3D structural model and kinematic interpretation of the Panixer Pass Transverse ~~Fold~~ Zone (Infrahelvetic Complex, eastern Switzerland)

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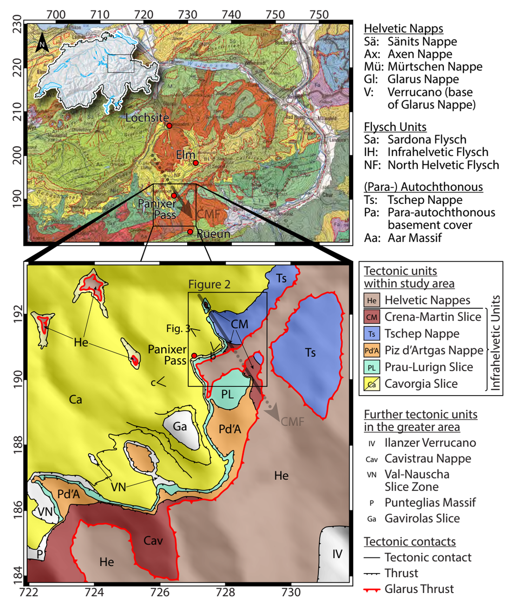
Introduction

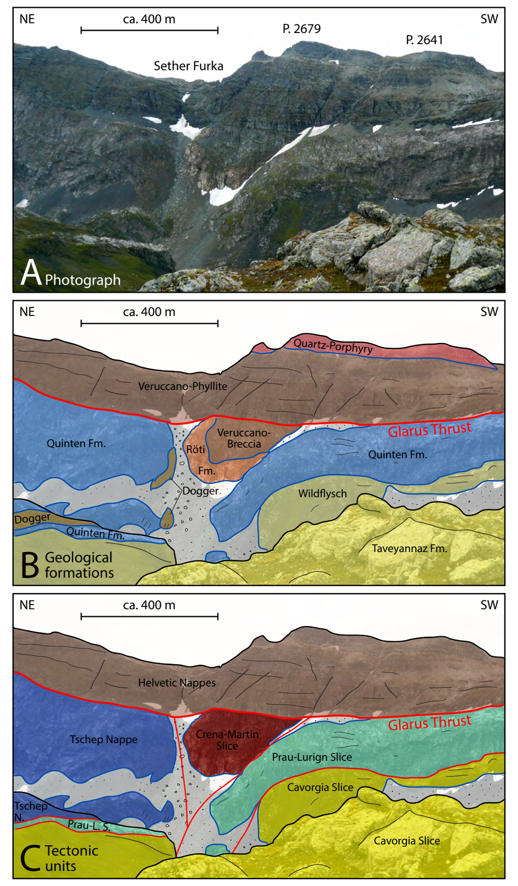
The Panixer Pass Transverse Zone (**PPTZ**) in the eastern Swiss Alps is a peculiar SSE-trending structure oriented approximately perpendicular to most alpine structures. It comprises a plunging fold (Crena-Martin Fold; **CMF**) with Permian Verrucano in its core, which is cut by the Glarus Thrust. Also, the structural buildup of the Infrahelvetic Complex changes considerably across the PPTZ; e.g. the para-autochthonous Tschep Nappe terminates at the PPTZ. Multiple theories of the structural evolution have been published (Oberholzer, 1933; Wyssling, 1950; Pfiffner, 1978); however, none of those is satisfying particularly because traditional 2D geological cross-sections have not been sufficient to fully understand the 3D complexity of the structure.

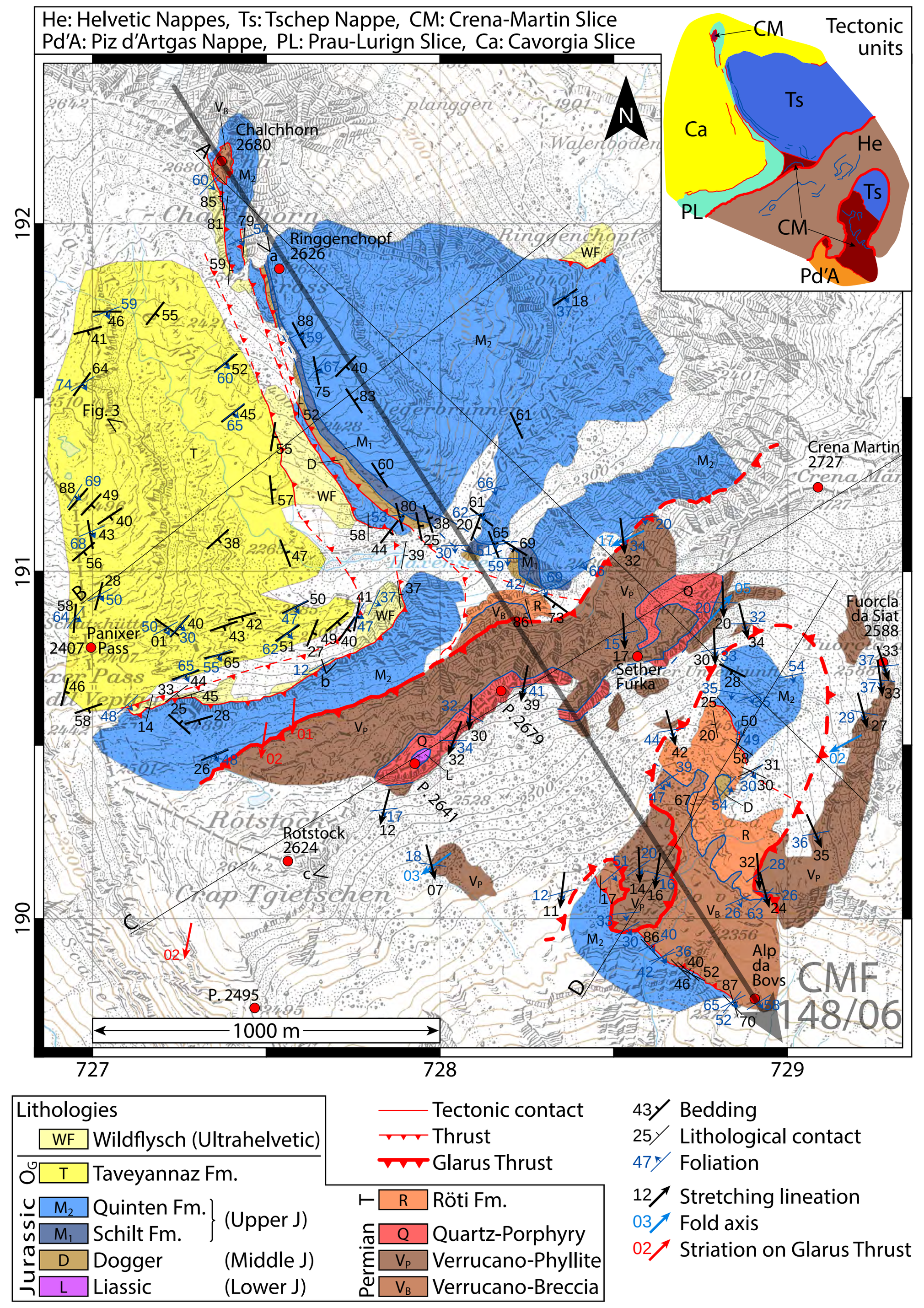
The main result and product of our study therefore is a 3D structural model of the PPTZ to get a better insight into its geometry. As input for the model, we produced a litho-stratigraphic map and collected structural orientation data. The final 3D structural model honors the observed surface geology and the expected 3D subsurface geometry. Our field data indicates that the shearing and transport direction was continuously NNW-directed, except for a phase of N-directed shearing during early movement along the Glarus Thrust and related foliation development in the Helvetic Nappes. The PPTZ developed prior to the penetrative foliation during a thrust-dominated deformation phase, for which we created a kinematic block model. According to this model, the PPTZ is the result of multiple lateral ramps and related lateral fault-bend folds that all developed in a similar positon amplifying each other. In particular, we do not propose ENE-WSW-directed shortening to form the PPTZ. Our kinematic model reproduces the key features of the 3D structural model.

Finally, we embed our kinematic model into the existing sequences of deformation phases (Schmid, 1975; Milnes and Pfiffner, 1977; Gasser and den Brok, 2008). We allow ourselves to reinterprete some of these proposed deformation phases to find a good correlation with our own observations.

Overview & Maps



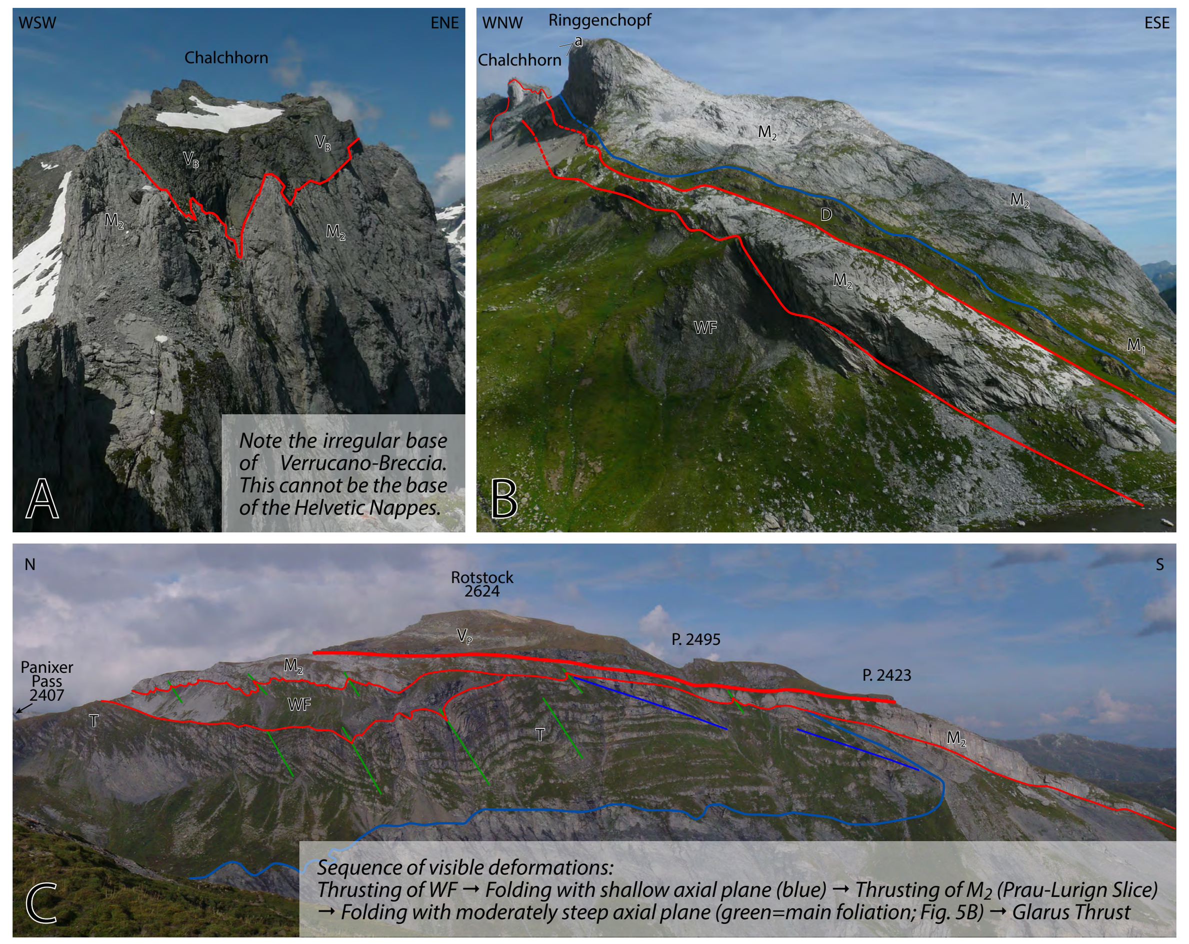




↖ *Fig. 1: Tectonic overview (after Pfiffner, 1978).*
↑ *Fig. 2: Litho-stratigraphic map and tectonic units (inset).*
← *Fig. 3: NW view of the PPTZ with the Crena-Martin Fold (CMF).*

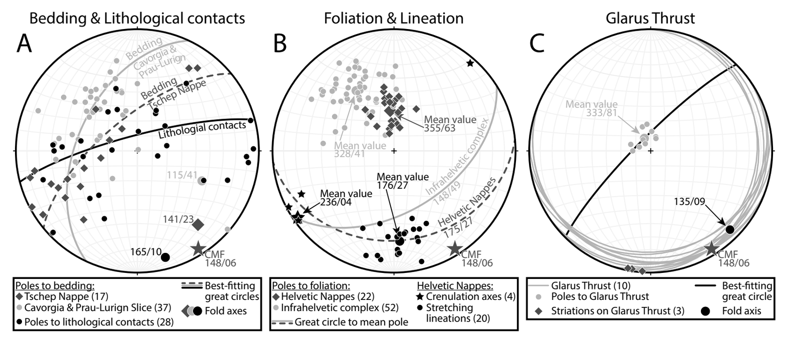
Field photographs

↓ *Fig. 4: For locations, see Fig. 1 & 3.*



Data

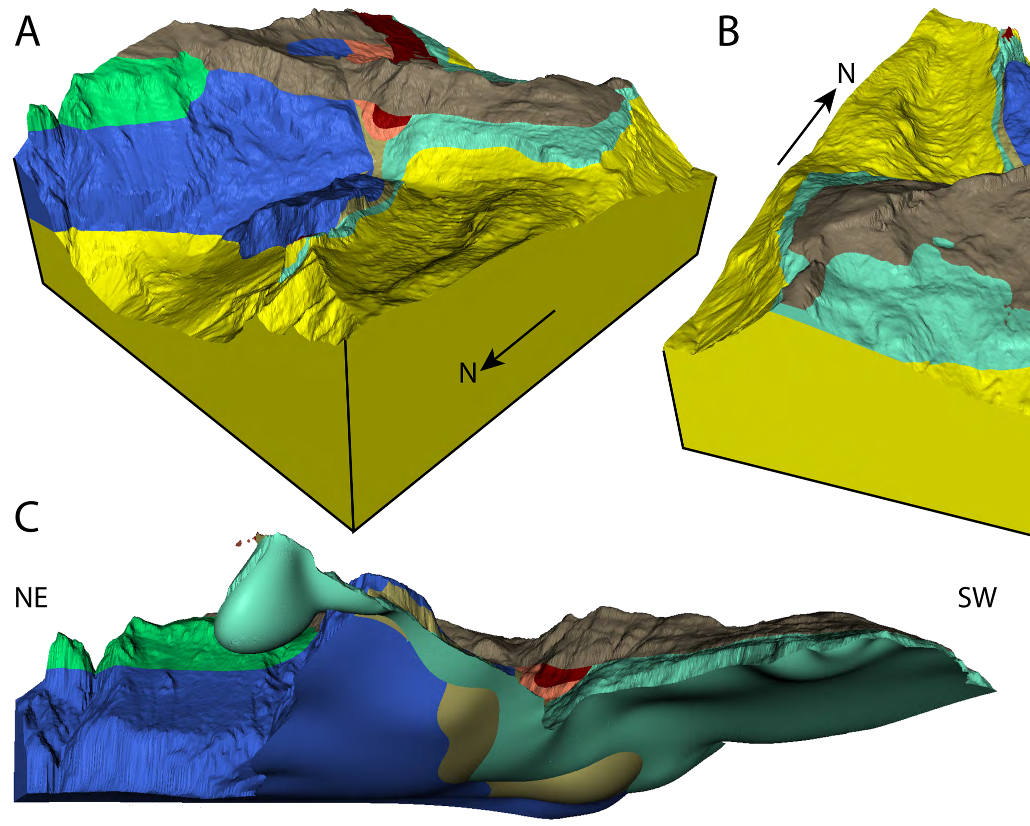
<u>Some observations:</u>
① Bedding is folded with a fold axis parallel to the CMF.
② Foliation is not affected by the CMF.
③ GT striations ≠ foliation dip and not perpendicular to crenulation in HN.



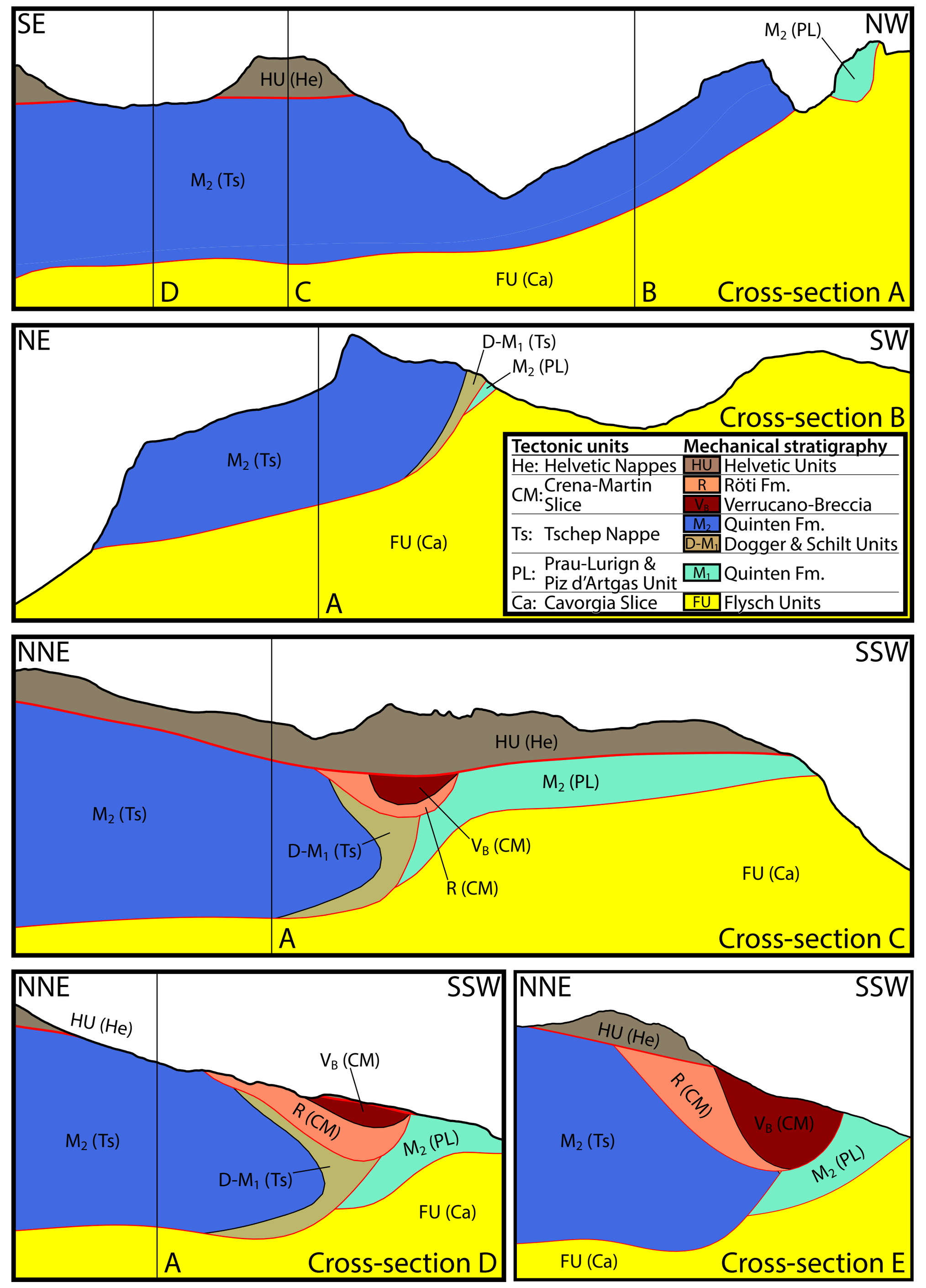
↑ *Fig. 5: Lower-hemisphere equal-area projections.*

3D structural model

We used the software Geomodeller to create a 3D structural model of the PPTZ. As input data we used the geological map (Fig. 3), all structural orientation data (Fig. 3 & 5), and a 2x2 m resolution DEM (swissALTI3D).



↖ *Fig. 6: Views of the 3D structural model. In C, the Flysch Units (Cavorgia Slice) are suppressed.*

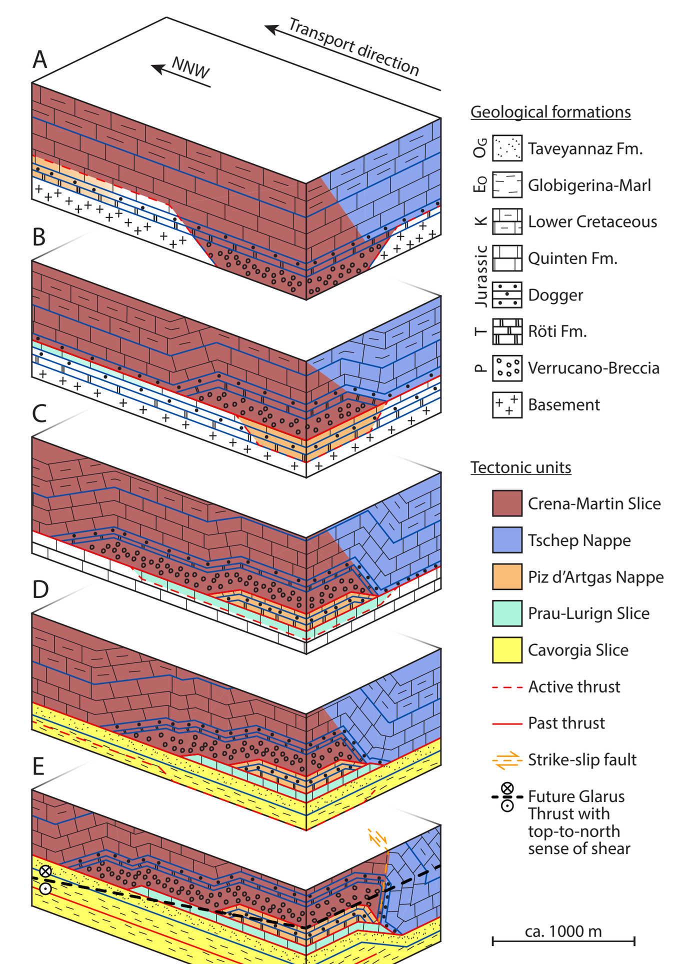


<u>Remark:</u> The Prau-Lurign Slice and the Piz d'Artgas Nappe are modelled as one unit.

<u>Some observations:</u>
Based on field observations, the geological map (Fig. 3) and the 3D structural model, we can make some observations:
④ Both the Wildflysch and the Prau-Lurign basal thrusts are folded by the CMF.
⑤ The Cavorgia Slice is folded into a monocline below the CMF.
⑥ The Crena-Martin Slice and the Tschep Nappe together constitute a continuous Permian- Lower Cretaceous stratigraphy; yet we find signs for a tectonic contact.

↖ *Fig. 7: Cross-sections through the 3D structural model; their traces are shown in Fig. 3. Cross-section C roughly corresponds to the photograph in Fig. 2.*

Kinematic model for PPTZ



We developed a thrust-dominated kinematic box model explaining the key features of the PPTZ.

Important points are:

- SW of the future PPTZ, thrusting steps down in the developing nappe stack; in the NE, thrusting remains at the Ts base.
- Therefore, multiple lateral ramps and related lateral fault-bend folds all develop in a similar position amplifying each other.
- During this development, the CM and Ts retain their stratigraphic contact; they only separate at the very end.

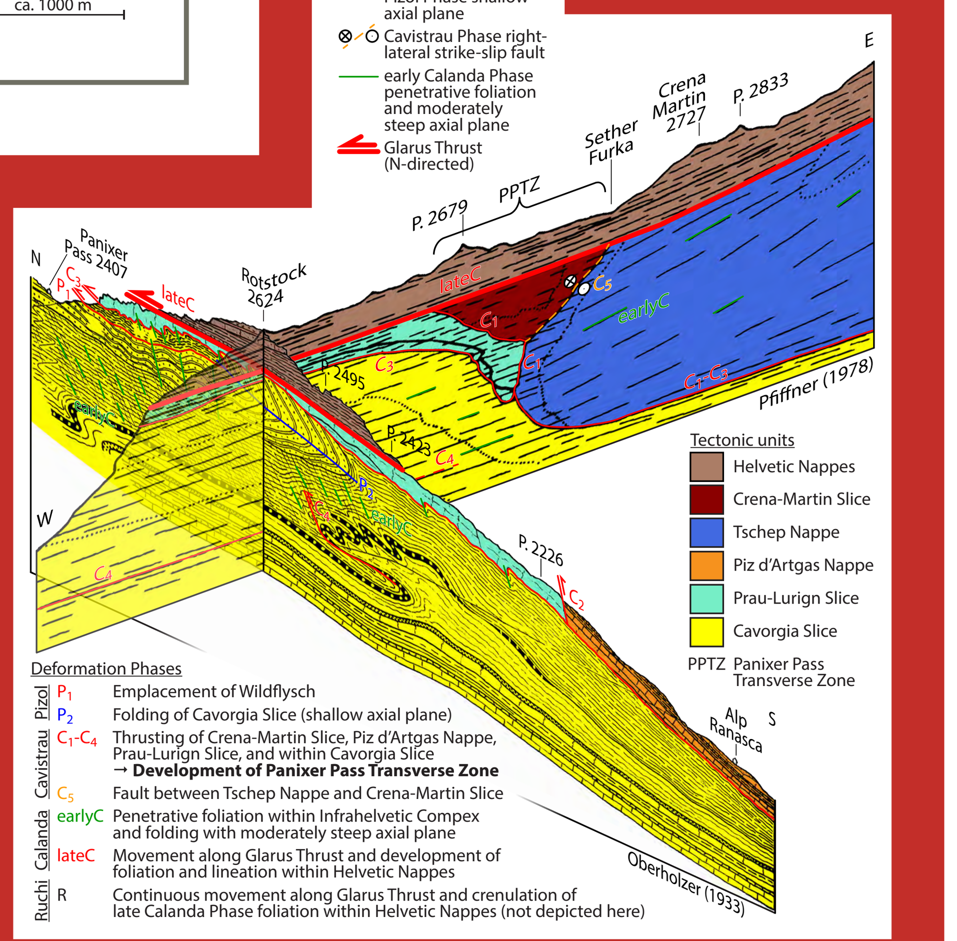
← *Fig. 8: Possible kinematic evolution of the PPTZ visualized as block models.*

Larger-scale interpretation

Based on ①, ②, ④, and ⑤, we place our kinematic box model after thrusting of Wildflysch and folding of the Cavorgia Slice (shallow fold axis) and prior to the main foliation; hence in the Cavistrau Phase (Milnes & Pfiffner, 1977).

We also tried to embed the development of the PPTZ and other field observations into existing sequences of deformation phases. This is however up for discussion.

↓ *Fig. 9: Pseudo-3D view of interpreted deformation phases.*



→ *Table: Our interpretations embedded into previously proposed sequences of deformation phases.*

Authors	Schmid (1975)	Milnes & Pfiffner (1977)	This study	Gasser & den Brok (2008)	Gasser & den Brok (2008)
Study area	Infrahelvetic Complex Sernft Valley	Infrahelvetic Complex Kunkels- and Kistenpass	Infrahelvetic Complex & Helvetic Nappes Panixer Pass Transverse Zone	New interpretation	Infrahelvetic Complex Landesplattenberg
Phase correlations	**Phase 3** Development of Glarus Thrust and crenulation cleavage below Glarus Thrust	**Ruchi Phase** Further movement along Glarus Thrust and crenulation cleavage below Glarus Thrust	**Ruchi Phase** Further movement along Glarus Thrust and crenulation of late Calanda Phase foliation within Helvetic Nappes and	Thrusting along Glarus Thrust; **Ruchi Phase** Foliation and folding	Thrusting along Glarus Thrust; **Ruchi Phase** Foliation and folding
	Thrusting of Subhelvetic Units				Thrusting of Subhelvetic Units
	Phase 2 Ductile penetrative phase of folding with axial plane foliation	**Calanda Phase** Ductile penetrative deformation (folding and foliation development) Movement along Glarus Thrust	**late Calanda Phase** Ductile N-directed shearing and stretching (penetrative foliation) within Helvetic Nappes and early movement along Glarus Thrust	Thrusting of Subhelvetic Units	**Plattenberg F2 Phase** Penetrative tectonic foliation and meter- to decameter scale folding
					Thrusting of Wildflysch Nappe
			early Calanda Phase Ductile NNW-directed deformation (folding and penetrative foliation) within Infrahelvetic Complex	**Plattenberg F2 Phase** Penetrative tectonic foliation and meter- to decameter scale folding	**Plattenberg F1 Phase** Folding up to hectometer-scale
		Cavistrau Phase Thrusting of Subhelvetic Units	**Cavistrau Phase** Thrusting of and within Infrahelvetic Complex and formation of Panixer Pass Transverse Zone	Thrusting of Wildflysch Nappe	
	Phase 1 Diverticulation, gravity sliding? of Blattengrat and Sardona Nappes	**Pizol Phase** Emplacement of Blattengrat and Sardona Nappes	**Pizol Phase** Emplacement of Blattengrat / Sardona Nappes, as well as Ultrahelvetic Wildflysch; Isoclinal folding with shallow axial plane	Emplacement of Blattengrat and Sardona Nappes and pre F1 folding; **Plattenberg F1 Phase** Folding up to hectometer-scale	Emplacement of Blattengrat and Sardona Nappes; Pre F1 folding

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Milnes A.G. and Pfiffner O.A., 1977: Structural development of the infrahelvetic complex, eastern Switzerland. Eclogae Geologicae Helvetiae 70, 83–95.
Oberholzer J., 1933: Geologie der Glarneralpen. A. Francke AG.
Pfiffner O.A., 1978: Der Falten- und Kleindeckenbau im Infrahelvetikum der Ostschweiz. Eclogae Geologicae Helvetiae 71, 61–84.
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Wyssling L.E., 1950: Zur Geologie der Vorabgruppe. PhD Dissertation No. 1807, ETH Zurich, Switzerland.

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