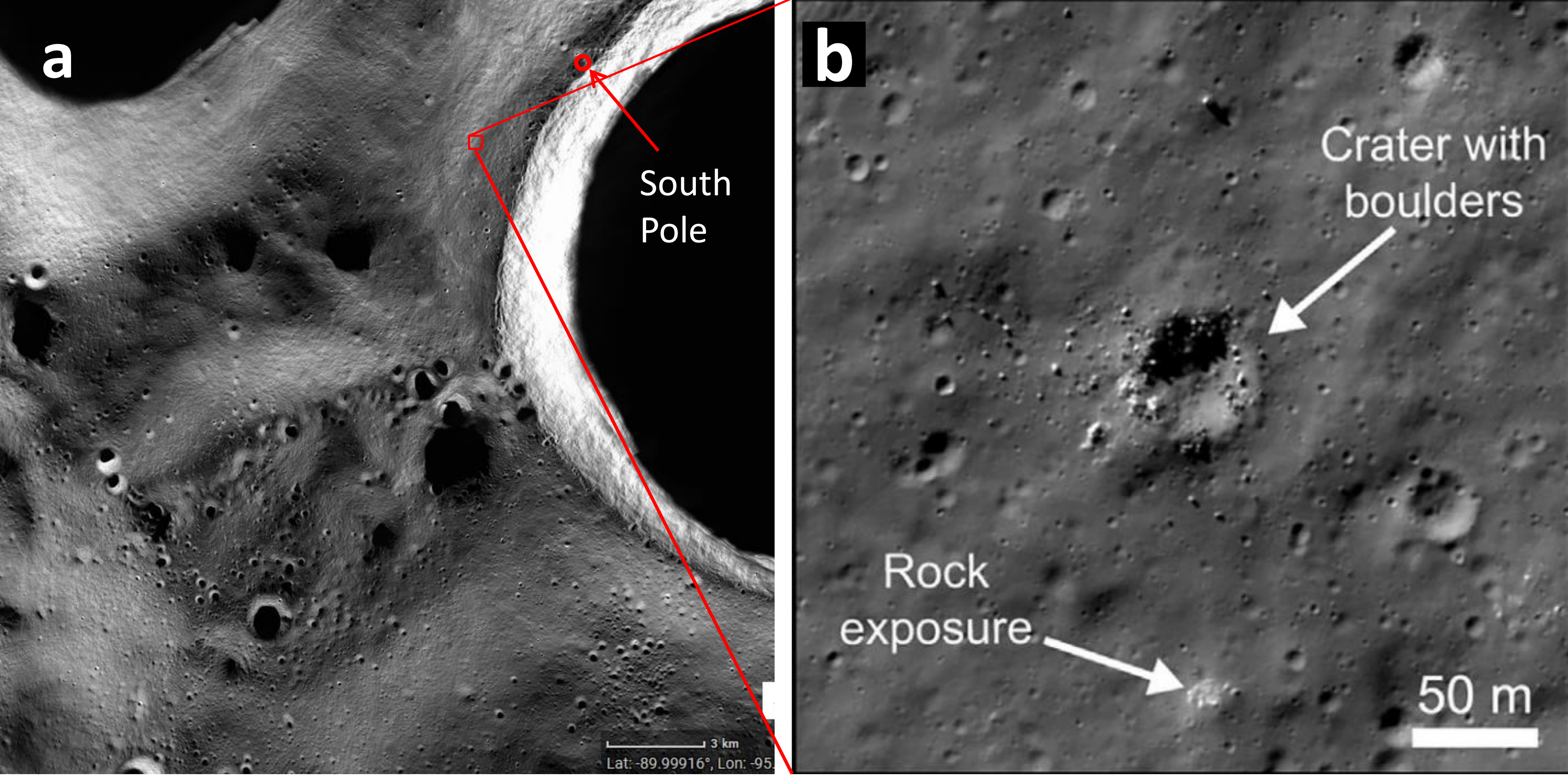


Fig.5. (a) Shackleton Crater, 21 km in size, at the rim of which is the Moon's South Pole. (b) (from Gawronska et al, 2020) shows a 300x300 meter section of the lunar surface around 89.914°S and 122.823°W. There are 20 craters with a diameter D from 10 to 50 meters, and ~1400 craters between 1 to 10 meters in diameter. The number of craters less than 1 meter in this area should be 10-100 times larger. The specific concentration for craters with D > 1 m can be estimated at ~ 10^4 per sq. km and for craters with D < 1 m - at ~10^5-10^6 per sq. km. If photographs from the rover's navigation cameras allow us to analyze a strip 10-20 meters wide, then from photographs taken along a 10-km route (Colaprete et al, PIP VIPER, 2021), we can compile a catalog of ~ 10^4-10^5 craters.

Imagery on Figs 5,6,8,9: NASA/MOONTrek (https://trek.nasa.gov/moon/)

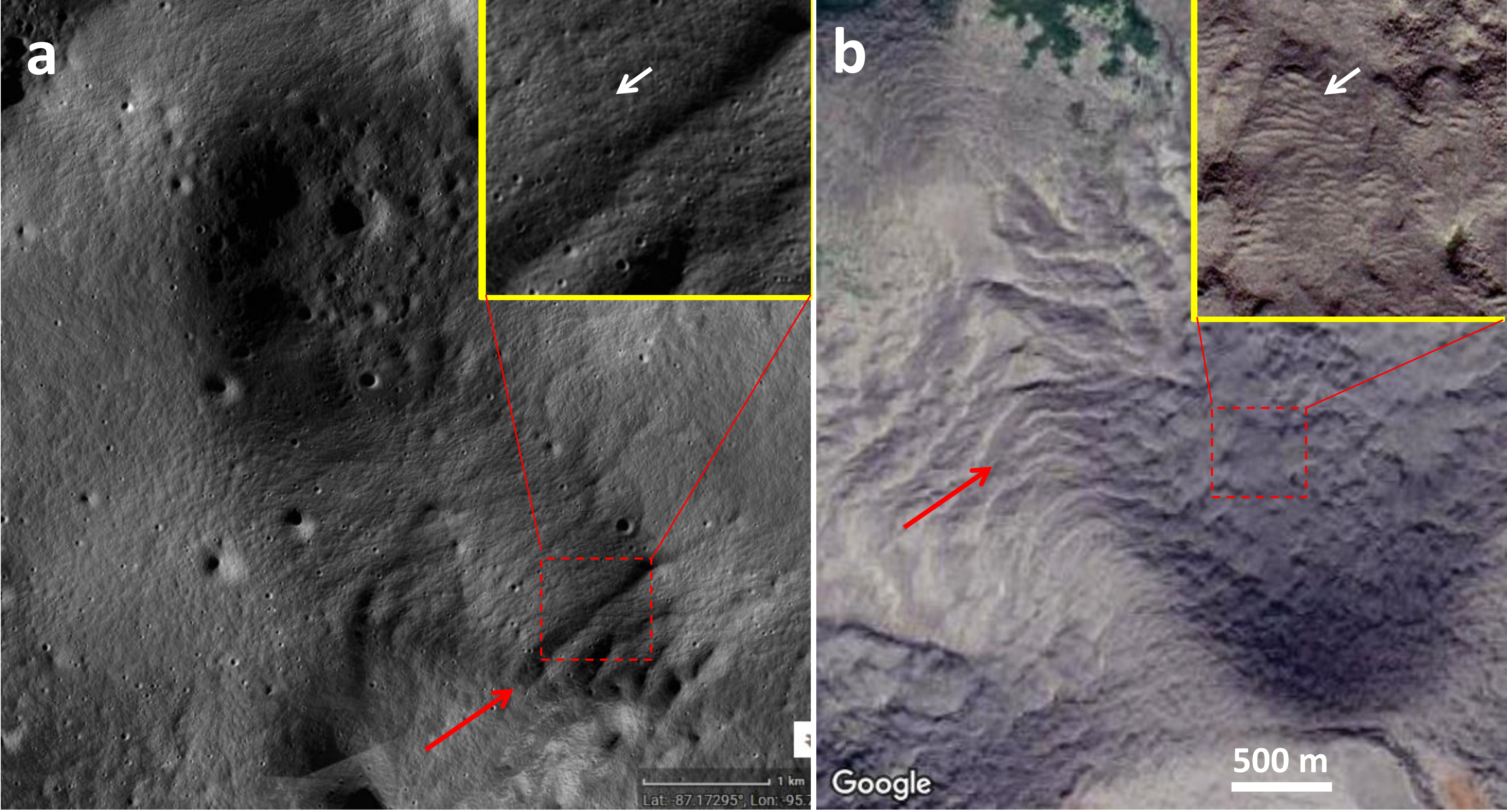


Fig.6. The concentration of water ice in the regolith at the LCROSS impact site (Cabeos crater, near 85°S) is estimated to be 5.6% by mass (Colaprete et al, 2010). The presence of a layer of permafrost under the lunar surface can change the shape of craters, as seen on Mars in its permafrost zone (Fig.9e). Indeed, near some craters in the region of the Moon's South Pole, traces of landslides are visible with various scales of structures (a). This is typical for landslides in the regions of the Earth's permafrost (b). Thus, the shape and other characteristics of craters in regions of the lunar poles may differ from the usual shape of craters in the mid- and low-latitude regions where the *Apollo* expeditions worked. If the Moon's South Pole has underground deposits of water ice and other volatiles, then the bottom of many craters can be expected to reach this layer.

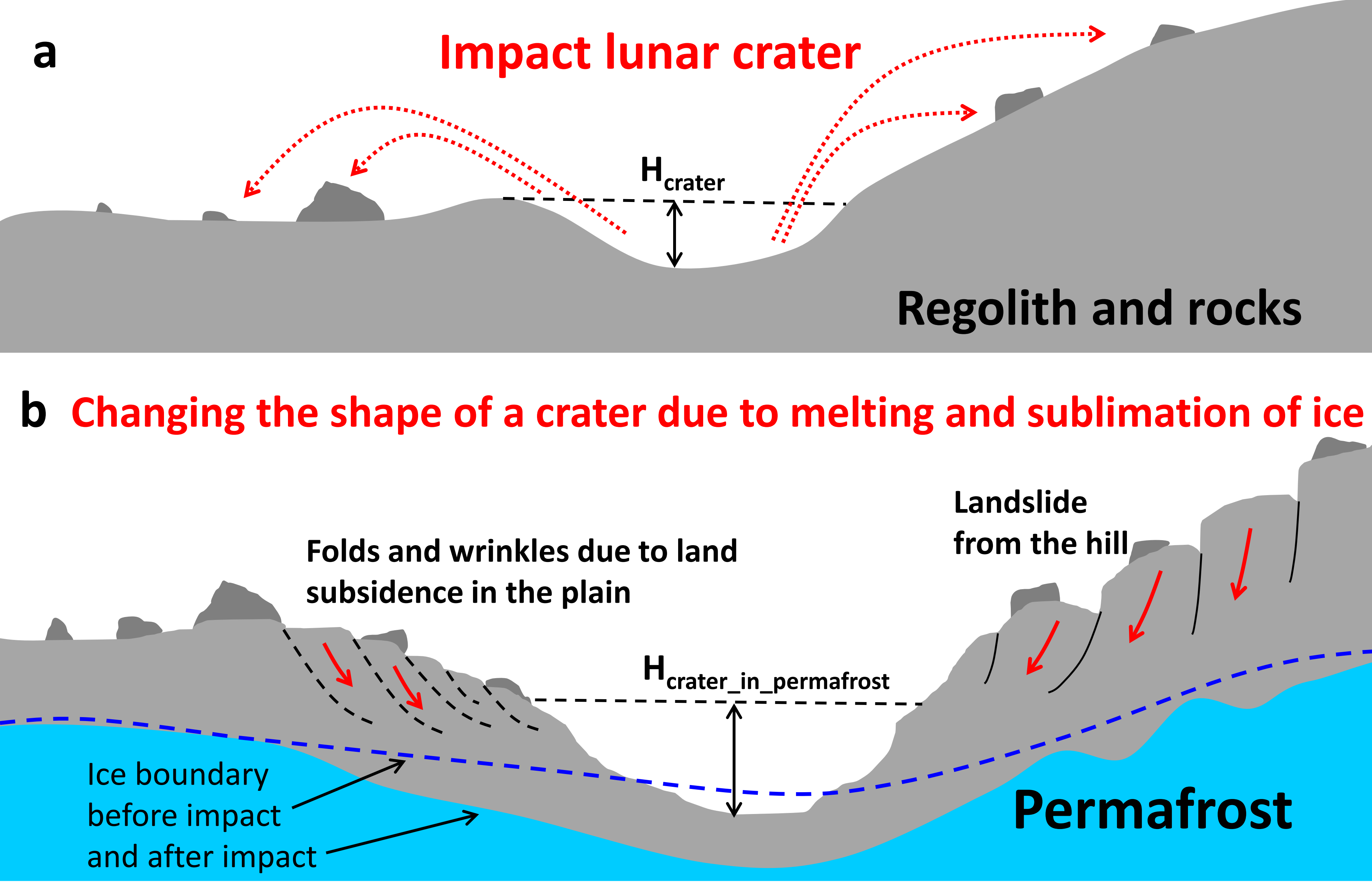


Fig.7. A presence of a significant amount of volatiles in the impact zone will cause a formation of the additional gas cloud. It is known that an air wave promotes the ejection of regolith from the impact zone. We anticipate that craters in the region of the Moon's South Pole may have a number of specific features.

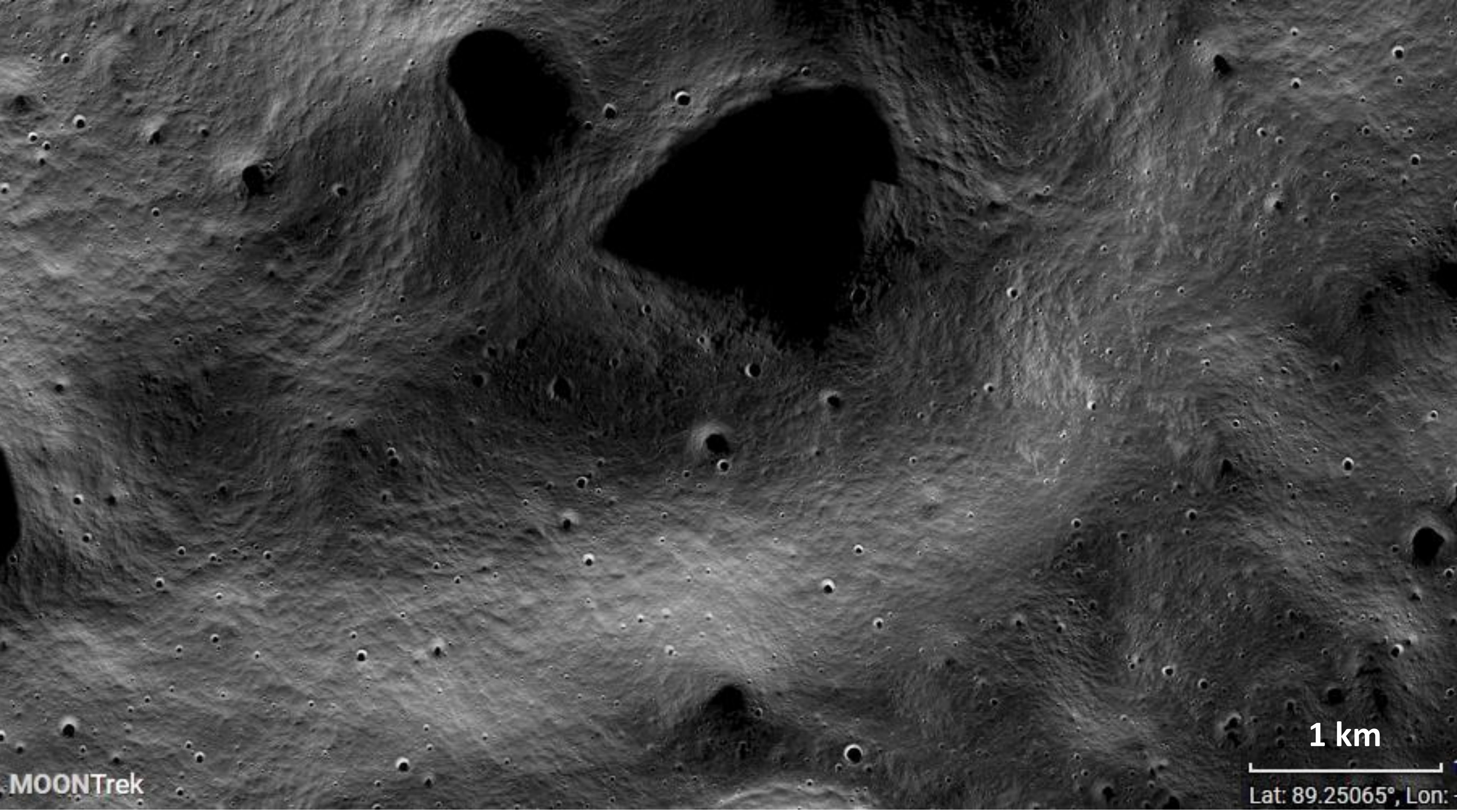


Fig.8. Analysis of photographs of the polar regions shows that small craters near the poles of the Moon are often distinguished by the following features (Figs. 8-9):

1. They have a smoother shape and the area around them has a characteristic pattern (Fig.8);

2. Outside the craters, landslides and cracks are visible (9a);

3. Patterned ground in and around the crater is often observed (9b,c);

4. On the inner slope, layers or steps are often visible (Fig.9d).

These features are characteristic of martian craters in the permafrost zone (crater Badger, 734 m, see Fig 9e, NASA/JPL/UArizona), as well as similar zones on Earth (see Fig 6b). We hypothesize that these features of lunar craters in the regions of the South and North Poles of the Moon are associated with the presence of permafrost.

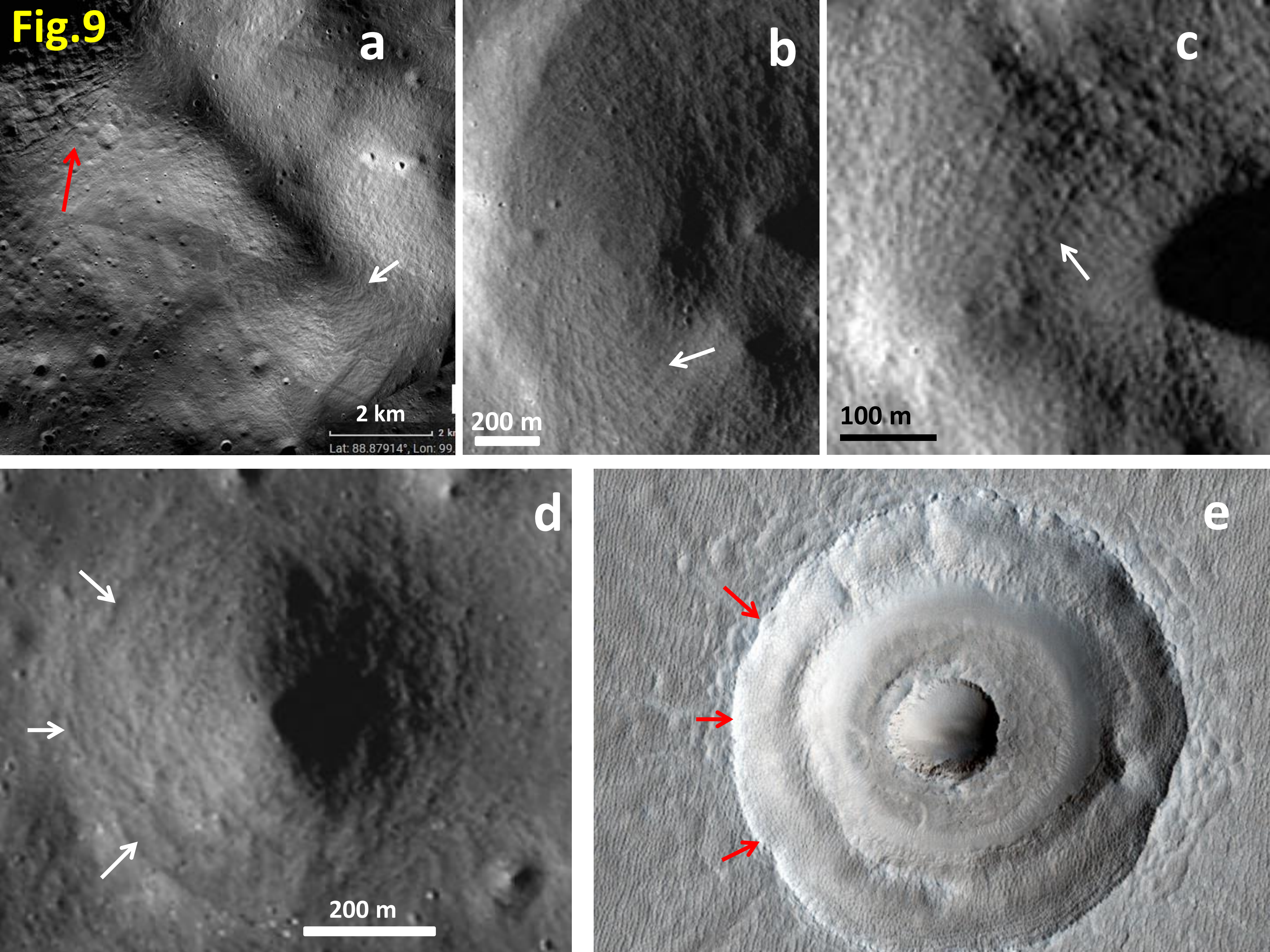


Fig.9
a
2 km
2 km
Lat: 88.87914°, Lon: 99.
b
200 m
c
100 m
d
200 m
e

Gorkavyi, N., Snyder, J., Lashlee J.D. “A Survey of Terrain Modeling Technologies and Techniques” ERDC/TEC TR-08-2, September 2007

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1. A large number of high quality digital photos with a sufficient resolution for the South Pole of the Moon, which is a key region for the landing of manned expeditions.
2. Images of the rover track enable using VIPER wheels as a tool for study of the regolith.
3. The low position of the Sun, which generates long shadows (Fig.4), creates favorable conditions for object recognition algorithm (ORA) analysis. Long shadows also create certain difficulties, masking some of the rocks and craters. We will overcome this issue by using photographs of specific scenes from different view angles when available.

Object recognition algorithms will be used to process images from VIPER cameras. Similar techniques have been used to extract large lunar and martian craters. The author has extensive experience in automatic image processing and cataloging of thousands of extracted objects, e.g. in the New Mexico desert. Each image from the VIPER mission will be processed to extract objects such as rocks, craters, rover tracks, any terrain details and flat terrain. Figure 10 shows a block diagram of image processing.

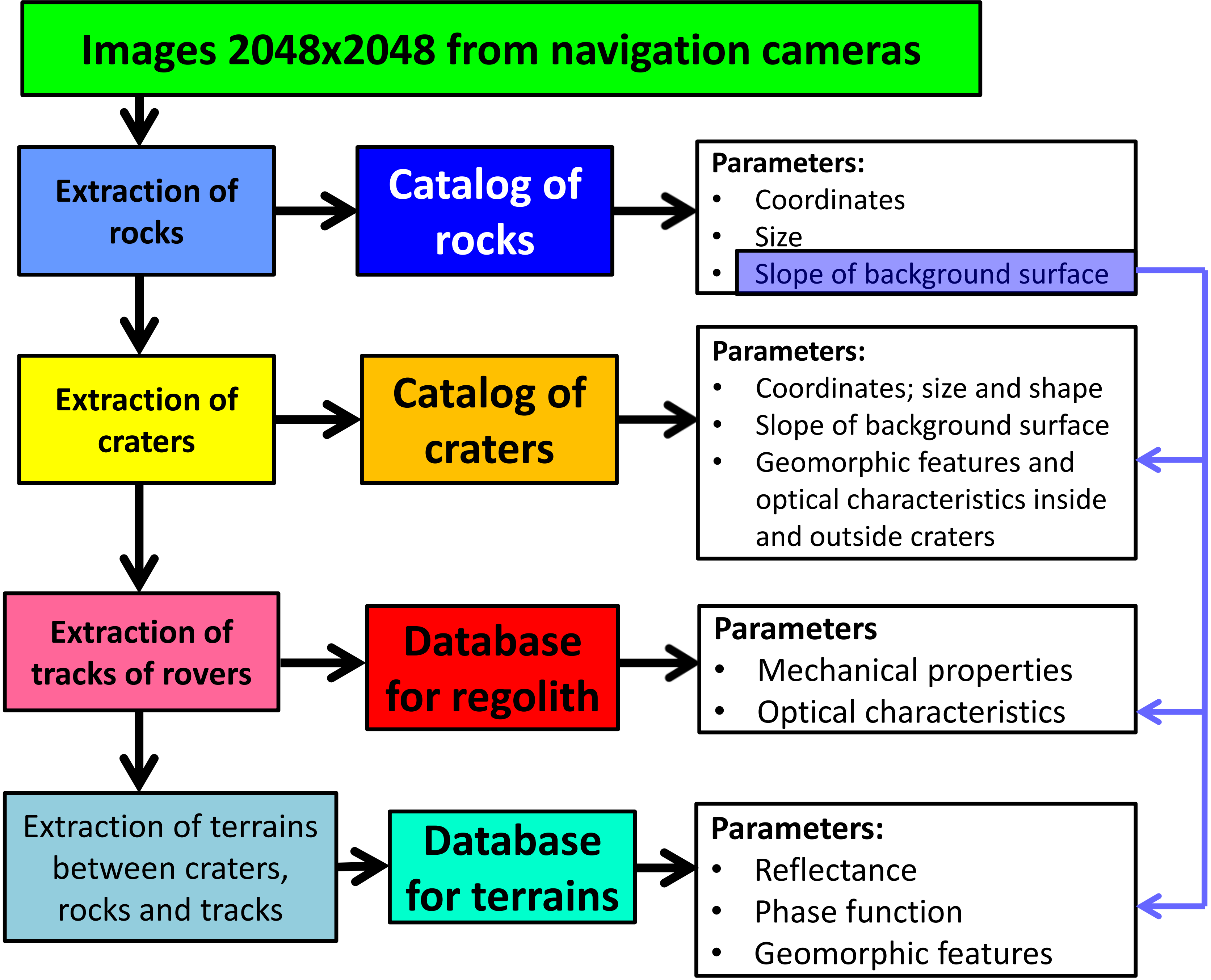

Fig.10 Block diagram of VIPER image processing