SMALL-SCALE FRACTURE CHARACTERIZATION IN THE GULF OF CADIZ

Sureje Lopes$^{(1,2)}$, M.C. Neves$^{(1,2)}$, A. Afilhado$^{(2,3)}$

$^{(1)}$ FCT, Universidade do Algarve, Ed 7, Campus de Gambelas, 8005-139 Faro, Portugal

$^{(2)}$ Instituto Dom Luís, Lattex-CGUL, FCUL, Campo Grande, Ed C6, Piso 2, 1749-016 Lisboa, Portugal

(3) ISEL - Instituto Superior de Engenharia de Lisboa, R. Conselheiro Emídio Navarro, 1, Portugal

Summary

The Gulf of Cadiz area has been intensively surveyed in the scope of numerous projects having a wide range of objectives, including seismic hazard assessment, understanding of tectonic and seismotectonic processes related to the Africa-Iberia plate boundary, studying the development of fluid escape structures, such as mud volcanoes and pockmarks, and so on. Seismic reflection profiles combined with detailed morpho-tectonic information collected from side-scan sonar images and multibeam bathymetry revealed the main structural trends and active faults. However, within any faulted area there are large numbers of faults that remain poorly resolved or undetected. In this study we propose to use geomechanical modeling to infer the positions and orientations of small-scale fractures that are often below the scale of seismic resolution. The modeling results may be used to improve the structural interpretations in the Gulf of Cadiz, help to find earthquake sources and establish the link between deep faulting and mud volcanism in the accretionary wedge.

Introduction

The Gulf of Cadiz experienced a complex geological history involving several processes (e.g. Gràcia et al., 2003): (1) extensional processes related to Pangea rifting and Atlantic opening which led to the creation of a passive margin in the western part of the Gulf; (2) convergence between the African and Eurasian plates that, since the Oligocene, dominates the structural and tectonic setting; and (3) the westward movement of the Alboran domain during the Miocene, responsible for the Betics and the Guadalquivir foreland basin, which caused the emplacement of allochthonous terrains. Diffuse brittle deformation is evidenced by widespread seismicity. The earthquakes have focal mechanism solutions consistent with predominant NNE–SSW striking thrusts and WNW–ESE trending strike-slip faults which are being reactivated under the present-day NW–SE direction of Africa-Eurasia plate convergence (e.g. Stich et al., 2006; Fernandes et al., 2007). The relation between large earthquakes and faults remains nonetheless unclear because the main faults are only imaged down to ~6 km beneath the seafloor in the seismic reflection profiles (e.g. Sartori et al., 1994; Zitellini et al., 2009) whereas most large earthquakes have focal depths between 10 and 40 km (e.g. Stich et al., 2006). Throughout the allochthonous unit there is vast evidence of carbonate mound formation including hydrocarbon-rich gas venting and mud diapirism (e.g. Pinheiro et al., 2005; Léon et al., 2009). Investigations of the active mud volcanoes showed that fluid expulsion and migration is primarily controlled by tectonic activity (e.g. Nuzzo et al., 2009; Medialdeia et al., 2009). A detailed characterization of the active faulting in the area is of great importance to unravel the sources of potentially large earthquakes and to explore the fluid migration pathways and their large-scale tectonic control. Three-dimensional numerical modelling of deformation based on continuum mechanics is here applied not only to check the consistency of faulted models but also to understand and quantify the spatial and temporal development of small-scale fractures.

Geomechanical modelling

The distribution of small-scale faults is determined by the regional tectonic stress and by the local perturbation of that stress state resulting from the nearby larger faults. In our modelling procedure the larger mapped faults are considered pre-existing structures and input to the models. The predicted fractures are assumed to form as the result of the interaction between the pre-existing structures and the regional tectonic field. Previous works have shown that under these assumptions an understanding of the timing of faulting is crucial for producing a good mechanical model (e.g. Maerten et al., 2006). The first step in the numerical modelling is therefore a carefully analysis of the timing of faulting to determine which faults developed in an earlier phase of the tectonic history.

To perform the model calculations we will use the Poly3D computer program, which is based of the analytical solution for the elastic boundary-value problem of an angular dislocation in a half space composed of homogeneous and isotropic linear-elastic material (Thomas, 1993; Crouch and Starfield, 1983; Becker, 1992). It has the advantage of modelling faults without the need to discretize the volume, produces faster simulations and will be used as a first approximation to predict the fault-induced perturbations of the elastic stress field. The development of the forward models involves the following steps (a) Build the 3D model geometry after recognition of the local structural scenario. The geometry includes the lithological layering and the known faults; (b) Specify material properties; (c) Impose remote loading and local boundary conditions; (d) Run the models to compute the stress and strain fields; (e) Perform sensitivity tests to fault timing, boundary conditions and material parameters; (f) Combine the results with a failure criterion to create maps of predicted fault strike and density. The modelled fault strike is computed using the Coulomb failure criterion. The maximum Coulomb shear stress is used as an index for fault density. The outcomes of this modelling may be used as constrains to stochastic simulations of fracture networks.

References

Becker, A.A., 1992. The boundary element method in engineering: New York. McGraw-Hill Book Company, 335 p.

Crouch, S.L., and Starfield, A.M., 1983. Boundary element methods in solid mechanics: With applications in rock mechanics and geological engineering: Winchester, Massachusetts, Allen and Unwin Ltc, 322 p.

Fernandes, R.M.S., Ambrosius, B.A.C., Noomen, R., Bastos, L., Wortel, M.J.R., Spakman, W., Govers, R., 2003. The relative motion between Africa and Eurasia as derived from ITRF2000 and GPS data, Geophys. Res. Lett., 30 (16), 1828p, doi:10.1029/2003GL017089.

Gràcia, E., Dañobeitia, J., Verges, J., Bartolome, R., 2003. Crustal architecture and tectonic evolution of the Gulf of Cadiz (SWIberian margin) at the convergence of the Eurasian and African plates, Tectonics, 22 (4), 1033p, doi:10.1029/2001TC901045.

León, R., Somoza, L., Giménez-Moreno, C.J., Dabrio, C.J., Ercilla, G., Praeg, D., Díaz-del-Río, V., Gómez-Delgado, M., 2009. A predictive numerical model for potential mapping of the gas hydrate stability zone in the Gulf of Cadiz, Marine and Petroleum Geology, 26, 1564-1579.

Maerten, L., Gillespie, P., Daniel, J.-M., 2006. Three-dimensional geomechanical modelling for constraint of subseismic fault simulation. American association of Petroleum Geologists Bulletin, 90 (9), 1337-1358.

Medialdea, T., Somoza, L., Pinheiro, L.M, Fernández-Puga, M.C., Vázquez, J.T., León, R., Ivanov, M.K., Magalhaes, V., Díaz-del-Río, V., Vegas, R., 2009. Tectonics and mud volcano development in the Gulf of Cádiz, Marine Geology, 261, 48–63.

Nuzzo, M., Hornibrook, E.R.C., Gill, F., Hensen, C., Pancost, R.D., Haeckel, M., Reitz, A., Scholz, F., Magalhães, V. H., Brückmann, W., Pinheiro, L.M., 2009. Origin of light volatile hydrocarbon gases in mud volcano fluids, Gulf of Cadiz — Evidence for multiple sources and transport mechanisms in active sedimentary wedges, Chemical Geology, 266, 350–363.

Pinheiro, L.M., Ivanov, M., Kenyon, N., Magalhães, V., Somoza, L., Gardner, J., Kopf, A., Rensbergen, P.V., Monteiro, J.H., Team, Euromargins-MVSEIS, 2005. Structural control of mud volcanism and hydrocarbon-rich fluid seepage in the gulf of Cadiz:

Recent results from the TTR-15 cruise, CIESM Research Workshop, Fluid Seepages/Mud Volcanoes in the Mediterranean and Adjacent Domains.

Sartori, R., Torelli, L., Zitellini, N., Peis, D., Lodolo, E., 1994. Eastern segment of the Azores–Gibraltar line (central–eastern Atlantic); an oceanic plate boundary with diffuse compressional deformation, Geology (Boulder), 22 (6), 555–558.

Stich, D., Serpelloni, E., Mancilla, F., Morales, J., 2006. Kinematics of the Iberia–Maghreb plate contact from seismic moment tensors and GPS observations, Tectonophysics, 426 (3–4), 295–317.

Thomas, A.L., 1993, Poly3D: A three-dimensional, polygonalelement, displacement discontinuity boundary element computer program with applications to fractures, faults, and cavities in the Earth's crust: M.S. dissertation, Stanford University, Stanford, California, 71 p.

Zitellini, N., Gràcia, E., Matias, L.M., Terrinha, P., Abreu, M.A., Alteriis, G.D., Henriet, J.-P., Dañobeitia, J., Masson, D.G., Mulder, T., Ramella, R., Somoza, L., Diez, S., 2009. The quest for the Africa–Eurasia plate boundaryWest of the Strait of Gibraltar, Earth and Planetary Science Letters, 280 (1–4), 13–50.