Structure of the 1999 Chi-Chi Earthquake Rupture and Interaction of Thrust Faults in the Active Fold Belt of Western Taiwan

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The 1999 Mw=7.6 Chi-Chi earthquake resulted from the reactivation of a major frontal thrust, the Chelungpu fault, within the Taiwan collision belt. In the northern segment of the earthquake surface breaks (referred to as the Shihkang-Shangchi Fault Zone), the surface ruptures turned clockwise to apart from the Chelungpu fault and produced a series of thrust-and-backthrust pop-up structures, about 15 km long in the ENE-WSW direction, forming several discontinuous subsegments. The bedding-parallel thrusting occurred on both sides (i.e., two limbs) of the regional synclinal structure of the Shihkang-Shangchi Fault Zone, whereas the thrust faulting cutting across the bedding planes developed in the central portion of the syncline. At several places, the pop-up structure developed on, and was inherited from, pre-existing local anticlines. Geological and morphological evidence shows that these gentle anticlinal folds seemingly started to develop recently in late Quaternary and have been reactivated during the last few earthquakes. We have proposed a kinematic model with a 3-D earthquake fault surface. We highlight the influence of both local and regional pre-existing structures on the development of the earthquake rupture, and hence the role of the structural inheritance. The striking northeast clockwise turn of the 1999 earthquake surface ruptures resulted not only from the 3-D geometry of regional lithology/structure, but probably also from an edge effect of the northward rupture propagation. This latter is related to the presence of a regional-scale NW-SE trending transfer fault zone to the north, as revealed by a local concentration of seismicity.

We find that one critical key feature of the Chelungpu fault is the stratigraphy-controlled slip surface: at the level of the uppermost few kilometers, the Chelungpu fault slip plane generally follows the bedding plane of the Pliocene Chinshui shale. The second key feature of the Chelungpu fault is the difference in structurally geometric configuration between its northern and southern segments. The northern Fengyuan segment shows a bedding-parallel thrust fault within east-dipping strata in both footwall and hanging wall. In contrast, the southern Tsaotun segment exhibits east-dipping strata are overthrust onto flat-lying recent alluvial deposits. These two features not only explain a hinterland imbricate thrusting on the hanging-wall of the Fengyuan segment, but also explain the change in strike of the Chi-Chi surface ruptures at the northern end. The southern end of the 1999 Chi-Chi rupture is interpreted to be linked to a series of NW-trending strike-slip faults. In particular, we propose that the Luliao strike-slip fault served as the lateral ramp of the Chelungpu fault, and the Gukeng strike-slip fault acted as a barrier to end the southern propagation of the 1999 rupture. Geomorphic features and paleoseismological data indicate that the range-front Chelungpu fault has generated large earthquakes during the last several thousand years. Alternatively, in the Miaoli area to the north and the Chiayi area to south, historical earthquakes as well as active geomorphic features are not restricted on the range-front thrust faults. Instead, more complicated structures, including tightly spaced folds, duplex structures, and strike-slip faults are involved in seismogenic processes. A more detailed investigation of regional structural characteristics is needed for mitigation against the seismic hazards in the 300-km-long active fold belt in western Taiwan, where several damaging large earthquakes have been documented during the last century.