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Variable Slip-Rate and Slip-Per-Event on a plate-boundary fault

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Understanding the irregular occurrence of large and damaging earthquakes in space and time on plate boundary faults is a longstanding critical problem in earthquake research. Simple elastic loading models predict fairly regular recurrence of slip events but most long earthquake records exhibit substantial variability in the timing of past surface ruptures. One problem is that most long paleoseismic records have been developed on only a few faults, so additional examples are required to better understand the variability of earthquake recurrence in time and space. We examine the Jordan Gorge (JG) segment of the Dead Sea Transform (DST) fault as a case study for plate-boundary transform faults. The JG fault is a relatively unique structure along the DST, as the plate boundary is fairly simple to the south in the Jordan and Arava Valleys, but is complex and multi-stranded to the north in Lebanon. Seven fault-crossing buried paleo-channels, laterally offset by the DST, were investigated using paleoseismic and geophysical methods. We resolved displacement on buried stream channels that record the past 3400 years of slip history for the JG fault segment.

The ~20 km long JG segment appears to be more active (in term of number of earthquakes) than its neighboring segments to the south and north. Based on three-dimensional trenching, slip in the past millennium amounts to only 2.7 m, similar to that determined in previous studies, whereas the previous millennium experienced two to three times this amount of displacement with nearly 8 m of cumulative slip, indicating substantial short term variations in slip rate. The slip rate averaged over the past 3400 years, as determined from 3D trenching, is 4.1 mm/yr, which agrees well with geodetic estimates of strain accumulation, as well as with longer-term geologic slip rate estimates. Paleoseismic data on both timing and displacement indicate a high COV >1 (clustered) with displacement per event varying by about a factor of four. The rate of earthquake production does not produce a time predictable pattern over a period of 2 kyr. We postulate that the seismic behavior of the JG fault is influenced by stress interactions with its neighboring faults to the north and south. Our results indicate that: 1) the past 1200 years appear to significantly lack slip, which may portend a significant increase in future seismic activity; 2) short-term slip rates for the past two millennia have varied by more than a factor of two and suggest that past behavior is best characterized by clustering of earthquakes. From these observations, the earthquake behavior of the Jordan Gorge fault best fits is a “weak segment model” where the relatively short fault section bounded by releasing steps, fails on its own in moderate earthquakes, or ruptures with adjacent segments.

We conclude that deriving on-fault slip-rates and earthquake recurrence patterns from a single site and/or over a short time period can produce misleading results. The definition of an adequately long time period to resolve slip-rate is a question that needs to be addressed and requires further work.