FAM-1 Borehole: first results from the scientific drilling of the Alhama de Murcia Fault, Betic Cordillera, Spain

Sondeo FAM-1: primeros resultados del sondeo de investigación de la Falla de Alhama de Murcia, Cordillera Bética, España

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Abstract: We present the preliminary results of the borehole FAM-1 a 175 m depth scientific drilling of the Alhama de Murcia fault. The borehole was drilled close to La Torrecilla rambla three km SW of Lorca where the fault zone shearing is more concentrated and it is dominated by well-developed clay rich fault gouge. To select the drilling point and to perform a prognosis of it, three trenches were excavated crossing the fault zone that allowed us to determine the detailed 3D structure of the fault zone. We have collected more than 100 m of unaltered high quality fault rock to be studied using mineralogical and microtectonic analysis, and geomechanical testing that will improve the knowledge of the influence of tectonic microfabric and mineralogy in the seismogenic behavior of the AMF. The borehole FAM-1 and the seismic monitoring borehole FamSis-1 constitute the first stage of a future geological-geophysical observatory for monitoring the activity of the AMF.

Key words: Betics, Alhama de Murcia fault, borehole, active fault, rheology.

Resumen: *Se presentan los resultados preliminares del sondeo de investigación FAM-1 de 175 m de profundidad en el que se ha perforado el tramo de fault gouge de la Falla de Alhama de Murcia (AMF) con mayor grado de exhumación. El sondeo se ha realizado en el sector de la rambla de La Torrecilla (3 km al SO de Lorca) donde la mayor parte del desplazamiento de la AMF se concentra en una única zona de cizalla de unos 130-150 m de espesor dominada por una fault gouge rica en arcillas. La cartografía y el registro de las trincheras realizadas para definir la prognosis del sondeo, y la información de éste han permitido determinar la estructura 3d de la zona de falla. Se ha podido extraer más de 100 m de roca de falla inalterada de muy alta calidad con el fin de ser utilizadas en análisis mineralógicos, microtectónicos y geomecánicos que permitirán mejorar el conocimiento de la influencia de la microfábrica tectónica y mineralógica en el comportamiento sismogénico de la AMF. El sondeo FAM-1 y el sondeo de monitorización sísmica FamSis-1 constituyen la primera fase de un futuro observatorio geológico-geofísico para el monitoreo de la actividad de la AMF.*

Palabras clave: *Falla de Alhama de Murcia, Beticas, falla activa, perforación científica, reología.*

INTRODUCTION

The damaging Lorca Mw 5.2 2011 earthquake was generated by the reactivation of a small section of the Alhama de Murcia Fault (AMF) located between the Lorca-Totana and Goñar-Lorca segments (Vissers and Meijninjer, 2011; Martínez-Díaz et al. 2012). The AMF is the source of Mw > 6.5 historical and pre-historical earthquakes. According to recent GPS data this fault accommodates ~1.5 ±0.5 mm/yr of the approximately 5 mm/year of convergence between Nubian and Eurasian plates (Echeverría et al., 2013). The AMF is part of the Eastern Betics Shear Zone and most of the largest damaging historical earthquakes are related with this structure (Massana et al., 2004) (Fig.1).

One of the aims of the InterGEO research project is the study of the tectonic fabric of exhumed fault gouges along the AMF to analyze rheological and geomechanical properties of the rocks involved in the fault movement at seismogenic depths to determine possible relations between the seismogenic behavior and the internal structure and mineralogy of the fault rocks. Previous works analyzing the frictional properties of the fault rocks of the AMF, performed mechanical experiments of samples obtained from surface outcrops (Niemeijer and Vissers, 2014). They suggest the spatial variation of the frictional properties along the AMF was an important factor controlling the nucleation and propagation of seismic slip during Lorca earthquake. However most of the experiments performed up to now on these materials are developed using crushed and remolded samples using altered rocks from surface. In order to investigate in detail the architecture of the fault zone and to collect unaltered core samples of fault gouge more suitable for mineralogical and microtectonic analysis we have performed a 175 m depth scientific drilling of the AMF fault zone. We selected the section of the fault where deformation is concentrated in a single fault zone. This area is located 3 km to the SW of Lorca, close to La Torrecilla rambla where the fault zone is dominated by well-developed clay rich fault gouge with a clear lithological banding. The excavation of several trenches before the drilling allowed us to determine a detailed structure of the fault zone. The borehole has provided core samples of fresh fault rock probably generated several kilometers deep near the hypocentral region of large earthquakes. In this work, we present the results obtained from the analysis of the local geology addressed to the borehole prognosis and the preliminary logging results.

FAM-1 BOREHOLE DRILLING

FAM-1 scientific drilling started on the up-thrown block of the fault, reaching a total depth of 174 m (Fig. 2). Wireline drilling and coring was chosen to favour good core recovery and hence establish a detailed stratigraphy. Lengths of core run were performed each 3?? m. Rock cores diameters were of 83 mm (PQ-3 size) during the first 120 m and of 61 mm (HQ-3 size) until the end of the borehole. Total core recovery was about 80 % (Fig.2). The fault gouge was reached at 64 m depth, getting more than 100 m of high quality fault rock core samples.

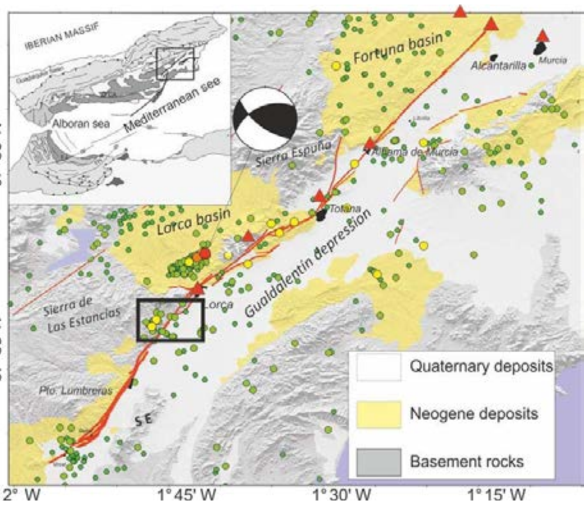

FIGURA 1. *Map of the Alhama de Murcia fault with the epicenters of the shallow seismic activity from 500 AD to 2012 (magnitude > 1.5). Triangles indicate damaging historical earthquakes. The focal mechanism of the 2011 Mw 5.2 Lorca earthquake (from López Comino et al. 2012) is showed. The black square points out the situation of the borehole FAM-1 (see figure 2).*

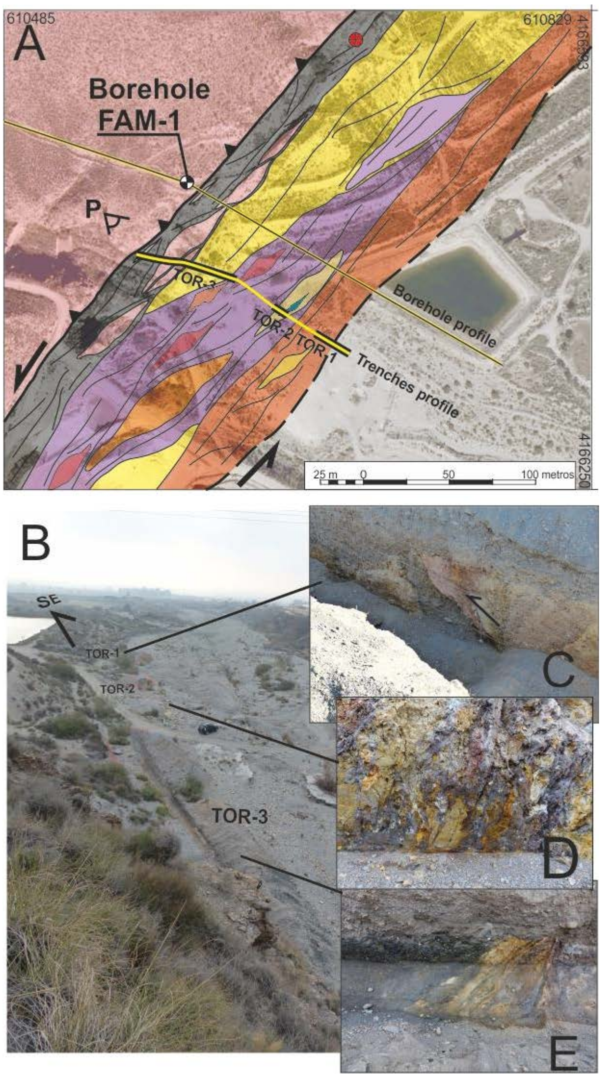

FIGURA 2. *Schematic map of the AMF fault zone close to La Torrecilla rambla. See legend of figure 4 for materials. Borehole FAM-1 and Borehole FAMsis-1 are showed with black and white and red circles.Se geological section of Fig. 4; B: General view of trenches Tor-1, 2 and 3 taken from point p on A; C: Detail of the overthrust of upper Miocene and older Quaternary on younger Quaternary terrace gravels. D: fault rock composed of Miocene marls and triasic phyllites showing a S-C fabric dipping NW (left); E: detail of the contact between the dark graphitic fault gouge and the block of protolith .*

Geological and geotechnical logging included the description of lithology and mineralogy, texture and fabric, type of discontinuities (relative dip, spacing) and weathering degree. In addition, the recovery rate was calculated, as well as the degree of fracturing by means of the Rock Quality Designation (RQD) and fracture frequency (number of fractures per meter). Some of the parameters are showed in Fig. 3.

27 rock core samples (18 encapsulated and 9 paraffined) were selected at different depths to analyse the microtectonic fabric and the geomechanical properties of the principal displacement zone of the fault, by means of geotechnical laboratory testing, micro-structural analysis, mineralogical analysis with

scanning electron microscopy, x-ray diffraction technique, etc.

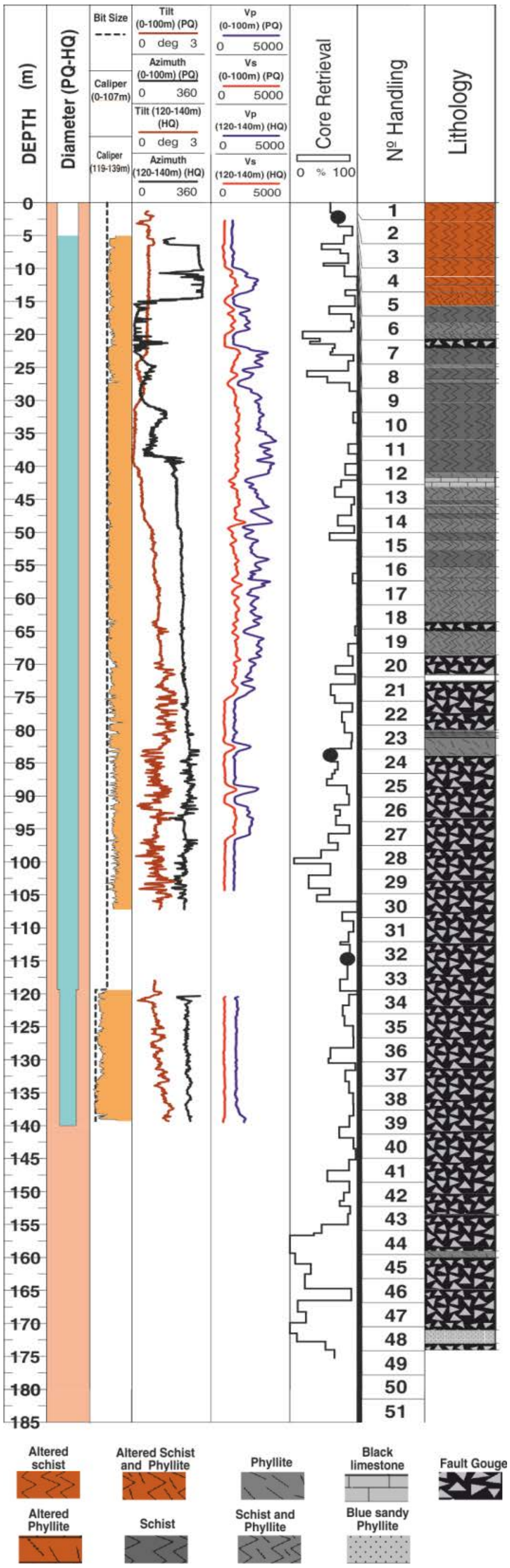

FIGURA 3. *Summary of some the parameters logged from the borehole. The right column shows the lithological column logged.*

A complete set of geophysical logs and oriented borehole televiewer images were acquired (Jurado et al., in this volume). Logging operations included the acquisition with borehole optical and acoustic televiewer, natural total and spectral gamma radiation, acoustic wave velocities, electrical resistivity and magnetic susceptibility as well as hydrochemical and temperature logs. These logs were run over selected intervals in order to characterize the in situ physical properties of the rocks and their variations with depth, and to define the structural setting and assess the present-day stress field. All the logs were run by the Instituto de Ciencias de la Tierra Jaume Almera (CSIC) Group and the data was analysed using WellCad software. The detailed borehole stratigraphy will allow us in the near future to correlate the geophysical logs with specific fault rock features. In addition to FAM-1 a second borehole will be drilled to install a permanent seismometer 50 m deep.

PRELIMINARY RESULTS AND CONCLUSIONS

The structure observed in the trenches (Fig.4) combined with detailed geological mapping and borehole geological logging indicate that the fault gouge that forms the principal displacement zone has a minimum width of 150 m.

The tectonic fabric of the fault gouge shows oblique-slip (sinistral-reverse) kinematics. From NW to SE in the trenches and from top to bottom in the borehole we observed: -a: several meters wide damage zone affecting paleozoic graphitic schists from the Alpujarride complex; -b: ~40 m of very dark clay-rich fault gouge containing graphite –c: a decimetric block of protolith (schist) that preserves its original internal structure, -d: ~60 m of a melange composed of blue-gray fault gouge formed by heterometric sigmoidal blocks of phyllite, with intercalated bluish gray-yellow miocene marls; -e: more than 20 m of orange Miocene sandstone with small sigmoidal blocks of yellow marls; -f: Quaternary alluvial limes and gravels an terrace deposits from the La Torrecilla rambla. All the materials involved in the fault zone, excepting quaternary deposits, show a penetrative S-C fabric with sigmoidal block whose sizes range from few cms to several meters. The alluvial deposits are affected by faulting probably related to one of several very recent surface rupture earthquakes. However, the dark fault gouge, located close to the range, is covered by undeformed Quaternary conglomerates. This supports that recent activity of the fault concentrates towards southeaster part of the fault zone, and the dark and clay-rich fault gouge represents the deeper fault rocks exhumed by the reverse component of movement and it is inactive in recent times. Recent vertical component of slip rate of ~0.1 mm/yr was calculated for the AMF in the Lorca-Totana segment from 3D paleoseismic data (Ferrater et al., 2016). This rate would explain a tectonic exhumation of at least 1 km since upper Miocene. The analysis of the internal structure of rock core samples shows that the S-C structure attitude is quite homogeneous, with a very constant dipping (70º NW) for the Y planes at depth.

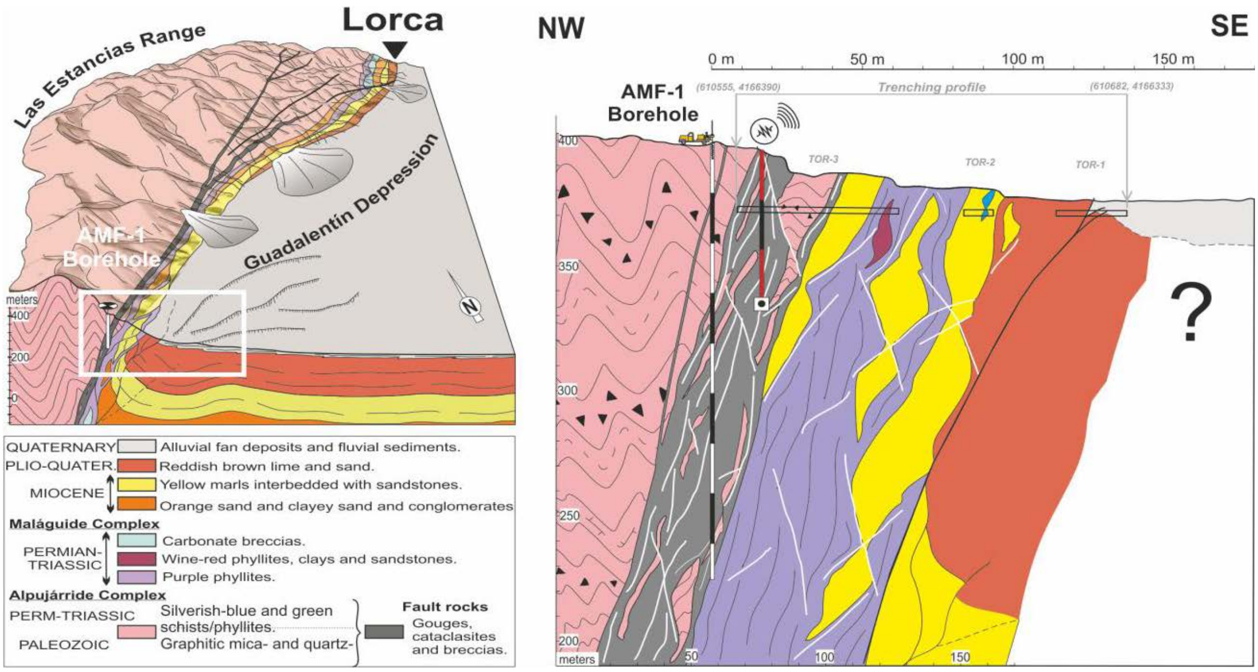

FIGURA 4. *Block diagram showing the local structure and the situation of the borehole. The geological section was done using the borehole logging and the information from the three trenches Tor1, 2, 3. The red borehole shows the position of the seismic monitoring borehole FamSis-1.*

The drilling of FAM-1 borehole provided more than 100 m of very high quality core samples of fault gouge that will be utilized in geomechanical tests, mineralogical analysis and microtectonic studies. The presence of different kinds of clays and graphite interbedded in the S-C fabric may be a key factor controlling the frictional properties of the fault.

The integration of the measurements and core sample observations, tests and analyses and testing will allow us to reach a better understanding on the seismogenic behavior of this slow fault. In particular, the effect of the tectonic fabric and the mineralogy on the fault strength and the evolution of the local fault zone architecture.

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