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Paleoseismology using bedrock fault planes

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Coseismic slip on bedrock fault planes was recently observed on several faults, for instance during the 2016 Apennine earthquake sequence (24.08.2016 Mw 6.0, 26.10.2016 Mw 5.9, 30.10.2016 Mw 6.5) and the 1981 Alkyonides earthquake sequence (24.02.1981 Mw 6.7, 24.02.1981 Mw 6.4, 04.03.1981 Mw 6.3). These earthquakes resulted in the exhumation of the fault planes by several decimeters, which can be easily identified by differences in color and roughness properties (e.g. Stewart, 1996; Wiatr et al., 2015; Baize, 2017).

This study uses different weathering indicators to reveal distinct stripes that are related to past exhumation events on limestone fault planes in Greece and Montenegro. For instance, the central part of the 25-km-long Pisia fault (eastern Gulf of Corinth) shows a clear stripe of contrasting color whose height is in accordance with the reported exhumation of ∼0.6-1.5 m during the 1981 Alkyonides earthquake sequence (Jackson et al., 1982). Above this stripe, we observed five to seven additional stripes of 25-100 cm height. They were detected by color changes, lichen colonization, karst features (pitting and solution flute termination), and by terrestrial laser scanning data analyses of both, near-infrared backscatter signal intensity and high precision surface roughness. These criteria revealed similar horizontal stripes on the fault planes of the ∼11-km-long Lastros fault (Crete), the ∼18-km-long Spili fault (Crete), and the ∼10-km-long Bar fault (Montenegro). For all three faults, up to three stripes were identified that indicate fault plane exhumations in the range of 10-40 cm.

The stripes are interpreted as indicators of coseismic slip events that stepwise exhumed the respective fault planes. Our observations are restricted to sites with negligible soil erosion and deposition, and without sliding events. A continuous mapping of distinct coseismic exhumation steps along the strike of the fault, allows an estimate of the paleoearthquake magnitudes using empiric correlations.

The timing of earthquake exhumation can be constrained using cosmogenic Cl-36 concentration modeling (Schlagenhauf et al., 2010; Cowie et al., 2017). In the case of the Pisia fault, paleoearthquake ages of ∼2.0 kyr (EQ2), ∼3.1 kyr (EQ3), ∼4.3-4.5 kyr (EQ4/4a,b), ∼6.0 kyr (EQ5), and ∼6.8-7.3 kyr (EQ6,6a,b) are obtained. These ages correspond to a slip rate of 0.5-0.6 mm/yr during the mid-late Holocene. The age uncertainties are ∼±0.7 kyr, which is in the same range as age uncertainties in traditional paleoseismic trenches. Hence, we suggest considering bedrock fault plane observations as a valuable option to reconstruct the Holocene seismic history.