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Fault reactivation in an extensional tectonic setting in central Apennines: evidence from the 1997 Umbria-Marche seismic sequence

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We present observations and numerical modelling results to discuss the architecture and the mechanical behaviour of a complex normal fault system in Central Apennines. The Umbria-Marche sector is characterized by a recent inversion of the tectonic stress field from compression to extension, resulting in a complex pattern of faults in this portion of the shallow crust (<10 km): Quaternary NW-trending normal faults are superimposed to the nearly NS thrust inherited from previous tectonics. Moderate magnitude ($5 < M < 6$) earthquakes rupture the normal faults dipping to the SW at 40˚- 50˚ and the seismicity rate of this region is one of the highest of the Apennines.

In September-October 1997 a sequence of six moderate magnitude earthquakes ruptured the SW dipping normal faults. We discuss the progressive activation of adjacent and nearby parallel faults of this complex normal fault system using earthquake locations and focal mechanisms of aftershocks and main shocks. The geometry of each segment is quite simple and consists of planar faults maintaining a constant dip angle through the entire seismogenic volume down to 8 km depth. We observe the activation of faults on the hanging wall and the absence of seismicity on the foot wall. The pre-existing thrusts inherited from previous tectonics intersect the active normal faults controlling the segmentation of the fault system and their maximum length. All the main shocks ($5 < Mw < 6$) and most of the aftershocks (70%) are associated with normal faulting. Late in the sequence a Mw 4.3 earthquake nucleated at shallow depth (1 Km) and ruptured a N10˚ right-lateral inherited structure with a left-lateral strike slip faulting. Numerous seismic events with similar left-lateral fault plane solutions have been located on two parallel N10˚ faults at very shallow depth (1 - 3 Km).

The comparison between geological observations and the seismological data reveals a consistent geometry for this strike slip fault, but opposite kinematics. We use both geological and seismological data to constrain fault geometry and we model stress transfer to study fault interaction and the reactivation of the strike slip faults. In particular, we have modelled Coulomb stress changes to investigate fault interaction among the normal fault segments and between normal and left-lateral strike-slip faults. Our modelling results reveal that normal faulting earthquakes enhanced the Coulomb stress onto the shallow portion of the N10° strike slip faults and promoted earthquakes with left-lateral faulting consistent with the stress perturbations. This is a clear example of fault reactivation with opposite slip direction. We also discuss the role of fluids in explaining the seismicity pattern as well as the triggering and migration of earthquakes during the sequence.