Effects of 3-D Slab Geometry and Oblique Subduction on Mantle Wedge Flow and Thermal Structure: Examples from NE Japan

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NE Japan

Slab geometry data from Kita et al. (2010), Nakajima and Hasegawa (2006), and Nakajima et al. (2009); compiled by F. Hirose
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Three-Dimensional Steady-State Finite Element Model

Governing Equations

\[ \nabla \cdot v = 0 \]
\[ \nabla \cdot \sigma' - \nabla P = 0 \]
\[ \nabla \cdot (k \nabla T) - \rho c_p \left( v \cdot \nabla T \right) + Q_H = 0 \]
Three-Dimensional Steady-State Finite Element Model

Model parameters
- Subduction rate ($v$): 82 mm/yr
- Trench-side geotherm: Slab age of 120 Ma (GDH1)
- Backarc-side geotherm: 88 mW/m² surface heat flow
  $T_m = 1300$
  0.3°C/km adiabatic gradient
A total of ~2 million elements and ~16 million grid nodes in our final calculation

- Incorporation of a realistic slab geometry
Model-Predicted Flow Directions at 80 km depth

- Inflow from N beneath Hokkaido
- Reduced inflow in the Hinge zone
- Inflow from W beneath Tohoku; little 3-D effect

- Outflow parallel to the subduction direction
Model-Predicted Flow Directions at 105 km depth

- Inflow from NNE beneath Hokkaido; variation in inflow direction with depth
- Little change in the outflow direction with depth
Average fast direction and delay time at each station

Spatially averaged fast direction
Inflow Direction and Volcanic Cross-Chain Orientation
Model-Predicted Mantle Wedge Temperature at 60 and 80 km depths

Compared to Tohoku...

- 50–100°C cooler in Hokkaido due to oblique subduction and steeper dip
- 100–200°C cooler in the hinge zone due to subdued mantle inflow
Seismic Attenuation and S-wave Structures in the Mantle Wedge

- Volcanic clustering
- “Hot fingers” [Tamura et al., 2002]

- “Wet fingers” [Nakajima et al., 2013]
Low-Velocity High-Attenuation Regions: Hot Fingers vs. Wet Fingers

Hot-Finger Model
(Low-Velocity Zones = Hot Regions)

Wet-Finger Model
(Low-Velocity Zones = Wet Regions)
Summary

• In Tohoku, a 2-D approximation is reasonable.
• In Hokkaido, oblique subduction results northerly inflow and west-northwestward outflow.
• In the hinge zone, the convergence of northerly inflow from Hokkaido and the westerly inflow from Tohoku discourages inflow from northwest.
• Compared to Tohoku, Hokkaido and the hinge zone are colder.
• Mantle inflow direction correlates well with the seismically fast direction and the orientation of volcanic cross-chains.
• A mechanism of volcanic clustering remains to be investigated.