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Miocene to present deformation rates in the Yakima Fold Province and implications for earthquake hazards in central Washington State, USA

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The Yakima fold province (YFP), located in the Cascadia backarc of central Washington, is a region of active distributed deformation that accommodates NNE-SSW shortening. Geodetic data show modern strain accumulation of $\sim$2 mm/yr across this large-scale fold province. Deformation rates on individual structures, however, are difficult to assess from GPS data given low strain rates and the relatively short time period of geodetic observation. Geomorphic and geologic records, on the other hand, span sufficient time to investigate deformation rates on the folds. Resolving fault geometries and slip rates of the YFP is imperative to seismic hazard assessment for nearby infrastructure, including a large nuclear waste facility and hydroelectric dams along the Columbia and Yakima Rivers.

We present new results on the timing and magnitude of deformation across several Yakima folds, including the Manastash Ridge, Umtanum Ridge, and Saddle Mountains anticlines. We constructed several line-balanced cross sections across the folds to calculated the magnitude of total shortening since Miocene time. To further constrain our structural models, we include forward-modeling of magnetic and gravity anomaly data. We estimate total shortening between 1.0 and 2.4 km across individual folds, decreasing eastward, consistent with geodetically and geologically measured clockwise rotation. Importantly, we find that thrust faults reactivate and invert normal faults in the basement, and do not appear to sole into a common décollement at shallow to mid-crustal depth.

We constrain spatial and temporal variability in deformation rates along the Saddle Mountains, Manastash Ridge and Umtanum Ridge anticlines using geomorphic and stratigraphic markers of topographic evolution. From stratigraphy and geochronology of growth strata along the Saddle Mountains we find that the rate of deformation has increased up to six-fold since late Miocene time. To constrain deformation rates along other Yakima folds, which lack syntectonic growth strata, we exploit 2-m LiDAR data and invert stream profiles to analytically solve for a linear solution to relative uplift rate. From stream profile inversion, we see an increase in incision rates in Pliocene time and suggest that this increased rate is tectonically controlled. Our analyses indicate that deformation rates along the Manastash and Umtanum Ridge anticlines are significantly higher than along the Saddle Mountains. We use our new estimates of slip rates along individual anticlines to calculate the time required to accumulate enough strain energy for a large magnitude earthquake ($M \geq 7$) along faults within the YFP. Our results indicate that it takes between several hundred to several thousand years to accumulate sufficient strain energy for a $M \geq 7$ earthquake, with the greatest hazard posed by the Umtanum Ridge anticline.