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Estimating Tensile Rock Strength from InSAR Observations

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The strength of rock is usually estimated in the laboratory using cm-scale cylindrical samples of rock material that are free of fractures or other obvious defects. Bulk strength of rocks is significantly lower than laboratory estimates, due to imperfections in the rock mass at scales of meters and tens of meters. The problem is, however, that bulk rock strength is difficult to determine, because large rock samples cannot practically be brought in for laboratory testing and there are not many methods to determine large-scale rock strength. Here we show how Interferometric Synthetic Aperture Radar (InSAR) measurements of a recent dyke intrusion in western Saudi Arabia provide an unusual insight into tensional bulk strength of rocks.

The dyke intrusion occurred in a lava province called Harrat Lunayyir in western Saudi Arabia in April-July 2009 and caused a number of small to moderate-sized earthquakes along with extensive surface faulting. 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. InSAR data of the area 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 normal faulting and by multiple smaller faults and cracks to the northeast. The observed deformation is well explained with a near-vertical dyke intrusion with a volume of $\sim$0.1 km^3 and a NW-SE orientation, approximately parallel to the Red Sea. The modeling suggests that the shallowest part of the dyke reached within only 2 km of the surface, resulting in the extensive surface faulting.

We use ascending and descending Envisat interferograms and ascending ALOS data, along with Envisat and ALOS multiple aperture radar interferometry (MAI) to determine the 3D displacements of the surface caused by the intruding dyke. From the 3D displacements we generate strain maps that show a large amount of extension above the intrusion. The interferometric data of this arid region are almost perfectly correlated, such that lineations due to faulting and fractures can be accurately mapped by tracing abrupt phase discontinuities. The discontinuity map and the 3D displacement map confirm that up to 1 m of normal faulting occurred to the southwest of the dyke on a single fault, while in contrast, multiple fractures are seen to the northeast of the dyke, exhibiting limited amount of vertical throw. Field observations affirm that the discontinuities to the northeast are indeed tensional cracks with no significant vertical displacement.

Comparison of observed tensional strain with the occurrence of tensional fractures shows where tension exceeded the tensional strength limit of the surface rocks. Surface strain exceeded 0.2 millistrain in places, although this high amount of surface strain is clearly coincident with tensional fractures, implying that the surface bulk rock strength was exceeded. Assuming a shear modulus of 10 GPa of the surface rocks in the area, preliminary results show that the tensional bulk strength of the rock is close to 1 MPa, a value that is 5-10% of the strength that typically is estimated from small cm-scale intact rock samples of similar rock types in the laboratory.