ERI Final Report

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The increasing pressure and temperature with increasing depth in the Earth should prevent earthquakes from occurring >50 km depth, yet they are observed occurring down to ∼700 km depth. At intermediate depths (50–350 km depth), the two most commonly invoked mechanisms to explain why the earthquakes occur are dehydration embrittlement and thermal shear instability. These two mechanisms have different implications for aftershock production — dehydration embrittlement would lead to aftershock patterns similar to those observed for shallow earthquakes whereas thermal shear instability would result in few aftershocks — so observing and quantifying the temporal decay of intermediate-depth aftershock sequences can help distinguish the causative source mechanism.

Japan's high earthquake activity, earthquake catalog with a low magnitude of completeness, and contrasting properties of the subducting Pacific and Philippine Sea Plates make it an excellent location to study intermediate-depth aftershock sequences and how different factors contribute to aftershock productivity. We analyze the 199 earthquakes in the JMA Unified Earthquake Catalog from 1985–2021 with $M_J \geq 5.7$ at 70–350 km depths (Figure 1) and are able to fit the modified Omori's Law to quantify the temporal decay for 21 of the aftershock sequences.

The aftershocks tend to be clustered around the mainshock, so an aftershock zone can be drawn that separates the aftershocks from the surrounding background seismicity. Earthquakes within this subjective aftershock zone are used to characterize the aftershock sequences. As an example, Figure 2 shows the aftershock sequence for the 15 January 1993 earthquake (M_J 7.5, 101 km depth) beneath Hokkaido with the modeled temporal decay for the sequence. Based on 31 years of earthquakes, the temporal decay has $p = 0.93$, $K = 28$, $c = 0.07$ days, $\mu = 0.0147$ earthquakes/day, and a duration of 9.3 years.

In comparison with shallow aftershock sequences, the characterized aftershock sequences have a similar temporal decay exponent $p \approx 1$ but much lower productivity. Preliminary results suggest that productivity is higher in the Pacific Plate than in the Philippine Sea Plate, in the upper plane of the double seismic zone than in the lower plane, and for shallower earthquakes. The characterized sequences last from ∼40 days to >30 years. The observations of characterized sequences are closer to our expectations for dehydration embrittlement than thermal runaway. Variations in productivity may relate to the amount of fluid available

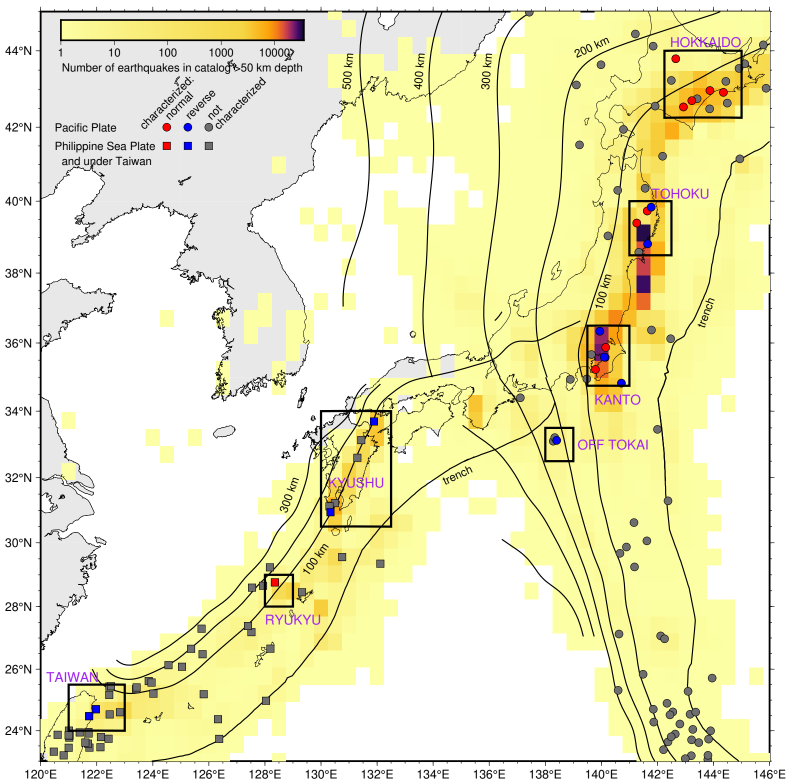

Figure 1: Map of the study area and analyzed earthquakes. Gray symbols are for all analyzed earthquakes and red and blue colors are for earthquakes with characterized aftershock sequences. Circles indicate earthquakes in the Pacific Plate whereas squares indicate earthquakes in the Philippine Sea Plate and under Taiwan. The background color is the number of earthquakes in the catalog. Slab2 contours are plotted every 100 km in depth.

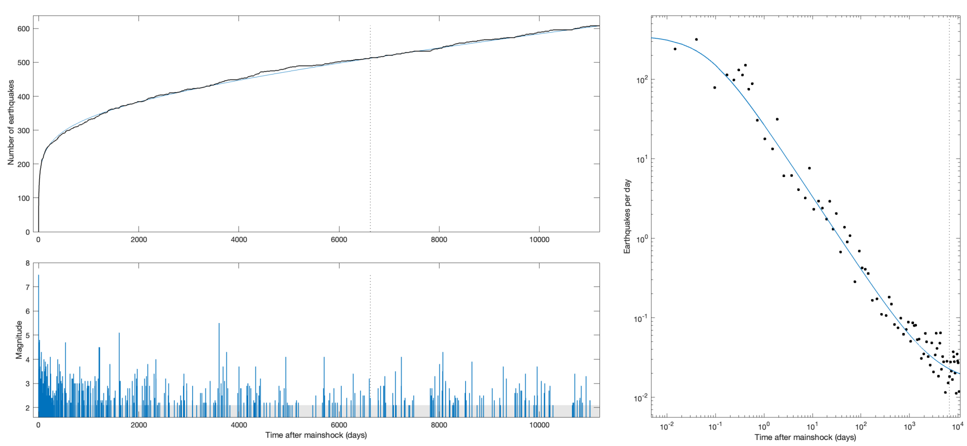

Figure 2: Observed aftershock sequence and modeled decay for the 15 January 1993 earthquake beneath Hokkaido. (top, left) The cumulative number of aftershocks observed (black) and for the best-fitting Omori decay model (blue). (bottom, left) Earthquakes within the aftershock zone plotted as vertical lines with height corresponding to the earthquake magnitude. (right) The aftershock temporal decay observed (black dots) and modeled (blue line). On all subplots, the vertical dotted lines indicates the time of the 2011 Tohoku earthquake.