EVIDENCES OF QUATERNARY ACTIVE FAULTS ACROSS THE DJIBOUTI HIGH AND THE ADRA RIDGE (ALBORAN SEA)

Evidencias de fallas activas cuaternarias a través del Alto de Djibouti y de la Cresta de Adra (Mar de Alborán)

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Resumen/resumo: Una fracción de la deformación producida por la convergencia entre las placas de Nubia y Eurasia es acomodada en la cuenca del Mar de Alborán por diferentes sistemas de fallas. En los mapas batimétricos de alta resolución hemos identificado varios lineamientos con dirección NE-SW a través del Alto de Djibouti. Estos lineamientos, destacando entre ellos el correspondiente a la falla de Djibouti, tienen longitudes de hasta 30 km y aparentemente desplazan la Cresta de Adra en sentido lateral derecho. Los perfiles de sismicidad multicanal de alta resolución adquiridos en la zona muestran que estos lineamientos corresponden a fallas que están rompiendo los reflectores correspondientes a las unidades Plio-Cuaternarias y en algunos casos incluso la superficie del fondo marino. Por lo tanto, estos lineamientos están asociados a fallas activas Cuaternarias y su localización y caracterización ayuda a mejorar nuestro conocimiento sobre la peligrosidad sísmica y de tsunamis alrededor del Mar de Alborán.

Palabras clave: Fallas activas; Fallas direccionales, Mar de Alborán, Métodos geofísicos.

Abstract: A small amount of the total strain produced by the convergence between the Nubian and Eurasian plates is accommodated in the Alboran Sea basin by different fault systems. High resolution bathymetric maps show several NE-SW lineaments across the Djibouti High, among them the Djibouti fault, that have lengths up to 30 km and are apparently offsetting the Adra Ridge in a right-lateral movement. High-resolution multichannel seismic profiles acquired in the area show that these lineaments correspond to faults that are displacing the reflectors corresponding to the Plio-Quaternary units and some of the faults affect the seafloor. Therefore, these lineaments are associated to Quaternary active faults and their location and characterization improves our knowledge about earthquake and tsunami hazard around the Alboran Sea.

Key words: Active faults, Strike-slip faults, Alboran Sea, Geophysical methods.

INTRODUCTION

The NW-SE convergence (4-5 mm/yr) between the Nubian and Eurasian plates controls the present-day crustal deformation along the southern Iberian and northern African margins (Koulali et al., 2011). The strain due to this convergence is accommodated over a wide deformation zone with significant seismic activity (figure1). Although seismicity is mainly characterized by low to moderate magnitude events, large and destructive earthquakes as the 1522 Almería (IEMS98 IX) or the 1910 Adra (IEMS98 VIII) have occurred in the region (Martínez Solares and Mezcua, 2002; Buforn et al., 1995; Stich et al., 2010).

The Alboran Sea basin is interpreted as a Neogene marine back-arc basin generated by crustal extension associated to the subduction in the Gibraltar Arc (Comas et al., 1999; Booth-Rea et al., 2007). During the Late Miocene the stress field changed from extension to contraction resulting in the present tectonic and physiographic configuration of the Alboran Sea (Comas et al., 1999; Gràcia et al., 2006; Ballesteros et al., 2008). The main active structures in the region are strike slip and thrust faults (figure 1), as the Yusuf, Carboneras or Alboran Ridge fault systems (Gràcia et al., 2006; Martínez-Garcia et al., 2011; Ballesteros et al., 2008; Martínez-Garcia et al., 2013). Nevertheless, the bathymetric maps (figure 1) and the seismic profiles acquired in the area show the presence of a number of smaller faults, that are probably active given their geomorphic expression (Gràcia et al., 2006; Gràcia et al., 2012; Martínez-Garcia et al., 2011; Martínez-Garcia et al., 2013; Ballesteros et al., 2008). Their location and characterization by means of active tectonics and submarine paleoseismological studies is essential to significantly improve our knowledge about earthquake and tsunami hazards along the surrounding Alboran Sea coastal areas.

The bathymetry of the central Alboran Sea shows a number of lineaments with direction N120E that are crossing the Djibouti High and Adra Ridge, being the most evident the one corresponding to the Djibouti fault (figures 1 and 2). The main objectives of this study are a) to describe the seafloor morphology of the area, and b) characterize the active faults, their geometry and kinematics.

DATA AND METHODS

The exploration of offshore active faults needs the integration of different geophysical acoustic methods.
covering a wide range of resolution (Bartolome et al., 2012; Gracia et al., 2012; Martinez-Lorient et al., 2013). On one hand, swath-bathymetric maps depict the physiographic features of the seafloor and allow us to identify morphologic lineaments that could correspond to surface ruptures or escarpments of active faults. On the other hand, seismic profiles enable us to determine the geometry of the faults and the seismo-stratigraphic units displaced by each fault. Especially shallow very high resolution seismic profiles allow to find evidences for past seismic activity, paleoearthquakes (Barnes and Pondard, 2010; Brothers et al., 2009).

Bathymetric map used in this study has a 70m grid size and corresponds to a multibeam compilation including data from different resolutions, cruises and institutions (figures 1 and 2). High resolution multichannel seismic profiles (HR-MCS) were acquired during the IMPULS (2006) and EVENT-DEEP (2010) cruises (figure 2). These profiles have NE-SW to ENE-WSW orientation which is perpendicular to the main faults trends. Their acquisition window is 4 seconds, but the penetration is limited to 2s as the objective was to image the shallow section. These profiles are very suitable for this study as they allow interpreting key seismo-stratigraphic units. During the seismic survey in parallel, parametric sub bottom profiles were acquired. These profiles give a very high resolution seismic image up to 200 m of the sedimentary cover. The combined and integrated data set allow having a good control on the displacement and geometry of the faults form surface to subsurface evaluation.

FIRST RESULTS AND FUTURE PERSPECTIVES

The main morphological features observed in the bathymetric map of the study area (figures 1 and 2) are: a) the NE-SW highs corresponding to the Alboran and Adra ridges; b) the Alboran Channel an NE-SW elongated and narrow flat area, bounded by the previous ridges, that connects the West and the East Alboran basins; c) the extensive flat areas corresponding to the East Alboran Basin and the Djibouti High; d) the Almeria Channel and its fan; and e) three different lineament directions, NE-SW, NW-SSE and NW-SE.
The main NE-SW lineaments correspond to the Carboneras (Gràcia et al., 2006) and Alboran Ridge faults (Martinez-Garcia et al., 2011). The approximately NNW-SSE lineaments have been interpreted as a number of closely spaced, en-echelon transtensional short faults (Gràcia et al., 2012). Finally, the NW-SE lineaments are those corresponding to the Yusuf fault (Martinez-Garcia et al., 2011) and those crossing the Djibouti High and the Adra Ridge. These last lineaments show a length between 25 and 30 km and appear that are offsetting the Adra ridge in a right-lateral movement from hundreds of meters up to few kilometers. The most representative and evident of them is the Djibouti fault (Pérez-Belzuz, 1999).

The HR-MCS profiles across the Djibouti High and the Alboran Channel (dark yellow and orange in figure 2) show a succession of five seismo-stratigraphic units above the Messinian unconformity (5.3 Ma). These units are bounded by 4 regional reflectors that have been attributed, from bottom to top, to an intra Lower Pliocene discontinuity (4.57 Ma), to the top of the Lower Pliocene (3.6 Ma), to the top of the Upper Pliocene (2.58 Ma) and to the top of the lower Pleistocene (0.79 Ma) (Comas et al., 1999; Booth-Rea et al., 2007; Martinez-Garcia et al., 2013; Martinez-Garcia et al., 2011; Gràcia et al., 2012). These profiles also show that the NE-SW lineaments that go across the Djibouti High correspond to faults that are offsetting all the seismo-stratigraphic units above the Messinian unconformity. Moreover, the parametric sub bottom profiles display that these faults attain the shallower reflectors and, also, that some of them are reaching and offsetting the seafloor demonstrating their Upper Quaternary activity.
The future work will be focused in: a) calculating the lateral and vertical slip rates of the NE-SW fault lineaments, from measuring the lateral displacements observed on the slopes of the Adra Ridge and the vertical displacements of the seismo-stratigraphic units recognized in the HR-MCS profiles; and b) providing new data to review the structural relationship between the Djibouti, the Alboran Ridge and the Yusuf faults and, thus, the relations between different crustal domains (Comas et al., 1999; Booth-Rea et al., 2007).

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