Erosive Denudation vs. Extensional Unroofing;
A Discussion on Exhumation of the Tauern Window

Susanne Schneider*[1], Audrey S. Bertrand[1], Silvia Favaro[1], Sebastian Garcia[1], Konrad Hammerschmidt[1], Mark R. Handy[1], Claudio L. Rosenberg[1], Andreas Scharf[1] and Stefan M. Schmid[2]
[1]Freie Universität Berlin, Institute of Geological Sciences
[2] Eidgenössische Technische Hochschule Zürich, Institute of Geophysics
*Sanne5@web.de

In this combined study we present new structural and geochronological results of the Tauern Window (Eastern Alps) from sub-millimetre scale to map view and compile them with literature data. We focus on the kinematics related to exhumation in Oligocene and Miocene time. Exhumation is higher and younger in the western than in the eastern Tauern Window. To understand the results in a dynamic sense, we discuss the influences of the driving forces South-Alpine indentation and subduction rollback within the Carpathians acting during Oligocene/Miocene time.

On the base of a new tectonic map and sections we divide the structural evolution of the Tauern Window into five deformation stages (Schmid et al. this vol.). Deformational stage (D4) is ductile and mainly responsible for the present day appearance of the tectonic window. The Tauern Window is a structural and metamorphic dome, to its western and eastern ends it is bordered by two km-scale normal fault systems (NFSs), the Brenner NFS in the west and the Katschberg NFS in the east. These NFSs consist of mylonitic shear zones (SZs), which are capped by co genetic brittle normal faults (NFs) during cooling (D5). To its northern and southern margins it is bordered by a series of ductile shear zones and brittle strike-slip faults.

During D4 pre-existing structures (D1-D3) were folded in upright fashion and form an orogen-parallel dome. Due to different style in deformation (D4) the Tauern Window is organised in eastern, central and western sub-dome. The central sub-dome preserves isoclinally folded nappe contacts (D2), which are less affected by D3 and D4 overprinting. The more open folds of the eastern sub-dome are slightly elongated and have broad hinges. They strike SE-NW and are separated by a tight syncline (Favaro et al., this vol.). Main foliation within the eastern sub-dome is a composite foliation (S1/S2) imbricated during D3 and folded during D4. The eastern end of the sub-dome is surrounded by the ductile Katschberg NFS, whose northern and southern ends bend into steep dextral and sinistral shear zones, respectively, which remain within the window. Main foliation along the Katschberg NFS is a mylonitic S4 foliation formed during doming and coeval extensional unroofing (Scharf et al., this vol.). In contrast in the west, upright, ENE-WSW trending folds (D4) are tight with km-scale amplitudes and associated with m- to km-scale, predominantly sinistral shear zones in their steep limbs and tight synclines. Main foliation within the western sub-dome is a sub-vertical axial plane foliation (S4) with a sub-horizontal stretching lineation. Along the bordering and intervening sinistral shear zones S4 foliation is mylonitic. To the western margin foliations (S4) become flat and form the Brenner SZ, a mylonite belt of ca. 5 km thickness with normal sense of shear. The spatial change over from steep into flat S4 foliations occurs continuously along the Olperer SZ within the window and along the Jaufen SZ outside, both showing combined sinistral and normal sense of shear. Towards the NE steep S4 foliations acquire NE trends in the vicinity of Mittersill and merge into the brittle sinistral SEMP line at its western end.

This structural difference between the eastern and western sub-domes coincides largely with a distinctive cooling history defined by Rb/Sr cooling ages of micas, Ar/Ar cooling ages of micas, apatite fission track ages (AFT) and zircon fission track ages (ZFT) but crosscut folded nappe contacts (D1-D3). In the eastern sub-dome isochronal cooling ages form a broad, triangular pattern, which runs parallel to the Katschberg NFS. More or less the entire sub-dome cooled from above 550° C below 230° C between 27-17 Ma. Because of consistency between structural and thermal patterns within the eastern sub-dome, ductile activity along the Katschberg NFS is constrained by cooling ages. Extensional unroofing (D4) terminated earlier in the east at ~ 17 Ma. In contrast the cooling pattern in the west is narrow, concentric and ENE-WSW elliptical. It has steep gradients in age values to its northern, southern and western margins and ZFT ages as young as ~11 Ma in the centre and the Brenner NFS. The western sub-dome cooled from above 600° C below 230° C between 20-11 Ma. Distribution of cooling ages displays two D4 structural features, the Brenner NFS on the one hand and upright tight folds on the other. These cooling ages overlap with formation ages of syn-kinematically grown phengites and K-feldspars, which range between 33-7 Ma. Post-kinematic blasts post-date mineral formation during sinistral shear at 15, 12 and 9 Ma. Within the eastern sub-dome the cooling pattern is dominated by extensional unroofing along the Katschberg NFS, whereas for the western sub-dome the cooling pattern is influenced by both, extensional unroofing along the Brenner NFS and upright, tight D4 folding followed by erosive denudation. The influence of the fold geometry on the cooling pattern nearly reaches the Brenner NFS, therefore we interpret the western sub-dome to be dominated by doming and consequently erosive denudation.

Published, late-stage (D4) uplift rates are about 3.6 mm/yr for the western and 4.5 mm/yr for the eastern sub-dome. During cooling the uplift rate decreased markedly to 0.4 mm/yr for the entire Tauern window, deduced from calculated age-elevation relation of ZFT data. Post-D4 uplift rates within the eastern sub-dome decreased further to 0.1 mm/yr, whereas uplift rate within the western sub-dome keep constant 0.4 mm/yr, deduced from age-elevation relation of AFT data.

Brittle deformation (D5) is mostly taken up by the Brenner NF at the western sub-dome and the fault zones bordering the South-Alpine indenter (Meran-Mauls and Pustertal line). The interior of the Tauern Window is mainly affected by strike-slip faulting passing into extensional faults close to the Brenner and the Katschberg NFSs. The direction of the minimal stress ($\sigma 3$) is ESE-WNW to ENE-WSW for the strike-slip regimes inside the Tauern Window, whereas along the Brenner and Katschberg NFs $\sigma 3$-direction is oriented ESE-WNW and SE-NW, respectively. The lack of evidence for a stress field compatible with upright folding suggests that the rocks affected in the brittle domain by the related inverse regime have been eroded since (Bertrand et al., this vol.). Active tectonics was deduced from combining GPS-data and seismicity over the entire Eastern Alps. Present motion of the entire Tauern Window is slightly northward. East of the window lateral extrusion of the Gurktal-block and the Styrian basin towards the northeast still occurs (Garcia, this vol.), with respect to stable Eurasia. Ongoing N-S convergence is mostly taken up within the Southern Alps while eastward extrusion occurs north of the SEMP line and east of the Katschberg NFS.

We interpret the central and eastern sub-dome to be decoupled at ~17 Ma from the western sub-dome and preserving an earlier structural stage, which has been overprinted in the western sub-dome. Continued N-S shortening was then taken up within the western sub-dome by brittle normal faulting along the Brenner NF, upright folding and sinistral strike-slip motion, which was transferred through the western sub-dome into the brittle SEMP line. We favour subduction rollback of the Carpathians and related E-W extension at ~25 Ma as the main reason for decoupling the central and eastern sub-dome from D4 doming induced by South-Alpine indentation.