# Modeling Lava Flows

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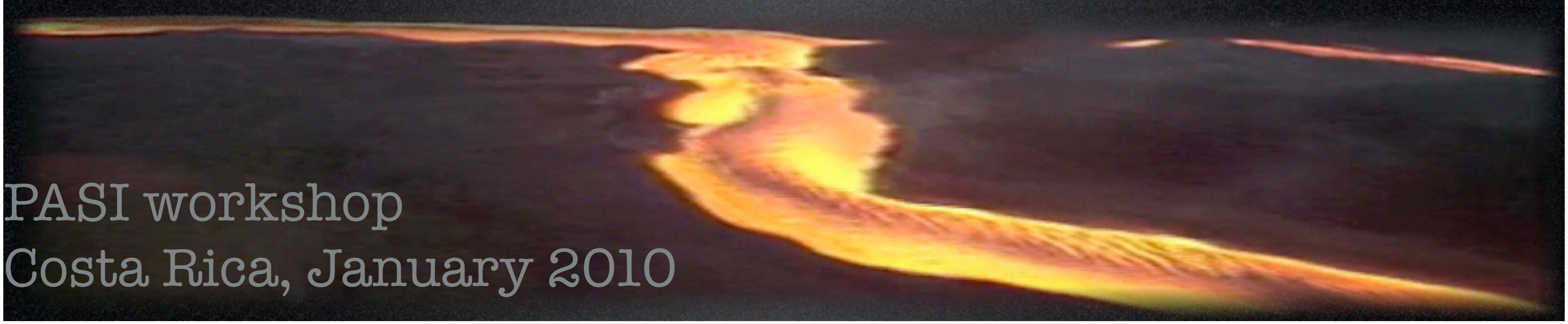


PASI workshop
Costa Rica, January 2010

# Under the oceans…

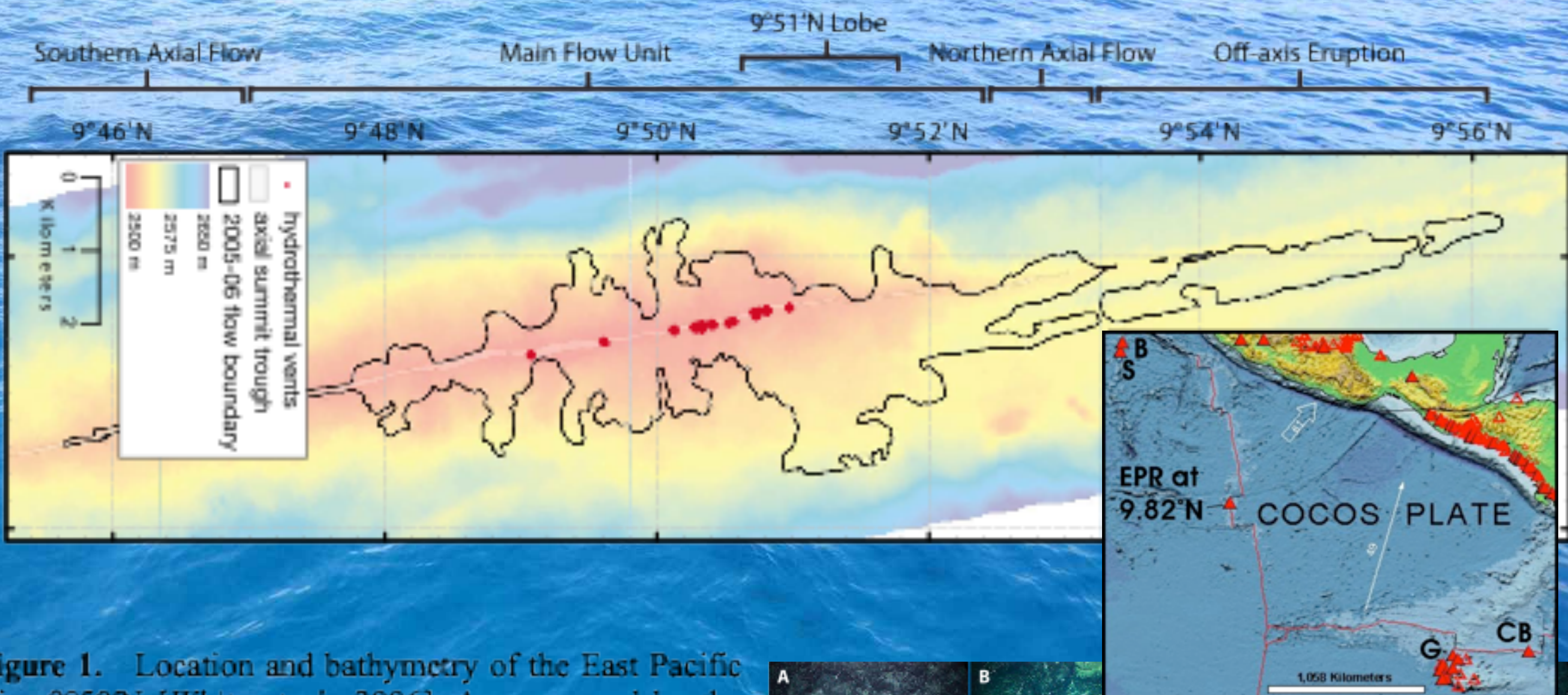
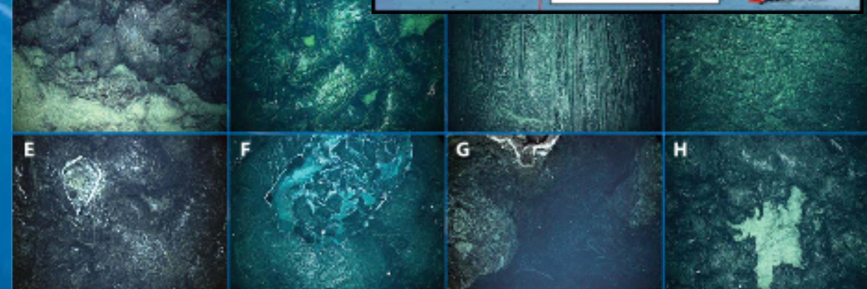
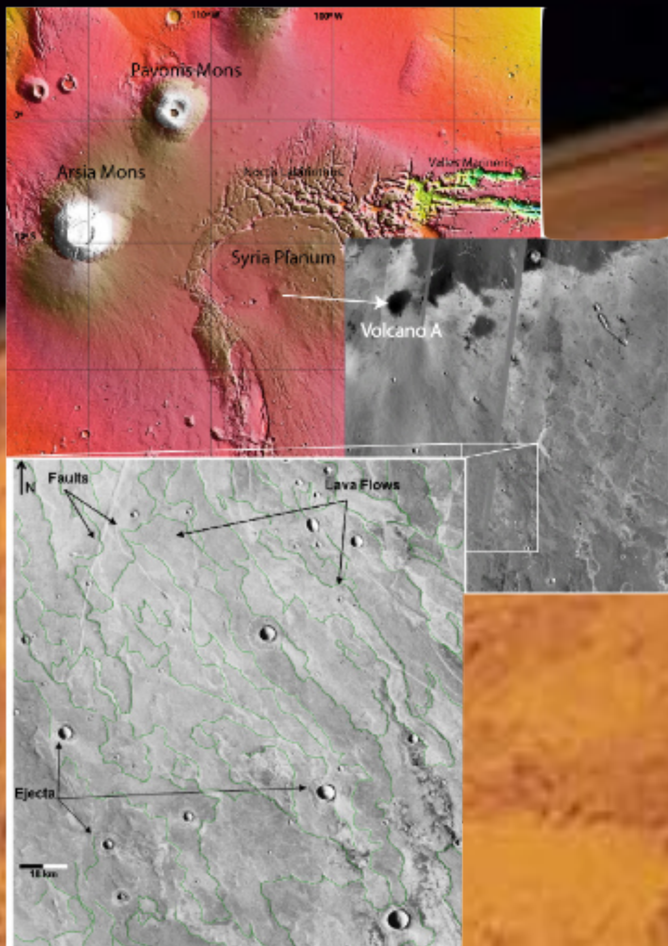



**Figure 1.** Location and bathymetry of the East Pacific Rise 9°50′N [*White et al.*, 2006]. Area covered by the 2005–2006 eruptions is outlined in black (derived from camera tow and side scan imagery data) and the four distinct regions of the flow are defined [*Soule et al.*, 2007]. Hydrothermal vents are marked by red dots.




Fundis et al G3 2010

# on Mars ...




Baptista et al 2007

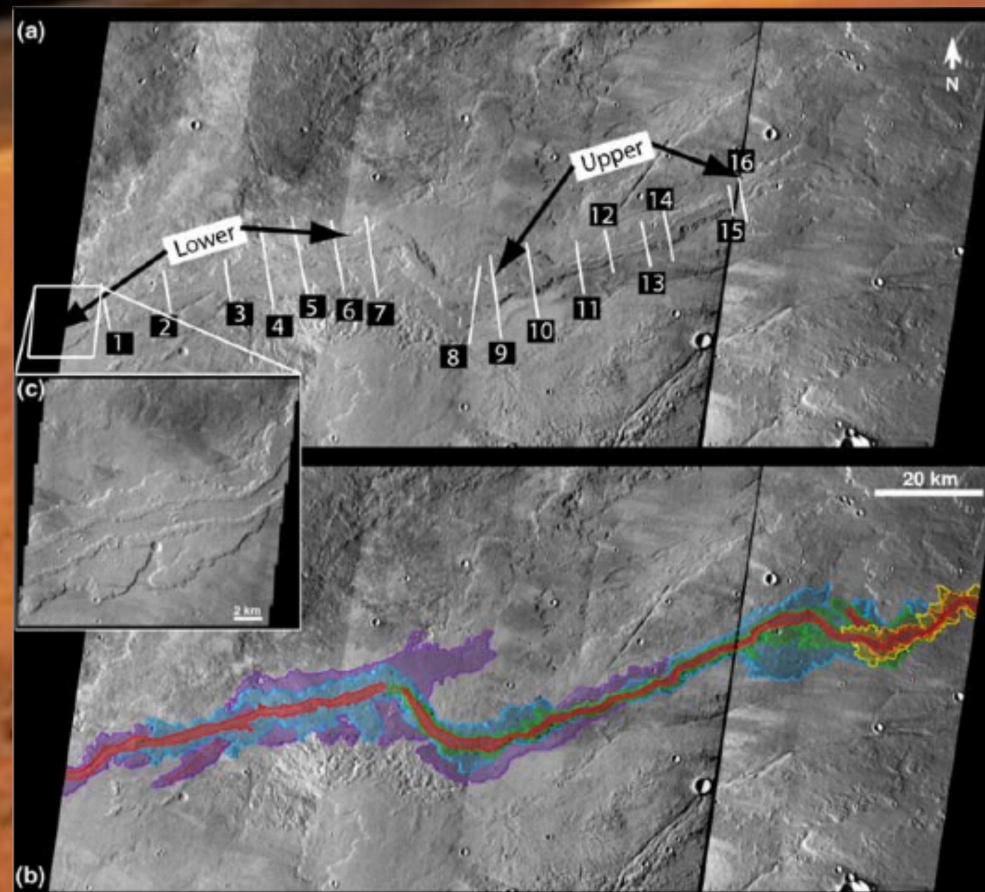


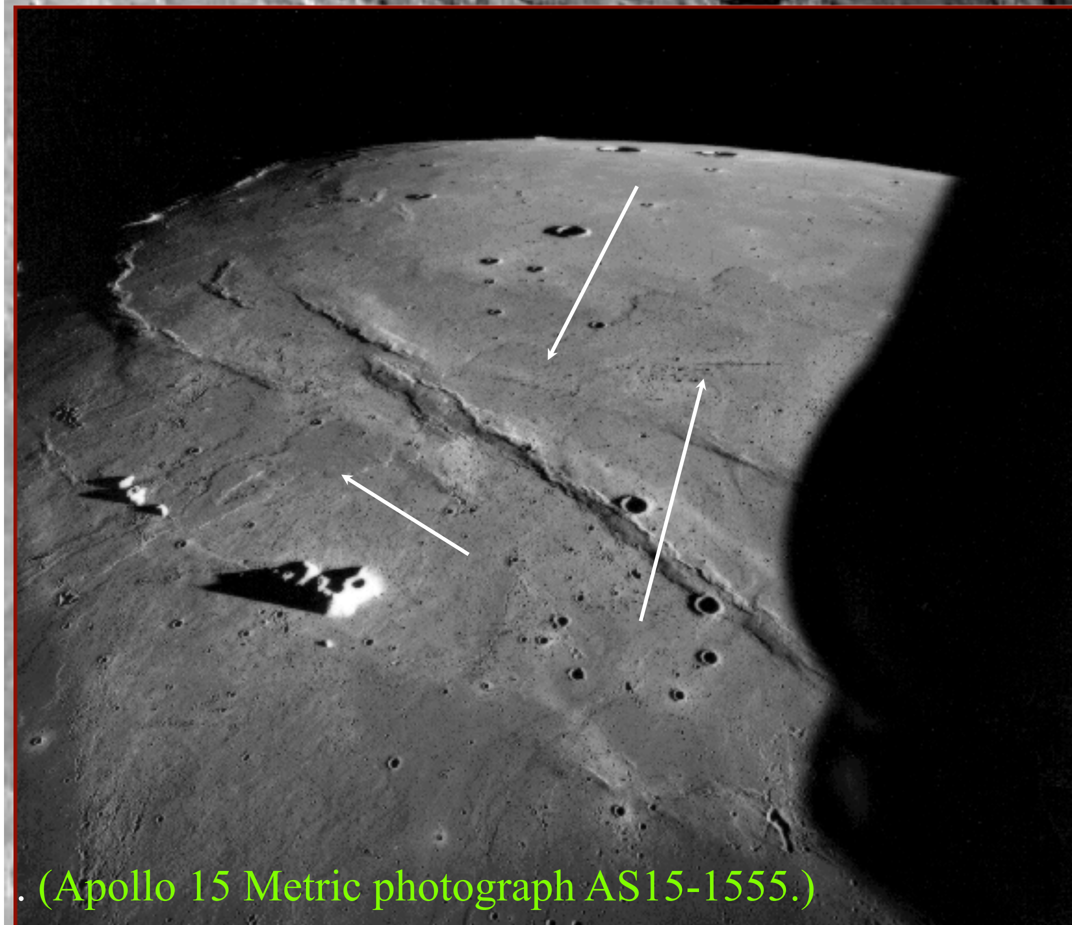

**Figure 1.** (a) Mosaic of Thermal Emission Imaging System (THEMIS) daytime infrared images (100 m pixel$^{-1}$) showing a 189 km long segment of a lava flow (flow 3 in Table 1 and Figure 7) in the Tharsis plains southwest of Alba Patera. Flow direction is from east to west (right to left). Cross-flow profile locations (white lines) and corresponding numbers refer to detailed measurement locations in Tables 4 and 5. (b) Coloration depicts central channel (red) and several generations of levees ranging in approximate order of youngest to oldest from orange, yellow, green, blue, and purple. (c) Inset is THEMIS Visible image V12686014 (37 m pixel$^{-1}$) showing detail of channel and levees.

Glaze et al 2009

# and Venus...

NASA’s Magellan project

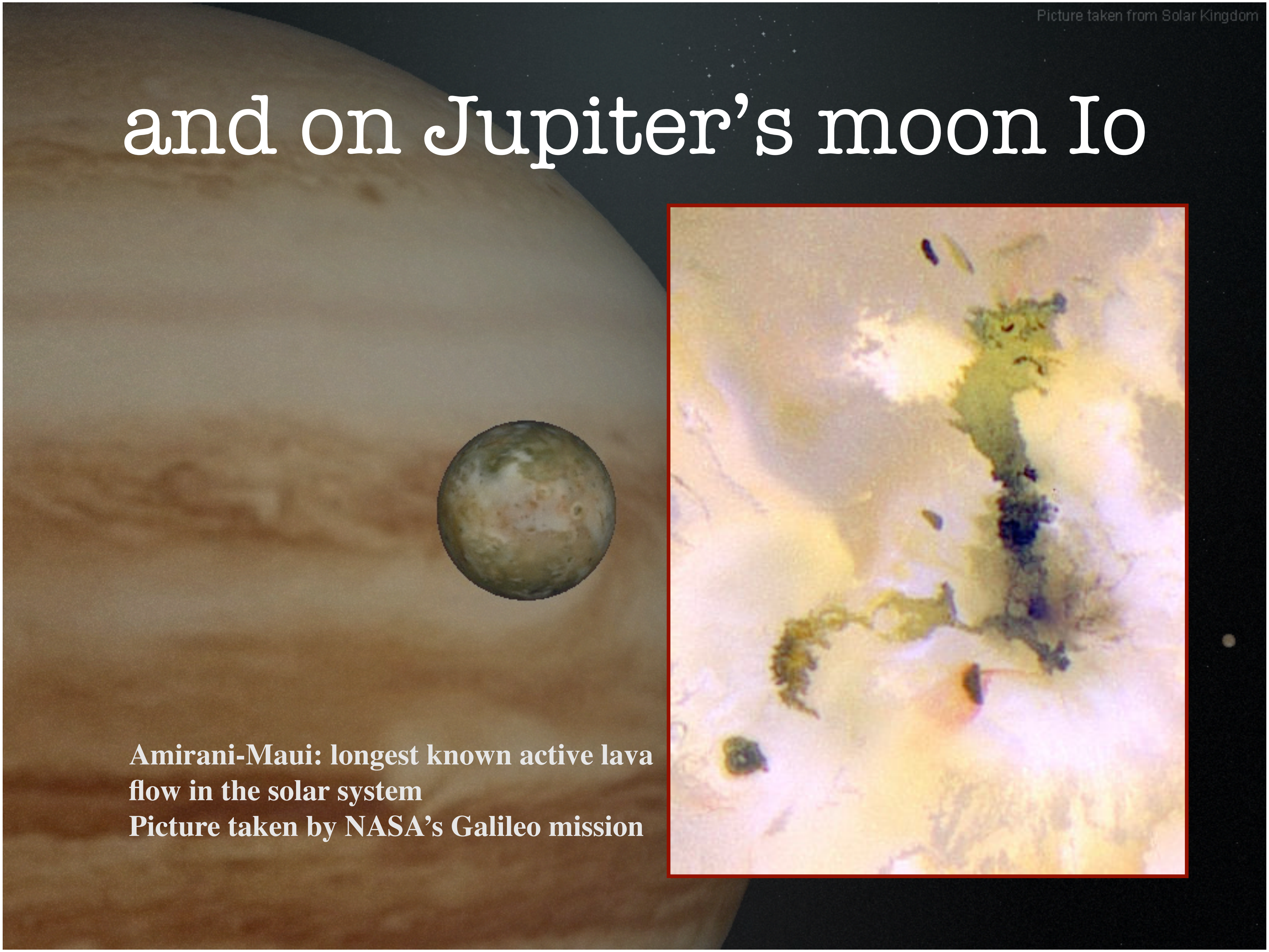
# On our moon



. (Apollo 15 Metric photograph AS15-1555.)


Zimbelman 2008

# and on Jupiter's moon Io




**Amirani-Maui: longest known active lava flow in the solar system**
**Picture taken by NASA's Galileo mission**

Fernandina,
Galapagos Islands
Marc Orbach, 1978 (courtesy of Tom Simkin, Smithsonian Institution)
Ceboruco,
Central America
Jim Luhr, 1980 (Smithsonian Institution)
an Miller, 1990 (U.S. Geological Survey)
Bezymianny,
Kamchatka
Richard Moore, 1977 (U.S. Geological Survey)
Kilauea,
Hawai'i
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Etna,
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Wally Johnson, 1988 (Australia Bureau
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Jaime Incer, 1982


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Jaime Incer, 1982

# Lava flows are beautiful

# But are also a hazard!



Etna south slope, 2004

# Why we need models?

- Understand processes, important effects
- Predict flow path and speed – before and during eruptions
- Help interpret past eruptions

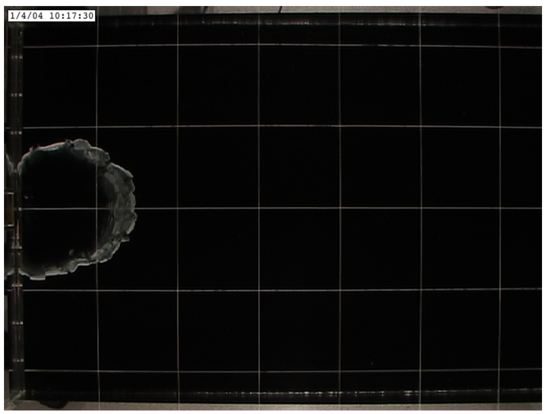
# Conceptual Types of Lava Flow Models

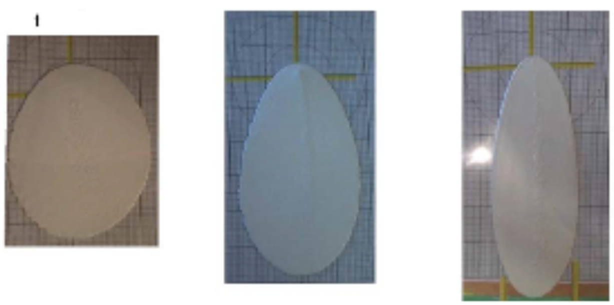
**Laboratory**

**Mathematical**

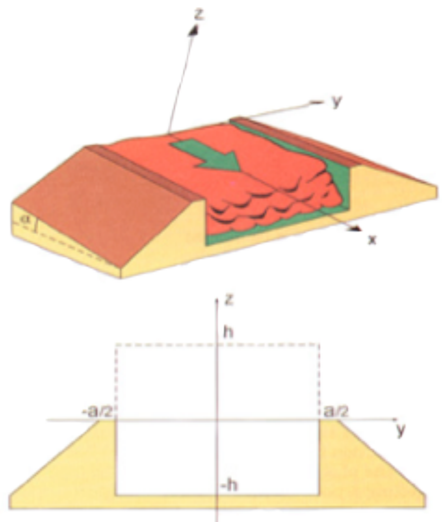
- **Process**
- **Flow simulation**

Kerr et al 2006

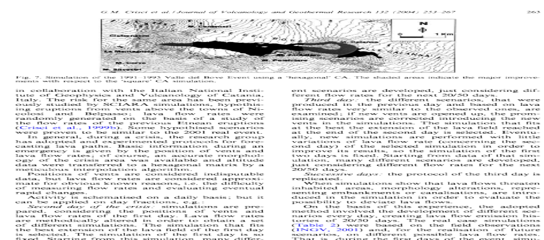


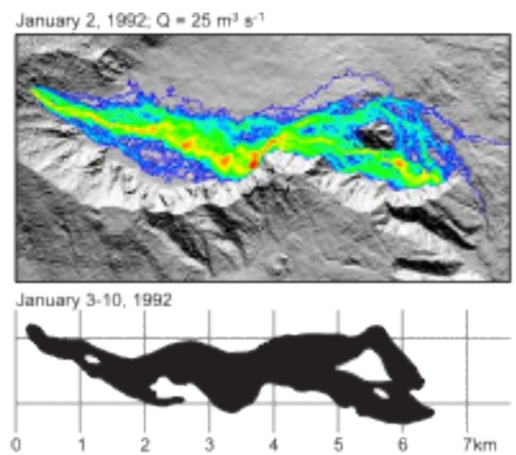
Balmforth et al. 2006




Tallarico and Dragoni, 2009



Crisci et al. 2004

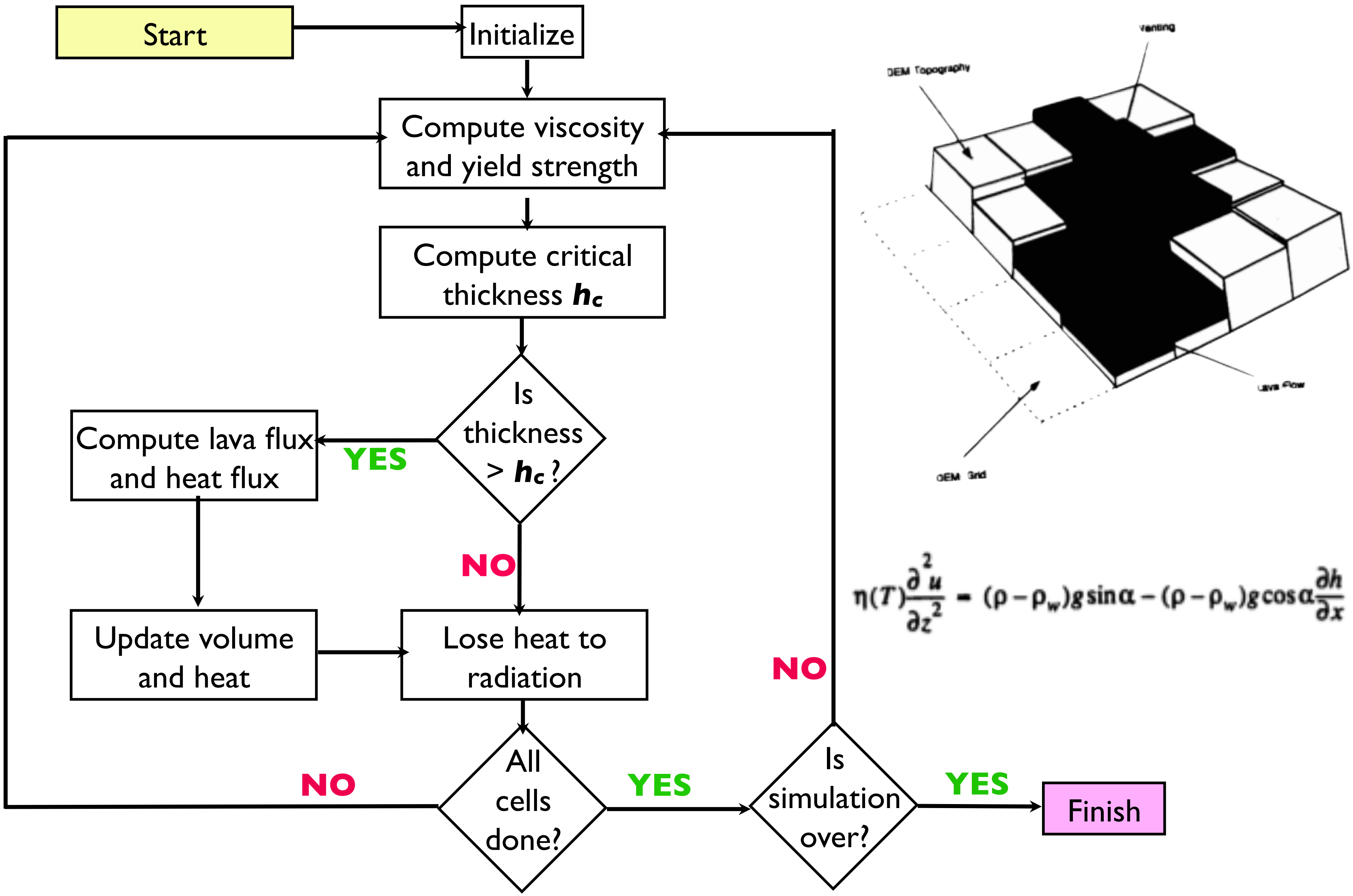



Wright et al. 2008

# Flow Simulation Codes

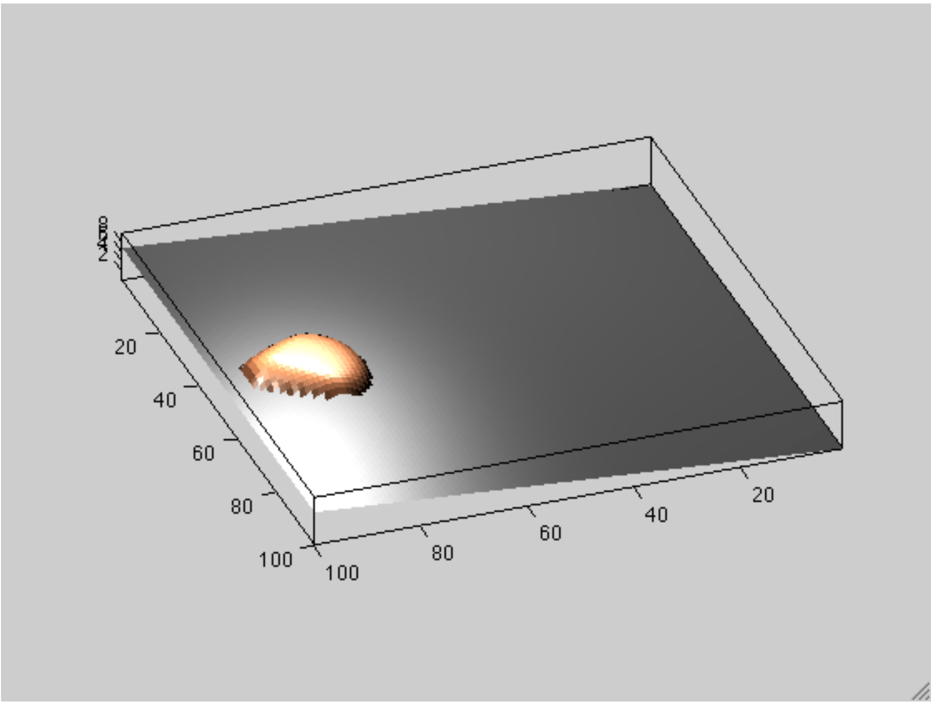
| Code name | Dimensions | Numerical technique | Rheology | References |
|---|---|---|---|---|
| FLOWGO | 1 | Control volume | Bingham | Harris and Rowland (2001); Harris et al. (2007) |
| FLOWFRONT | 2 map view | Implicit description of flow front | Bingham or power-law | Young and Wadge (1990) |
| Ishihara | 2 map view | Cellular Automata | unspecified | Ishihara et al (1990) |
| SCIARA | 2 map view | Cellular Automata | Temperature-dependent 'adherence parameter' | Barca et al. (1993); Crisci et al. (2003); Crisci et al. (2004); Spataro et al. (2004); D'Ambrosio et al. (2005) |
| Miyamoto and Sasaki | 2 map view | Cellular Automata | Bingham | Miyamoto and Sasaki (1997) |
| MAGFLOW | 2 map view | Cellular Automata with Monte Carlo | Bingham | Vicari et al. (2007); Del Negro et al. (2008) |
| Costa and Macedonio | 2 map view | Shallow water approximation, CLAWPACK Finite Volume package | Bingham | Costa and Macedonio (2005) |
| LavaSIM | 3 | Simplified Marker and Cell (SMAC) | Bingham | Hidaka et al. (2005); Proietti et al. (2009) |
| SPHysics | 3 | Smoothed Particle Hydrodynamics | power-law | Vicari et al. (2010) |

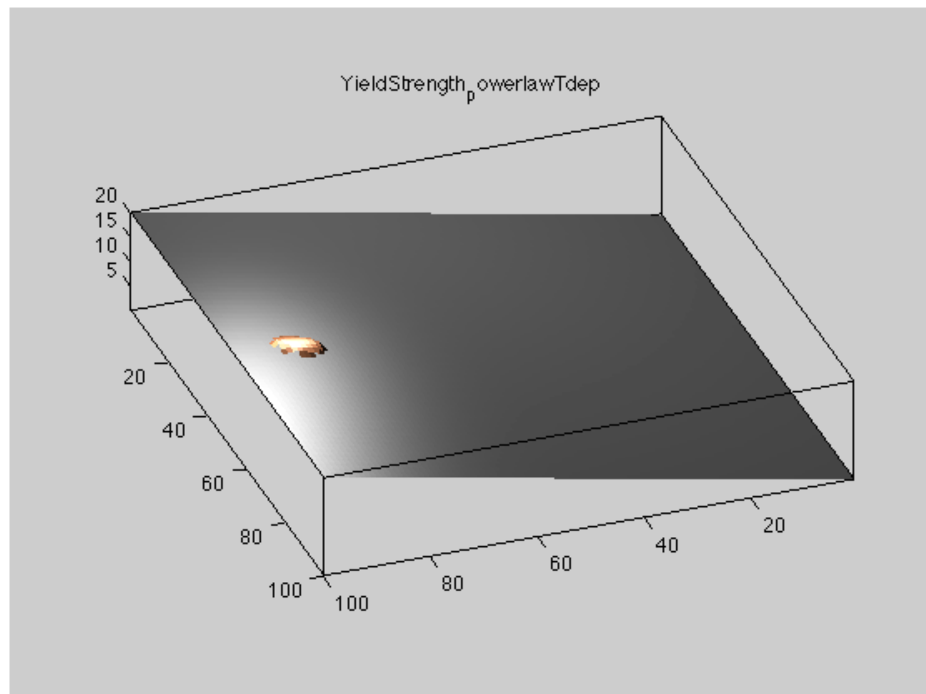
# Cellular Automata




$$\eta(T)\frac{\partial^2 u}{\partial z^2} = (\rho-\rho_w)g\sin\alpha - (\rho-\rho_w)g\cos\alpha\frac{\partial h}{\partial x}$$

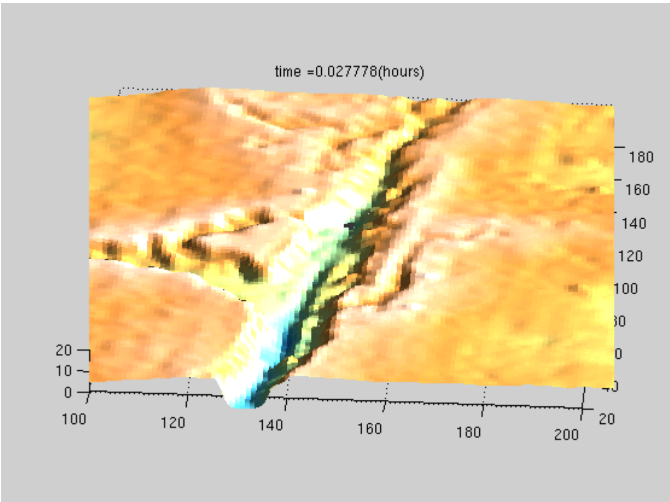
# Cellular Automata



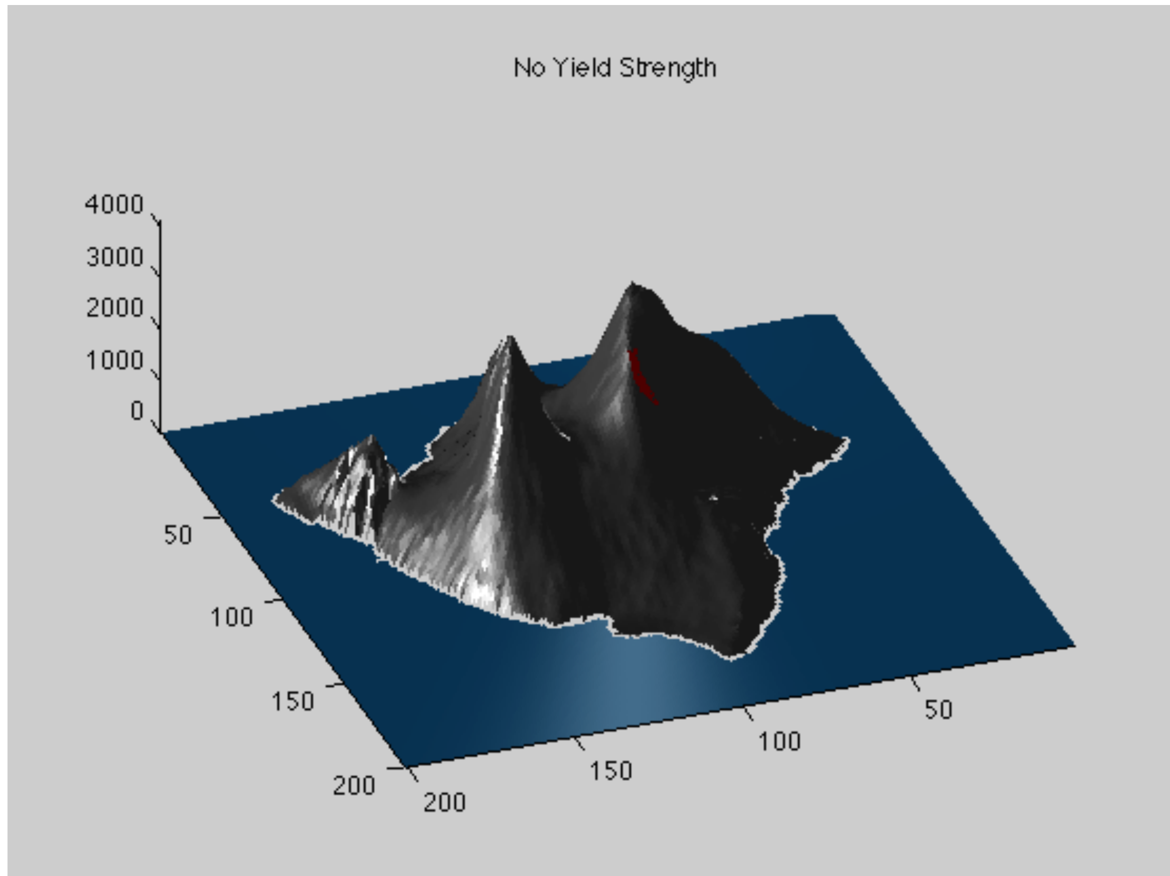




Flow on inclined plane:
Note the influence of changing viscosity and yield strength

# Cellular Automata




Viscous lava, on East Pacific Rise topography




Weak lava with no yield strength
Big Island of Hawai'i topography

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# Why 3D is important?

Processes difficult/impossible in vertically-integrated models:

- Self-channelization
- Levee construction and breaching
- Pressure ridges
- Thermal erosion
- Lava tubes

Lava flow on Santiaguito.
Thanks to Rüdiger P. Escobar Wolf

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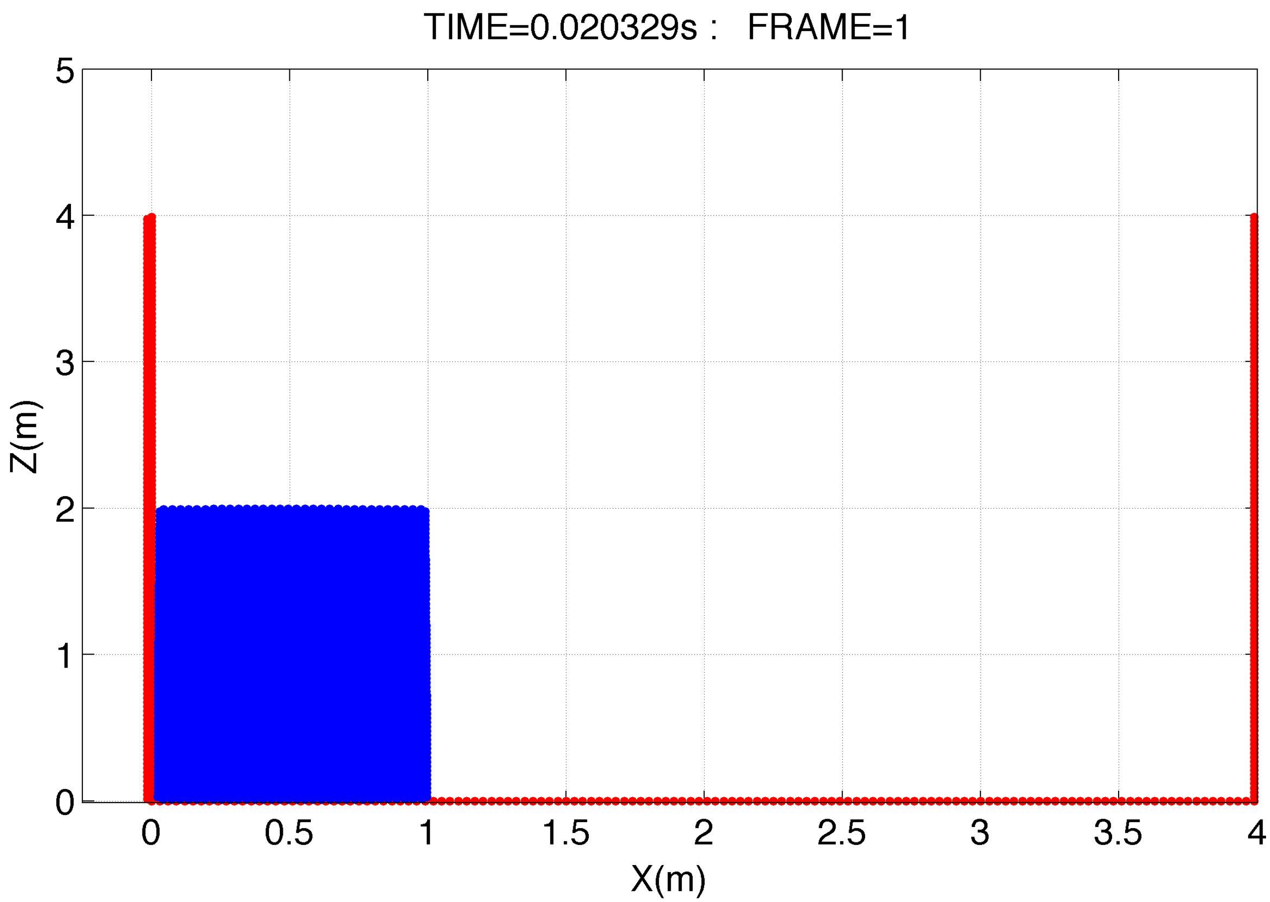
# Smoothed Particle Hydrodynamics (SPH)

Free surface is straight forward

Might be computationally expensive

Codes usually free

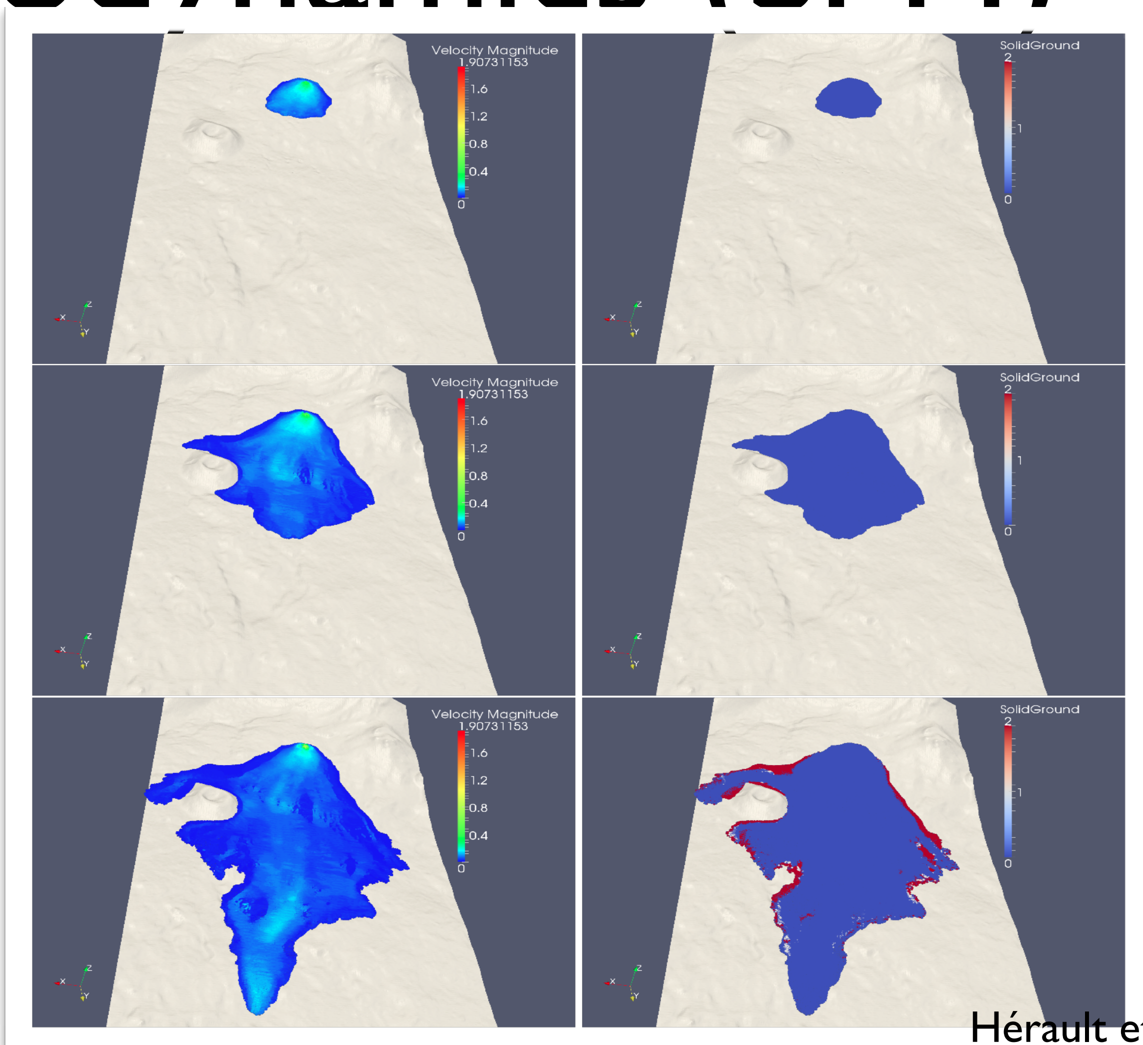



*Animation made using SPHysics*

# Smoothed Particle Hydrodynamics (SPH)

Fast – runs on GPUs using CUDA

Under development, not fully validated




Hérault et al 2010

# Adaptive Finite Element

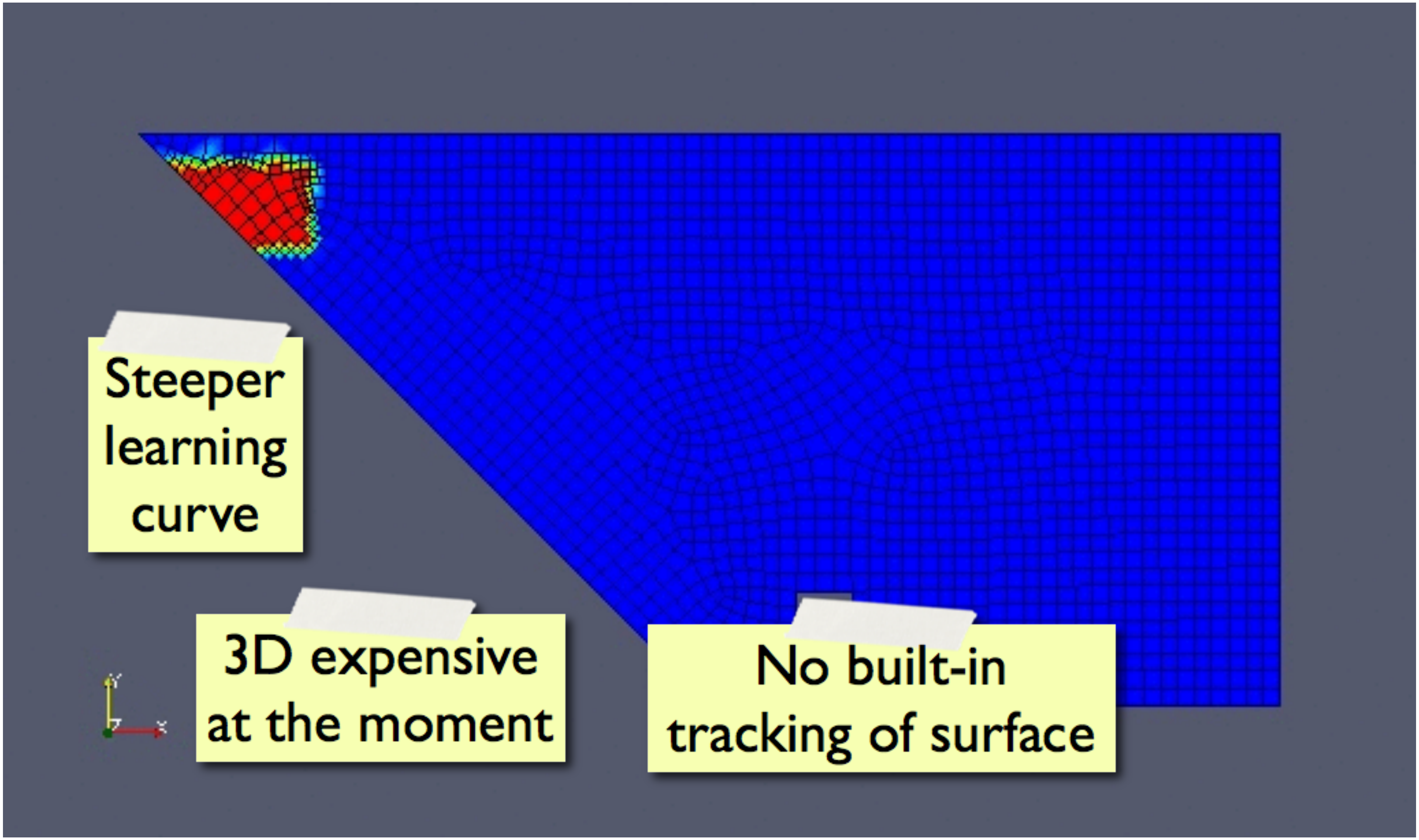
Solve fluid dynamics equations

Wide range of rheologies

Support for high variability

*deal.ii* website

# Adaptive Finite Element




Animation: *deal.ii* website

# The Next Step ("wish list")

- Flow-scale models that have:
  - Vertical and horizontal variations
  - True free surface
  - Solution of flow equations directly
  - 3D capabilities, to enable:
    - Self channelization
    - levee construction and breaching
    - Pressure ridges
  - Wide range of lava rheologies