Toward better fault hazard assessment: Lessons from the 2016 Kumamoto, Japan, earthquake

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The 16 April 2016 Mw=7.0 (Mjma=7.3) Kumamoto earthquake struck the city of Kumamoto, towns of Mashiki, Nishihara and Minami-Aso in central Kyushu, southwest Japan, and brought significant damage to buildings, killing 50 people. An ENE-trending ~31-km-long surface rupture emerged during the earthquake along the previously mapped Futagawa and northern Hinagu faults (Kumahara et al., 2016 JpGU abstract). The rupture zone also included a previously unknown 5-km-long fault within the Aso Caldera, one of the active volcanos in Kyushu island. The hypocenter is located ~5 km west from the junction of the Futagawa and Hinagu faults those strikes compose of a 25°-transpressional bend. The 14 April 2016 Mw=6.2 (Mjma=6.5) earthquake, claimed as a foreshock, was preceded on the Hinagu fault zone, 2.5 km south of the fault junction. From the viewpoints of fault displacement hazard assessment, we here present three key features as lessons learnt from the Kumamoto earthquake.

1) Unpredictable multiple scale en echelon step-overs and short conjugate faults

The rupture zone is mostly composed of right-lateral slip sections, with a maximum of 2.5 m coseismic slip. On a scale of 1:50,000 map, most of the rupture traces preoccupied the previously mapped faults that already display fault branching and multiple parallel traces, except the ones inside the Aso Caldera. However, observed surface breaks are much more complex than the inferred ones in large scale maps. A remarkable feature was left-stepping en echelon step-overs on various scales from meters to a few kilometers. The other significant characteristic is several short NW-trending left-lateral faults (up to ~300 m) as a conjugate fault to the primary right-lateral fault. These unpredictable features are probably due to the combination of thick unconsolidated volcanic sediments derived from the caldera and complex structure in and around the fault junction.

2) Coseismic slip partitioning

Another noteworthy feature observed in the field are ~10-km-long segmented normal fault scarps, dipping to the north-west, mostly along the previously mapped Idenokuchi fault (Research Group for Active Faults of Japan, 1991), 1.2 to 2.0 km south of and subparallel to the Futagawa fault. The maximum amount of coseismic throw on the Idenokuchi fault is ~2 m, which is nearly equivalent to the maximum slip on the strike-slip rupture. The locations and slip motions of the 2016 rupture also manifest as interferogram fringe offsets in InSAR images. Together with geodetic and seismic inversions of subsurface fault slip, we illustrate a schematic structural model where oblique motion occurred on a north-west-dipping subsurface fault and the slip is partitioned at the surface into strike-slip and normal fault scarps (Toda et al., 2016, Earth Planets, and Space). The Kumamoto case would be the second significant slip-partitioned earthquake around the globe.

3) Triggered slips on short peripheral faults

Multiple InSAR images for the Kumamoto earthquake consistently display more than 200 triggered fault slips as offsets of interferogram fringes around the primary rupture zone (e.g., Fujiwara et al. 2016, Earth Planets, and Space). While slips on most of them are smaller than a range of one interferogram fringe (~12 cm), significant multiple slips larger than 20 cm occurred in a part of the mountainous outer rim of the Aso caldera, ~15 km far away from the main rupture zone, without any significant aftershocks. We found a ~6-km-long NW-trending discontinuous minor breaks bisecting the urbanized area of Kumamoto (Goto et al., 2017, Earth Planets, and Space), which might have been related to local damage. The post-earthquake geomorphic investigation using vertically exaggerated anaglyph images suggests these fractures occurred on the pre-existing faint normal fault scarps.

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