ASPERITIES AND BARRIERS, OR, BARRIERS AND ASPERITIES?

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INTRODUCTION

The two dominant geological features along the Peruvian coast are the Peru Trench, in the West, and the Andean Cordillera, on the East. Such configuration is the results of the variable collision process of the Nazca plate below the South America plates since the Late Cretaceous (Pardo-Casas & Molnar, 1987). Recent GPS observations report a present variable convergence rates varying from Northern Peru (55±3mm/year) to Southern Peru (65±3mm/year) (Norabuena et al., 1999). Given that a constant relative angular velocity of the plates creates a variable local velocity field along their convergence with a magnitude proportional to the radius of the Earth (Cox & Hart, 1986), it would be desirable to model the mechanical processes of the crust and upper mantle leading to such variation of the convergence rate. Unfortunately, most 3D stress and strain deformation models are made for a flat Earth or for specific 2D cross-sections of crust and mantle, ignoring the Earth's lateral curvature (shell) effect.

Focal-mechanisms solutions propose a set of geological structure pattern along a subducted lithosphere. These patterns convey the effect of the bending of the lithosphere due to subduction, but not the shell effect due to the Earth's curvature. The main purpose of the work described in this abstract is to present evidence of a possible correlation between convergence rate variations (large or small) and sets of particular focal-mechanisms along different active subduction zones in the Earth. The particularity of those focal-mechanisms is that they are different from those expected in subduction zones, not yet understood or mostly ignored. The conjecture is that those mechanisms correspond to earthquakes associated with the formation of barriers, as defined by Das and Aki (1977). Barriers are regions on the fault plane particularly resistant to slip either because of low applied stress or their exceptionally high strength properties. The seismic activity aligned perpendicular to the trench creates, precisely, zones of low stress.

At present, it is generally accepted that an earthquake occurs when an asperity breaks and stopped at barriers. We propose that the presence of a barrier eventually creates the stress conditions for an asperity to breaks away, and the earthquake to occur.

FOCAL-MECHANISM SOLUTION FILTER

A filter window was used to extract focal-mechanism solutions with strikes oriented roughly (within 25° of) perpendicular to the trench. We need to recall that focal-mechanism solutions offer two possible planes of rupture and that both cases were considered. We also divided earthquakes before and after a major mainshock (Mw>8.0). Such filtering reduces the number of focal mechanism solutions presented to a small range varying from 0.5 % to 2.0 %. In such representation, typical thrust faulting focal-mechanism solutions are absent. We discuss three cases of apparent barriers and how their limits define the earthquake rupture zones, which occurred later. In subsequent figures, apparent barriers are indicated with extended red dotted lines or red arrows. Focal-mechanisms are displayed with a colour depth scale to discriminate solutions within the Lithosphere. It can be observed that, some focal mechanisms nearby the corners of most the rupture area boxes displayed, seem to lay in the limits of the future rupture zones before an earthquake occurrence.

JAPAN (MARCH 11TH 2011 EARTHQUAKE)

Using Iinuma et al. (2011) as a reference, we are able to observe the seismic activity close to the border rupture area (pink box) both in Figure 1 (before the March 11th 2011 Earthquake) and in Figure

2 (by March 2012). One can observe seismic activity, perpendicular to the trench (West to the pink area) and nearby by the limits of the Miyagi-oki asperity; area not affected during the March 11th 2011 Earthquake.

INDONESIA (DECEMBER 26TH 2004 & MARCH 28TH 2005 EARTHQUAKES)

Using Nalbant et al. (2005) (red box) and Chlieh et al. (2007) (blue and green boxes), we present Figure 3 (before the December 26h 2004 earthquake) and Figure 4 (by March 2012) to reproduce the rupture areas, we present the filtered seismic activity. It is noticeable the seismic activity clustering close to the rupture area borders, before and after the main event.

PERU (JUNE 23RD 2001 & AUGUST 15TH 2007 EARTHQUAKES)

In this case we open the filter window (within 38° of perpendicular) to allow for the trench direction change, covering a bigger area in one single display. Blue, green and red boxes correspond to rupture areas from Chlieh et al. (2011) as in Figure 5 (before the June 23rd 2001 earthquake) and Figure 6 (by March 2012). Once again it is noticeable the seismic activity clustering close to the rupture area borders. It is also noticeable the possible appearance of perpendicular to the trench alignments close to Trujillo (8S, 79W), Lima (12S, 77W) and Ilo (18S, 71W). Such activity needs to be monitored and compared to activity within areas of previous earthquakes (blue, green and red boxes).

MODIFIED MOGI DIAGRAMS

Modified Mogi diagrams present focal-mechanism solutions from narrow areas, in the space and time domains. No previous filter is done. All solutions are presented. The horizontal axis represent time (in current years) and the vertical axis the distance (in 10Km units) along the surface of the Earth from a pole to each focal-mechanism considered. In figure 7, the pole is located in the South Atlantic Ocean. Several horizontal alignments are observed at several distances even in areas with no recent earthquakes. In figure 8, the pole is located in the Central Atlantic Ocean, and several horizontal alignments are observed. Notice the absence of thrust fault-mechanism solutions along the indicated alignments. Such activity might correspond to a barrier activity and not an asperity activity. Focal mechanisms solution correlation between figures 6, 7 and 8 is strongly suggested.

DISCUSSIONS, CONCLUSIONS AND FUTURE WORK

Events discussed previously correspond to focal mechanism solutions of high dip (strike-slip) or eventually low dip (almost horizontal). In both cases perpendicular to the main rupture area. Kanamori and Stewart (1979) study a slow earthquake with similar focal mechanism solution (strike-slip) to the ones we are presenting in this research, and, they conclude: Detailed studies of this kind of anomalous events are important for understanding the constitutive relation of the material in the fault zone and triggering mechanism of earthquakes under crustal pressure-temperature conditions. Previous work in the San Andreas fault area, by Huang et al (1996) find low dip events, (using a lower magnitude threshold $Mw \geq 3.0$) but they do not explain their cause. Kanamori (2008) indicates that different events exists and considers such existence as interesting.

A possible explanation can be obtained under the hypothesis of a spherical coordinates (stress and strain) earthquake tectonic model based on the convergence rate variation effect, together with Plate Tectonics parameters and Earth curvature implications.

To study the effect of Earth´s curvature on the seismicity of a region close to a subduction margin requires the use of a magnitude threshold $Mw \geq 3.0$. Data from Harvard CMT displays ($Mw \geq 5.0$) worldwide earthquakes, where bigger magnitudes have generally more robust solutions. An improved analysis can only be possible if smaller magnitude earthquakes are incorporated. This will reduce the uncertainty to define barrier´s possible location and eventually will help us learn how to monitor future asperities. Access to local data is critical to understand earthquake rupture process.

The seismic activity is related, among other factors, to both the absolute plate convergence rate and its variation along the collision area. A 500 to 1500 years 3D spherical coordinate synthetic seismicity numerical modeling is proposed to reproduce the Peruvian seismic activity. Results will help to monitor future earthquake activity along the Peruvian territory.

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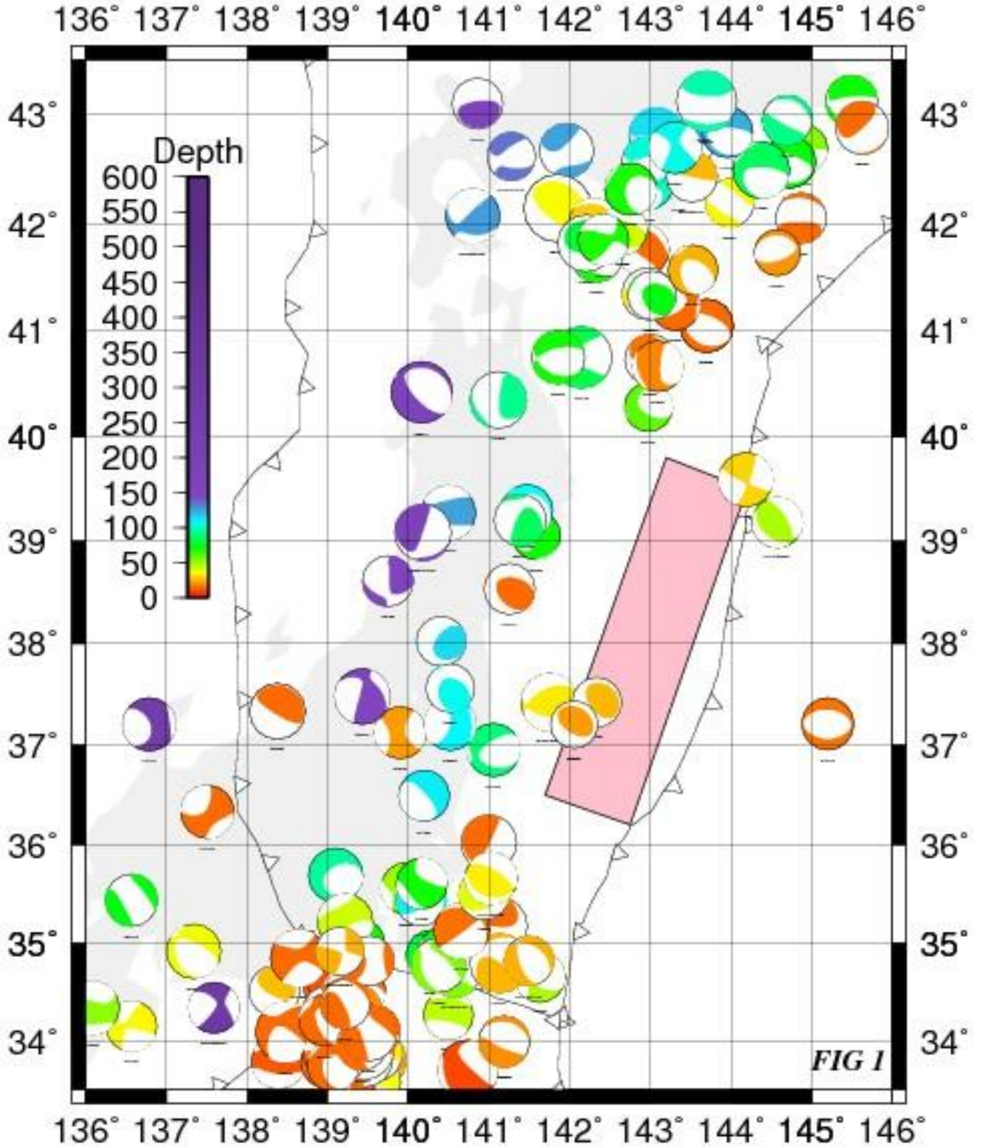

Figure 1
Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (pink box after Iinuma et al. (2011)) before the March 11th 2011 earthquake.

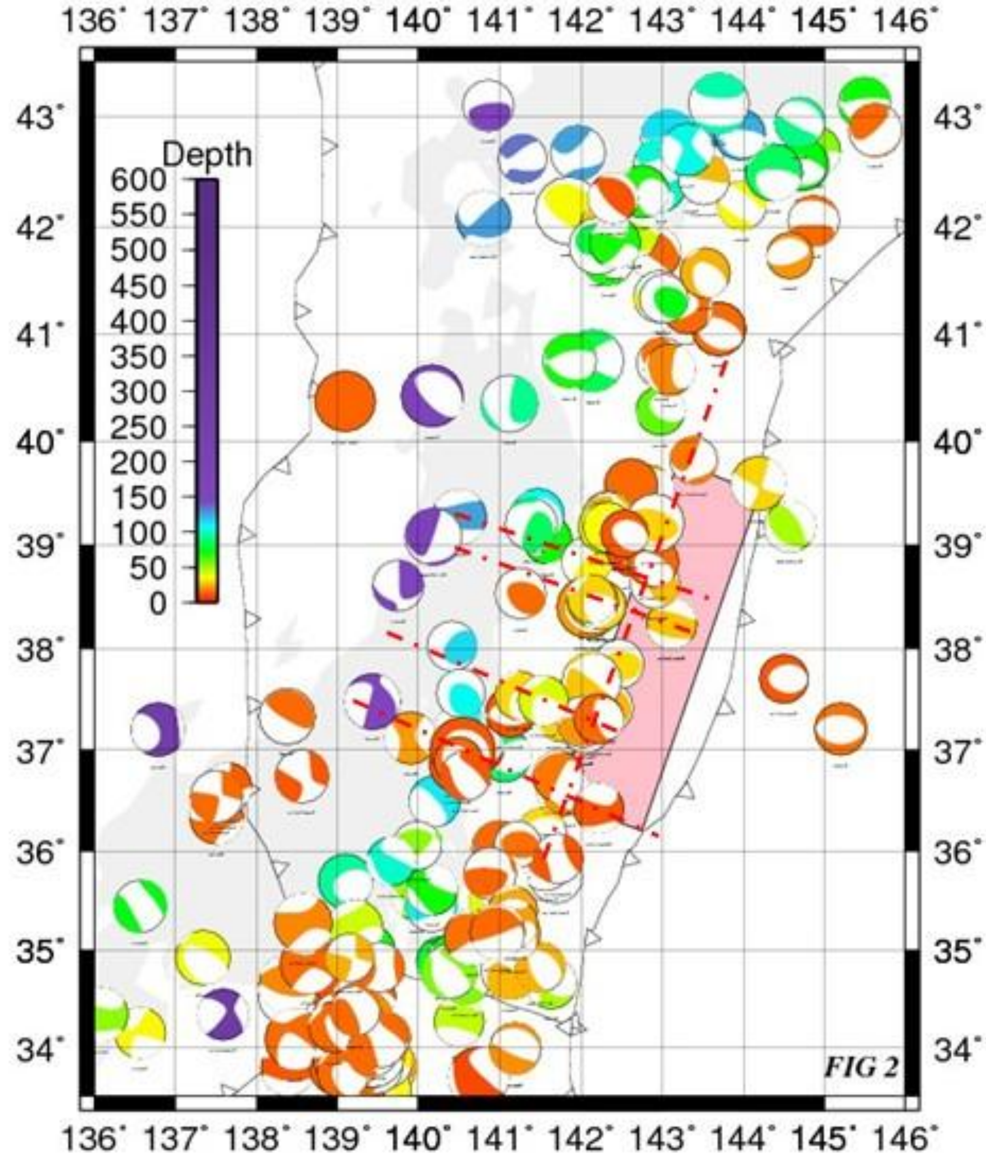

Figure 2

Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (pink box after Iinuma et al. (2011)) (by March 2012). One can observe seismic activity, perpendicular to the trench (West to the pink area) and nearby by the limits of the Miyagi-oki asperity; area not affected during the March 11th 2011 earthquake.

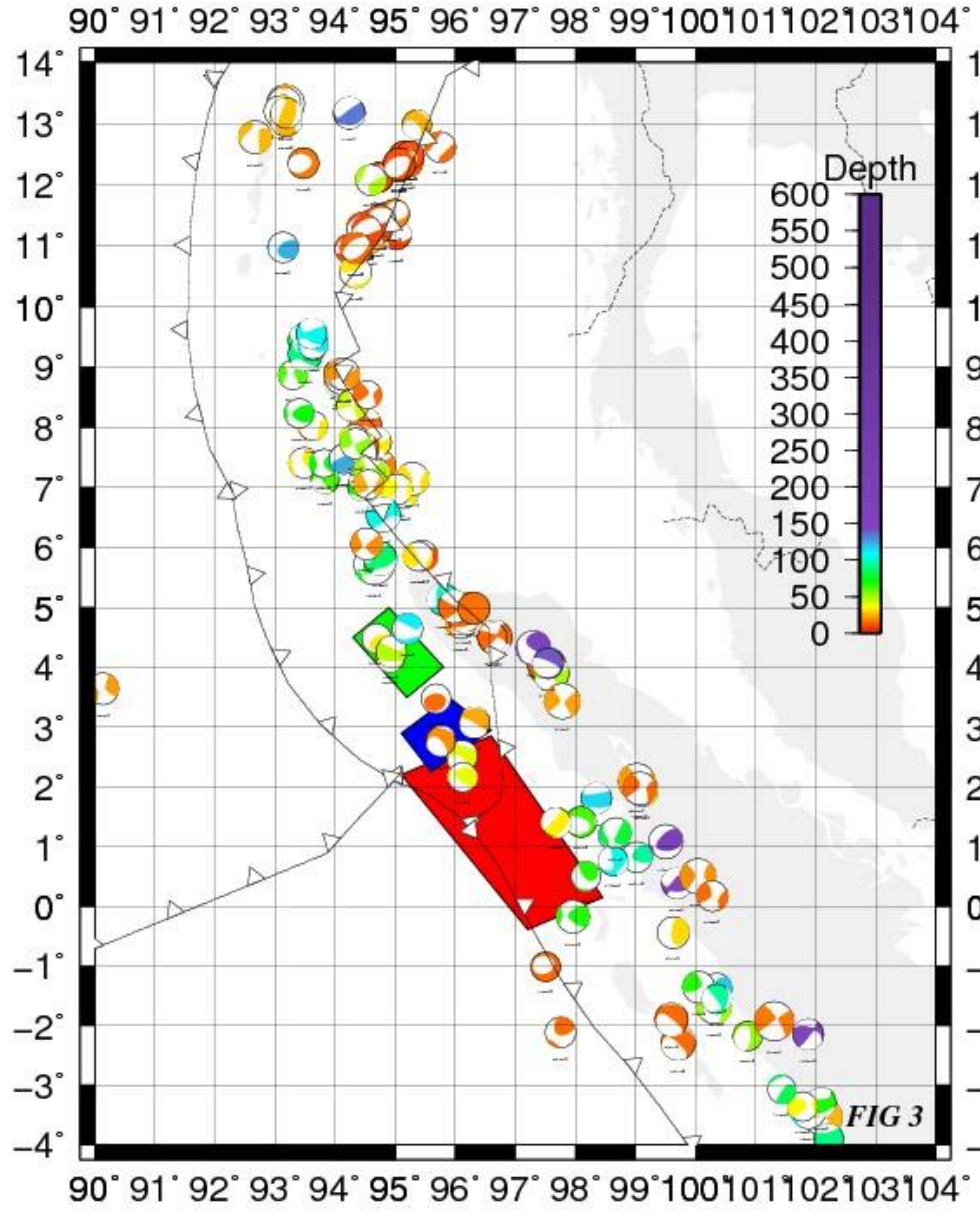

Figure 3
Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (after Nalbant et al. (2005) red box and Chlieh et al. (2007) blue and green boxes) before the December 26h 2004 earthquake.

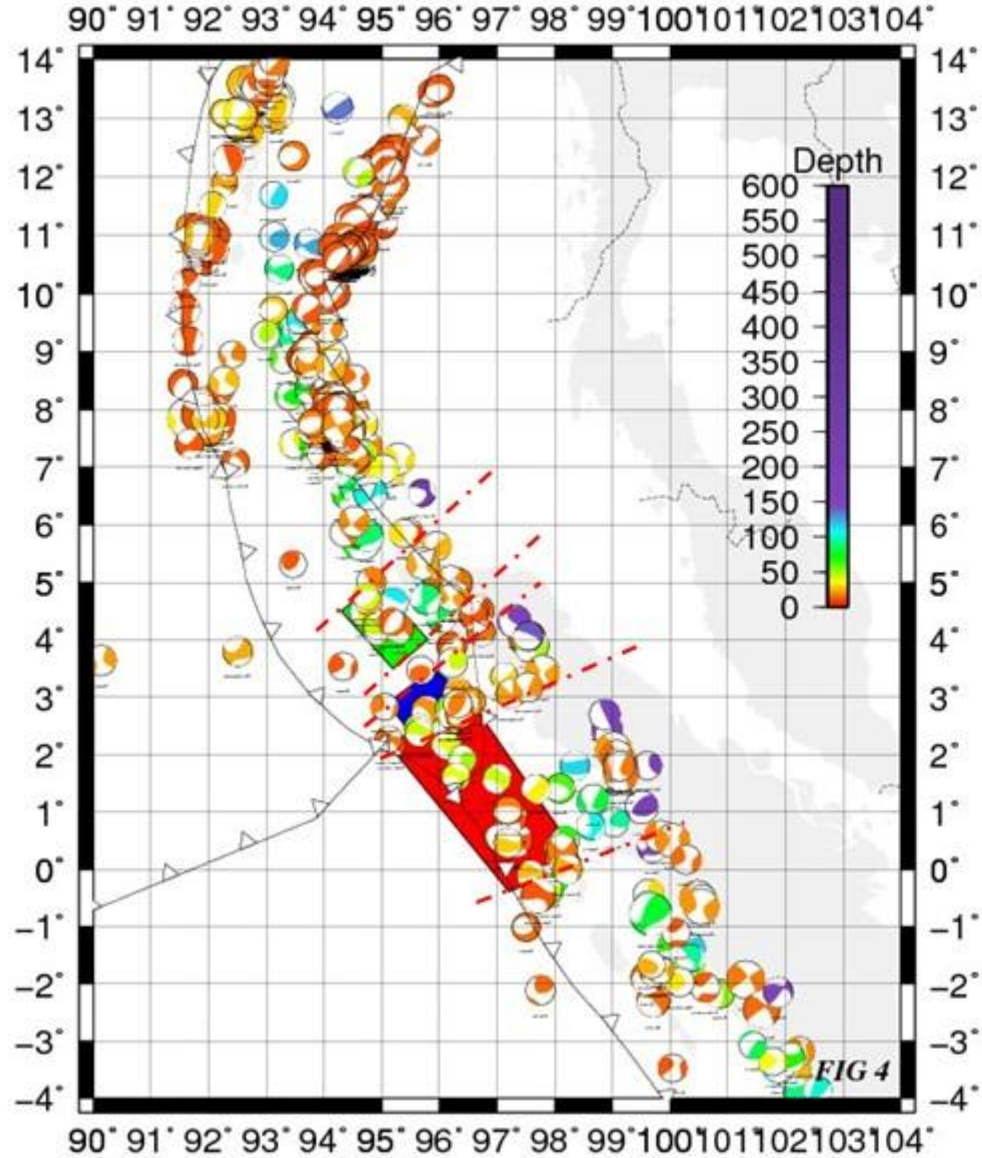

Figure 4
Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (after Nalbant et al. (2005) red box and Chlieh et al. (2007) blue and green boxes) by March 2012. It is noticeable the seismic activity clustering close to the rupture area borders, before and after the main event.

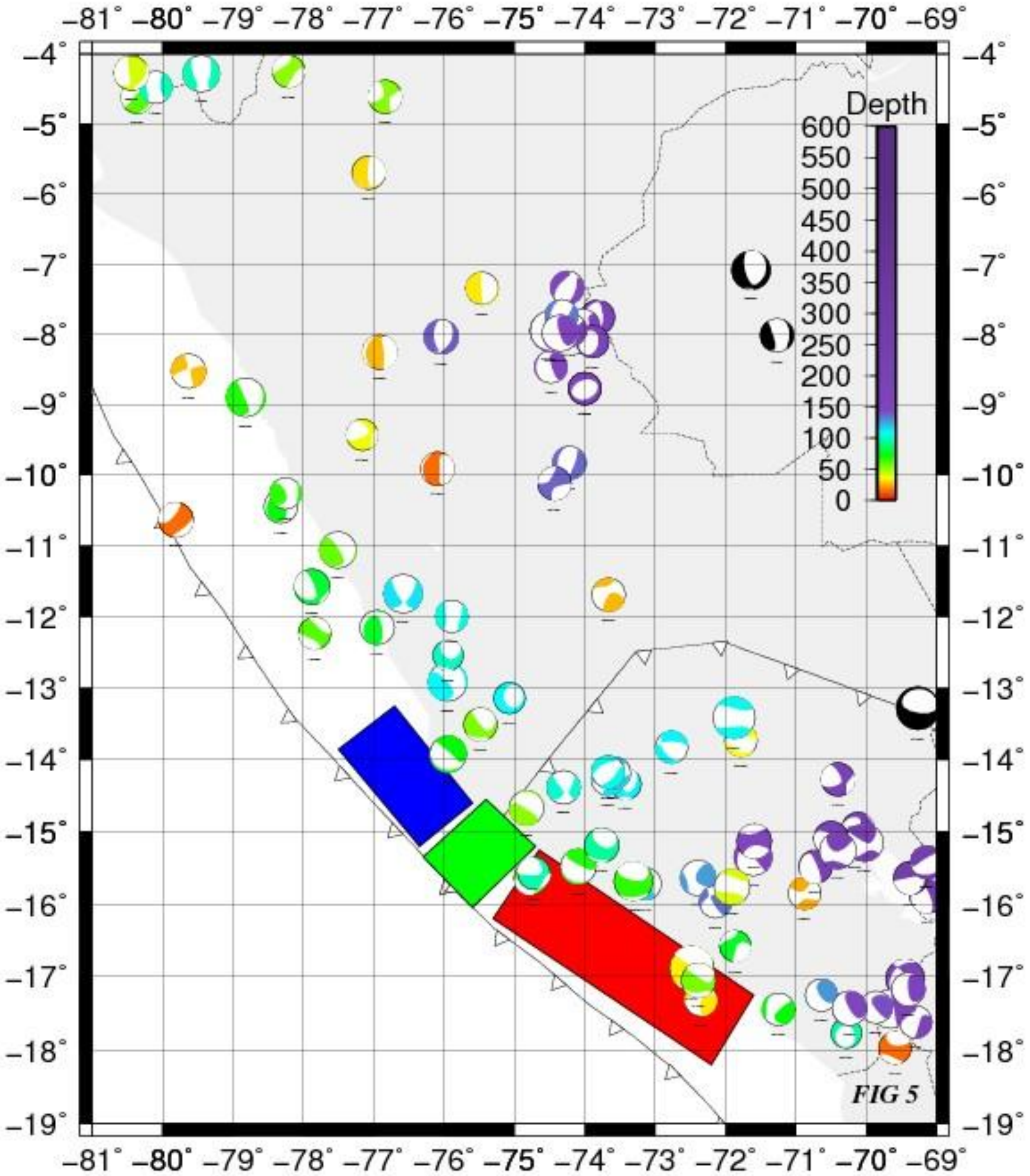

Figure 5
Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (after Chlieh et al. (2011) blue, green and red boxes) before the June 23rd 2001 earthquake.

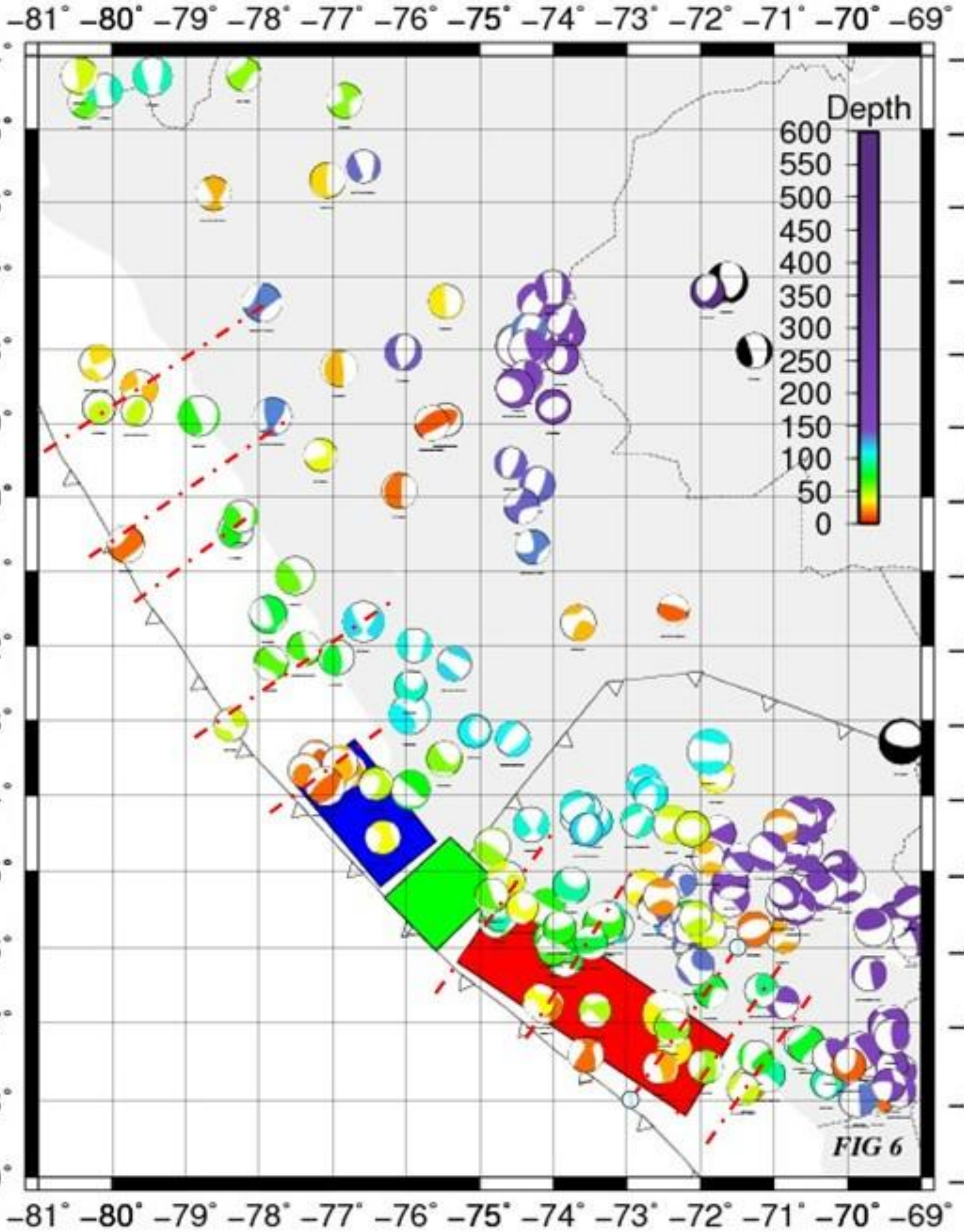

Figure 6
Filtered (within 25° of perpendicular to the trench) seismic activity close to the border rupture area (after Chlieh et al. (2011) blue, green and red boxes) before the by March 2012. It is noticeable the seismic activity clustering close to the rupture area borders. It is also noticeable the possible appearance of perpendicular to the trench alignments close to Trujillo (8S, 79W), Lima (12S, 77W) and Ilo (18S, 71W). Such activity needs to be monitored and compared to activity within areas of previous earthquakes (blue, green and red boxes).

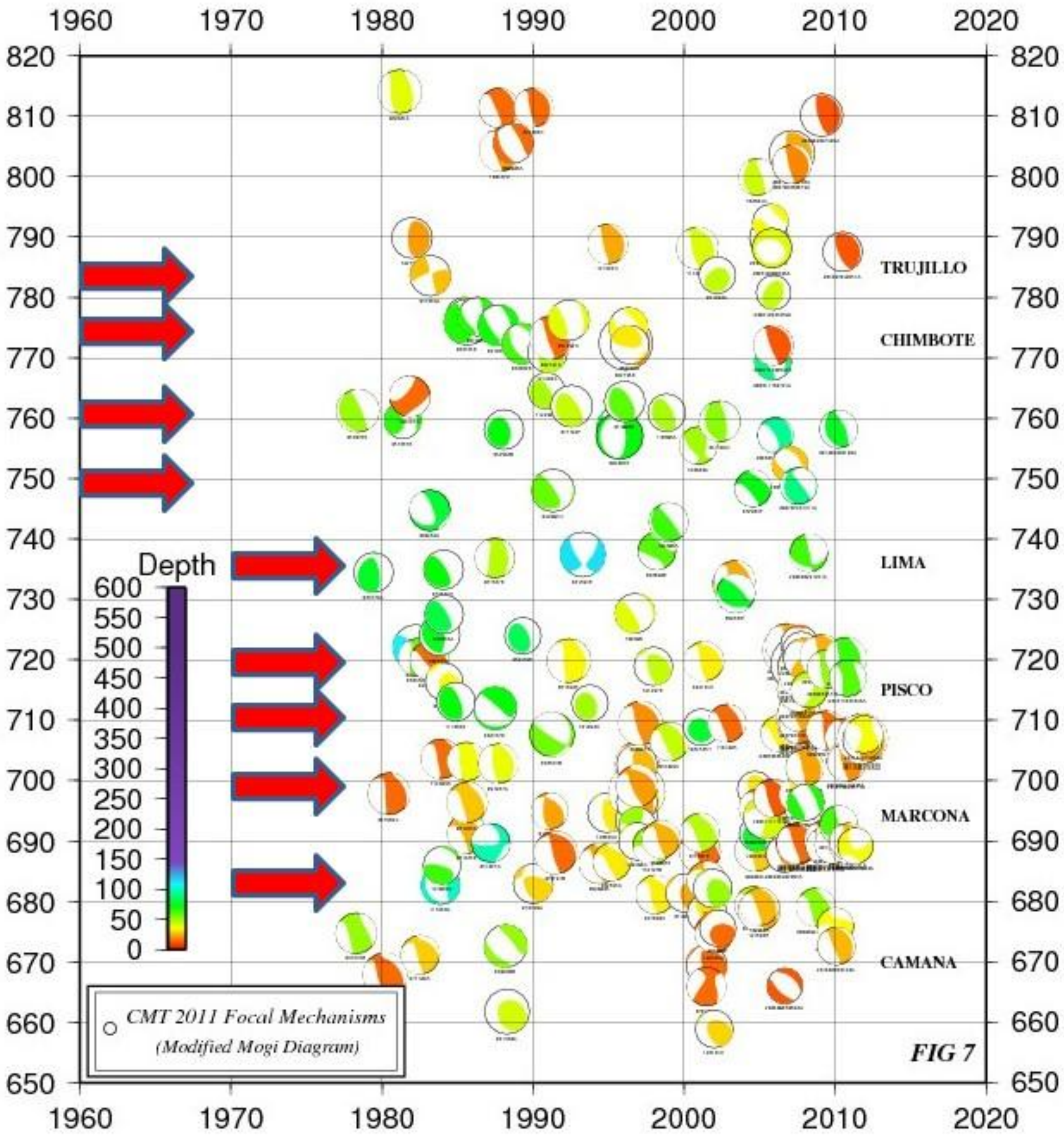

Figure 7
Several horizontal alignments are observed at several distances even in areas with no recent earthquakes. Notice the absence of thrust fault-mechanism solutions along most of the indicated alignments. Such seismic activity might correspond to a barrier activity and not an asperity activity. The horizontal axis represent time (in current years) and the vertical axis the distance (in 10Km units) along the surface of the Earth from a pole to each focal-mechanism considered. The pole is located in the South Atlantic Ocean. (Modified Mogi diagrams present focal-mechanism solutions from narrow areas, in the space and time domains. No previous filter is done. All solutions are presented.)

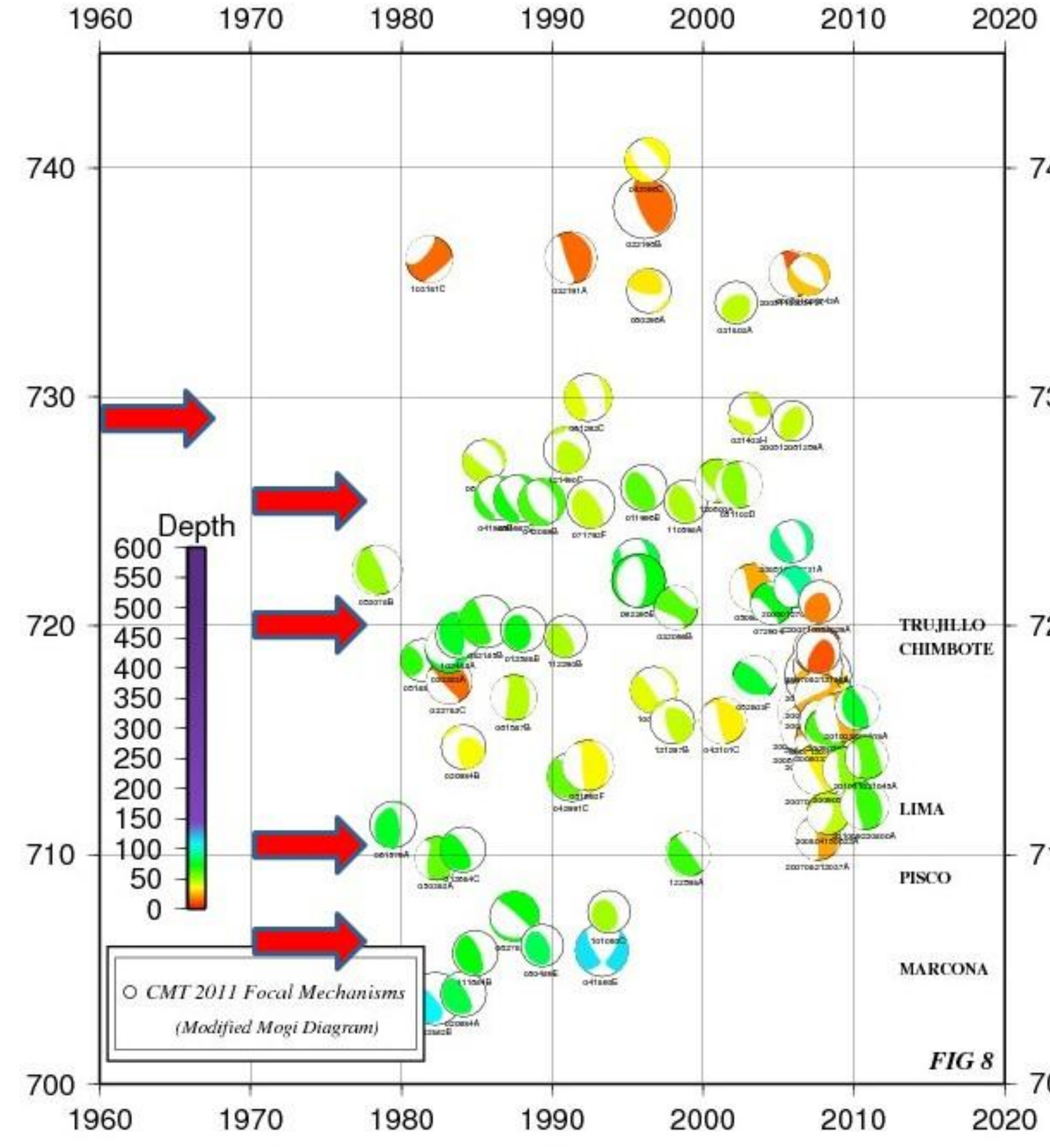

Figure 8
Several horizontal alignments are observed at several distances even in areas with no recent earthquakes. Notice the absence of thrust fault-mechanism solutions along most of the indicated alignments. Such activity might correspond to a barrier activity and not an asperity activity. The horizontal axis represent time (in current years) and the vertical axis the distance (in 10Km units) along the surface of the Earth from a pole to each focal-mechanism considered. The pole is located in the Central Atlantic Ocean. (Modified Mogi diagrams present focal-mechanism solutions from narrow areas, in the space and time domains. No previous filter is done. All solutions are presented.)