Neotectonics and seismic hazard in the northern Alpine foreland (Northern Switzerland, adjacent France and Germany)

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I. Neotectonic scenario

The northern limit of the presently uplifted and deformed Alpine foreland (Fig. 1) can be followed from the southernmost Rhine Graben (E France & NW Switzerland) through Basel into the Lake Constance area (SW Germany & NE Switzerland). This northern limit coincides with the northern rim of a Permo-Carboniferous (=PC) trough, detected in the subsurface of Northern Switzerland (Fig. 2).

II. The controversy: Thick-skinned versus thin-skinned deformation

It is unclear yet, how the presently ongoing deformation in the Northern Alpine foreland, associated with **convergence rates in the order of 1 mm/a or less**, is partitioned between basement (crystalline basement, including Permo-Carboniferous troughs) and sedimentary cover, the latter being rheologically decoupled along Triassic evaporites. There is a consensus that classical Jura folding and thrusting was "thin-skinned". However, it is not clear yet as to what extent NW-SE- to N-S directed shortening within the basement might have migrated northward into Northern Switzerland and adjacent France and Germany since Pliocene times, inducing a change from former "thin"- to presently active "thick-skinned" deformation.

Knowledge of the rate and mode of deformation within the basement is crucial for any Seismic Hazard Analysis.

Evidence is still conflicting concerning the nature of present-day tectonic activity (thick-skinned versus thin-skinned deformation).

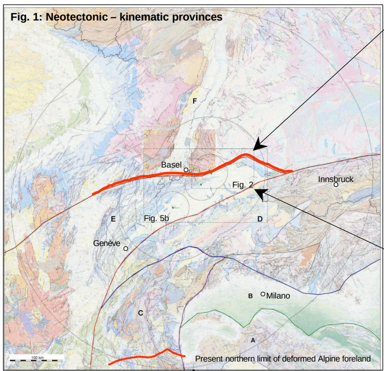
For example, evidence derived from fault plane solutions (seismotectonics), mostly collected from faulting within the basement, argues for presently ongoing transtension with a NE-SW-oriented axis of principal stretch (Fig. 3, 5b, 7). Geological evidence, collected within the sedimentary cover, indicates N-S to NW-SE-directed shortening and/or transpression, occasionally directly above reactivated basement faults (Fig. 6b and 6c).

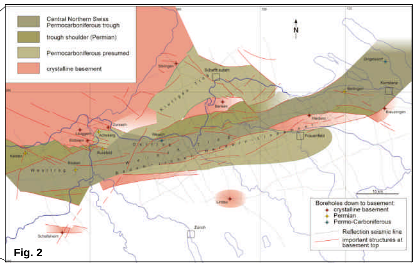
Terminology used

Thick-skinned deformation
- Basement and cover shortened by equal amounts.
- Decoupling between basement and cover minor or absent.

Thin-skinned deformation
- Sediments entirely detached from basement.
- Passive basement underneath Jura folds.
- Corresponding basement shortening confined to northern front of the Alps ("distant push").

Fig. 1: Neotectonic – kinematic provinces

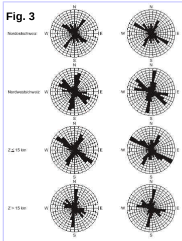




Key to Fig. 1

A: Apennines	D: Central and Eastern Alps
B: Adria plate	E: Proximal Alpine foreland
C: Western Alps	F: Distal Alpine Foreland

Fig. 2: Permo-Carboniferous (PC) trough system of Northern Switzerland. Its northern edge separates Provinces E and F (MÜLLER et al. (2001), NAGRA NTB 99-08)



Pre-existing fault sets in the Alpine foreland

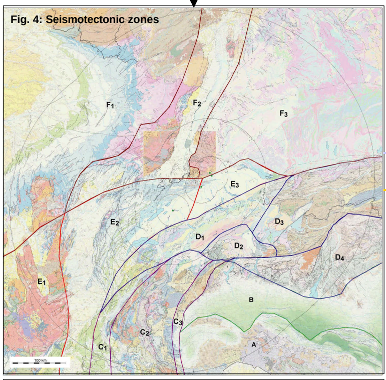
Fault system 1: (NNE-SSW) "Rhenish"

Fault system 2: (NW-SE) "Hercynic"

Fault system 3: (ENE-WSW) "Permo-Carboniferous"

Fig. 3 (left): earthquake nodal planes in the Northern Alpine Foreland. Note absence of planes related to system 3.
Fig. 5b (below): fault plane solutions in the Alpine foreland.
(both from: MÜLLER et al., 2001: NAGRA NTB 99-08)

Fig. 4: Seismotectonic zones



C1: Western „compressional" belt of Western Alps
strike-slip to thrusting

C2: Central extensional belt of Western Alps
normal faulting

C3: Eastern „compressional" belt of Western Alps
strike-slip to thrusting

D1: Northern „compressional" area
strike-slip, subordinate thrusting

D2: Central dome:
no fault plane solutions

D3: Austroalpine extensional domain
normal faulting, subordinate strike-slip

D4: Southern „compressional" area
no seismotectonic evidence

E1: Massif Central: reactivation mode unknown

E2: Bresse Graben – Jura - Western Molasse
strike-slip mode

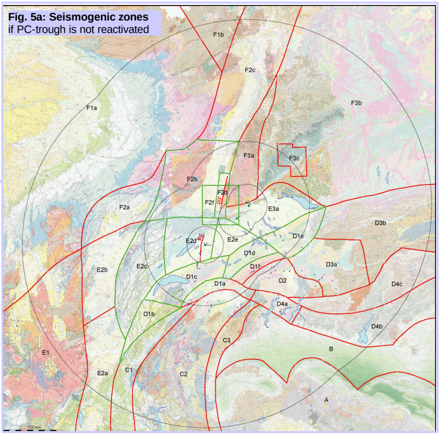
E3: Eastern Molasse basin
strike-slip to normal faulting

F1: Paris basin: strike-slip to normal faulting

F2: Upper Rhine Graben: strike-slip mode

F3: Black Forest - Schwäbische Alb
strike-slip to normal faulting

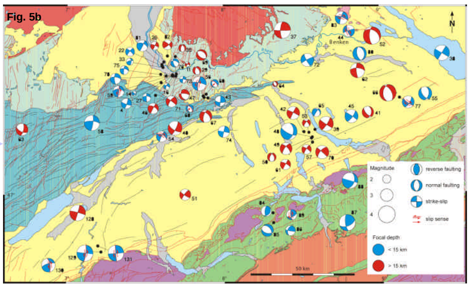
Fig. 5a: Seismogenic zones
if PC-trough is not reactivated



A to C: no further subdivision, see Fig. 4 and 5
D1a: Westernmost part of Valais-Simplon-Garda movement zone
D1b: Savoy part of northern Alps margin
D1c: Western Switzerland part of northern Alps margin
D1d: Central Switzerland part of northern Alps margin
D1e: Eastern Switzerland part of northern Alps margin
D1f: Aar massif
D3a: Mittelbünden – Engadine - Alta Valtellina area
D3b: Western Austria
D4a: Insubric part of Valais- Simplon-Garda movement zone
D4b: Southern Alps part of Valais-Simplon-Garda movement zone
D4c: Trento area
E2a: Basse Dauphinée
E2b: Bresse Graben
E2c: Western Jura
E2d: Western Molasse basin
Line source FF: Fribourg Fault
E2e: Central Molasse basin
E2n: Eastern Jura
E2f: southern PC-trough
E2s: southern Molasse basin
E3a: Eastern Molasse basin, south of PC-through
E3b: eastern part of PC-through
F1a: Paris basin
F1b: Lower Rhine Graben area
F2a: western part of Bresse-Rhine transfer area
F2b: eastern part of Bresse-Rhine transfer area
F2c: Upper Rhine Graben
Line source RF: Basel quake on Reinach fault
F2d: Basel quake re-activates fault set 1
F2e: western part of northern PC-trough
F2f: Basel quake due to interference between fault sets 1 and 3
F3a: Eastern flank of Upper Rhine Graben
F3b: SW Germany
F3c: Schwäbische Alb

Seismotectonic evidence – no system 3 faults reactivated?

Fig. 5b



Geological evidence – system 3 faults reactivated?

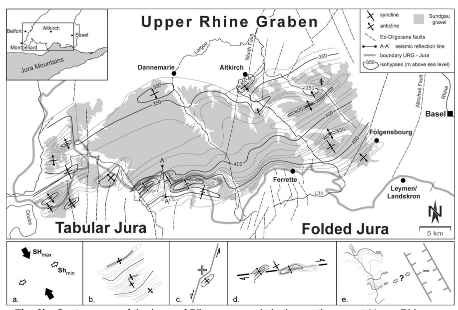


Fig. 6b: Contour map of the base of Pliocene gravels in the southernmost Upper Rhine Graben, illustrating Post-2.9 Ma shortening of its sedimentary cover. Within the recent stress field (a.), viable kinematic scenarios for the observed deformation (b. – e.) are indicated. En-échelon-aligned anticlines are thought to have formed above reactivated system-3 faults.

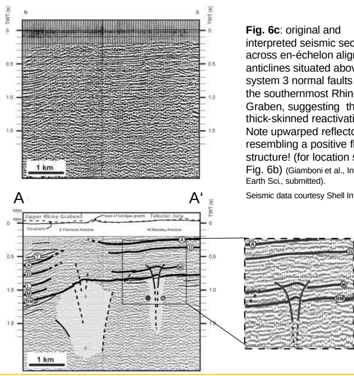
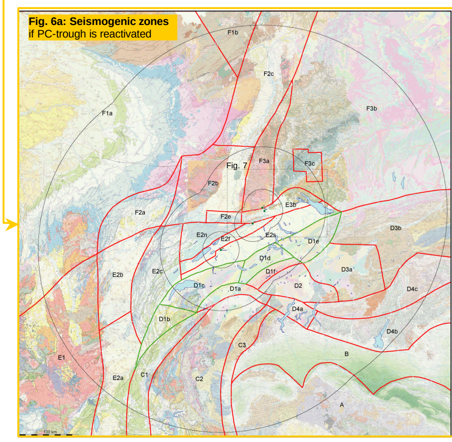
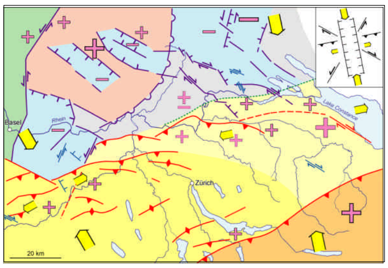


Fig. 6c: original and interpreted seismic section across en-échelon aligned anticlines situated above system 3 normal faults in the southernmost Rhine Graben, suggesting their thick-skinned reactivation. Note upwarped reflectors, resembling a positive flower structure! (for location see Fig. 6b) (Giamboni et al., Int. J. Earth Sci., submitted).

Seismic data courtesy Shell Int. EP

Fig. 6a: Seismogenic zones
if PC-trough is reactivated





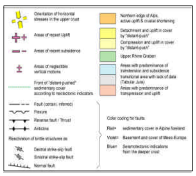


Fig. 7: Geodynamic concept for Northern Switzerland, incorporating seismotectonic and geological observations, as well as geodetic (precision levelling) data. (MÜLLER et al. (2001), NAGRA NTB 99-08)

Possibilities to explain the discrepancies

(**1**) Present-day deformation is thin-skinned, causing pronounced strain partitioning between basement and cover, as well as deviating associated stress fields.

(**2**) Present-day deformation is thick-skinned, in which case the presently monitored seismotectonic activity would not be representative for longer time periods and/or large cumulative strains.

(**3**) Complex interplay between still active "distant push" and the reactivation of pre-existing faults in the basement of Northern Switzerland, including inversion of PC-troughs (system 3 faults).

(**4**) Local decoupling - strike slip faulting in the basement is transformed into folding and thrusting of the cover across Triassic evaporites (so called "Pavoni model").

Outlook and future research

The resulting epistemic uncertainty will be built into a Probabilistic Seismic Hazard Analysis. Further investigations within ENTEC will hopefully significantly reduce these uncertainties. Knowledge about the seismic source of the 1356 AD Basel earthquake (strike slip, thrust or normal faulting? Reactivation of Oligocene or PC-faults?) is also crucial for the hazard assessment.

Evidence provided by the investigations of the "Reinach fault" are not considered as conclusive.

Evidence concerning recent rates of uplift and denudation gathered by NAGRA are compatible with results from ENTEC. Hence, stability of a planned high level repository is expected to be granted. Erosion of the hosting Aalenian „Opalinuston" formation is not expected within the coming million years.