Geodynamic models of a Yellowstone plume and its interaction with subduction and large-scale mantle circulation

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Yellowstone – a classical hotspot?

associated with
Large Igneous Province (LIP)

recent volcanism on young end

age-progressive volcanic chain

Figure from Smith et al. (JVGR, 2009)
... in a very untypical location!

reconstructed eruption site not along LLSVP margin
→ s-wavespeed anomalies in lowermost mantle,
→ reconstructed LIPs (green)
→ likely deep hotspots (stars)
→ after Torsvik et al. (2006)

Only LIP since 300 Ma in area of recent subduction

Subduction locations and amounts (color intensity) from a global plate reconstruction (see Steinberger and Torsvik, 2012, for details)
but possibly still caused by a mantle plume …

maybe even from the lowermost mantle?

Model of plume embedded in large-scale mantle flow
→ predicts hotspot track and shape of plume conduit
→ compare with observations

dynamical model of a plume from above CMB, separated off the LLSVP margin by subduction

→ and some speculations
Model of plume embedded in large-scale mantle flow

- density anomaly derived from SMEAN tomography model (Becker and Boschi, 2002; “thermal” scaling below depth 220 km
- large-scale flow computed with spectral code (Hager & O’Connell, 1979, 1981)

Initially vertical conduit

Motion of conduit elements

Vector sum

Advection + buoyant rising

Tilted conduit
Geodynamic model conduit: global-tomography-based flow typically ~eastward
→ ~east-west tilt

Plume conduit in regional tomography model: NW-SE tilt
Slab depths from model UU-P07 (Amaru, 2007) courtesy of Wim Spakman.
The image contains four maps representing different seismic wave models:

1. **p-wave model UU-P07**
   - This map shows the distribution of p-waves, with color coding indicating depth in kilometers.
   - Depth range is from 1000 to 3000 km.

2. **Steve Grand S-wave**
   - This map illustrates the S-wave model, with a focus on the time of subduction in Ma (百万年).

3. **GFZ Helmholtz Centre Potsdam**

   - The maps include various markers:
     - **Yellowstone HS** star
     - **~ plume at “660”** yellow circle
     - **Columbia River Basalts reconstructed** green circle
     - **Yellowstone plume at D”** red circle

These models and markers provide insights into the subduction and plume dynamics in the geological context.
Low-velocity anomaly
In lowermost mantle
In region where plume conduit is predicted to originate

🌟 Yellowstone hotspot

● predicted plume source in D''
Dynamic model (Steinberger and Torsvik, G-Cubed, 2012):

- Subduction zone moving ~2 cm/yr
- Typical hotspot motion <= 1 cm/yr
- Plume overridden by subduction zone (Yellowstone at ~50 Ma)
- Plume reaches surface behind slab
Conclusions

• Geodynamic models of plume embedded in large-scale mantle flow predicts
  (a) plume coming up from ~West (at “660” ~200-250 km to W)
  (b) plume moving eastward at 2-3 cm/yr

• Tomography models indicate plume coming up from NW
  (~200-250 km to NW at “660”)

• Plume motion helps explaining age progression along hotspot track (Snake River plain)

• Geodynamic model of plumes generated at margins of Large Low Shear Velocity Provinces (LLSVPs) predicts plume beneath North America to
  (a) be separated off Pacific LLSVP due to fast advancing (~2 cm/yr) of
    subduction zone
  (b) reach surface East of the subduction zone

• If Yellowstone plume rises from lowermost mantle, we might be sitting right
  on top of its source.