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Discriminating exhumation models of ultra-high-pressure rocks in the Western Alps by structural record

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Despite extensive research, the dynamics of tectonic nappes exhibiting high- and ultrahigh-pressure rocks [(U)HP] is still debated. We classify existing models for nappe formation into two types, and refer to them as the thrust and intrusion models.

Classical thrust models approximate the orogen as a wedge with a rigid buttress behind and a subducting lithospheric slab beneath. The dominant process of nappe formation is thrusting (brittle and/or ductile) that generates a dominant top-to-the-foreland sense of shear. Thrust models can explain the imbricate nappe stacking and first-order structural observations in the Western Alps.

However, in the last decades (U)HP rocks were found in nappes, and it is usually assumed that metamorphic pressure is a good indicator of maximum burial. In intrusion models, (U)HP rocks are subducted to mantle depths (>100 km) and return to crustal depths by buoyancy-driven or tectonically-forced flow. Intrusion models could reproduce the first-order patterns of P-T-t paths of the Western Alps.

Nappe formation at such mantle depths cannot be explained by the thrust model; nappe intrusion from large depths into shallower areas seems more appropriate. This argument against thrust models, however, is solely based on the assumption that metamorphic pressure indicates maximum burial (assuming lithostatic pressure). This very assumption is the only argument in favour of the intrusion models. If, however, significant and positive deviations from lithostatic pressure existed during nappe formation, then (U)HP rocks would have been formed at significantly shallower depth, and thrust models could be applicable to the Western Alps reconciling both structural and P-T-t records.

Discrimination between the two nappe-forming models can better be achieved by examining the absence of a particular structural record and not by evaluating the existing structural and P-T-t records. A fundamental kinematic (rheology and driving force independent) feature of the intrusion scenario is the upward movement of tectonic units from depths >100 km that requires the presence of a major extensional shear zone in the hanging wall of the exhuming (U)HP unit. However, in several well-studied nappes of the Western Alps exhibiting (U)HP rocks such a major extensional shear zone has yet to be identified. By contrast, the earliest and dominant coherent structures recorded along the upper boundary of these (U)HP units are top-to-the-foreland shear zones consistent with the thrust model.

In summary, the structural data lend support to the thrust model and rejects the intrusion model, while the P-T-t data favour the intrusion model, given the assumption of negligible non-lithostatic pressure. Completely different and again rheology independent argument rules out negligible non-lithostatic pressure in mountainous areas by requiring positive non-lithostatic pressure anomaly to support the gravitational potential energy of topography and crustal roots. The magnitude of the pressure anomaly is of the same order of magnitude as the plate-driving forces.