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Fault segmentation, off-fault deformation, and fault maturity

Yann Klinger
Université Paris Cité, Institut de Physique du Globe de Paris - CNRS, Paris, France (klinger@ipgp.fr)

Large continental strike-slip earthquakes produce significant surface ruptures, tens to hundreds of kilometers long, with displacement that can reach several meters, depending on the magnitude of the earthquake. However, this information, and more specifically the detail of the surface ruptures has long been overlooked, as we missed efficient ways to document extensive ruptures. In the last decade, with the emergence of new remote sensing tools, our community came to realize that earthquake surface ruptures could bear significant information about fault structure and the way deformation is accommodated during earthquakes. Hence, through a systematic survey of surface ruptures, based on field observation and remote sensing data, we demonstrate that it is possible to define a fault segmentation that would not be arbitrary, but instead is related to some first-order characteristic of the brittle crust, the thickness of the brittle crust, also called the seismogenic thickness. This observation result has been tested and confirmed through a series of analogue and numerical experiments that allowed us to systematically study fault segmentation when varied the thickness of the brittle material. We also questioned the distribution of deformation along those fault segments during earthquakes, as the development of high-resolution image correlation technics gives us access to a more detailed picture of the ground deformation distribution around large strike-slip earthquake ruptures. More specifically, we have been able to show that in some places a significant part of the deformation is distributed off fault, up to 30%, accommodated by micro-cracks, or even in the bulk. This deformation is almost impossible to measure in the field and thus is not considered in classic models of earthquake source inversion. It might in fact be the reason why many models involve some shallow slip deficit, which is physically not understood, while it might only be an artefact of modeling. Eventually, the evolution through time of fault geometry and off-fault deformation is questioning the long-term evolution of fault geometry, a potential proxy for fault maturity. Here we show through analogue experiments that in fact, once a growing fault system has gone pass through a localization stage, where distributed deformation is drastically reduced, the fault system never simplifies further and keeps having some level of complexity associated with a steady amount of distributed deformation close to 20%, independently of the total amount of deformation accommodated by the fault system, suggesting that a fault system can probably be considered definitively mature almost immediately after its localization stage, for a small amount of total displacement.