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Dyke Intrusion and Arrest in Harrat Lunayyir, western Saudi Arabia, in April-July 2009

Sigurjón Jónsson (1), John Pallister (2), Wendy McCausland (2), and Salah El-Hadidy (3)

(1) King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia (sigurjon.jonsson@kaust.edu.sa), (2) U.S. Geological Survey, Vancouver, USA, (3) Saudi Geological Survey, Jeddah, Saudi Arabia

Dyke intrusion in Harrat Lunayyir (also known as Harrat Al-Shaqah), one of the volcanic provinces in Saudi Arabia, caused numerous small to moderate-sized earthquakes and extensive surface faulting in April-July 2009. The most intensive earthquake activity took place on 17-20 May when six magnitude 4.6-5.7 earthquakes occurred, resulting in some structural damage and prompting the Saudi civil protection authorities to evacuate more than 30000 people from the area. While the earthquake activity significantly decreased after 20 May, it continued throughout June and July with a few earthquakes as large as magnitude $\sim$4, before quieting down in August.

Much of what we have learned about the activity comes from interferometric satellite radar (InSAR) observations and from analysis of the seismic data collected by a broadband seismic network that was installed soon after the earthquake swarm started in April. The InSAR data show that large-scale (40 km $\times$ 40 km) east-west extension of over 1 m took place as well as broad uplift amounting to over 40 cm. The center of the uplifted area was transected by northwest-trending graben subsidence of over 50 cm, bounded by a single fault to the southwest showing up to $\sim$1 m of faulting and by multiple smaller faults and cracks to the northeast.

The observed deformation is well explained with a near-vertical dyke intrusion and graben-bounding normal faulting. The strike of the model dyke is NNW-SSE, parallel to the Red Sea rift, and its volume is about 0.13 km^3. The modeling suggests that the shallowest part of the dyke reached within only 2 km of the surface, right below where the graben is the narrowest and under an area with a number of cinder cones from previous volcanic events.

The main graben-bounding surface fault, to the southwest of the dyke, grew from $\sim$3 km to $\sim$8 km with the magnitude 5.7 earthquake on 19 May. Soon after this event the overall earthquake activity dramatically declined. The faulting appears to have significantly changed the stress state in the shallow part of the crust, leading to an arrest of the dyke and thus preventing further vertical magma migration towards the surface. Crustal deformation continued after the main shock, with 25% of the total deformation taking place after 27 May, which shows that significant amount of magma was added to the dyke without further vertical magma migration.