Layered mantle flow beneath the NE Asia from inversion of surface wave dispersion using rj-MCMC method

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1 Background

2 Data and Method

3 Results and Discussion

4 Conclusion
• **Geological background**

• **Trench-arc-backarc features:**

  ➢ **Volcanism:** Arc volcanoes and **Intraplate volcanoes**

  ➢ **Extensional Basins,** e.g. Songliao Basin, Bohaiwan Basin etc.

  ➢ **Marginal sea:** Sea of Japan

  ➢ **Large fault zone:** Tan-Lu Fault Zone

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- MS = Molucca Sea minor plate; BH = Bird’s Head minor plate; WPB = West Philippine Basin; SB = Shikoku Basin; PVB = Parece Vela Basin; MT = Mariana Trough.
- NEC = northeast China; ENCC=Eastern North Chian Craton ; KP = Korean Peninsula; KS = Korea Strait; SoJ = Sea of Japan; JI = Japanese Island.
- CBV = Changbaishan volcano; JPHV = Jingpohu volcano; LGV = Longgang volcano; XJDV = Xianjingdao volcano; CRV = Chuga-Ryong volcano; ULV = Ulleung volcano; HLV = Halla volcano; FJV = Fukue-jima volcano.
- TLFZ = Tanlu fault zone.
• Questions about intraplate volcanoes

➢ How is the large-scale mantle upwelling related to specific volcanoes?

(Faccenna et al., 2010)  

Zhao et al., 2009

(Faccenna et al., 2010)
• Questions about geodynamic process reflected in mantle flow
  ➢ What performance?
  ➢ Controlled by subduction? Back arc extension? Other reason?
Data and Method

- Classical representation of Rayleigh-wave and shear wave velocity azimuthal anisotropy

  ➢ For phase velocity:

  Rayleigh wave

  \[
  \delta c_R(\omega, \psi) \approx a_0(\omega) + a_c(\omega) \cos 2\psi + a_s(\omega) \sin 2\psi
  \]

  \[
  a_{c,s}(\omega) \approx \int_0^H \left( \frac{\partial c_R(\omega)}{\partial A} \right) \frac{G_{c,s}}{\partial L} d\psi
  \]

  \[
  \gamma(i) = \frac{B_{c,s}}{A(i)} + \frac{G_{c,s}}{L(i)}
  \]

  \[
  a_{c,s}(\omega_f) \approx \sum_{i=1}^{\Sigma} \left( \gamma(i) A^{(i)} \frac{\delta c_R(\omega)}{\delta A^{(i)}} + L^{(i)} \frac{\delta c_R(\omega_f)}{\delta L^{(i)}} \right) \frac{G_{c,s}^{(i)}}{L}
  \]

  Inversion: phase velocity \( c_R + a_{c,s} \) ➔ Shear wave velocity \( V_{SV} + G_{c,s}/L \)

  ➢ For shear wave velocity:

  \[
  V_{SV}(\psi) \approx \sqrt{\frac{L + G_c \cos 2\psi + G_s \sin 2\psi}{\rho}}
  \]

  \[
  \frac{G_{c,s}}{L} \ll 1
  \]

  \[
  \approx V_{SV} \left( 1 + \frac{G_c}{2L} \cos 2\psi + \frac{G_s}{2L} \sin 2\psi \right)
  \]

  \[
  = V_{SV} \left( 1 + A_{VS} \cos(2\psi - \phi_{VS}) \right)
  \]

  Notice: \( |A_{VS}| = 0.5 \sqrt{\left( \frac{G_c}{L} \right)^2 + \left( \frac{G_s}{L} \right)^2} \)

  \[
  \phi_{VS} = 0.5 \arctan(G_s/G_c)
  \]
Data and Method

- **Previous work:** Two-station surface wave tomography (Fan et al., GRL, 2020)

Average dispersion along interstation paths → Phase velocity on all Knots: \( c_R(\omega, \psi) \) → Isotropic+Anisotropic Rayleigh wave phase velocity map

Data in this study

Distribution of stations, ray paths and selected earthquakes (Fan et al., 2020)
- **reversible jump Markov Chain Monte Carlo**

**Bayes theory:** \( P(m|d) \propto P(d|m) \cdot P(m) \)

**Model dimension is variable:**
- MCMC is **reversible** itself
- Transdimensional sampling — “jumping” between dimension-different model space

**Trans-dimensional proposal**

Balance the uncertainty and misfit automatically

**Simultaneous Inversion:**
Shear wave velocity + anisotropy
Our improvement: Layered prior for Shear wave velocity

Surface wave: insensitive to discontinuities

Data and Method

Depth min $V_S$ (km/s) max $V_S$ (km/s)

0~min Moho 3.0 4.2
In Moho Range 3.5 4.7
max Moho~300km 4.0 5.0
300~400km 4.0 5.5

Moho: CRUST1.0±7.5km
Vs: Layered prior setting

Uniform prior? ×  Complex prior √

Efficiency ↑
Accuracy ↑
Results and Discussion

1. Single Knot

Data fit

Example A

A: near Changbaishan Volcano

Example B

B: near high-velocity block of SW Korean Peninsula
1. Single Knot

**Results and Discussion**

**Model result**

- **Example A**
  - A: near Changbaishan Volcano
- **Example B**
  - B: near high-velocity block of SW Korean Peninsula

![Graphs showing Vs, Gc/L, Gs/L, and Discontinue](image)

- (a) Depth vs. Vs (km/s)
- (b) Depth vs. Gc/L (%)
- (c) Depth vs. Gs/L (%)
- (d) Depth vs. Probability (discontinue)
Results and Discussion

2. 3-D model

Horizontal slices at different depths
Results and Discussion

2. 3-D model

Point 1: About Intraplate Volcanoes

- **Beneath volcanoes**
- **Localized low-velocity area**: high-velocity block:
  - Extending to ~150km
  - Near volcanoes

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**Legend**

- **L1**: 3.57 km/s
- **L2**: 4.59 km/s
- **L3**: 4.37 km/s
- **HV1**: 4.36 km/s

- **Plate motion**: 30 mm/yr
- **Anisotropy**: 1%

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![Diagram of 3-D model showing plate motion and anisotropy](image-url)
Point 1: About Intraplate Volcanoes

- **Localized low-velocity related to deeper upwellings**

The upwelling from deeper mantle of big mantle wedge display a characteristic of localized low-velocity area at the uppermost mantle.
Results and Discussion

2. 3-D model

Point 1: About Intraplate Volcanoes

Lithospheric block to ~150km

HV1:

- NE China, Supporting: Downwelling of Songliao Basin, inducing localized convective upwelling induced by

(Tang et al., 2014)

(Guo et al., 2016)
2. 3-D model

**Point 1: About Intraplate Volcanoes**

- **Lithospheric block to ~150km**
  - **SW Korean:**
    - Possible cratonic root
    - Possible process of lithospheric dripping and convective upwelling

**Diagram:**
- HV2: Delamination-style convective lithospheric downwelling in the Colorado Plateau (Levander et al., 2011)
- Song et al., 2020
Results and Discussion

2. 3-D model

Point 2: About Mantle Flow (two-layer model)

- Upper layer: perpendicular to the Pacific slab
  Possibly Controlled by Pacific subduction and back arc extension

(Kameyama, 2012)
Results and Discussion

2. 3-D model

Point 2: About Mantle Flow (two-layer model)

- Lower layer:
  - Seems to be unrelated to the mantle flow caused by the subduction plate
  - Background mantle flow associated with plate movement?
  - Mantle flow caused by other factors?
2. 3-D model

Point 2: About Mantle Flow (two-layer model)

- Two-layer model: SKS check

- Prediction based on this model fits well with observations in this region, especially about the fast direction

- A trend converging in SW Japan
2. 3-D model

Point 2: About Mantle Flow (two-layer model)

- Two-layer model: SKS check

  Prediction based on this model fits well with observations in this region, especially about the fast direction

- A trend converging in SW Japan

Possible mantle flow across the Nankai through caused by the expansion of Philippine Sea Plate (See background)
Conclusion

• About the rj-MCMC method
  - Good distribution can be obtained through rj-MCMC inversion. The efficiency and reliability of inversion can be greatly improved when adding the layered prior.

• About the intraplate volcanism
  - Localized upwelling with lateral connections between volcanoes can be observed in uppermost mantle, apart from upwelling in the whole big mantle wedge from deeper mantle.
  - Convective local upwelling induced by lithospheric dripping may exist in South Korea.

• About the anisotropy and related dynamical feature
  - Apparent anisotropy related to back-arc extension can be found beneath the Japan Sea.
  - Two-layer anisotropy can be observed in this region. The predicted SKS splitting patterns based on it fit well with the observations, showing more complex mechanism of mantle flow.
  - The anisotropy pattern with a trend converging in SW Japan may be related to possible mantle flow across the Nankai through caused by the expansion of Philippine Sea Plate (See background).
Reference


Thanks!

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