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New GPS constraints on active deformation along the Africa–Iberia plate boundary

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ABSTRACT

We use velocities from 65 continuous stations and 31 survey-mode GPS sites as well as kinematic modeling to investigate present day deformation along the Africa–Iberia plate boundary zone in the western Mediterranean region. The GPS velocity field shows southwestward motion of the central part of the Rif Mountains in northern Morocco with respect to Africa varying between 3.5 and 4.0 mm/yr, consistent with prior published results. Stations in the southwestern part of the Betic Mountains of southern Spain move west–southwest with respect to Eurasia (~2–3 mm/yr). The western component of Betics motion is consistent with partial transfer of Nubia–Eurasia plate motion into the southern Betics. The southward component of Betics motion with respect to Iberia is kinematically consistent with south to southwest motion of the Rif Mountains with respect to Africa. We use block modeling, constrained by mapped surface faults and seismicity to estimate the geometry and rates of strain accumulation on plate boundary structures. Our preferred plate boundary geometry includes one block between Iberia and Africa including the SW Betics, Alboran Sea, and central Rif. This geometry provides a good fit to the observed motions, suggesting a wide transpressive boundary in the westernmost Mediterranean, with deformation mainly accommodated by the Gloria–Azores fault system to the West and the Rif–Tell lineament to the East. Block boundaries encompass aspects of earlier interpretations suggesting three main deformation styles: (i) extension along the NE–SW trending Trans-Alboran shear zone, (ii) dextral strike-slip in the Betics corresponding to a well defined E–W seismic lineament, and (iii) right lateral strike-slip motion extending West to the Azores and right-lateral motion with compression extending East along the Algerian Tell. We interpret differential motion in the Rif–Alboran–Betic system to be driven both by surface processes related the Africa–Eurasia oblique convergence and sub-crustal dynamic processes associated with the long history of subduction of the Neotethys ocean lithosphere. The dextral slip identified in the Betic Mountains in Southern Spain may be related to the offshore fault that produced the Great 1755 Lisbon Earthquake, and as such may represent a significant seismic hazard for the West Mediterranean region.

1. Introduction

The African–Eurasian plate boundary in the most western part of the Mediterranean lies at the transition from the oceanic transform plate boundary to the west in the Atlantic to the continental plate boundary comprising the Iberia and Maghreb regions. The general tectonic framework of this region has been related to Eurasia–Africa convergence that began during the Cretaceous (Dewey et al., 1988). This convergence is juxtaposed with extension within the Alboran basin reflecting the complex deformation in this plate boundary zone (Jolivet and Faccenna, 2000; Platt and Vissers, 1989). Along the transition zone between Morocco and Spain, seismicity is broadly distributed over ~300 km (Fig. 1), where earthquakes are of moderate to low magnitude and mostly occur at shallow depths (0–40 km) (Buforn et al., 1995; Stich et al., 2003). Recent geophysical studies are providing much more detailed information on the crustal and subcrustal properties of the western Mediterranean, including seismic profiles (Simancas et al., 2003), seismic tomography (e.g.; (Blanco and Spakman, 1993); (Calvert et al., 2000); (Spakman and Wortel, 2004)), gravity modeling (Ayarza et al., 2005) and heat flow (Rimi et al.,

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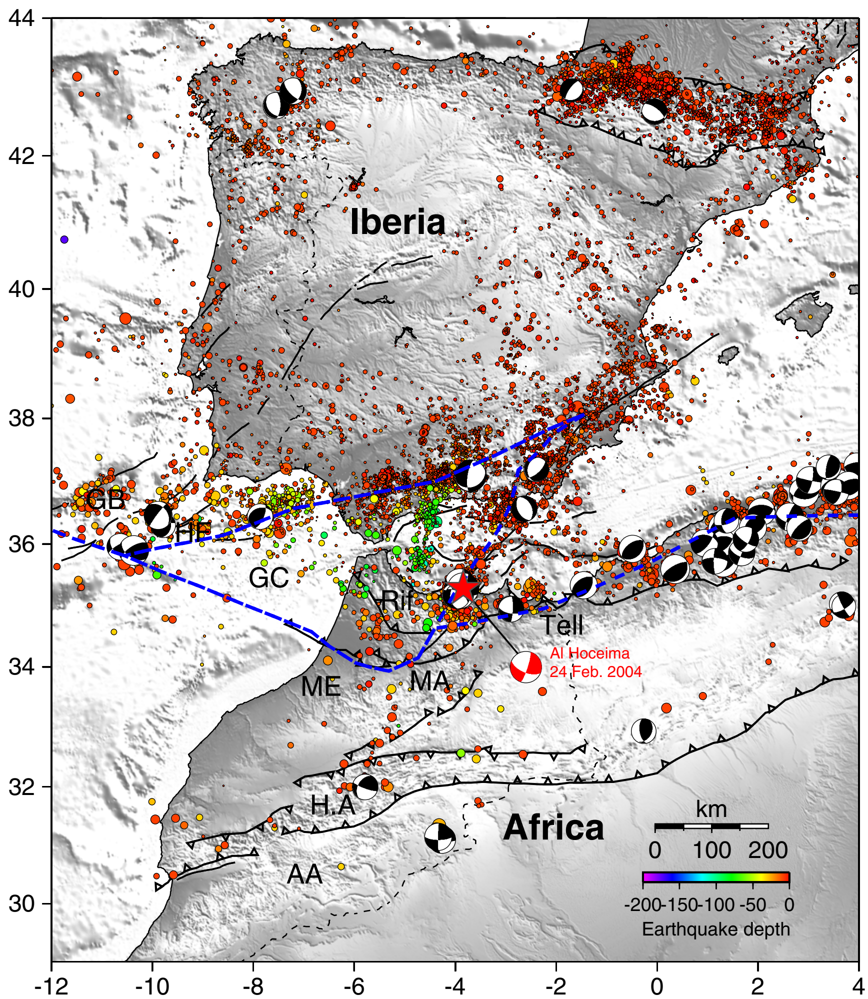

Fig. 1. General structural setting map: seismicity and major faults in the Iberian–Maghreb region. Faults in this figure as well as in the following figures are taken from Gomez et al. (2000); Serpelloni et al. (2007). Topography and bathymetry are from SRTM (http://topex.ucsd.edu/www_html/srtm30_plus.html). The blue line corresponds to the proposed kinematic model (see text for discussion). The seismicity is from NEIC catalog (http://earthquake.usgs.gov/earthquakes/eqarchives/epic/). Focal mechanisms are from Harvard CMT catalog (http://www.seismology.harvard.edu/CMTsearch.html). Abbreviations are: AA: Anti Atlas, HA: High Atlas, MA: Middle Atlas, GC: Golf of Cadiz, ME: Meseta, GB: Goringe Bank, HF: Horseshoe Fracture zone.

1998). Different models have been proposed to explain how the topographic symmetry around Gibraltar could develop coevally with extension of the Alboran Sea and shortening of the Betics and Rif mountains, including (i) convective removal of the upper mantle (Calvert et al., 2000; Platt and Vissers, 1989; Seber et al., 1996). (ii) breakoff of a subducting lithospheric slab ((Blanco and Spakman, 1993)), and (iii) backarc extension driven by the westward rollback of an eastward-subducting slab (Faccenna et al., 2004; Gutscher et al., 2002; Lonergan and White, 1997; Royden, 1993; Spakman and Wortel, 2004). Recent GPS data ((Fadil et al., 2006; Tahayt et al., 2008; Vernant et al., 2010)) emphasized the importance of dynamic processes below the crust for driving surface deformation, including delamination and southward rollback of the subducted African lithosphere beneath the Alboran/Rif domains (Perouse et al., 2010).

In this paper we combine the GPS data from surveys carried out in Morocco and from new continuous stations from Morocco and southern Spain to determine a new velocity field across the most western part of the Africa–Eurasia plate boundary. We present a kinematic model for the Rif–Alboran–Betic complex and western Mediterranean plate boundary zone using a block model that includes rigid block rotation and elastic strain accumulation on block boundaries (e.g. (McCaffrey, 2002; Meade and Hager, 2005)). The new model defines a single block including the southern Betics, western Alboran Sea, and the central Rif Mountains (BAR block) that is distinct from both Africa and Iberia. The northern boundary of the BAR block extends ~500 km roughly east–west across southern Spain and offshore across the Gulf of Cadiz with right-lateral strike slip of ~4 mm/yr. This structure may be associated with the fault that produced the Great 1755 Lisbon Earthquake, and as such may represent a potentially significant seismic hazard in this region.

2. GPS observations

We analyze data from 65 continuously recording GPS stations extending from Morocco to southern Spain (Fig. 2). The continuous GPS stations are part of the MIT network in Morocco, the Andalusia Positioning Network known as RAP (Red Andaluza de Posicionamiento), the Murcia Region Network, the Valencia region Red Errva Network, and some continuous stations from the IGS and EUREF networks that were included in order to determine velocities with respect to the stable Eurasian and Nubian plates. Campaign GPS data presented here are an extension of previous surveys (Fadil et al., 2006; Vernant et al., 2010), observed between 1999 and 2009. The GPS observations were processed with the GAMIT/GLOBK software suite (Herring et al., 2009; http://gpsg.mit.edu/simon/gtgk). We analyzed the GPS data using a three-step approach (McClusky et al., 2003). In the first step we used GPS phase observations for the western Mediterranean region to estimate daily positions using loose a priori