EGU2020-10802
https://doi.org/10.5194/egusphere-egu2020-10802
EGU General Assembly 2020

Quantitative paleoseismology in Carinthia, Eastern Alps: Calibrating the lacustrine sedimentary record with historical earthquake data

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In intraplate settings with moderate seismicity, recurrence intervals of strong earthquakes (M_w >6) typically exceed the short time span of instrumental and historical records. To assess the seismic hazard in such regions, lake sediments are increasingly used as earthquake archives: they can record strong seismic shaking as mass transport deposits (MTDs), turbidites or sediment deformations, preserved over several thousands of years. To provide information on paleo-earthquake size, however, the sedimentary imprints need to be thoroughly calibrated with independent information on seismic shaking strength.

In Carinthia (Eastern Alps, Austria), numerous lakes have experienced several devastating historical earthquakes with local seismic intensities (SI) ranging from V-XI (EMS-98 scale), although being located in an intraplate environment. Given that i) these events are well-spaced in time (AD1201, AD1348, AD1511, AD1690, AD1857 and AD1976), ii) due to historical earthquake research, an exceptional historical documentation exists, and iii) accurate shakemaps can be built based on a local Intensity Prediction Equation (IPE), we can examine the relationship between seismic intensity and the type, size and spatial distribution of sedimentary imprint in the lakes.

Here, we present investigations on two large lakes – Wörthersee and Millstätter See – by a dense grid of reflection seismic profiles (~640 km overall), 80 short (~1.5 m) sediment cores and multibeam bathymetry. The lakes consist of several sub-basins with potentially different intensity thresholds for the generation of sedimentary imprints. Mapping of MTDs, their scarps and associated turbidites as well as accurate dating (radiocarbon and varve counting on sediment thin sections) shows that the AD1348 earthquake (M_w ~7) led to extensive slope failures in both lakes. The AD1511 (M_w ~6.9) and AD1690 (M_w ~6.5) events, which exhibited lower local intensities (~VII) compared to those of AD1348 (VIII), are recorded as minor MTDs and turbidites. Quantitative description of earthquake-related event deposits (cumulative turbidite thickness, volume of mass transport deposits/megaturbidites) suggests a linear correlation with the respective local intensities in both Wörthersee and Millstätter See.

The AD1976 earthquake (M_w ~6.5; SI V-VI at the lakes) is not evidenced in the sedimentary record and therefore can be used for constraining the minimum threshold intensity for seismically-

induced event deposits. By applying a grid-search approach using an empirical intensity-attenuation relationship, we can narrow down possible earthquake scenarios. Our data suggests that the highly debated epicentre of the AD1348 earthquake was much closer to the Austrian-Italian border than the epicentre of the AD1976 Friuli earthquake, possibly originating from the Periadriatic lineament. The AD1511 event probably had its epicentre southeast of our study area in Slovenia, and therefore further east than previous studies suggested. The AD1690 earthquake, however, is most likely of a local origin.

Our study reveals that investigating one lake, let alone one sediment core, is insufficient to reconstruct a region's seismic history. Due to the exceptional setting of Carinthia, however, we can constrain the intensity pattern and localise the most likely epicentral region and fault source of past earthquakes. In an ongoing interdisciplinary study, we use this calibration to construct long calibrated lacustrine records for the last 14 ka.