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Temporal slip rate variability in the Lower Rhine Embayment, Northwest Europe

Ryan Gold, Simon Kuebler, and Anke Friedrich

Low strain regions may be characterized by long periods of seismic quiescence, punctuated by periods of clustered earthquake activity. This type of non-periodic recurrence behavior challenges accurate seismic hazard analysis. The Lower Rhine Embayment in the German-Belgium-Netherland border region presents a unique opportunity to characterize the long-term record of faulting to evaluate the periodicity of earthquake occurrence in a low strain region. The Lower Rhine Embayment is covered by a high-resolution record of Quaternary terraces associated with the Rhine and Maas (Meuse) Rivers and their tributaries. These terraces are cut by numerous NW-trending faults and record cumulative displacements that exceed 100 m in numerous locations. In this study, we exploit this rich record of faulted fluvial terraces and find convincing evidence for temporally varying rates of Quaternary fault movement across the Lower Rhine Embayment. First, we document a significant increase in vertical fault slip rates since 700 ka, compared to the average slip rate since the start of the Quaternary using the top and base of the Main Terrace, respectively. Increases in slip rate exceed 500% along many of the faults, including the Swist/Erft, Stockheim, Viersen, Sandgewand, and Kirspenich fault systems. This increase in fault slip rate corresponds to a regional period of increased tectonic uplift of the Rhenish Massif, increased volcanism in Eifel, and incision of the Rhine River. In a second and related analysis, we synthesize terrace offset and age information from the Feldbiss fault system along the western boundary of the Lower Rhine Embayment, which transects a flight of Quaternary terraces associated with the Mass river. This analysis reveals evidence for secular variation in slip rate. In particular, we identify two periods of higher slip rate (800-400 ka and 130-100 ka), where fault slip rate exceeds the longer-term average slip rate of 0.04-0.05 mm/yr by as much as a factor of two. These results show that in the Lower Rhine Embayment low-strain region, the tempo of strain release (and therefore earthquakes) is non-steady. This variable slip behavior should be incorporated into future efforts to characterize seismic hazard across the region.