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# Which Factors Modulate Earthquake-Triggered Soft Sediment Deformation? Moving Towards Quantitative Lacustrine Paleoseismology

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Earthquake-induced soft sediment deformation structures (SSDS) can be used to resolve earthquake recurrence rates, but also to provide more quantitative information on past earthquake shaking intensities. Thorough understanding of the interplay between i) different ground motion characteristics, ii) sediment properties, iii) slope morphology and iv) seismic site effects is paramount for full exploitation of the paleoseismological potential of subaqueous SSDS records. However, we lack comparative studies investigating different SSDS records related to well-documented earthquakes, varying sediment types and site morphologies.

We investigated 17 slope and three basin sediment cores from two South-Central Chilean lakes: lakes Riñihue and Calafquén. Using X-ray computed tomography (CT) data, six different types of SSDS were observed: i) disturbed lamination, ii) folds, iii) intraclast breccia, iv) faults, v) load structures and vi) injection structures. We directly linked SSDS to five well-documented megathrust earthquakes using stratigraphic correlation of sediment sequences to well-dated basinal seismo-turbidite records.

Sediment of both lakes consists of varve couplets of diatomaceous ooze and organic-rich terrestrial material intercalated with coarse-grained tephras and fine-grained lahar deposits. From the 49 SSDS intervals, 61% are assigned to one of the five megathrust earthquakes. Of the SSDS intervals not assigned to megathrust earthquakes, 68% are located directly above a tephra or lahar deposit. We suggest that dewatering of volcanic deposits could have weakened overlying sediment and facilitated deformation during later earthquakes.

Slope gradient at coring sites range from 0.2-9.5° and 0.2-14.2° in lakes Riñihue and Calafquén, respectively. Deformation occurs from 0.2° and total deformation increases with slope angle in both lakes. Total deformation in lake Calafquén increases less with slope angle than in lake

Riñihue. Our observations suggest seismically-induced shear stress alone can suffice to deform sediment, but even minor increases of gravitational downslope stress will ease deformation. Smaller increase of total deformation with slope angle for lake Calafquén could be explained by higher diatom content. Diatoms enhance shear strength through high particle interlocking and surface roughness. Therefore, we suggest that enhanced diatom content reduces sediment susceptibility to shear-induced deformation.

We evaluate the effect of ground motion characteristics by correlating SSDS to peak ground acceleration (PGA) and bracketed duration (BD) of the causative strong megathrust earthquakes as derived from ground motion prediction equations. As first suggested for SSDS in the Dead Sea area, disturbed lamination develops to folds and finally intraclast breccia and is driven by earthquake-induced shear causing Kelvin-Helmholtz Instability (KHI). In lake Riñihue, SSDS type and count correlates best with PGA suggesting amplitude of ground acceleration as the main control of KHI-driven deformation.

Future comparative analysis of lacustrine SSDS records in different geodynamic settings will put our findings in a broader perspective. Sediment types will be quantified by measuring characteristics like grain size, diatom and organic content, density, viscosity and Atterberg limits. Our study is the first to allow direct comparison of three different factors—sediment type, ground motion characteristics and slope morphology—with related earthquake-triggered SSDS, thereby advancing lacustrine paleoseismology towards a more quantitative interpretation of SSDS records.