Intraplate tectonic regimes such as the European Alps are characterized by low crustal deformation rates and thus long recurrence rates of severe earthquakes. High-quality paleoseismic archives are required to overcome our limited perspective of earthquake recurrence and maximum magnitude. However, especially on-fault paleoseismic evidence is scarcely found because of high erosion rates, gravitational slope processes and penetrative anthropogenic landscape modification, which often obscure geomorphic features related to surface ruptures.

Here, we present the inneralpine lake archive of Achensee in the Northern Calcareous Alps (6.8km² area; 133m water depth) cross-cut by a major fault and potentially holding a continuous paleoseismic archive since the last deglaciation at ~18 ka BP. This major fault is a Cretaceous-Paleogene relatively steep-dipping thrust, with at least 15km length and several hundreds of meters geological offset, located within the current area of enhanced seismicity and oriented to be preferentially re-activated in the current stress field. We used a high-resolution multi-beam bathymetry, a combination of a very dense grid of 3.5kHz “pinger” subbottom profiler and single-channel high-frequency (~0.8-2.0kHz) “sparker” reflection seismsics to investigate the postglacial infill with high-resolution and image the deeper structures (e.g. the glacially scoured valley). The seismo-stratigraphic interpretation was ground-truthed and \(^{14}C\)-dated by five, up to 11m long sediment cores from the two main subbasins.

We discovered at least eight strong earthquakes hitting the region in the past 11,000 years by off-fault paleoseismic evidence expressed by coeval, multiple mass-transport deposits (MTDs) and co-genetic turbidites. These earthquakes must have reached seismic intensity of >VI (EMS-98) at the lake site calibrated with the strongest known historical earthquake of the region (M<sub>L</sub> 5.2 in Hall CE1670). MTD size and extent corresponding to the CE1670 earthquake compared to the other earthquake imprints let us infer that at least four of the paleo-earthquakes reached higher intensities at Achensee.

Strikingly, Achensee has also recorded on-fault evidence expressed by steeply-dipping to vertical faults offsetting the lacustrine stratigraphy. These stratigraphic offsets can be traced downwards...
to the acoustic basement, which hints at faulting originating in the bedrock. For at least two stratigraphic levels, these faults are directly overlain by multiple MTDs indicating that fault activity and slope failures have occurred quasi-simultaneously. The faults observed on the seismic data, affecting the sedimentary infill of the lake, are located above the inferred trace of the major fault where it crosses the lake. Based on this rather unique combined on-fault and off-fault evidence we propose strong paleo-earthquakes documenting activity of this major thrust at ~8.5 ka BP and in the Late Glacial period (below reach of sediment cores). We suggest that these earthquakes have reached $M_L \sim 5.5-6$, which is within the magnitude capability of this thrust and at the lower limit of generating surface ruptures according to worldwide magnitude-surface rupture relationships. The other six event horizons lacking in on-fault evidence either represent earthquakes sourced from another fault in the region, earthquakes with a smaller magnitude not capable of surface rupturing like the $M_L 5.2$ earthquake in Hall CE1670 or on-fault evidence is blurred in seismic data by subsequent stacking of MTDs.