Modeling the Construction and Evolution of Distributed Volcanic Fields on Earth and Mars

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Acknowledgements

Some Collaborators

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Judy McIlrath	Jake Bleacher
Paul Wetmore	Lori Glaze

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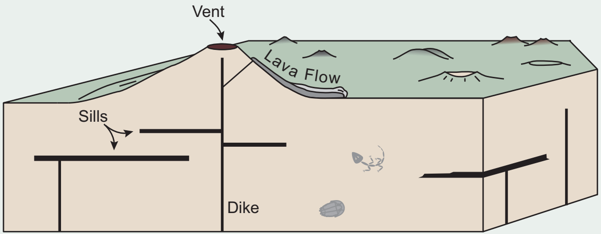
Distributed-style Volcanism

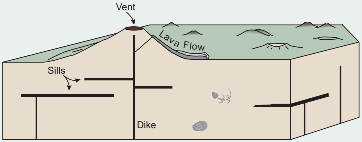
Characteristics

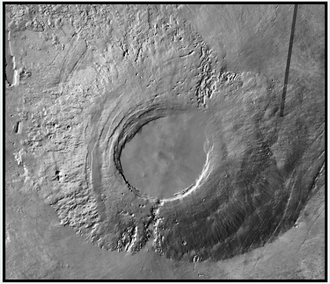
- Clusters of volcanoes are formed, sometimes associated with large volcanoes
- New eruptions form new vents
- Eruptions are fed by small volume batches of magma
- Long periods of quiescence



Outline of Talk

- Volcanic fields, from the inside out
  - The role of sills in the formation of volcanic fields (Richardson et al., *Geology*, 2015)
  - The spatial organization of vents in volcanic fields (Richardson et al., *LPSC*, 2012)
  - Simulating lava flow emplacement (Kubanek et al., *Bull. Volc.*, 2015)
- Evolution of volcanism at Arsia Mons
  - Can its recent rate of volcanism be determined by studying a volcanic field with only satellite data?
- Conclusions

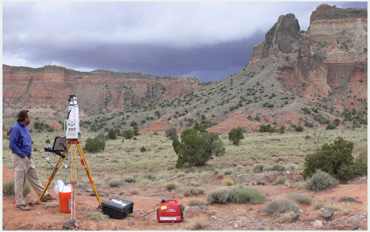




The Igneous Plumbing System

San Rafael Volcanic Field, Utah

- Pliocene volcanic activity
- Now eroded to depth of ∼1 km
- Sills and Dikes exposed



Chuck Connor with a Terrestrial Lidar (L. Connor)

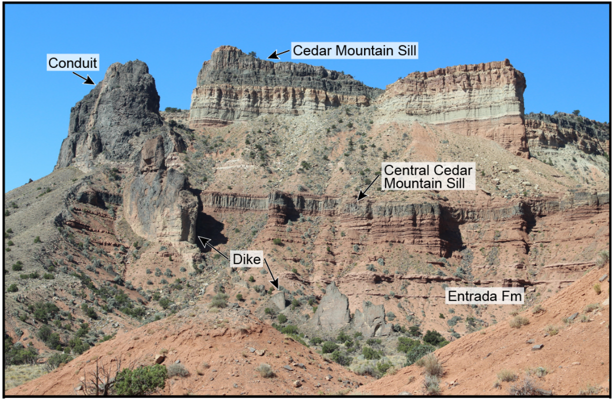
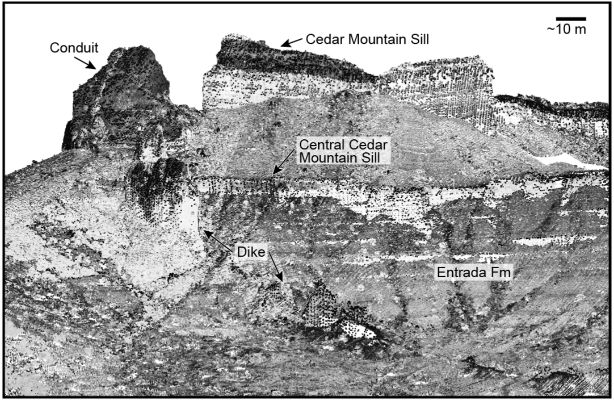


Photo Credit: Judy McIlrath

The Igneous Plumbing System

Results of lidar survey

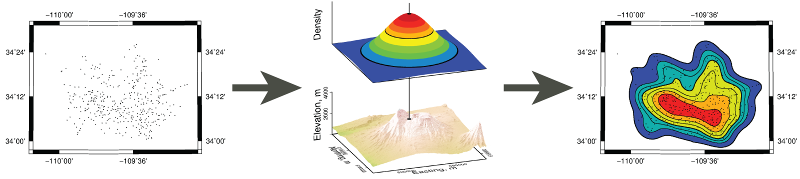
- Sill volume comparable to volume thought to have erupted at surface
- Sills had ability to modulate eruption style by interacting with volcanic conduits
- Conduits deliver magma from depth to distributed volcanoes



Richardson et al., Geology, 2015

Volcano organization in fields

The spatial organization of volcanoes is modeled as a density function



A plot of every volcanic vent location in the San Francisco Volcanic Field

Drape a Gaussian Kernel Function over each vent

Add each function to coalesce a density model

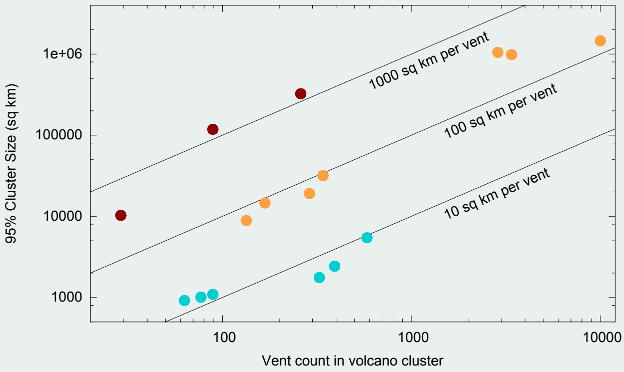
- Area of volcanic field defined as 95^{th} percentile of density function

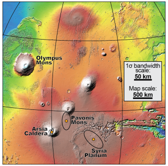
$$\text{Average vent intensity} = \frac{\#\ \text{volcanic vents}}{\text{field area}}$$

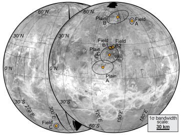
- This model is applied to fields on Earth, Mars, and Venus

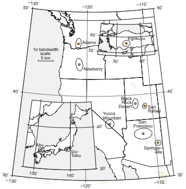
Vent Spatial Intensity across the Solar System

Average Vent Intensity, Colored by Planet

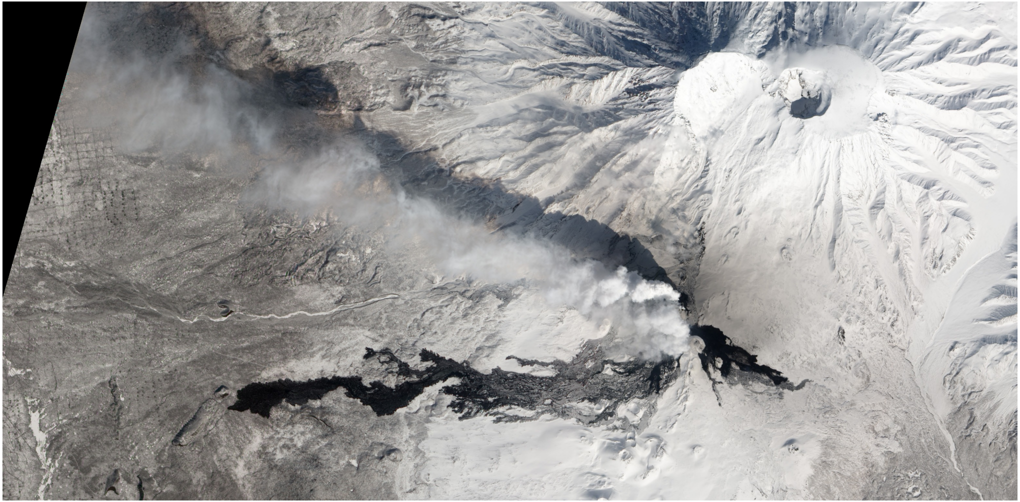








The 2012-3 Tolbachik Lava Flow



NASA Earth Observing-1 Mission, 1 February 2013

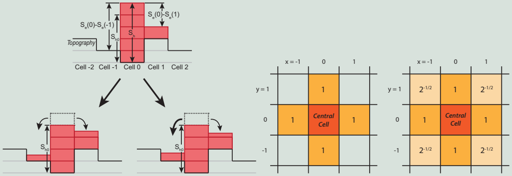
Lava Flows/Simulators

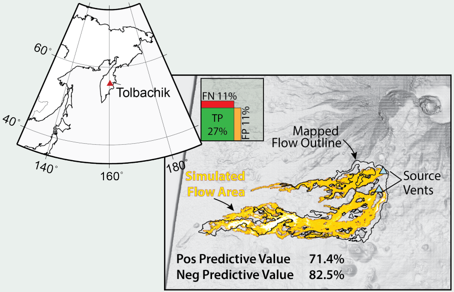
MOLASSES — Modular Lava Simulation Software

- MOLASSES developed after Connor et al., *JAV*, 2012
- Spreads lava over a grid according to universal rules

Using TanDEM-X satellite data, flow simulations match the 2012-3 Tolbachik flow between 70-85%.

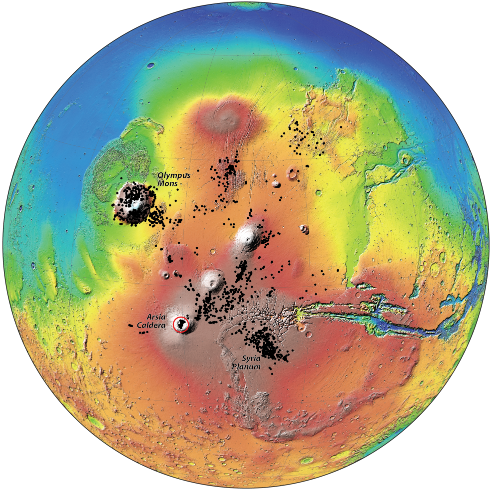
Optional Spreading Rules





Kubanek et al., Bull. Volc., 2015

Distributed Volcanism of the Tharsis Volcanic Province



Tharsis Vent Catalog

- >1,000 small volcanic vents cataloged

(Richardson et al., *JVGR*, 2013, Bleacher et al., *JVGR*, 2009)

- Groups of vents form isolated clusters

Research Questions

- How does distributed-style volcanism occur over time and space in Tharsis?
- How do volcanic fields relate to the larger volcanoes on Mars?

Arsia Mons

- Large ($1.5 \cdot 10^6$ km^3) shield volcano with 110 km diameter caldera
- A cluster of volcanic vents lay in the caldera!

Motivation

What are the recurrence rate of volcanism and delivery rate of magma to the surface?

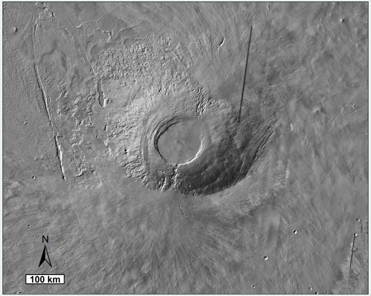
Arsia Mons Overview

Recurrence Rate and Magma Delivery Rate

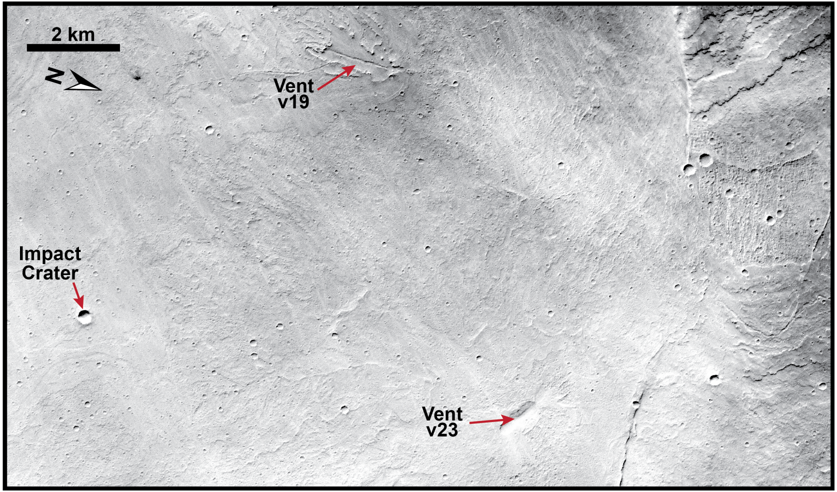
$$\text{Recurrence Rate} = \frac{\text{Number of Events - 1}}{\text{Time elapsed}}$$

$$\text{Delivery Rate} = \frac{\text{Total Volume}}{\text{Number of Events}} \times \text{Recurrence Rate}$$

- Lavas from these vents can be mapped to estimate volume and timing of emplacement

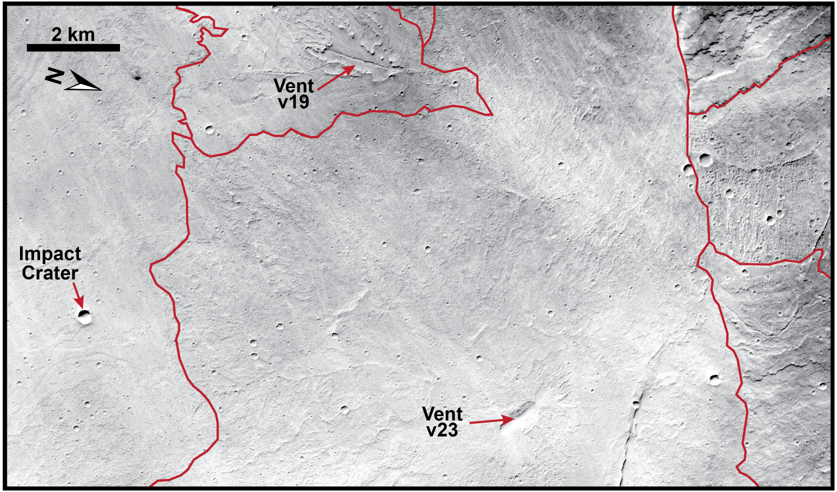


Mapping Volcanic Vents



CTX Image: G10_022160_1710_XN_09S120W (NASA/JPL-Caltech/MSSS)

Mapping Lava Flows



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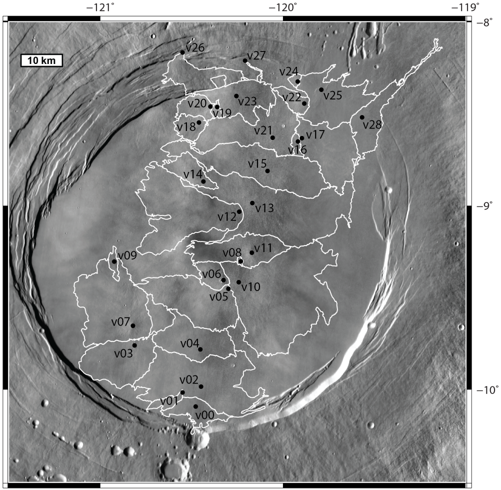
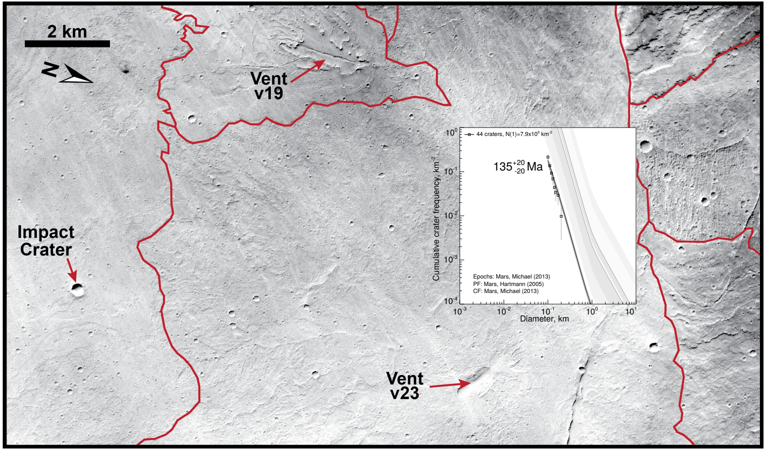
Lava Flow Map of Arsia Mons' Caldera



Mapping results

- 29 vents are cataloged, each with long lava flows
- Lava flow areas are 10s–100s km^2
- Flow thicknesses assumed to be 10–80 m (Mouginis-Mark & Rowland, Icarus, 2008)
- From this, volumes estimates range from 10^{-2}–70 km^3

Ages: Crater Counting



CTX Image: G10_022160_1710_XN_09S120W (NASA/JPL-Caltech/MSSS)

Impact craters on each flow are cataloged

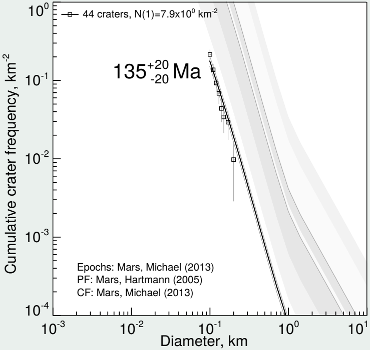
More craters generally indicates older age

Ages and uncertainties modeled in *craterstats2* (Michael, *Icarus*, 2013)

Ages: Crater Counting

Ages of flow emplacement are modeled as Normal Distributions

- Estimated age from *craterstats2* is used as the Mean Value
- Age Uncertainty is Standard Deviation



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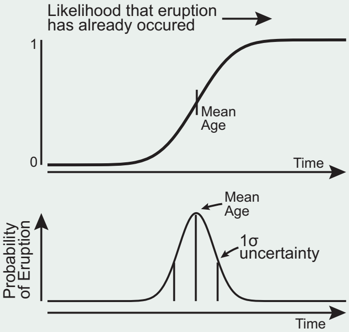
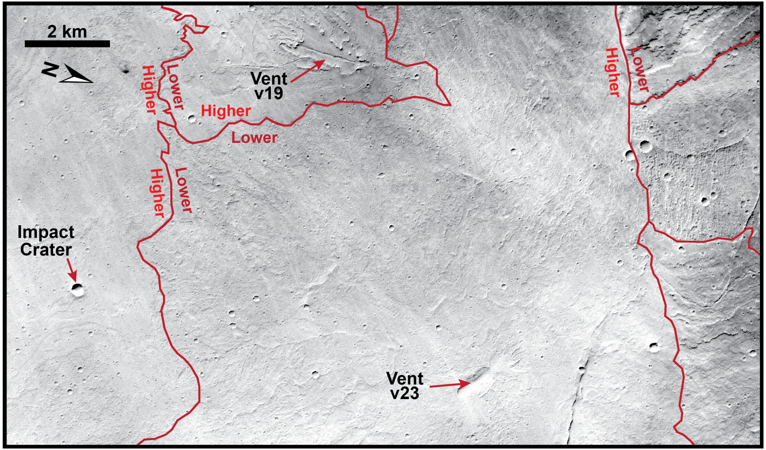


Ages: Stratigraphy

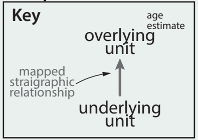


CTX Image: G10_022160_1710_XN_09S120W (NASA/JPL-Caltech/MSSS)

Stratigraphic relationships relatively date events.

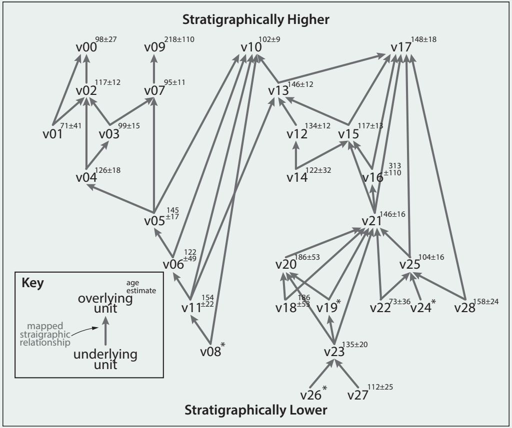
Lava from v19 overlies v23 lavas

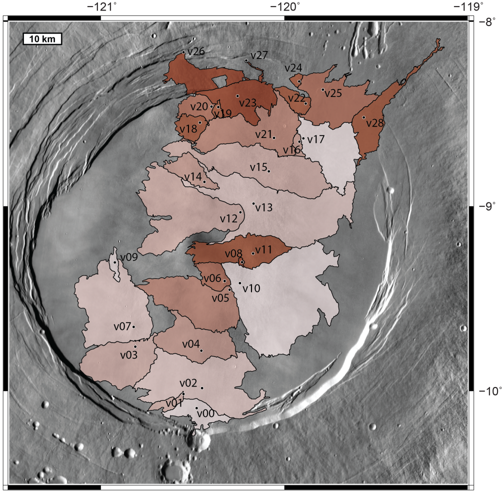
Graphical Form:



Combined Age Information

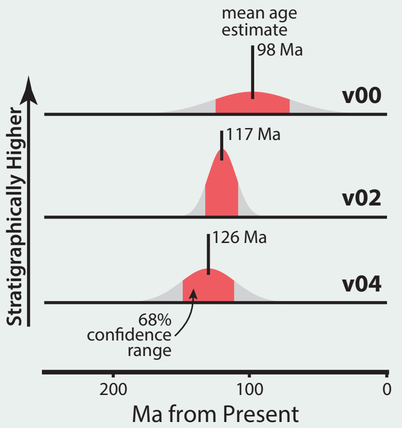
Stratigraphy "Web"

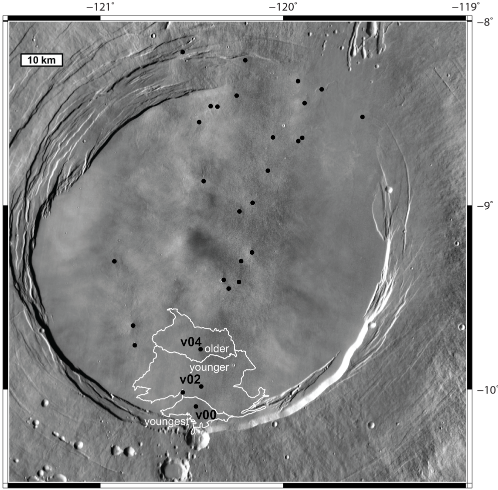




Ages: Information Conflicts

Mean crater ages can agree stratigraphy...



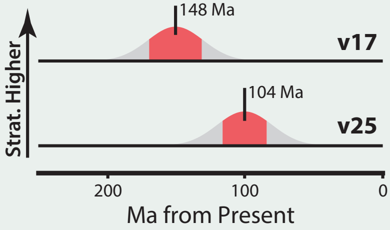


![USF School of Geosciences]

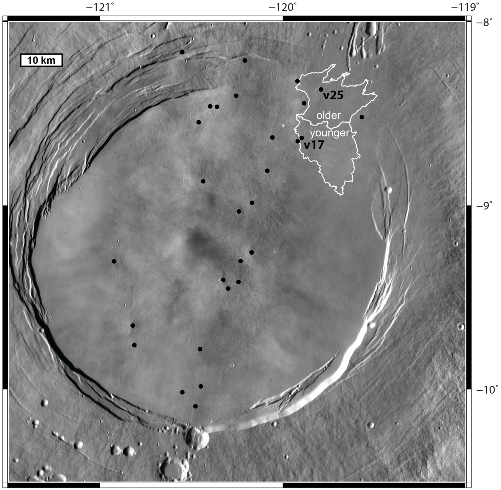
Ages: Information Conflicts

Volcanic Fields on Earth & Mars
Jacob Richardson
Introduction
Overview
Sills
Vent Intensity
Lava Flows
Arsia Mons Volcanic Field
Methods
Results
Implications
Conclusions

...or mean age can disagree with strat.



But by probabilistically modeling age, possible ages can still be identified



Volcanic Event Recurrence Rate Model (VERRM)

Step 1: Find potential ages of all events in the field (Monte Carlo)

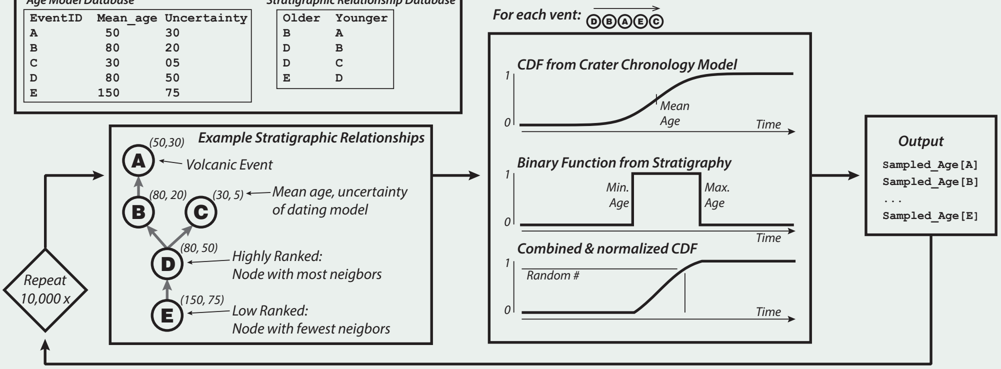
Input Files

Age Model Database

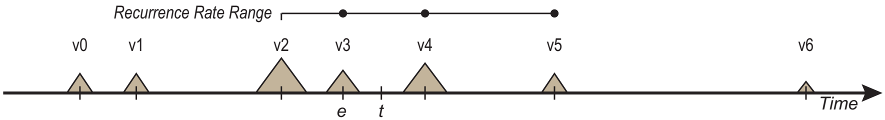
EventID	Mean_age	Uncertainty
A	50	30
B	80	20
C	30	05
D	80	50
E	150	75

Stratigraphic Relationship Database

Older	Younger
B	A
D	B
D	C
E	D



Volcanic Event Recurrence Rate Model (VERRM)



Step 2: Calculate Recurrence Rate of Volcanism

For each Monte Carlo simulation (i.e. each set of potential ages), model Recurrence Rate (RR) through time:

$$\mathrm{RR}(t) = \frac{3}{\mathrm{T}_{e-1} - \mathrm{T}_{e+2}}$$

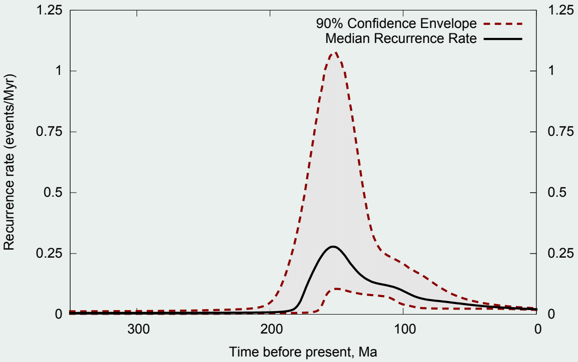
Step 3: Calculate Magma Delivery Rate

Model Magma Delivery Rate (Flux) through time:

$$\mathrm{Flux}(t) = \frac{\mathrm{Volume}_e}{\mathrm{T}_e - \mathrm{T}_{e+1}}$$

Results

Recurrence Rate through time

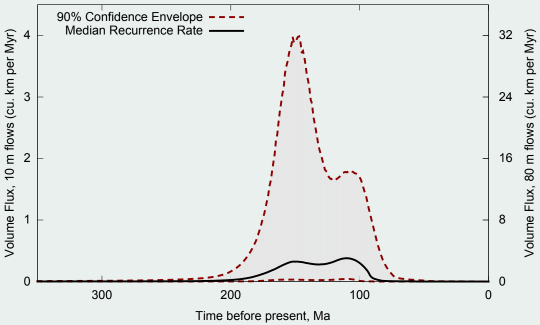


- All 10,000 Recurrence Rate functions are combined
- Rate peaks at 150 Ma, producing 1 vent per 1-10 Myr (Median value: 0.25 events Myr^{-1})
- Rate has decreased monotonically: RR$(t = 0) \to 0$

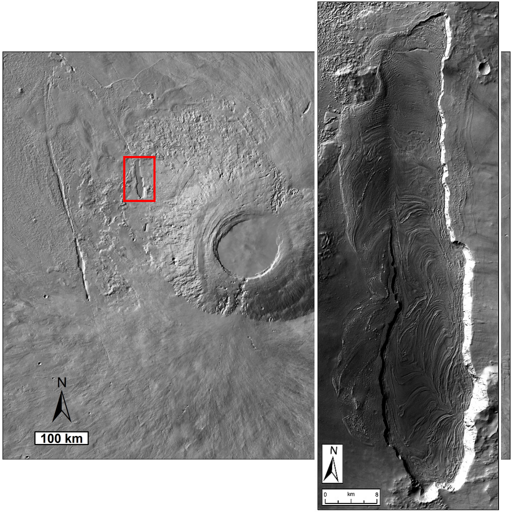
Volume Flux

Magma Delivery Rate through time

- All 10,000 Magma Delivery Rate functions are combined
- Median rate plateaus at at 150 Ma (0.4-3 km^3 Myr^{-1}), remains steady until 100 Ma before rapidly waning.
- Uncertainty in magma delivery rate is about 1 order of magnitude to either side of the median



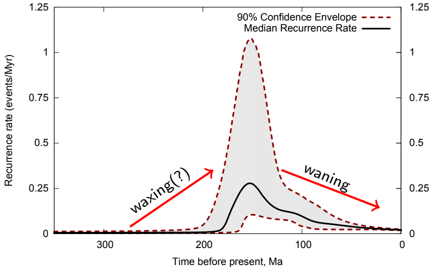
Tie-in with ashes and glaciers

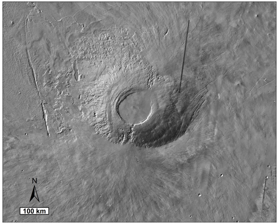


- Extant glaciers are preserved on Western flank of Arsia
- Preserved for ∼200 Ma by ashes (Kadish et al., *P&SS*, 2014)
- If ashes were sourced near-summit (Mouginis-Mark, *GRL*, 2002), our effusive volcanism might be predated by explosive activity

←*from Shean et al., JGR Planets, 2007*

Model of waning volcanism of Arsia





1. Large magma chamber fed edifice-building, sometimes explosive eruptions (Wilson et al., *JGR*, 2001)
2. Ashes coated ice-rich deposits before 200 Ma
3. The chamber cooled from waning magma flux
4. Volcanism evolved from explosive to effusive as magma waned
5. Volcanism is now in haitus $(\mathrm{RR}(t=0) \to 0)$

Conclusions

Arsia Mons

1. Late volcanism at Arsia Mons emplaced a volcanic field in its caldera
2. Multiple dating methods used on lavas can be combined to estimate rate of volcanism, which peaked 150 million years ago
3. Volcanism waned and likely ceased 10-90 million years ago
4. This field might be related to a larger waning of volcanism at Arsia
5. Vents in this field are less concentrated than vents in terrestrial volcanic fields
6. Lava flows are an order of magnitude larger in volume than flows in most terrestrial fields

Conclusions

Overall Conclusions

- Volcanic fields have complex, voluminous roots
- Emplacement of lavas in these fields can be modeled
- Volcanic vent distribution in fields has a wide variation across the solar system
- These tools can be used to gain knowledge about volcanic fields on Mars with spaceborne instruments