# *TrackPreQuake: Tracking Preparation Processes of EarthQuakes*

**How do earthquakes start?** Scientists have long sought to answer this question, but it remains one of the greatest challenges in seismology. Before an earthquake occurs, there are often subtle signals of stress changes and deformation, deep within the Earth's crust. Understanding these **E**arthquake **P**reparation **P**rocesses (**EPP**) is crucial for prediction when and where earthquakes might happen. Existing models, like cascade and pre-slip, are too simplistic to capture the intricate interactions within tectonic fault systems. Moreover, the uniqueness of each earthquake, shaped by its specific geological history, makes precise predictions exceptionally difficult.

**Anthropogenic Seismicity (AS)** - earthquakes triggered by human activities like mining, geothermal energy production, or reservoir filling - adds another layer of complexity. Although AS might seem easier to study because of its links to controlled technological activities, its preparatory phases are poorly understood. AS is influenced by a mix of natural and human factors, posing risks to industries crucial for a low-carbon future.

The *TrackPreQuake* project represents a bold, interdisciplinary effort to direct these challenges, to a research hypothesis that links laboratory-scale phenomena, anthropogenic seismicity, and natural earthquakes into a unified geomechanical and statistical framework. This is the first attempt to systematic investigation whether Earthquake Preparation Processes share commonalities across these vastly different scales. By treating earthquakes as multi-parameter phenomena and analysing their evolution in a multidimensional space, the project aims to establish a universal model of EPP - a potential breakthrough in seismology.

Recent research provides promising observations. Patterns such as **S**ubcritical **F**racture **G**rowth (**SFG**) and **C**lustering **F**actor (**CF**), identified in laboratory experiments and field data, may reveal how stress builds up before earthquakes. Studies show that AS earthquakes exhibit similar patterns to those preceding powerful natural earthquakes (magnitude 8.0+). SFG describes the slow, progressive growth of cracks under stress below critical level, while CF measures "distances" between earthquakes in a transformed multi-parameter space, tracking their evolution in time and space. By analysing how these "distances" evolve, CF provides a novel way to quantify and visualize changes in seismic activity across diverse contexts.

*TrackPreQuake* also explores unique phenomena like “anti-repeaters.” These pairs of earthquakes occur in the same area but behave like opposites: one earthquake involves fault motion in one direction, and the anti-repeater reverses it. These patterns provide valuable insights into fault interactions and stress redistribution.

The project combines cutting-edge tools such as **A**rtificial **I**ntelligence (**AI**), advanced statistical modelling, laboratory experiments, and real-world data from diverse sources, including mining, geothermal sites, and natural seismicity. This integrated approach not only bridges disciplines - seismology, physics, geomechanics, and AI - but also connects scales, from microfractures in the laboratory to large tectonic ruptures. By considering earthquakes as multidimensional events, *TrackPreQuake* aims to redefine how we understand their preparatory processes, breaking new ground in seismology.

The societal and scientific implications of the project are profound. If successful, *TrackPreQuake* will provide a universal framework for understanding EPP, leading to improved seismic hazard assessments and safer management of subsurface industries like geothermal energy and $CO_2$ storage. Its findings will be shared globally through platforms like the EPISODES Platform, fostering international collaboration. Ultimately, *TrackPreQuake* aims to redefine earthquake preparedness and risk management, paving the way for safer, more resilient communities and supporting the transition to sustainable energy solutions.