Enhancing paleoseismological record through multi-methods cave deformation analysis tested in diverse Hellenides tectonic regimes

Paleoseismology aims to unravel the history of earthquakes using geological evidence. Earthquakes induce primary and secondary deformations, whereas secondary effects provide insight into quake intensity. However, these effects can erode with time, posing challenges for prehistoric studies. Caves offer a unique solution by preserving hidden deformations shielded from surface erosion. Damaged speleothems aid in dating deformations, and cave passage offsets enable kinematic reconstruction. Furthermore, speleothem failure criteria offer seismological information. Physical studies suggest tall speleothems can break if earthquakes exceed a critical horizontal ground acceleration. Yet, field evidence shows long, thin speleothems in regions with significant seismic activity, contrary to physical expectations. Only recently, holistic methods integrating structural, geochronological, and geophysical analyses have emerged. Despite these advances, understanding seismic wave behavior in caves remains elusive. Recent Finite Element Method (FEM) applications focus on individual speleothem fragments, predicting failure parameters. Yet, previous studies tested undamaged stalagmites in low-seismic regions. This research proposal broadens these analyses to enhance seismic hazard assessment, by developing and testing FEM for speleothem vulnerability analysis, considering both intact and broken stalagmites in a region with known historical and present-day earthquakes. Enhancing FEM analysis for speleothem vulnerability in regions with historical earthquakes is critical. A dedicated postdoc will conduct FEM analysis, mirroring earlier studies, extending to fractured stalagmites. Eigenfrequency analysis will determine wave direction, aiding seismic source identification. Historical seismic events and PGA data will validate the impact on a given cave. Coupling modeled vulnerability with real seismic data will refine speleothem vulnerability understanding. This proposal aims to solve speleothems vulnerability issue by an integrative and quantitative approach combining experiments, numerical models, and test sites with quite well-known active tectonic settings and seismic hazards. The speleothems vulnerability analysis, in contrast to previous studies conducted in low-seismic regions, will be put in the context of active seismotectonic settings - Hellenides. This approach has two huge advantages. First, it will test and calibrate modeling results with real seismic data. Secondly, using speleotectonic tools, we will extend the paleoseismic record for each studied region.

Greece's geological setting, rich in limestone, presents abundant caves for tectonic research. The Hellenides orogenic region boasts diverse tectonic regimes, each featuring unique cave networks. Aegean tectonics underwent changes from Pliocene to Quaternary, shifting extensional deformation orientation and fault activity due to Anatolia's westward movement. This project will date cave deformation to reveal detailed spatiotemporal stress field changes. Limited cave-based research in Greece offers potential for enhanced paleoseismic understanding, extending knowledge to over 0.5 Ma using Th/U and U-Pb dating. The study benefits local seismic hazard assessment in studied areas, as well as, broader applications in varied tectonic settings due to collaboration with experts and positions for a Ph.D. student and postdoc dedicated to improving the methodology.

This study concentrates on four distinct regions: Crete, proximate to the Hellenic Subduction Zone; Amorgos, which experienced the largest earthquake in Greece in the 20th century (Mw7.4 1956); Eastern Macedonia and Thrace, north of the Northern Anatolian Fault, with much slower strain rate and yet strong earthquakes; and the Corinth Rift, characterized by rapid extension. By examining diverse regions, this research aims to extend knowledge of prehistoric earthquakes in the Hellenides, contributing to seismic hazard and broader geodynamics.

The research tests hypotheses by conducting fieldwork on both mainland and islands, considering varying tectonic regimes and geodynamic settings. The proposed methods involve fault-slip data reconstruction and microstructural analysis. Dating damaged speleothems will provide timing insight. This, in turn, will allow us to extend the paleoseismic record and recognize recurrence intervals of strong earthquakes.