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Earthquake rupture directivity inferred from depth-dependent frictional properties

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The Alhamia de Murcia Fault (AMF) is a regional fault in the Betic Cordillera of SE Spain that forms part of a NE-SW trending belt of faults and thrusts. The AMF is at present a contractional fault with an oblique reverse sense of motion that generated a magnitude 5.1 earthquake in May, 2011, hitting the city of Lorca and causing over [U+FFFD] 1200 million damage. The hypocentre of the earthquake was initially estimated at ∼2-3 km NE of Lorca between 1-2 km depth but has since been re-located to a depth of about 4 km. Close to the city of Lorca and the epicentre of the earthquake, the AMF is spectacularly exposed, showing numerous fault gouges that anastomose around more competent relics of wall rock consisting of basement phyllite of the Betic crust.
Here, we report on friction experiments under in-situ conditions of stress, temperature and fluid pressure on crushed powders of outcrop samples of AMF wall rock and gouges. Simulated fault gouges were sheared both at room temperature and at elevated temperature under conditions simulating a lithostatic gradient of ∼30 MPa/km, a geothermal gradient of 35 ºC/km and hydrostatic pore pressure conditions (λ=0.33). The highest temperature and stress conditions used are representative of a depth of ∼ 6 km. We conducted velocity-stepping sequences to determine the rate and state parameter (a-b). A negative value for (a-b) indicates that samples have the potential for unstable, seismic slip.
Our results show that at room temperature the wall rock exhibits only positive values of (a-b) with a background coefficient of friction (μ) ∼of 0.7. The fault gouges show some negative (a-b) values, particularly at low stress and sliding velocity, with a background μ of 0.4-0.5. In contrast, at elevated temperature the wall rock samples exhibit negative (a-b) values, in some cases evidenced by unstable, stick-slip phenomena (“laboratory earthquakes”), whereas the gouges show positive values for (a-b).

Our results suggest that seismicity along the Alhamia de Murcia Fault can potentially nucleate at shallow depth in the phyllitic wall rock, whereas the fault gouges that are produced from the wall rock will tend to inhibit seismic slip. However, because of the weakness of the AMF gouges and the potential of rapid dynamic weakening in these, rupture propagation is likely to occur along along these. In addition, because (a-b)-values for gouges are lower at shallower depth, rupture propagation should be easier towards the surface as was indeed observed in the 2011 Lorca earthquake. The complex anastosmosing structure of the fault rocks as exposed near Lorca indicates that motion along this fault mostly likely involves aseismic creep of fault gouges, loading the intervening asperities of wall rock, until their strength is exceeded and these fail in a seismic event that propagates through the frictionally weaker gouges.