The Search for a Solar Record in Lunar Paleoregolith through Numerical Modeling and Analog Experiments

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1. Introduction

Solar and galactic cosmic ray particles were found in regolith core samples brought back during the Apollo missions. These cores provide important information about the regolith's recent exposure history, but due to continuous bombardment at the lunar surface, they do not contain information about past exposure to space [1-4]. Discovery of datable paleoregoliths and extraction of extra-lunar volatiles would give us insight into the behavior of the early Sun [1,5].Regolith deposits that have been covered by a lava flow would be protected from further bombardment and the lava would provide samples to isotopically date, revealing the exposure age of the deposit [1,6,7]. However, the lava would have heated the upper portions of the regolith, volatilizing many of the extra-lunar particles and destroying the record of solar history to a certain depth [8]. We have completed numerical models simulating this heat transfer to determine the depths beneath which volatiles will be preserved [9]. Here we take the first steps toward investigating the depths to which a regolith deposit will be heated by overlying lava through a series of experiments.

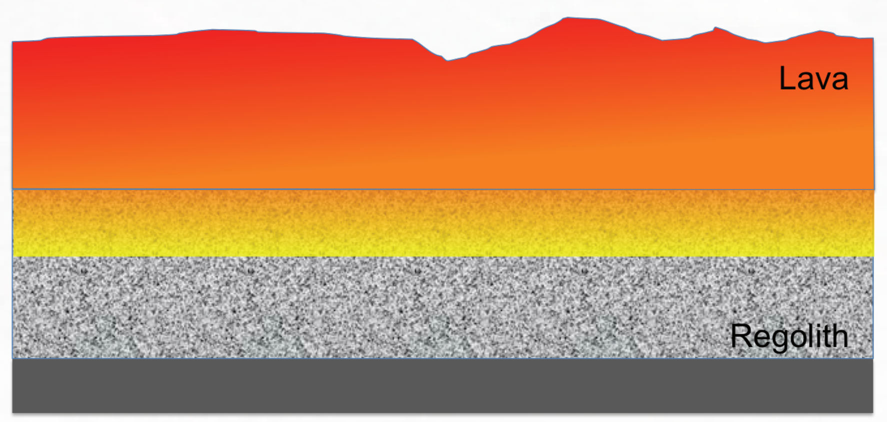


Figure 1 Paleoregoliths may be sheilded from continued bombardment by an overlying lava flow, however, the flow will heat the regolith, releasing volatiles.

Species	Temperature Range
H_2, He	300–700 °C (573–973 K)
CH_4, Ne, Ar	500–700 °C (773–973 K)
CO, CO_2, N_2, Xe	>700 °C (>973 K)

Figure 2 Temperature ranges over which primary solar and galactic species will volatilize [10].

2. Modeling the Experiment

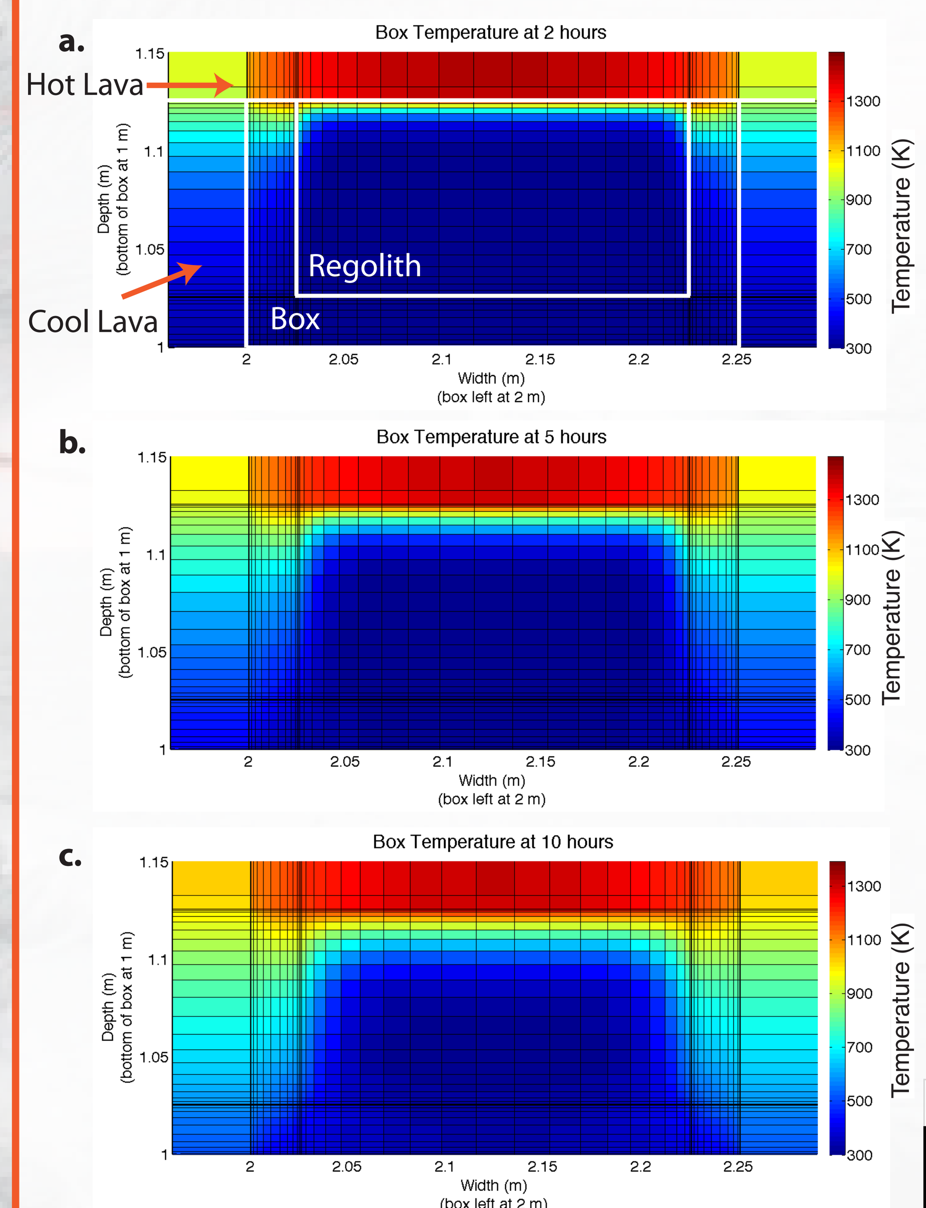


Figure 3 Simulated cross-sections of temperatures within box after emplacement of overlying lava flow. **a)** 2 hours after emplacement, **b)** 5 hours after emplacement, and **c)** 10 hours after emplacement

Before constructing a field device, we created a numerical model to simulate the heating of the proposed device over the anticipated duration of experiments (Figure 3). This allowed us to predict heating within the regolith in order to determine the optimal dimensions needed to minimize the size and maximize the potential for data collection.

PHOENICS (http://cham.co.uk), a fluid dynamics software program, was used to create the model. Simulation replicated the "Main Box" of the Field Device seen in Figure 6. The initial temperature of regolith, box, and underlying and surrounding lava was taken as 300 K, and 0.5 m of lava initially at 1500 K was emplaced at time = 0. Internal box dimensions are 20x20x10 cm. Box wall thickness 2.54 cm. The figures above show the temperature distribution with time after emplacement, a) 2 hours, b) 5 hours, and c) 10 hours.

Figure 4 is a summary of depths reached by pertinent isotherms at the center of the box with time after emplacement.

	Isotherm Depth (mm)		
Isotherm	**300°C**	**500°C**	**700°C**
Time			
2 hours	6	4	2
5 hours	17	11	7
10 hours	25	15	9

Figure 4 Depths reached by pertinent isotherms (see Figure 2) within regolith by heating from overlying lava.

3. Experimenting the Model I: Field

We have begun field trials of a device designed to measure the in situ conduction of heat from an active lava flow into lunar regolith simulant, GSC-1 [11]. Successful experiments will lead to validation of our numerical models predicting the depth to which extra-lunar volatiles can be found in paleoregoliths buried beneath lava flows on the Moon.

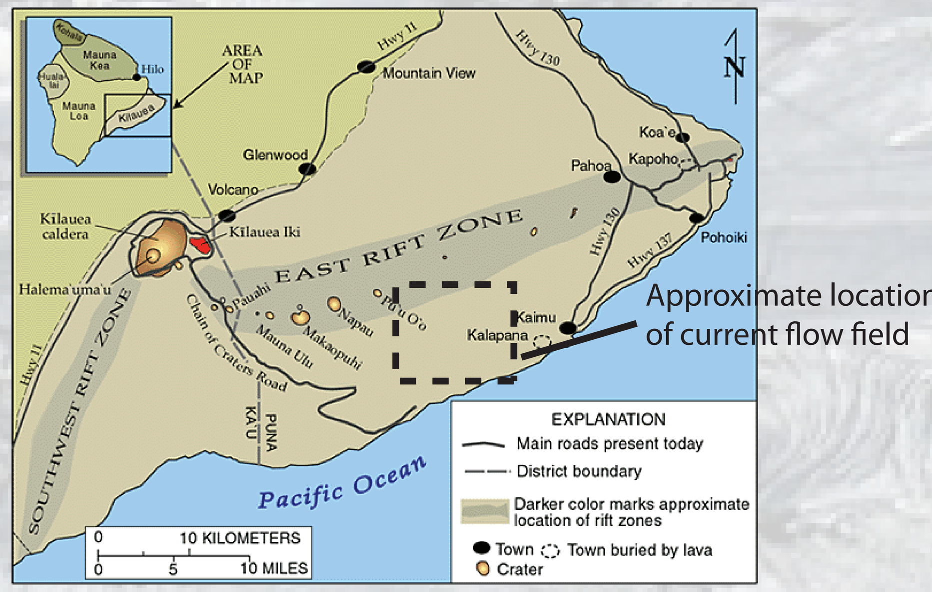


Figure 5 Location map indicating Kilauea Volcano on the island of Hawai'i. Pu`u `Ō`ō Crater can be seen near center of map [13].

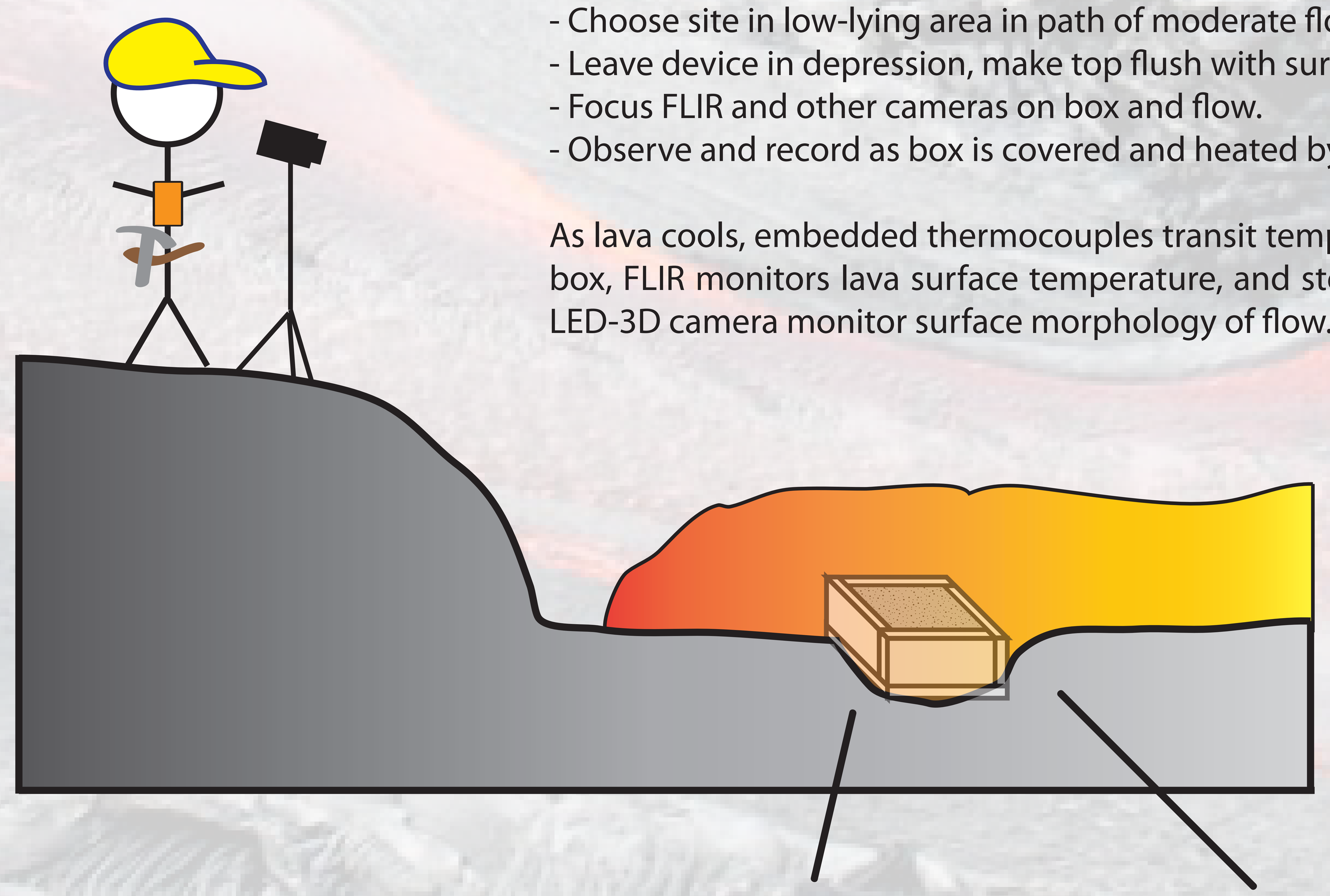
Location: Kilauea Volcano, HI

The Pu`u `Ō`ō eruption at Kilauea Volcano, HI has offered nearly continuous effusion of basaltic lava since 1983 [12]. Its flow fields are often used as analogs to basalt fields on the Moon and Mars. The short distance between the University of Hawaii at Manoa and Kilauea Volcano allows for timely undertaking of field excursions and natural collaborations with the Hawaiian Volcano Observatory (HVO).

Field Methods

- Choose site in low-lying area in path of moderate flow.
- Leave device in depression, make top flush with surrounding terrain.
- Focus FLIR and other cameras on box and flow.
- Observe and record as box is covered and heated by lava.

As lava cools, embedded thermocouples transit temperatures within box, FLIR monitors lava surface temperature, and stereo cameras or LED-3D camera monitor surface morphology of flow.



Field Device

Our experimental devices consist of boxes constructed from high-temperature calcium silicate insulation panels [14]. These are filled with regolith simulant (GSC-1) [10], embedded with a vertical thermocouple array, and deployed ahead of an advancing lava flow. The vertical temperature profile in the simulant is then recorded as the box is inundated by lava.

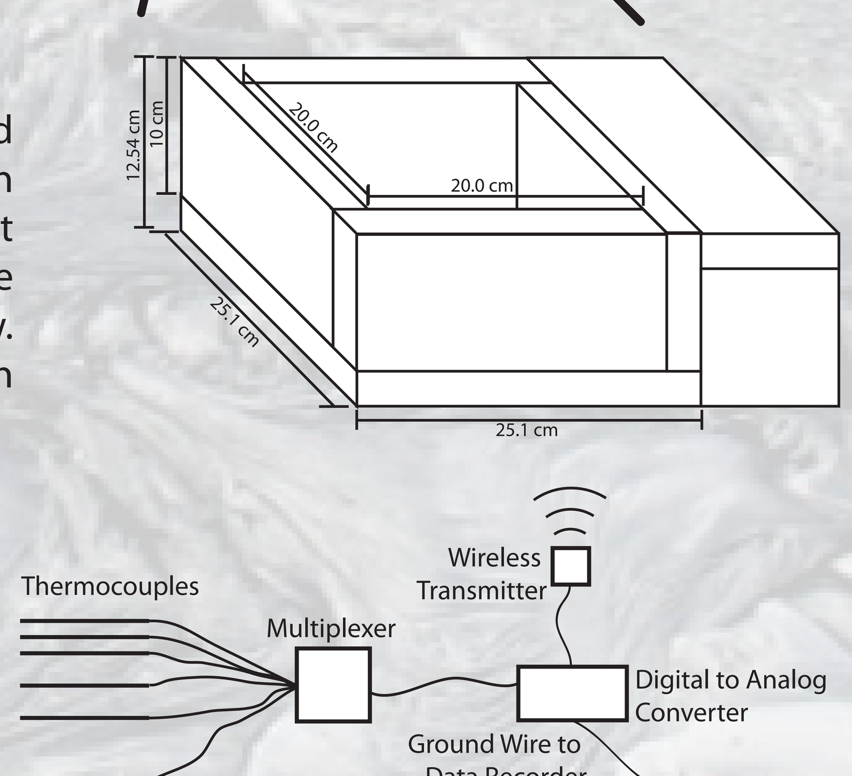


Figure 6 Diagram of field device **a)** Main box will be filled with regolith simulant and embedded with thermocouples. Annex will house electronics and shield them from excess heat. **b)** Device electronics. Thermocouple data is combined to one channel by multiplexer, which sends signal to converter. Data istransmitted through hardwire and wireless signal to data recorder.

4. Experimenting the Model II: Laboratory

We have also designed a set of complementary laboratory experiments using the GSC-1 [10] regolith simulant and melted Kilauea basalt as a lunar lava analog. A device similar to the field device will be built to contain the simulant and molten basalt. Thermocouples will be embedded throughout to monitor internal temperature. External temperature will be monitored by FLIR. Laboratory experiments will provide increased control over the environment for a more accurate measurement of heat conduction through the regolith simulant.

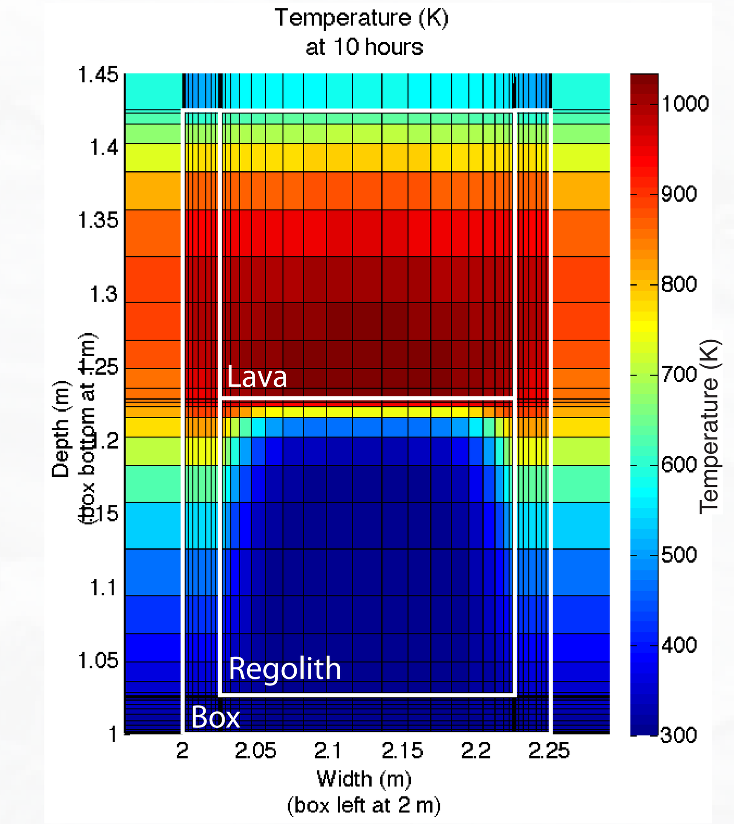


Figure 8 (above) Simulated cross-section of temperature within labaoratory box 10 hours after emplacement of overlying lava flow. Internal box dimensions are 20x20x40 cm. Box wall thickness 2.54 cm. 20 cm of lava (initially at 1500 K) emplaced on top of 20 cm of regolith (initially at 300 K).

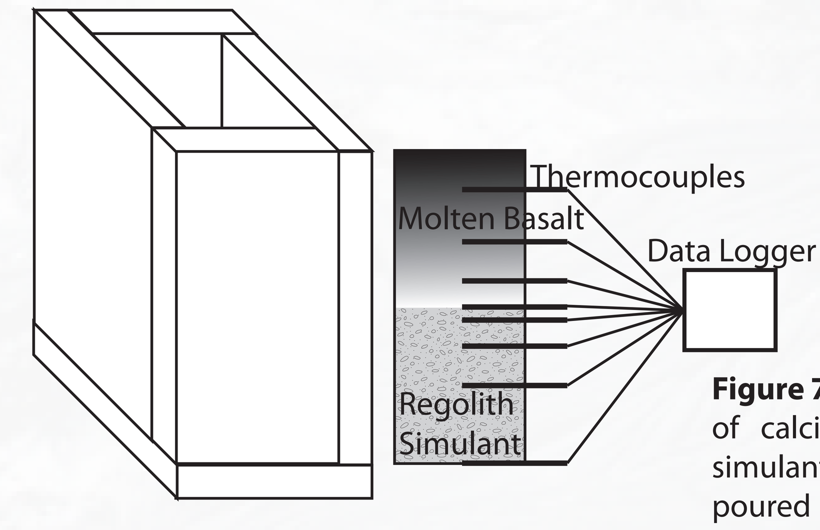


Figure 7 (left) Diagram of laboratory device. Device will be constructed of calcium silicate insulation, partially filled with lunar regolith simulant, and embedded with thermocouples. Molten basalt will be poured on top of the simulant and temperatures monitored as the system cools.

5. Application to Lunar Surface

Along with numerical modeling, the series of experiments described here will allow us to accurately determine the depths lava flows on the Moon would have heated volatile-rich paleoregoliths. We have been using the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) [15] data to locate areas on the lunar surface that have alternating layers of paleoregoliths and lava flows. Lunar Orbiter Laser Altimeter (LOLA) [NASA/GSFC] data can then be used to measure the thicknesses of individual lava flows and possibly regolith deposits between them. Flow thicknesses and estimated ages will be used to determine the likelihood of volatiles preservation at these locations

Recommendations will be made for exploration of key sites during future missions to the Moon. Discovery and extraction of paleoregoliths containing ancient solar wind, solar flare, and galactic cosmic ray particles would provide vital insight about the history and future of our solar system.

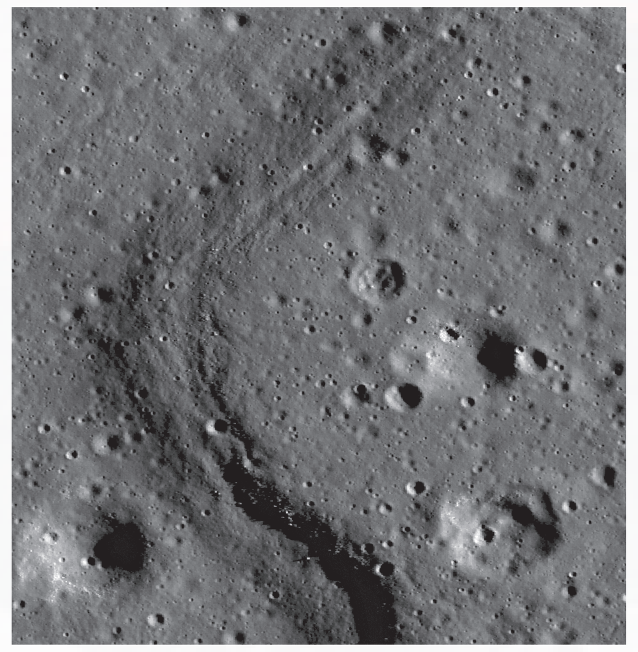


Figure 9 Layered boundary between two flow units on the floor of Apollo Basin. Layers imply that the flow unit is composed of several thin lava flows. Image is 880 mwide, and north is up. NAC M114953774LE [15].

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References
[1] Spudis, P.D. (1996) The Once and Future Moon, Smith. Inst. Press. [2] Crawfard, I. A. (2004) Space Policy, 20, 91-97. [3] National Research Council (2006) The Scientific Context for Exploration of the Moon. [4] McKay, D.S., et al. (1991) in: The Lunar Sourcebook, 285-356. [5] Crawford I.A., et al. (2010), Earth, Moon, & Planets, 107, 75-85.[6] McKay, D. S., et al. (1989) LPSC XIX, 19-41. [7] Spudis, P.D., & Taylor, G. J. (2009) LPSC XL, abs# 1039. [8] Taylor, G.J., et al. (1991) in: The Lunar Sourcebook, 183-284. [9] Fagents, S. A., et al. (2010), Icarus, 207, 595-604. [10] Simoneit, B.R., et al. (1973), Proc. LSC II, 1635-1650. [11] Taylor, P.T., et al. (2008) LPSC 39, abs#2054. [12] Hawaiian Volcano Observatory, hvo.wr.usgs.gov[13] J. Johnson (2000) HVO. [14] McMaster-Carr, www.mcmaster.com. [15] NASA/GSFC/Arizona State University.