Evolution of a Fossil Subduction Zone: Insights from the Tauern Window, Eastern Alps

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Subduction zones play a crucial role in the evolution of Earth's lithosphere. In many orogens, deeply subducted coherent high-pressure (HP) nappes were exhumed from deep to shallow parts of subduction channels. This process significantly affects the deformation pattern and internal structure of the orogen. Exhumation seems to occur preferentially during the transition from subduction to collision, when dense oceanic lithosphere has been consumed entirely and more buoyant continental lithosphere from a passive continental margin enters the subduction zone. Here, we present a detailed study on the structural, kinematic, and metamorphic evolution of a well-preserved paleo-subduction channel within the Tauern Window (Alps).

First, we reevaluated the metamorphic history and regional tectono-stratigraphy of the tectonic units in the central Tauern Window. These units originate from the Alpine Tethys oceanic domain and the adjacent European passive continental margin. They experienced HP conditions during Alpine subduction, which was followed by exhumation to their current position in the Alpine nappe stack. By integrating new structural data and the well-preserved stratigraphy of the ocean-continent transition, we reconstructed the structure and kinematics of the nappes in great detail. Notably, we document a recumbent, tens-of-kilometers-scale sheath fold formed during pervasive top-to-the-foreland shear. This sheath fold comprises an isoclinally folded thrust that transported ophiolite relicts from the former Alpine Tethys onto a distal part of the European continental margin during early stages of subduction. It formed under HP conditions, immediately after the Europe-derived rocks in its core reached their maximum burial depth. The non-cylindrical shape of the sheath fold suggests its nucleation at a promontory of the former margin, inherited from Mesozoic rifting and subsequently amplified to a sheath geometry during top-to-the-foreland shear in the subduction zone.

To gain insight into the temperature (T) structure of the sheath fold, we employed Raman spectroscopy on carbonaceous material (RSCM) thermometry on a large number of samples with high spatial resolution. The systematic spatial temperature trends reveal distinct domains related to the original subduction metamorphism and later T-dominated (Barrovian) metamorphic overprint. Integrating the peak-temperature pattern with the fold geometry unveils a two-stage process of nappe formation and sheath folding during exhumation.

Our results highlight the existence of considerable along-strike heterogeneity within the deep portion of a fossil subduction zone, likely influenced by inherited rift structures and exhumation processes. Understanding such heterogeneities is crucial for interpreting seismic sections and numerical simulations of subduction zones, emphasizing the need to consider three-dimensional complexities beyond the idealized cylindrical models often used. By unraveling the structural and metamorphic evolution of exhumed HP nappes in the Tauern Window, this study contributes to a better understanding of the dynamic processes operating within subduction zones and their implications for mountain building.