Serpentinization is a process in which ultramafic rocks (rich in magnesium and iron but poor in silica) react with water. As a result, new minerals form, hydrogen (H_2) is released—sometimes also methane (CH_4)—and carbon dioxide (CO_2) becomes permanently stored in the form of carbonate minerals. Although this process is widespread in the Earth's crust, many of its stages remain poorly understood—especially those that occur very rapidly, are reversible, and leave no lasting trace in the rock record.

Our project introduces an entirely new method: a high-pressure fluid-percolation system that allows serpentinization to be simulated under conditions similar to those in the Earth's crust. Moreover, this system enables continuous, non-destructive sampling of gases and fluids in real time. Because the amount of fluid used is extremely low relative to the rock, chemical changes in the fluid directly reflect what's happening inside the rock. This allows us to observe reactions "live"—including short-lived phenomena that are typically invisible in natural samples.

One of the key features of the project is the use of so-called CC water—a specially prepared fluid with an unusual isotopic composition of hydrogen and oxygen. This enables us to track the most subtle isotopic changes in the system. By using different flow directions (forward and backward) and different water types (natural and synthetic), we can study how the chemistry and isotopes of the fluid evolve, and what minerals form under different conditions. The project uses the latest analytical techniques, including so-called *clumped isotopes*. These tools allow us to distinguish between isotopic effects that result from chemical equilibrium and those caused by rapid reactions or mass transport.

This approach will help answer key questions: how fast does serpentinization proceed, under what conditions do minerals like brucite and carbonates form, what marks the beginning of the process, and which isotopic signals remain unchanged over time. Flow modeling, carried out in collaboration with a theoretical physics group, will further help us understand how factors such as turbulence affect the reaction progress. The results will be relevant not only for geochemistry and Earth sciences but also for CO_2 storage technologies, natural hydrogen exploration, and understanding processes occurring in the Earth's crust. This project represents a breakthrough attempt to capture serpentinization in its real, dynamic form.