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Using ultra-high resolution methodologies to imaging active submarine faults: The STRENGTH 2023 cruise in the Alboran sea

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Introduction

Great earthquakes and the possibility to generate destructive tsunamis are geohazards of key societal concern, as they may impact world economies, disturb submarine structures and affect coastal areas with the associated risk for local populations (Bilham, 2010). We still have in our mind catastrophic episodes, such as the giant events of the Sumatra earthquake and tsunami in 2004 in the Indian Ocean of magnitude (Mw) 8.7, and the Tohoku-Oki earthquake and tsunami in 2011 in the northwest of Japan, of magnitude (Mw) 9.0-9.1. Nevertheless, seismic events of moderate to large magnitude (Mw 6-7.3) in areas of low to moderate tectonic deformation, and with long recurrence intervals, such as the Alboran Sea in the Western Mediterranean, might also have a significant effect. Accordingly, during the last decades there has been an expansion of paleoseismology to marine areas, both on-fault and off-fault investigations (Pantosti et al., 2011; Perea et al., 2021a).

Even if paleoseismological analysis has been mainly applied to very active areas such as California and Cascadia margins (Goldfinger et al., 2012; Perea et al., 2021b) or New Zealand (Lamarche et al., 2006), areas of relatively slow tectonic deformation with faults capable of generating large-magnitude earthquakes (Mw > 6) with long recurrence intervals (> 1000 yr), such as the faults in the Alboran Sea, deserve special attention. During the last decade, a continuous effort has been made to adapt the paleoseismological approach to slow active faults offshore. However, even the most advanced hull-mounted or deep-towed marine geophysical instrumentation do not provide the same degree of observation detail and accuracy as the current paleoseismological techniques used onland, such as trenching. A way around this limitation is offered by the use of Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV). The use of this high-technology equipment is crucial to improve our knowledge about seismic and tsunami hazard.

The STRENGTH cruise consisted in a 38-day in situ investigation using state-of-the-art underwater vehicles and scientific equipment (AUV, ROV, ocean bottom seismometers, towed high-resolution side-scan sonar and high-resolution seismics) to survey the active seismogenic faults in the Alboran Sea (Al Idrissi Fault, Carboneras Fault and North-South Faults; Fig. 1), located at the SE Iberian and NE Moroccan margins. The main objective of the STRENGHT cruise was to acquire high- and ultra-high-resolution data to characterize in detail the 3D structure (i.e. seafloor and sub-seafloor) of the largest active fault systems in the Alboran Sea, to appraise the role of these systems, as potential seismic and tsunami generators, and to determine the crustal domains they bound. In order to achieve such a high degree of resolution we needed to use cutting-edge marine equipment that allow a metric resolution in surface mapping (geomorphic evidence) and at depth (stratigraphic evidence).

Geological Setting: The Eastern Alboran Sea

The Alboran Sea was formed during the Neogene by westward migration of the mountain front and late-orogenic crustal extension coeval with the plate-convergence between the African and Eurasian plates (Platt and Vissers, 1989; Comas et al., 1999; Booth-Rea et al., 2007). From the Late Miocene to Holocene, a contractive reorganization with the implantation of a NNW-SSE maximum horizontal shortening direction has been responsible for the present-day morphology of the basin (Martínez-García et al., 2017; Estrada et al., 2018; Perea et al., 2018; Gràcia et al., 2019).

Regional seismicity in the Ibero-Maghrebian region is diffuse and does not clearly delineate the present-day European-African plate boundary (Palano et al., 2015). Broadly, the area is characterized by continuous, shallow seismic events of low to moderate magnitude (Mw < 5.5) (Buforn et al., 1995; Stich et al., 2010). Even though a number of historical large earthquakes have occurred, such as the Torrevieja (1829, I=X), Vera (1518, I=IX) and Almería (1522, I=IX with possible submarine epicenter) earthquakes (Martínez Solares and Mezcua, 2002).

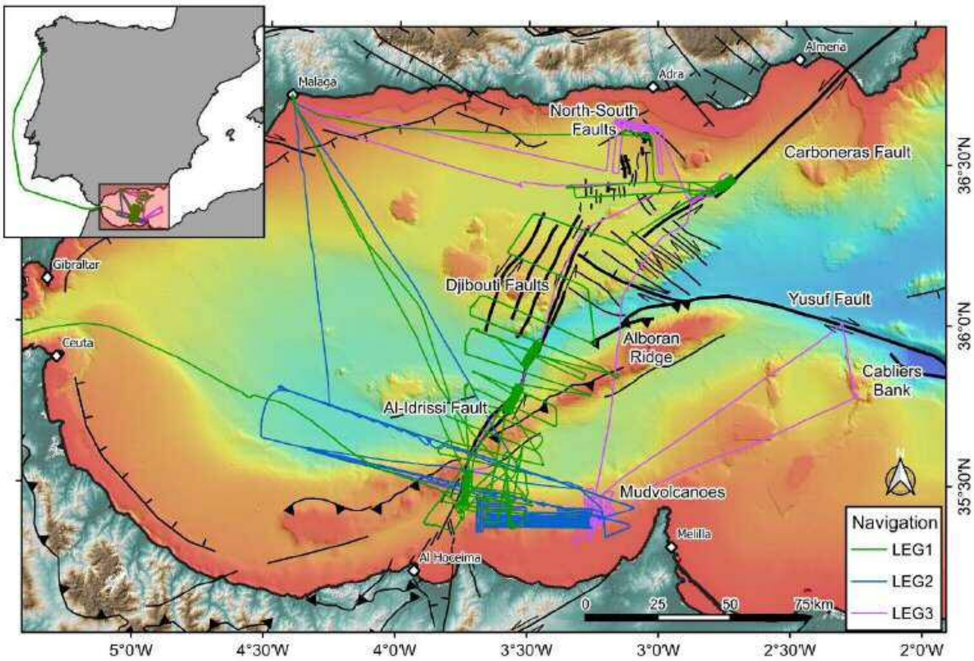

Figure 1. Map of Alboran Sea showing the main fault systems and the navigation carried out during the STRENGTH cruise.

The main fault systems in the Alboran Sea, the Carboneras, the Al Idrissi, the Yusuf and the Alboran Ridge Faults (Fig. 1), have been well characterized (i.e. geometry and kinematics, seismostratigraphy, seismic potential) during previous studies. The Carboneras fault is the southernmost fault system of the Eastern Betics Shear Zone (Fig. 1). It is a left-lateral strike-slip fault trending NE-SW. It has a length of about 150 km that includes a segment that runs on land and two segments that run at sea. In the offshore, the estimated slip rate for the Quaternary is about 1.3 mm/year (Moreno, 2011). The Al-Idrissi fault is located between the coasts of Morocco and the Djibouti plateau (Fig. 1). The fault is a left-lateral strike-slip fault system, that is composed of three segments, north, central and south, with an approximate direction NNE-SSW and 180 km long (Gràcia et al., 2019). Finally, the Yusuf and Alboran Ridge faults could be the largest structure located in the Alboran Sea with a length of about 230 km, going from the vicinity of the city of Oran in Algeria and crossing the Alboran Channel to intersect with the Djibouti Faults (Fig. 1). The Yusuf Fault is made up of two main segments that, in the area where they overlap, have generated the formation of a pull-apart basin (Perea et al., 2018; Gràcia et al., 2019; Gómez de la Peña et al., 2022). This is a right-hand strike-slip fault, but towards its western termination it arches and a reverse component becomes predominant. This zone with predominance of the inverse component corresponds to the northern termination of the inverse fault system of the Alboran Ridge thrust fault, the activity of which has caused the uplift of a NE-SW trending ridge. The slip rate of the Yusuf fault might range between 2.3 and 5.6 mm/year and for the Alboran Ridge between 1.8 and 3.0, for the last 5.3 Ma in both cases (Gómez de la Peña et al., 2022).

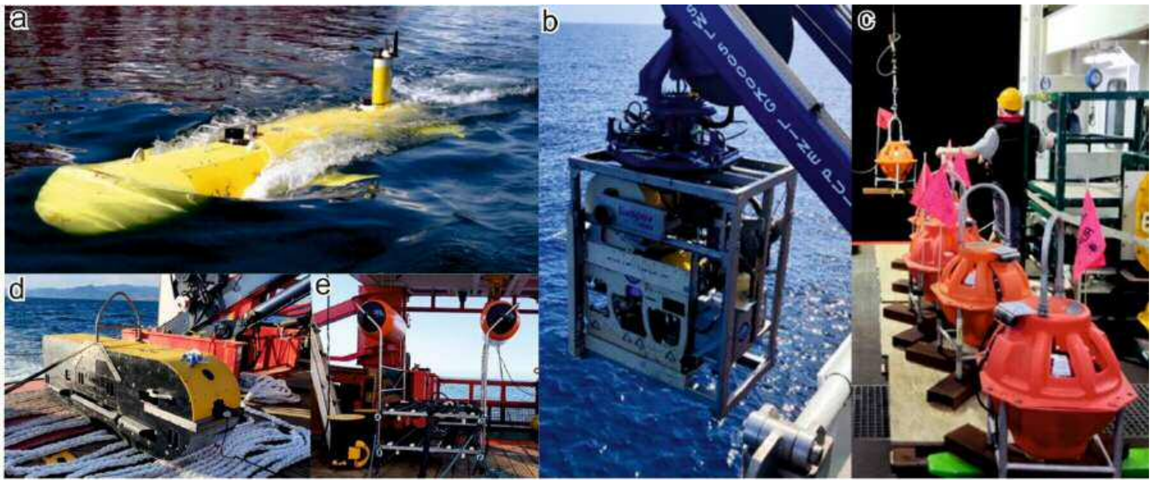

Figure 2. High-technological equipment used during the STRENGTH cruise. a) Autonomous Underwater Vehicle (AUV) AsterX (Ifremer, France); b) Remotely Operated Vehicles (ROV) Liropus (IEO, Spain); c) Ocean Bottom Seismometers (OBS) (Ifremer, France, and UTM, Spain); d) high-resolution side scan sonar DT-1 Edgetech (UTM, Spain); and e) high-resolution sparker seismic system (UTM, Spain).

The STRENGTH Cruise and Equipment

The STRENGTH cruise (Fig. 1) had allocated ship time onboard the Spanish RV Sarmiento de Gamboa to carry out an in situ marine active tectonics and paleoseismic investigation of active faults and its associated processes. The first part of the cruise (Leg 1: March 15 - April 1; 18 days) was devoted to acoustic seafloor investigation to acquire seafloor micro-bathymetry and high-resolution seismic reflection data searching for fault ruptures and on-fault/near-fault co-seismic seafloor deformation. To this we used the AUV "AsterX" (Fig. 2a) and a high-resolution sparker seismic system and digital multichannel streamer (Fig. 2e). The second part of the cruise (Leg 2: April 3 to 11, 9 days), was devoted to acquire wide-angle seismic data using ocean bottom seismometers or OBS (Fig. 2c) to determine crustal structures and domains in the southern Alboran Sea. The third and final part of the STRENGTH cruise (Leg 3: April 13 to 21, 9 days) aimed to have direct visual seafloor exploration (i.e. scarps related to earthquake ruptures) using the ROV "Liropus" (Fig. 2b) and acquire high-resolution side scan sonar data with the DT-1 Edgetech (Fig. 2d). The preliminary onboard processing and analyses of the acquired data show evidence of the Quaternary activity on the studied fault systems.

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