Western U.S. Volcanism due to Intruding Oceanic Mantle Driven by Ancient Farallon Slabs

Project PI: Lijun Liu, Univ. of IL at Urbana-Champaign
Presenter: Quan Zhou
NCSA team: Ryan Mokos, Bill Gropp, Darren Adams, Yifeng Cui

Zhou and colleagues use a numerical model to investigate the volcanic history of the western US. They show that the majority of volcanism could be explained by mantle flow induced by the intruding Farallon plate. In this scenario, hot oceanic mantle from beneath the Pacific Ocean is drawn eastward, passing through tears in the subducting Juan de Fuca plate.

June 5
Blue Waters Symposium
What are the processes forming these volcanoes?
Process I: Subduction

http://www.bgs.ac.uk/discoveringgeology/hazards/volcanoes
Process II: Mantle plume

A. Plate motion
   - Lithosphere
   - Head
   - Tail
   - Rising plume
   - Mantle
   - Core

B. Flood basalts
   - Hot spot
   - Rising plume
   - Mantle
   - Core

C. Volcanic trail
   - Hot spot volcanic activity
   - Rising plume tail
   - Mantle
   - Core

© 2010 Tasa Graphic Arts, Inc.
Earth Tomography

https://geology45.blogspot.com/2016/12/describe-how-seismic-waves-are-used-to.html
Observations in mantle
Seismic Tomography

(Obresbki et al. 2010)
Earth mantle simulation

Governing Equations

\[
\nabla \cdot \vec{u} = 0
\]

\[\n-\nabla P + \nabla \cdot [\eta(\nabla \vec{u} + \nabla^T \vec{u})] + (\alpha Ra T + Ra_b C) \vec{e}_r = 0 \quad (2)\]

\[
\frac{\partial T}{\partial t} + \vec{u} \cdot \nabla T = \kappa \nabla^2 T
\]

Assume the mantle is an incompressible fluid, which satisfies the Boussinesq approximation
Method

Data assimilation mantle convection simulation

Data can be assimilated:

Plate motion and sea-floor age

Tomography

(Schmandt & Lin 2014)
<table>
<thead>
<tr>
<th>Method</th>
<th>Summary</th>
<th>Data assimilated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward /Sequential</td>
<td>Solving the governing equations forward in time, updating the model when observational constraints are available (imposing plate motion, and updating oceanic lithosphere temperature based on sea-floor age)</td>
<td>Plate Motion Sea-floor age</td>
</tr>
<tr>
<td>Simple Backward Inverse(SBI)</td>
<td>Solving the governing equations backward in time, either neglecting thermal diffusion or using normal diffusion.</td>
<td>Plate motion Tomography</td>
</tr>
<tr>
<td>Adjoint /Variational</td>
<td>Starting with a first guess of the initial condition, normally generated from the SBI. And then a forward integration predicts the present-day mantle structure, whose difference from the observed structure is integrated back to the initial time using the adjoint solver, correcting the initial condition.</td>
<td>Plate motion Tomography</td>
</tr>
<tr>
<td>Hybrid (forward+adjoint)</td>
<td>First, obtaining a rough estimate of the initial condition through SBI. Second, applying the sequential method to forward predict the present-day mantle structure. Third, introducing the adjoint method to further refine the initial condition and subsequent mantle evolution.</td>
<td>Plate motion Sea-floor age Tomography</td>
</tr>
</tbody>
</table>
Why Blue Waters

- CitcomS has a very good scalability, up to \(~10,000\) CPUs on Blue Waters.

- Blue Waters is compatible with the softwares we use, including CitcomS, DrexS and FSTRACK.

- Larger capacity leads to larger allocation and shorter waiting time.
Modeled vs. observed present mantle structure based on the hybrid convection model

(Schmandt & Lin 2014)

(Zhou et al. 2018)
Subduction and Mantle Flow

(Zhou et al. 2018)
Implication on Intra-plate volcanism

0 Ma

(Zhou et al. 2018)
Conclusions

 ✓ The sinking ancient Farallon slab drives the hot anomalies below the oceanic lithosphere to intrude into the western U.S.

 ✓ The propagation of oceanic hot anomalies below the western U.S. induces the intra-plate volcanisms
Driving force: Ancient Farallon Slab
Driving force: Ancient Farallon Slab

(Zhou et al. 2018)
Why Blue Waters

• CitcomS has a very good scalability, up to ~10,000 CPUs on Blue Waters.

• Blue Waters is compatible with the softwares we use, including CitcomS, DrexS and FSTRACK

• Larger capacity leads to larger allocation and shorter waiting time.