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Seismogenic-driven hydroplastic deformation of soft sediments (Hirlatzhöhle, Austria)

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Deformed Quaternary cave sediments, which are well protected from both the erosional processes occurring at the Earth's surface and anthropogenic activities, provide a detailed archive of paleoseismic events, as well as an opportunity to assess potential regional seismic hazards.
Hirlatz Cave, which lies about 2 km SW of Hallstatt, in the Salzkammergut area of Upper Austria, formed in a Triassic carbonate platform in the Dachstein Nappe, part of the Northern Calcareous Alps. With an overall length of 101 km, this is the third largest cave system in Austria. The present study focuses on an approximately 6.8 m long x 3 m high outcrop of Quaternary deposits that lie 2.8 km southeast of the cave entrance, in the so-called Lehmklamm. The succession comprises alternating packages of (a) pale grey sediments 3-25 mm thick and (b) finely laminated (1-2 mm) alternations of grey and lighter and darker brown sediments in layers 10-34 mm thick.

X-ray diffraction analyses of the unconsolidated, finely laminated clay-sized sediments show a varve-like layering of brighter, carbonate and quartz-rich, and darker, clay mineral-rich layers of fluvio-lacustrine deposits. Heavy mineral analyses indicate an amphibolite facies source area that underwent a greenschist facies overprint. This indicates that the crystalline Central Alps lying to the south of the cave was likely the source.
The succession contains abundant millimetre to centimetre-sized seismogenically-induced flame and fishtail structures, domino-boudins and syn-slumping structures such as folds and faults (normal and thrust faults) with flanking structures. Geometric analogues that are 2-3 orders of magnitudes larger have been described close to the Dead Sea Fault (e.g. Alsop et. al., 2011). Quantitative techniques, such as the reconstruction of the aspect ratios of boudins, the fault system polarity, the variation coefficient of faults and kinematic balancing have been used to interpret the structures.

This suggests that (i) the formation of the soft-sediment structures in Hirlatz cave was triggered by cyclic seismic events, (ii) the structures were mainly formed in the uppermost, highly water saturated layers, and (iii) liquefaction resulted in density discontinuities decreased the shear strength within the stratified layers. Minor seismicty recorded along the Salzach-Ennstal-Mariazell-Puchberg (SEMP) sinistral strike-slip fault, which has a maximum displacement > 60 km, prove recent fault activity. This lies approximately 17 km south of the outcrop and accommodates the active eastwards extrusion of the Eastern Alps towards the Pannonian Basin.