Thermal Modeling of the Yellowstone Volcanic Complex: Implications for Crustal Structure of the Magma System and Eruption Dynamics

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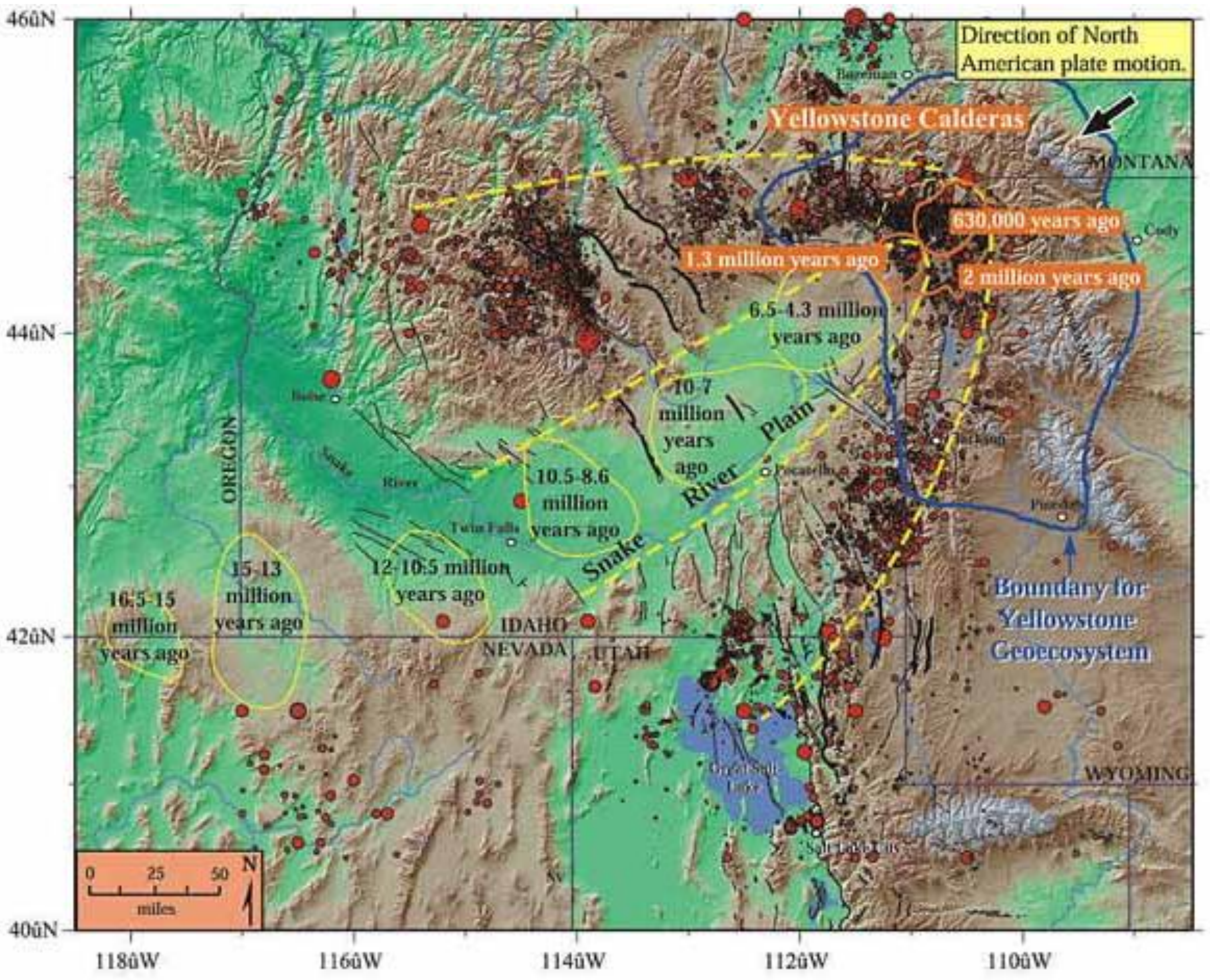
Yellowstone Volcanic Complex

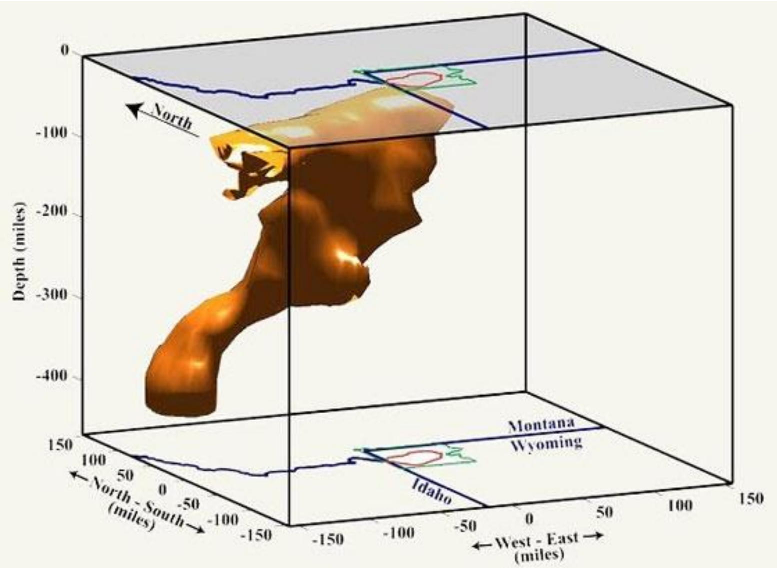
Map showing the path of the Yellowstone hotspot (USGS, 2019)

The Yellowstone Volcanic Complex (YVC) of Wyoming’s Yellowstone National Park (YNP) inspires intense geologic interest

- What is the source of the crustal hot-spot?
- When will Yellowstone explosively erupt again?

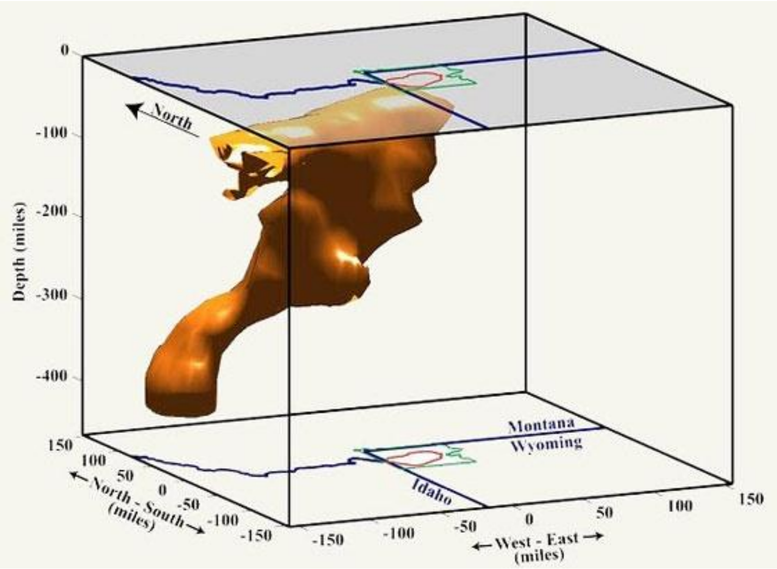


Introduction



- A number of exciting models have been created of the subsurface of the Yellowstone-Snake River Plain area in order to seek answers to our questions

Introduction



- To date, most or all of the study of the YVC has involved seismology and tomography, earthquake and geomagnetics, GPS and InSAR, Bouguer gravity anomaly, and combinations therein [8, 9, 10, 11, 12, 15, 16, 20, 25, 29, 30, 34]

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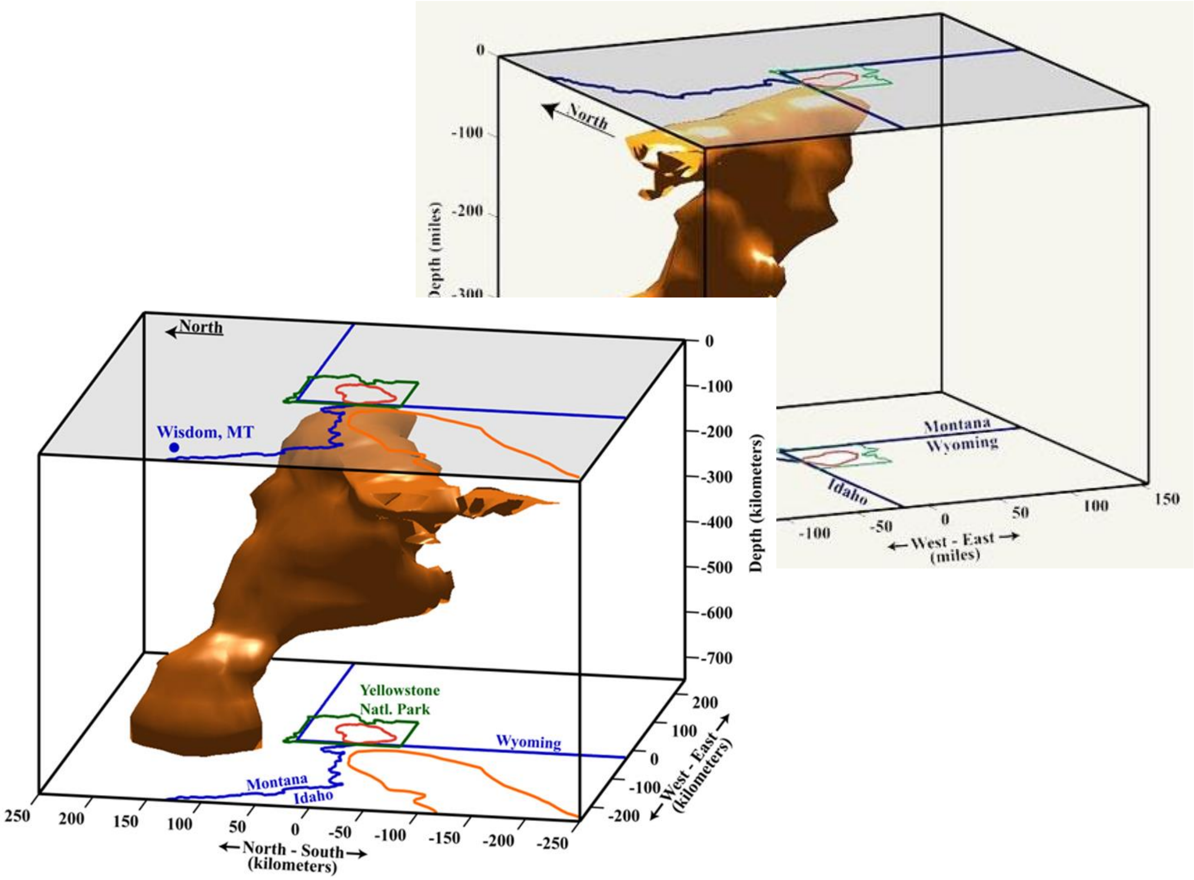

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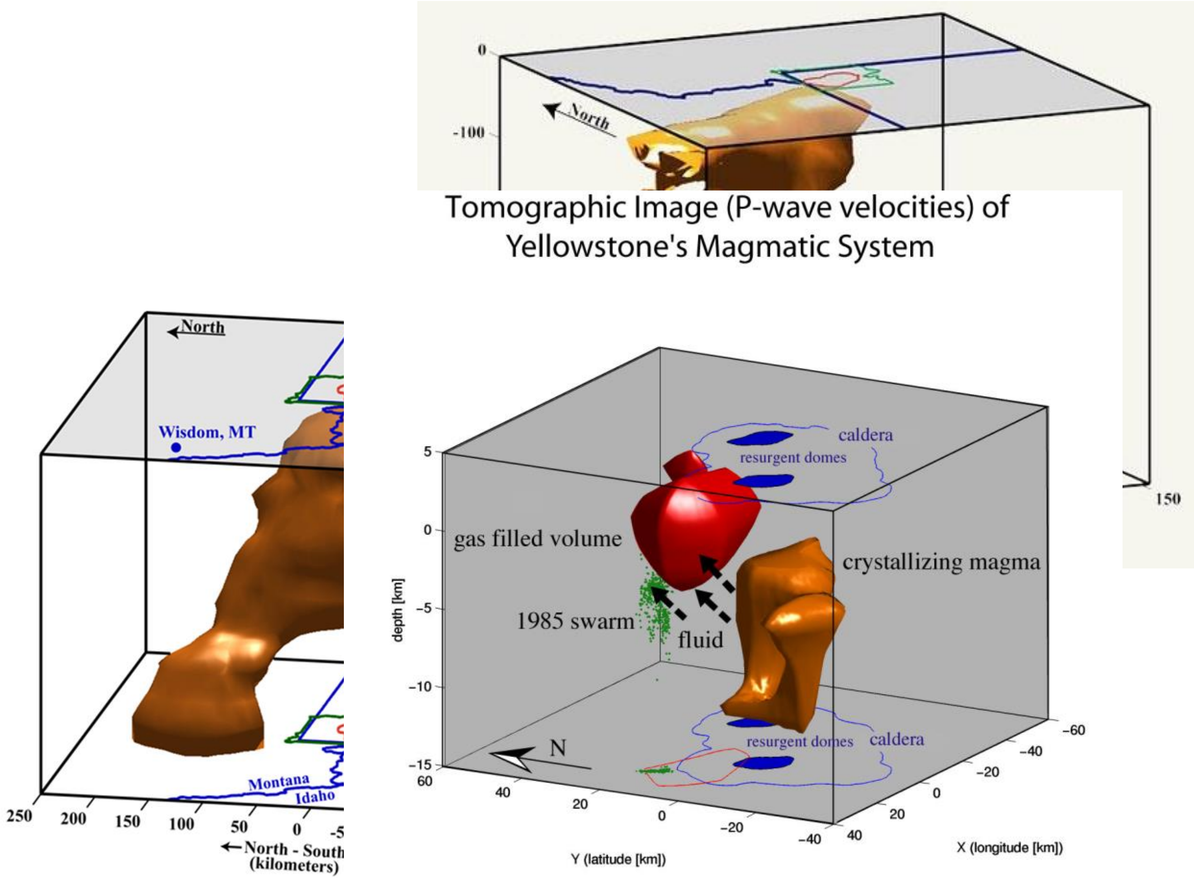

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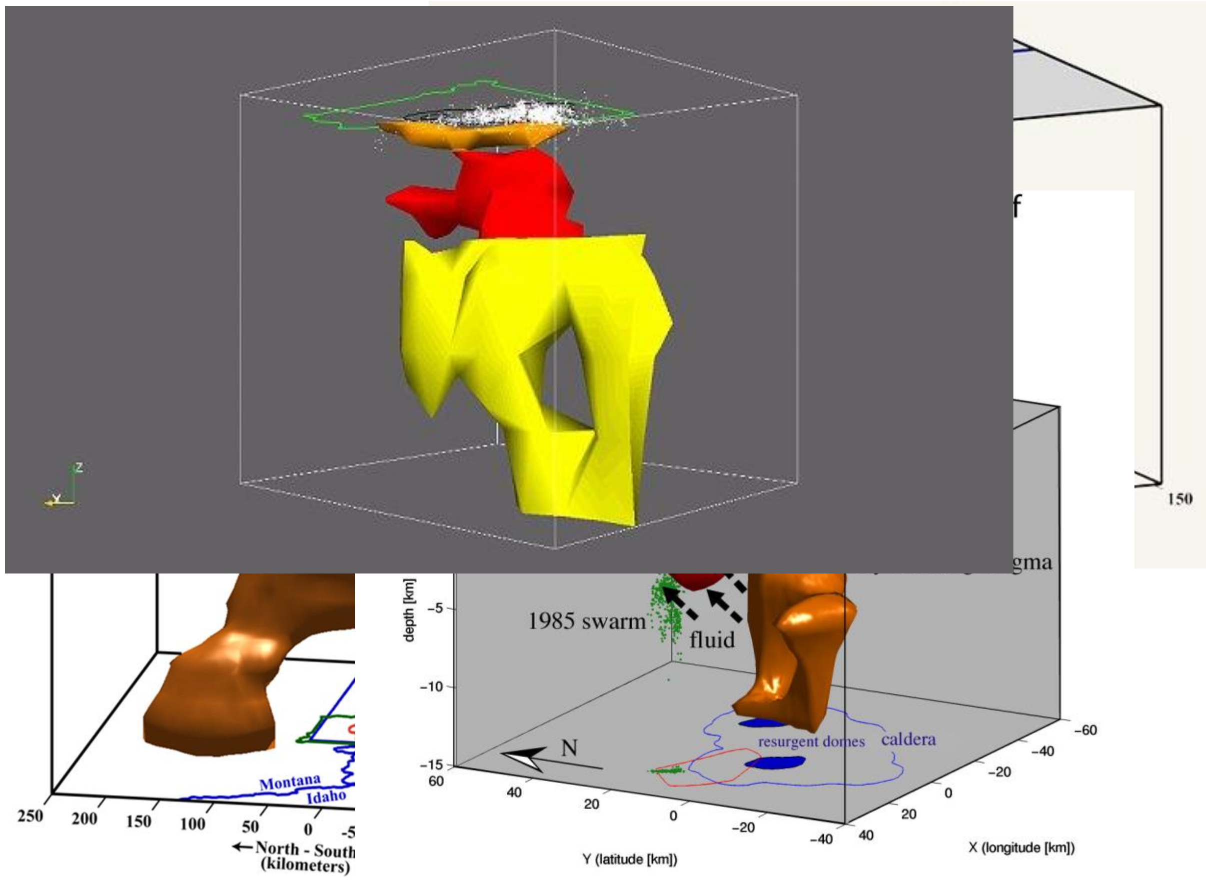

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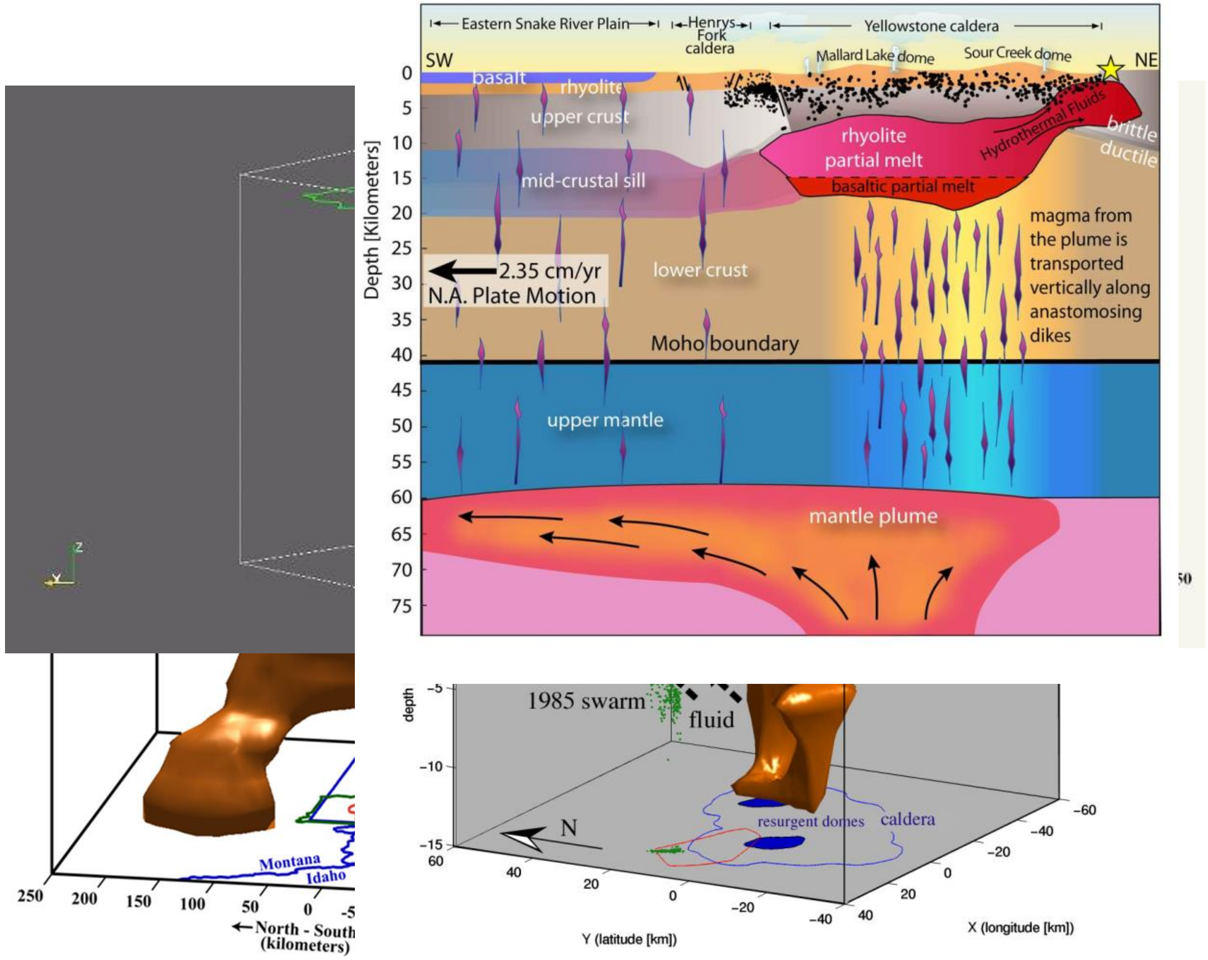

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Introduction

- U. Utah's Seismology and Active Tectonics Research Group - (DeNosaquo et al., 2009) utilizes heat flow data
  - Constraint of focal depths for earthquakes in and around YVC
  - No computational heat flow modeling at depth pertaining to eruption dynamics has been accomplished by their group or any other
- Solution: de Silva and Gosnold, 2007
  - Study of Altiplano-Puna Volcano Complex
  - Numerical and computational thermal modeling approach

Introduction

- Present study
  - a geophysical study of the magma system and eruption conditions existing previously and currently in the Yellowstone Volcanic Complex (YVC) of Wyoming’s Yellowstone National Park (YNP)
    - Rheology and lithospheric strength analysis
    - Crustal heat flow modeling

Methodology

1. Intrusion Rate
2. Mechanical Strength Profile
3. Crustal Heat Flow Modeling

Finite Difference Heat Flow Simulation, or “ARC” – Crustal Heat Flow Modeling

Example computer screen capture of an ARC model simulation in progress Brunson, 2017.

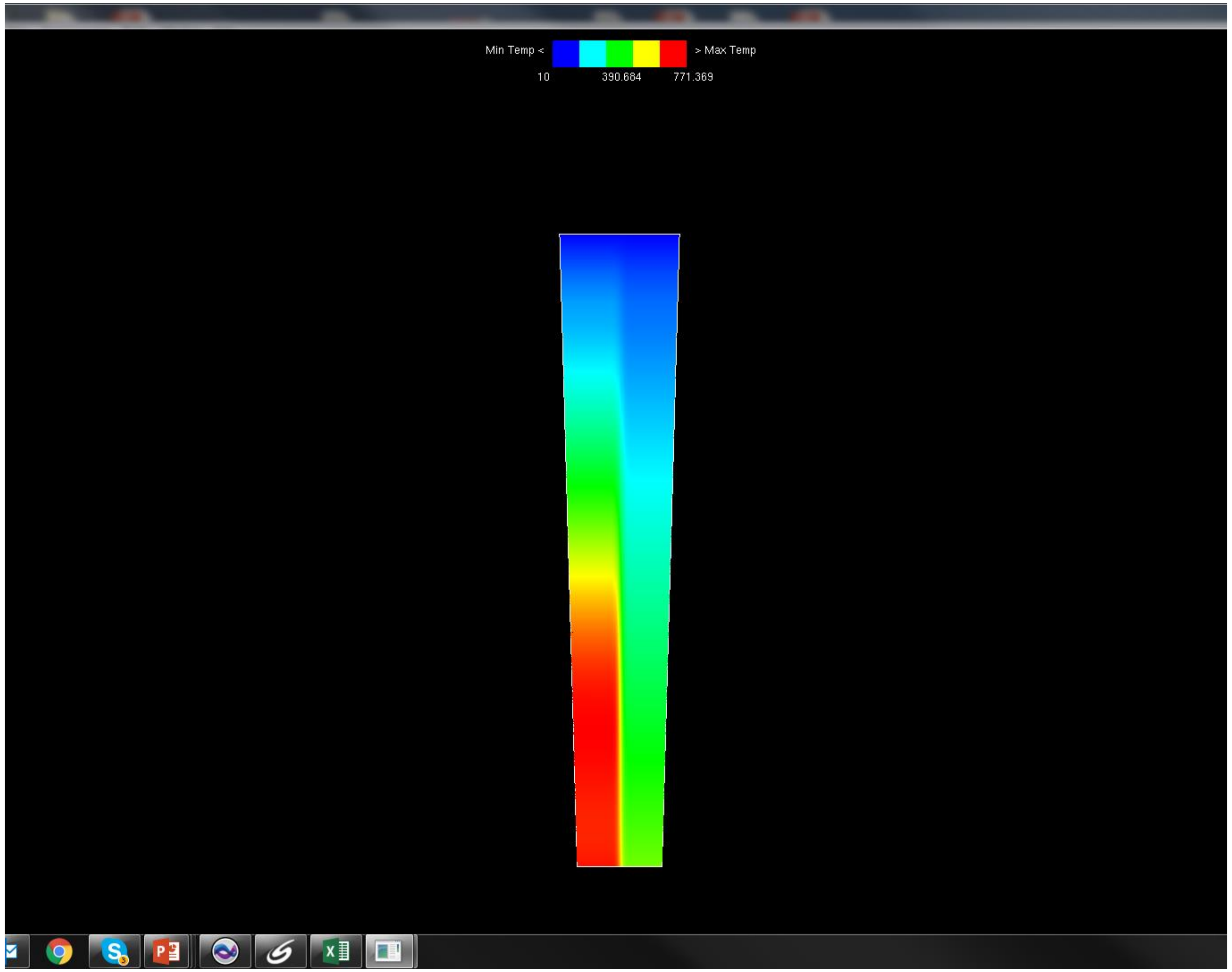
Finite difference determination of steady-state heat flow

- calculating temperature and heat generation for a given system subdivided into cells
- heat transfer to and from surrounding cells [13]

System is modeled using ASCII format input codes [4, 13] and desired values of system parameters in a Microsoft Excel file:

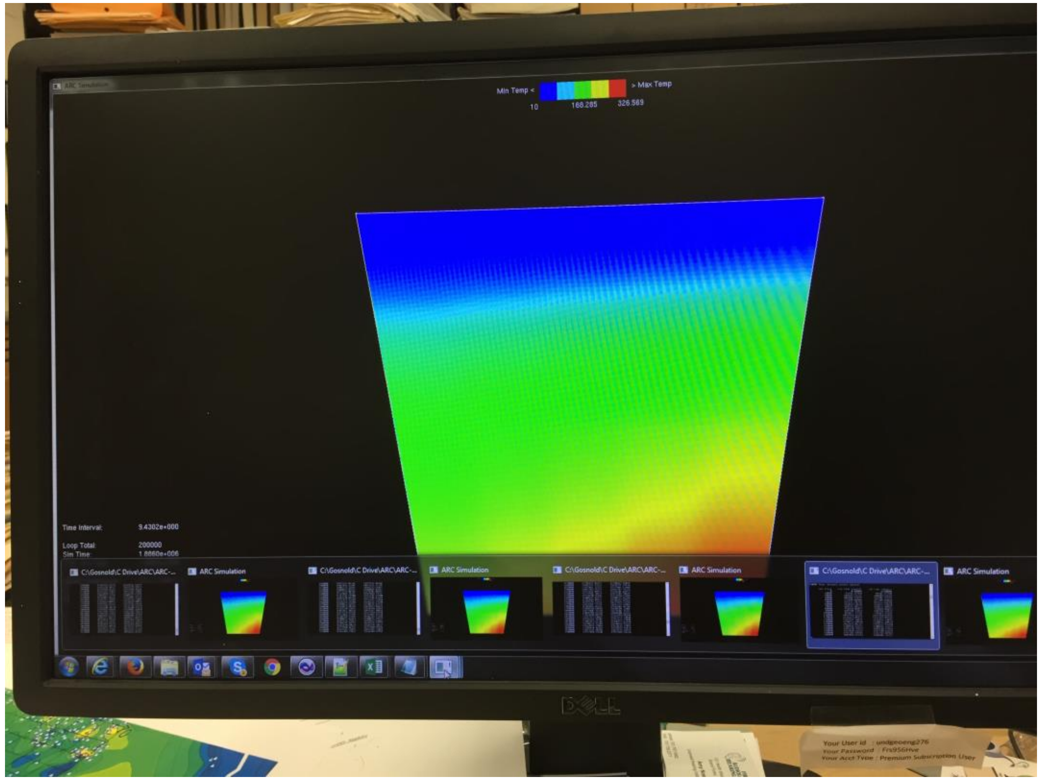
- Thermal conductivity
- Radiogenic heat production
- Basal heat flow
- Heat capacity of rock and fluid density
- Advection constraints
- Starting temperatures
- Velocity
- Direction and cell size and model dimensions

Open-source, lightweight, and flexible program

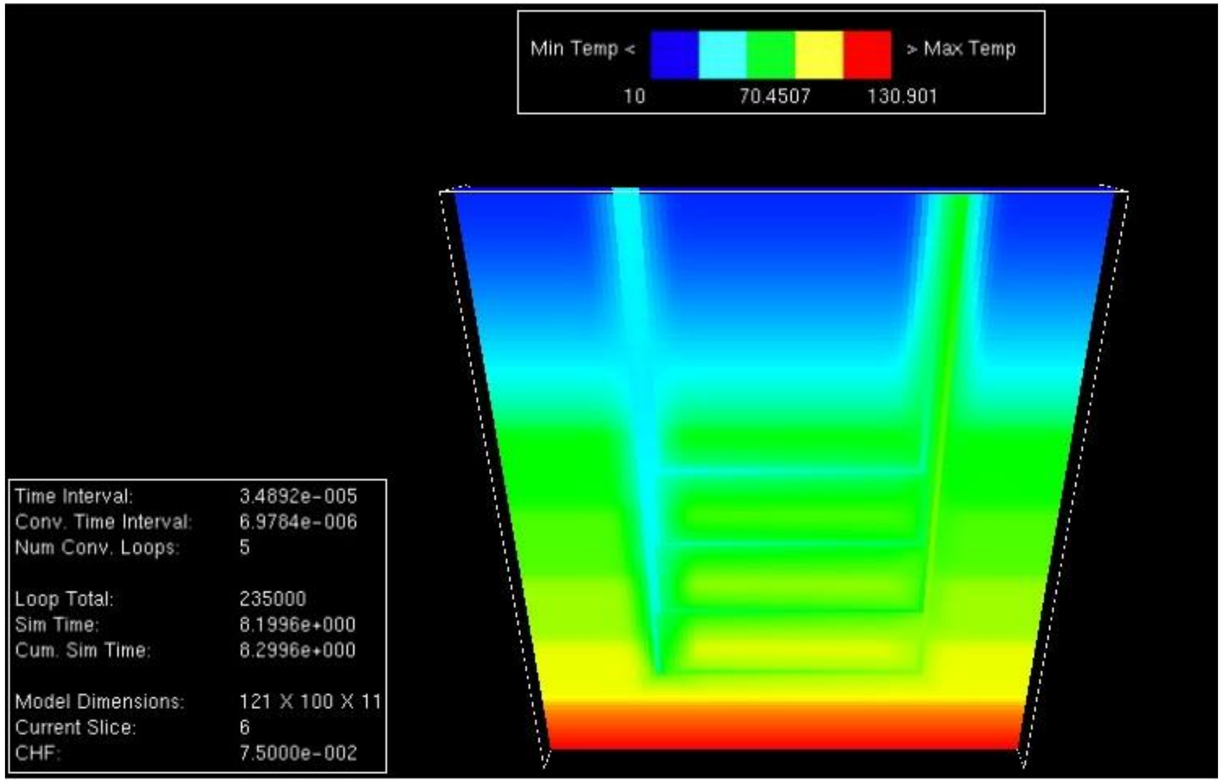


Finite Difference Heat Flow Simulation, or "ARC"

Multiple Simulations Running Simultaneously



Complex Systems Modeling (e.g., Practical Geothermal Energy System)

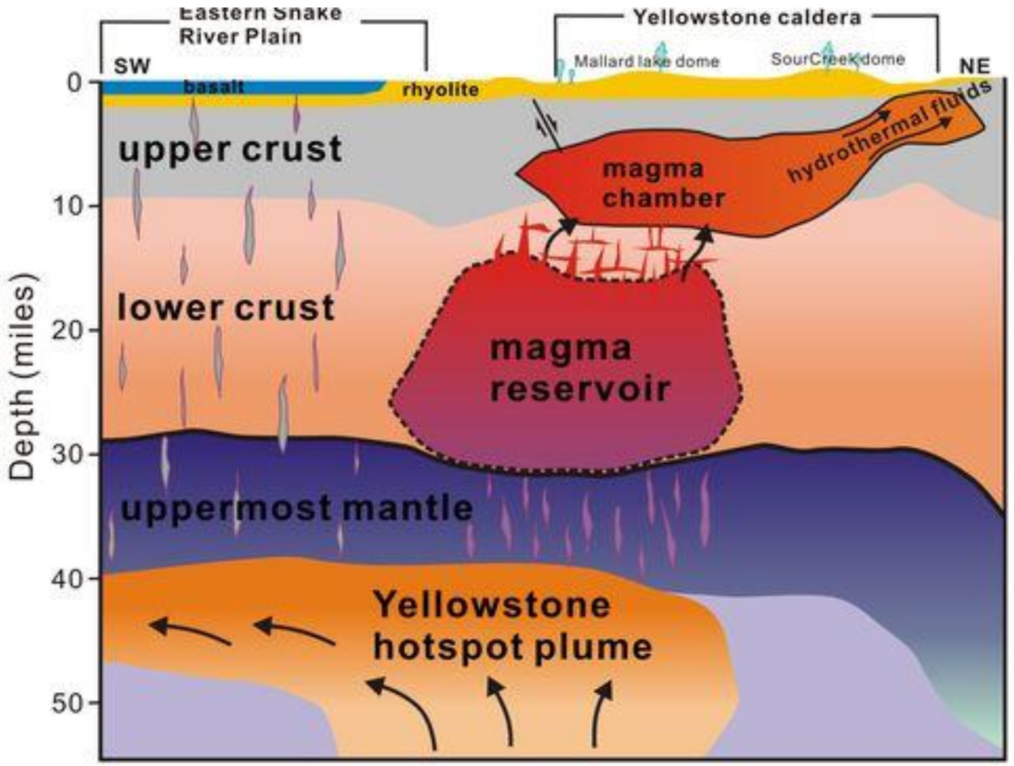


Preliminary Results

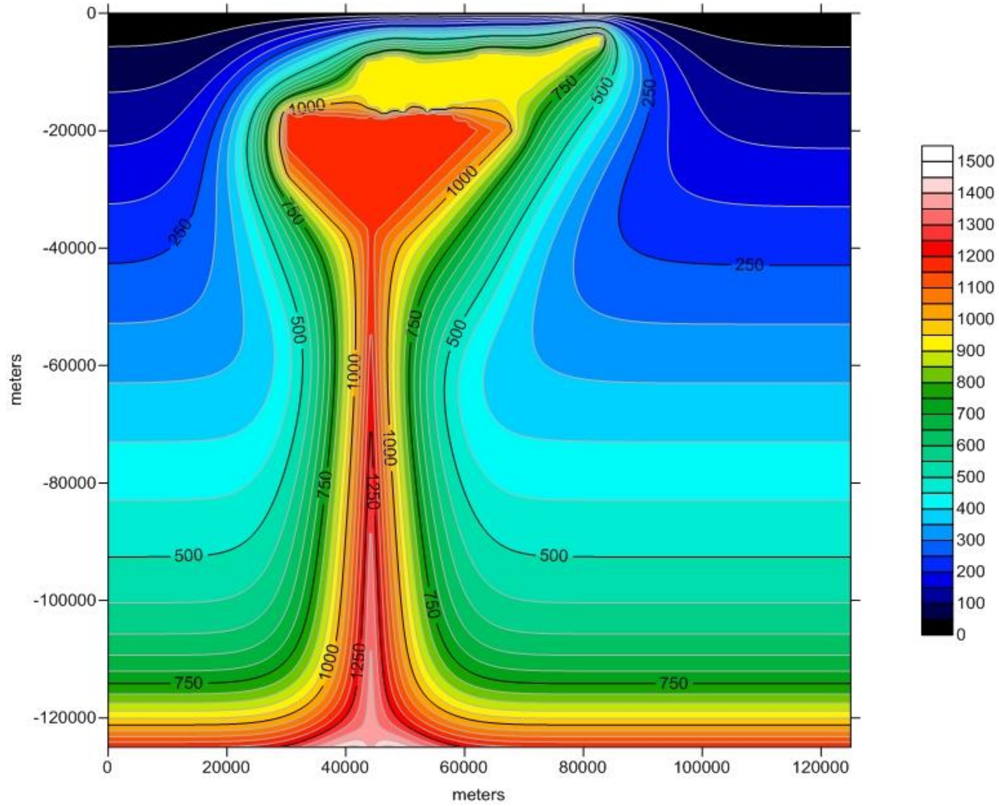
Establishing confidence in the proposed study methods

Arc Heat Flow Model of YVC Subsurface

Huang et al., 2015

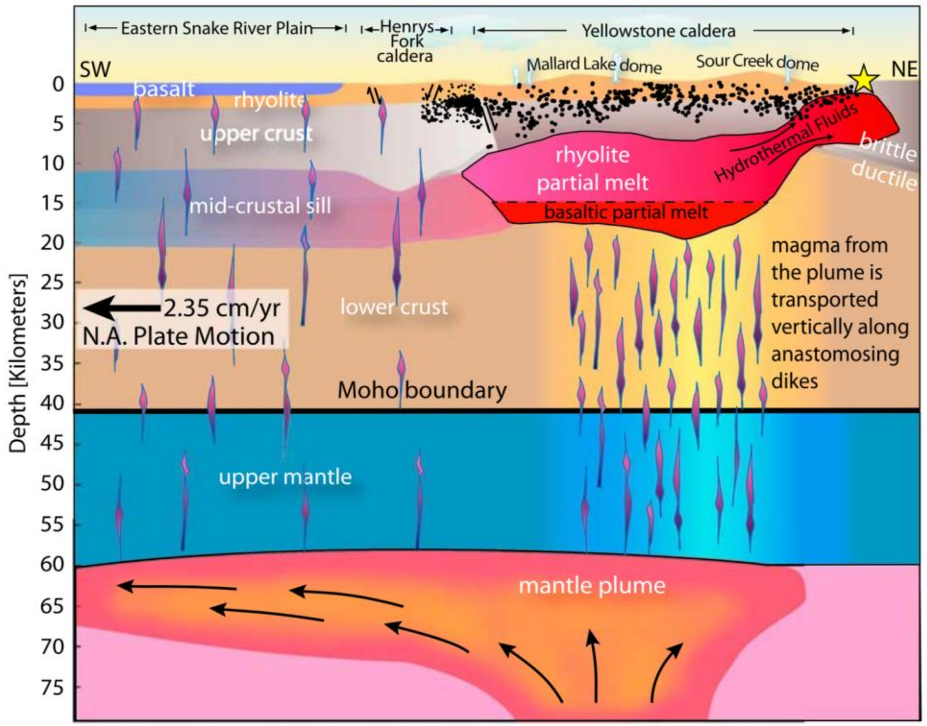


UND Geothermal Lab, 2020

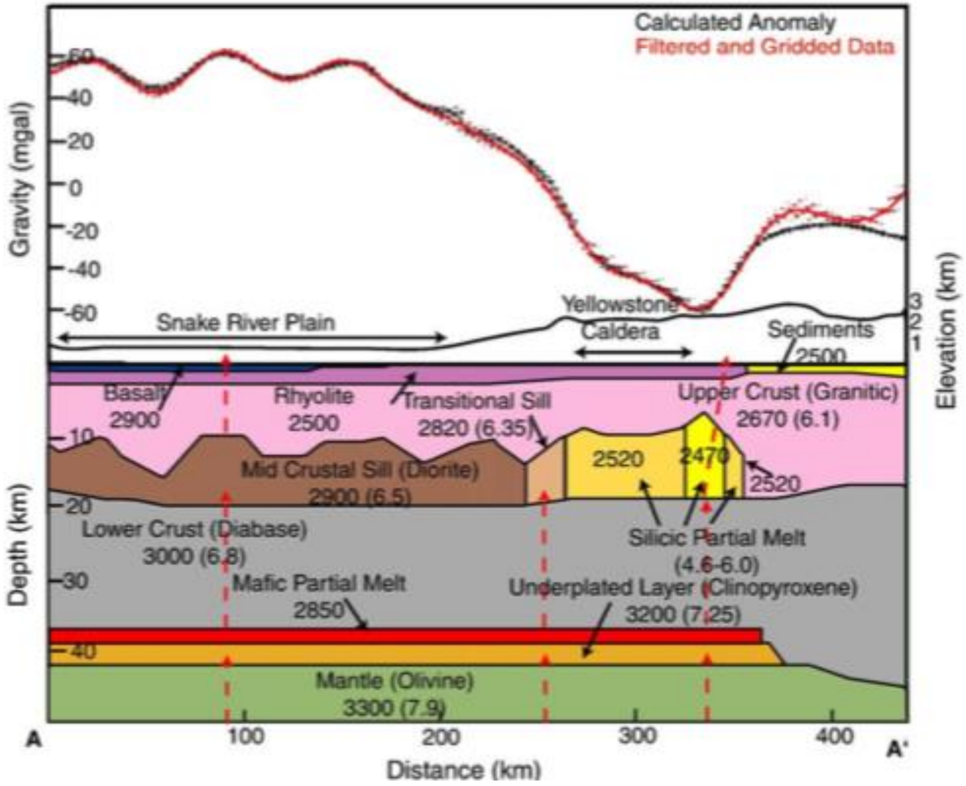


Other Models Available to Inform Heat Flow Model Experiment

Farrell, et al., 2014



DeNosaquo et al., 2009



Preliminary Results Summary

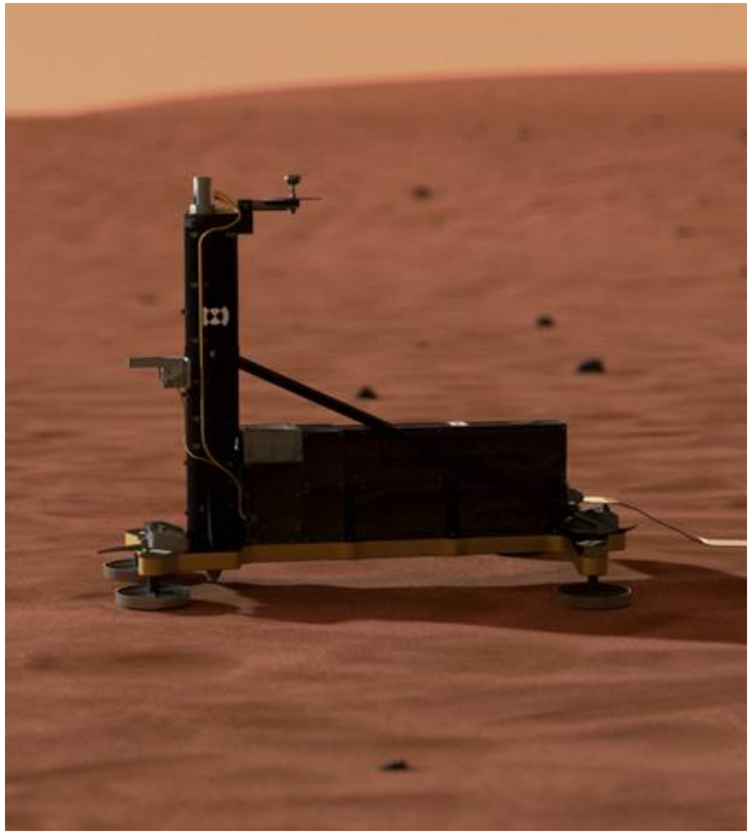
- Preliminary results are highly encouraging
- A completed study should provide some added ability to understand the geological processes and mechanisms at work in volcanic systems and help constrain eruption timing of YVC.

NASA Relevance

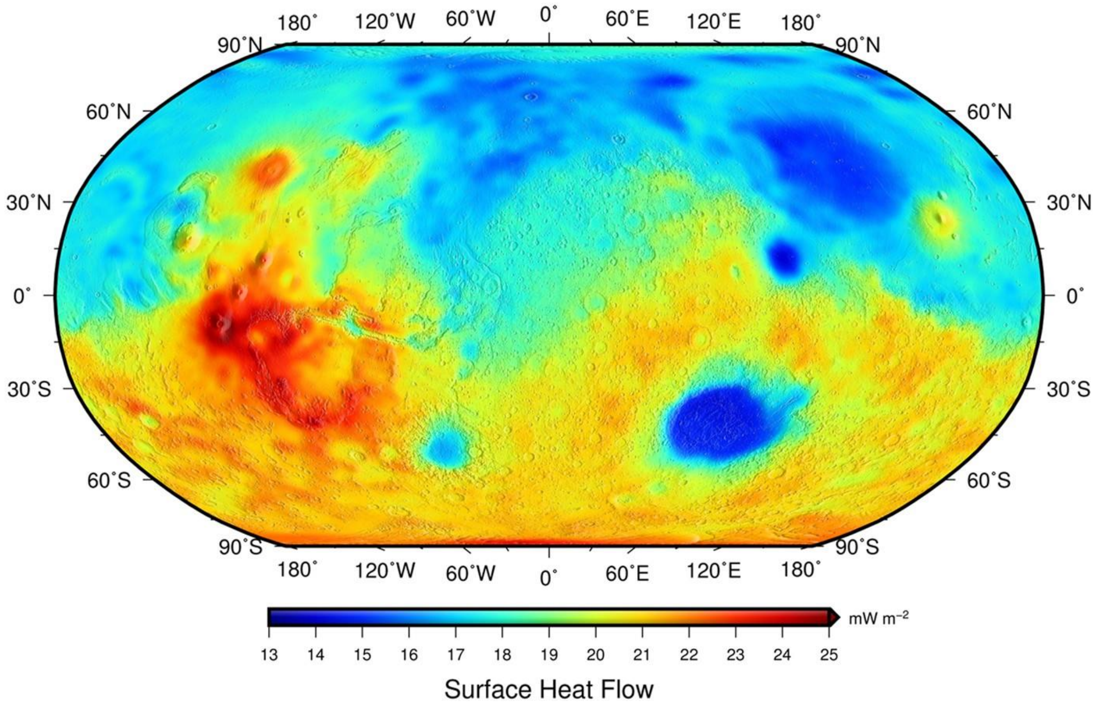
Planetary formation and evolution, the understanding of which would fall within the 2018 NASA Strategic Plan Objective 1.1 [37], is heavily constrained by heat flow [2]

NASA Relevance

Heat Flow and Physical Properties Package (HP3) - Mars InSight Lander



Preferred present-day surface heat flow model for Mars [26]



NASA Relevance

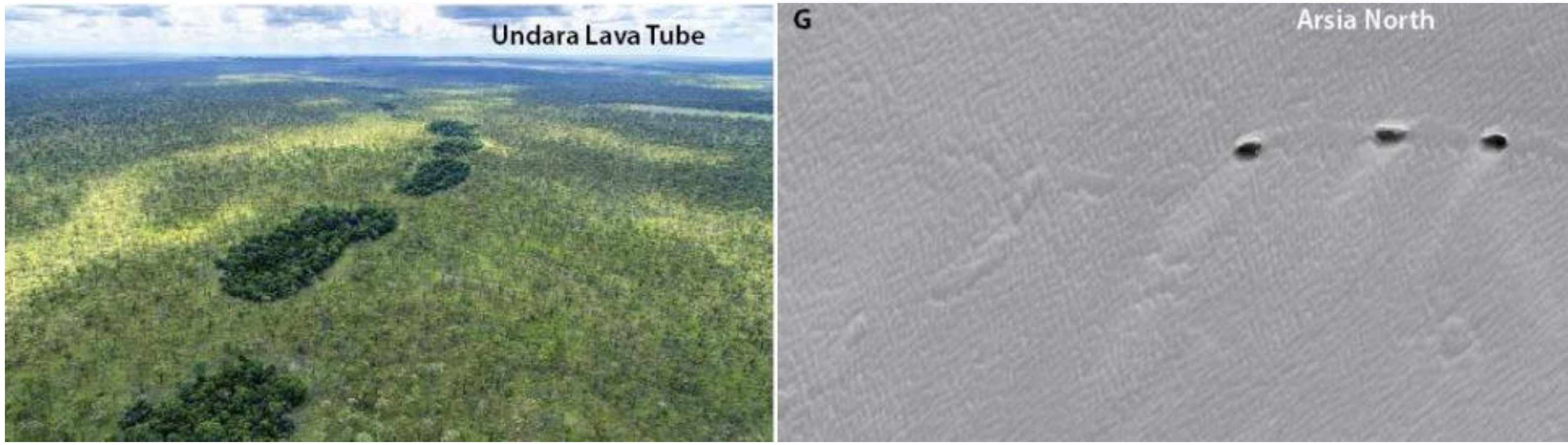
"Thermomechanically Extreme Environment Analysis Toolset" simulation capabilities (TX11.3.7) utilizing "Fortran compatible and interoperable parallel libraries" (TX11.2.4) [38]

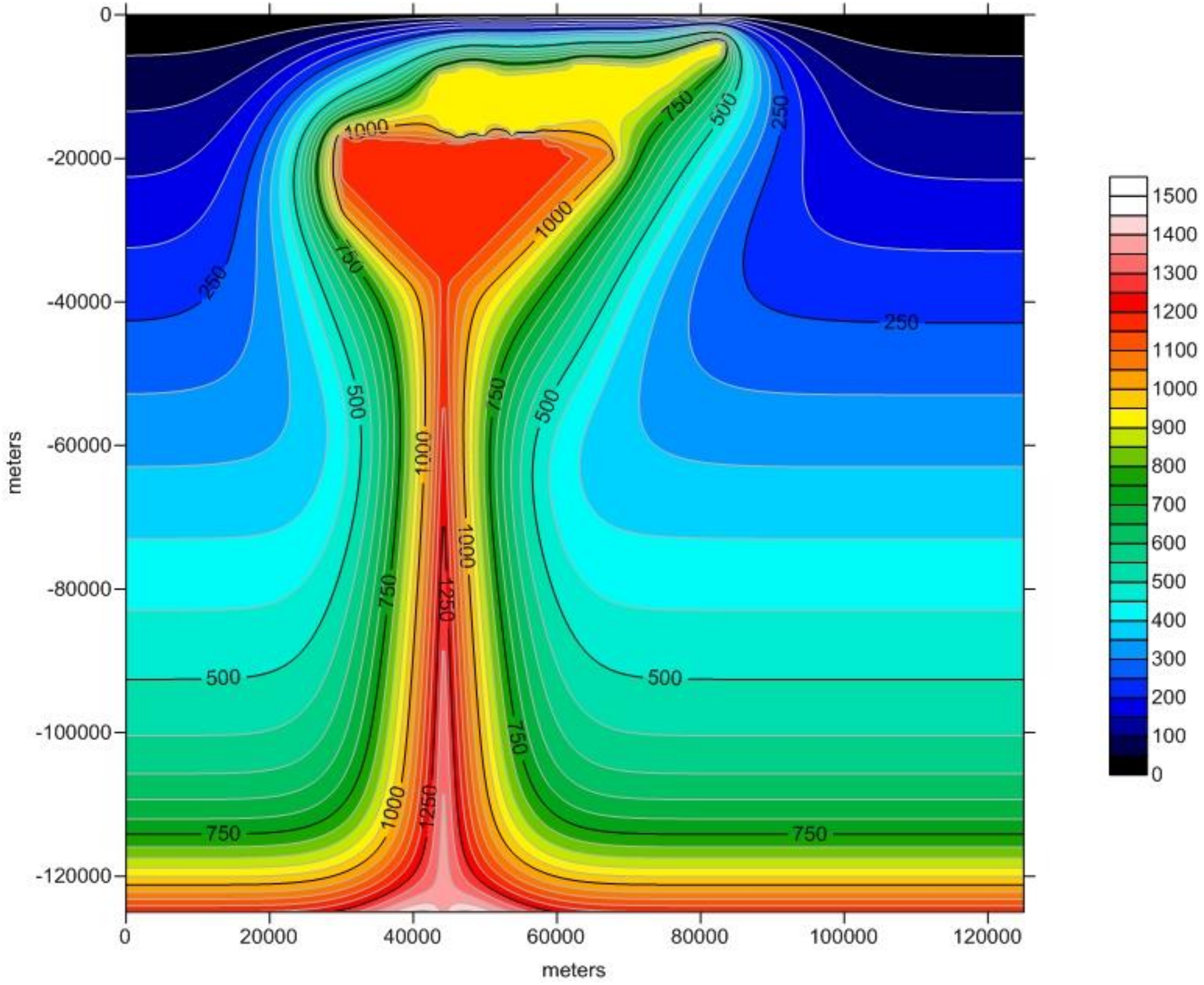
NASA Relevance

Lava tubes on Earth and Mars - left is Australia's Undara Lava Tube; right is a Martian lava tube at Arsia Mons [24]

Investigation of heat flow -> habitability in deep space exploration

Underground, extinct lava tubes as spaces protected from dangerous surface radiation in which to inflate a habitat [24]





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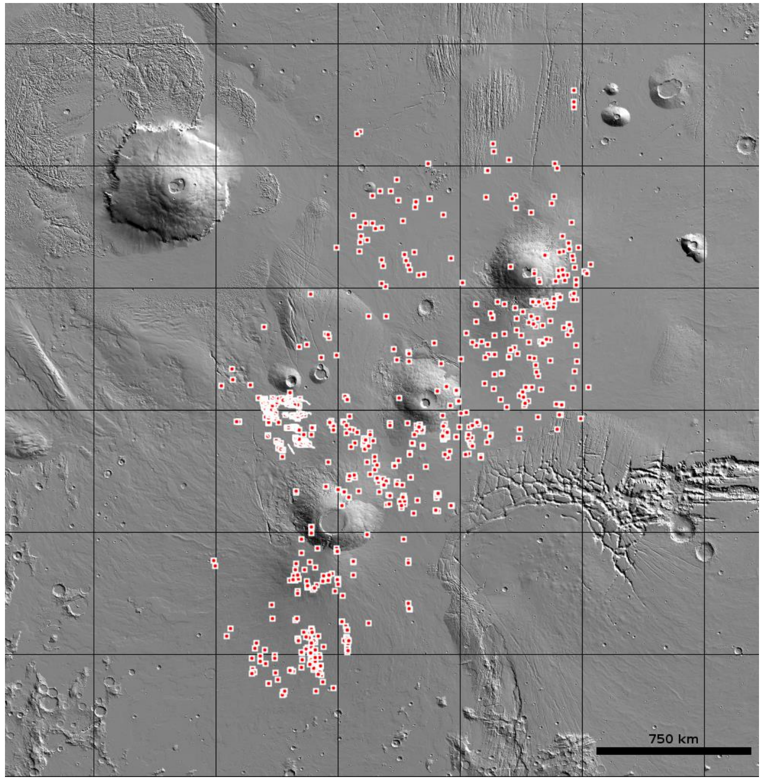
NASA Relevance

Preplanning Missions Through Models



Hawai'i Space Exploration Analog and Simulation (HI-SEAS)

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Questions?