Geophysical Research Abstracts
Vol. 20, EGU2018-2362, 2018
EGU General Assembly 2018

Postseismic deepening of the brittle-ductile transition zone depth

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For scientific reasons and in the context of hazard assessment it is important to better understand the physics and rupture characteristics of large, destructive earthquakes. One of those characteristics is an earthquakes average coseismic stress drop. It was observed and independently derived from elastic models that coseismic stress drop is independent of earthquake size and that fault slip should be proportional to the smallest rupture dimension (i.e. rupture length or width). Following this notion, fault slip is expected to seize growing once the earthquake saturates this smaller dimension. However, slip observations for many large strike-slip events (i.e. that saturate the seismogenic layer) show that fault slip continues to gradually increase with growing rupture length. If the rupture width of those events is indeed limited by the base of the seismogenic layer, these observations would imply larger stress drops and possibly other processes involved in large earthquake rupture. On the other hand, if the rupture width of large earthquakes is not limited by the base of the seismogenic layer but were allowed to extend beyond this depth, then the increasing slip may be explained without an increase in stress drop or additional rupture mechanisms for large earthquakes.

For the study we present here, we analyzed the temporal evolution of aftershock depth for a number of large earthquakes. These aftershocks show that rupture beyond the interseismic brittle ductile transition zone depth is possible and is a function of the size of main shock. For example, based on hypocenter depth of small earthquakes along the Landers fault (causing the 1992 M7.3 Landers earthquake), we identified the base of the seismogenic layer at 8-10 km. Aftershocks that occurred days after the Landers earthquake had maximum depths of approximately 18 km, suggesting that rupture of the main shock extended this far down and therefore went well below the inter-seismic base of the seismogenic layer. Maximum aftershock depth then decayed roughly logarithmically, reaching the previous value of 8-10 km after about 5.5 years.

We argue that these observations are a logical consequence of the visco-elastic rheology of crustal rocks: Coseismically highly increased strain rates elevate the crustal stiffness, temporarily lowering the base of the seismogenic layer and permitting initiation of slip instabilities at depths that are otherwise characterized by viscous behavior.