Updates from Lake Paleoseismology as contribution to improve seismic hazard assessment and awareness of secondary earthquake effects in Austria

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In intraplate tectonic regions, only limited knowledge exists on the occurrence of severe earthquakes, their maximum possible magnitude, potential source areas and secondary effects such as seismically-triggered rockslides. This is mainly due to long recurrence rates exceeding the time span of instrumental earthquake records and historical documentation. Yet, knowledge of the earthquake history provides an important foundation of seismic hazard assessment. Motivated by the mission to fill the gap in long-term records of severe earthquakes and their consequences in Austria, we have studied lakes in Carinthia and Tyrol with a "Lacustrine Paleoseismology" research approach: We combined geophysical, sedimentological, and geochemical techniques to unravel and precisely date high-resolution lacustrine sedimentary sequences comprising records of past seismic shaking as subaqueous landslides, turbidites and in-situ sediment deformation. Based on the sedimentary imprint of well-documented historically and instrumentally recorded earthquakes with intensities ranging from V to IX (EMS-98) we derived (i) seismic intensity thresholds for different lake basins and (ii) scaling relationships between measurable sedimentary parameters and seismic intensity. These natural ground motion indicators have then been applied to the prehistoric lacustrine sedimentary records of different lakes to establish a first calibrated and multi-scale paleoseismic dataset for Carinthia and Tyrol. In Carinthia, the sedimentary archive of Wörthersee spanning the last ~14,000 years recorded 44 earthquakes of intensity > V (ranging between V and IX), with three intervals of strongly enhanced seismicity. Recurrence statistics and calculating the exceedance probability in 50 years of a certain intensity reveals the following conclusions: (1) Poissonian earthquake recurrence, as used in the probabilistic seismic hazard assessment by ZAMG, is confirmed for the last 2,800 years; (2) the current seismic hazard curves of the study area agree with the lacustrine paleoseismic record; (3) intervals of enhanced earthquake frequency can occur and need to be considered in seismic hazard analysis; (4) compared to the whole record, the last ~800 years show a relatively high number of strong intensity events. In Tyrol, our results show that 25 severe earthquakes are recorded in the three studied lakes Plansee, Piburgersee, and Achensee over the last ~16,000 years, from which four left imprints in two or more lakes. Earthquake recurrence intervals range from ca. 1,000 to 2,000 years with a weakly periodic to aperiodic recurrence behaviour for the individual records. Plausible epicenters and magnitude estimates of paleoearthquakes, as derived by a reverse application of an empirical intensity prediction equation in a geospatial scenario analysis, coincide with the current enhanced seismicity regions. Here, MW 5.8-6.1 paleo-earthquakes might have occurred that were larger than the more recent historical earthquakes. The largest prehistoric earthquake might have reached up to Mw 6.3 at Achensee, where primary paleoseismic evidence documents coseismic surface rupture of a lake-crossing thrust at ~8.3 ka BP. Furthermore, temporal and spatial coincidence of paleoseismic evidence with multiple rockslides at ~4.1 and ~3.0 ka BP reveals that severe earthquakes (ML 5.5–6.5; epicentral intensity VIII<I0<XI) have triggered the Fernpass and Tschirgant Rockslides, respectively.