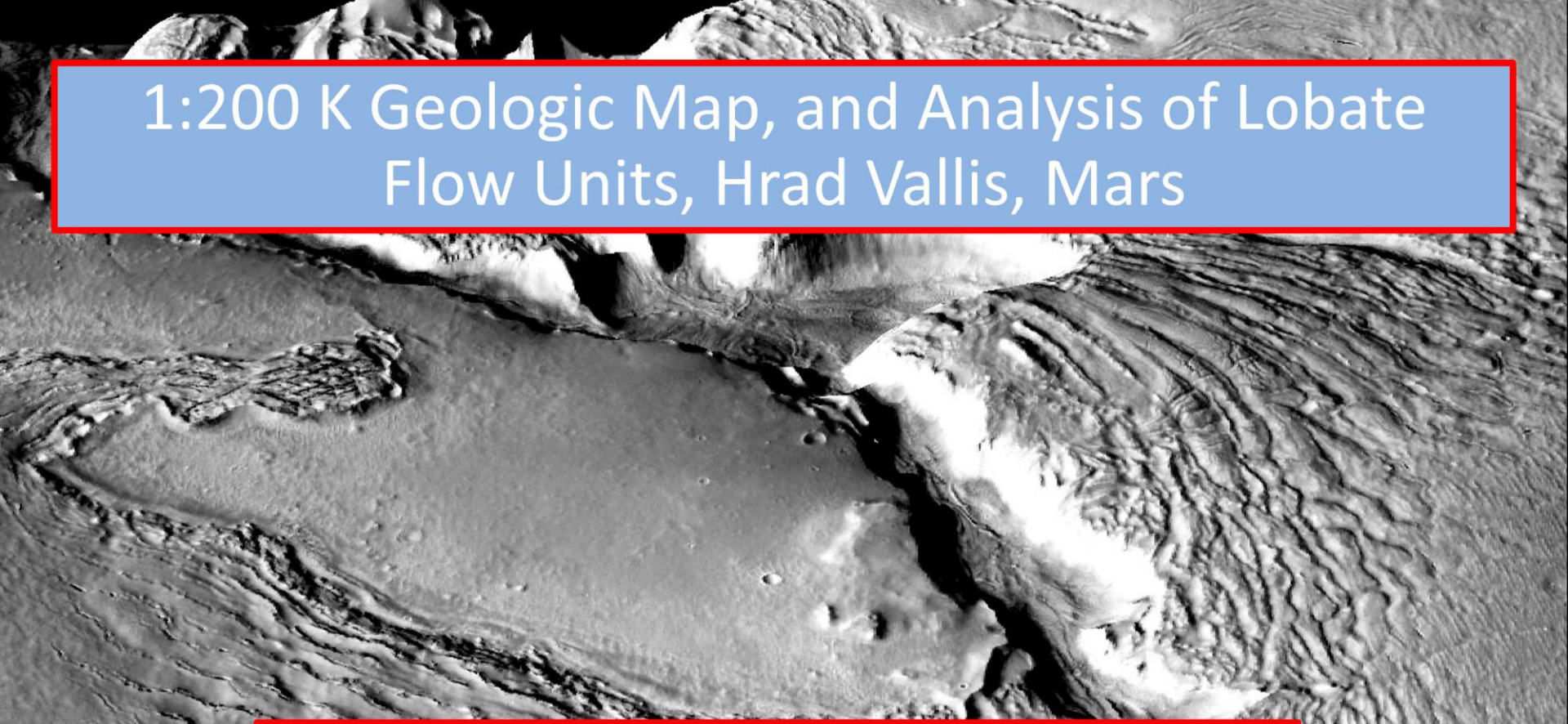
1:200 K Geologic Map, and Analysis of Lobate Flow Units, Hrad Vallis, Mars



Christopher W. Hamilton, Univ. Arizona
Peter J. Mouginis-Mark, Univ. Hawaii
Michael M. Sori, Stephen P. Schedit, and Ali M. Bramson, Univ. Arizona

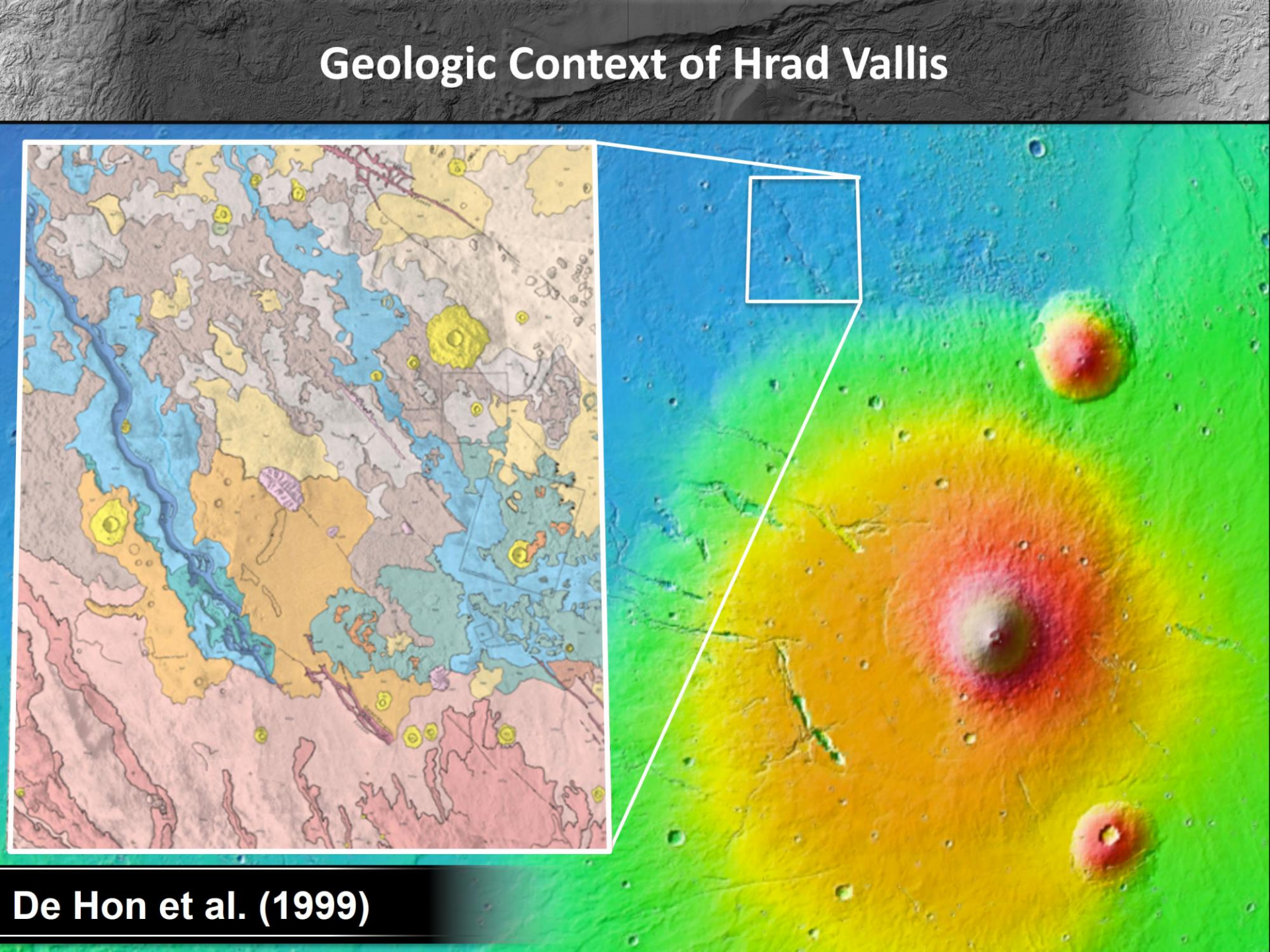
NASA

UA SCIENCE
LUNAR & PLANETARY LABORATORY

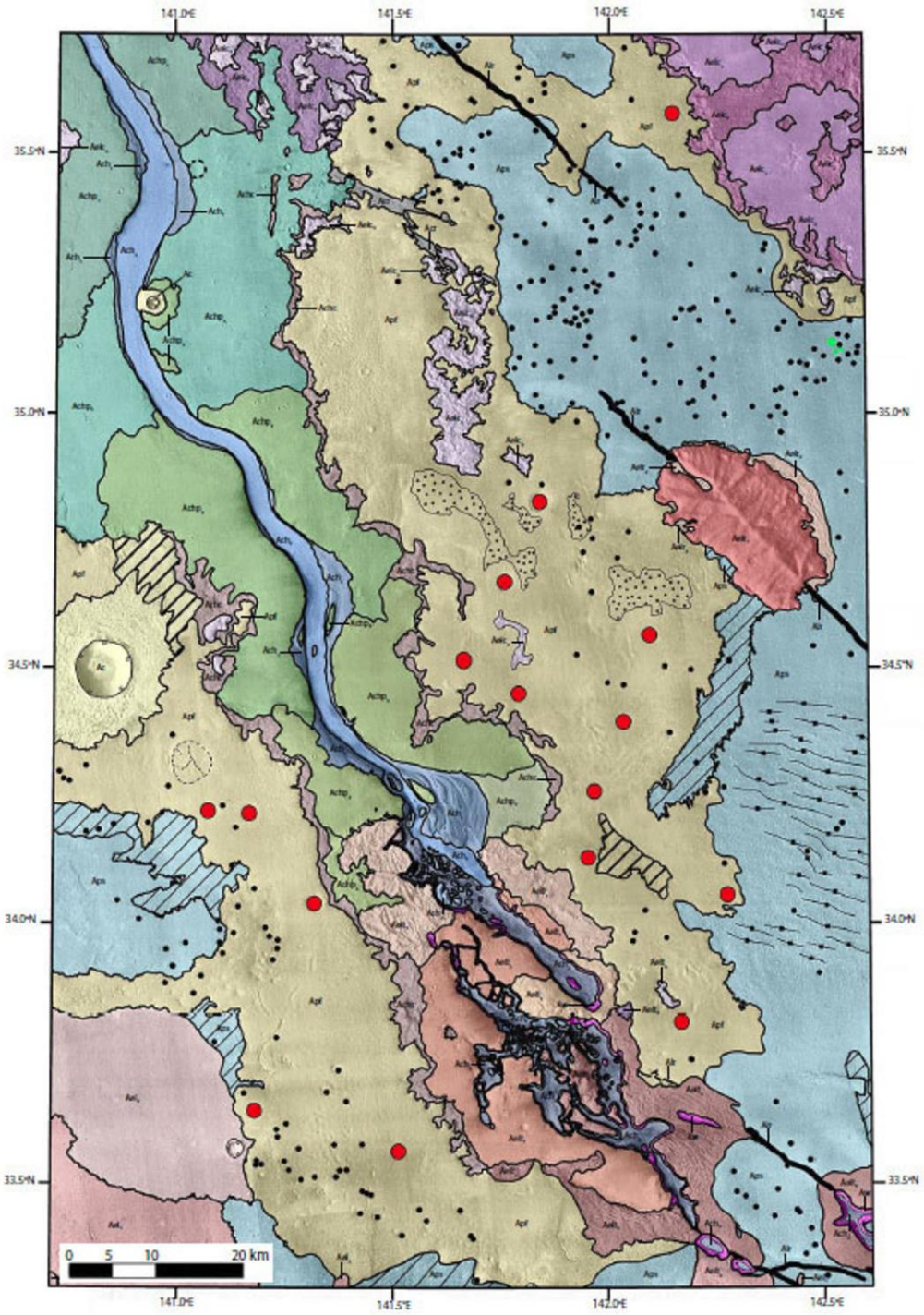
UNIVERSITY OF HAWAI'I

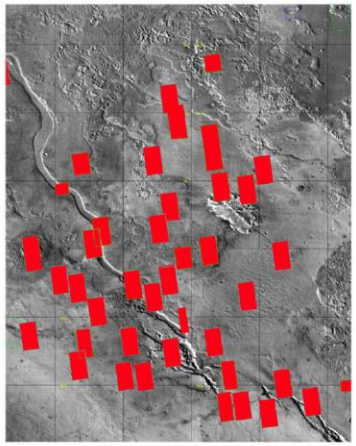
HIGP Hawai'i Institute of Geophysics & Planetology

Geologic Context of Hrad Vallis

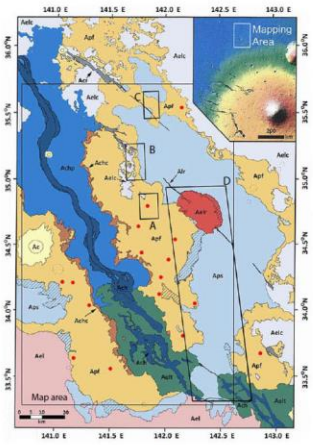


De Hon et al. (1999)





HiRISE image coverage of map area, as of May 2017

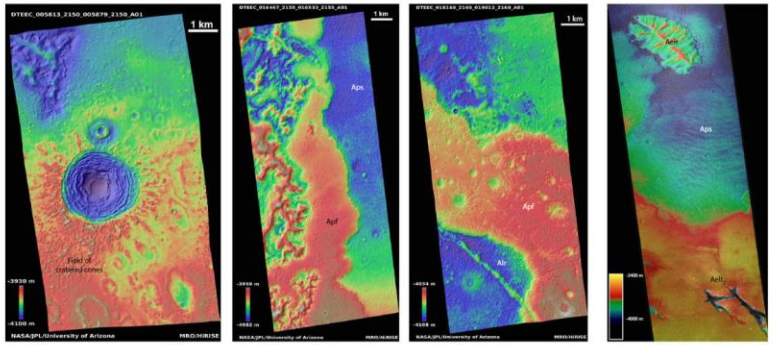


Broader geologic context of map area. Boxes indicate coverage of DEMs shown below.

Correlation of Map Units

Channel Materials	Hrad Vallis Materials	Lowland Terrain Materials
Ach_3, Ach_2, $Achh_1$ $Aelt_3$, $Alet_2$, $Aelt_1$ $Achp_3$, $Achp_2$, $Achp_1$, $Achp_0$, $Achp_2$	Apf Alr Aelr Aps	Achc Acr $Aelc_2$, $Aelc_1$, $Aelc_2$ Ael_2, Ael_1, Ael_1

Ac	Fractured crater	Topographic depression	Ridge crest
Disrupted terrain	Crater rim	Mound	Field of cratered cones
	Buried crater		



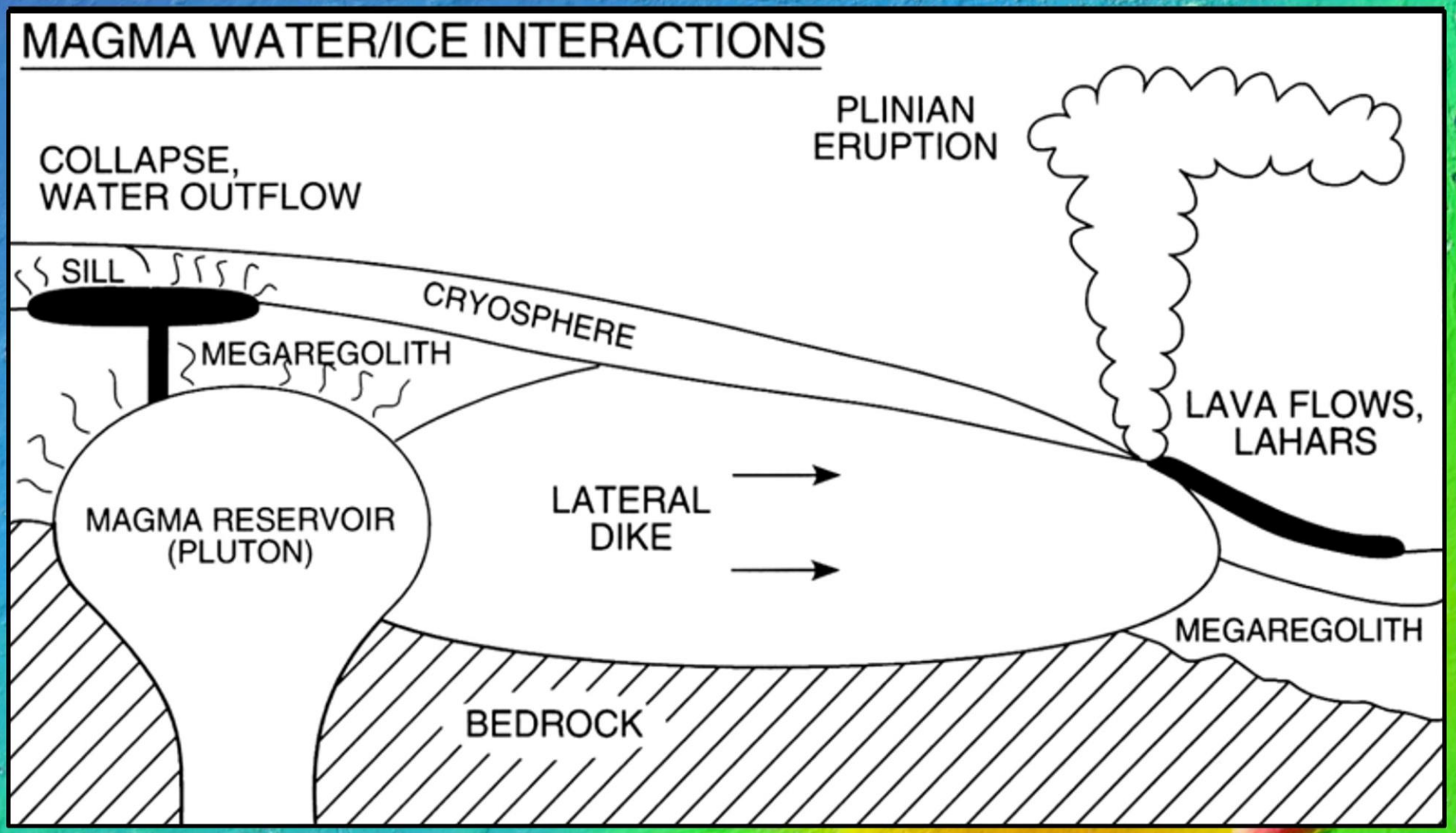
A. DEM of potential lava pit. See map at top right for locations

B. DEM of potential inflated flow, unit Apf

C. DEM of flow (Apf) with lava pits and dike (Alr)

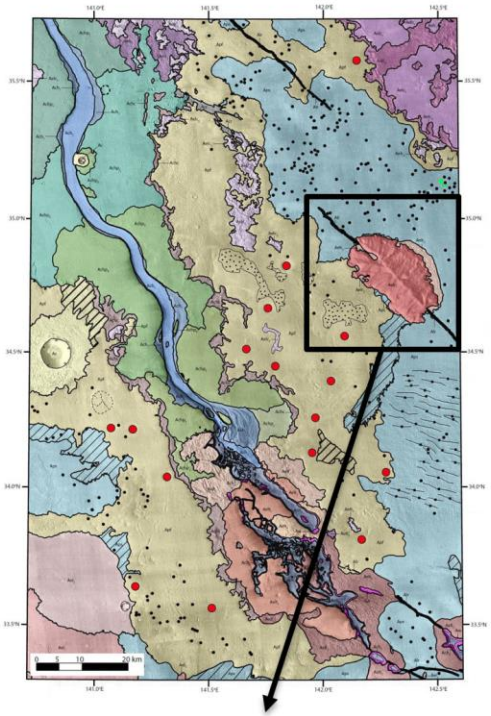
D. CTX DEM of flow (Aps) and Galaxias Mons (Aelr)

Geologic Context of Hrad Vallis



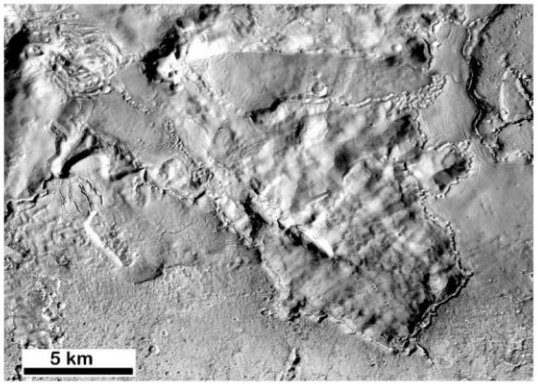
Smellie and Chapman (2002)

Recent Related Publication

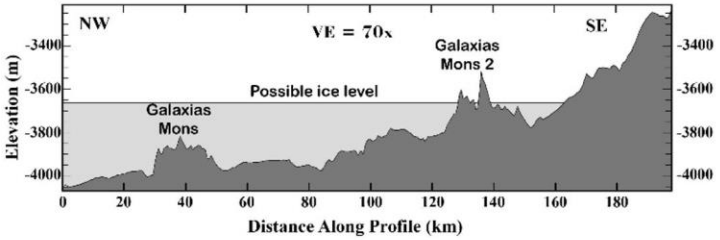


- Mouginis-Mark and Wilson (2016). Possible sub-glacial eruptions in the Galaxias Quadrangle Mars. *Icarus* 267, 68 – 85.
- Good evidence that this area was once partially covered by ice - based upon current topography and flow paths.
- Galaxias Mons is of intermediate age compared to two major flow events, and that an origin as a hyaloclastite ridge is plausible (Chapman *et al.*, 2000). Role of intrusives for this area is important.

Galaxias Mons

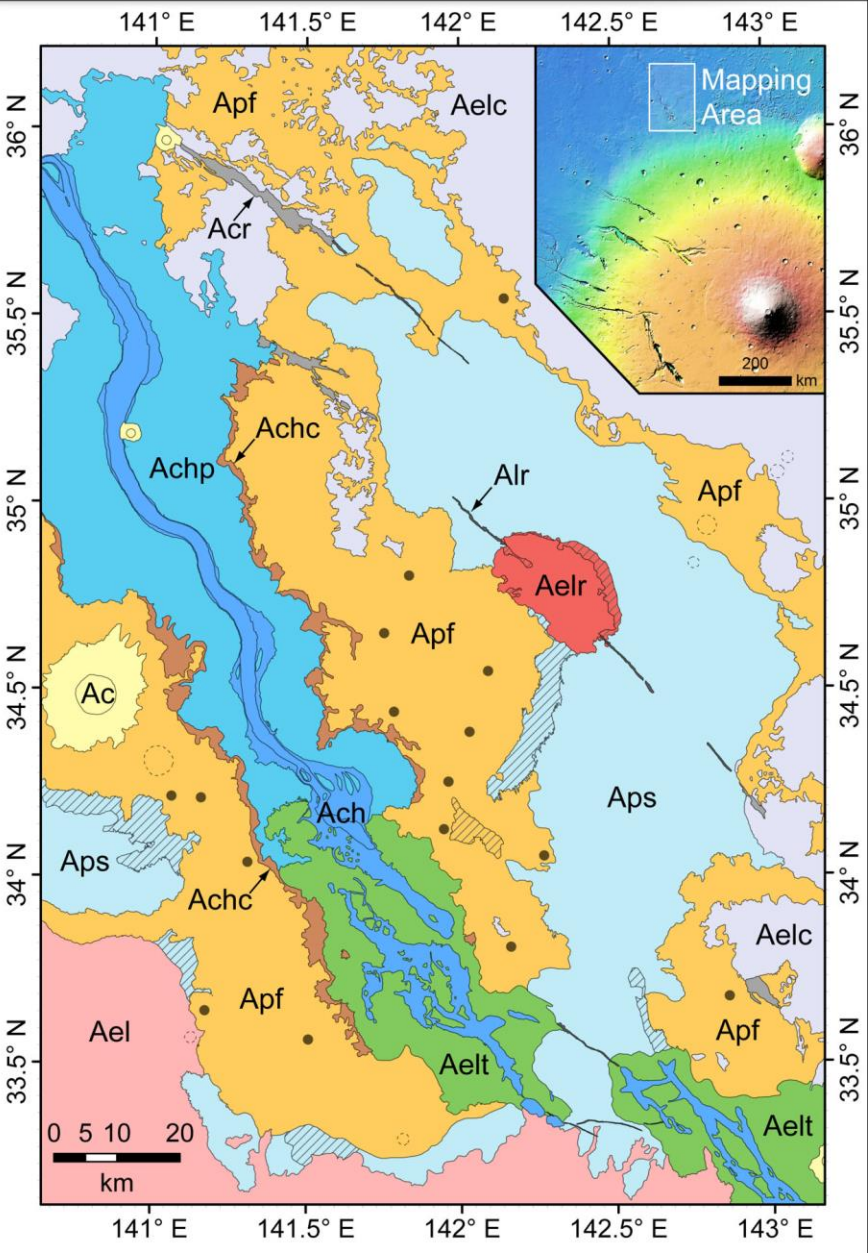


Galaxias Mons 2



New Geological Map of the Hrad Vallis Region

- Aelc, Rugged
- Ael, Plains-forming
- Aps, Smooth Plains
- Aelr, Ridge
- Alr, Linear Ridge
- Acr, Crenulated
- Apf, Lobate
- Achc, Chaotic
- Aelt, Ridge and Trough
- Achp, Flood Plain
- Ach, Channel
- Ac, Crater Material
- Disrupted Terrain
- Topographic Depressions
- Crater Rim
- Buried Crater Rim



Hamilton et al. (2017) – Submitted to EPSL

Summary

- Aelc, Rugged
- Ael, Plains-forming
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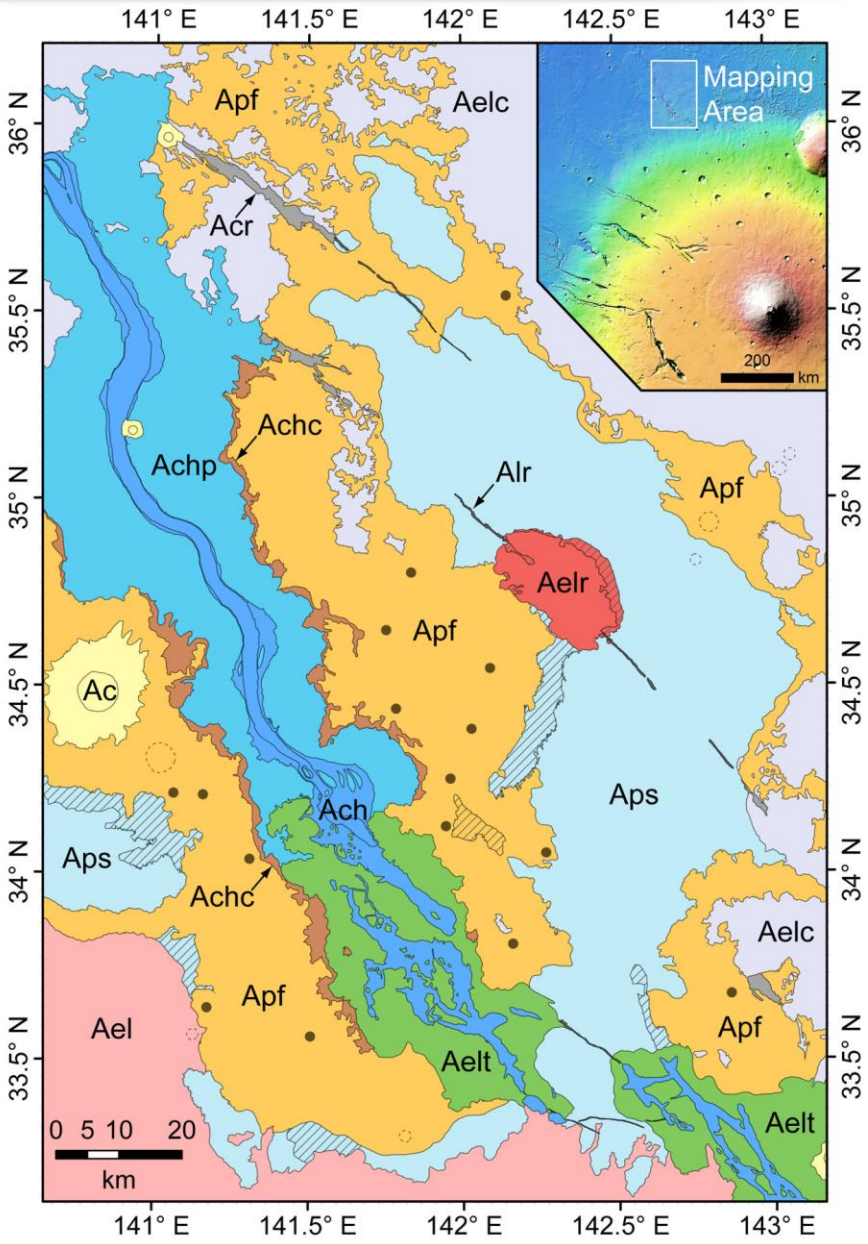
Aps was emplaced as a lahar and froze to form an ice body that gradually sublimed.

Dikes were intruded into ice to form ***Alr***, and were partially exhumed prior to *Apf*.

Apf is an inflated lava flow with lava-rise pits, not a second frozen lahar.

Apf was emplaced in contact with ice to form topographically inverted kipuka and steam explosions.



Smooth Plains, Linear Ridge, and Lobate Units

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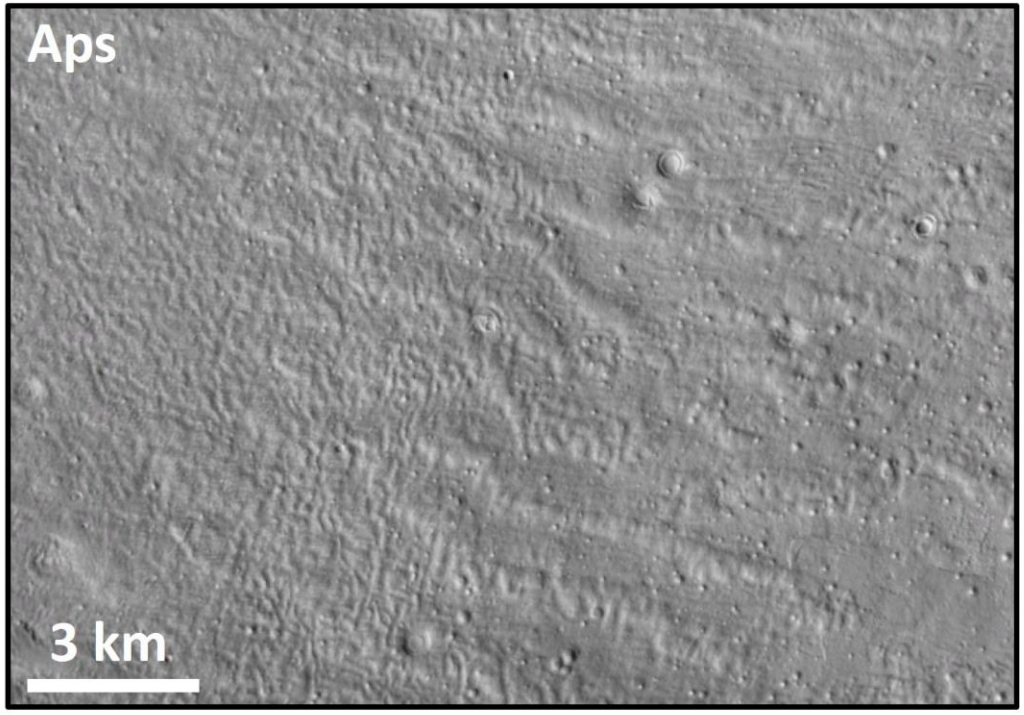

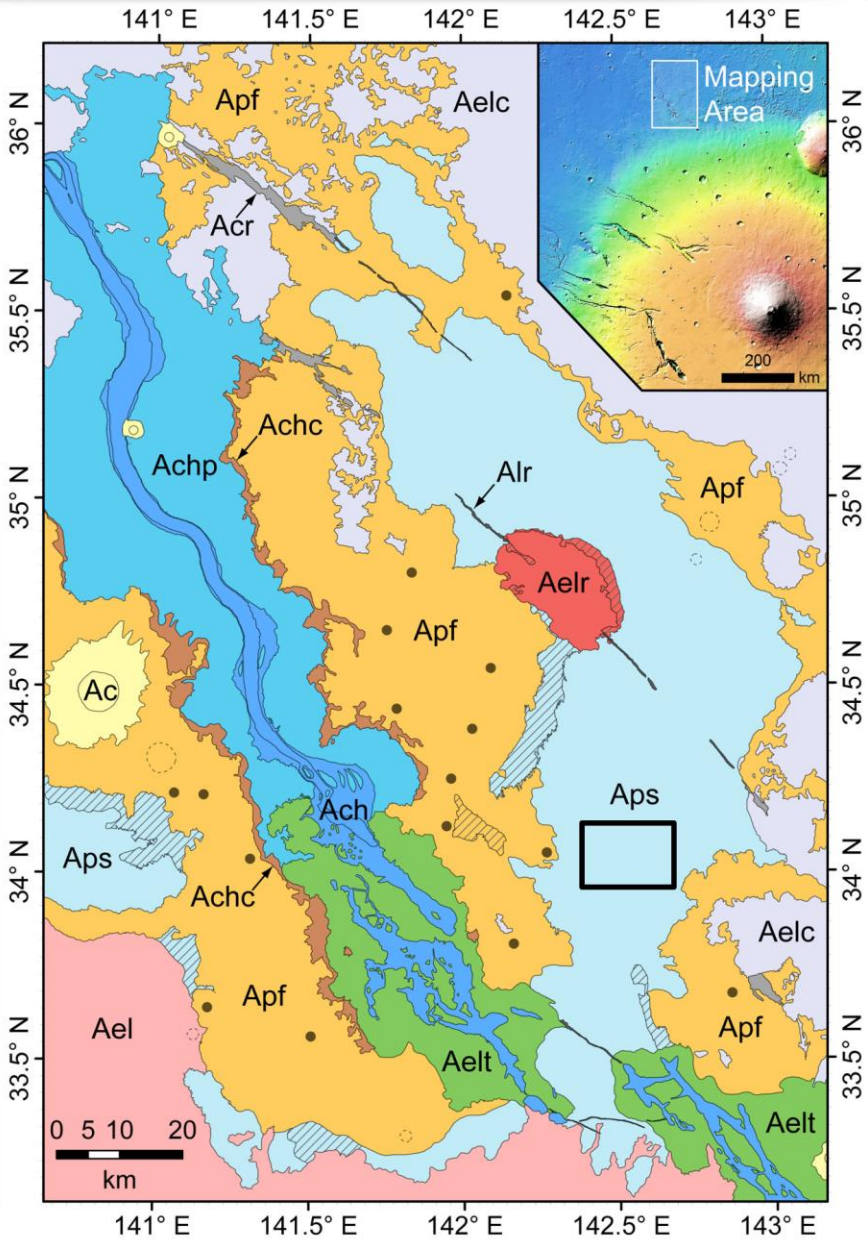

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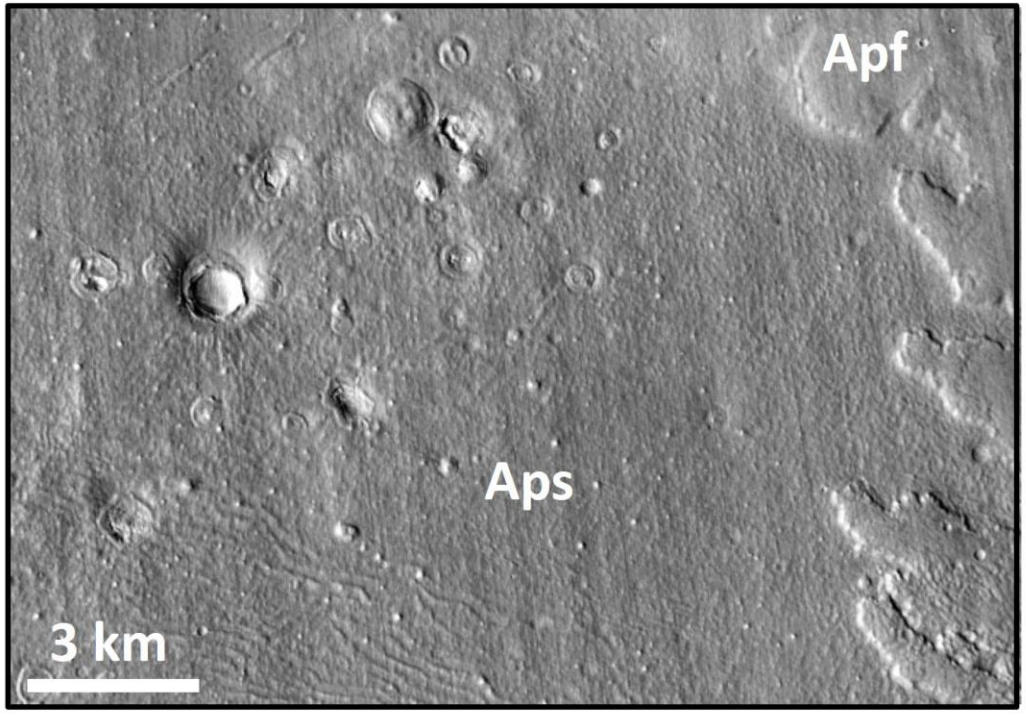

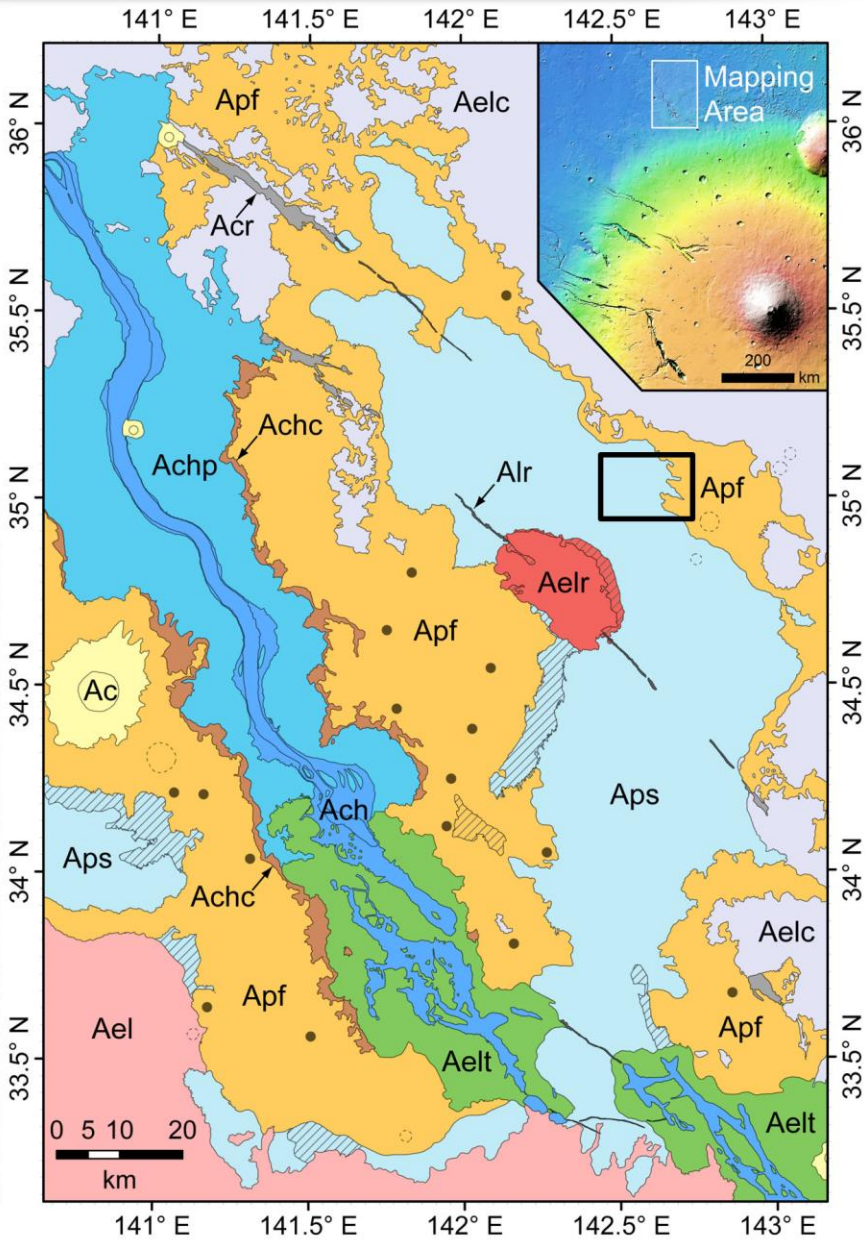

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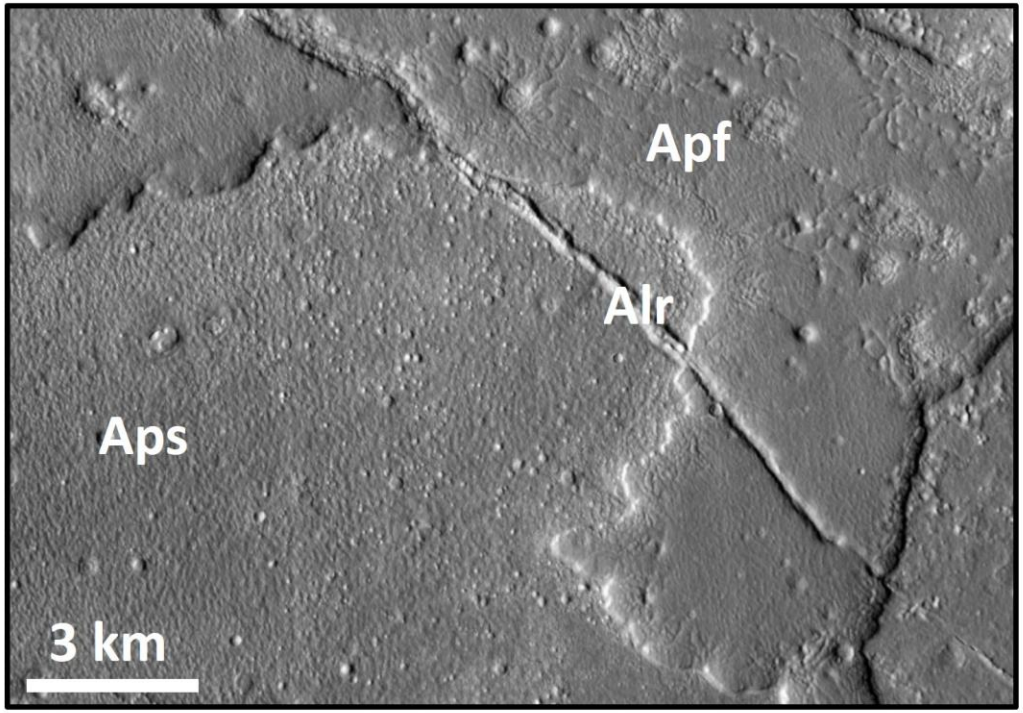
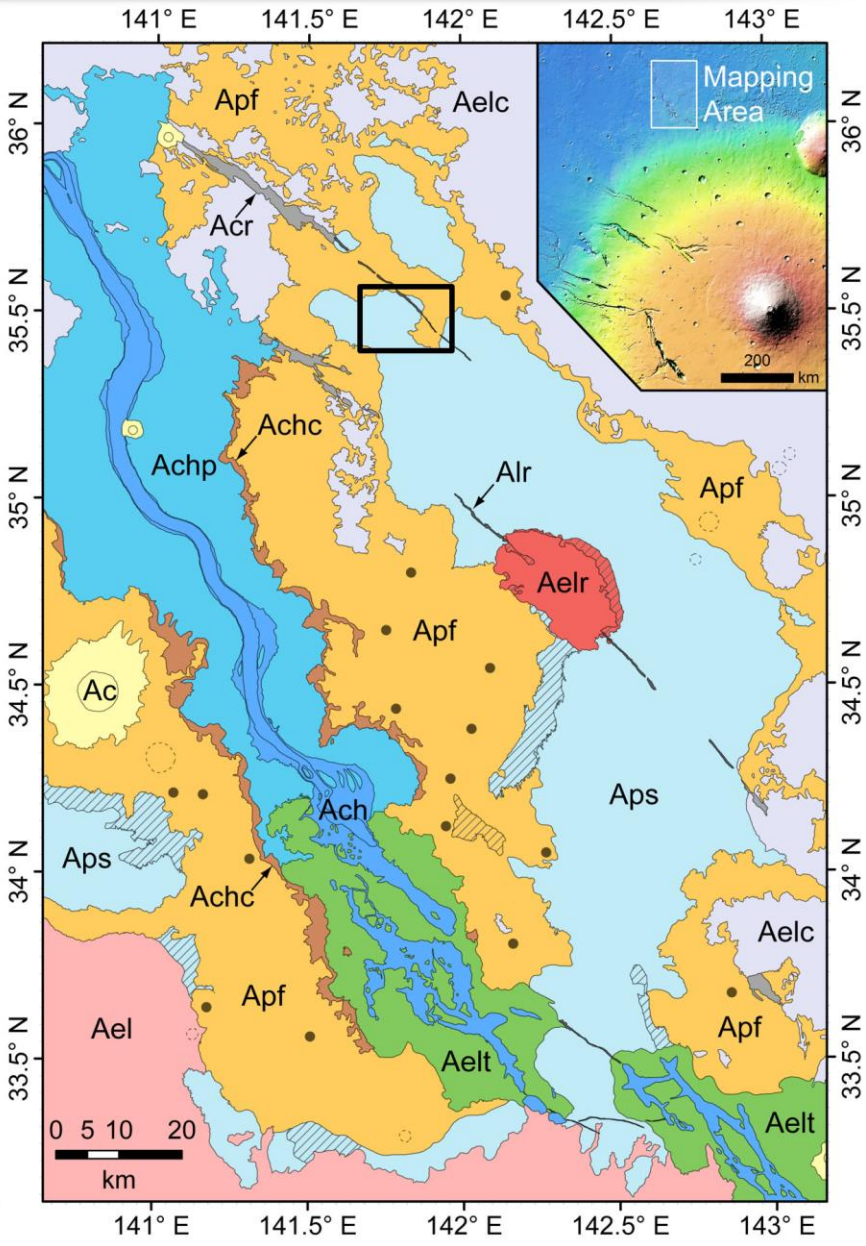
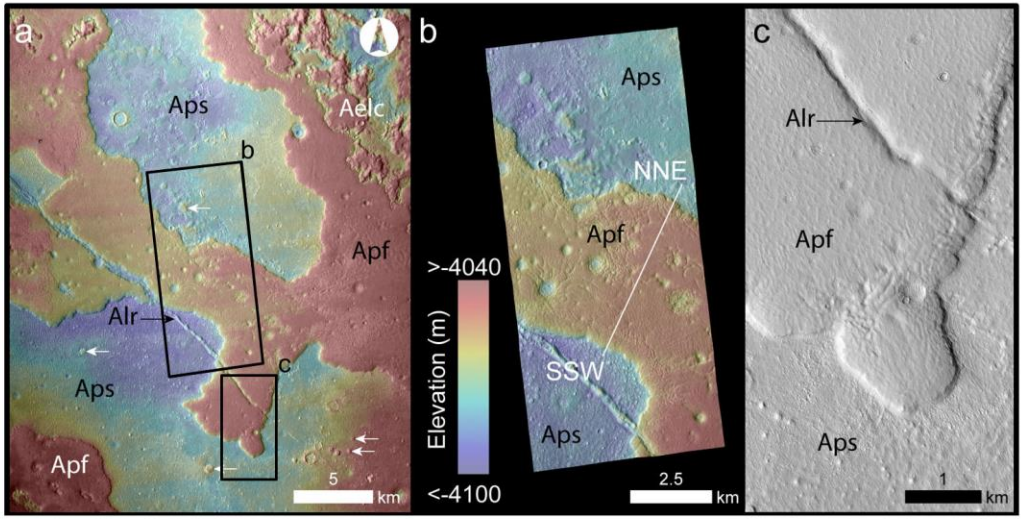
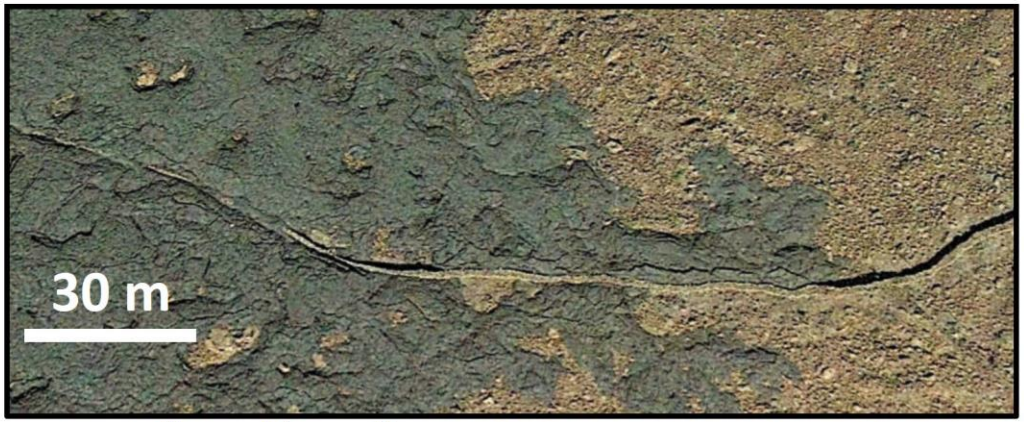


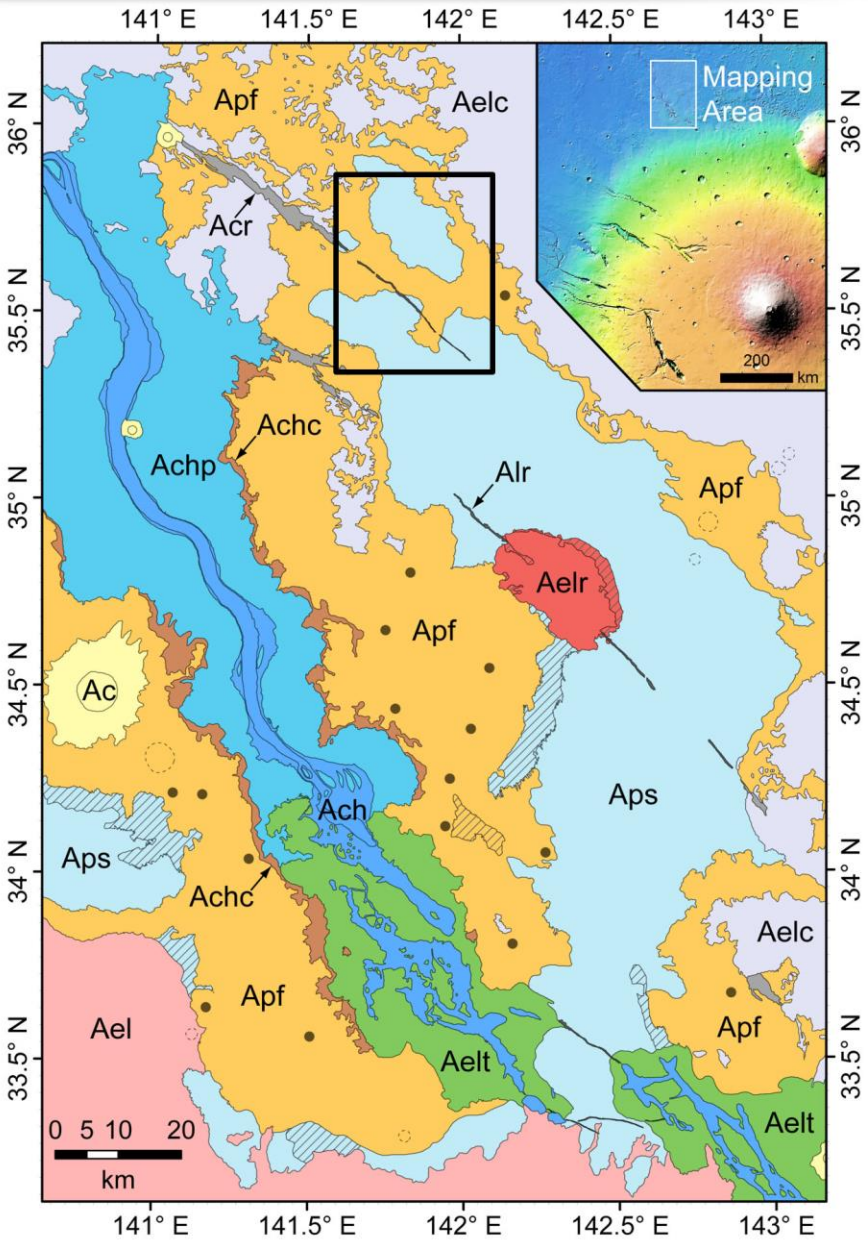


Frozen Lahar or Inflated Lava Flow?





Inflated lava flow at Mauna Loa, Hawaii



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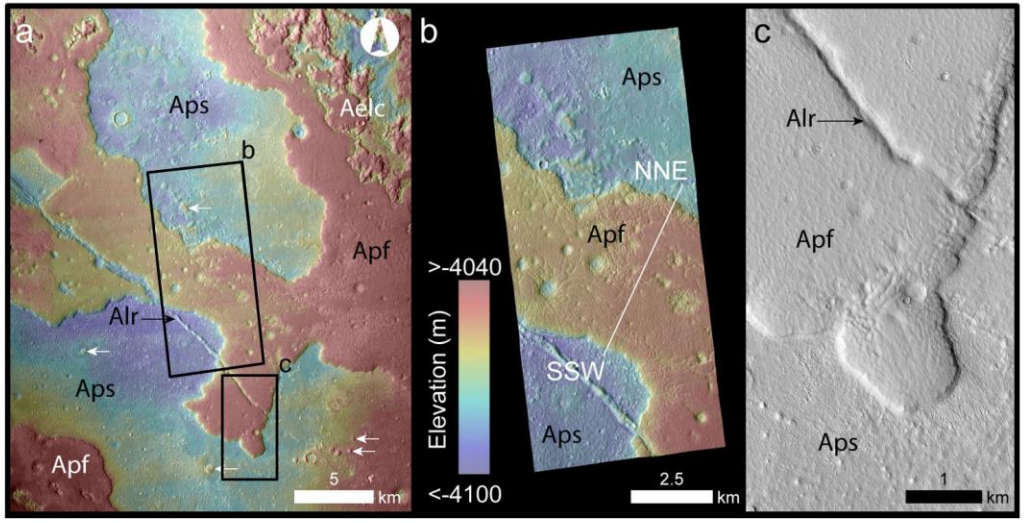

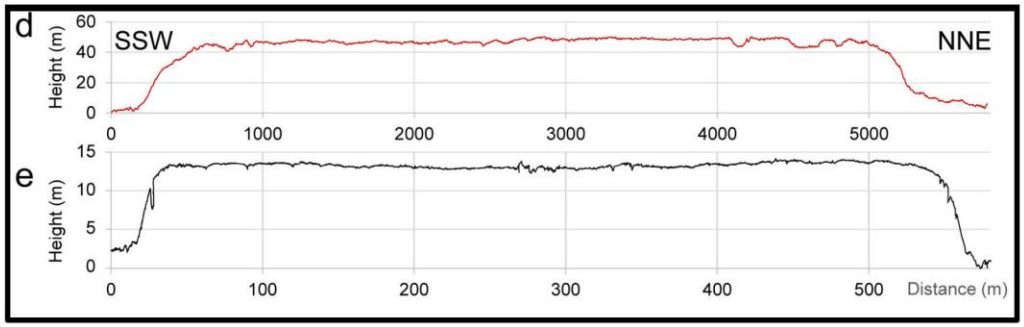

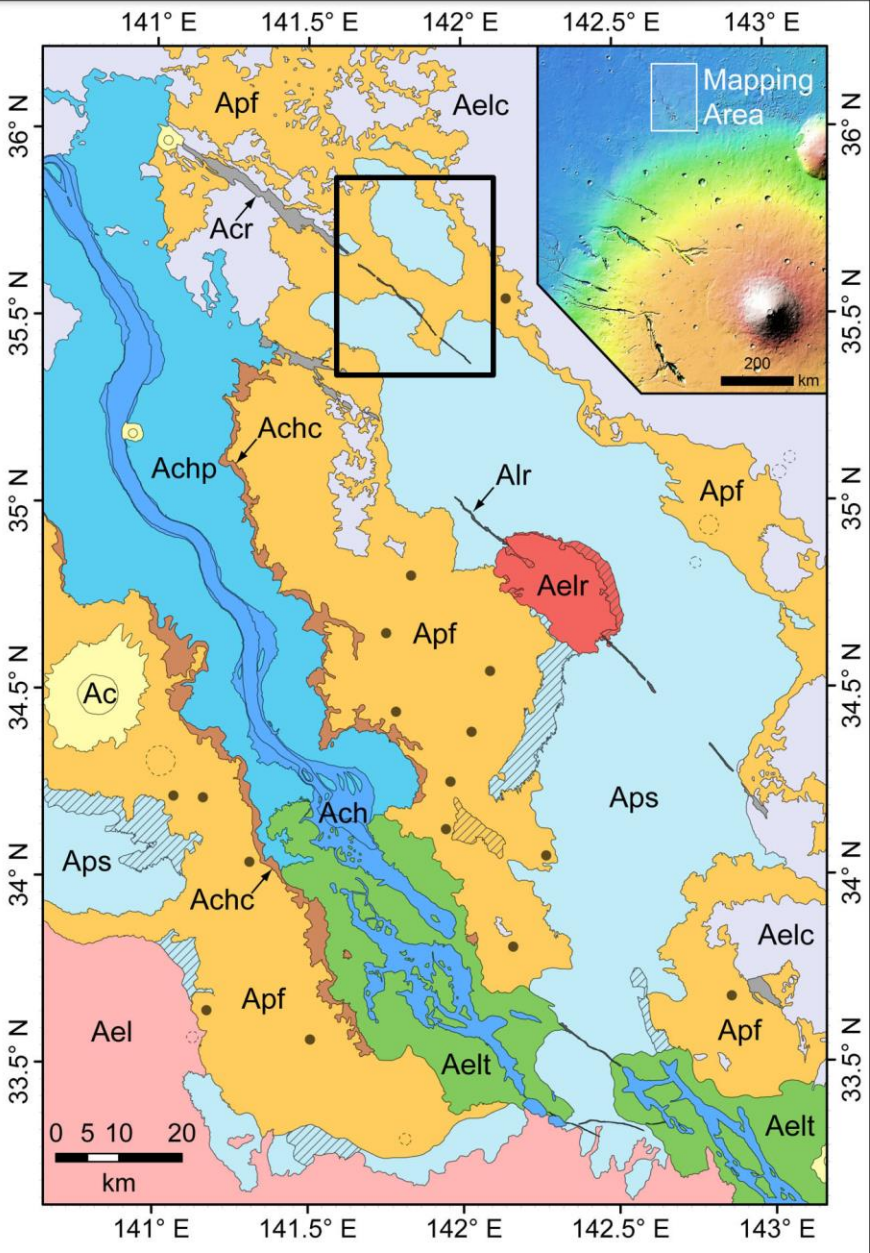

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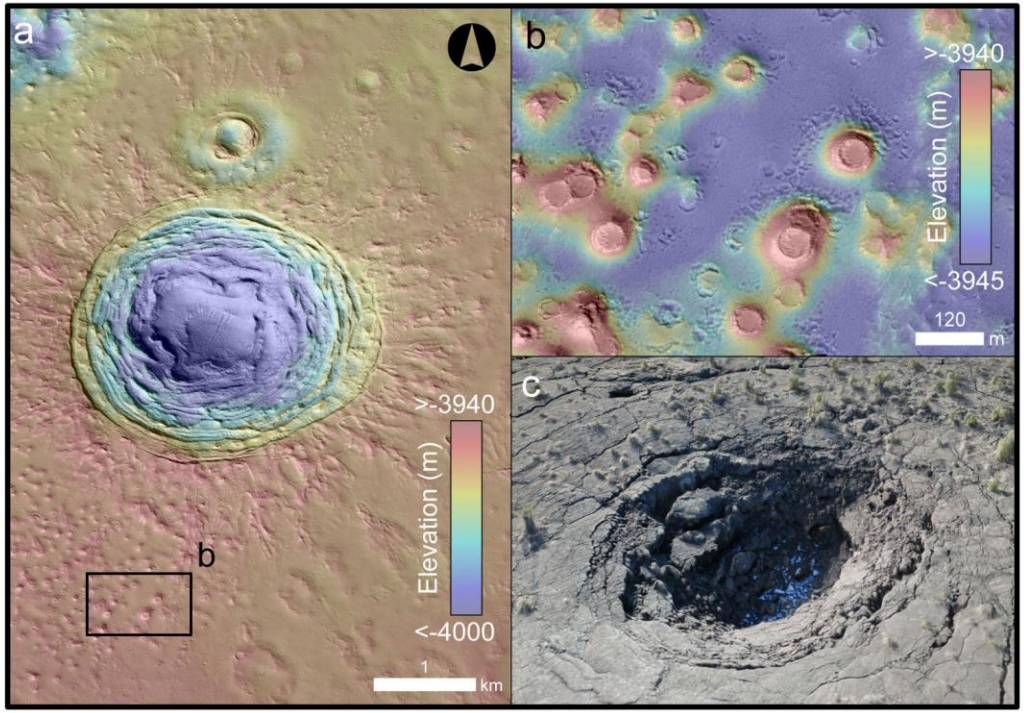
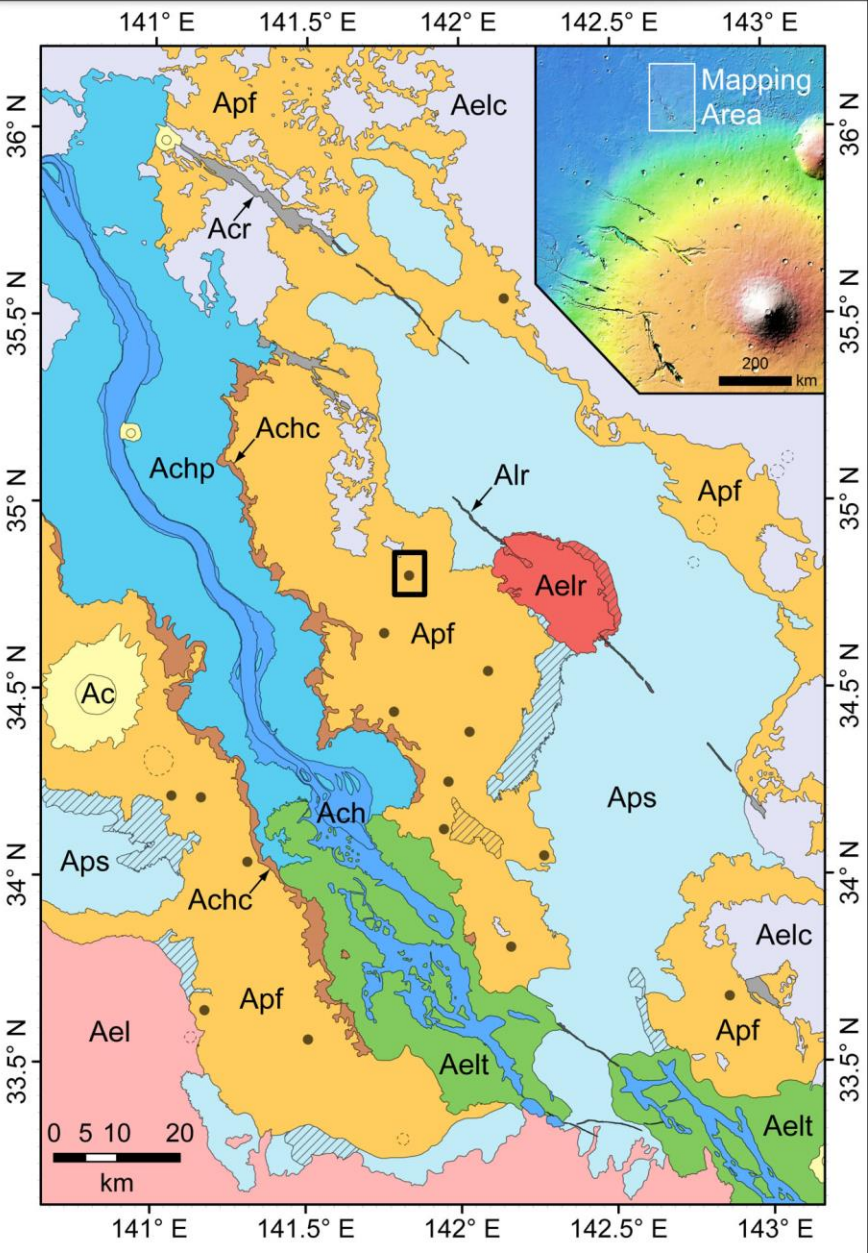
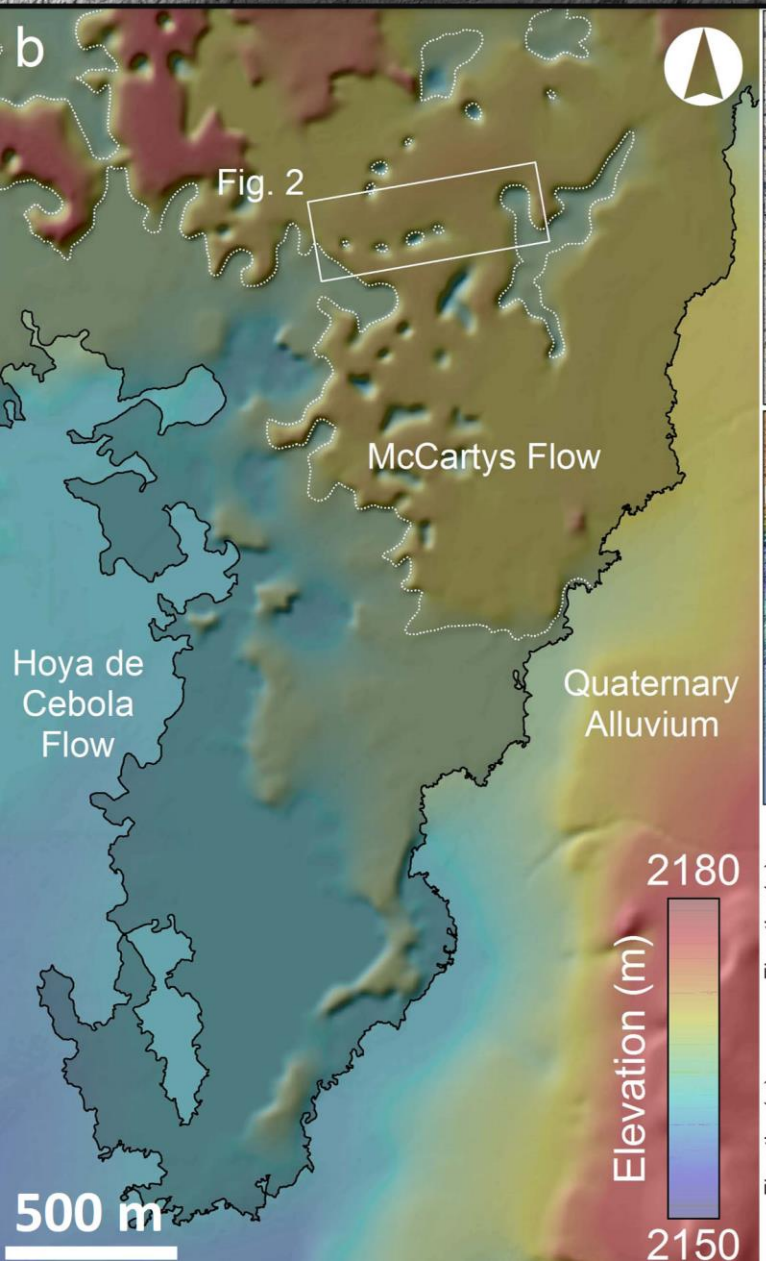
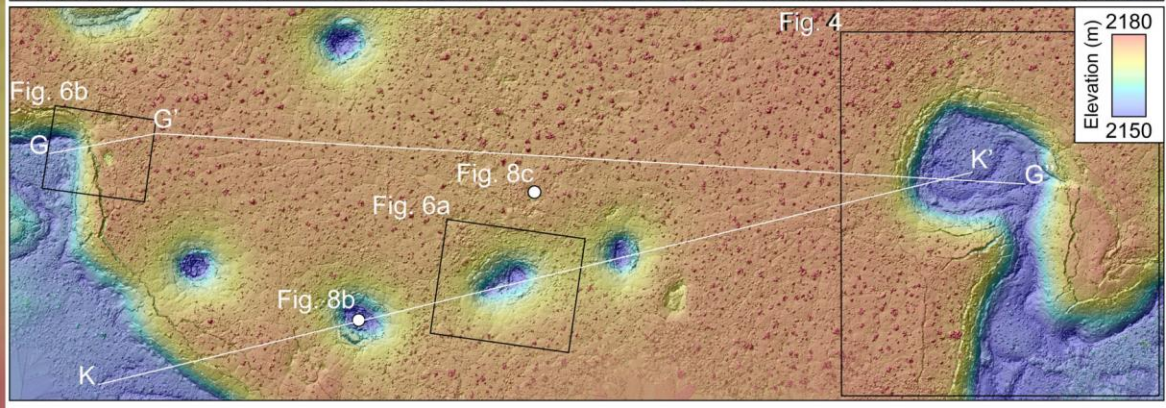
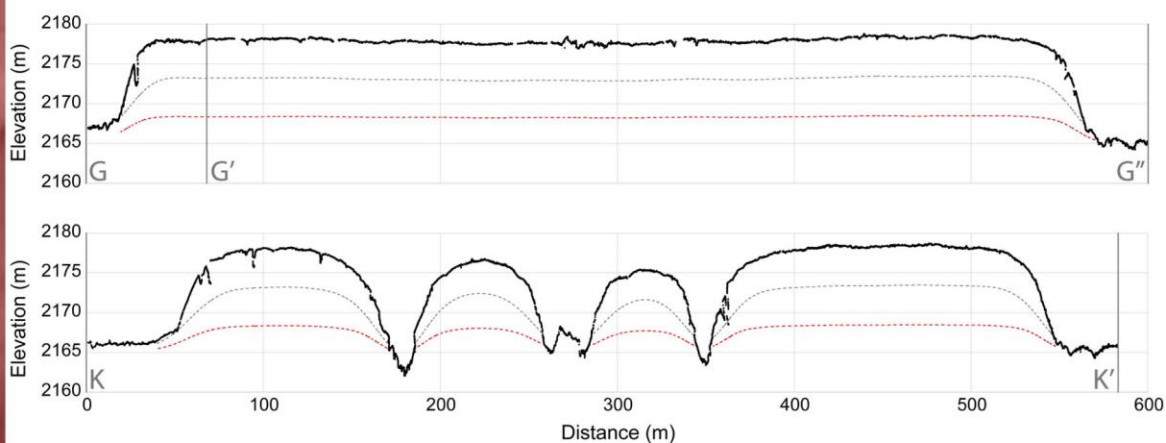




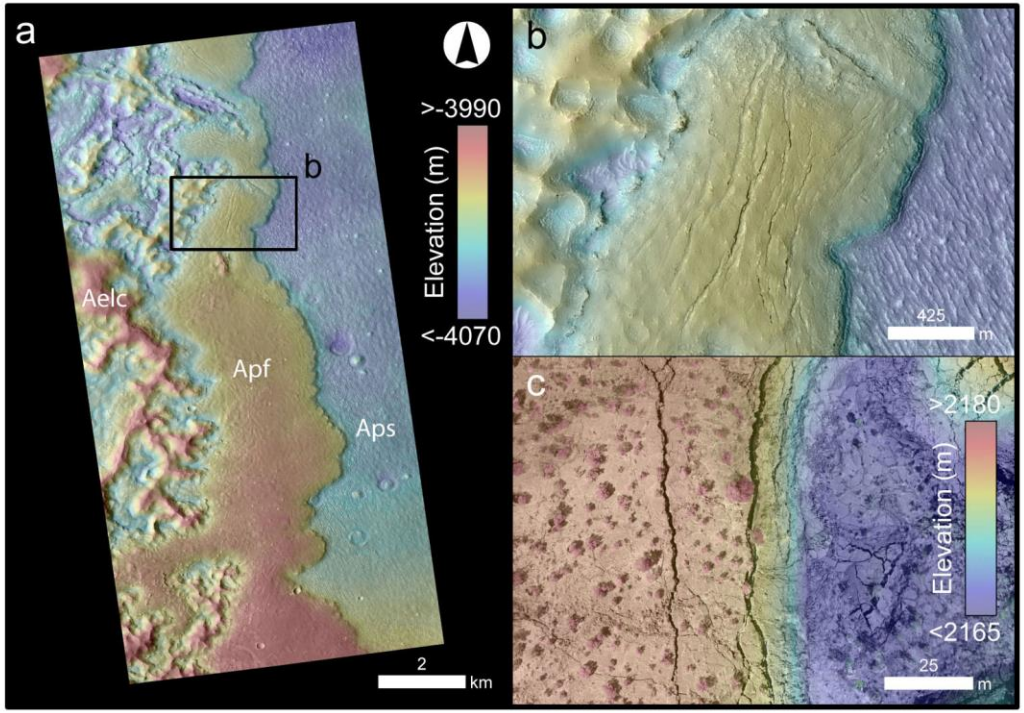
Lava-Rise Pleateaus within the McCartys Flow

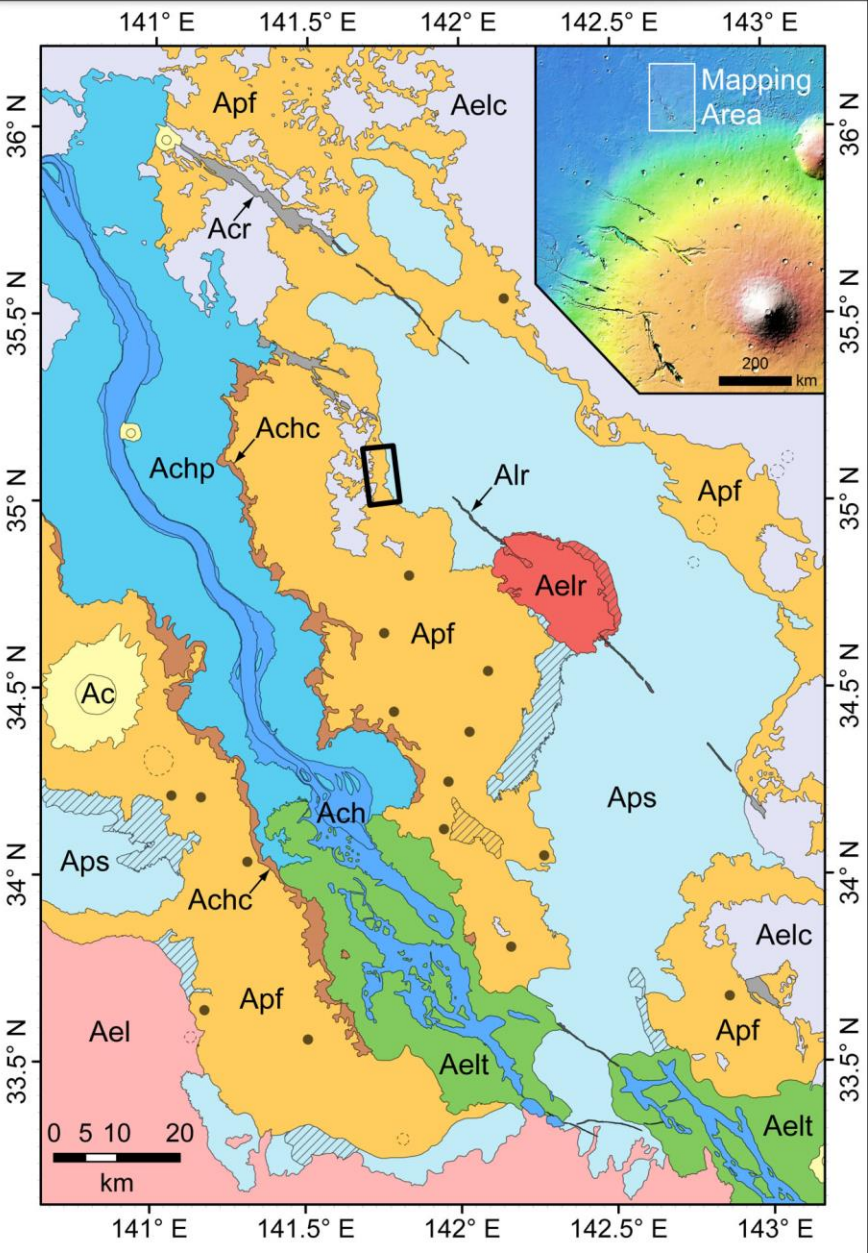




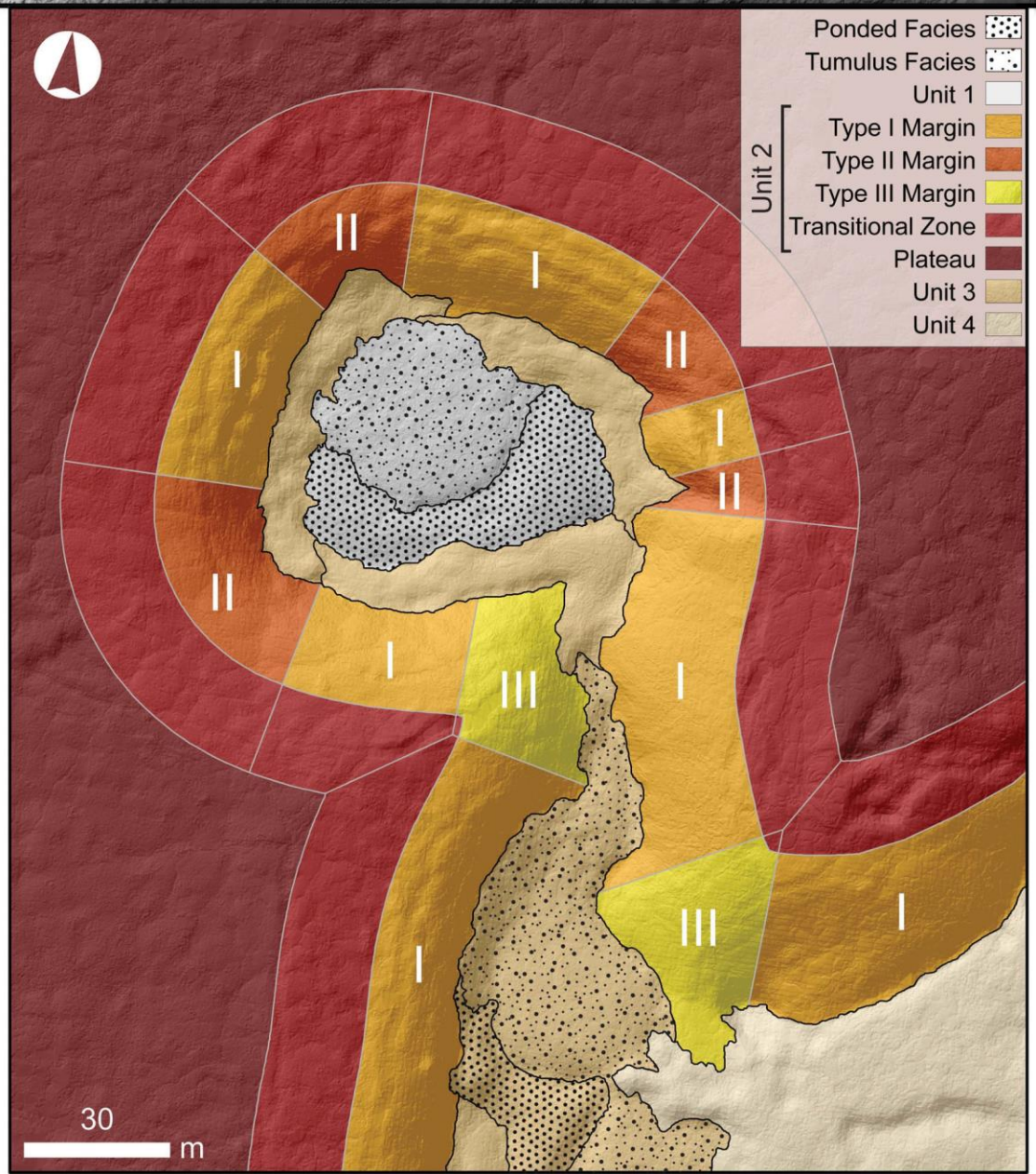


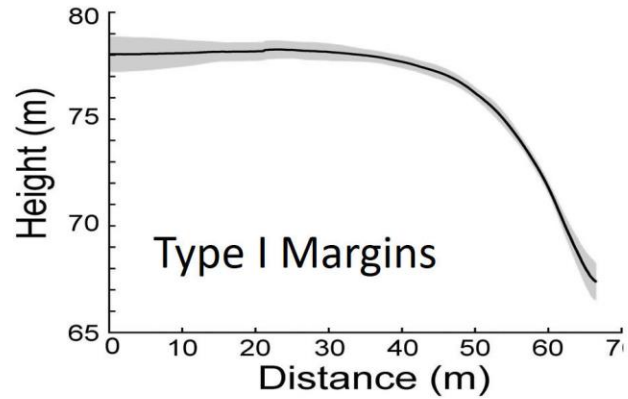
Frozen Lahar or Inflated Lava Flow?

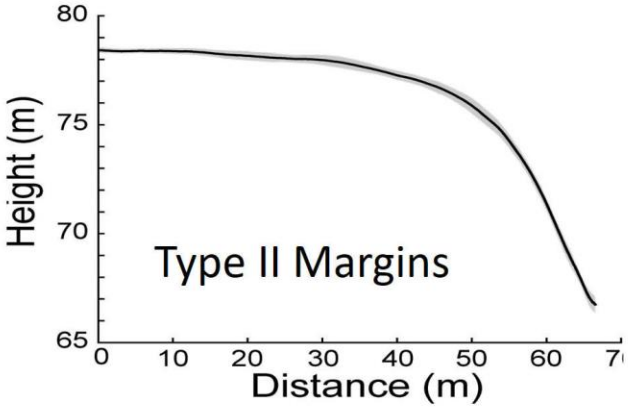


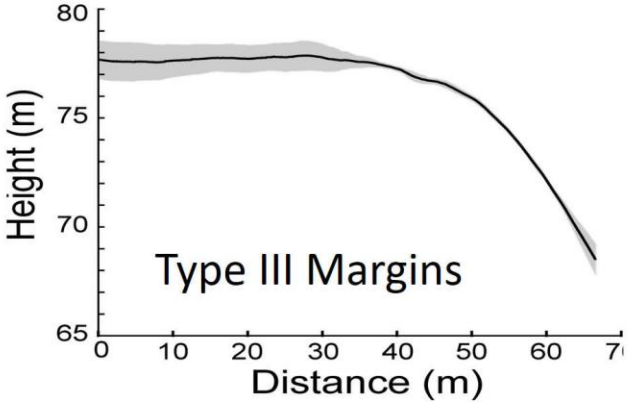


Lava-Rise Plateau Margins

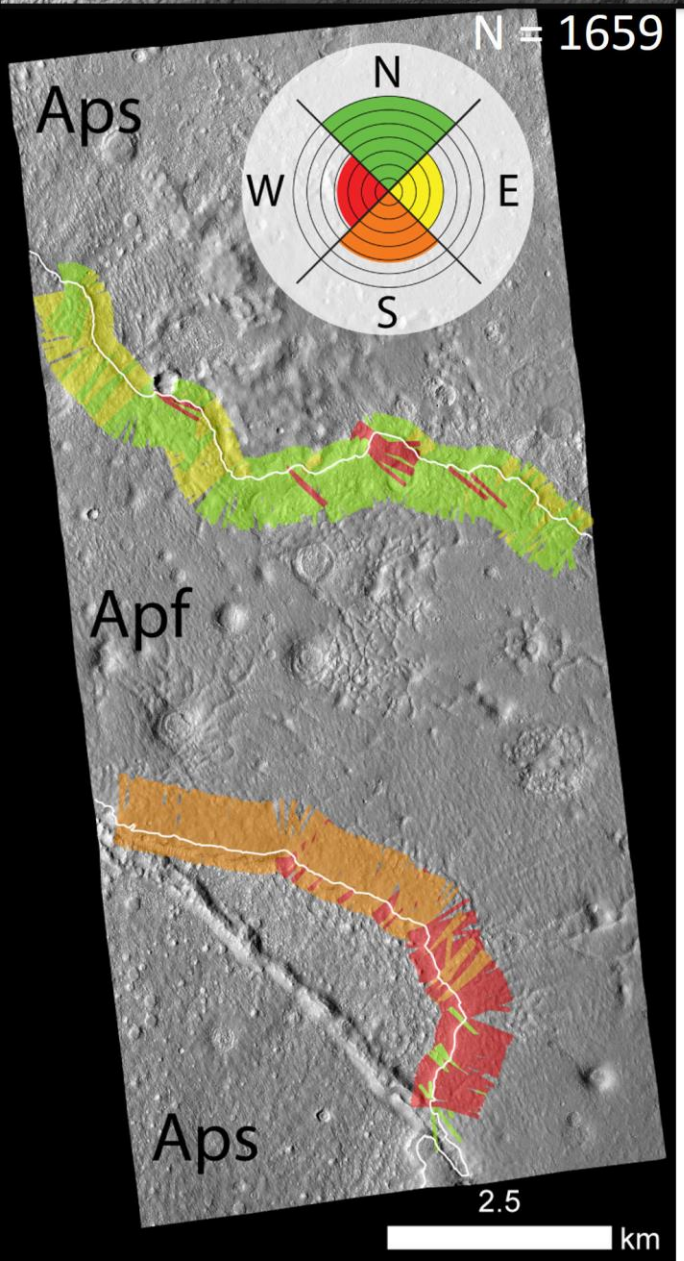


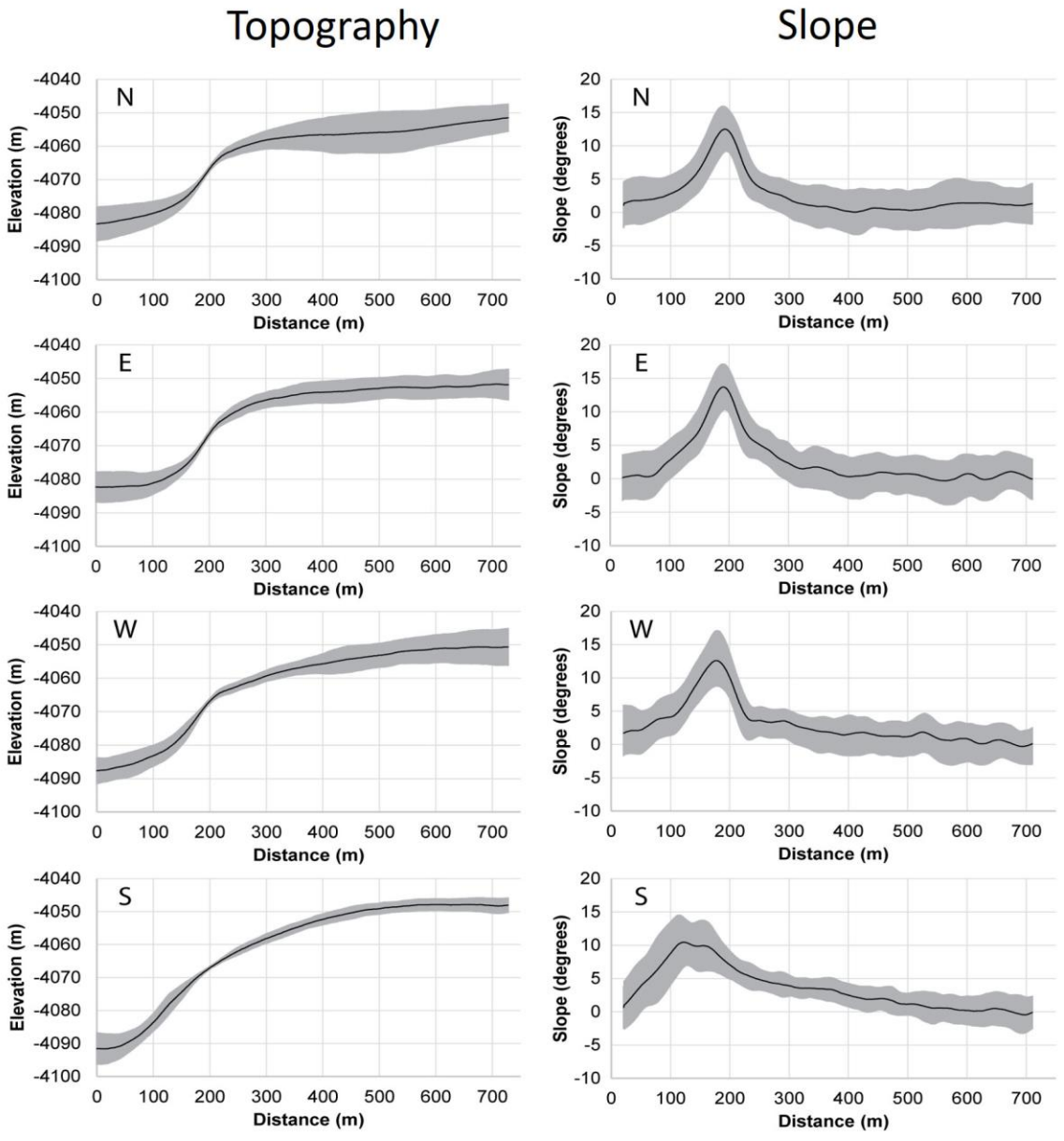






Testing the Frozen Lahar Hypothsis





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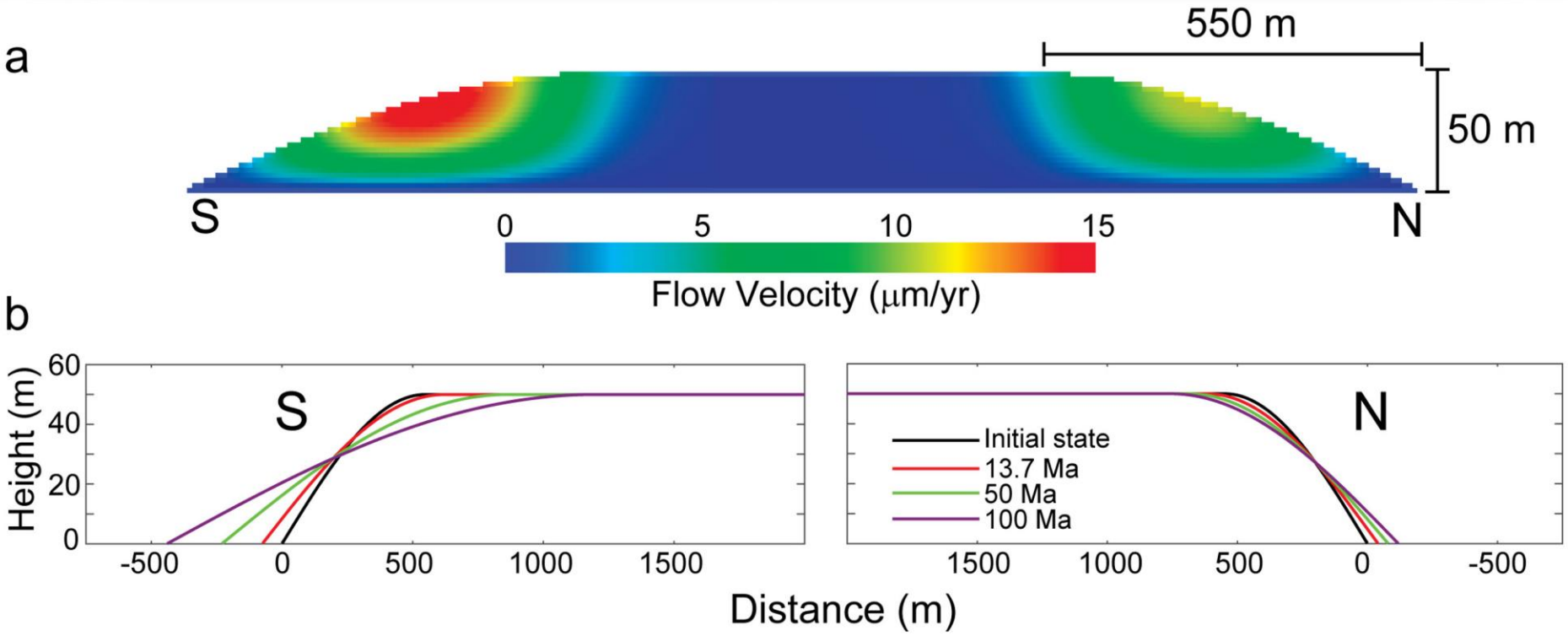
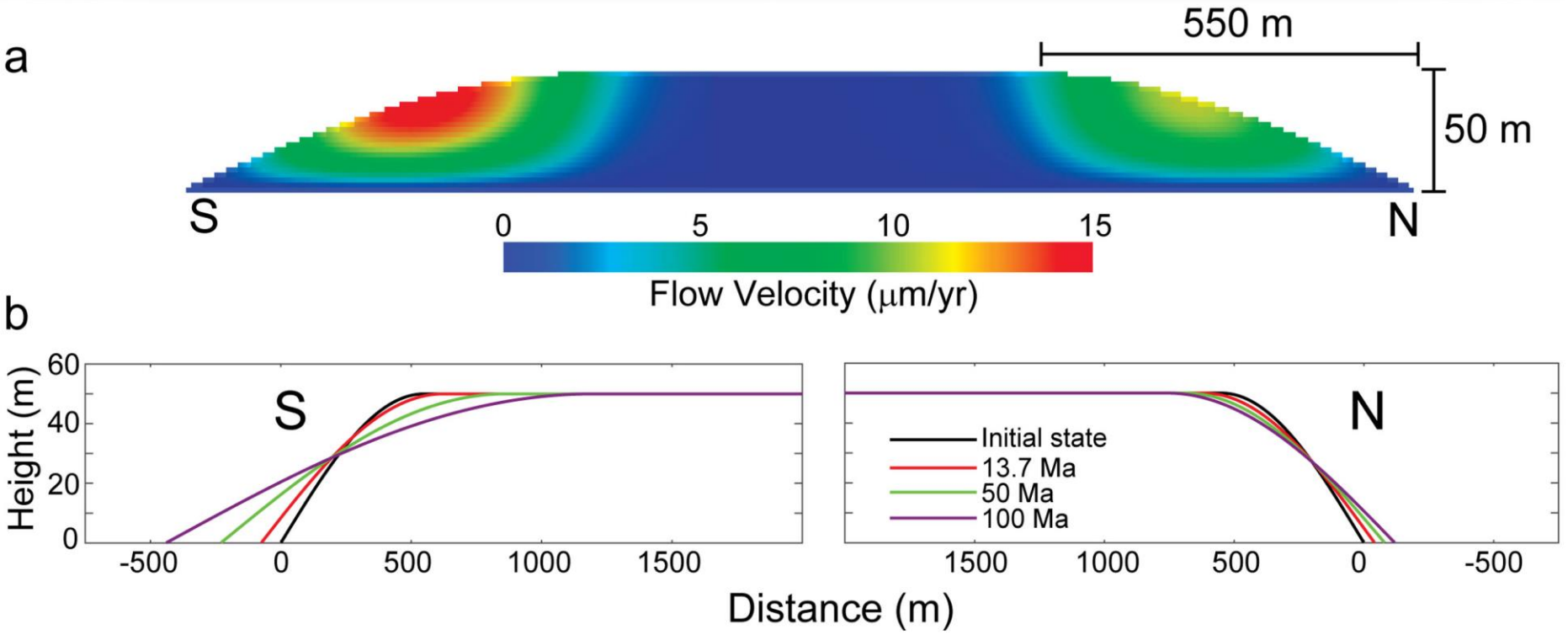
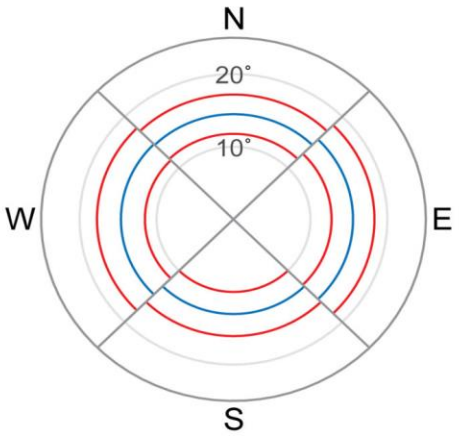


Cross section through our finite element model showing flow velocities in a pure ice unit with an average temperature of **218 K** on its equatorward-facing (southern) slopes and **212 K** on its poleward-facing (northern) side. The flow velocities for the 40% ice case are 2–3% compared to pure ice case.

Testing the Frozen Lahar Hypothsis





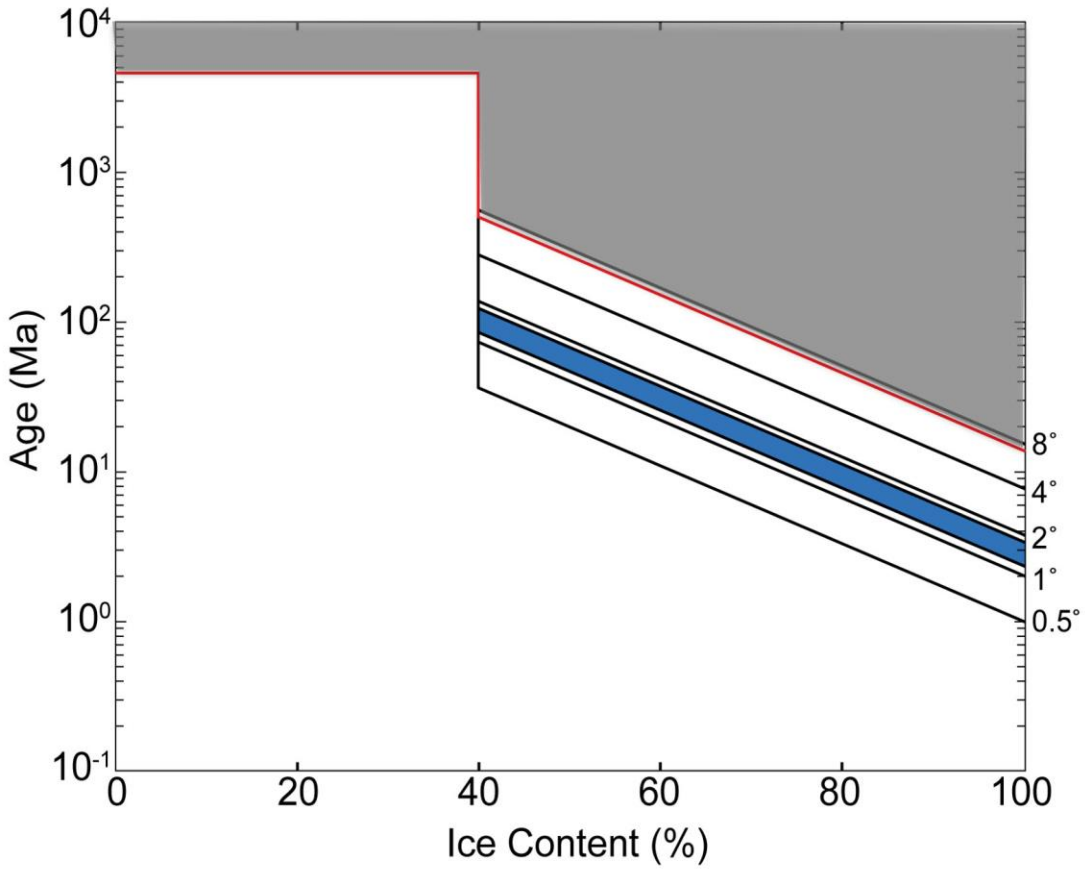
The mean maximum slope within the north- and south-facing quadrants differ by 1.34°, but statistically significant N–S asymmetries are not distinguishable for differences <7.18°, based on a 1σ detection threshold.

Testing the Frozen Lahar Hypothsis

Blue: Range of ice contents and ages consistent with 1.18–1.70° asymmetry (i.e., mean slope difference ± $1\sigma_e$)

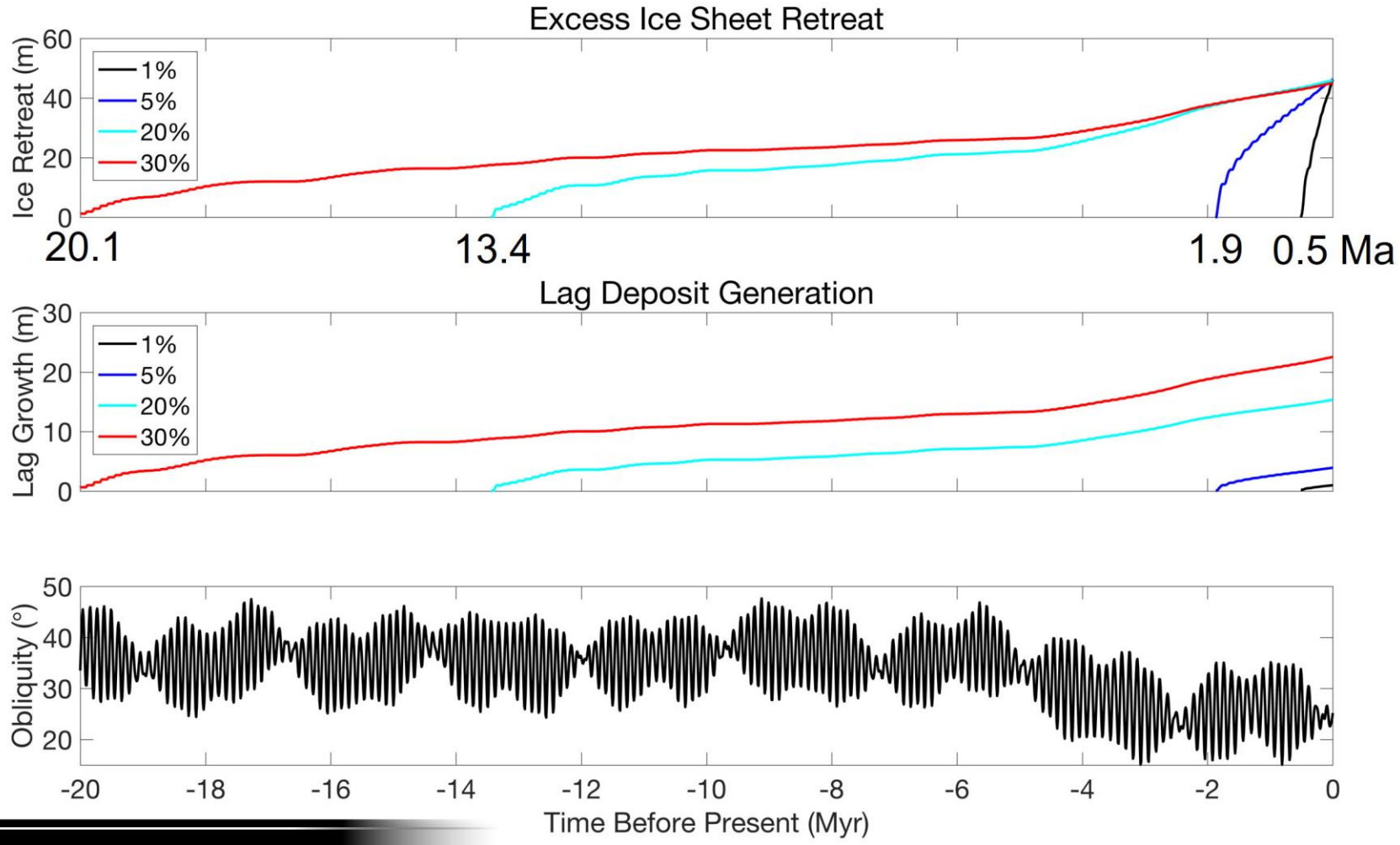
Red Line: Conservative case with a detection limit of 7.18°, which is the maximum difference between the mean slopes ± 1σ

Conservatively, we conclude that if ***Apf*** is a frozen lahar, **then it is younger than 13.7 Ma** (if pure ice), **younger than 471.3 Ma** (if it contains 40% ice), or potentially older if it was emplaced in the debris flow regime (<40% ice).



Testing the Frozen Lahar Hypothesis

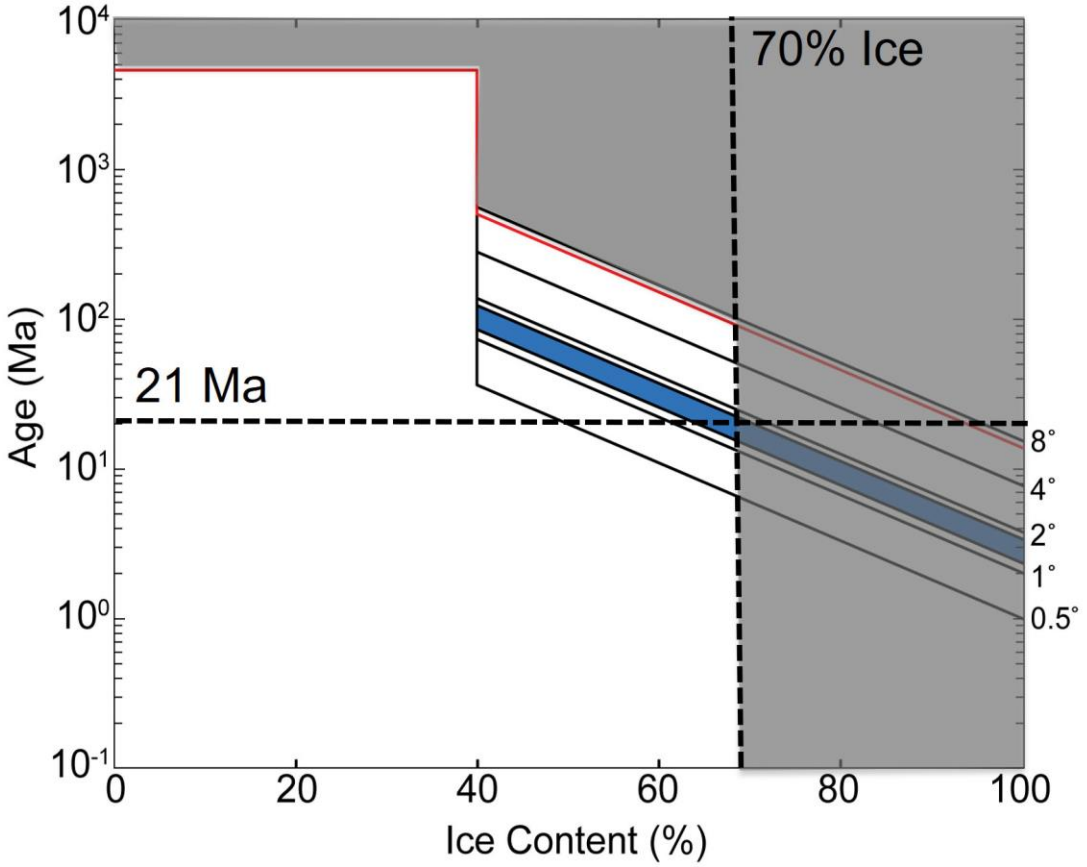
Model runs resulting in 45 m of ice retreat for various sediment contents within ice at 36°N, which provides an upper limit of the age of 45-m-thick ice between 33−36°N.



Ali Bramson

Testing the Frozen Lahar Hypothsis

Ice Content	Maximum Age for 45-m-thick ice at 33–36°N
99%	510 ka
95%	1.87 Ma
90%	7.5 Ma
80%	13.4 Ma
70%	20.1 Ma
60%	>21 Ma
50%	>21 Ma



Young ages are unrealistic for ice-rich (>70% ice) units because they would sublimate away before developing detectable asymmetries by viscous flow.

Ice-poor (<70% ice) units could survive for >21 Ma, but would be expected to generate thick lag deposits, which are inconsistent with observations.

Conclusions

- ***Aps* may be a sublimation lag associated with a former lahar**
- ***Apf* provides one of the best examples of an inflated pahoehoe-like lava flow on Mars and a compelling candidate for interaction between a lava flow and surficial ice**
- **Topographic depressions within *Apf* are consistent with the characteristics of lava-rise pits, and need not evoke a formation mechanism involving impacts into a frozen lahar**
- ***Aps* and *Apf* do not appear related to the same event**
- **This implies that Hrad Vallis is a complex outflow channel system generated through alternating episodes of catastrophic aqueous flooding events and effusive eruptions**

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Conclusions

- *Aps* may be a sublimation lag associated with a former lahar
- *Apf* provides one of the best examples of an inflated pahoehoe-like lava flow on Mars and a compelling candidate for interaction between a lava flow and surficial ice
- Topographic depressions within *Apf* are consistent with the characteristics of lava-rise pits, and need not evoke a formation mechanism involving impacts into a frozen lahar
- *Aps* and *Apf* do not appear related to the same event
- **This implies that Hrad Vallis is a complex outflow channel system generated through alternating episodes of catastrophic aqueous flooding events and effusive eruptions**