Alpine rock reveals dynamics of plate movements in Earth's interior

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Professor Lucie Tajčmanová, Heidelberg University, examines the whiteschist sample from the Dora Maira Massif of the Western Alps. Credit: Sebastian Cionoiu, Heidelberg University

Geoscientists analyze rocks in mountain belts to reconstruct how they once moved downward into the depths and then returned to the surface. This history of burial and exhumation sheds light on the mechanisms of plate tectonics and mountain building.

Certain rocks that sink far down into Earth's interior together with plates are transformed into different types under the enormous pressure that prevails there. During this UHP metamorphosis (UHP: ultra-high pressure), silica (SiO_2) in the rock, for example, becomes coesite, which is also referred to as the UHP polymorph of SiO_2. Although it is chemically still silica, the crystal lattices are more tightly packed and therefore denser.

When the plates move upwards again from the depths, the UHP rocks also come to the surface and can be found in certain places in the mountains. Their mineral composition provides information about the pressures to which they were exposed during their vertical journey through Earth's interior. Using lithostatic pressure as a unit of measurement, it is possible to correlate pressure and depth: the higher the pressure, the deeper the rocks once lay.

Until now, research had assumed that UHP rocks were buried at a depth of 120 kilometers. From there, they returned to the surface together with the plates. In the process, ambient pressure decreased at a stable rate, i.e., statically. However, a new study by Goethe University Frankfurt and the universities of Heidelberg and Rennes (France) published in *Nature Communications* calls this assumption of a long, continuous ascent into question.

Among those involved in the study on the part of Goethe University Frankfurt were first author Cindy Luisier, who came to the university on a Humboldt Research Fellowship, and Thibault Duretz, head of the Geodynamic Modeling Working Group at the Department of Geosciences.

The research team analyzed whiteschist from the Dora Maira Massif in the Western Alps, Italy. "Whiteschists are rocks that formed as a result of the UHP metamorphosis of a hydrothermally altered granite during the formation of the Alps," explains Duretz. "What is special about them is the large amount of coesite. The coesite crystals in the whiteschist are several hundred micrometers in size, which makes them ideal for our experiments."

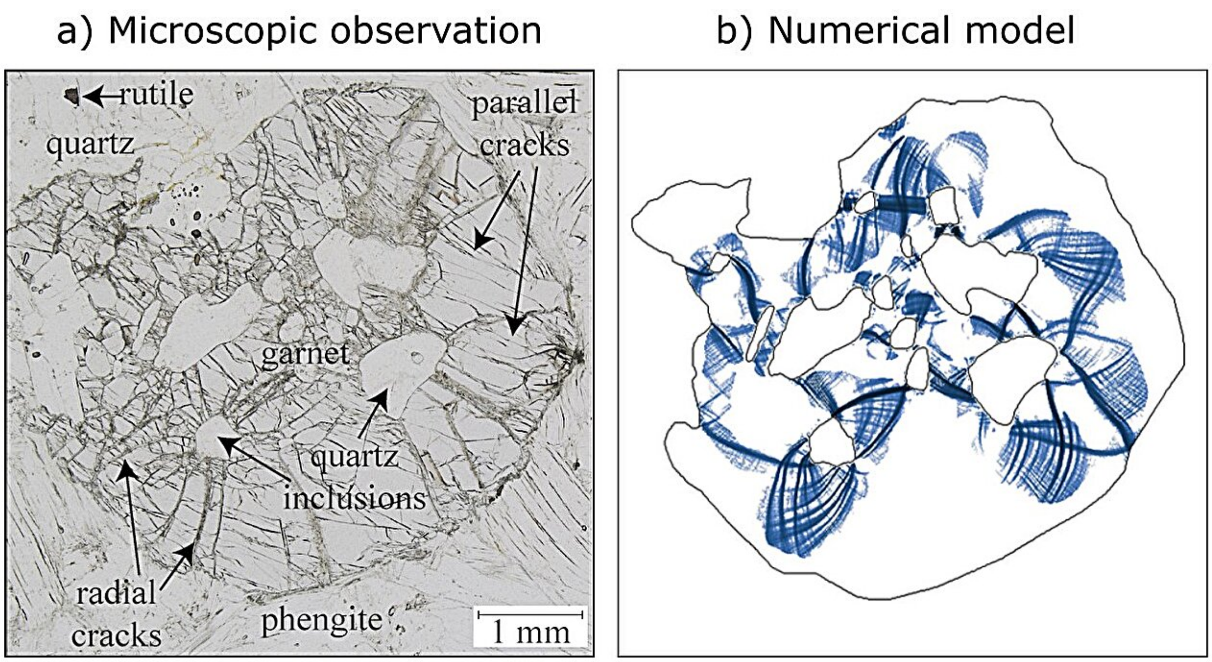
For the microscopic examination, a thin section of the white shale was glued to a glass slide (center of the picture). Credit: Sebastian Cionoiu, Heidelberg University

The piece of whiteschist from the Dora Maira Massif contained pink garnets in a silvery-white matrix composed of quartz and other minerals. "The rock has special chemical and thus mineralogical properties," says Duretz. Together with the team, he analyzed it by first cutting a very thin slice about 50 micrometers thick and then gluing it onto glass. In this way, it was possible to identify the minerals under a microscope. The next step was computer modeling of specific, particularly interesting areas.

These areas were silica particles surrounded by the grains of pink garnet, in which two SiO_2 polymorphs had formed. One of these was coesite, which had formed under very high pressure (4.3 gigapascals). The other silica polymorph was quartz, which lay like a ring around the coesite. It had formed under much lower pressure (1.1 gigapascals).

The whiteschist had evidently first been exposed to very high and then much lower pressure. There had been a sharp decrease in pressure or decompression. The most important discovery was that spoke-shaped cracks radiated from the SiO_2 inclusions in all directions: the result of the phase transition from coesite to quartz. The effect of this transition was a large change in volume, and it caused extensive geological stresses in the rock. These made the garnet surrounding the SiO_2 inclusions fracture.

"Such radial cracks can only form if the host mineral, the garnet, stays very strong," explains Duretz. "At such temperatures, garnet only stays very strong if the pressure drops very quickly." On a geological timescale, "very quickly" means in thousands to hundreds of thousands of years. In this "short" period, the pressure must have dropped from 4.3 to 1.1 gigapascals. The garnet would otherwise have creeped viscously to compensate for the change in volume in the SiO_2 inclusions, instead of forming cracks.



Fine structure of the whiteschist sample: One of the pink garnet grains (left image, embedded in a matrix of quartz, rutile and phengite) with SiO_2 inclusions (quartz inclusions), from which cracks originate. Numerical models (right image) predicts the generation of garnet failure. Credit: Thibaut Duretz, Goethe University Frankfurt

According to Duretz, the previous assumption that UHP rock reaches a depth of 120 kilometers seems less probable in view of this rapid decompression because the ascent from such a depth would take place over a long period of time, which does not equate with the high decompression rate, he says. "We rather presume that our whiteschist lay at a depth of only 60 to 80 kilometers," says the geoscientist.

And the processes underway in Earth's interior could also be quite different than assumed in the past. That rock units move continuously upwards over great distances, from a depth of 120 kilometers to the surface, also seems less probable than previously thought.

"Our hypothesis is that rapid tectonic processes took place instead, which led to minimal vertical plate displacements." We can imagine it like this, he says, "The plates suddenly jerked upwards a little bit in Earth's interior—and as a result the pressure surrounding the UHP rock decreased in a relatively short time."

More information: Cindy Luisier et al, Garnet microstructures suggest ultra-fast decompression of ultrahigh-pressure rocks, *Nature Communications* (2023). DOI: 10.1038/s41467-023-41310-w

Provided by Heidelberg University

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