INTRINSIC VERSUS EXTRINSIC SEISMIC ANISOTROPY - THE RADIAL ANISOTROPY IN REFERENCE EARTH MODELS

N. WANG[1], J.P. MONTAGNER[1], A. FICHTNER[2], AND Y. CAPDEVILLE[3]
1: Seismological Laboratory, Institut de Physique du Globe de Paris (IPGP), Paris, France. Contact Email: **nwang@ipgp.fr**
2: Department of Earth Sciences, Swiss Federal Institute of Technology (ETH), Sonneggstrasse 5, 8092 Zurich, Switzerland.
3: *É*quipe de sismologie, Institut de Physique du Globe de Paris, CNRS, France.

1. ABSTRACT

Evidence for seismic anisotropy in the Earth's mantle has been steadily growing over several decades. Anisotropy (azimuthal or radial anisotropy) is necessary to explain various seismological and mineralogical data, and it provides invaluable information on the geodynamics and rheology of the Earth. However, observed anisotropy usually arises from different mechanisms, which include lattice or crystallographic preferred orientation (LPO, CPO), alignment of cracks with or without fluid inclusions, fine layering or partial melting. This makes the interpretation of anisotropy in terms of intrinsic (LPO, CPO) versus extrinsic (other mechanisms) properties difficult and non-unique. For the one-dimensional, global spherically symmetric reference Earth, the azimuthal anisotropy is averaged out, which results in predominant radial anisotropy. This radial anisotropy is usually claimed to be intrinsic (due to LPO). Here we explore whether the radial anisotropy in the reference Earth models including PREM and the constrained reference Earth model ACY400 can be explained by extrinsic anisotropy, especially in relation to fine layering. To investigate this possibility, we choose a characteristic finely layered model where the average scale is much smaller than the seismic wavelength: the periodic, isotropic, two-layered (PITL) model. **We conclude that as well as intrinsic anisotropy, extrinsic anisotropy introduced by finely layered models, might explain the lithospheric anisotropy in PREM; but cannot explain its asthenospheric anisotropy. We also find that radial anisotropy in model ACY400 is mainly intrinsic due to its petrological constrains.**

2. INTRODUCTION

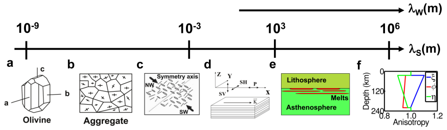

Figure 1. The existence of anisotropy from the microscale to the macroscale. (a) The anisotropic olivine crystal. (b) The anisotropic aggregate as an example of CPO. (c) Cracks filled with fluid inclusions with a symmetry axis. (d) A finely layered model showing seismic radial anisotropy. (e) Seismic anisotropy produced by partial melting at the lithosphere and asthenosphere boundary. (f) Radial anisotropy parameters in the top 200 km of the upper mantle of the 1D global earth model - PREM.

In this work, we concentrate on the radial anisotropy which is usually described by density ρ, the velocities of horizontally and vertically propagating P waves (A=ρV^2_{PH}, C=ρV^2_{PV}), polarized S waves (N=ρV^2_{SH}, L=ρV^2_{SV}), and the anisotropic parameter F. The three related radial anisotropy parameters are: ξ=N/L, ϕ=C/A, and η=F/(A-2L).

We propose that fine layering (extrinsic anisotropy) is possible for the interpretation of the global averaged radial anisotropy of the Earth.

3. THE PITL MODEL

The periodic, isotropic, two layered (PITL) model is periodic in the vertical direction, and it consists of alternating isotropic layered materials (Backus,1962).

By defining the thickness proportion of the first layer as the fraction p_1, the square of the ratios of S-wave velocity to P-wave velocity of each material as θ_1 and θ_2, the shear moduli of the PITL model μ_1 and μ_2, the effective model of the PITL model can be calculated by these five parameters.

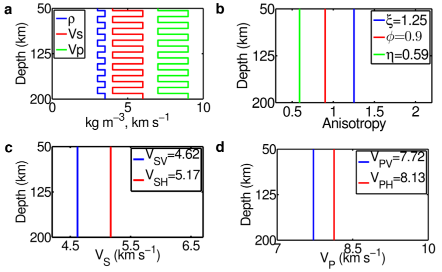

Figure 2. An example of a PITL model and its effective model showing the long wavelength equivalent effect.The parameters ξ, ϕ and η are different from one. Moreover, V_{PH}>V_{PV} implies ϕ<1; V_{SH}>V_{SV} implies ξ>1, which is always the case for the effective model.

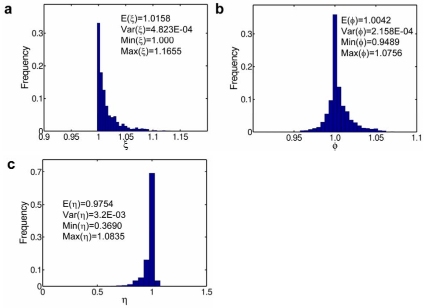

Figure 3. The histograms of the anisotropic parameters (a)ξ, (b)ϕ and η of the effective model of the PITL model. The parameters of the PITL model satisfy the uniform probability distribution.

The mean values of the anisotropic parameters are close to one, it means fine layering may be not so efficient to explain large amount of observed seismic anisotropy in the real Earth from a statistic point of view.

But the anisotropic parameters change in a wide range, it means some specific finely layered models can produce large observed anisotropy.

3. THE PITL MODEL

Fine layering combined with partial melting sometimes can physically explain large levels of seismic anisotropy (Kawakatsu et al., 2009).

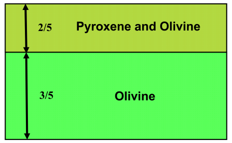

Figure 4. A petrological lithosphere-asthenosphere model.

For this model, we try to find an equivalent PITL model to explain its 15% extrinsic S-wave radial anisotropy. The corresponding physical solution is α=μ_1/μ_2 = 0.45 and p_1 = 0.6.

Thus, the PITL model with some partial melting might explain the S-wave anisotropy in this lithosphere-asthenosphere model.

4. THE SLWER TESTS

We now investigate whether the anisotropy in the lithosphere and asthenosphere of PREM can be explained by PITL models.

For an isotropic model to be stable, its elastic parameters should satisfy: μ>=0 and 0<=θ<=3/4. We derive the sets of necessary and sufficient conditions (described by parameters ρ, A, L, ξ, ϕ and η) when a stable anisotropic model could be long wavelength equivalent to a stable PITL model. We define the ranges satisfying these conditions as the stable long wavelength equivalent region (SLWER).

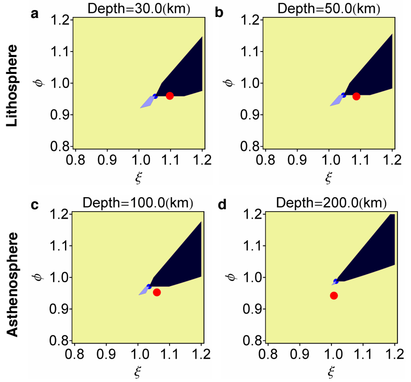

Figure 5. The stable long-wavelength equivalent region test of the radial anisotropy in the lithosphere and asthenosphere of PREM.

Therefore, some extrinsic anisotropy introduced by fine layering can explain the lithospheric anisotropy in PREM, in addition to the commonly claimed intrinsic anisotropy; while the asthenospheric anisotropy cannot be explained simply by PITL models, and it requires intrinsic anisotropy.

5. THE SLWER TESTS

We also explore the radial anisotropy in another reference Earth model ACY400 (Montagner and Anderson, 1989).

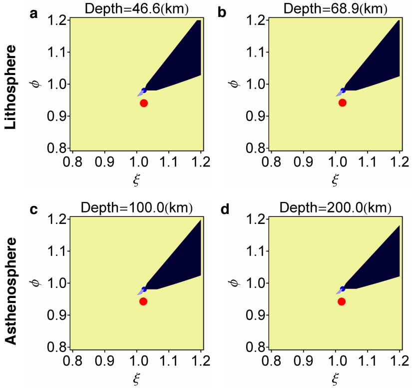

Figure 6. The stable long-wavelength equivalent region test of the constrained reference Earth model ACY400 in its lithosphere and asthenosphere.

For this model, we find that the radial anisotropy in both lithosphere and asthenosphere cannot be explained by the PITL model. The reason is probably that the ACY400 model uses petrological constraints that were derived from petrological mantle models, and its anisotropy, in particular, favours intrinsic anisotropy.

6. DISCUSSION

We address the issue of the petrological and geodynamic interpretations of the observed seismic anisotropy. We claim that the observed anisotropy is most of the time the mixing of several competing mechanisms.

We show it is possible to discriminate the origins of anisotropy in the lithosphere and asthenosphere of PREM.

We find that the radial anisotropy in the constrained ACY400 model is mainly intrinsic due to the petrological constrains.

We expect more investigations on the possibility of fine layering that can explain both radial and azimuthal anisotropies in 3-D geodynamic models.

7. REFERENCES

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