High-speed metamorphism: Do mineral growth rates match the experiments?

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Metamorphism is a fundamental geological process in which rocks are transformed by heat and pressure, resulting in the formation of new minerals and textures. This transformation occurs over a range of spatial and temporal scales and plays a central role in the geodynamic cycle. It shapes mountain ranges, drives crustal recycling and contributes to the formation of economically important resources. Metamorphism also induces dehydration and densification, processes that actively influence plate tectonics and are associated with rapid geological phenomena such as seismicity. *But what controls the rate at which metamorphic reactions, particularly mineral transformations, proceed?* While field-based petrological observations suggest timescales of hundreds of thousands to millions of years, experimental data often yield much shorter timescales – on the order of days to weeks.

In this MSA distinguished speaker lecture I will present a case study using data-driven approaches to unravel the evolving conditions and timescales of a specific lower crustal metamorphic reaction. I will show how advances in analytical techniques and the development of user-friendly software for big data analysis are crucial to answering the long-standing question of the rates of metamorphic processes in natural systems.

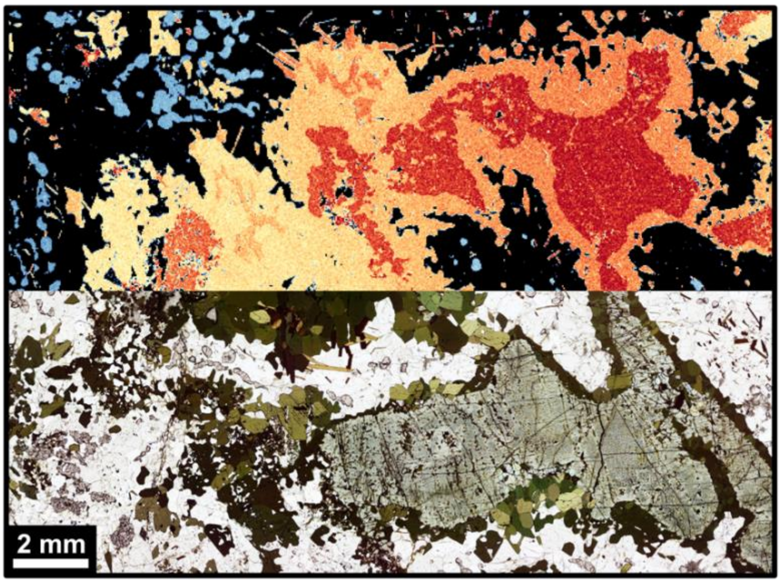

***Figure**: Chemical variations in a metagabbro reflecting chemical potential gradients during metamorphic reactions. Understanding the rate at which this metamorphic reaction occurs is crucial for grasping the link between metamorphic reactions and seismicity.*

Equilibrium dreams and metastable realities: Lessons from compositional maps

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Predictive models based on equilibrium thermodynamics have become an important tool for simulating the transformation of solids and liquids in the Earth's interior. For instance, these models can predict the successive transformations of minerals, fluids and/or melts under different tectonic, magmatic and metamorphic conditions. However, a growing body of evidence in the literature suggests that existing models cannot replicate certain observed trends in mineral composition in experiments or in nature. *Is it the fault of the model parameters, or is the equilibrium assumption underlying the models not valid for crustal metamorphism?*

In this MSA Distinguished Speaker Lecture, I will discuss how the development of software tools for quantitative compositional mapping has challenged the application of phase diagrams to natural rocks. Many metamorphic minerals in nature exhibit compositional zoning, suggesting sluggish diffusion and only partial re-equilibration. I will discuss how this information can be integrated into more advanced models. I will also talk about how our modelling capabilities have evolved from simple thermobarometric equations to a thermodynamic framework based on internally consistent databases couple to geochemical models and share my thoughts on the emergence of machine learning techniques.

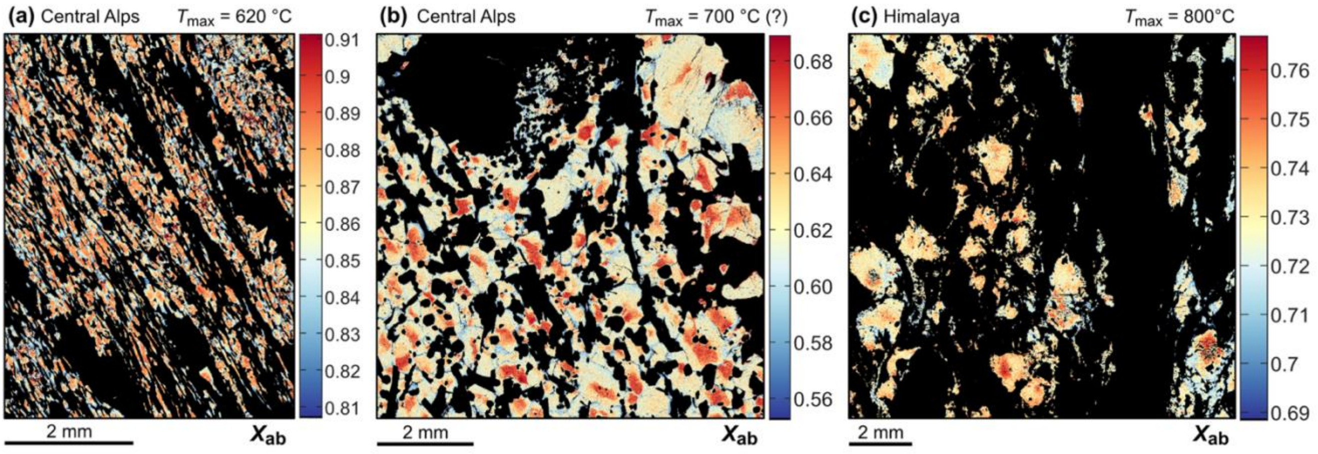

***Figure**: Chemical variations of plagioclase observed in three metapelite samples from the Alps and the Himalayas, which experienced peak metamorphic conditions between 620 °C and 800 °C. The abbreviation X_{ab} represents the proportion of albite and is related to the amount of sodium (Na) in plagioclase. Understanding the degree of disequilibrium in these samples is crucial for comprehending the transformation of rocks during their journey into the Earth's interior.*

Short speaker biography

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Dr Pierre Lanari is a multidisciplinary geologist and professor at the University of Lausanne in Switzerland. He received his PhD in Earth Sciences from the University of Grenoble, France, in 2012, after which he spent 12 years at the University of Bern as a postdoctoral researcher, senior scientist and assistant professor. His work aims to understand the conditions and rates of metamorphic processes by combining high-resolution geochemical analysis with thermodynamic modelling. Pierre has contributed to the development of important community tools, including the mapping software XMapTools and major petrochemical modelling tools and databases. He has been awarded in 2020 an ERC Starting Grant entitled Prograde metamorphism Modelling: a new petrochronological and computing framework (PROMOTING), co-edited a volume of the Reviews in Mineralogy and Geochemistry series on petrochronology, and received several medals and prizes including the Barrow Award 2024.