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L. B. Loughran (Ed.)

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VII.3 Seismic modelling of an anisotropic boundary layer

Various parts of the upper mantle have been proposed to be anisotropic. More recently it has been suggested that anisotropy may also be present at other depths, especially in boundary layers experiencing differential flow. D" is such a layer. More specifically, we may need to consider a model of D" with two distinct structures, resembling the continent-ocean division of the lithosphere. The possibility of observing the appearance of a layered structure would be restricted to the permanent (continental-type) zones, whereas intrinsic anisotropy predicted by boundary layer theory would prevail in the transient (ocean-floor type) zones. The possibility of lateral heterogeneity has an added significance in this context because it has been suggested that, when interpreted in terms of one-dimensional models, such structures may appear anisotropic (Crampin et al, 1984). For the purpose of seismic modelling, we assume uniaxial anisotropy (with symmetry axis vertical), often termed transverse isotropy in the seismological literature, not that we believe this to apply locally, but because we assume that azimuthal anisotropy is averaged out by the several wave paths used in observational work. The required modifications to reflectivity type of methods have been discussed, a.o. in a recent contribution (Doornbos et al, 1985). Piecewise smooth models were considered here. The formal expressions for (generalized) reflection coefficients are unchanged, but the required modifications concern the fundamental matrices, and the vertical slownesses and their integrals over radius, the so-called "Tau functions".

One inference is that for radius r not far from the turning point r_0, τ is determined mainly by the profile of horizontal wave velocity. This is in accordance with the results of a numerical experiment giving the effect of anisotropic D" on the diffracted wave fields of P and SH. In Fig. VII.3.1 are shown the changes (relative to the isotropic approximation) in logarithmic attenuation with distance and $dT/d\Delta$, as functions of frequency, which is the form in which most observational data have been presented. From these results we conclude that diffracted P and SH are mainly controlled by the horizontal velocities

α_L and β_L, respectively, and these are related to the elastic constants A and N of a uniaxial structure. On the other hand, five elastic constants (A,C,N,L and F) are needed to fully characterize this structure, and four constants (A,C,N and F) are needed to obtain the bulk modulus K. What is usually inferred for the purpose of temperature calculations is an apparent bulk modulus K' based on the assumption of an isotropic structure: $\lambda+2\mu = A$, $\mu = N$. We find

$$K/K' \approx \frac{3}{(3-4N/A)} \cdot \frac{1-N/A-(F/A)^2}{2-N/A-2F/A} - \frac{1-C/A}{3(3-4N/A)} \qquad (1)$$

where

$$F/A = \eta(1-2\frac{N}{A} \cdot \frac{L}{N})$$

Results based on eq. (1) are given in Table VII.3.1. These results can be used to conclude that a small amount of anisotropy requires a correction to the seismically inferred temperature increment based on K'. For D" it is estimated that the correction can be up to about 400°K.

D.J. Doornbos

References

Crampin, S., E.M. Chesnokov and R.G. Hipkin (1984): Seismic anisotropy - the state of the art, II. Geophys. J. R. astr. Soc. 76, 1-16.

Doornbos, D.J., S. Spiliopoulos and F.D. Stacey (1985): Seismological properties of D" and the structure of a thermal boundary layer, submitted for publication.

η \ L/N	0.9	0.92	0.94	0.96	0.98	1.00
0.9	1.005	0.997	0.990	0.983	0.976	0.968
0.92	1.012	1.004	0.997	0.990	0.982	0.975
0.94	1.018	1.011	1.004	0.996	0.989	0.981
0.96	1.025	1.018	1.010	1.003	0.995	0.987
0.98	1.032	1.025	1.017	1.009	1.002	0.994
1.00	1.035	1.031	1.024	1.016	1.008	1.000

Table VII.3.1 Ratio of uniaxial and isotropic bulk modulus K/K'
Assumed relation between isotropic and uniaxial elastic constants:

$$\lambda + 2\mu = A, \quad \mu = N$$

Results based on eq. (1) with N/A = 0.28 and C/A = 1. If C/A ≠ 1, subtract (1-C/A)/5.64 from all results. The broken line encloses the ranges of elastic constants that appear to us to be the most plausible.

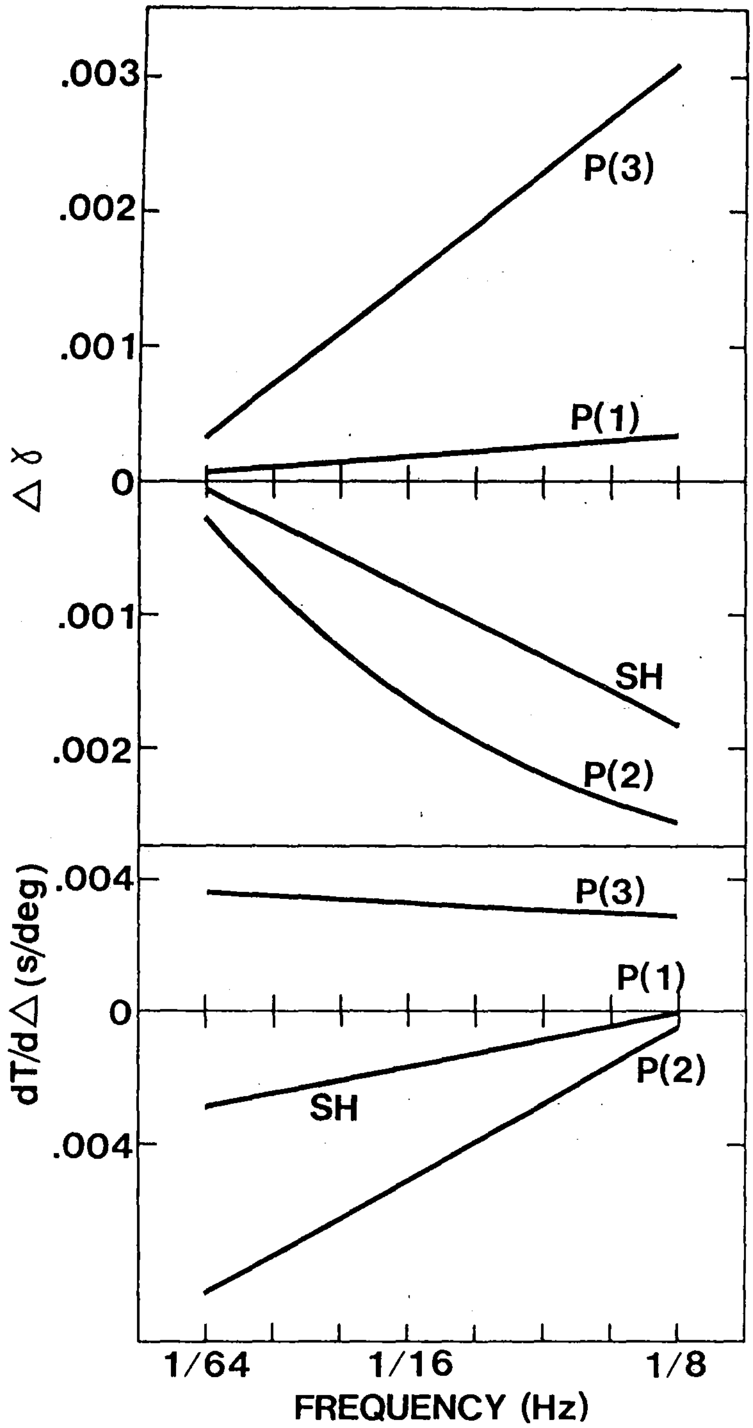

Fig. VII.3.1 Effect of a transversely isotropic layer on logarithmic attenuation (γ) and dT/dΔ of diffracted P and SH around the core. The distance range considered is 100-135°. The velocities α and β in the isotropic part of the model, and the horizontal velocities α_h for P and β_h for SH in the layer, correspond to model A of Doornbos et al (1985). The anisotropy is zero at the top of the layer, and the maximum at the bottom. The maximum anisotropy for SH is $\beta_h/\beta_v = 1.02$. The three P-wave anisotropies considered are (1) $\alpha_h/\alpha_v = 1.01$, $\eta = 1$, $\beta_h/\beta_v = 1$; (2) $\alpha_h/\alpha_v = 1$, $\eta = 0.95$, $\beta_h/\beta_v = 1$; (3) $\alpha_h/\alpha_v = 1$, $\eta = 1$, $\beta_h/\beta_v = 1.02$. The values plotted are differences from results with isotropic model A.