Heterogeneous distribution of mineral phases and seismic velocity in the transition zone from convection modelling based on self-consistent thermodynamics

M.H.G. Jacobs, A.P. van den Berg, *Department of Theoretical Geophysics, Faculty of Geosciences, Utrecht University, Budapestlaan 4, 3584CD, Utrecht, The Netherlands.*

ISES

Universiteit Utrecht

Aims and scope

We have modeled convection in the Earth's mantle using a self-consistent thermodynamic model for an olivine-pyroxene composition in the system MgO-SiO_2 (Jacobs & de Jong, 2007). The thermodynamic model is based on a lattice vibrational method allowing the calculation of density, thermal expansion, compressibility, specific heat, phase equilibria and seismic velocities in the complete *P-T* regime of the Earth's mantle.

Our modelling results show a complex structure in the behavior of physical properties, in particular the seismic shear velocity, in the depth range of the mantle transition zone, 400-660 km. We demonstrate that this behavior is related to the distribution of mineral phases in the olivine-pyroxene system.

Especially near cold downwelling flows, representing subducting lithospheric plates, the results of our model show strong lateral variation of mineral phases and associated shear velocity. We show that typically pockets of contrasting mineral phases smaller than 100 km occur in subduction regions.

In line with current developments in seismic reflectivity imaging of the mantle transition zone we have computed reflectivity profiles from the shear velocity distribution obtained from the convection results. We applied frequency filtering to the raw reflectivity data to investigate the requirements for resolving the heterogeneous structure of the transition zone. Our results show that most structures are resolved for periods of ten seconds which may be feasible in seismic imaging applications.

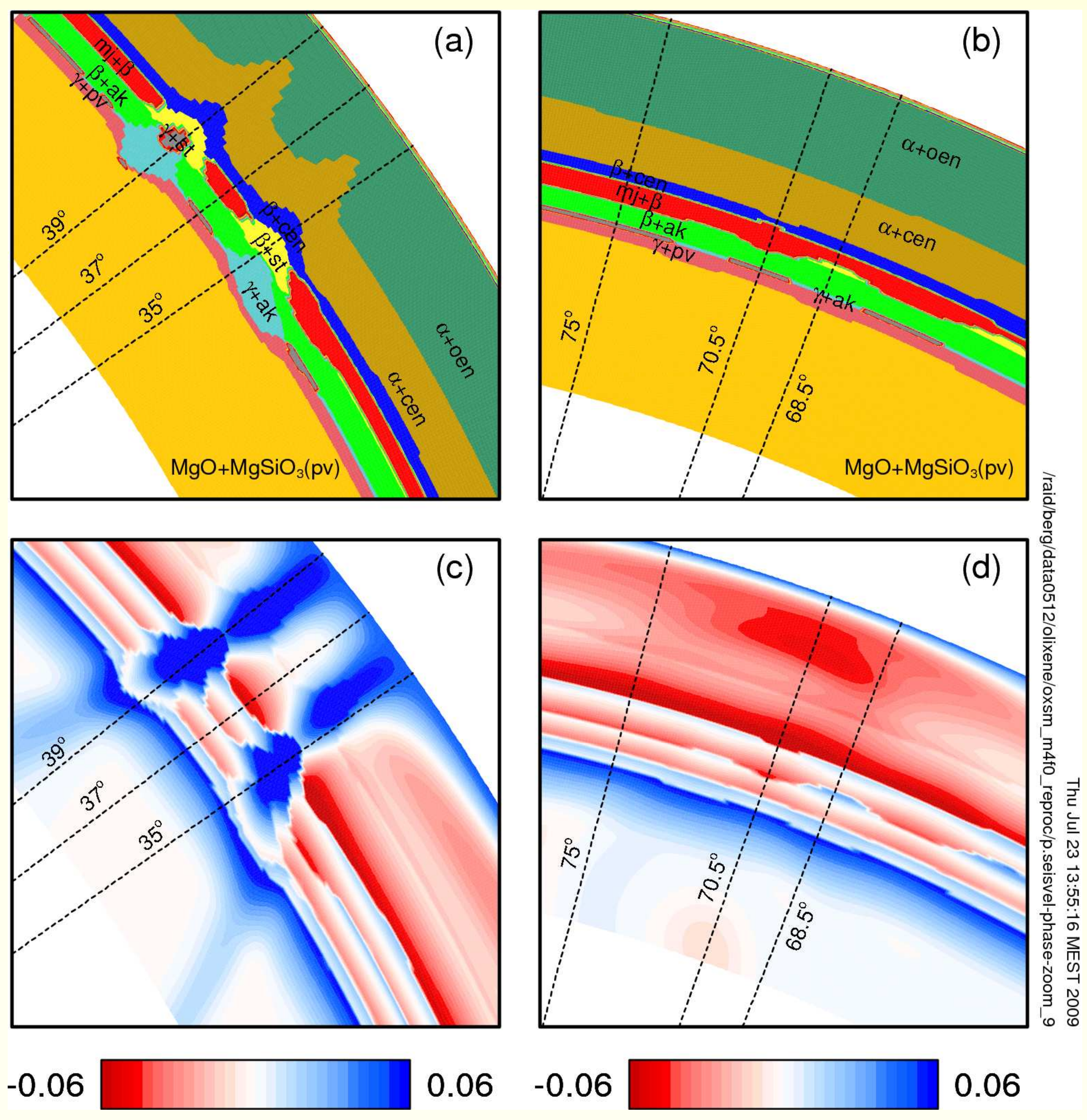

Fig. 2. **(a) Zoom-in on the spatial mineral phase distribution near the cold downwelling shown in *Fig. 1*. Dashed lines indicate the position of radial profiles. (b) Similar zoom-in as in (a) near the hot mantle region shown *Fig 1*. Individual mineral domains in (a,b) have been labeled according to the phase diagram shown in *Fig. 3*. Frames (c,d) show the lateral variation of the shear velocity, Δv_s for the same zoom-in windows as in (a,b) respectively.**

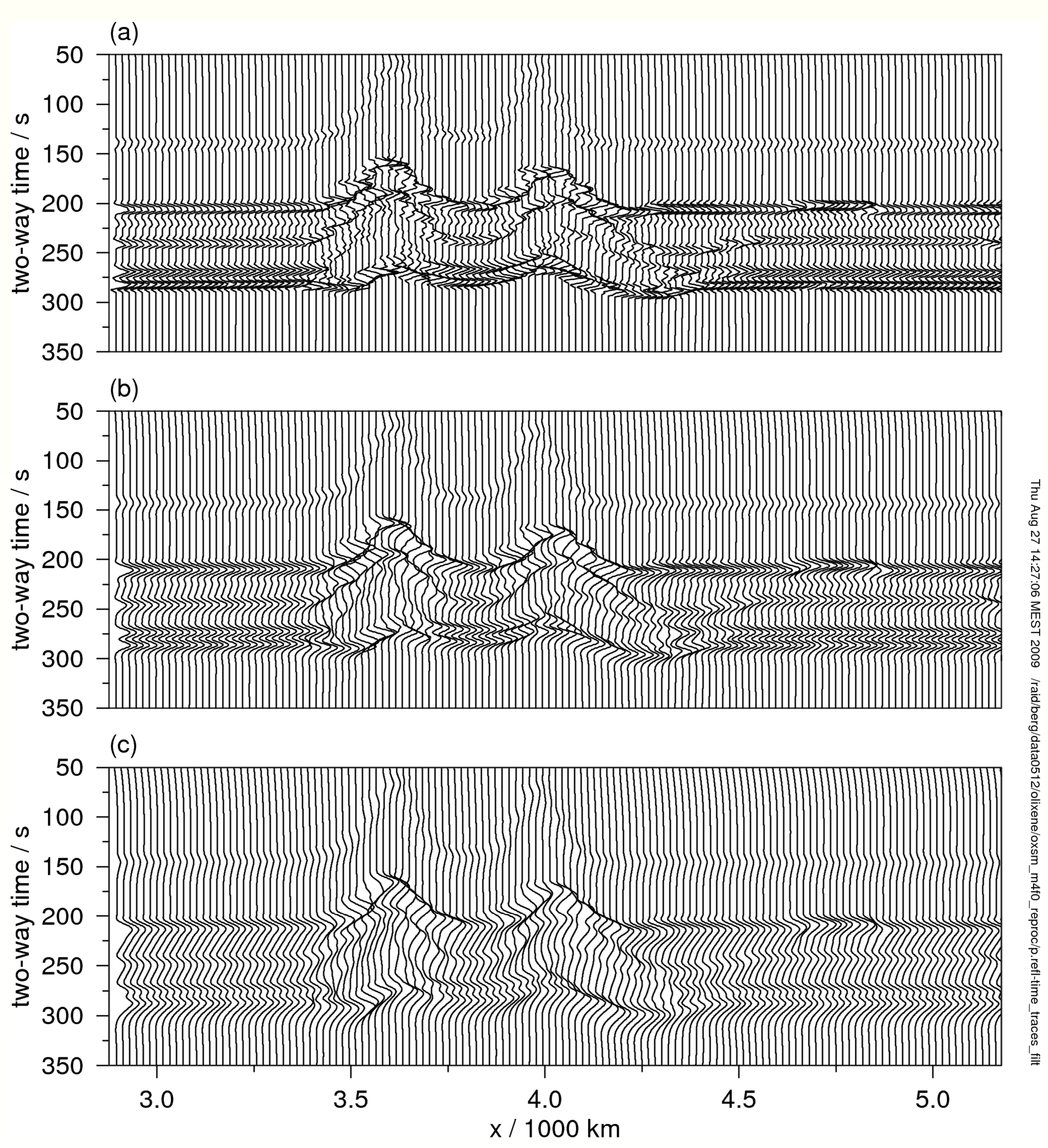

Fig. 4. **Reflectivity-time traces derived from the s-velocity distribution corresponding to the zoom-in window shown in *Fig. 2a,c*. The corresponding s-velocity distribution is shown in *Fig. 2c*. *(a)* shows the raw data derived from the convection model. *(b)* and *(c)* show corresponding time traces after application of low-pass Butterworth filters with corner-period settings of 20 sec. and 40 sec. respectively.**

Methodology

The convection model is based on a finite element solution of the coupled Stokes and energy equations in the anelastic liquid approximation.

We use a 2-D cylindrical domain with a 90º opening angle shown in ***Fig.1a,d***. Thermophysical material properties of the finite element model are derived from the vibrational thermodynamics model tabulated for the *P,T* range of the entire mantle.

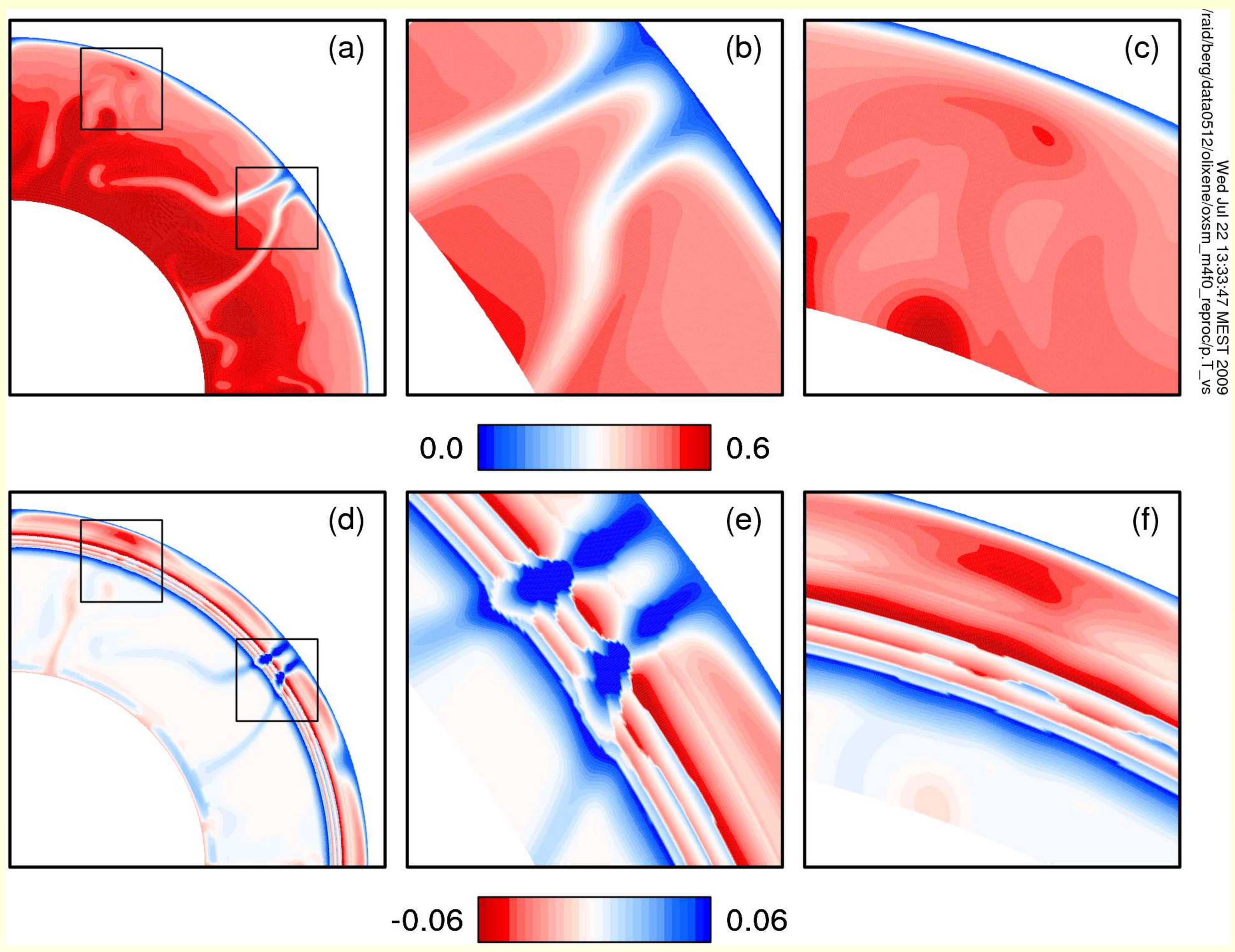

Fig. 1. **(a) Full domain temperature snapshot showing two colliding cold downwellings and a hot mantle upwelling. Black boxes represent zoom-in windows corresponding to frames (b,c). (b) zoom-in temperature of the cold downwellings flow. (c) zoom-in temperature of the shallow head of a hot upwelling. (d) Full domain distribution of the lateral variation of the shear velocity Δv_s with respect to the smooth background profile. (e) zoom-in of Δv_s of the cold downwelling. (f) zoom-in of Δv_s of the hot mantle plume head.**

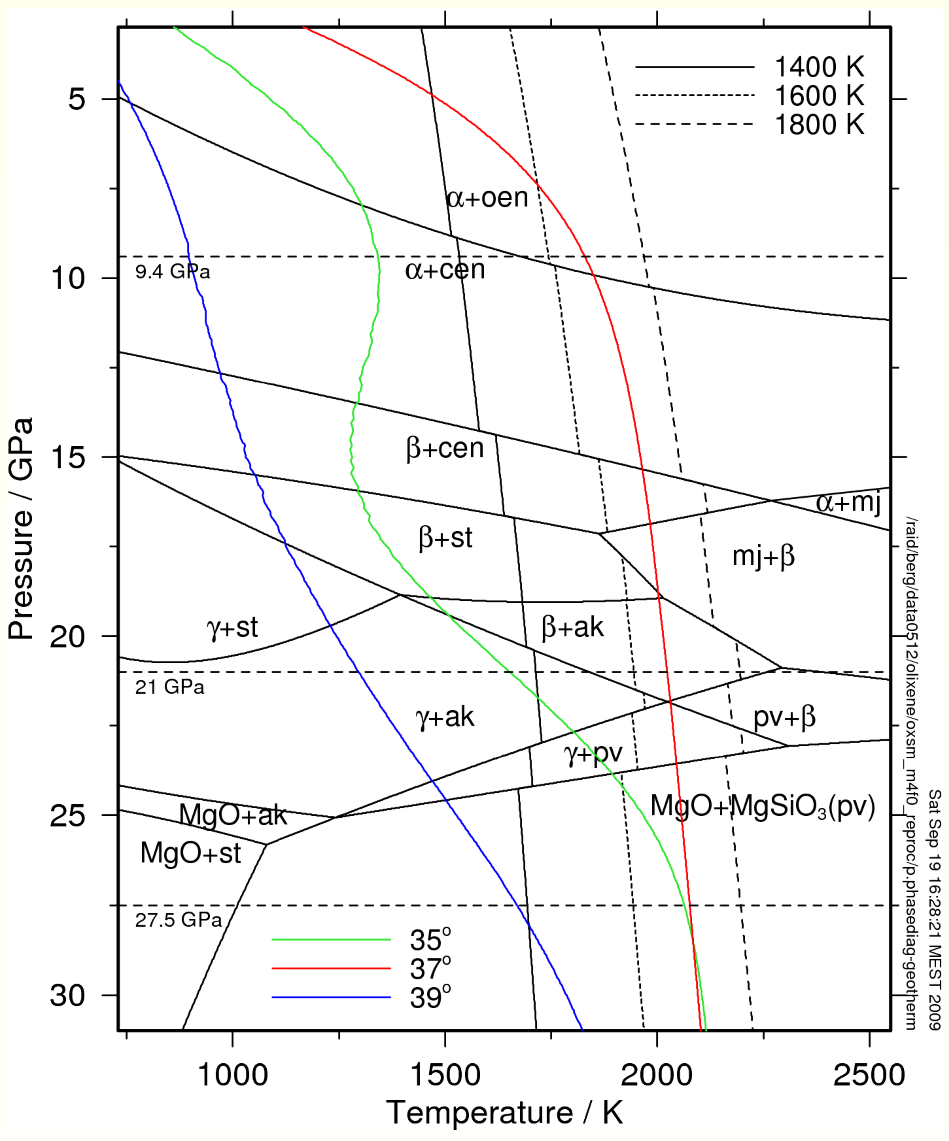

Fig. 3. **Phase diagram of the olivine-pyroxene magnesium endmember model used in the convection model. Adiabats of potential temperature T_p between 1400 and 1800 K are plotted for reference. Solid curves represent radial temperature profiles, with angular position shown in the legend, and corresponding to the dashed lines in *Fig. 2a*.**

Conclusion

Smooth temperature fields from mantle convection modelling show a complex distribution of mineral phases and seismic velocity in the depth range 400-700 km of the mantle transition zone. As a result the material properties, including seismic shear wave speed, cannot be derived from simple scaling relations in terms of temperature as is common in seismic tomography. 1-D reflectivity profiles computed from the heterogeneous velocity distribution show that this mantle structure can, in principle, be resolved by recently developed seismological methods imaging the reflectivity (Deuss, 2009, Cao et al., 2009).

References

Cao, Q., Wang, P., Lamm, R., van der Hilst, R.D., and M.V. de Hoop, Imaging the upper mantle transition zone with a generalized Radon transform of SS precursors, submitted to *Phys. Earth Planet. Inter.* 2009.

Deuss, A, Global Observations of Mantle Discontinuities Using SS and PP Precursors, *Surveys in Geophysics,* **30**, 301-326, 2009.

Jacobs, M.H.G. and B.H.W.S. de Jong, Placing constraints on phase equilibria and thermophysical properties in the system MgO-SiO_2 by a thermodynamically consistent vibrational method, *Geochimica et Cosmochimica*, **71**, 3660-3655, 2007.

http://www.geo.uu.nl/Research/Theoretical_Geophysics