SEISMIC ACTIVITY IN THE AZORES REGION IN THE CONTEXT OF THE WESTERN PART OF THE EURASIA-NUBIA PLATE BOUNDARY

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SUMMARY

The western part of the Eurasia-Nubia plate boundary, with different tectonic features, extends from the Azores Islands to the Strait of Gibraltar. Based on focal mechanisms of large earthquakes, we observe the conversion of an extensional regime (Strike-slip and normal dip-slip motion) near to the Azores to a compressional regime (strike-slip and reverse dip-slip motion) in the east of the Atlantic Ocean (Gulf of Cádiz). The character of this plate boundary is defined by a clear seismicity, which is mainly controlled by the tectonic activity existing along the Azores Gibraltar Fracture Zone (AGFZ), which extends from the Azores Islands to the Strait of Gibraltar. Seismic activity and moment tensor solutions of earthquakes indicate that present-day interplate collisional coupling in the Western Mediterranean region is most pronounced in western Iberia and the offshore Atlantic marked by NW to N-directed horizontal compressional stresses. This is also reflected by the occurrence of large historical and instrumental earthquakes, in particular by the recent earthquakes occurred on 1980 (Mw=6.8), 1997 (Mw=6.2), 1998 (Mw=6.2) and 2007 (Mw=6.3, Mw=6.1) in the Azores Islands and on 1969 (Mw=7.8) and 2007 (Mw=6.1) off coast of South-Western Portugal. In this work we discuss the seismic activity of the Azores region in the context of the Eurasia-Nubia plate boundary.

1. INTRODUTION

The western part of the Eurasia-Nubia plate boundary, with different tectonic features, extends from the Azores Islands to the Strait of Gibraltar. The interaction between Iberia and Africa results in a complex region located in the western part of the Eurasian-African plate boundary. This region corresponds to the transition from an oceanic boundary (between the Azores and the Gorringe Bank), to a continental boundary where Iberia and Africa collide. The plate boundary is very well delimited in the oceanic part, from the Azores Islands along the Azores-Gibraltar fault to approximately 12ºW (west of the Strait of Gibraltar). From 12°W to 3.5°E, including the Iberia-African region and extending to the western part of Algeria, the boundary is more diffuse and forms a wider area of deformation (Buforn et al., 2004; Borges et al., 2007).

In this paper we have divided the western part of the Eurasia-Nubia plate boundary, from the Mid-Atlantic Ridge in the west to Algiers in the east, into six zones: zone I (from 30°W to 27°W, Triple junction to Terceira Island), zone II (from 27°W to 23°W), zone III (from 23°W to 11°W, Gloria Fault t), zone IV (from 11°W to 6°W, Gorringe Bank to Cadiz), zone V (from 6°W to 1°W, Betic, Rif Cordilleras and Alboran Sea) and VI (from 1°W to 3.5°E, northwest Algeria and Tell Mountains). We will examine the different characteristics of these six zones using observations and changes of seismicity and focal mechanisms (Figure 1 and Figure 2).

This work is a review and an update of two papers published recently by Buforn et al. (2004) and Borges et al. (2007). The tables cited in the text are annexed to the paper included in the CDROM.

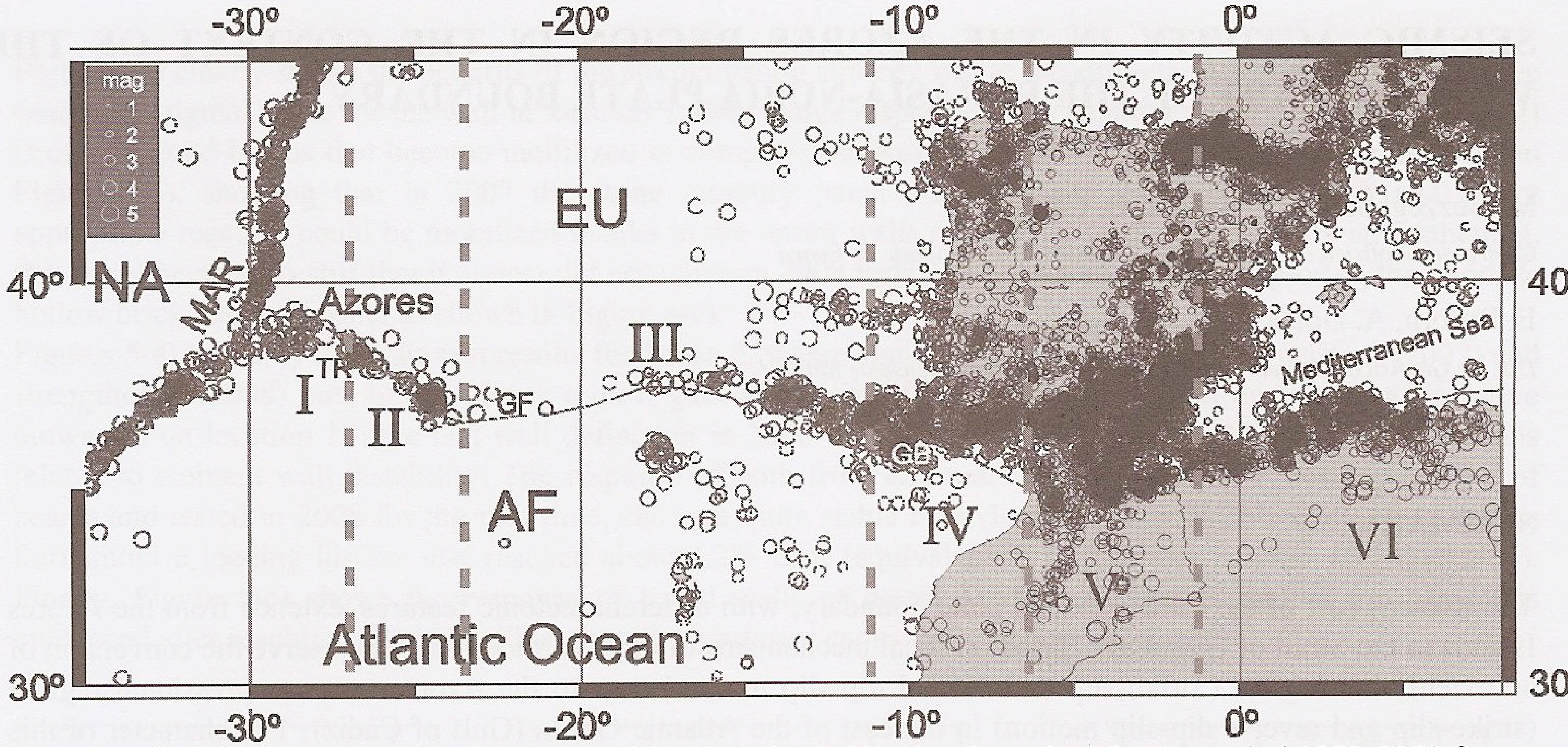

Figure 1: Seismicity for the western part of the Eurasia-Nubia plate boundary for the period 1973-2008 for magnitude M≥ 1.0 (NEIC Data File). MAR = Middle Atlantic Ridge; TR = Terceira Ridge; GF = Gloria Fault; GB = Gorringe Bank; NA = North American plate; EU = Eurasian plate; AF = African plate; P = Portugal; S = Spain; M = Morocco; A = Algeria. The roman numbers (from I to VI) indicates the six zones studied and described in the text.

2. WESTERN PART OF THE EURASIA-NUBIA PLATE BOUNDARY

The Azores-Gibraltar-North Algeria plate boundary, which may be divided into six zones, corresponding with changes in the seismicity. In zone I and II, (Azores plateau) two types of mechanisms are present, in zone III (Central region) one type, in zone IV, V and VI (Iberian–Maghrebian region) three types for shallow earthquakes and one for intermediate depth earthquakes.

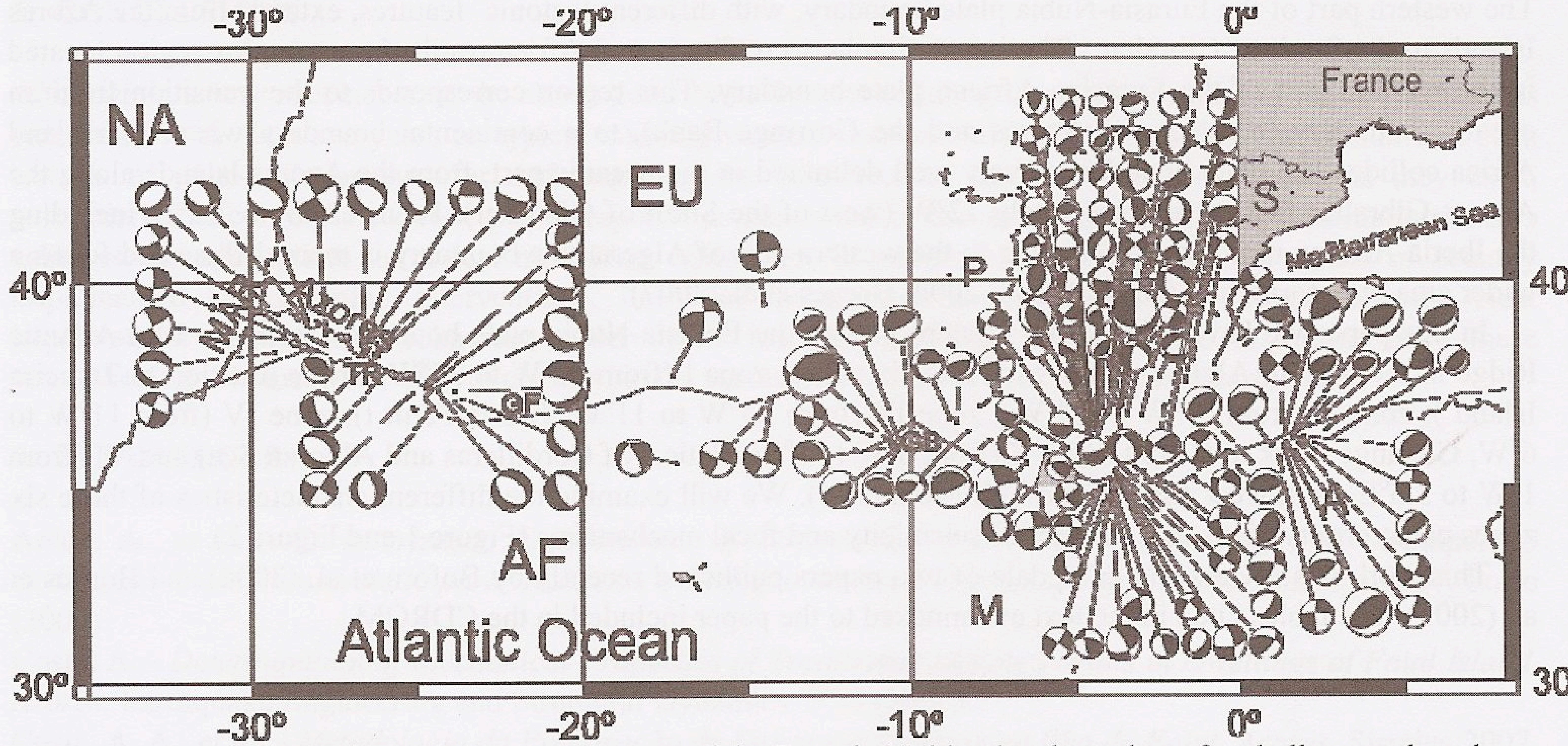

Figure 2: Focal mechanisms, in the western part of the Eurasia-Nubia plate boundary, for shallow earthquakes (h<40 km) and $m_b \geq 5.0$, before 1975 and $m_b \geq 4.0$ after 1975, for intermediate depth earthquakes (40<h<150 km) and for very deep depth earthquakes (h>600 km). Size is proportional to magnitude. Solutions parameters for focal mechanisms are listed in Table 1 (annexe, see CD). P = Portugal; S = Spain; M = Morocco; A = Algeria. MAR, TR, GF, GB, NA, EU e AF as in Figure 1.

Azores region: The seismicity in zone I is in direction ENE-WSW, and in zone II in NW-SE direction. Earthquakes located in region I show left-lateral strike-slip motion with horizontal extension in a N-S to NNE-SSW direction and horizontal compression in E-W direction. This difference in the stress pattern for regions I and II is also present in the velocities estimated from seismic data, faster in region I, 6.7 mm/yr, versus 3.1 mm/yr in region II. The over all regional stress pattern for both zones corresponds to a horizontal extension with an average velocity for the whole region of 2.3 mm/yr.

Central region: Zone III is characterized by a long linear feature in E-W direction along the Eurasian-Africa plate boundary controlled by right-lateral strike-slip motion with occurrence of some large earthquakes (1939, Ms=7.9; 1941, Ms=8.41; 975, Ms=7.9). The westernmost part (Gloria fault, GF) has a very scarce seismicity and it is considered to be a seismic gap. From the longitude 18°W, it is possible to identify two alignments of earthquakes: the first, oriented E-W, is an extension of the GF and correspond to the plates boundary; the second, oriented NW-SE, correspond to a fracture that begins near the GF and reaches the Moroccan coast at Agadir. Both alignments, joined with the seismic activity associated to the Atlas Mountains, define the limits of a sub-triangular plate (Buforn et al., 1988). For the central region we obtain a slip velocity of 1.8 cm/yr (Borges, 2003). This value is less than 3.39 cm/yr, obtained by Buforn et al. (1988) (probably due to the lower period of time considered and the high scalar seismic moment of the event 1 with $Mo = 1,6 \times 10^{19}$ Nm). This value is also less than 2.3 cm/yr given by NUVEL model-I (DeMets et al., 1990).

Ibero-Maghrebian region: in the Gulf of Cadiz and Algeria (zones IV and VI) the plate boundary between Eurasia and Africa corresponds to a narrow band well defined by the seismicity, where large earthquakes (M>7) occur in association with horizontal compression N-S to NNW-SSE due to the convergence of Eurasia and Africa (Fig. 3, Tab. 1, 2 and 3). The intermediate-depth earthquakes in zone IV, with a distribution in E-W direction and limited by a narrow band less than 20 km wide that broadens as we move to the Strait of Gibraltar, may also be associated with the convergence process of the Eurasia-Africa plates. In these areas (IV and VI) the material is relatively rigid and the stresses are released by larger earthquakes. In area V the plate boundary is more diffuse and corresponds to a wider area that includes the Betics, the Alboran Sea and the Rif. It is difficult in this case identify a simple line that corresponds to the plate boundary. In this area (V), the material is more fragmented, with a large number of small faults, and consequently the stresses are released by frequent small to moderate earthquakes. As a consequence the plate boundary is not well defined in area V and it corresponds to a wide area where deformation is manifested by the continuous occurrence of small earthquakes, and only occasionally, some moderate events occur. However, in the past, also large events have occurred in this area as shown by the historical seismicity and the lack of large earthquakes in the 1900-1999 period and the consequent low values of slip velocity, may be only due to an anomalous period of seismic quiescence during the last century. In the 19th century at least two earthquakes (1829 and 1884) took place in southern Spain with magnitude greater than 6. For this region the time period selected (1900-1999) does not adequately represent the long range seismic activity of the region. The stress regime obtained from the focal mechanisms of shallow events is compatible with horizontal N-S to NW-SE convergence of Eurasia and Africa. However in the Betics-Alboran area there is also a horizontal extension in an approximately E-W direction.

The existence of seismic activity at intermediate depth (60 to 150 km) in the eastern side of the Strait of Gibraltar, extending in a very narrow vertical band 50 km wide in N-S direction. may be explained by the existence of a seismogenic block in the upper mantle, of approximate dimensions 200 km long, 150 km deep and 50 km wide. Inside this block, the stress regime, deduced from focal mechanisms of earthquakes, corresponds to nearly vertical tension dipping to the SE. Different tectonic models have been proposed for this region, such as some kind of subduction process, extensional collapse of thickened continental lithosphere, continental lithospheric delamination, backarc extension caused by subduction rollback, convective thinning (Houseman, 1996) or subduction and breaking of a slab of material (Buforn et al., 2004). Some of these models, such as continental lithospheric delamination, are not compatible with the presence of the intermediate-depth earthquakes and their focal mechanisms. The results presented here are consistent with the model presented by Buforn et al. (1997) of an almost vertical slab of material with strike N-S driven by the extensional E-W forces and under NW-SE compressive forces present at the Alboran Sea. The slab is being stretched downward, possibly by gravitational instability processes.

The presence of the very deep earthquakes (650 km) under southern Spain is a further sign of the complexity of area V. Their focal mechanisms correspond to pressure and tension axes trending E-W and dipping about 45°. The relation of this deep activity with that of intermediate depth is not clear, but results of focal mechanisms and tomographic studies suggest different origins for them. In both cases these may be related to subduction processes, more recent for intermediate-depth shocks and older for very deep activity.

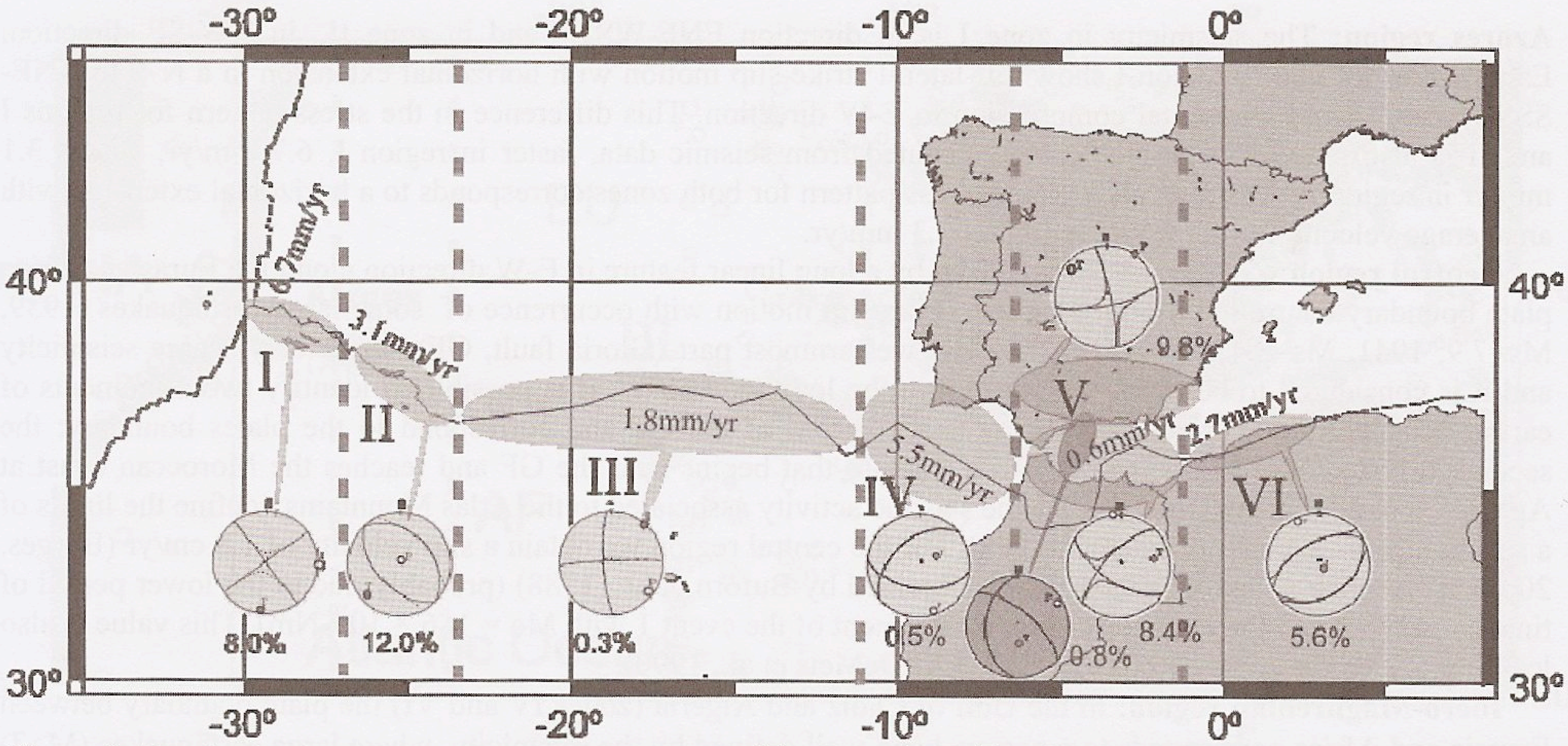

Figure 3: Total seismic moment tensor, western part of the Eurasia-Nubia plate boundary, for shallow (grey) and intermediate (dark grey) earthquakes in the six studied zones. The CLVD component for each region is indicated below the moment tensor. Values of slip velocity obtained from seismic strain of shallow seismicity are indicated along the boundary. The roman numbers (from I to VI) indicates the six zones studied and described in the text.

3. DISCUSSION

The change in the seismicity along the Azores-Gibraltar-Algeria Plate boundary zone confirms that the present plate movement is transtensional in the Azores, dextral along the Gloria transform and convergent between the SW Atlantic margin and the Ibero-Maghrebian zone (Figure 3). The convergence rate decreases west (Azores plateau) to east (Ibero-Maghrebian zone) (Figure 3, Table 3, see CD). Energy released by aseismic process, in the form of folding, thickening, plastic deformation or slow aseismic slip, which is not include in our estimation of slip velocity. This means that seismic strain analyses may underestimate the geological deformation. The velocity obtained in this work may be considered as instantaneous and independent from this derived from geodetic data. In addition, the slip rate assumes that the earthquake cycle is much shorter than the history of available earthquakes. For the Azores region this condition is not met. Due to the uncertainty we have on large historic earthquakes (Table 1 and 2 annexe, see CD), only instrumental period has been used for this estimation. The adequacy of seismic catalogues to estimate earthquake recurrence rate depends on the area of the region, catalogue duration, and regional strain rates (Ward, 1998). To define a catalogue adequacy parameter Aasha et al. (2006) suggest to consider the product of the duration of the earthquake record, the area of the region, and the average strain rate, as estimated by space geodetic methods. Given the shortness of the catalogue duration and variability in absolute rates of plate motion, spatial similarity between geodetic deformation and seismicity is not necessarily expected. We do not attempt in this article to revise seismic estimates for Azores-Gibraltar-Algeria Plate boundary; however, analysis of seismic versus aseismic deformation inferred from earthquakes and geodetic data is an interesting study we suggest for future work.

4. ACKNOWLEDGMENTS

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