From subduction to exhumation: interpretation of fold interference in the NW Tauern Window

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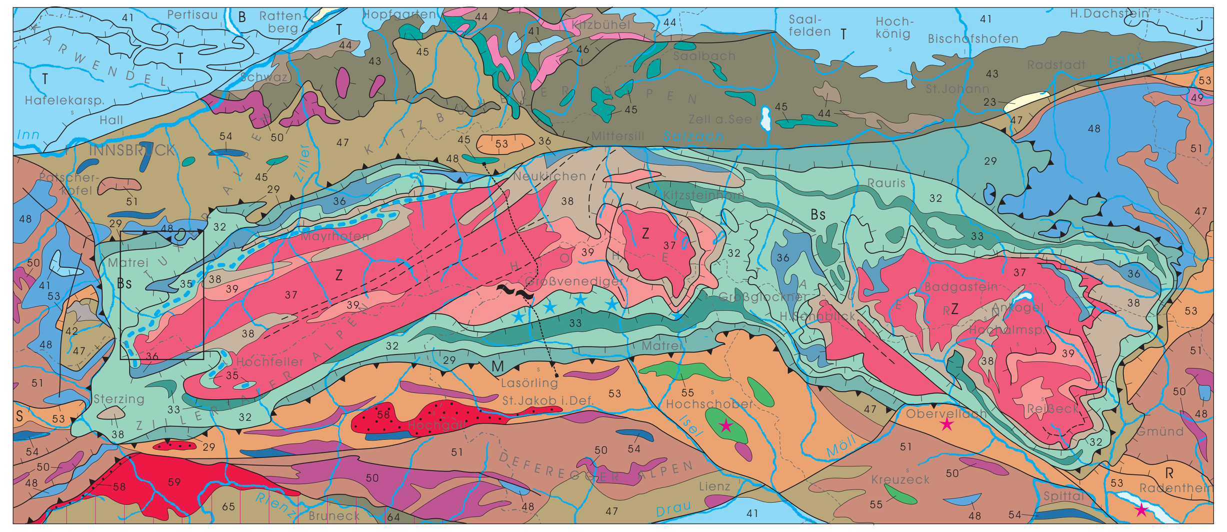
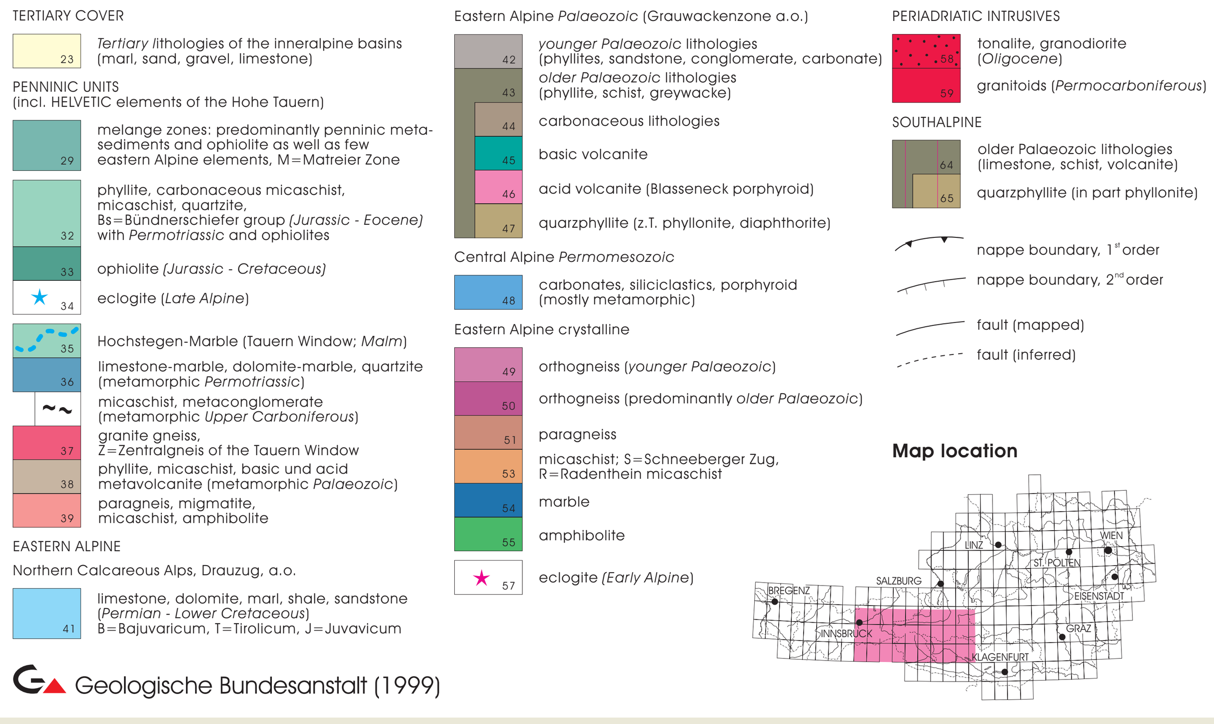
The Tauern Window (Pennine, Central Alps, Austria) is well-known for its subduction- and exhumation history. Our geological mapping in the NW Tauern Window revealed a complex fold interference pattern not identified on this scale before. These overprint relationships result from a sequence of folding phases in a setting that changed from subduction and nappe stacking to lateral extrusion and exhumation of the Tauern Window. The area of interest is situated at the NW edge of the Tuxer Zentralgneiskern (Subpenninic). Structures in the subpenninic Venediger-, Wolfendorn- and Modereck-nappes (Rockenschaub et al., 2007) were investigated in the Schmirn-, Kaserer-, Wildlahner- and Vals valleys.

Geological overview map of the Tauern Window

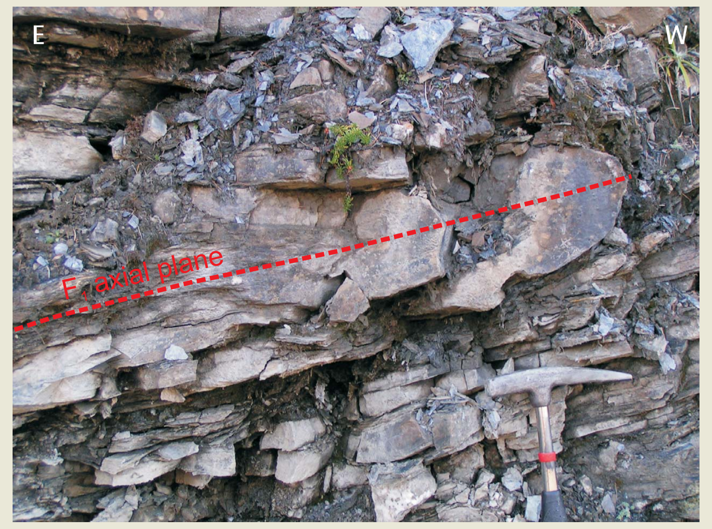


Cutout from the "Geologische Übersichtskarte der Republik Österreich 1: 1 500 000 (ohne Quartär)", published by the Geologische Bundesanstalt, Vienna 1999 - changed and ammended due to scale. Topography after ÖK 500 of the Bundesamt für Eich- und Vermessungswesen in Vienna.

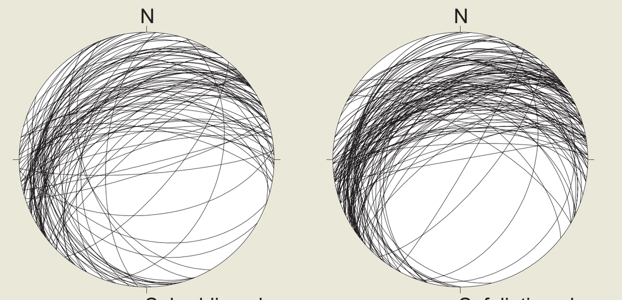


D$_1$

Folds of the first folding phase (D$_1$) are high amplitude highly similar isoclinal intrafolial folds from microfold (< 1 mm) to nappe fold (> 1 km) scale. Microfabric relationships indicate that the thermal peak, the Tauern crystallisation at ca. 30 Ma (Fügenschuh, 1997), followed F$_1$-folding. Microfabrics and mineralogy indicate a temperature jump across the Modereck nappe thrust, so after F$_1$ at least some movement occurred at the nappe thrusts. We estimate > 450 °C (Grt-in) in the Wolfendorn- and < 450°C (Bt-in, no Grt) in the Modereck nappe. The generally E-W striking configuration of the Tauern Window and the N-vergent nappe structures, including F$_1$ folds, are consistent with the orientation of smaller scale isoclinal fold structures.



Isoclinal D$_1$ fold in turbidites of the 'Bündnerschiefer'.



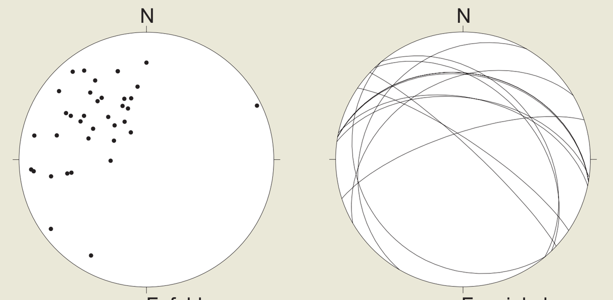
S$_0$ bedding planes

S$_1$ foliation planes

D$_2$

Folds of the second folding phase (D$_2$) generally are tight with NW-plunging fold axes and have only been observed close to the Tuxer Zentralgneiskern, particularly in the Wolfendorn nappe and at the base of the Modereck nappe. The Modereck nappe thrust is also F$_2$-folded. An axial plane foliation is developed only very locally, but is generally absent.

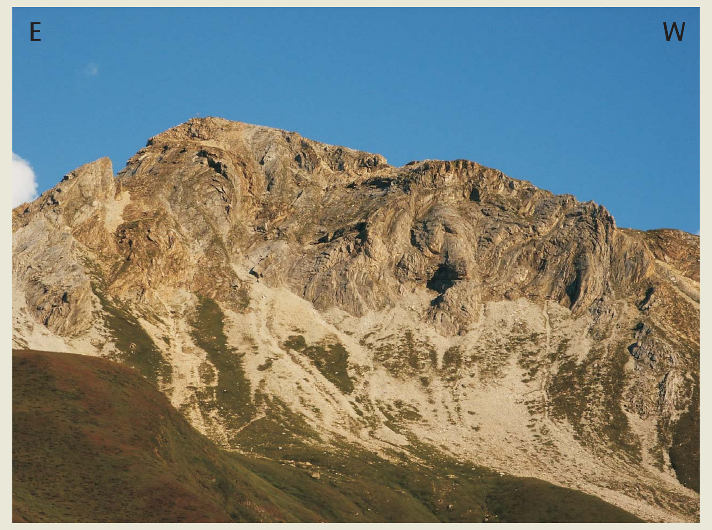
F$_2$ fold structures have been mapped up to km scale, particularly around and below the Modereck nappe thrust. We identified such folds at the Tuxer Joch, like Rosenberg (2006), and further SW on a larger scale. These folds have developed after peak temperature was reached.



F$_2$ fold axes

F$_2$ axial planes

NW-plunging F$_2$ folds in quartzites of a Permoscythian olistolith in the Kaserer group.

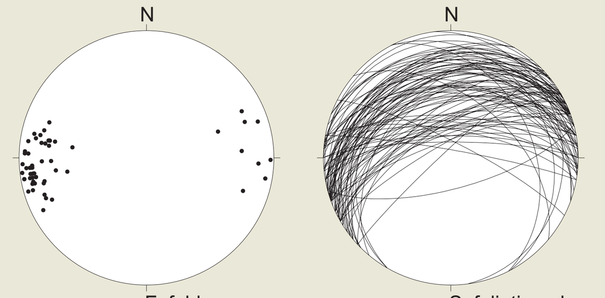


Approximately E-W trending ridge of the Schöberspitzen, parallel to the F$_3$-structure, with large NW-plunging F$_2$ folds.

F$_2$ folded Hochstegen marble and Kaserer group (km scale fold with NW-plunging fold axis).

D$_3$

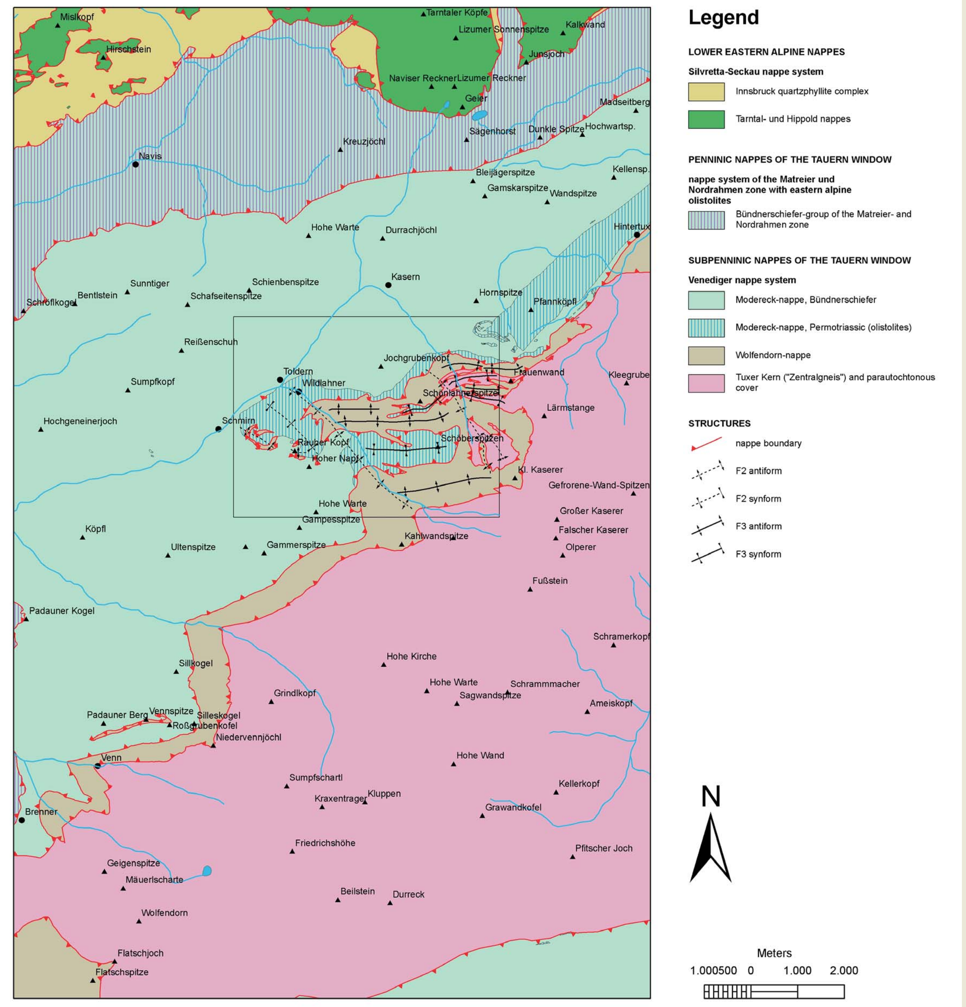
D$_3$ is characterised by S-vergent similar folds with steeply dipping axial planes and parallel stretching lineations. Top-W extensional shearbands related to the Brenner extensional fault interfered with these concurrently developed F$_3$-folds. The Brenner extensional fault system was active from the Eocene-Oligocene boundary to late Miocene (Fügenschuh et al., 1997 and references therein). Pressure solution, involving calcite, white mica, chlorite and quartz was dominant during D$_3$. This is best observable in the calcphyllites of the 'Bündnerschiefer' in the Modereck nappe and indicates that the main deformation occurred at ~ 300-200 °C.

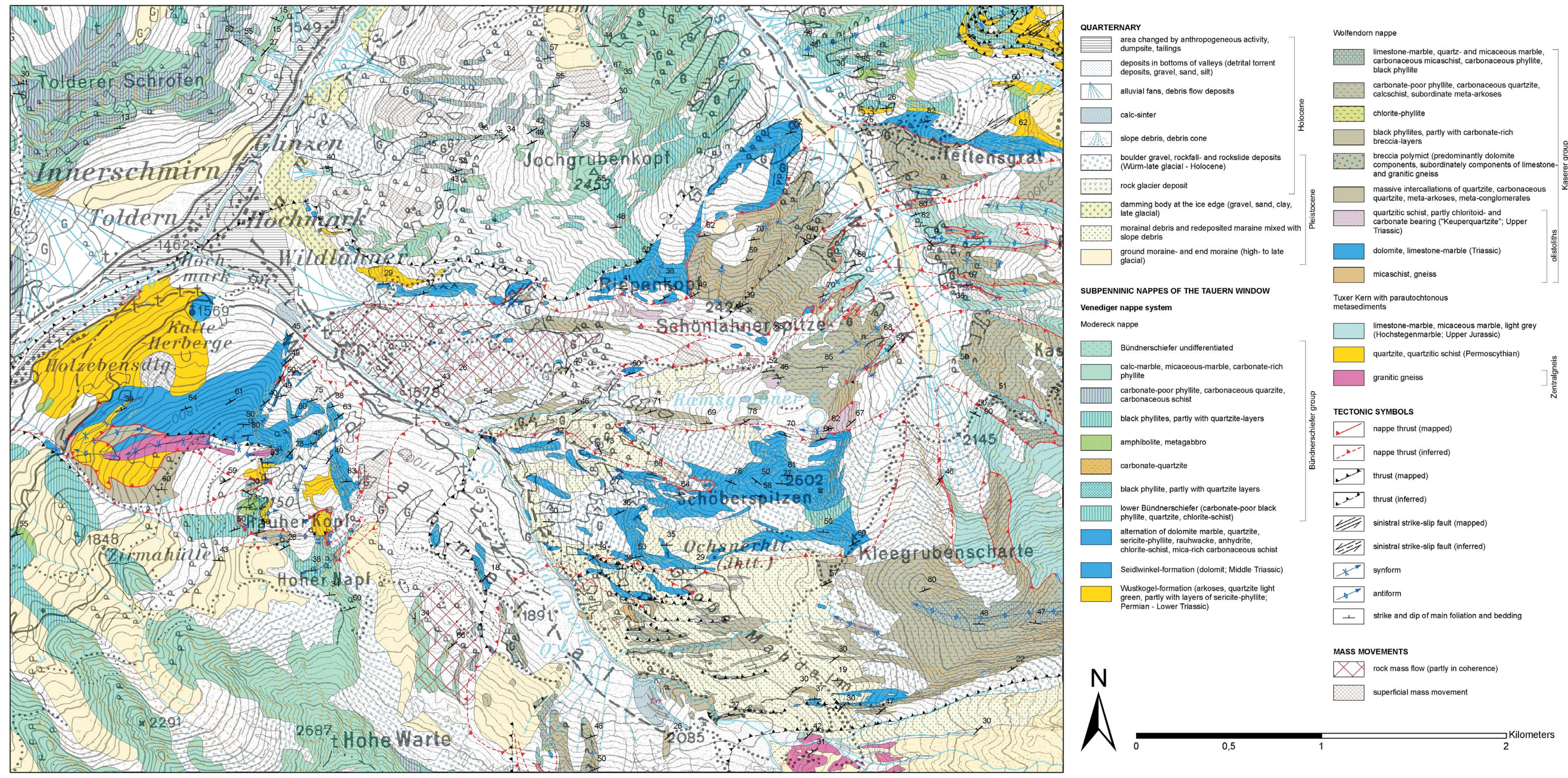


F$_3$ fold axes

S$_3$ foliation planes & F$_3$ axial planes

F$_3$ folded quartzitic phyllites of the 'Bündnerschiefer' with well-developed axial plane foliation.





Due to D$_3$- and D$_2$ overprinting relationships at the western extension of the Tauern Window the general structure does not simply plunge westward, as previously thought. It has been observed on up to km-scale that the general structure structure continues in SW- directionand downwards in a stepwise manner. These steps follow E-W striking segments along F$_3$ fold axes and shorter NW-plunging segments along D$_2$ fold axes. At the NW extension of the Tuxer Zentralgneiskern the Permotriassic at the base of the Modereck nappe is clearly affected by these overprint relationships. This resulted in very much thickened masses where fold hinges of large scale (F$_1$-,) F$_2$- and F$_3$-folds interfere, like the Permotriassic of the Schöberspitzen, whereas in the fold limbs the Permotriassic is very much reduced in thickness.

Typical F$_2$-F$_3$ interference pattern on sample scale, similar to mapped on km scale. View towards the South.

We relate these folding phases to a sequence of events that starts with subduction of the narrow Penninic oceanic basin, in which the 'Bündnerschiefer' of the Modereck nappe and of the Nordrahmenzone (Penninic, accretionary wedge) was being deposited. Overprint- and microstructural relationships, the attained P-T conditions as well as the tectonic configuration suggest that the isoclinal F$_1$-folds are related to nappe thrusting. This nappe thrusting occurred during and after subduction in the South.

The oblique NW-dipping orientation of F$_2$-fold axes relates to transpression with a sinistral component. So, D$_2$ occurred during initial lateral extrusion of the Tauern window whilst shorting was still going on. The estimated D$_2$ P-T conditions at the presently exposed structural level are lower than during D$_1$, indicating that extension was already going on in the presently eroded roof of the Tauern Window. During the subsequent D$_3$-phase deformation became more brittle and strain partitioning increased, leading to E-W striking strike-slip zones preferentially developing along F$_3$-fold limbs that separate E-W-trending large-scale F$_3$-antiforms. During the relative uplift of the Tauern Window the Brenner fault system increasingly interfered with the other D$_3$-structures. This can be seen in the area described here, but closer to the Wipptal this evidence is greater, as is the importance of the Brenner fault system.

Deformation scheme of the Wolfendorn and Modereck nappes of the NW Tauern Window

Deformation phase		D$_1$	D$_2$	D$_3$
Axial plane foliation (Characteristics/ Orientation)		S$_1$ Usually the main foliation, generally transposes bedding. N-dipping (generally shallow) axial plane foliation of isoclinal recumbent folds.	S$_2$ Very locally developed, generally absent	S$_3$ Penetrative steeply N-dipping variably strong developed spaced pressure solution foliation. Interference with fabrics of the Brenner normal fault system.
Fold style				
Fold axes (Plunge direction)		F$_1$ Subhorizontal ~ 240°. Locally reoriented due to younger folding phases.	F$_2$ ~ 45° NW plunging	F$_3$ Subhorizontal ~ 270°, closer to the Brenner normal fault steeper.
Lineation		StrLin$_1$ Parallel to F$_1$ fold axes	No stretching lineation recognisable	StrLin$_3$ Generally very well developed and dominant. Subhorizontal parallel to F$_3$ fold axes, closer to the Brenner normal fault steeper.
P-T conditions	Wolfendorn nappe	>450° (Grt-in)	Lower than during D$_1$	~ 300 – 200 °C (pressure solution fabrics)
	Modereck nappe	<450 (Bt-in, no Grt)	Lower than during D$_1$	~ 300 – 200 °C (pressure solution fabrics)
Age		Thermal peak at 30 Ma (Heidorn et al., 2002)	?	~ 15 – 10 Ma (according to data of Fügenschuh et al., 1997)
Deformation regime		Development of isoclinal nappe folds and top to NW thrusting	Sinistral ductile transpression	N-S constriction and exhumation by E-W extension.
Tectonic setting		Nappe stacking (related to subduction in the S)	Transition from nappe thrusting to updoming, whilst temperatures decreased by unroofing	Lateral extrusion, doming and exhumation of the Tauern window. Toward the West stronger interference with the Brenner normal fault.

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Rosenberg, 2006: Exhumation, thickening and orogen-parallel extension in the Eastern Alps: laboratory models and field observations. Pangeo 2006, oral presentation, conference series, 290.