The legacy of pre-existing structures for Palaeogene to recent tectonics - the southern Upper Rhine Graben

K. Ustaszewski*, M. Schumacher*, S. Schmid*

*) Geologisch-Paläontologisches Institut
Bernoullistrasse 32
Universität Basel
CH-4056 Basel
Switzerland

1. Regional geology

Integration of subsurface and surface data into a map of basement structures reveals the importance of pre-existing, Palaeozoic faults for the Palaeogene to recent structural evolution of the southern Upper Rhine Graben and Jura Mountains.
Trends of basement faults were derived from industry type reflection seismic lines and published subcrop maps (DEBRAND-PASSARD & COURBOULOIX, 1984; DIEBOLD, 1990), as well as gravimetric data (LUTZ, 1999). These data have been implemented into a manually contoured map of the top basement - base Mesozoic interface in an approximately 30 * 20 km large area W of Basel (Fig. 1).

a. Palaeogene rifting

Contemporaneous opening of the Palaeogene Upper Rhine Graben (URG) and Bresse Graben system was kinematically linked by the Rhine-Bresse transform zone (RBTZ), which formed along pre-existing crustal discontinuities inherited from the Variscan orogeny (LACOMBE et al., 1993) and subsequent (Late Carboniferous to Permian) post-orogenic transtension. Within the studied region, Palaeogene rifting initiated in Upper Eocene (Late Priabonian) times and encompassed sinistral transtensive reactivation of ENE-oriented basement faults and normal faulting along (N)NE-striking ("Rhenish") faults (SCHUMACHER, 2002). These movements were accommodated in the Mesozoic sedimentary cover by the formation of ENE-oriented flexures and "Rhenish"-striking half grabens with growth faults in the hanging wall. With respect to the paleostress field, the "Rhenish" faults were oriented perpendicular to $\sigma 3$ (E-W to ESE-WNW) and accommodated considerably higher amounts of vertical throw compared to ENE-oriented faults.
Superposition of flexuring and growth faulting resulted in increased subsidence with localised depocenters.
Half graben formation ceased with the Upper Rupelian "Meeressand" transgression and was followed by a wider and more uniform subsidence that encompassed areas previously unaffected by rifting.

b. Mio- Pliocene thin-skinned tectonics

Mio- to Pliocene (Post 11 Ma; KÄLIN, 1997), thin-skinned folding and thrusting of the Jura Mountains encountered the rift-related structural pattern, which had disrupted the Triassic basal décollement. This inherited pattern controlled the nucleation of thrusts and folds as well as transfer zones during the NW-directed transport of the detached sedimentary skin. This is evidenced in the high semblance of subsurface faults and surface structures in the Folded Jura.

c. Latest Pliocene to recent thick-skinned tectonics

Evidence for latest Pliocene to recent, thick-skinned reactivation of "Rhenish"-striking faults in a sinistral transpressive mode is found in reflection seismic data and is hitherto not discernible in Mesozoic sediments. It led to the formation of positive flower structures along the western end of the Folded Ferrette Jura arc and folding/upwarping of Pliocene sediments along its front.

A compressive or transpressive overprint of the formerly extensional flexures resulted in the formation of two ENE-striking, strongly curved en-échelon aligned anticlines along the northern edge of the otherwise horizontally layered Tabular Jura. This event resulted in post-Pliocene folding of the fluviatile Sundgau gravels together with their Mesozoic and rift-related substratum (GIAMBONI et al., submitted). Folding of the sedimentary skin prevails. The en-échelon geometry required differential shortening between the anticlines, which was accommodated by subordinate tear faults. These thin-skinned structures are located precisely above flower-structure-type basement features, suggesting that they are kinematically linked to the reactivation of deeply rooted structures.

2. Palaeostress versus recent in-situ stresses

Trajectories of the maximum principal stress (σ1), derived from fault plane data along the deformed northern margin of the Jura (comprising the en-échelon aligned anticlines of the Tabular Jura and the Ferrette arc of the Folded Jura) reveal a NNE- to NW-oriented σ1 with slightly divergent fan geometry (Fig. 2). This suggests divergent, outward-directed motion with respect to a reference point to the S (i.e. in concordance with a thin-skinned origin of the Folded Jura). Wrench faulting and arc-parallel extension veins, contemporaneously active with thrusting and folding (documented especially in the area of strongest curvature of the Ferrette arc) facilitated the formation of the highly arcuate shape of the frontal Jura segments. The fan-shaped stress trajectories could have resulted from a deflection in the proximity of transfer zones or basement faults.

The recent stress field in the sedimentary (Mesozoic to Tertiary) cover, as established from in-situ-stress measurements on borehole breakouts (BECKER, 2000), reveals N-S- to NNW-SSE-oriented maximum horizontal stresses Sh_{max}. They are thus in agreement with the obtained paleostress orientations and imply that the stress field in the investigated area remained constant ever since the onset of thin-skinned Jura folding ca. 11 Ma BP. This explains why any movements postdating this phase are not discernible in the Mesozoic cover using outcrop scale tectonic criteria, such as overprinting relationships on faults.

On the other hand, in-situ-stresses in the basement (HÄRING, 2001) and inversion of earthquake focal mechanisms (PLENEFISCH & BONJER, 1997; DEICHMANN et al., 2000) reveal a more NW-SE-orientation of Sh_{max}. This anticlockwise rotation of Sh_{max} from cover to basement is apparently a systematic phenomenon, found throughout northern Switzerland (MÜLLER et al., 2001) and gives evidence of a stress decoupling between sedimentary cover and its basement. Thus, both thin- and thick-skinned tectonics can superpose each other through time and space.

3. Conclusions

a. Inferences for seismic behaviour

Earthquake focal mechanisms display most seismicity along NE- to NNE-oriented faults (the “Rhenish” direction), predominantly in strike-slip mode. Seismic activity along ENE-trending faults of late Palaeozoic origin, on the other hand, is hitherto not documented within the presently available seismotectonic network.
However, with the considerations about stress decoupling made above and recurrence rates presumably longer than the time period of current seismic monitoring, the momentarily aseismic behaviour of ENE-oriented faults cannot be used to regard them as seismically entirely dormant.

b. Future research aims

The discrepancy in deformation styles between cover (predominantly folding and thrusting) and its basement (wrench faulting) along tectonically active structures is still not satisfactorily explained.
Implementation of further seismological and subsurface information from seismic tomography in a cooperation with the Strasbourg team (LOPES CARDOZO, GRANET), into a geodynamic model explaining all observed phenomena (e.g. in terms of a re-equilibrated critical taper) is the primary aim of coming research within the Basel group.

References cited:

BECKER, A., 2000. The Jura Mountains - an active foreland fold-and-thrust belt? Tectonophysics, 321: 381-406.

DEBRAND-PASSARD, S., COURBOULOIX, S., 1984. Synthèse Géologique du Sud-Est de la France, 126. BRGM.

DEICHMANN, N., BALLARIN DOLFIN, D., KASTRUP, U., 2000. Seismizität der Nord- und Zentralschweiz. NAGRA Technischer Bericht, 00-05. NAGRA, Wettingen, 94 pp.

DIEBOLD, P., NAEF, H., 1990. Der Nordschweizer Permokarbontrog. Nagra informiert, 2: 29-36.

GIAMBONI, M., USTASZEWSKI, K., SCHUMACHER, M., SCHMID, S., WETZEL, A. (submitted): Plio-Pleistocene Transpressional Reactivation Of Paleozoic And Paleogene Structures In The Rhine-Bresse Transform Zone (Northern Switzerland And Eastern France). Int. J. Earth Sci., submitted.

HÄRING, M., 2001. Horizontale Hauptspannung im Grundgebirge. http://www.geothermal.ch/.

KÄLIN, D., 1997. Litho- und Biostratigraphie der mittel- bis obermiozänen Bois de Raube-Formation (Nordwestschweiz). Eclogae Geologicae Helvetiae, 90(1): 97-114.

LACOMBE, O., ANGELIER, J., BYRNE, D., DUPIN, J., 1993. Eocene-Oligocene tectonics and kinematics of the Rhine-Saone continental transform zone (Eastern France). Tectonics, 12(4): 874-888.

LUTZ, H., 1999. Cartographie, Traitement et Interpretation des Donnes Gravimetriques du Fosse Rhenan Meridional (Projet Geofrance 3D). Diplôme d'ingénieur Thesis, Université Louis Pasteur - Strasbourg I, Strasbourg.

MÜLLER, W.H., NAEF, H., GRAF, H. R., 2001. Geologische Entwicklung der Nordschweiz, Neotektonik und Langzeitszenarien, Zürcher Weinland. NTB 99-08, NAGRA, Wettingen.

PLENEFISCH, T., BONJER, K., 1997. The stress field in the Rhine Graben area inferred from earthquake focal mechanisms and estimation of frictional parameters. Tectonophysics, 275: 71-97.

SCHUMACHER, M., 2002. Upper Rhine Graben: the Role of Pre-Existing Structures during Rift Evolution. Tectonics, 21(1), 10.2029/2001TC900022 (6-1 – 6-17).