Upper Mantle Anisotropy in SE and Central Brazil from SKS Splitting

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Abstract

We present a compilation of upper mantle anisotropy derived from measurements of SKS and SKKS splitting in SE and Central Brazil. The fast polarization direction shows consistent orientation over hundreds of kilometers and is generally parallel to the structural trend of the last major orogeny. In the Brasilia fold belt, SW of the São Francisco craton, the fast polarization direction has a NW-SE trend, parallel to the Goiânia flexure, consistent with a final collision between a cratonic block beneath the Paraná basin and the São Francisco craton. In the Ribeira belt the anisotropy direction is remarkably parallel to the WSW-ENE trend of the shear belt, specially in the southern Ribeira belt where transcurrent shear zones predominate. This pattern is interpreted as due to escape tectonics during the Brasiliano collision with a cold, thick São Francisco craton. In some sites the amount of anisotropy reaches a total splitting delay of 2.4s which is one of the largest delays worldwide. In the northern part of the Ribeira belt, the anisotropy pattern is more complex, which is probably related to the transition between vertical shear deformation in the south to a more E-W compressional tectonism in the north where N-S trending reverse faulting and nappes predominate. In the central part of the Paraná basin, the anisotropy direction tends to be E-W oriented. Although the reason is not yet clear, this direction is consistent with possible E-W extension in the Paleozoic. In the Tocantins province, Goiás, a trend of SW-NE orientation is observed, roughly parallel to the Transbrasiliano lineament.

Introduction

SKS and SKKS phases are S waves converted to P at the core-mantle boundary and converted back to S when leaving the core on their way up to the surface, arriving at the station at nearly vertical incidence. Because of the P-to-S convertion at the core-mantle boundary, they should be polarized along the radial direction if the mantle were isotropic. Quite often, however, SK(K)S waves exhibit some energy on the recorded transverse component which is best explained as the result of shear-wave splitting during propagation in some anisotropic layer beneath the station. The splitting is usually of the order of 1 sec, although up to 2.5 s has been observed (e.g., Silver, 1996). Anisotropy of normal crustal rocks cannot contribute more than 0.1 or 0.2 s to the observed SK(K)S splitting (e.g., Barruol & Mainprice, 1993). The reduced contribution from the crust, and other seismological considerations, indicate that most of the observed SK(K)S splitting originates at the upper mantle, above 400 km depth. Seismic anisotropy in the upper mantle results from preferential mineral orientation (specially olivine) which can be caused by deformation and flow of mantle rocks during past and present orogenic activity (e.g., Silver & Chan, 1991; Vinnik et al.,1992; Mainprice & Silver, 1993; Silver, 1996). For this reason SKS splitting is a useful tool to investigate strain processes in the mantle and its correlation with tectonic crustal deformation observed at the surface (e.g., Vauchez et al., 2000)

In intraplate areas, far from present plate margins, Vinnik et al.(1992) attributed most of the observed SKS anisotropy as being caused mainly by flow in the asthenosphere due to the present absolute plate motions. However, the measured fast polarization direction often correlates well with the structural trends observed in the upper crust due to the last major orogeny which indicates an alternative explanation: past orogenic processes that affected the crust could also leave the lithospheric upper mantle with a preferred mineral orientation still observable today ("frozen" anisotropy; e.g. Silver, 1996). Growing observational evidence suggests that frozen anisotropy in the lithosphere (such as observed in SE Brazil by James & Assumpção, 1996) is probably more important than present asthenospheric flow. This indicates that orogenic mechanical processes affect the entire lithosphere and can be preserved over geological time. For this reason, measurements of upper mantle anisotropy from SKS splitting can be used to assess different models of orogenic processes, such as done for continental rifting by Vauchez et al.(2000).

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SKS anisotropy observations in Brazil

Following the initial results of James & Assumpção (1996) seismic anisotropy in the upper mantle beneath SE Brazil has been investigated with an extensive cooperation program between the University of São Paulo, Brazil, and the University of Montpellier, France, since 1996. Results from portable broad-band stations (both Brazilian and French) have been deployed in more than 20 sites in SE Brazil, specially in the coastal Ribeira fold belt.

The analysis of the SK(K)S splitting was carried out with the method of Silver & Chan (1991) and an example is shown in Figs. 1 to 3 for the station *pazb*. Fig. 1 shows the radial and transverse components of the SKS phase as recorded at the station (top two traces). The signal observed in the transverse component ("T-obs.") is a result of splitting which causes the fast and slow components to arrive at the station out of phase making the particle motion eliptical instead of linear (Fig. 2). The fast polarization azimuth (Az) and the lag time between fast and slow components (dt) are determined with a grid search by correcting the observed components from the anisotropy effect so as to minimize the energy in the transverse component (Fig. 3). The two bottom traces in Fig. 1 are the radial and transverse components corrected from the effect of anisotropy. Note that the anisotropy parameters (Az= 60°, and dt= 1.65 sec, Fig. 3) which best corrects the SKS phase also reduces the transverse energy of the SKKS phase (Fig. 1, "T-corr."). Results from SKS and SKKS measurements are usually consistent.

Table 1 shows the anisotropy results from the stations in the Tocantins Province (Goiás), the central part of the Paraná basin (SP), and the Ribeira belt (SP, MG, RJ). In Fig. 4 we plot the data from Table 1 including the previous results of James & Assumpção (1996). The data for the permanent Brasilia station (BDF) is a preliminary average of the values determined by Russo & Silver (1994) and Vinnik et al.(1992): Az=53° and 40°, respectively.

Discussion

In the Brasilia fold belt, SW of the São Francisco craton, the fast polarization direction has a NW-SE trend, parallel to the Goiânia flexure, and the general structural trend, consistent with a final collision between a cratonic block beneath the Paraná basin and the São Francisco craton.

In the Ribeira belt the anisotropy direction is remarkably parallel to the WSW-ENE trend of the shear belt, specially in the southern Ribeira belt where transcurrent shear zones predominate. This pattern is interpreted as due to escape tectonics during the Brasiliano collision with a cold, thick São Francisco craton (Vauchez et al., 1994). In some sites the amount of anisotropy reaches a total splitting delay of 2.4s (Igarata', SP) which is one of the largest delays observed worldwide. In the northern part of the Ribeira belt, the anisotropy pattern is more complex, which is probably related to the transition between vertical shear deformation in the south to a more E-W compressional tectonism in the north where N-S trending reverse faulting and nappes predominate. In this transition zone, some stations (*natb* and *barb*) seem to suggest different anisotropy directions for SKS waves arriving from the south compared to waves arriving from the north (see Table 1); further work on this problem is necessary, however.

In the central part of the Paraná basin, the anisotropy direction tends to be E-W oriented. Quintas (1995) and Quintas et al.(1999) analysed subsidence rates in the central part of the Paraná basin to estimate crustal stretching factors during the basin evolution. Although stretching factors are not large, the area of maximum stretching for the two main events in the Paleozoic (at 440 Ma and 296 Ma) trend roughly in the N-S direction. Maybe these results indicate that the lithosphere was extended in the E-W direction causing the E-W oriented anisotropy. However, it is not clear why this anisotropy was not destroyed during the Mesozoic flood basalt volcanism around 140-130 Ma. Interestingly, in the Ribeira belt, the WSW-ENE direction of the anisotropy, parallel to the Brasiliano structural trend of the fold belt, does not seem to have been much affected by the extensional deformation during the Mesozoic Atlantic rifting.

In the Tocantins province, state of Goiás, the few available measurements indicates a fast anisotropy direction roughly SW-NE, parallel to the Transbrasiliano Lineaments. Although structural patterns observed in the upper crust are rather complex, a general SSW-NNE direction would mark the final suture between the Amazon and São Francisco cratons. In southern Goiás, a station at Corumbá (*corb*) has a well defined E-W anisotropy direction, somewhat intermediate between the patterns of northern Goiás and the Brasilia belt.

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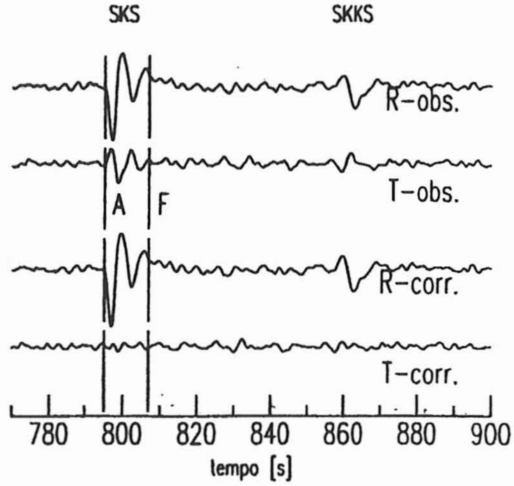

Figure 1: Example of SKS and SKKS at station *pazb*. Observed and corrected radial and transverse components; A-F is the window used to minimize the transverse component; origin of time scale is arbitrary.

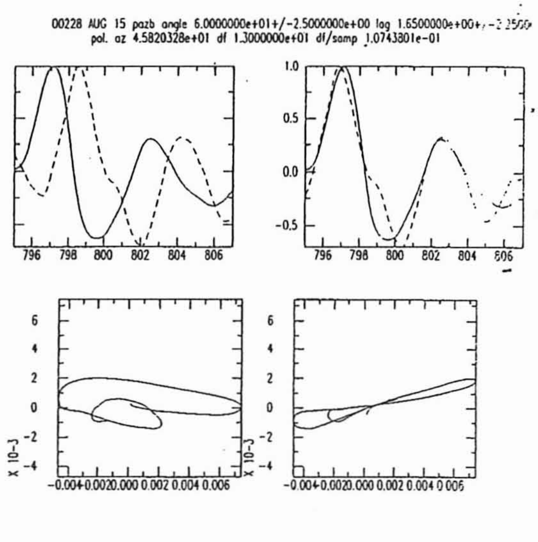

Figure 2: Analysis of the SKS phase of Fig. 1. Clockwise from top left: normalized fast and slow components with the estimated splitting delay, same components corrected for the delay, observed elliptical particle motion, linear particle motion after removing the effect of the splitting delay.

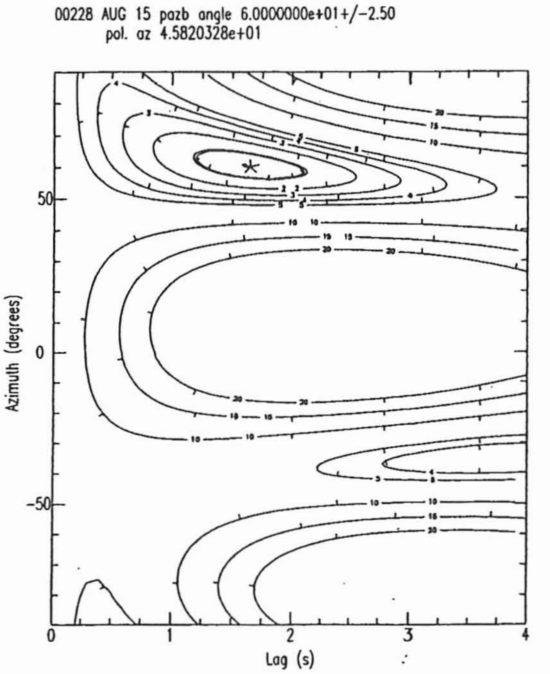

Figure 3: Contours of the transverse energy to find the best azimuth of the fast anisotropy polarization and the delay (lag time) between fast and slow components.

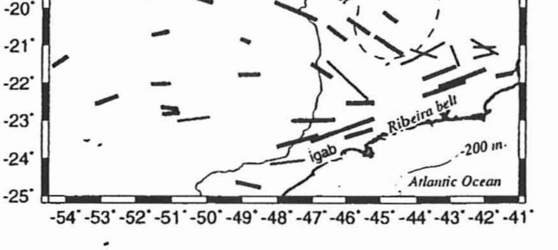

Figure 4: Anisotropy directions in Central and SE Brazil. Bar length denotes delay time between fast and slow components; thin bars are less reliable measurements based on few events.

sta.	lat.	long.	Az.	dt	comments
Ribeira belt					
bscb	-20.998	-44.763	-57	1.1	Bom Sucesso, MG
natb	-21.055	-42.004	90	0.8	Natividade, RJ. SW
natb	-	-	-61	1.1	back azimuth North
barb	-21.222	-43.801	63	1.7	Barbacena, SE+SW
barb	-	-	-73	1.0	back azim. NE+NW
LJM	-21.286	-42.053	77	0.7	Lage do Muriaé, MG
atdb	-21.290	-42.861	-23	0.8	Astolfo Dutra, MG
jfob	-21.728	-43.326	70	1.3	Juiz de Fora, MG
camb	-21.784	-41.429	80	0.6	Campos, RJ
ALP	-21.880	-42.664	70	1.8	Além Paraiba, RJ
SJM	-21.931	-45.962	-48	2.0	S. João da Mata
trrb	-22.154	-43.195	72	1.6	Três Rios, MG/RJ
brsb	-22.535	-45.585	89	1.0	Brasópolis, MG
vabb	-23.002	-46.966	89	1.6	Valinhos, SP
igab	-23.252	-46.116	71	2.4	Igaratá, SP
SPB	-23.540	-47.430	75	1.5	Geoscope, SP
juqb	-24.093	-47.716	83	1.2	Juquiá, SP
rstb	-24.697	-48.828	-77	0.9	Tijuco Altó, SP
Paraná basin					
popb	-22.456	-52.837	70	0.8	P. Primavera, SP
canb	-22.961	-50.378	83	1.1	Canoas, SP
Tocantins Province					
porb	-13.330	-49.079	70	0.8	Porangatu, GO
pazb	-15.137	-50.863	63	1.6	Araguapaz, GO
BDF	-15.664	-47.903	47	1.3	Brasilia, DF
corb	-17.743	-48.689	-88	1.1	Corumbá, GO

Table 1: New SK(K)S splitting results for SE and Central Brazil. "Az" is the direction of the fast polarization; uncertainties are usually around 5° to 10°. "dt" is the splitting delay time; its uncertainty is usually about 0.2 to 0.4 sec.