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Recent coseismic deformation recorded in near-surface sediments along active faults: Some examples from paleoseismic trenching in Belgium

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Since 1996, the Royal Observatory of Belgium is conducting paleoseismic research on the border faults of the Roer Valley graben (RVG), one of the seismically most active areas in intraplate NW Europe. Paleoseismology is the study of past large earthquakes capable of leaving a signature at the Earth's surface. The main objective is to identify individual paleoearthquakes, to estimate their size from their offset and/or rupture length, and to determine their timing. The fault that has been best studied so far is the Geleen fault, which is part of the Feldbiss fault zone, the SW border fault of the RVG. It extends NW-SE over a distance of ~30km between Bree (B) and Geleen (NL). The Geleen fault intersects Maas River terraces of different age, which is reflected in varying vertical topographic offset: on the Middle Pleistocene Main Terrace, the fault is expressed by a ~20 m high scarp, the Bree fault scarp, whereas on the Late Weichselian Maasmechelen terrace covering a large part of the Belgian Maas River valley, the relief is reduced to 1 m maximum. In the latter area, we mapped the surface trace of the Geleen fault using electric-resistivity tomography and georadar. We thus discovered a ~500 m wide stepover and a ~2 km wide bend with a more northerly strike. As the dimension of this stepover is generally considered to be too low to constitute a segment boundary, the Geleen fault likely defines a single fault segment that could rupture in one earthquake. Terrace offsets indicate a long-term slip rate of ~0.06 mm/yr.

A total of eight paleoseismic trenches have been excavated across the Geleen fault, all of them revealing well-defined, near-vertical faults extending upward to just below the plough layer. In most cases, the fault zone is very narrow, consisting of a few fault strands. Fault strands are sharp in sand, but in gravel deformation is more distributed, showing a clear shear fabric. Commonly, fault strands have a bleached aspect down to a few m depth, which can be attributed to eluviation; fine particles including Fe and Mn are transported downward and redeposited near the water table, where the fault zone has a stained aspect. Individual paleoearthquakes can be identified in the stratigraphy by identifying the event horizon, this is the ground surface at the time of the earthquake. Layers below the event horizon have been faulted in the event, whereas layers above were deposited after the event. Primary, on-fault evidence for an event horizon typically consists of one or more of the following features: upward termination of fault strands and fissures, colluvial wedges resulting from degradation of a fault scarp, angular fault-zone unconformities produced by folding and tilting, stepwise downward increase in offset, buried soils, etc. Secondary evidence, produced by seismic shaking, both near the fault and in the far field, can be provided by liquefaction and fluidization features and other soft-sediment deformation features. By dating the deposits below and above an event horizon, we can obtain an age bracket for the event.

Almost all of the above-mentioned deformational features have been recognized in the trenches across the Geleen fault. Due to soil development and bioturbation down to 1 m depth, it is typically difficult to macroscopically identify the most recent event horizon. However, using thin sections we were able to confirm that a faintly visible horizon in two trenches near Rotem in the Maas River valley indeed corresponds to a paleoearthquake event horizon, by demonstrating the presence of an in situ soil below and colluvium with elements derived from this soil above. In one of these trenches, we could date the most recent paleoearthquake between 2.5 ± 0.3 and 3.1 ± 0.3 kyr. BP (OSL), and between 2790 ± 20 and 3770 ± 50 calibrated years before AD 2005 (radiocarbon). The time interval between the two most recent events has a range of 11,800 – 16,800 yr (2σ). In a trench across the Bree fault scarp in an interfluvial setting, we obtained a longer history of faulting. We could identify six paleoearthquakes, five of which occurred since ~125 kyr. The two most recent events are evidenced by downward stepwise increasing offset, the four older events by colluvial wedges that apparently formed in periglacial conditions.

In almost all trenches we observed one or more types of soft-sediment deformation. The most prominent features can be attributed to liquefaction of sand, and associated fluidization or water escape. Liquefaction is commonly caused by earthquakes due to cyclic loading by shear waves. If a low-permeability cap is present above a liquefied sand layer, the water expelled from the liquefied zone can create sand blows, these are intrusions of fluidized sand into the overlying cap through feeder dikes (fractures created by hydraulic fracturing or lateral spreading). Sand blows are widely regarded as the type of soft-sediment deformation that is most indicative of seismic shaking. In the investigated area, it appears that the Late Glacial coversands that lie atop the fluvial terraces are very susceptible to liquefaction. In one trench, we identified unequivocal sand blows intersecting a soil profile, the top of which can be correlated with an event horizon in the fault zone. In a second trench, we even observed a gravel dike rising ~0.9 m from the otherwise horizontal top of the Maasmechelen terrace. In a third trench, we observed small-scale intrusions of sand laminae into silt laminae. In trenches situated on relatively steeper slopes, we observed several other features that can be attributed to deformation of a liquefied sand layer under the influence of gravity. These features include: folding due to a combination of downward flow and differential settling, small-scale intraformational upslope-dipping faults accommodating downslope flow of a liquefied sand layer, and a detachment slide with harmonica-like folding of sand and pebble horizons at its toe. Although it is not always possible to exclude an alternative origin, it is not likely that these features represent cryogenic deformation, which was common when periglacial conditions existed in the region. Collectively, the abundant features of soft-sediment deformation corroborate the coseismic nature of faulting in the RVG.