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A reassessment of earthquake depths in the Zagros with observations from InSAR and local seismic data

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The Zagros mountains of Iran are one of the most seismically active fold-and-thrust belts in the world, with frequent reverse faulting earthquakes of Mw 5 – 6 and rare larger events of up to Mw ∼6.7. Earthquakes in the Zagros rarely rupture the surface, and there is a long-standing debate over whether faulting is restricted to the basement or also occurs within the thick (∼10 km) sedimentary cover. In addition, there is little consensus on whether the buried reverse faults control the growth of 'whaleback' anticlines that dominate the topography of the range, or whether faulting and folding are detached along weak layers in the sedimentary cover.

To address these problems we investigated some recent earthquakes in the south-eastern Zagros, at Qeshm Island (27 November 2005 and 10 September 2008) and Fin (25 March 2006). We used radar interferometry (InSAR) to map coseismic ground displacements for each earthquake, and modelled these data using elastic dislocation theory to determine the source parameters, including the geometry and the top and bottom depths of the causative faulting.

In each case, we found rupture was concentrated between a bottom depth of 8 – 10 km and a top depth of 3 – 5 km. These results confirm that Mw ∼6 earthquakes do occur within the folded sediments, probably within the thick 'competent group' of Paleozoic and Mesozoic conglomerates and platform carbonates that make up the lower part of the cover. Furthermore, patterns of coseismic uplift showed little correlation with the location of surface anticlines, implying that locally the two are decoupled.

We also measured the distribution of smaller aftershocks using data from local seismic networks. Most of these occurred within the crystalline basement, at depths of ∼10 km to ∼20 km, substantially and resolvably deeper than the main-shock faulting. This vertical separation indicates that the main earthquakes failed to rupture the full thickness of the seismogenic layer, and probably reflects the influence of the mechanically-weak Hormuz Salt Formation at the base of the cover, which may have formed a barrier to main-shock rupture propagation.

Using source dimensions estimated from earthquake-scaling relations, we argue that over the last 45 years only the Mw 6.7 Ghir (10 April 1972) and Khurgu (21 March 1977) earthquakes appear large enough to have ruptured the full (∼20 km) thickness of the seismogenic layer. These big events are associated with steeply asymmetric anticlines, which expose otherwise rare Paleozoic strata at the surface and across which significant changes in stratigraphic level and elevation are observed. By contrast, many smaller events (like those at Qeshm and Fin) occur beneath open detachment folds, on faults that are limited by detachment horizons such as the Hormuz Salt Formation. The Zagros fold-and-thrust belt therefore comprises a mixture of fault propagation and detachment folding.