How to investigate Late Quaternary to present activity of seismogenic faults ?

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One of the key questions in the field of quantitative active tectonics concerns the seismic behavior of active faults: how are large earthquakes (M > 6.5) distributed over time? Do they occur in quasi-periodic cycles (i.e. constant fault slip rate over time) or as clusters followed by periods of quiescence (i.e. temporal variations in fault slip rate)? We may investigate this question through two approaches: paleo-seismology and slip rate determination at different time scales. This talk illustrates examples from the left-lateral Dead Sea Fault, which is the plate boundary between Arabia and Africa, and the fold-and-thrust belt of Taiwan.

Paleo-seismology consists in digging a trench perpendicular to the active trace of a fault, at a location where the co-seismic paleo-surface ruptures are likely to be preserved thanks to burial under fine sediments. The earthquake sequence can be observed on the trench walls from the deformed stratigraphy; each event is bracketed by the deposition age of the layers above and below the "event horizon". I show an example from the Dead Sea Fault in Lebanon, where I identified a total of 10 paleo-earthquakes. Due to the dearth of organic matter datable by ^{14}C in this trench, the earthquakes remain to be dated. The recent analysis of some of the sedimentary layers by X-ray diffraction revealed the presence of quartz and feldspar minerals that make Optically Stimulated Luminescence (OSL) possible.

The simple geometry of the southern segment of the Dead Sea Fault enables combining tools involving different time scales of deformation, from a few years to ~90 ka. From two surveys of a GPS campaign network within 6 years I observed the displacement field around the fault. Using a simple elastic locked-fault model, I determined a present-day, interseismic, fault slip rate of 4.9 ± 1.4 mm/a and estimated the locking depth to ~12 km (Le Beon et al., 2008). In parallel, we identified two sites where abandoned alluvial markers are laterally offset by the fault. Cobbles were collected from the surface of the deposits for ^{10}Be cosmogenic dating; this technique provides an exposure age. Combining offsets and ages, I determined at one site a fault slip rate of 5.4 ± 2.7 mm/a during the Holocene. At the second site, age scattering suggests complex mechanisms of transport and deposition. The slip rates we obtained are 4.5 ± 0.9 mm/a since ~37 ka and 8.1 ± 2.9 mm/a since ~90 ka. We show the similarity between present-day, Holocene, and geological (5Ma) (3-7 mm/a) slip rates. In spite of larger uncertainty, the ~90-ka slip rate also overlaps these values. The present-day slip rate is likely to correspond to the rate of regional tectonic loading, without transient variations at the present stage of the seismic cycle. The activity of the fault would be regular at the scale of ~10 ka, probably due to its simple geometry. However, because of large uncertainty on the ~90-ka slip rate we cannot completely rule out slip rate variations at longer time scales (Le Beon et al, 2010).

In order to reduce the age uncertainty on the ~90-ka offset alluvial surface and draw further conclusions regarding the seismic behavior of this fault, we targeted the same site for OSL dating (provides a burial age) on quartz and feldspar minerals. OSL ages from the same deposit are consistent with each other, yet they are all much younger than the ^{10}Be ages: ~39 ± 7 ka instead of ~90 ± 30 ka. Such young ages and the associated offset measurements are inconsistent with ages and offsets from previous studies at different sites, strongly suggesting that the OSL ages are underestimated. On-going analyses should help understand this age discrepancy and hopefully provide insights to determine an accurate age.

At the northern tip of the Chelungpu Thrust in the Western Foothills of central Taiwan, a series of abandoned terraces, progressively uplifted and folded, enable to investigate the activity of the thrust over time. The deformation style of the terraces is related to the sub-surface geometry of the fault that shows a ramp of varying dip, parallel to geological strata. We determined the cumulative fault slip recorded since abandonment of each terrace level based on three morphologic criteria: the terrace elevation, the relief across the fold and the width of the fold. Three terrace levels have been dated by OSL on quartz minerals from alluvial sand. We obtained cumulative slips of 700 ± 30 m since 30 ± 4 ka, 600 ± 50 m since 22 ± 1 ka, and 200 ± 20 m since 17 ± 1 ka. These preliminary results reveal temporal variations of fault slip rate, from ~38 mm/a between 30 and 17 ka to ~11 mm/a since 17 ka. This slow down may be related to interactions with the most frontal Changhua thrust, with a possible control of interactions between climate, erosion, sedimentation, and tectonics. Reconstruction of the shortening history on the most frontal Changhua thrust and insights from analog modeling will help resolve this question.