Geophysical Research Abstracts
Vol. 20, EGU2018-1435, 2018
EGU General Assembly 2018

Evidence for a 145-year-long aftershock sequence in central Washington State, USA

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Omori's law and rate-and-state models predict that aftershocks may persist for hundreds or even thousands of years in regions having low deformation rates. Perhaps the best-documented example of a long-lived aftershock sequence resulted from the Mw 7.5 1891 Nobi earthquake in Japan, where aftershocks persisted for more than 100 years. Here we present evidence for another long-lived aftershock sequence, located in central Washington State, USA. In this location, there is a well-defined ongoing and prolific seismicity cluster, near Entiat, located in the epicentral area of the December 14, 1872 earthquake, the largest historic crustal earthquake in Washington State. A fault scarp likely produced by the 1872 earthquake lies within the Entiat cluster, and the locations and areas of the cluster and the estimated 1872 slip plane are comparable in plan view. Seismic intensities and the 1 to 2 m of coseismic displacement suggest a magnitude range between 6.5 and 7.2 for the 1872 earthquake, whose location near Entiat is also supported by the concentration of ground failures and water effects there, as well as by reports of aftershocks being felt there for several years. Earthquakes in the Entiat cluster are shallow, between 3 and 8 km deep, and since the installation of the regional seismic network in 1976 have occurred at a constant rate of about 64 earthquakes per year. They exhibit predominately oblique thrust focal mechanisms consistent with N-S convergence in the region. To investigate whether earthquakes in the ongoing Entiat cluster might represent aftershocks, we calculated the numbers of aftershocks expected for a M6.5 to 7.0 earthquake for three different time intervals, each having different catalogs: for (1) the felt earthquakes during the first several hours following the 1872 earthquake, (2) the largest felt earthquakes between 1900 and 1974 thought to have the most complete catalog (having Modified Mercalli intensities of V and VI), and (3) the M$\geq$2.0 seismicity within the Entiat cluster from 1976 through 2016. We found that the number of observed earthquakes in the Entiat area for these time intervals are consistent with our aftershock modeling for these magnitude ranges. Thus, we conclude that the current seismicity in the Entiat cluster could represent aftershocks of the 1872 earthquake. The low deformation rates in the Entiat area determined from InSAR and GPS data, 2-3 nanostrain/yr or 0.2-0.3 mm/yr over a baseline of 100 km, make it unlikely that the earthquakes in the Entiat cluster result from ongoing tectonic deformation because seismicity clusters of comparable duration are not observed in other slowly deforming parts of Washington and Oregon. On the other hand, paleoseismic trenching of the fault scarp produced by the 1872 earthquake yielded evidence for two surface rupturing earthquakes since about 7700 years ago. This frequency is consistent with rate-and-state models suggesting that a $\geq$145-yr-long aftershock sequence would be expected for mainshock recurrence intervals of 1500 to 6000 years.