Upper Mantle Shear Wave Anisotropy Under Stations Around the Southern Gulf of California

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ABSTRACT

The anisotropy beneath broadband seismic stations around the southern Gulf of California was measured. For stations in mainland Mexico, east of the Gulf, the fast polarization direction is oriented with the absolute plate motion of the North American plate. It also agrees with the extension direction prior to the opening of the Gulf of California. The fast polarization direction for the southernmost station in the Baja California peninsula may be related to asthenospheric flow associated to the subduction of the Farallon plate. It was difficult to quantify the anisotropy for the four adjoining stations to the north because a number of null measurements were obtained. However, the available data may also indicate the same relationship to the Farallon plate. Arc magmatism created the "La Giganta volcanic belt" and may perhaps be the cause for the null measurements reported under these stations.

METHOD

The crustal and upper mantle anisotropy is calculated using the approach by *Silver and Chan* [1991]. A time segment containing the *SKS, SKKS* or *PKS* arrival is selected from the radial and transverse components (Figure 1). The space of possible solutions is then searched in one-degree intervals with φ ranging between 0 and 180°. Specifically, the coordinate axes are rotated in one-degree increments. For each value of φ, the delay time solution space is also searched in 0.05 s increments. Then the corresponding autocorrelation and crosscorrelation between the components is calculated. Next the eigenvalues for each δt and φ combination are calculated. In the presence of noise, the desired solution will be given by the matrix which is most nearly singular. The 95% confidence region for the measurement is calculated (Figure 2). The shapes and the difference in the arrival times of the fast and slow waves were compared to make sure that the result is robust (Figure 3). In order to check our results, we applied a correction in the amount of the measured δt and φ to the original records and then rotated them to make sure that the anisotropy disappears (Figure 4). As a further check, the polarization of the particle motion for the radial and transverse components before and after correction was plotted (Figure 5).

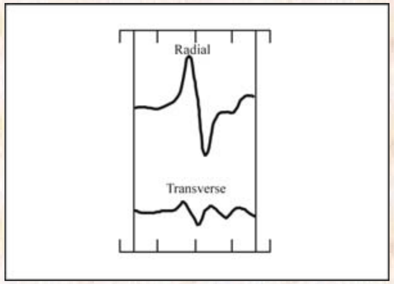

Figure 1. *SKS* wave from the event of April 8, 1999 in the Japan Subduction Zone (43.60° N, 130.53° E, h=560 km, M_w = 7.2) recorded at broadband station Mazatlán (MAIG) from Mexico's Servicio Sismológico Nacional network. The epicentral distance is 95.37°. The radial and transverse components are shown. *SKS* can be seen clearly in the radial component and it has a lower amplitude in the transverse component. In general, observation of *SKS* waves in the transverse component may be an indication of upper mantle anisotropy under the station.

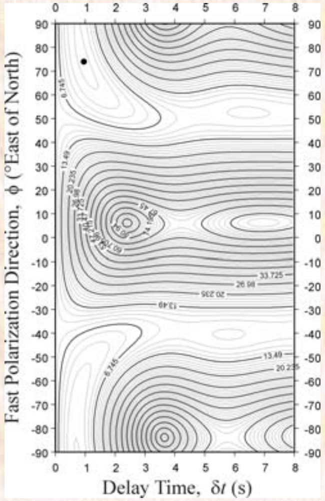

Figure 2. Contour plot showing the minimum value in (φ, δt)-space as indicated by the dot. In this case the fast polarization direction is N74°E and the delay time is 0.95 s. The first contour around the dot bounds the 95% confidence region.

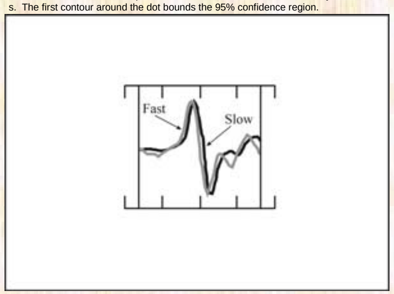

Figure 3. Once the fast polarization direction is known, the N-S and E-W horizontal records are rotated through the angle φ in order to obtain the slow and fast components of the *SKS* pulse. The slow and fast components are shown normalized to the same amplitude. In order to make sure that the estimated values for φ and δt do indeed describe the anisotropy, we have checked that the fast and slow components have roughly the same shape and that the fast *SKS* does indeed arrive earlier than the slow *SKS.*

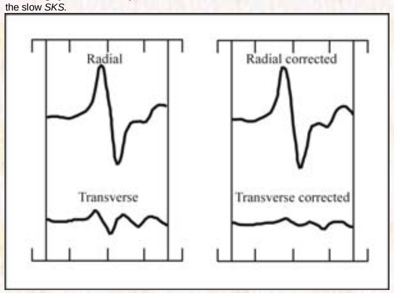

Figure 4. One further check was conducted by applying the calculated values of φ and δt in order to correct the radial and transverse components. We sought to remove from the transverse component the *SKS* energy that bled from the radial. (Left) Radial and transverse components before correction. (Right) Radial and transverse components after correction. As expected, the *SKS* pulse disappears from the corrected transverse component, while the amplitude of *SKS* is increased in the corrected radial component.

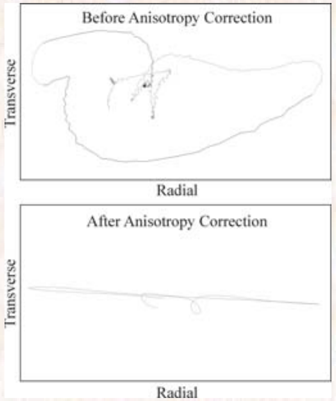

Figure 5. Yet another check was the comparison of the radial and transverse particle motion. (Top) Before correcting for the anisotropy the particle motion is elliptical. (Bottom) Once a correction for the measured anisotropy is applied, the particle motion becomes nearly linear.

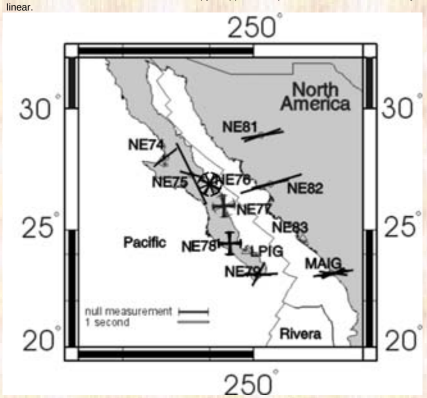

Figure 6. Individual measurements of φ and δt obtained for stations around the southern Gulf of California.

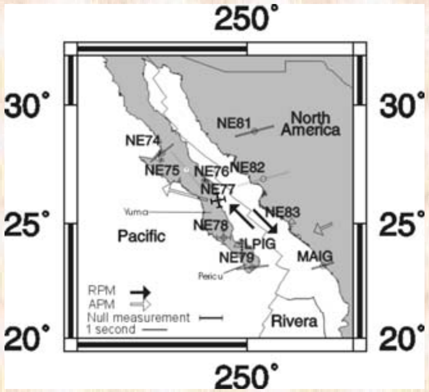

Figure 7. Average measurements of φ and δt obtained for stations around the southern Gulf of California.

RESULTS

The records used were taken from Mexico's Servicio Sismológico Nacional broadband network and from the NARS-Baja California deployment [*Trampert et al.,* 2003]. Individual measurements (Figure 6) at any given station were averaged (Figure 7) following the method of *Wolfe and Silver* [1998].

	Splitting Parameters				Coordinates		Number of Measurements	
Station	φ, deg	δt, s	σφ , deg	σδt , s	Latitude (ºN)	Longitude (ºE)	Split	Null
NE74	52	1.15	30	1	28.01	-114.01	1	0
NE75	-51†	1.85†	25	0.85	27.29	-112.86	2	0
NE76	00	-	-	-	26.89	-112.00	0	3
NE77	79	-	-	-	26.02	-111.36	0	4
NE78	1	-	-	-	24.40	-111.11	0	2
NE79	84	1.3	12	0.2	23.12	-109.76	3	0
NE81	75	1.65	5	0.2	28.92	-109.64	2	2
NE82	75†	2.0†	2	0.5	26.92	-109.23	2	3
NE83	-	-	-	-	24.73	-107.74	0	0
LPIG	-	-	-	-	24.10	-110.31	0	0
MAIG	74	0.95	5	0.2	23.19	-106.42	7	1

DISCUSSION

On mainland Mexico, east of the Gulf of California, stations NE81, NE82 and MAIG (Mazatlán) show a fast polarization direction approximately ENE-WSW, consistent with the absolute plate motion (APM) for North America. Due to the few records available, it was not possible to obtain reliable measurements at NE83. Additionally, the current fast polarization direction agrees with the extension direction for the region prior to the initiation of rifting along the axis of the modern Gulf of California [*Sedlock et al.,* 1993].

For the data available, null measurements were obtained at stations NE76, NE77 and NE78. For station NE76 we have measurements from two different nonorthogonal back azimuths. This observation is interpreted to mean that anisotropy is below the detection threshold ($\delta t \leq 0.5$ s). For NE77 there are two possible directions for the fast axis, either φ = 79° or φ = -11°. Under NE78 the allowed directions for the fast polarization direction are either N-S or E-W. Under both NE77 and NE78 it is also conceivably possible that $\delta t \approx 0$ s. Unfortunately, it was not possible to determine the anisotropy under station LPIG (La Paz) because of the lack of good quality records. Farther south, the fast direction at station NE79 is oriented nearly E-W. Therefore, it is possible that the fast axis is oriented roughly E-W for stations NE77, NE78 and NE79. If this is the case, the orientation of φ cannot be explained by the APM of the Pacific plate. Asthenospheric flow produced by the subduction of the Farallon plate has been proposed as an explanation for the E-W orientation of the fast polarization direction under stations in the northern Baja California peninsula [*Obrebski et al.,* 2006]. The nearly E-W direction for φ under stations at the southern tip of the peninsula could also be caused by subduction of the Farallon plate. Station NE79 belongs within the "La Paz plutonic complex" [*Ortega-Gutiérrez et al.,* 1992] and also within the Pericú tectonostratigraphic terrane [*Sedlock et al.,* 1993]. On the other hand, stations NE76, NE77 and LPIG belong within the "La Giganta volcanic belt" geological province [*Ortega-Gutiérrez et al.,* 1992], otherwise known as the "Comondú Formation" [*Morán-Zenteno,* 1994]. According to *Sedlock et al.* [1993], these stations belong within the Yuma terrane. Station NE78 belongs to a different geological province but it is located near the La Giganta volcanic belt. While both the La Paz plutonic complex and the La Giganta volcanic belt were adjacent to mainland Mexico prior to the opening of the Gulf of California, La Giganta underwent arc magmatism between 24 and 11 Ma [*Sedlock et al.,* 1993]. It may be more difficult to measure upper mantle anisotropy under the stations running from NE76 south to LPIG (as compared with NE79) because of their relationship to the La Giganta volcanic belt. In principle, it is also possible that $\delta t \approx 0$ s for stations NE77, NE78 and LPIG, just as it was measured at NE76. If this were the case, the explanation could also be related to the La Giganta volcanic belt. Hopefully more data from these stations will make it possible to settle this question.

For stations NE74 and NE75 farther north in the peninsula, the direction of the fast polarization direction is approximately NE-SW and NW-SE, respectively. No explanation is readily available for these observations.

CONCLUSIONS

We determined the upper mantle anisotropy under stations around the southern Gulf of California. East of the Gulf, in mainland Mexico, the orientation of the fast polarization direction agrees with the direction of the absolute plate motion for North America and also with the direction of extension prior to the opening of the Gulf. In the southern Baja California peninsula a significant number of null measurements were obtained. The cause for these null measurements may be related to the local conditions under the La Giganta volcanic belt. These observations for southern Baja California are consistent with results farther north in the peninsula and suggest that anisotropy is related to asthenospheric flow produced by the subduction of the Farallon plate.

ACKNOWLEDGMENTS

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