SEISMOTECTONICS OF THE GULF OF CADIZ: NEW INSIGHTS FROM INSTRUMENTAL SEISMICITY

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***Abstract**: The Gulf of Cadiz offshore SW Iberia is an area linked with episodic destructive seismic and tsunamigenic events, such as the 1st November 1755 Lisbon earthquake. The association of active faults to this kind of high magnitude event has been intensively studied specially due to the contribution of several international team projects, working in this area for more than two decades. However, the meaning of the persistent small to intermediate magnitude seismicity recognized in this region is still particularly misunderstood. This problem is mostly related to the lack of an accurate hypocenter location of these events resulting from an asymmetrical geographical distribution of the permanent seismic network. To address this problem the EC project NEAREST (Integrated observation from NEAR shore sourcES of Tsunamis: towards an early warning system) conducted a passive seismic experiment in the Gulf of Cadiz where 24 broadband seismometers (plus the GEOSTAR multi-parameter deep-sea observatory) were deployed from September 2007 to July 2008. The examination of the continuous data stream allowed the detection of a large number of local events that were not detected by the land networks. The analysis of the complete data set reveals 3 main clusters of earthquakes, two of them coincide with the location of the 3 larger instrumental earthquakes in the area: i) the 28th February 1969 (Mw~8.0); ii) the 12th February 2007 (Mw=6.0) and iii) the 17th December 2009 (Mw=5.5). Many of the small magnitude earthquakes are located in the mantle (at depths between 30 and 60 km), like the hypocenters of these three earthquakes derived from waveform inversion. However, focal mechanisms show a mixed pattern, mostly strike-slip and reverse dip-slip with a very few normal mechanisms, showing us that processes related with this seismicity must be complex probably involving the interaction between different active geological structures and reflecting particular local rheological contrasts.*

***Key words**: Gulf of Cadiz, Seismotectonics, Horseshoe Fault, Active Faulting*

The Eurasia – Africa Plate Boundary in the region of the Gulf of Cadiz SW Iberia is particularly complex, corresponding to a 200 km elongate wide diffuse area of deformation (Sartori et al., 1994). The plate kinematic models for this area estimate a convergence of 4-5 mm/yr (Argus *et al.*, 1989,

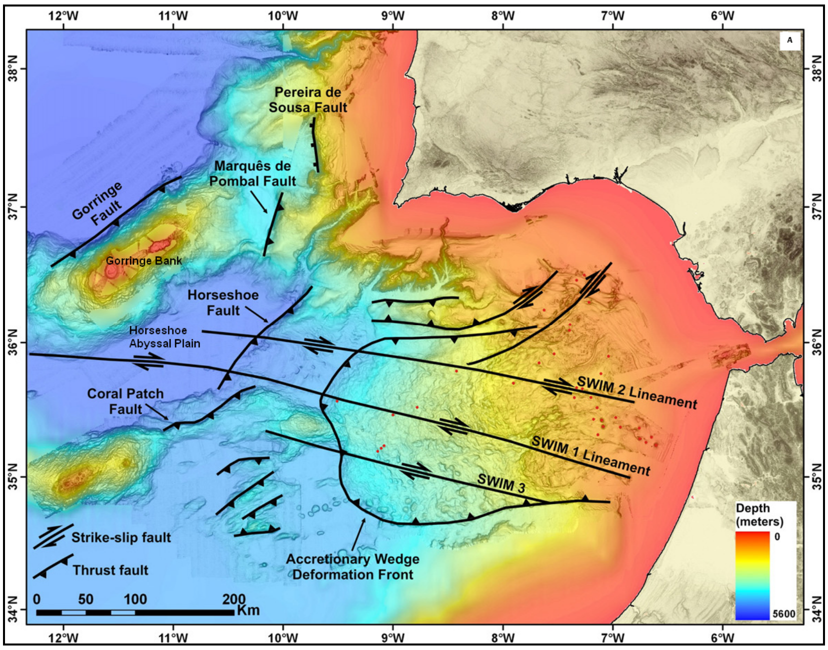

Figure 1: Simplified Map of the active tectonic structures in the Gulf of Cadiz (from Duarte et al., 2010).

DeMets et al., 1994, Nocquet and Calais, 2004, Stich *et al.*, 2006). The regional horizontal average compression is defined as NW-SE, solution based on borehole, focal mechanisms and moment tensor analysis (Ribeiro et al. 1996, Borges *et al.,* 2001, Stich et al., 2006, Heidbach et al,. 2008). Two main systems of active faults are present (Fig.1): NE-SW, NW verging thrust faults (e.g. Horseshoe Fault and Gorringe Fault) and WNW-ESE dextral strike-slip faults SWIM Lineaments (Zitellini et al., 2009).

Most of the instrumental seismicity in this area is considered of moderate magnitude and shallow to intermediate depth, mostly above 60 Km (Buforn et al., 2004). However, it is well known the occurrence of high magnitude earthquakes, both historical and instrumental, in Gulf of Cadiz area. The 1st November 1755 earthquake, had an estimated magnitude of 8.8 (Richter, 1958; Abe, 1979) and It was associated with a large tsunami with magnitude 8.6 (Abe,1979). The 28th February 1969 earthquake, with a magnitude 8.0 (USGS), is the most important instrumentally recorded event in this region. The hypocenter was located beneath the Horseshoe Abyssal Plain (Fig. 1). The focal mechanism is described as thrust faulting with a small strike slip component on a striking NE-SW fault plane (Fukao, 1973). Within the same area occurred the 12th February 2007 earthquake with M_w of 6, corresponding to an oblique reverse faulting solution at 40 km depth sub-parallel to the Horseshoe Fault (Stich et al., 2007). The last 17 th December event had Mw of 5.5 (USGS), it was located near the NE limit of the Horseshoe Fault (Fig.1), having an nearly pure strike-slip solution (USGS).

The identification and characterization of seismogenic sources in Gulf of Cadiz area requires an accurate comprehension of seismicity impossible to establish using only the land stations network. To address this problem, as part of the NEAREST project (Integrated observation from NEAR shore sourcES of Tsunamis: towards an early warning system GOCE, contract n. 037110), 24 broadband Ocean Bottom Seismometers (OBS) and a seafloor multiparametric station GEOSTAR (Geophysical and Oceanographic Station for Abyssal Research) acquired between September 2007 and July 2008 passive seismic data in this region.

The OBS instruments specifically referred as LOBSTER (Longterm Ocean Bottom Seismometer for Tsunami and Earthquake Research) were manufactured by K.U.M. Umwelt- und Meerestechnik Kiel GmbH, Germany. They were equipped with a Güralp CMG-40T broadband seismometer incorporated in a titanium pressure housing, a hydrophone, and a GEOLON MCS (Marine Compact Seismocorder) data logger from SEND GmbH Hamburg, Germany (Carrara et al., 2008)).

The GEOSTAR is an observatory station which comprises a set of geophysical and oceanographic sensors for continuous data acquisition, developed in a project coordinated by the Istituto Nazionale di Geofisica e Vulcanologia –INGV. This station incorporates a 3 component broadband seismometer and a hydrophone (Carrara et al., 2008).

During OBS acquisition time and in a range of 75km distance from de closest OBS, 276 events were identified by land stations, with ML from 0,5 to 4,7 (data provided by Fernando Carrilho from IM, Carrara et al., 2008).

For the epicentre, hypocentre and local magnitude determination it was only considered OBS and GEOSTAR network stations. However, for the

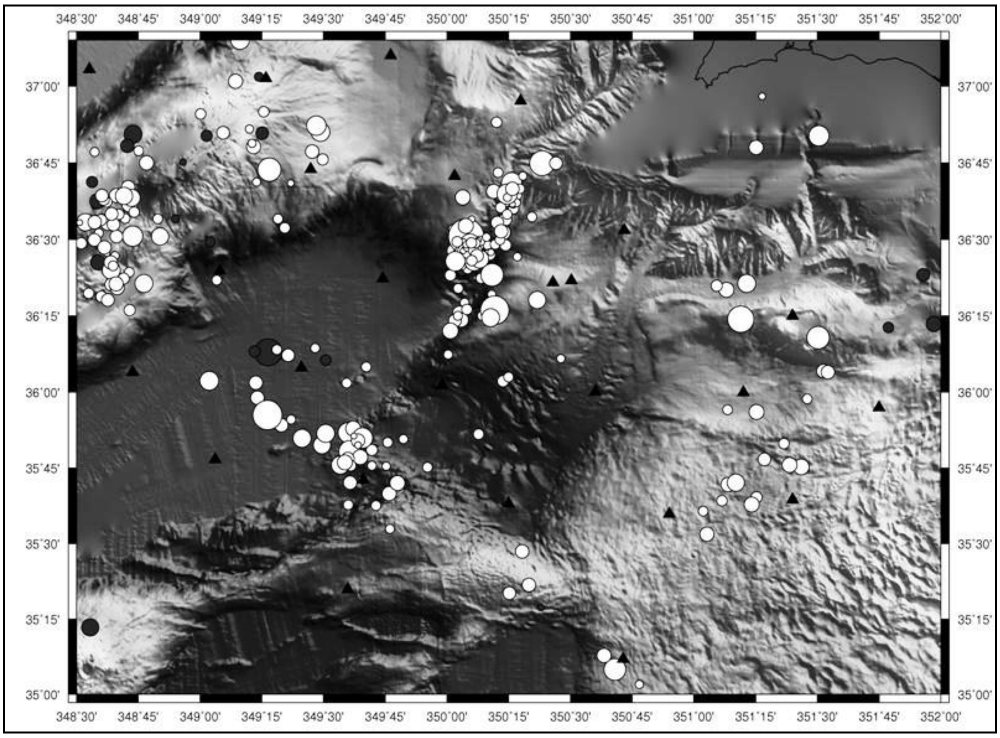

Figure 2: The epicentre distribution of the events derived from Nearest Network, gray circles represents depth < 30Km, white circles depth > 30 Km, the black triangles refers to the seismic network (Bathymetric map adapted from Zitellini et al. 2009)

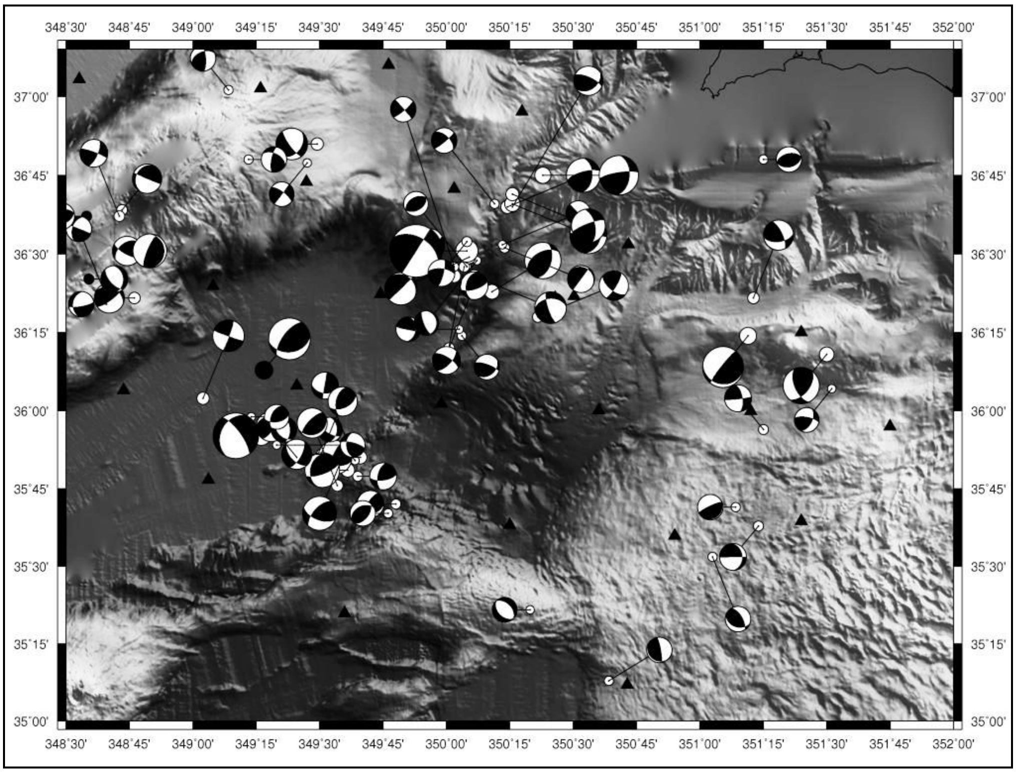

Figure 3: The focal mechanisms solutions derived from Nearest Network, the black triangles refers to the seismic network, gray circles represents depth < 30Km, white circles depth > 30 Km (Bathymetric map adapted from Zitellini et al. 2009)

purpose of computing the focal mechanisms the data from land stations were also incorporated.

The epicentre distribution of the analysed data is presented in Figure 2. Three clusters of earthquakes can be identified: i) in the Gorringe Bank; ii) in the Horseshoe Abyssal Plain; iii) near the NE limit of the Horseshoe Fault.

The depth distribution of the hypocentres varies from shallow to intermediate. From Figure 2 it is easily recognized that most of the events are located at depths > 30km, meaning in the upper mantle. The local magnitudes vary between 1.2 and 4.5.

The focal mechanisms are varied (Fig. 3), mostly dominantly strike-slip and reverse dip-slip solutions, although there are also present some normal solutions.

With the Nearest Network it was possible to detect a large number of local earthquakes that could not previously be identified with the existent network. Moreover, when the location of events detected by the landstations network is compared with that of the Nearest network it is clear that the latter is dislocated to the SW and the events are deeper. In fact, based in this analysis the depth discrepancy can be of 30km.

Having presented these new data it is now possible to discuss how to it can contribute to our view on the seismotectonics of the Gulf of Cadiz area. There are two relevant results to discuss: i) the depth distribution of the events; ii) complexity of the focal mechanims

The deep distribution of the hypocentres implies, as Stich et al (2010) referred, a brittle behaviour of the upper mantle. So, if we consider that some of the previously identified faults can be are related with the low to moderate seismicity then we can suggest that these structures (observed only down to 15 km, maximum, using seismic reflection data) can extend downwards till 30 to 50km in depth.

The wide-ranging solutions of focal mechanisms implies that the source processes that generate this seismicity are complex. It can reflect the interaction of different active geological structures and local rheological contrasts. Rosas et al. (2008) refers that the interference of SWIM faults and the Horseshoe Fault originate curved faults linking in depth these two systems. These new faults can locally affect the stress field resulting in the mixed focal mechanism solutions observed in the earthquake cluster of the Horseshoe Abyssal Plain (Fig. 3).

The results obtained in this work improves our knowledge about the local seismicity and related actives faults in the Gulf of Cadiz area, giving a new contribution to access to the seismic hazard in this critical region.

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