STUDY OF SEISMIC ANISOTROPY IN THE UPPER MANTLE IN THE BRAZILIAN AMAZON BY THE DELAY TIME METHOD.

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Abstract

One big earthquake occurred under Amazonian region is studied to determine principal axis of anisotropy in upper mantle. Residual time analysis for P wave give as result W-E direction of low velocity zone. The anisotropy indicates crystalline structure of rocks around the focus, which enforces the theory of phase changes as origin of stress release. This direction correlates well with SHmax direction of stresses in South-American plate and would be explained by presence of a drag force under the plate. In resume, axis of crystallization in upper mantle and direction of main stresses in lithospheric plate are apparently related in a syngenesis way.

Introduction

For a long time it was believed that the major earthquake occurred on Brazil it is Serra do Tombador (1955/01/31) earthquake, with 6.6 mb magnitude. But there are one 7.1 Mw magnitude earthquake (2003/06/20/06:19:39). The epicentre is located in Amazonas state, depth of focus reach 555 km which locates into the superior mantle and below any probable extension of subducting Nasca plate. That kind of earthquakes is believed to have an origin different to tectonic earthquakes; one explanation says the stress release is due to a phase change in crystalline structure of rocks, maybe olivine to spinel or olivine-spinel to perovskyte (Wang et al., 1997). The volume of the mineral is affected, as this occur suddenly great amounts of mass are relocated along planes defined by crystal axis. Anisotropy is related to crystalline systems, the direction of some axis has highest seismic velocity than others, reversely, some crystalline axis creates zones of low seismic velocity. Then an azimuthal analysis of residual times in seismic stations could give an image of anisotropy around the focus. We've concentrated first to show that the environment where the energy is released is a crystalline rock. There are a few seismological studies related to deep focus earthquakes on Amazonian region (Okal and Rina, 2001), this is probably the first one trying to show anisotropy in upper mantle under Amazonian region.

Method

The technique to determine residual time in a seismic station and for a specific earthquake begin with the lecture of P wave arrival time in the seismogram. This procedure gives us the observed time for P wave (tp_0). Then using an appropriate program (ttimes) we got the theoretical travel time for P wave (tp_t), we need to know epicentre distance and depth of focus. The residual time for that station is given by $tr = tp_0 - tp_t$. The residual time is a parameter indicating the difference between a theoretical model of velocities for the earth (iasp91) and the real distribution of velocities in the path from the hipocenter to the station. If the observed P wave appears in the seismogram after the mark of theoretical time it means that exists a zone of low velocity in some interval of the path. Conversely, a P observed before the calculated P time, indicates a zone of high velocity. At this step is necessary to reveal the influence of earth surrounding earthquake focus.

We can think in an azimuthal direction at which some seismic rays have a positive residual time (low velocity); but the low velocity zone may be located below the seismic station, in the middle of the travelling route or near the focus. Averaging the residual times for a solid angle we can expect the mean is zero if the variation of tr follows a random pattern (alternated low velocity and high velocity zones below stations), by other side a great amount of tr means a coherent bias which will be attributed to the earth inside the solid angle and near the focus. Delay travel times mostly reflect the structure inside the upper mantle which contains the largest part of the ray path (Schulte-Pelkum et al., 2001).

Results

The figure 1 presents the location of the earthquake in question. There are other that should be studied later to determinate the anisotropy in upper mantle, but we've used this one in Serra do Tombador first to presents partial results.

The moment tensor solution shows a normal fault as probable origin at source of earthquake; but this is a tectonic model, different to phase change proposed here. Then the tensor is relevant just for axis of tension and pressure directions. Tension axes is 76º azimuth and semi-horizontal; pressure axis is quasi-vertical.

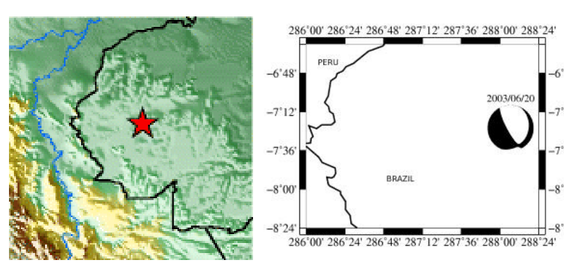

Figure 1 – Location and CMT of 2003-06-20 earthquake

The figure 2 shows the theoretical propagation time of the P wave to IASPEI-91 model, when the figure 3 presents the seismogram that shows the arrival of the P wave for the earthquake.

Figure 2 – Theoretical propagation time of the P wave to IASPEI-91 model

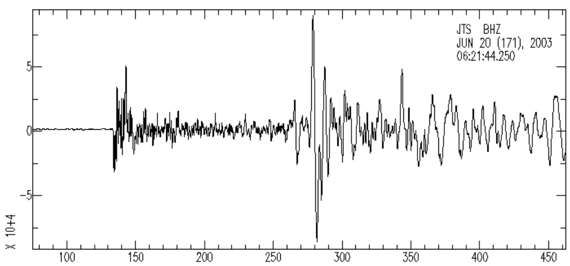

Figure 3 – Seismogram that shows the arrival of the P wave of 2003-06-20 earthquake

Applying the methodology to the seismograms of 122 stations what registered the biggest earthquake of Brazil we found the result of figure 4.

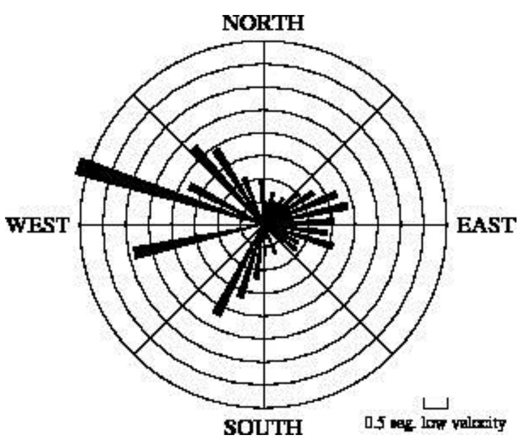

Figure 4 – Rose diagram with residual times for P wave related to IASPEI-91 model.

Residual times were averaged at intervals of 10 degrees (azimuth, angle from epicentre to station); all data are positive indicating low velocity anomaly. The greatest tr plotted in rose diagram out-range 4 seg.; some authors considers more than 1 seg. is sufficient evidence of anisotropy (Martynov et al., 2004). In azimuth, the biggest tr's are at 285 and 253 degrees, in opposite sense the minor tr's (no anomaly) are in the 0 – 45 degrees quadrant and in the 135 – 180 degrees quadrant. Exist 90 degress in angle difference from the low velocity azimuth to the no anomaly directions. The quadrant who goes from 45 degrees to 135 degrees contains residuals large enough to consider anomalous. Analysing the complete rose diagram appears a preferential direction W-E for low velocity anomalies; indicating this is a direction of one axis of crystalline lattice.

Conclusions

The Nasca plate subducting under western side of South-American plate has a flat slab (low angle slab dip) in the region (Cahill and Isacks, 1992) which can be extended to reach the Amazonian region where occur the biggest earthquake registered in Brazilian territory, but at 150 km depth, so it is improbable the origin would be tectonic. Is most reliable propose a phase change in crystalline structure as mechanism of stress release. A primary condition to this phase change is the presence of a crystalline lattice in rocks around the earthquake focus, but this implies anisotropy for elastic properties. Conversely, if we can found anisotropy in the region, this is a proof of crystalline structure. Extending this kind of reasoning to focal mechanism, we can say that it is due to stress drop by massive phase change in rocks. The rose diagram of residual times for P waves shows low velocities in the W-E direction; approximately same direction has tension axis on CMT solution. This direction coincides with $SH_{\max}$ preferential direction for stresses in South-American plate (Zevallos, I., 2001). This would be relevant if we think in the presence of basal drag force as one of the components of forces acting over the plate to compose the stress field inside the plate.

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