

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction
Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

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

Jacob A. Richardson

School of Geosciences
University of South Florida

19 February 2016

Acknowledgements

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons

Volcanic Field

Methods

Results

Implications

Conclusions

Some Collaborators

Chuck Connor

Laura Connor

Sylvain Charbonnier

Judy McIlrath

Paul Wetmore

James Wilson

Lis Gallant

Julia Kubanek

Jake Bleacher

Lori Glaze

Funding Agencies

NASA Mars Data Analysis Program

NSF SSI

Introduction

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

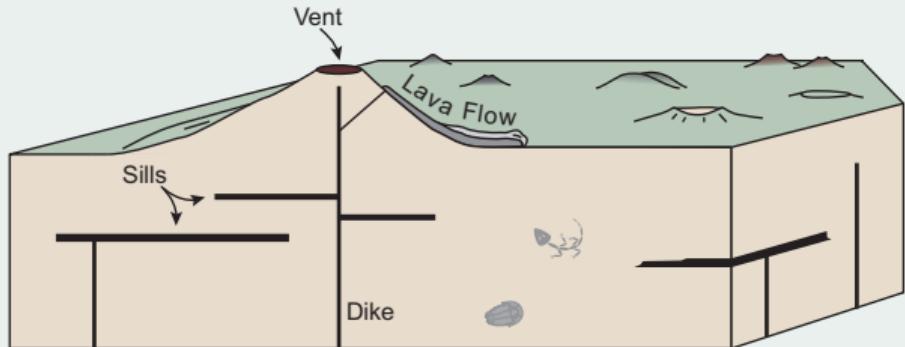
Methods
Results
Implications

Conclusions

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 on
Earth & Mars

Jacob
Richardson

Introduction

Overview

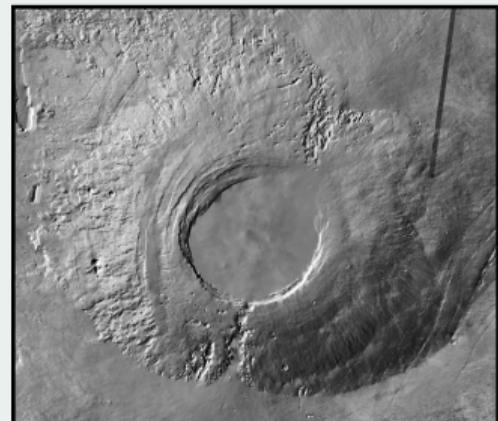
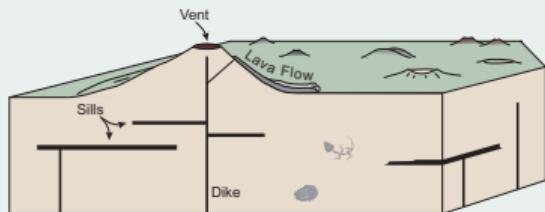
Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

- 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
 - Simulating lava flow emplacement (Kabanek et al., *Bull. Volc.*, 2015)
- Evolution of volcanism at Arsia Mons
 - Major Mars Volcano with a young volcanic field in its caldera
 - Estimated eruption timing & magnitude
- Conclusions



Sills in the San Rafael Swell

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons
Volcanic Field

Methods

Results

Implications

Conclusions

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

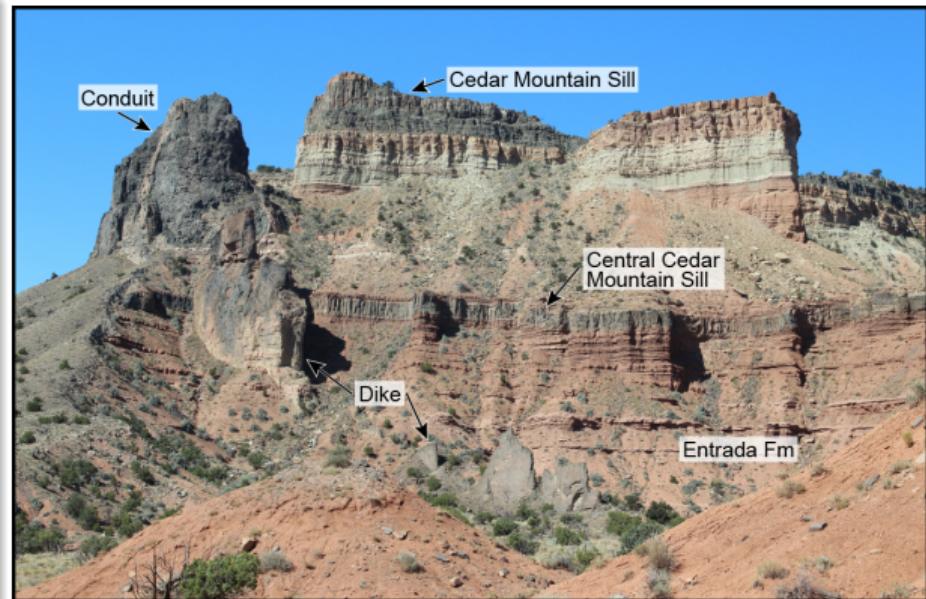


Photo Credit: Judy McIlrath

Sills in the San Rafael Swell

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

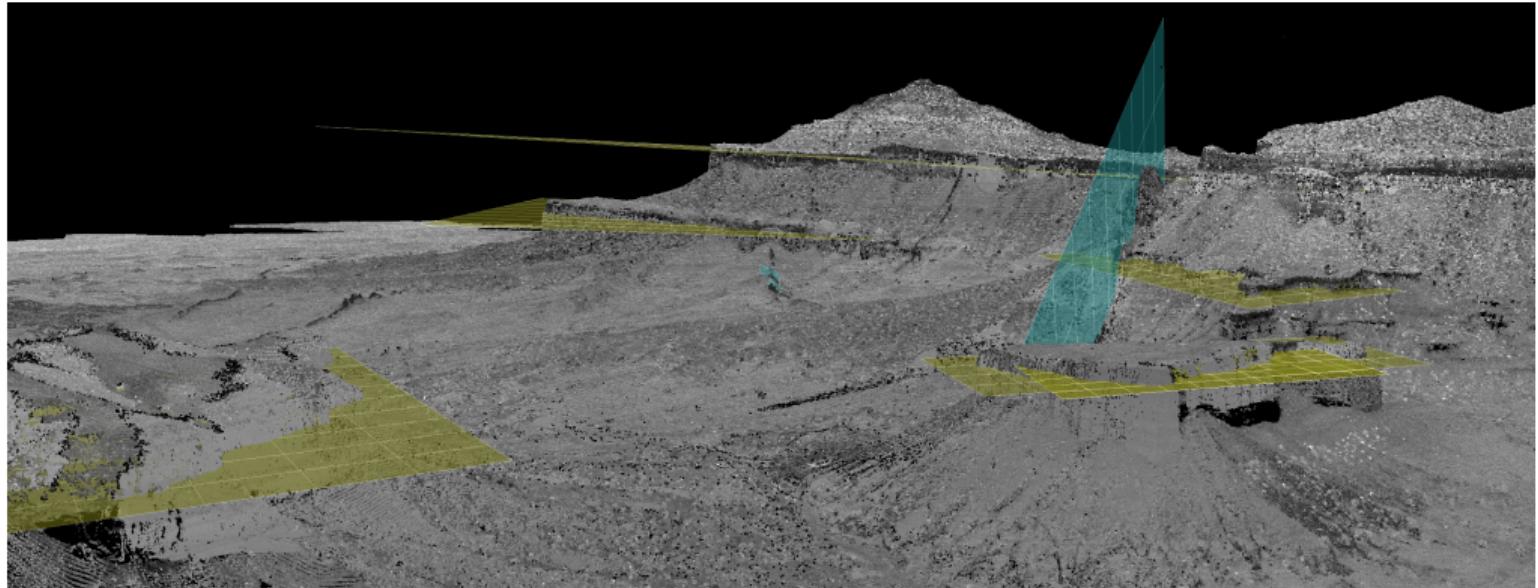
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Richardson et al., *Geology*, 2015



Sills in the San Rafael Swell

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

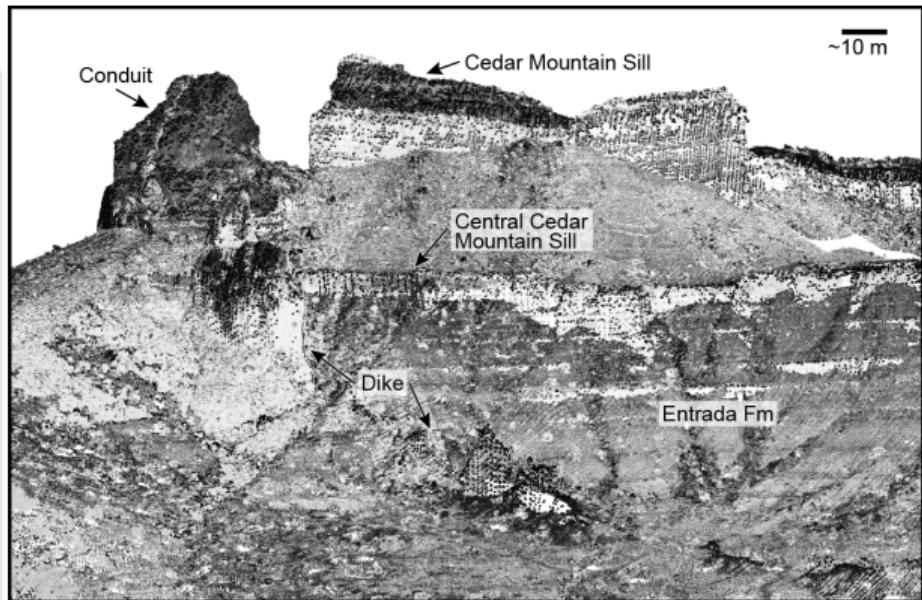
Overview
Sills

Vent Density
Lava Flows

Arsia Mons
Volcanic Field
Methods
Results
Implications
Conclusions

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



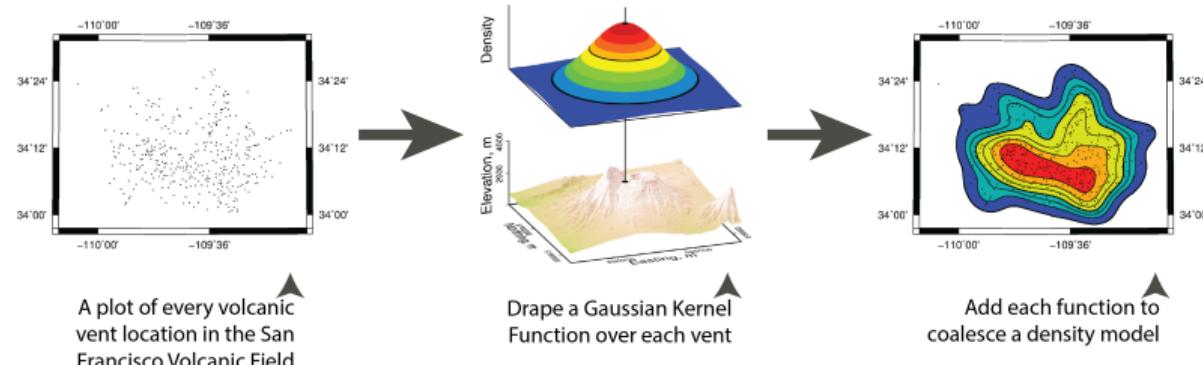
Richardson et al., Geology, 2015

Spatial Density of Clusters

- Spatial density of volcanoes is modeled by Kernel Density Estimation
- Size of volcanic field determined by a set contour (95%)

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

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



Spatial Density of Clusters

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons

Volcanic Field

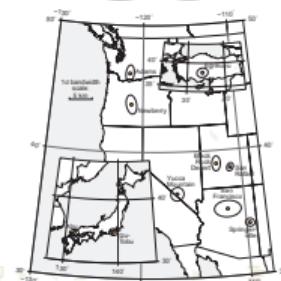
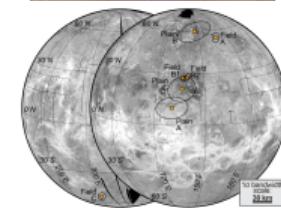
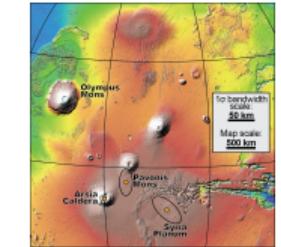
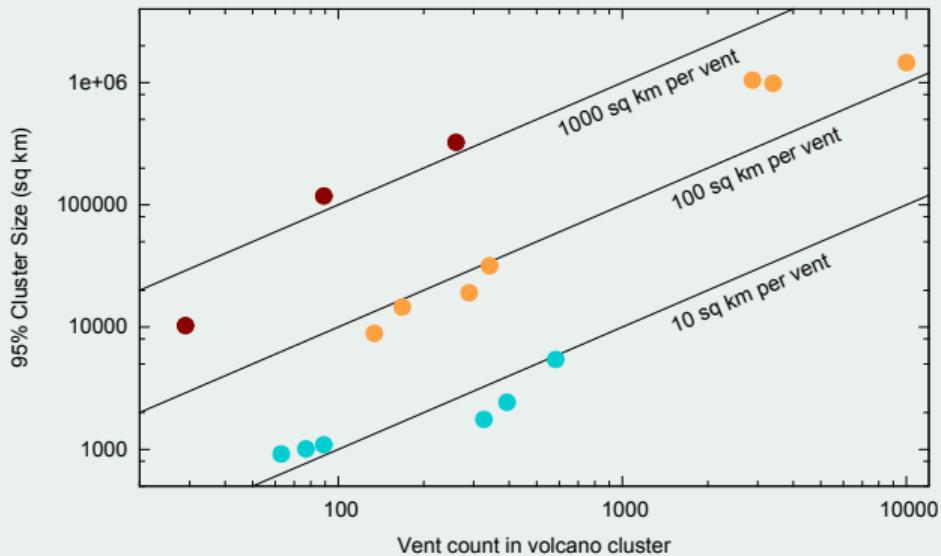
Methods

Results

Implications

Conclusions

Average Vent Intensity, Colored by Planet



Lava Flows/Simulators

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

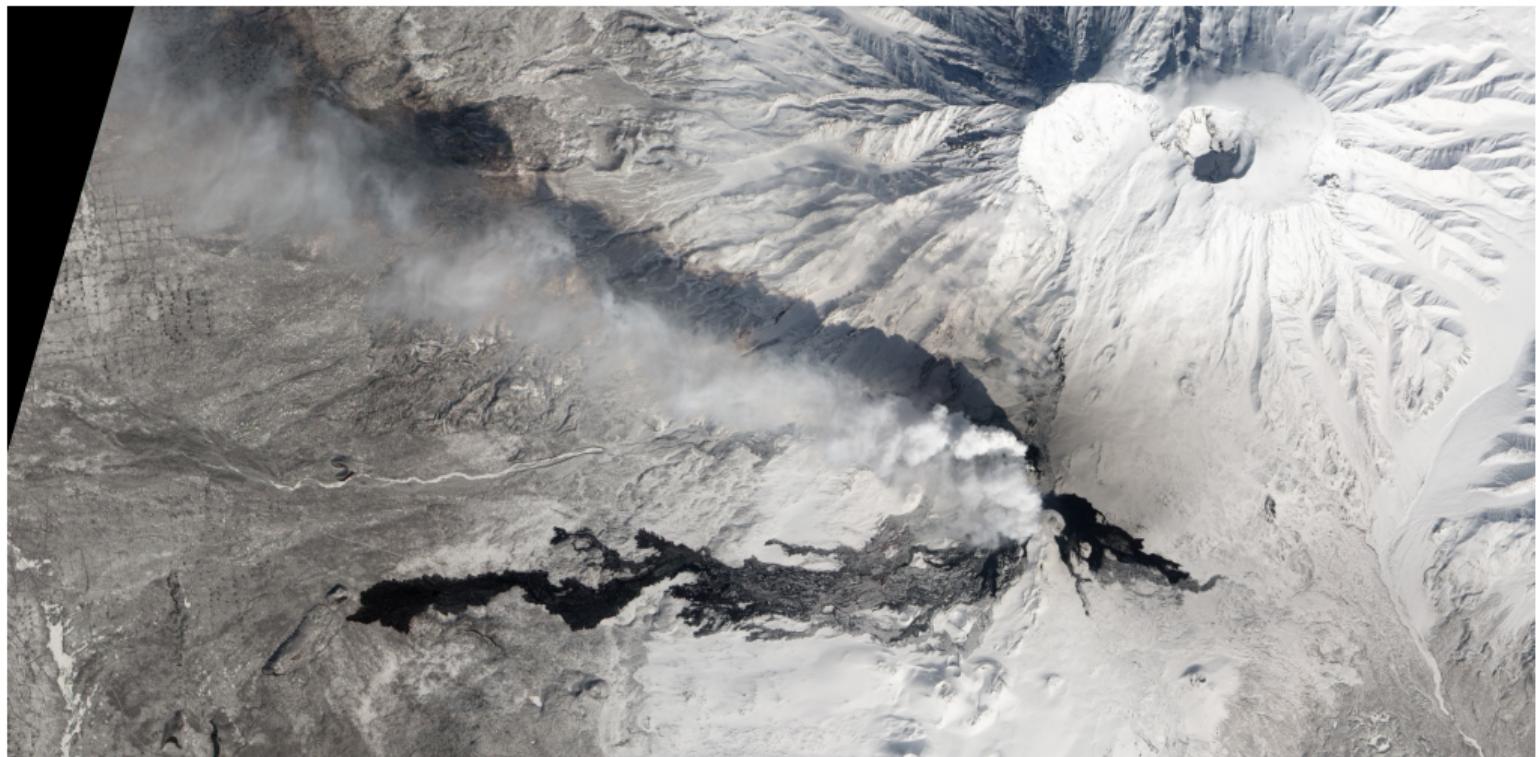
Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field
Methods
Results
Implications

Conclusions



Lava Flows/Simulators

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

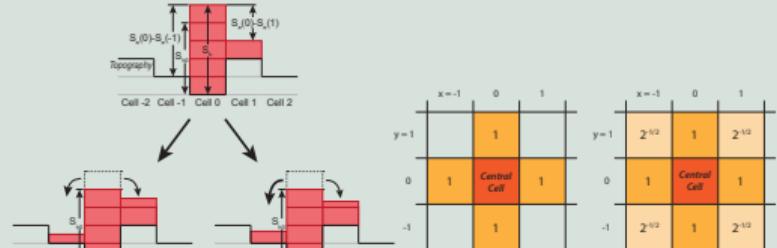
Overview

Sills
Vent Density
Lava Flows

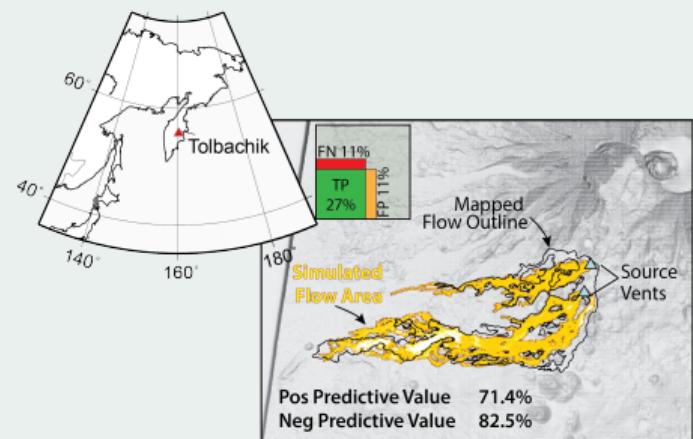
Arsia Mons
Volcanic Field
Methods
Results
Implications
Conclusions

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

Optional Spreading Rules

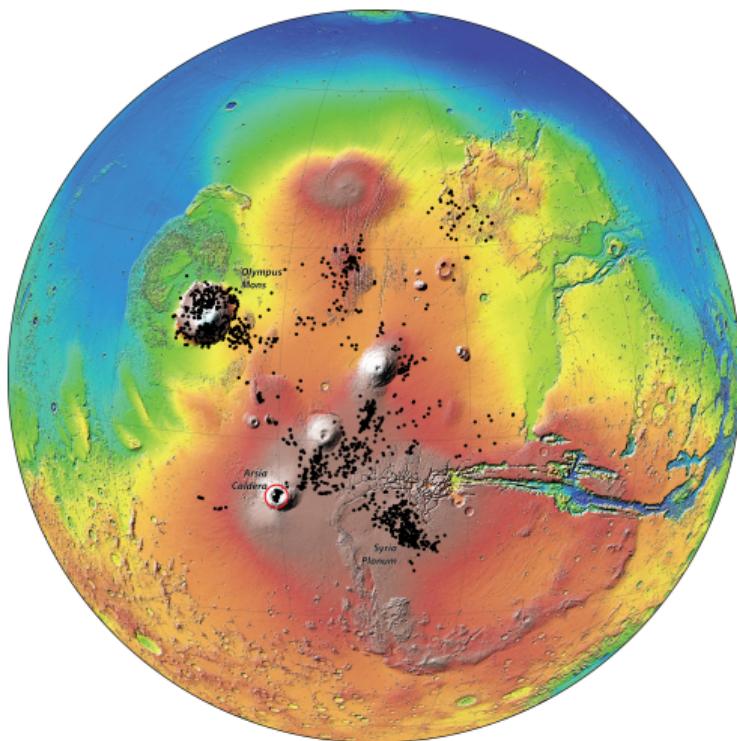


Using TanDEM-X satellite data, flow simulations match the 2012-3 Tolbachik flow between 70-85%.



Kubanek et al., *Bull. Volc.*, 2015

Distributed Volcanism of the Tharsis Volcanic Province



Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons
Volcanic Field

Methods

Results

Implications

Conclusions

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 Overview

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons
Volcanic Field

Methods

Results

Implications

Conclusions

Arsia Mons

- Large ($1.5 \cdot 10^6 \text{ km}^3$) 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

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction
Overview
Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field
Methods
Results
Implications
Conclusions

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
Fields on
Earth & Mars

Jacob
Richardson

Introduction

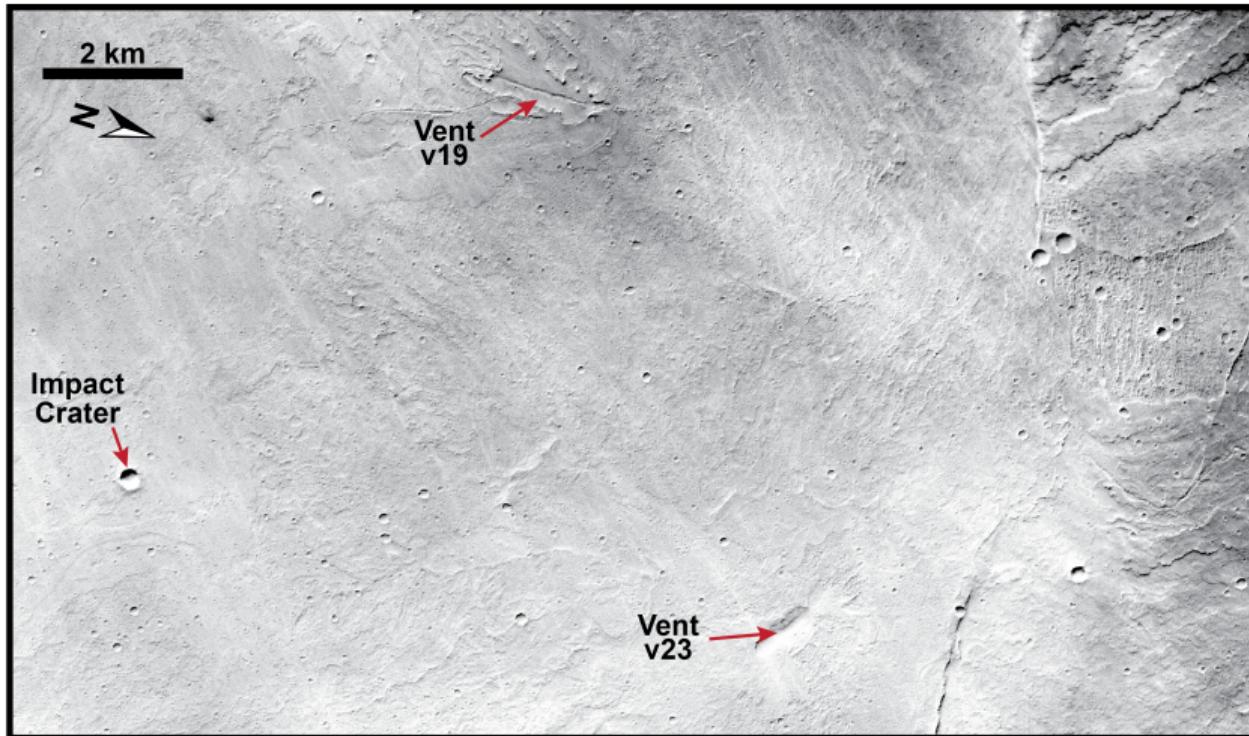
Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions



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

Mapping

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

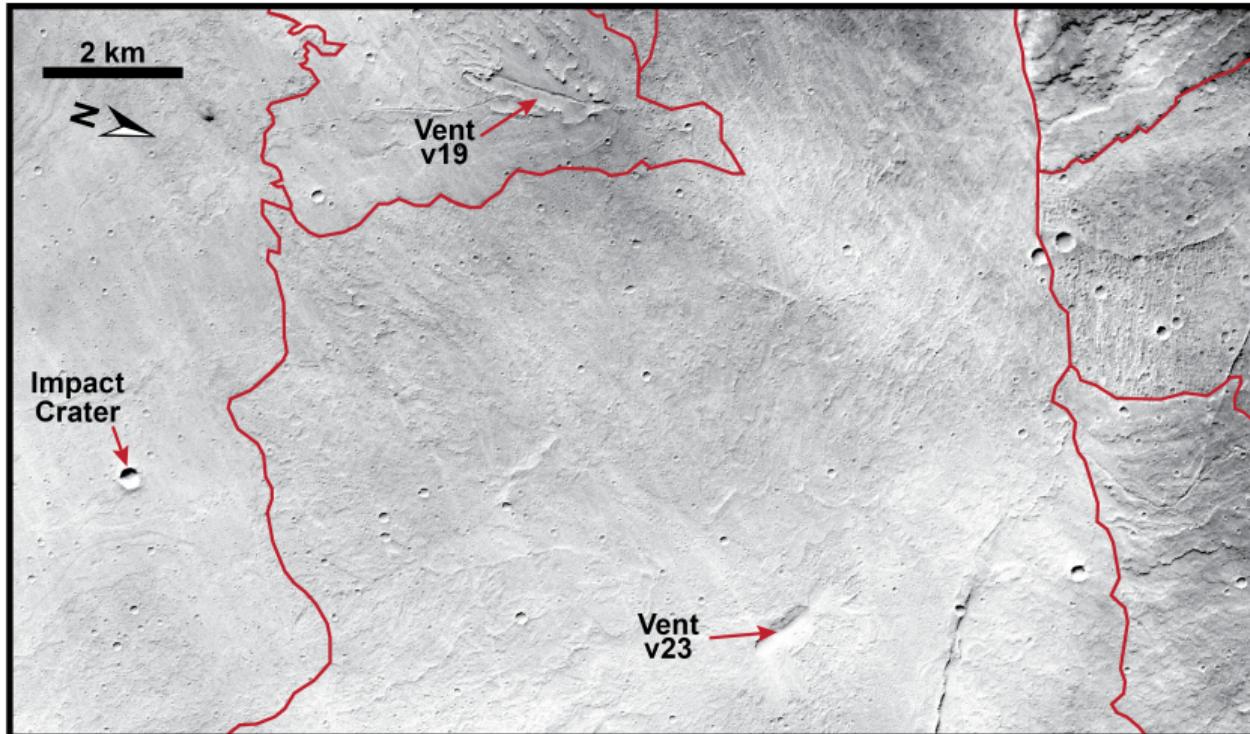
Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions



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



Mapping

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

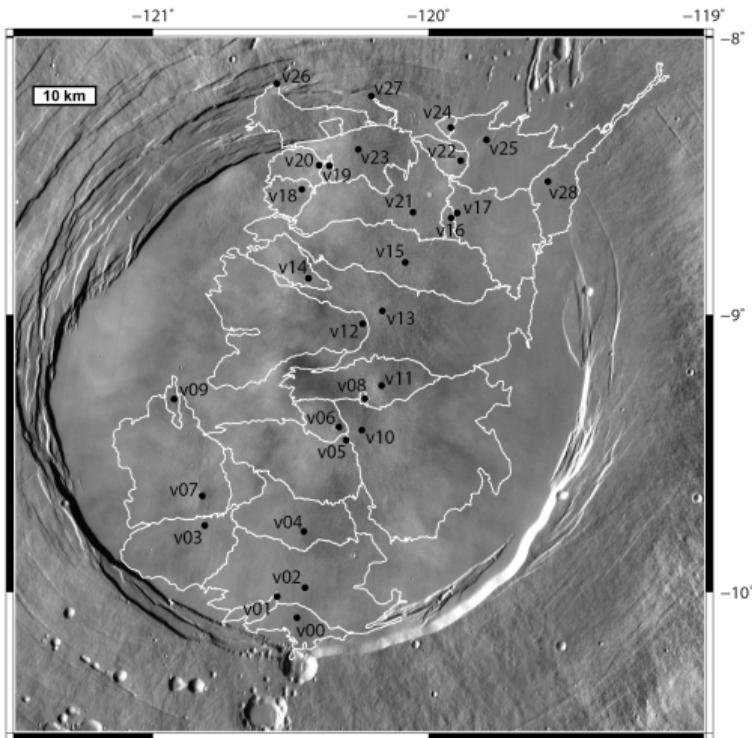
Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field
Methods
Results
Implications

Conclusions



Mapping results

- 29 vents are cataloged, each with long lava flows
- Lava flow areas are 10s–100s km²
- Flow thicknesses assumed to be 10–80 m (Mouginis-Mark & Rowland, *Icarus*, 2008)
- From this, volumes estimates range from 10⁻²–70 km³

Ages: Crater Counting

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

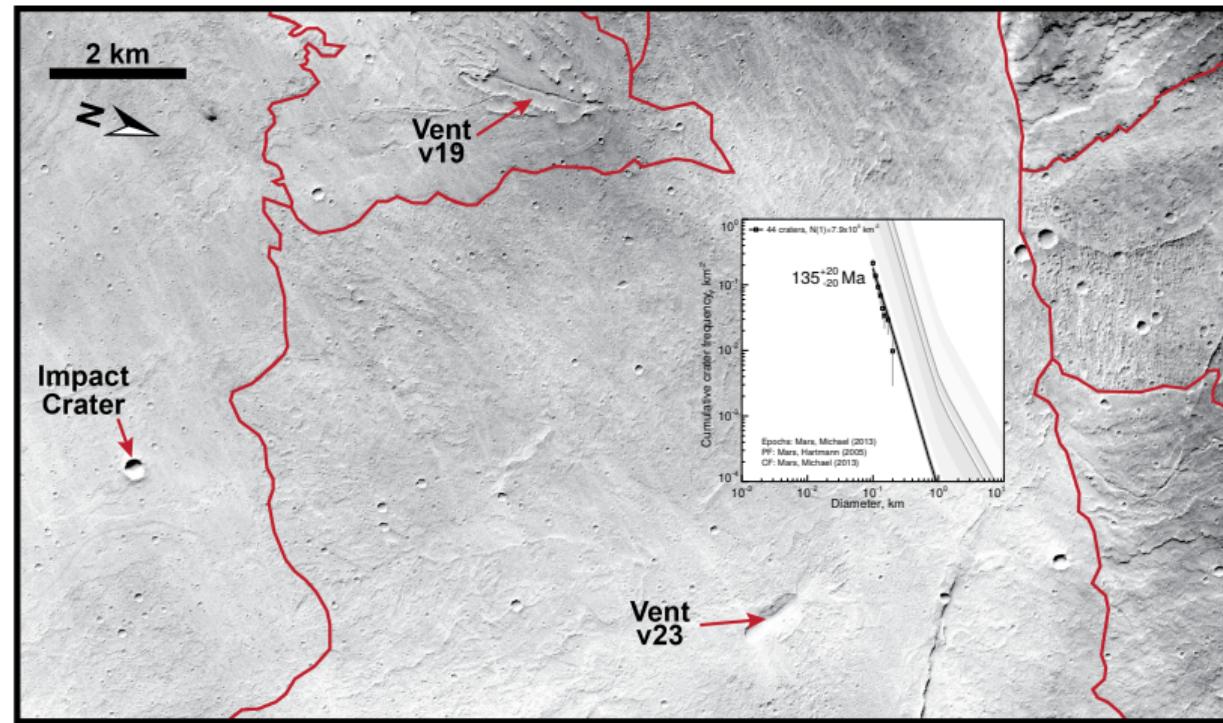
Overview

Sills
Vent Density
Lava Flows

Arisia Mons
Volcanic Field

Methods
Results
Implications

Conclusions



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

Ages: Crater Counting

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

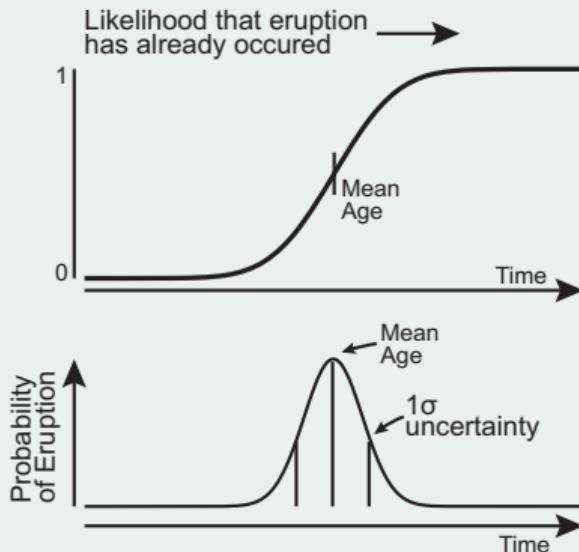
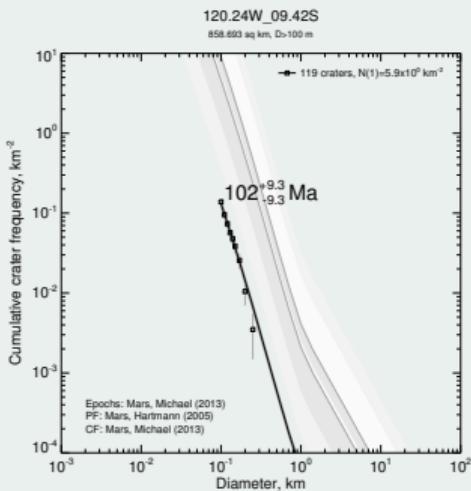
Sills
Vent Density
Lava Flows

Arisia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

craterstats2 results form normally distributed models of emplacement time.



Ages: Stratigraphy

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

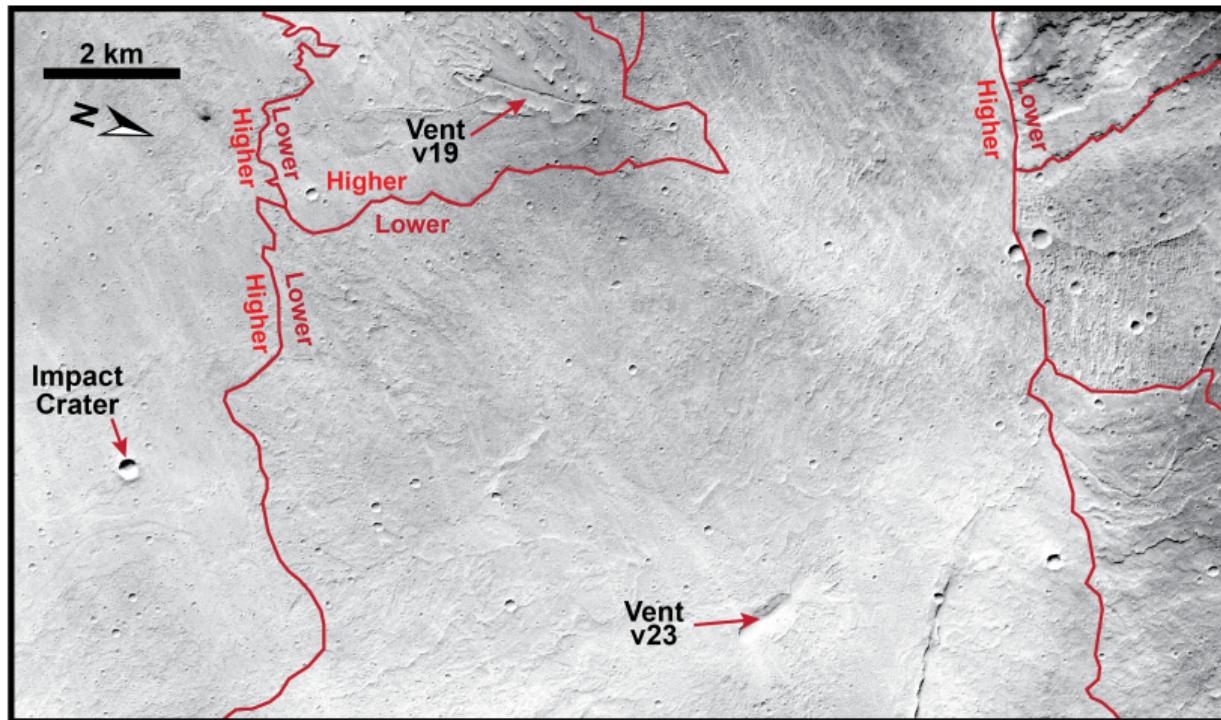
Overview

Sills
Vent Density
Lava Flows

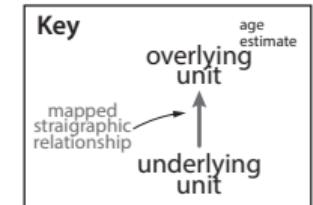
Arisia Mons
Volcanic Field

Methods
Results
Implications

Conclusions



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



Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

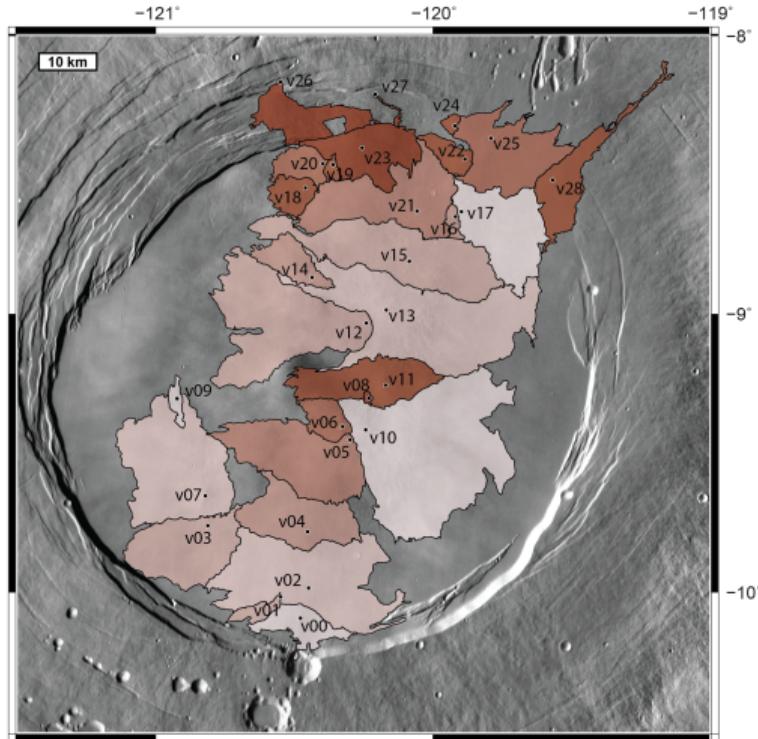
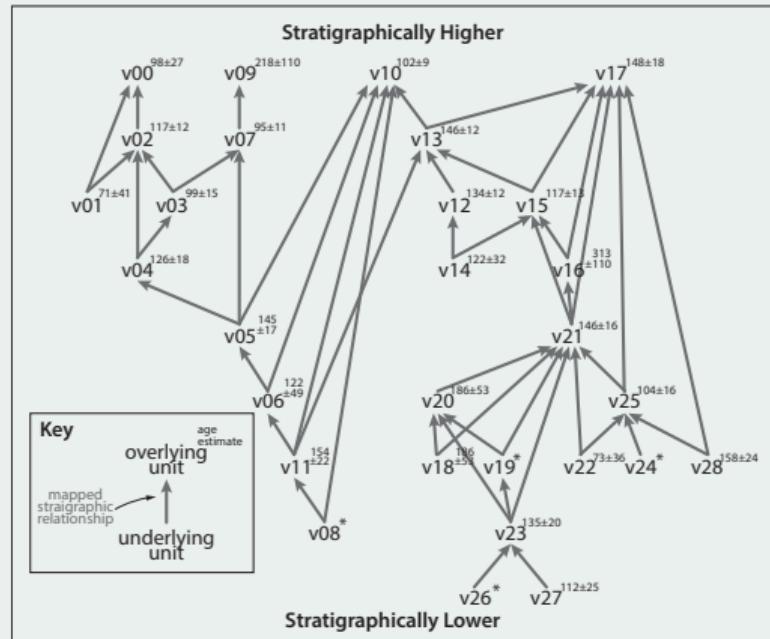
Sills
Vent Density
Lava Flows

Arisia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Stratigraphy “Web”



Ages: Information Conflicts

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

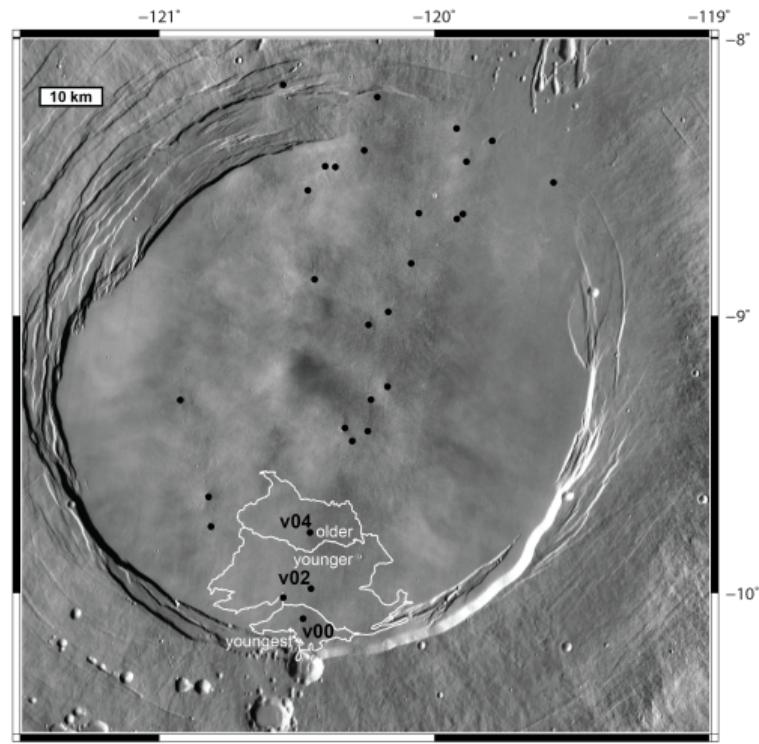
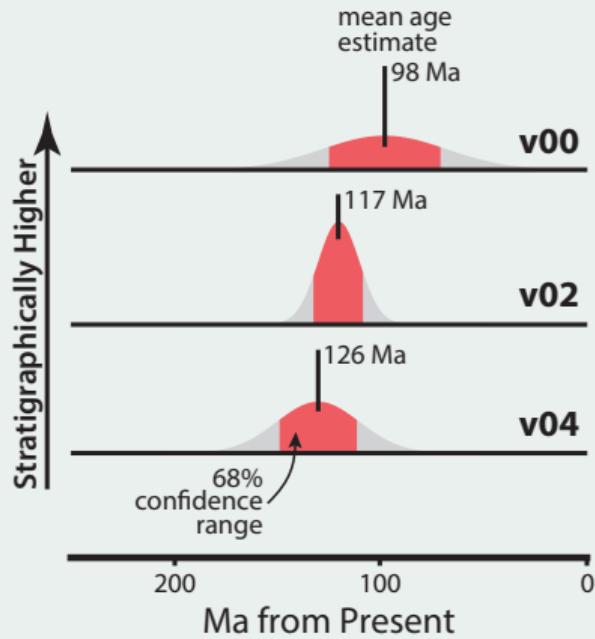
Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Mean crater ages can agree stratigraphy...



Ages: Information Conflicts

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

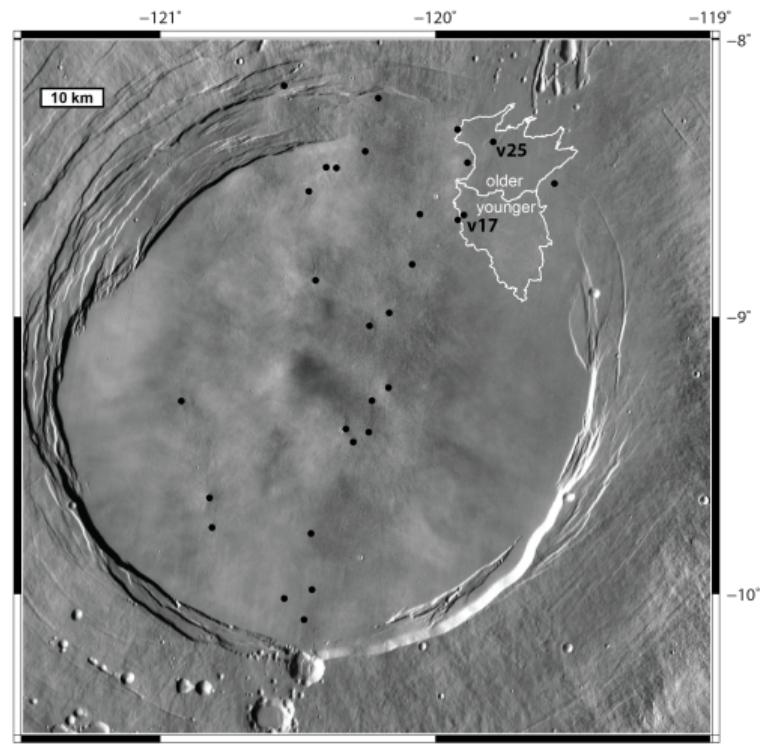
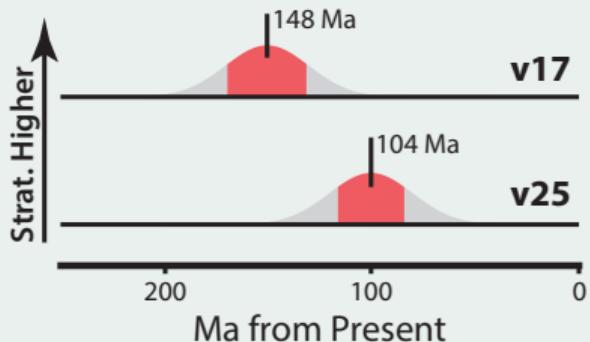
Sills
Vent Density
Lava Flows

Arisia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

... or they can disagree



Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

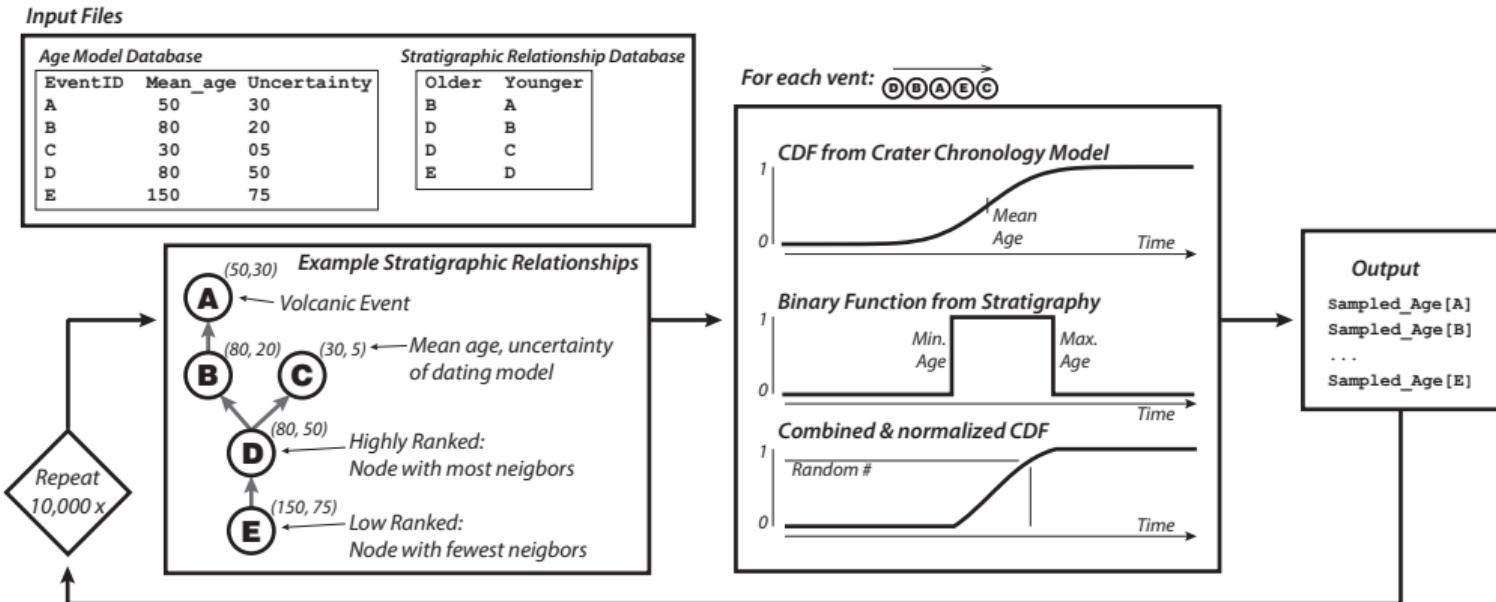
Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions



Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills

Vent Density

Lava Flows

Arsia Mons
Volcanic Field

Methods

Results

Implications

Conclusions

Recurrence rate calculation Volume Flux Calculation

Results

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

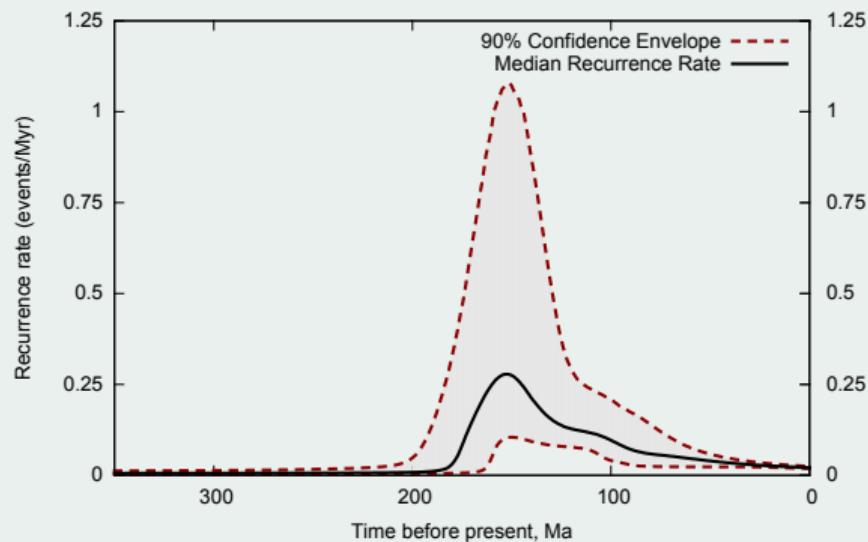
Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Recurrence Rate



Volume Flux

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

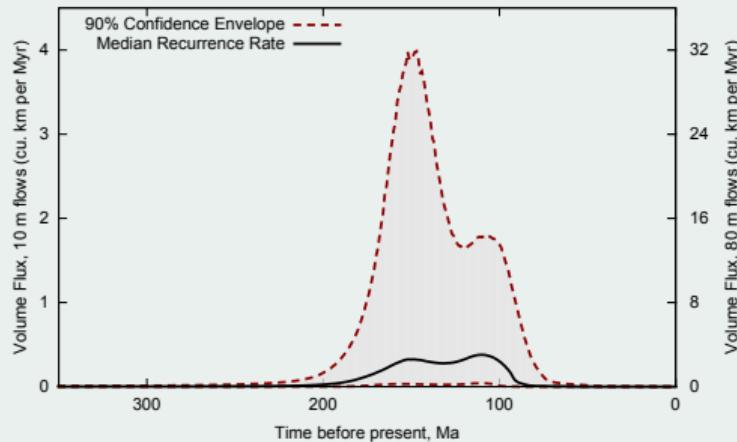
Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

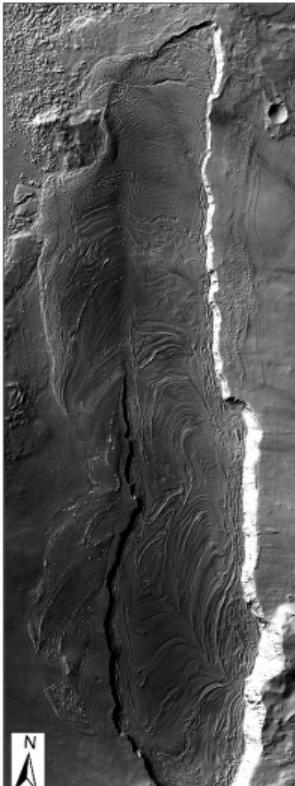
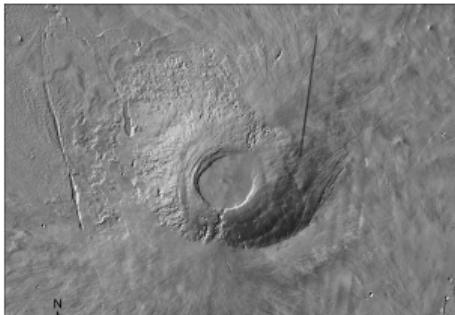
Methods
Results
Implications

Conclusions

Discharge rate through time



Tie in with Ashes and glaciers?



Jacob Richardson

Volcanic Fields on Earth & Mars

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Model of waning volcanism of Arsia

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

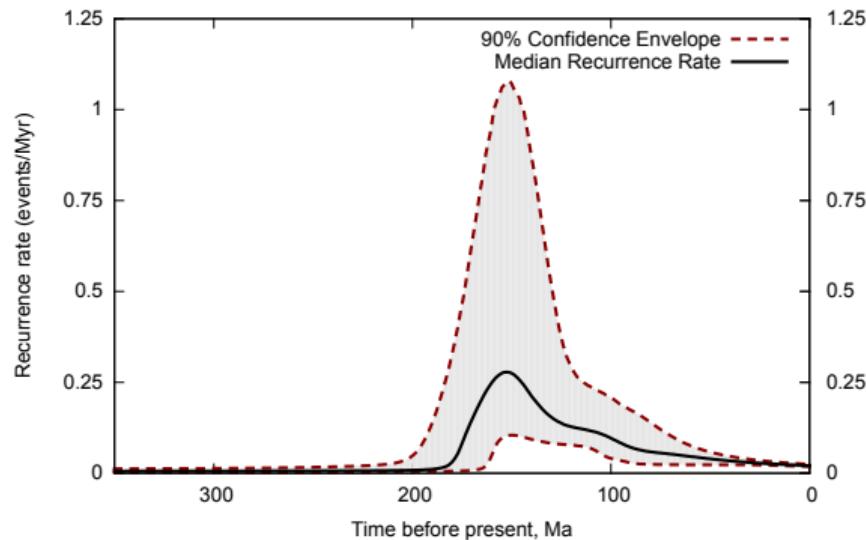
Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field
Methods
Results
Implications

Conclusions

Volcanism transitioned from explosive to effusive
Corresponds to a waning of recurrence rate of volcanism



Arsia Specific Conclusions

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Other Conclusions

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Additional Thanks

Volcanic
Fields on
Earth & Mars

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

Arsia Mons
Volcanic Field

Methods
Results
Implications

Conclusions

Questions?

**Volcanic
Fields on
Earth & Mars**

Jacob
Richardson

Introduction

Overview

Sills
Vent Density
Lava Flows

**Arsia Mons
Volcanic Field**

Methods
Results
Implications

Conclusions