

 Franziska M. Stamm

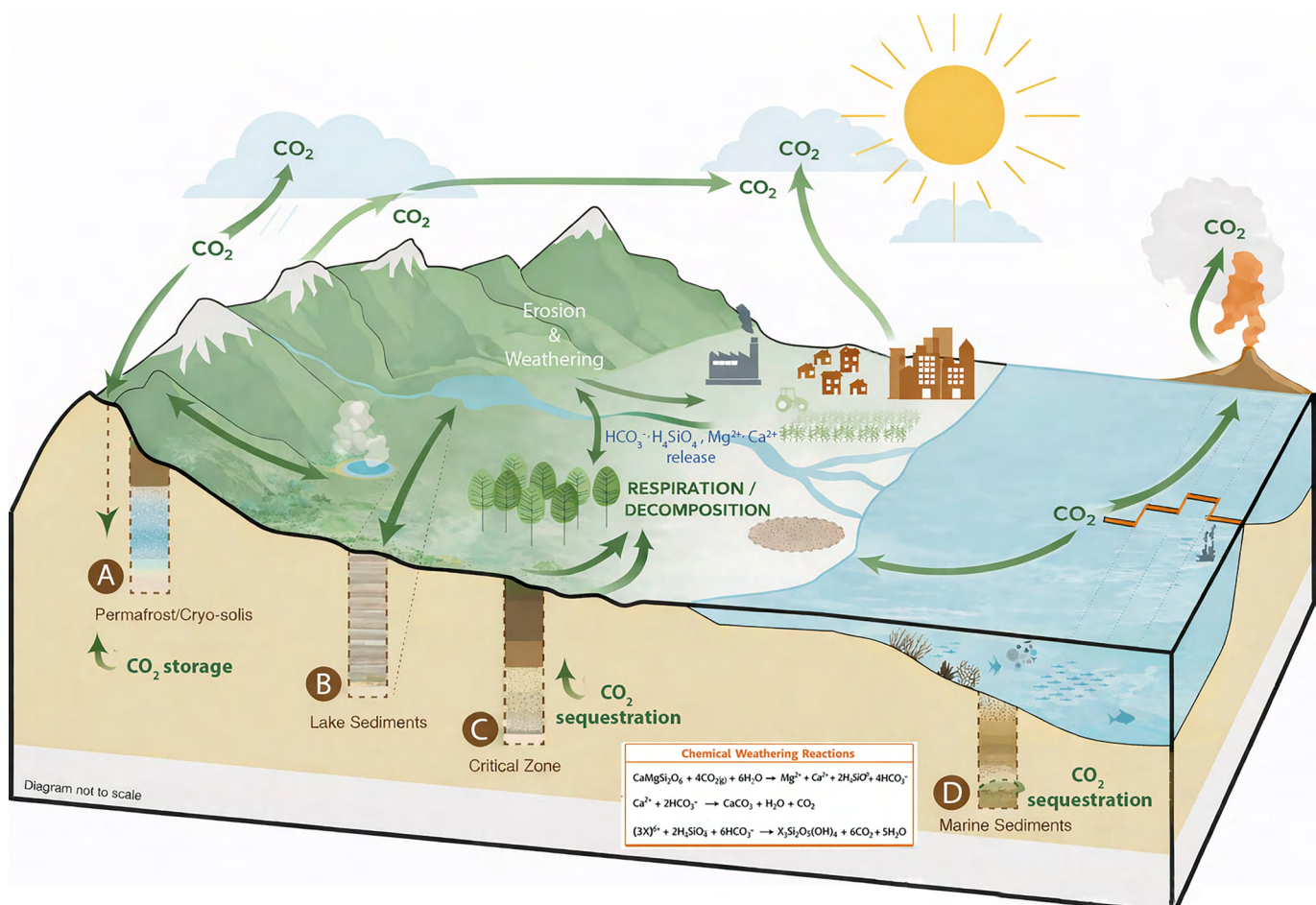
# The Hidden Life of Minerals: Can Amorphous Silica Phases Help Us to Understand Climate Change?

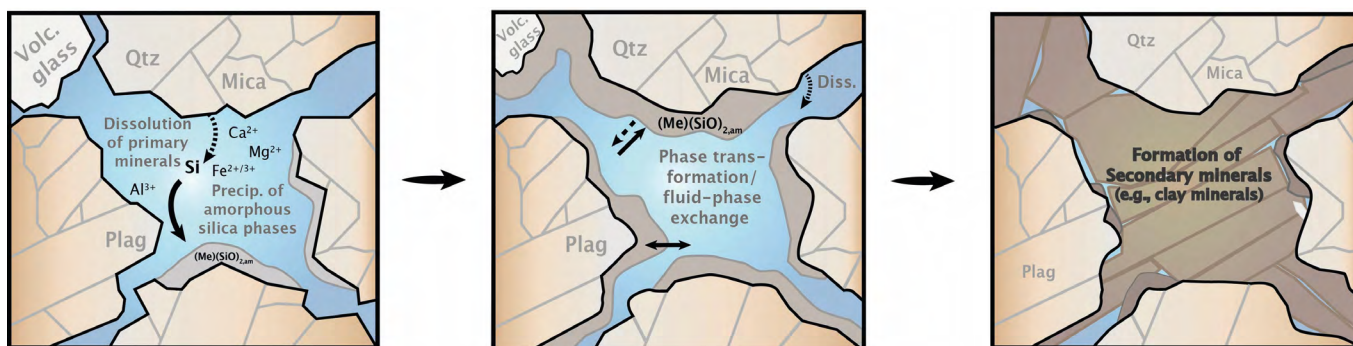
Rocks have long helped regulate Earth's climate by removing CO<sub>2</sub> through silicate weathering. Yet key intermediates known as amorphous silica phases remain poorly understood. The ISO2CARE project funded by the FWF (Austrian Science Fund) uses silicon isotopes as tracers to uncover how these phases control element cycling and carbon sequestration. The project aims to answer a pressing question: can the Earth's own geological dynamics be better understood and perhaps even optimized to help mitigate climate change?

At the heart of Earth's long-term climate regulation lies a delicate balance between carbon sources and sinks. Among the most important natural sinks of carbon is the chemical weathering of silicate rocks. When silicate minerals dissolve in the presence of water and carbon dioxide (CO<sub>2</sub>), they release

dissolved cations (e.g., calcium, magnesium, aluminium, iron; see Fig. 1), silicic acid and bicarbonate into natural waters (e.g., groundwater, soil solutions, rivers, ocean). These products can ultimately lead to the formation of carbonate minerals, locking carbon away over geological timescales.

This seemingly straightforward process, however, is governed by a complex network of dynamic dissolution and re-precipitation reactions, which in turn are influenced by environmental factors such as temperature, pH, carbon dioxide concentration and the presence of organic





matter. Moreover, the products of primary mineral dissolution do not simply remain in solution; they frequently recombine to form secondary minerals, notably clays. Secondary mineral formation typically proceeds through metastable intermediates, most prominently amorphous silica phases, which act as gateways toward clay mineral formation. These intermediates regulate how key elements (calcium, magnesium, silicon, aluminum, iron) are stored, released or transformed within natural systems (Figure 1).

Despite their importance, these intermediate solid phases remain surprisingly elusive. They are short-lived and constantly changing, evolving through processes such as ongoing structural reorganization driven by dissolution and re-precipitation, commonly referred to as Oswald ripening. This dynamic behaviour makes them difficult to capture and study in real time. As a result, key questions about how they form, transform and persist over longer timescales remain unanswered, especially in natural environments, where multiple processes

occur simultaneously. Yet these very processes likely modulate the efficiency with which silicate weathering removes atmospheric carbon.

To better understand this complexity, modern geochemistry relies on stable isotopes. Isotopes are slightly different forms of the same element that vary only in their mass while remaining chemically identical and not undergoing radioactive decay. These subtle differences cause them to distribute unevenly during chemical reactions: a process known as isotope fractionation. As a result, they act as natural tracers. Much like **fingerprints** at a crime scene, isotopic signatures – in this case **stable isotopes of silicon** – preserve a record of chemical reactions, helping us to reconstruct and predict kinetics, mechanisms and pathways **of carbon sequestration reactions and climate change** that are otherwise invisible.

Building on this approach, the ISO2CARE project funded by the FWF combines controlled laboratory experiments with observations from natural environments.

↑ **Conceptual illustration of silicate weathering and secondary mineral formation in natural waters occurring in soils and (marine) sediments. Primary minerals dissolve in the presence of CO<sub>2</sub>-rich water, releasing dissolved elements that initially form amorphous silica phases. These transient intermediates undergo continuous transformation and fluid–solid exchange before ultimately evolving into more stable secondary minerals such as clay minerals.**

Source: Franziska M. & Anna-Sophia Stamm

In the laboratory, we will form amorphous silica phases under carefully controlled physicochemical conditions. By systematically varying parameters such as temperature, pH, carbon dioxide concentration, element composition and the presence of organic molecules, we can observe how these phases form and transform over time. This allows us to isolate individual processes to investigate secondary (clay) mineral formation which are otherwise intertwined in nature.

← **Figure 1: Schematic overview of the coupled CO<sub>2</sub> cycle and silicate weathering reactions across different Earth surface environments (A–D). Chemical weathering of silicate rocks consumes atmospheric CO<sub>2</sub> and releases dissolved elements that are transported through soils, rivers, and oceans, where they participate in mineral formation and carbon sequestration. Silicon isotope ratios ( $\delta^{30}\text{Si}$ ) serve as tracers to follow these processes and to unravel reaction pathways and rates in both terrestrial and marine systems. In the chemical weathering reactions shown, X denotes alkali and metal cations such as Fe<sup>2+</sup>, Mg<sup>2+</sup>, 2Na<sup>+</sup>, and 2/3Al<sup>3+</sup>.**

Source: Franziska M. Stamm

**Figure 2: Young researchers at work.** →  
**Karla Resel (master's student in geosciences, left) and Rylee Lindner (PhD student, right) preparing experiments to investigate amorphous silica formation and isotope behaviour.** Source: Rylee Lindner



A central part of this work is carried out together with a dedicated team of young researchers (Figure 2). Two students, Rylee Lindner (PhD) and Karla Resel (Master), are closely involved in designing experiments, analysing samples and interpreting isotope data. Their contributions are essential to the project and provide valuable training at the interface of analytical techniques, experimental (isotope) geochemistry and climate research.

Laboratory experiments alone, however, cannot fully capture the complexity of natural systems. To complement this, the project also investigates natural systems, which act as real-world laboratories. One such site is located in the Schladminger Tauern (Styria, Austria, Figure 3), studied

in collaboration with partners from the University of Graz at the NAWI Graz Geocenter. Here, the formation of amorphous silica phases can be observed under natural conditions. By linking experimental results with field observations, ISO2CARE bridges the gap between fundamental processes and their expression in the environment.

Ultimately, this combined approach will improve our understanding of how amorphous silica phases influence element cycling and carbon sequestration. In doing so, the project contributes to a more accurate assessment of silicate weathering as a natural climate regulator and its potential role in future strategies to mitigate atmospheric CO<sub>2</sub>. ●



**Figure 3: Natural laboratory in a periglacial rock glacier environment (Schladminger Tauern, Austria). The striking turquoise colour of the lake is caused by the precipitation of amorphous silica phases, likely triggered by the mixing of acidic waters released from degrading permafrost within the rock glacier with less acidic surface waters.**

Source: Franziska M. Stamm



Source: Hermann Stamm

Franziska M. Stamm is an experimental isotope geochemist at the Institute of Applied Geosciences at the NAWI Graz Geocenter (discipline: Mineralogy and Hydrogeochemistry, TU Graz). She studied geosciences in Bonn and specialized in isotope geochemistry during her PhD in Toulouse, focusing on low-temperature mineral–fluid interactions. Her research investigates how silicate weathering regulates element cycles and contributes to long-term carbon sequestration. Using stable isotopes as tracers, she studies reaction pathways and kinetics in both laboratory experiments and natural systems. She leads the FWF-funded project ISO2CARE, which explores the role of amorphous silica phases in weathering processes and their relevance for climate mitigation.