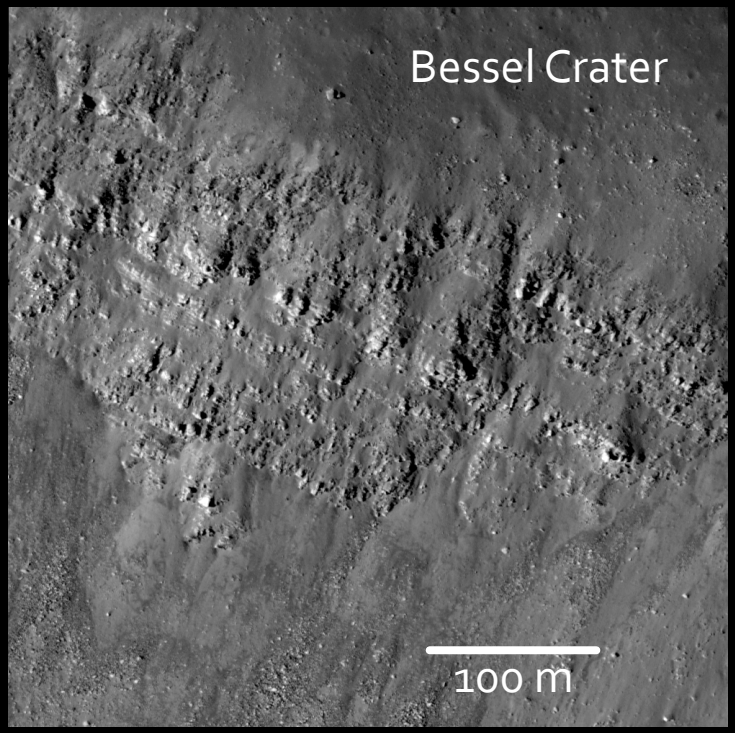
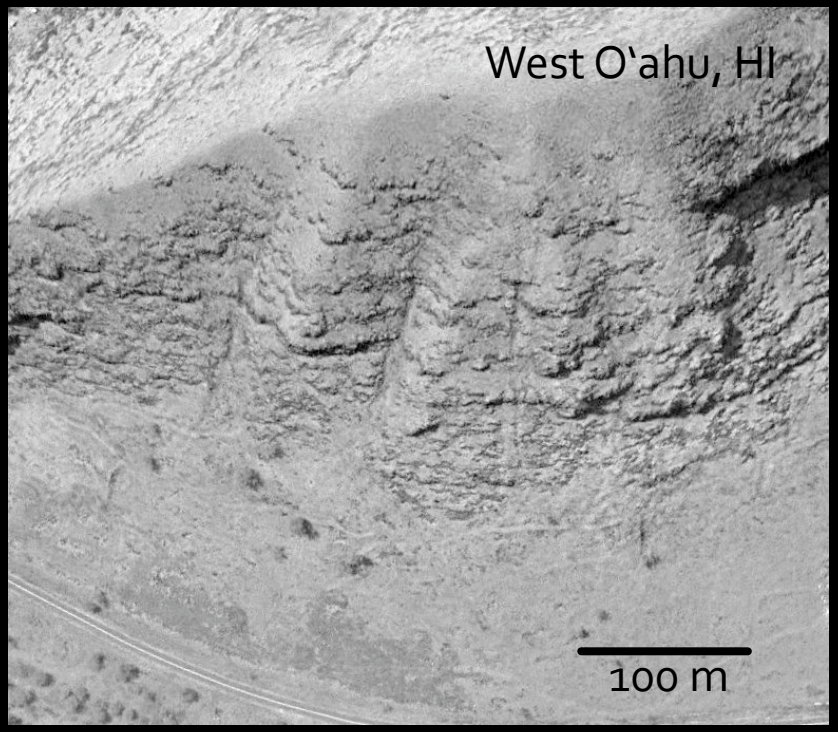
Thicknesses of lunar lava flows:
Comparison of layered mare units with terrestrial analogs





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Heidi Needham
Sarah A. Fagents

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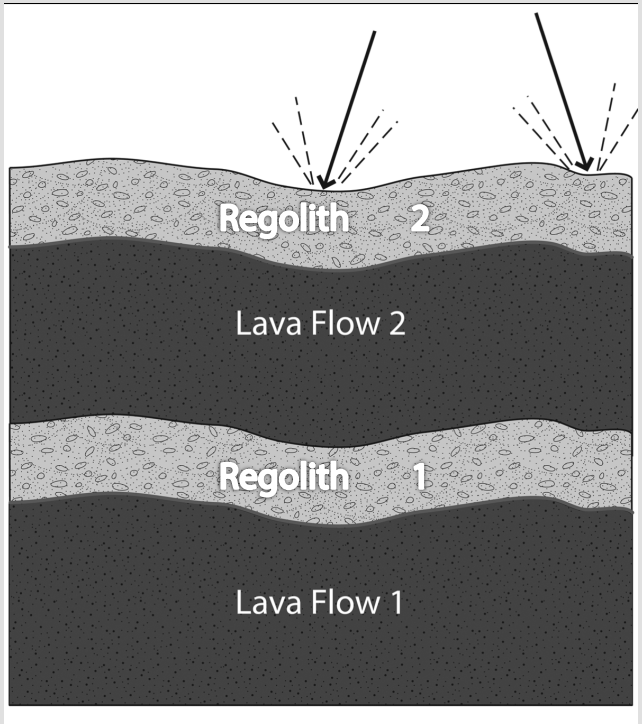
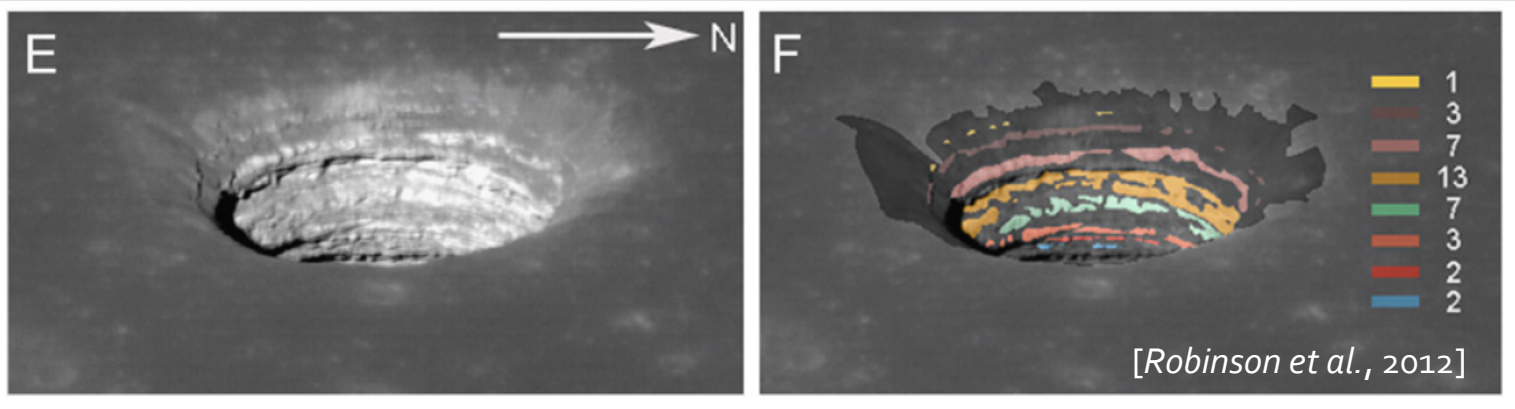
Introduction – Mare Thicknesses

- Interpretations of eruption rates, flow velocities, rheological properties of lava flows [e.g., *Wilson & Head*, 2003].
- Preservation of exogenous volatiles in paleoregolith protected by overlying lava flows [e.g., *Fagents et al.*, 2010; *Rumpf et al.*, 2013].

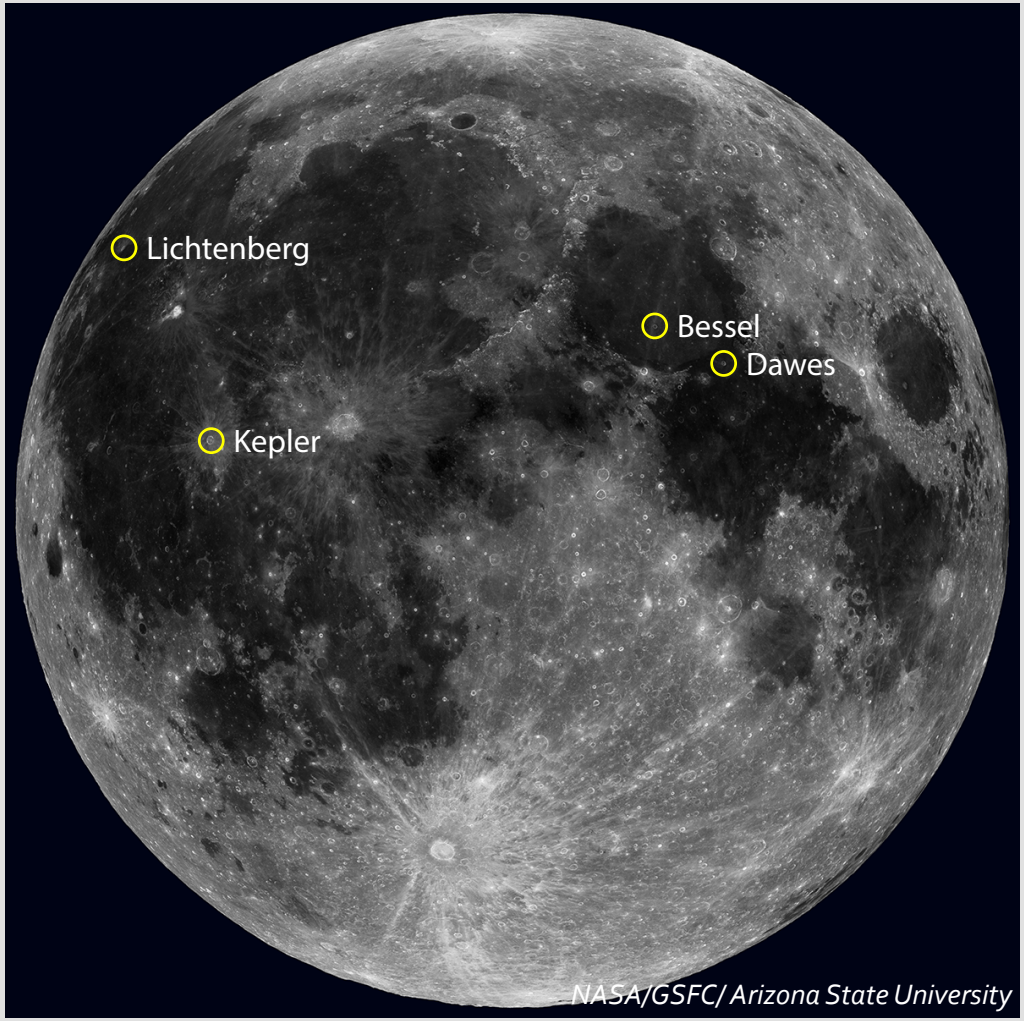


Introduction - LRO

- Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC)
  - High resolution imagery (~0.5 m/pixel) [*Robinson et al., 2010*]
- Lunar Orbiter Laser Altimeter (LOLA)
  - Elevation (~10 cm accuracy) [*Smith et al.*, 2012]
- Mare flow thickness estimates
  - Pit craters -- 3-14 m [*Robinson et al.*, 2012]
  - Impact crater-- 2-5 m; 6-25 m [*Robinson et al.*, 2012; *Enns & Robinson*, 2013]

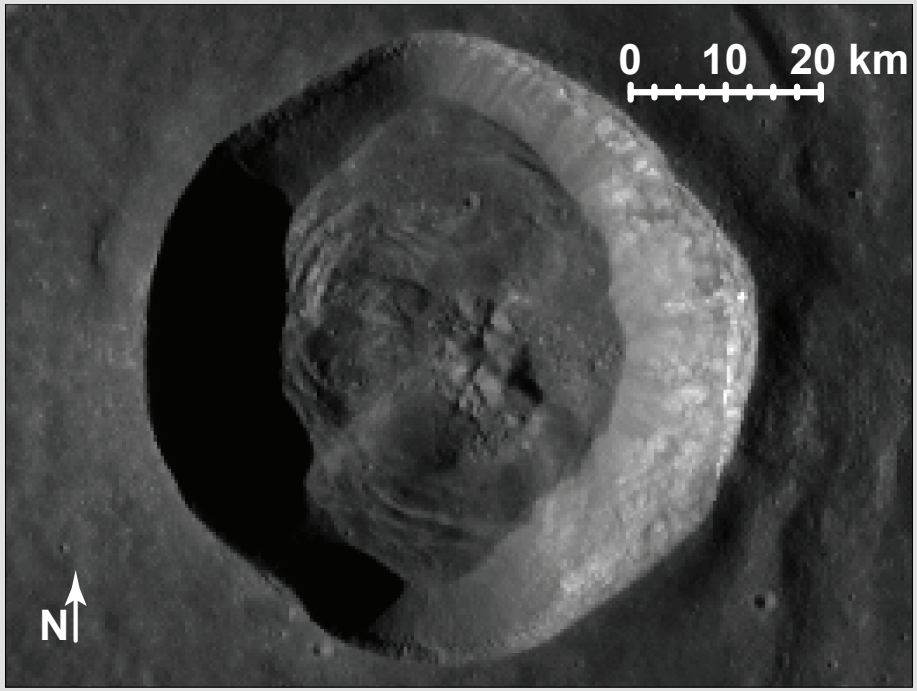


Lunar Remote Sensing



Lunar Remote Sensing

Dawes Crater – 32 km diameter

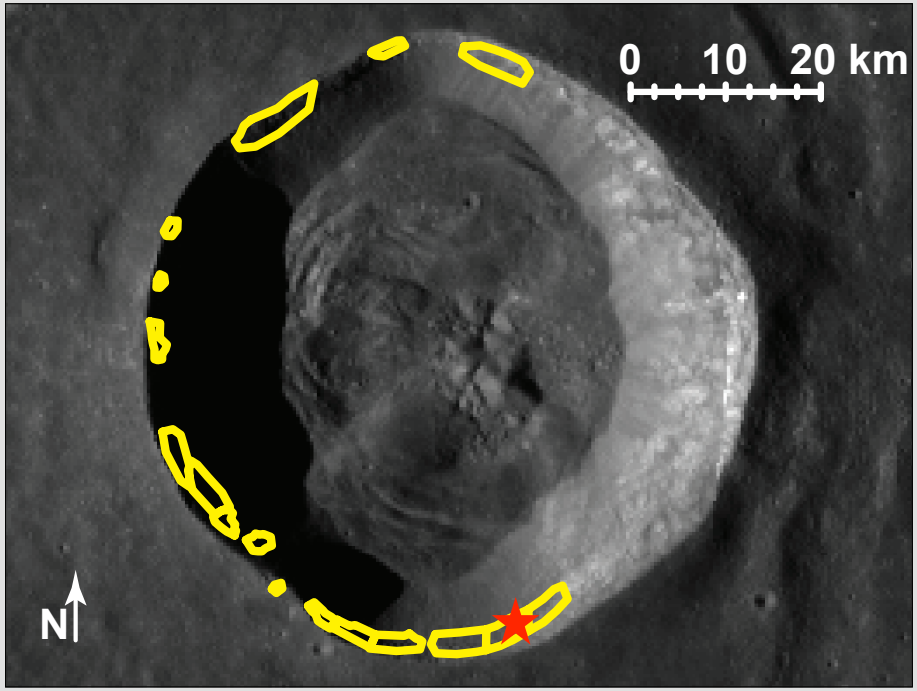


- Criteria
  - LROC NAC coverage
  - Laterally continuous layering
  - LOLA tracks

NASA/GSFC/ Arizona State University

Lunar Remote Sensing

Dawes Crater – 32 km diameter



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NASA/GSFC/ Arizona State University

Lunar Remote Sensing

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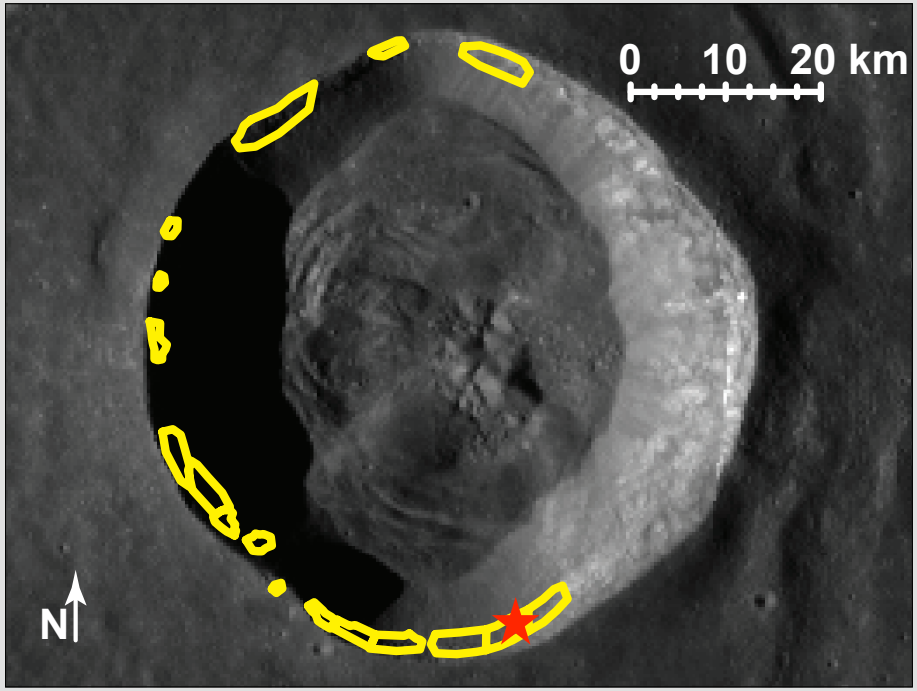

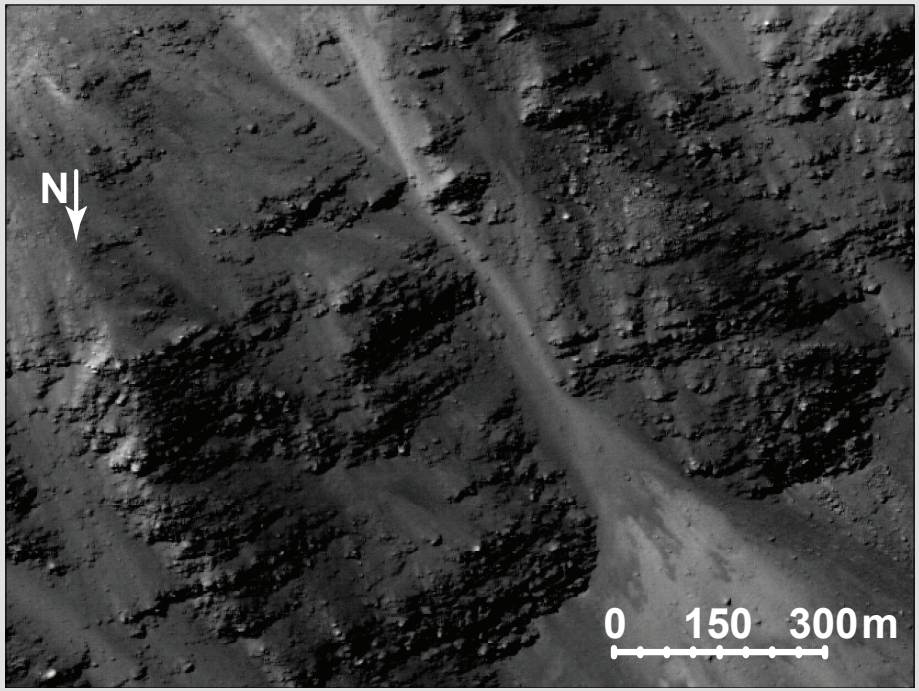

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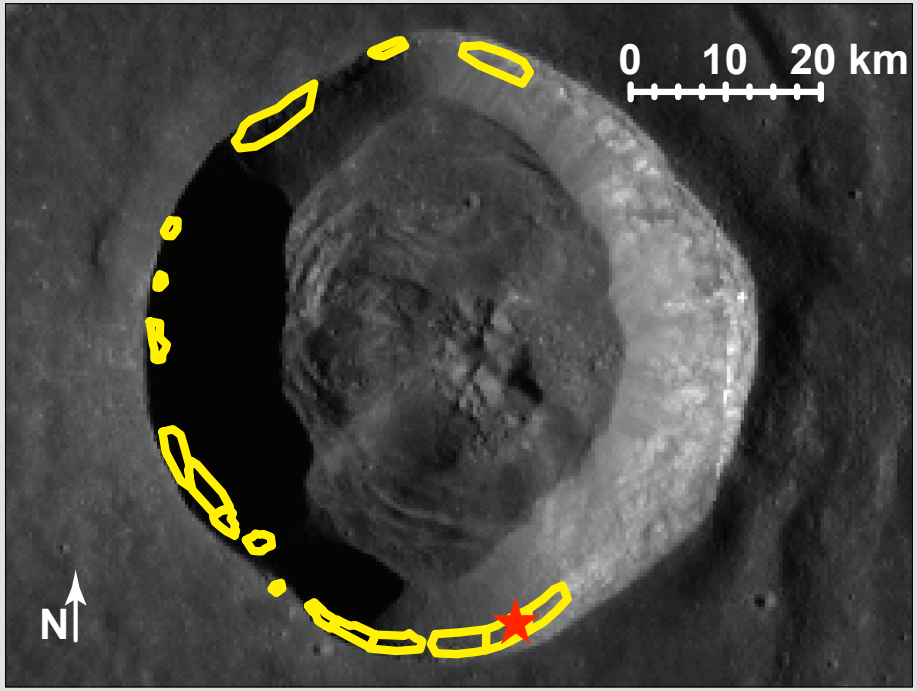
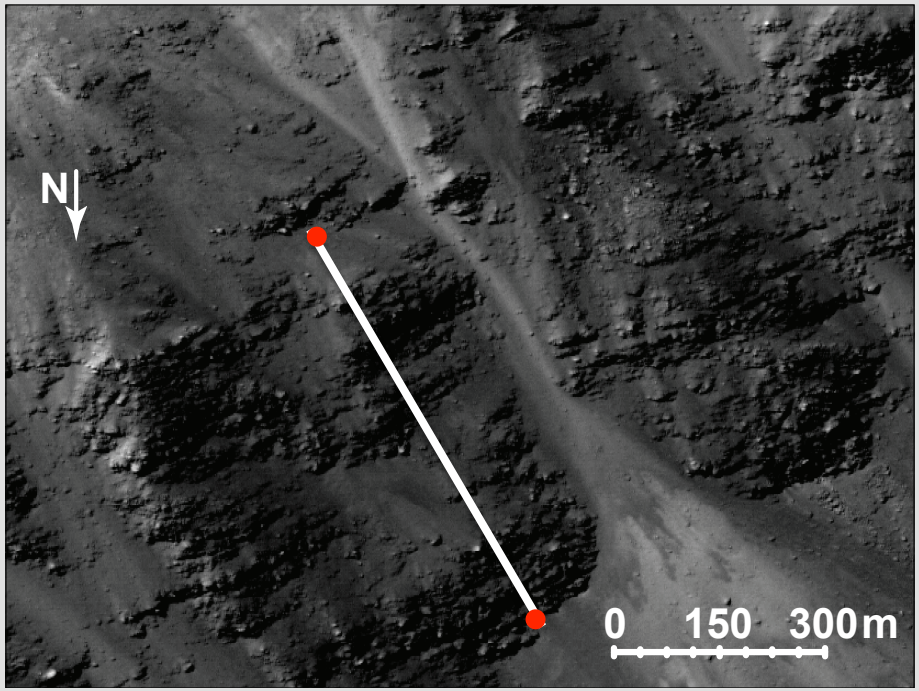
Lunar Remote Sensing

Dawes Crater – 32 km diameter





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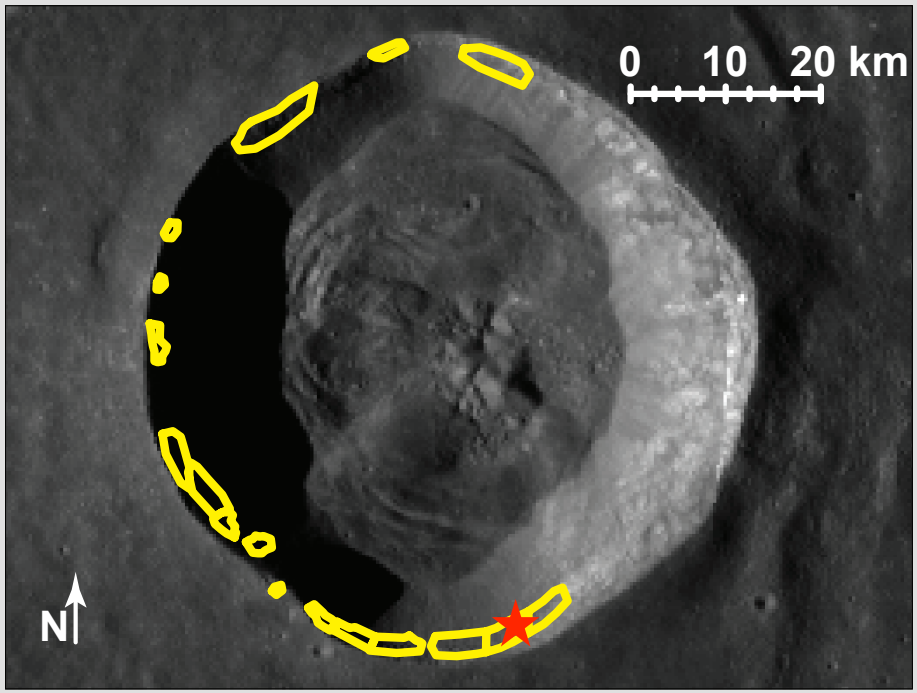
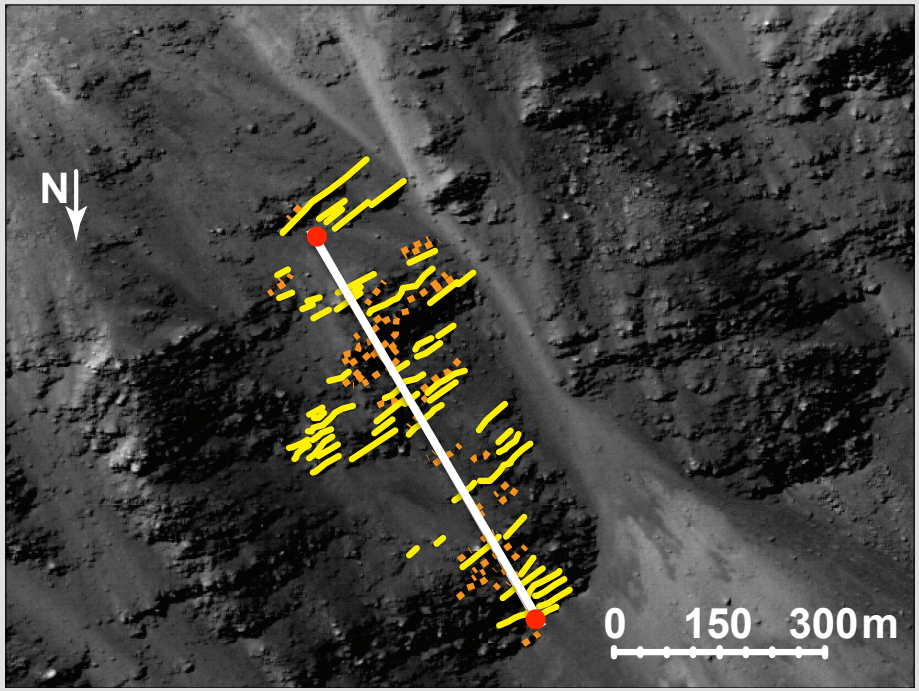
Lunar Remote Sensing

Dawes Crater – 32 km diameter





NASA/GSFC/ Arizona State University

LOLA elevation / # flows = avg. thickness

Lunar Remote Sensing

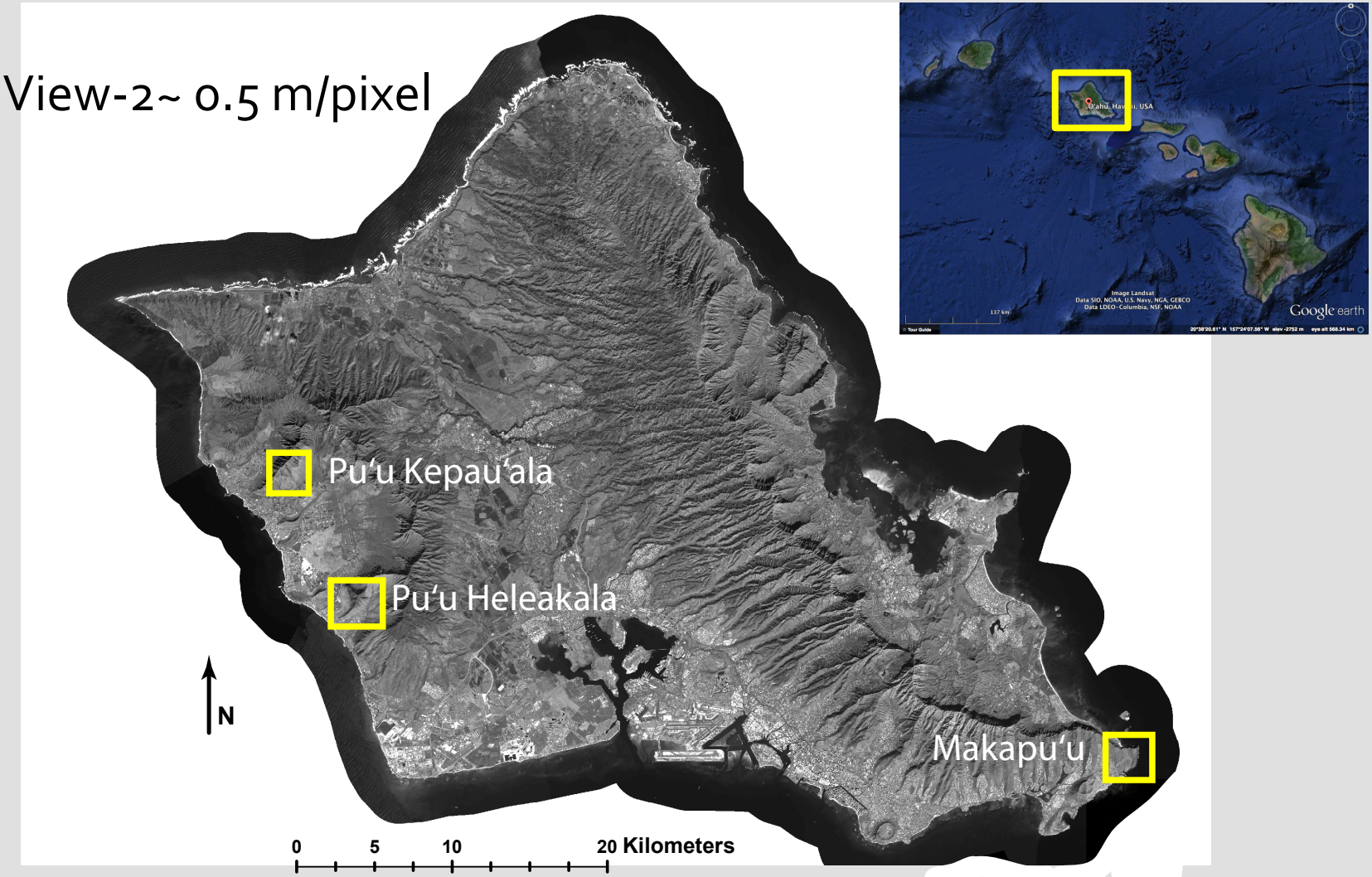
Crater	Number of Transects	Max. Flow Thickness ±St. Dev. (m)	Min. Flow Thickness ±St. Dev. (m)
Dawes	10	23.5 ±12.3	4.2 ±3.0
Kepler	28	17.0 ±7.5	5.3 ±1.8
Bessel	4	20.3 ±5.9	8.2 ±3.1
Lichtenberg	4	16.7 ±6.5	6.7 ±1.9

Other measurements: 2-5 m; 6-25 m

[*Robinson et al.*, 2012; *Enns & Robinson*, 2013]

Terrestrial Remote Sensing

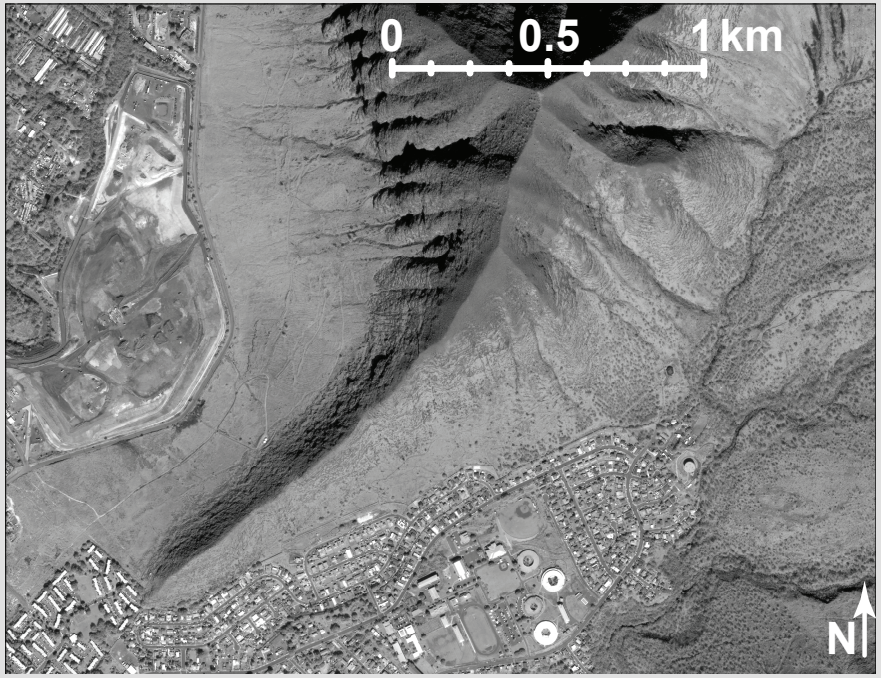
- WorldView-2~ 0.5 m/pixel



DigitalGlobe

Terrestrial Remote Sensing

Pu'u Heleakalā, West O'ahu

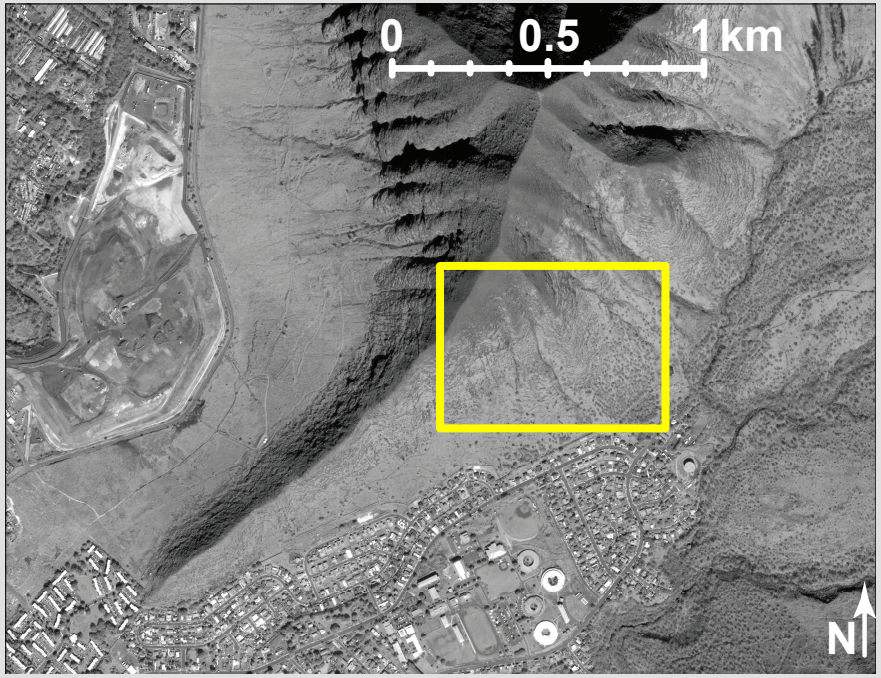


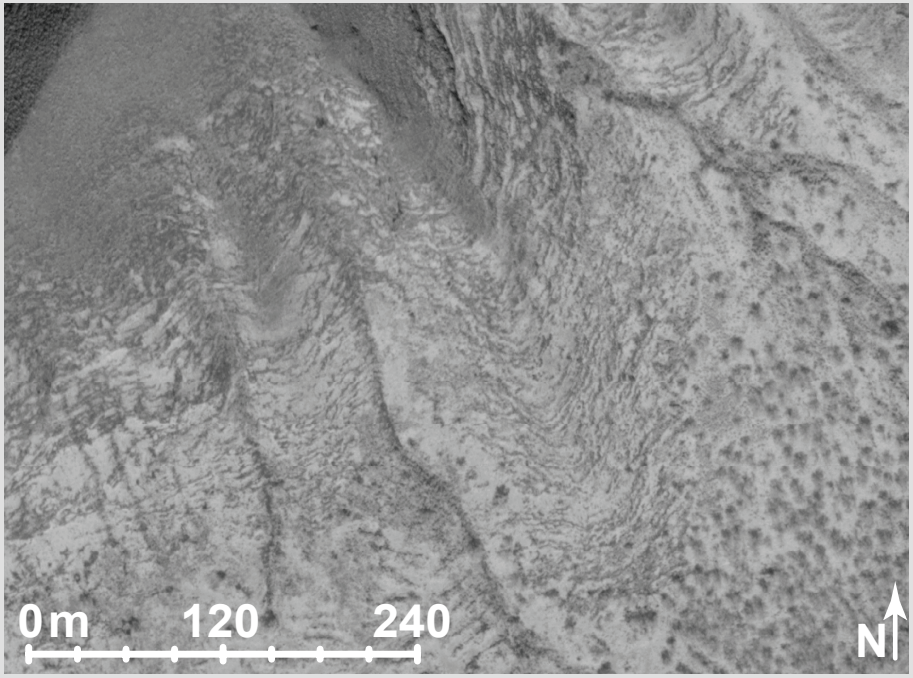
- Criteria
  - WorldView-2 coverage
  - Laterally continuous layering
  - Accessible (land owner, slope)

DigitalGlobe

Terrestrial Remote Sensing

Pu‘u Heleakalā, West O‘ahu

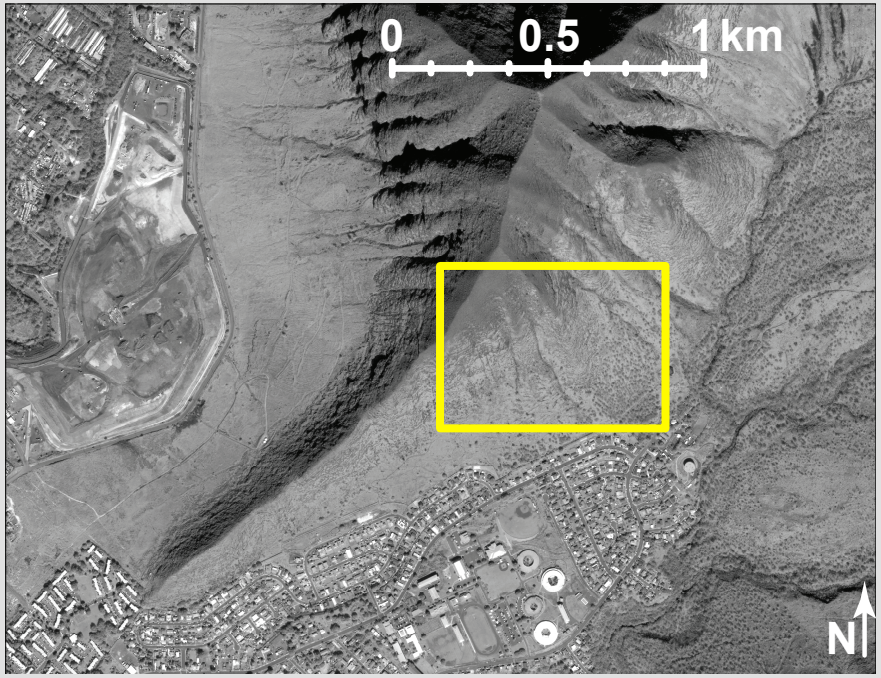


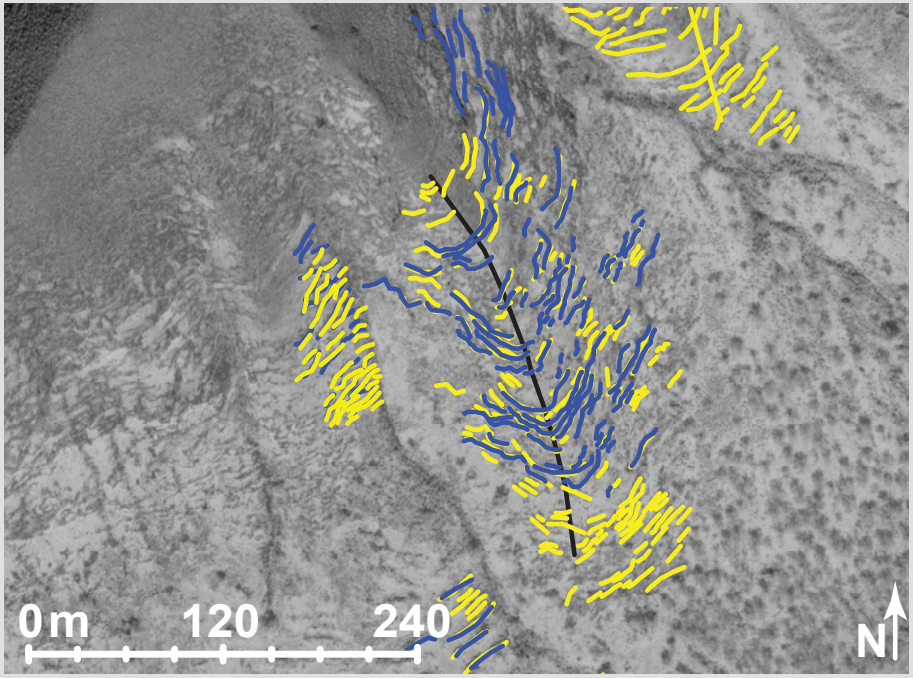


DigitalGlobe

Terrestrial Remote Sensing

Pu'u Heleakalā, West O'ahu





DigitalGlobe

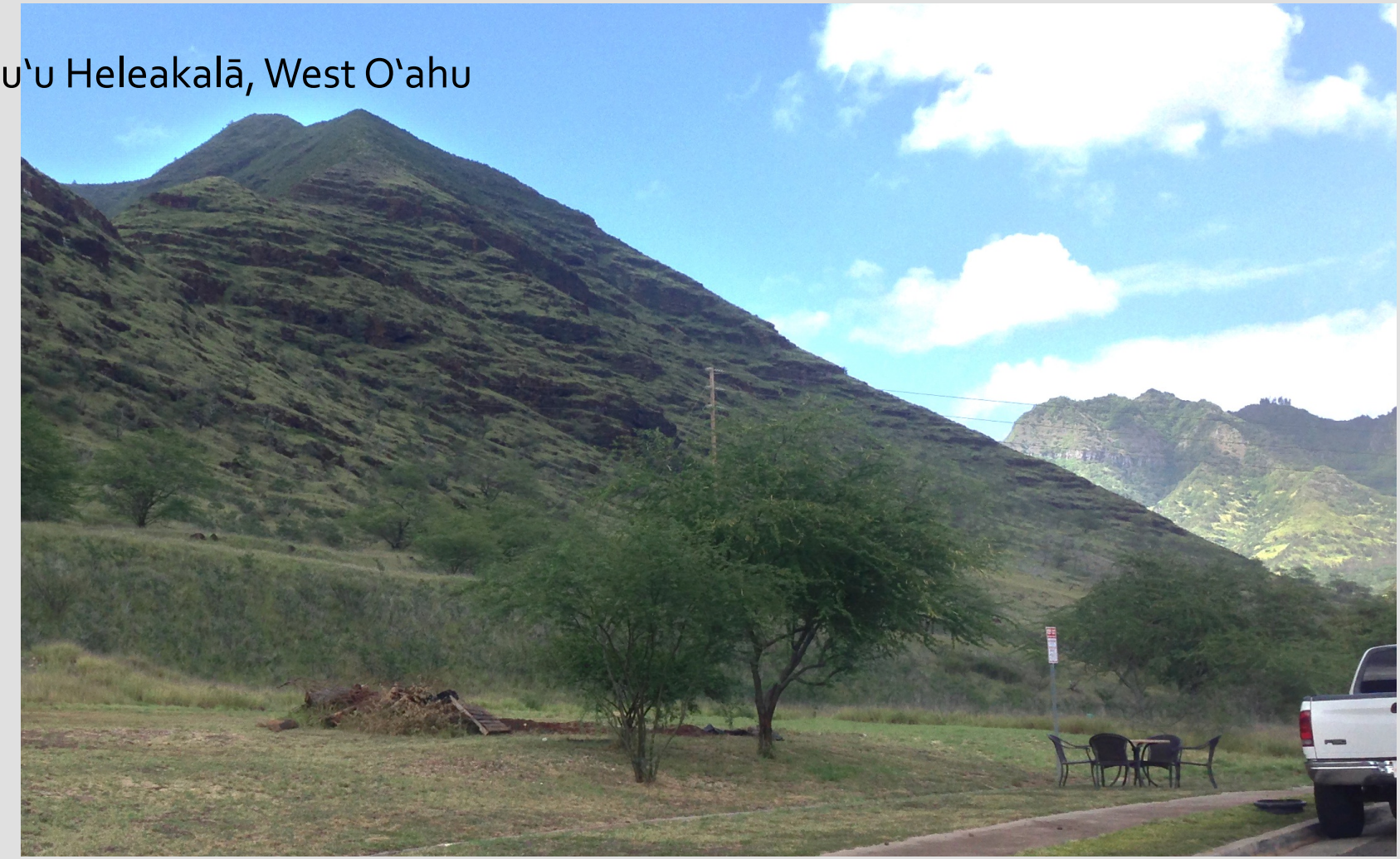
USGS elevation / # flows = avg. thickness

Terrestrial Remote Sensing

Location	Number of Transects	Max. Flow Thickness ±St. Dev. (m)	Min. Flow Thickness ±St. Dev. (m)
Puʻu Heleakalā	2	7.4 ±3.0	3.6 ±1.6
Puʻu Kepauʻala	3	7.7 ±1.7	4.1 ±0.7
Makapuʻu	3	3.2 ±0.3	2.0 ±0.4

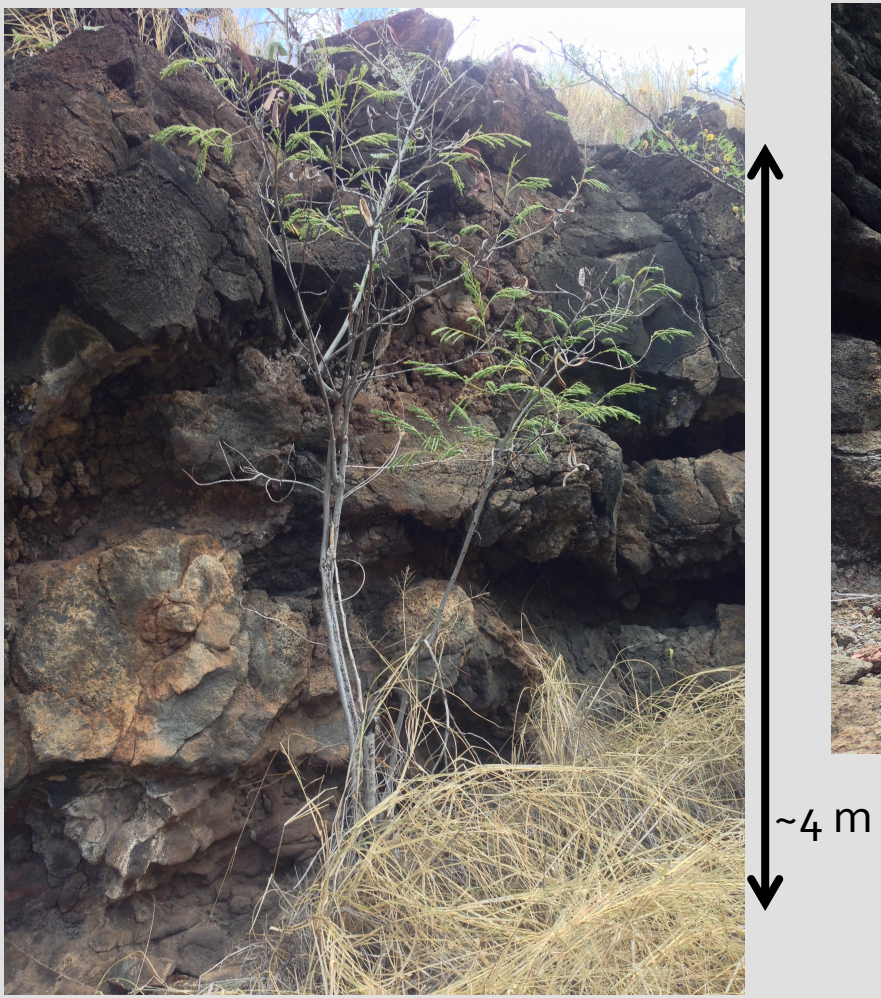
Terrestrial Ground Truthing

Pu‘u Heleakalā, West O‘ahu



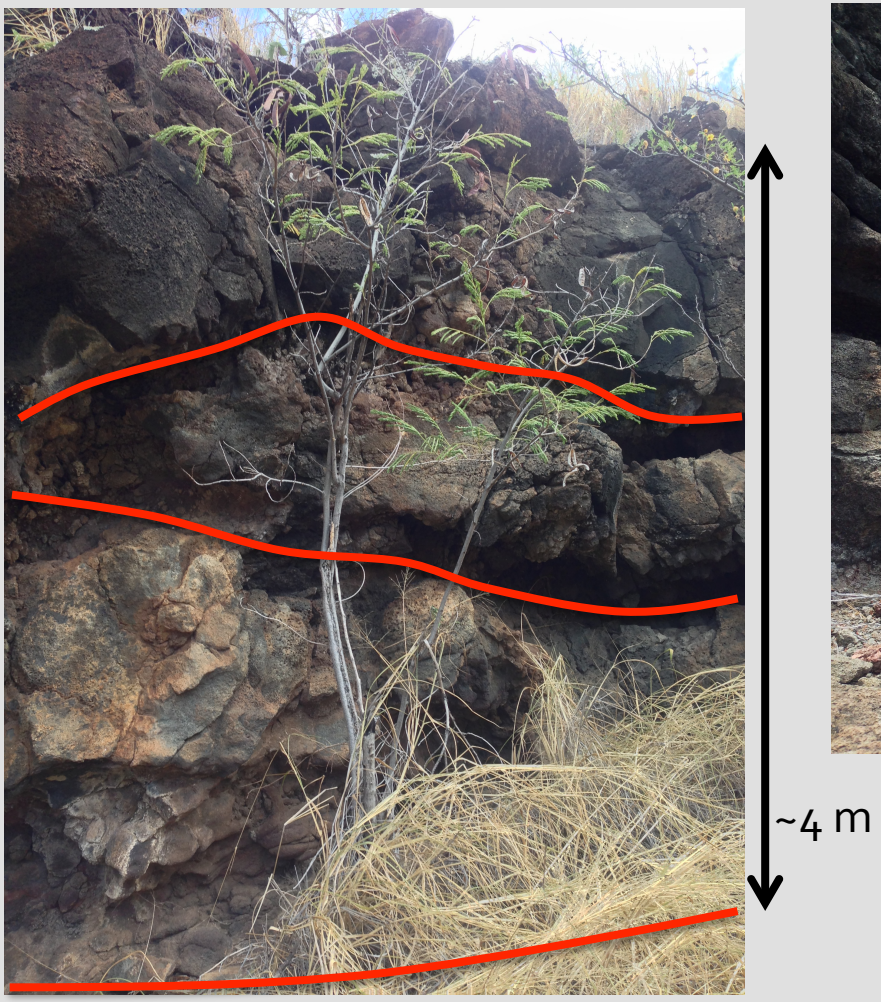
Terrestrial Ground Truthing

Outcrop Observations



Half of all measured outcrops contain more than one lava flow unit.

Outcrop Observations



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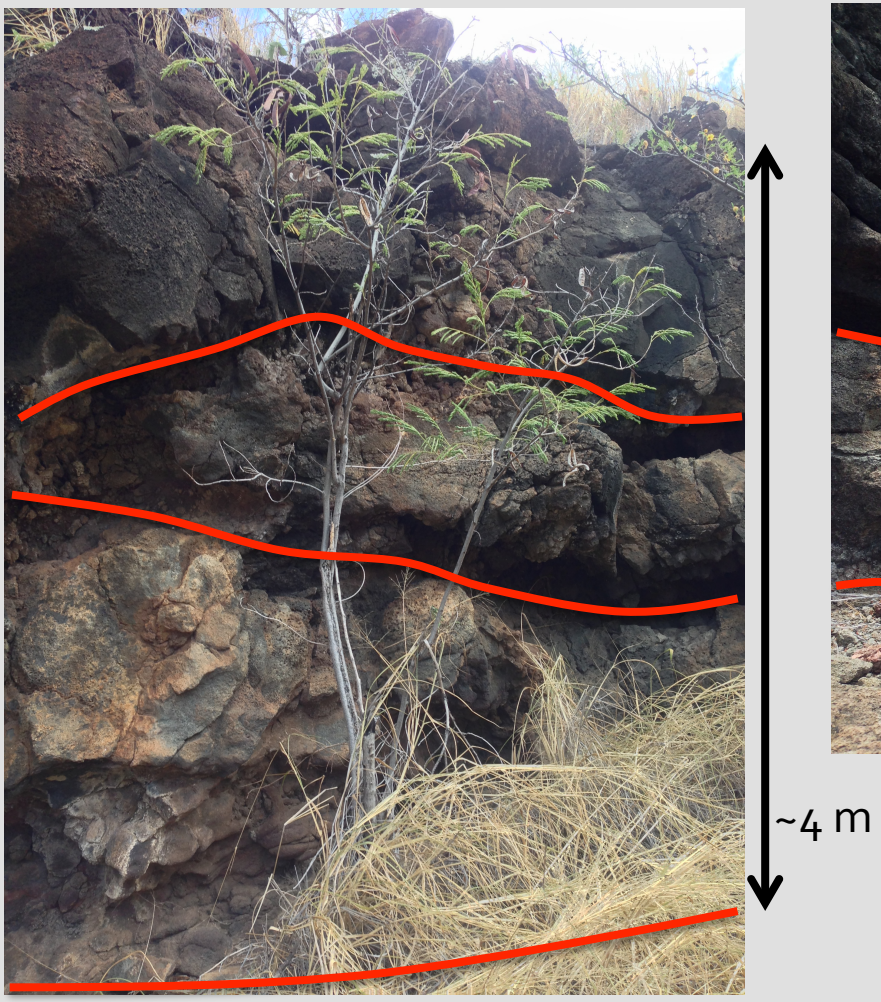

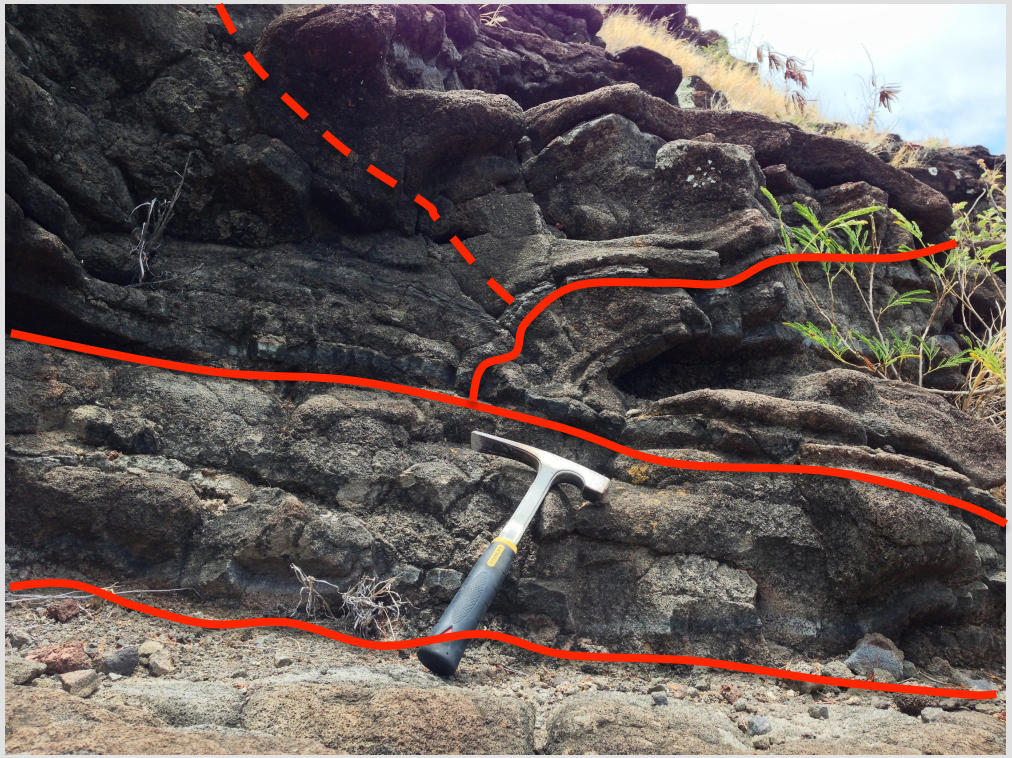

Half of all measured outcrops contain more than one lava flow unit.

Terrestrial Ground Truthing

Location	Transect	Average Flow Thickness (m)	Ratio Max. Satellite/Field Flow Thickness	Ratio Min. Satellite/Field Flow Thickness
Puʻu Heleakalā	1	1.5	2.7	1.2
	2	1.6	6.3	3.1
Puʻu Kepauʻala	1	1.7	5.1	2.8
	2	1.9	4.5	2.1
	3	2.7	1.6	1.0
Makapuʻu	1	1.4	2.0	1.1
	2	2.6	1.3	0.9
	3	2.4	1.5	1.0

Terrestrial Ground Truthing

Location	Transect	Average Flow Thickness (m)	Ratio Max. Satellite/Field Flow Thickness	Ratio Min. Satellite/Field Flow Thickness
Pu'u Heleakalā	1	1.5	2.7	1.2
	2	1.6	6.3	3.1
Pu'u Kepau'ala	1	1.7	5.1	2.8
	2	1.9	4.5	2.1
	3	2.7	1.6	1.0
Makapu'u	1	1.4	2.0	1.1
	2	2.6	1.3	0.9
	3	2.4	1.5	1.0

Image interpretations overestimate flow thickness

Terrestrial Summary

- Satellite layer counts are similar to number of outcrops, not number of flows.
- Outcrops, not individual flow units, are counted in satellite images.
- ½ of measured outcrops include more than one flow unit.
  - Up to 5 units in one outcrop.
- Thicknesses of lava flows are overestimated using remote sensing data (here, by factors up to 6.3).

Lunar Implications

- Lunar outcrops may similarly contain more than one flow unit.
- Measurements interpreted from remote sensing techniques are likely overestimating mare flow thicknesses.
- Lunar flow unit thickness measurements should be interpreted as maximum thickness estimates.
- Misinterpretations may lead to erroneous estimates of rheology and emplacement and misrepresentation of volatile preservation.
  - Jeffery's Equation, $V = \rho g h^2 / B \eta \sin\alpha$ [*Jeffery*, 1922]