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The 1356 earthquake: what do we really know?

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Abstract

Isoseismals based on historical and archaeological data strike E-W to ENE-WSW, which is oblique to perpendicular with respect to the Rhine graben. An ancient fault line following the southern border of the graben within the Basel-Dijon transfer zone passes through the center of the isoseismals. As a reactivated zone of inherited weaknesses it seems to fit best the admittedly skimpy data set as the fault responsible for the quake. Current seismicity indicates a stress field with the principal compressive component striking NW, which is not compatible with the Paleogene Rhine graben tectonics either. GPS data define a field of strain accumulation which, too, is at variance with Rhine graben tectonics. It defines a compressive field in the Alpine foreland, though closely related to the shape of the arc of the western Alps, and represents the current position of the southern boundary of the Europa plate. Basel is located within this currently active southern boundary. Therefore, the 1356 Basel earthquake should be termed a plate boundary event - even though the mechanics of the Africa-Europa plate boundary zone is not well understood. Rhine graben tectonics enters the picture only as a set of inherited faults, weak surfaces that are being reactivated under entirely new tectonic conditions.

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Different issues - matter for discussion

Pre-instrumental earthquakes are the domain of historians and archaeologists. The damage field is the basis for estimating physical parameters. The archival and archaeological documentation for the 1356 earthquake is rather skimpy. However, the recent reassessment by Werner Meyer (2006) is the most thorough and trustworthy investigation by the arguably best qualified person (Fig. 1).

An older but regionally more extensive appraisal of the damage field and implied isoseismals had been published already in 1979 by Mayer-Rosa and Cadiot (Fig. 2). The isoseismals in both maps are elliptical, with the long axis striking E-W to ENE-WSW, more or less perpendicular to the Rhine graben but conforming with the transferzone of Basel-Dijon between the Eo-Oligocene Rhine and Bresse grabens. This at first seemed strange, as conventional wisdom had always tied the earthquake to the Rhine graben. On closer examination of the tectonic situation, however, it was realized that the current stress field is compressional with the main horizontal axis striking NW and had nothing to do with the extensional Eo-Oligocene Rhine graben proper. The graben was but a zone of weakness - a scar - whose faults were reactivated in places with an entirely new dynamical function dictated by the compressive stress field. The truth of this statement was emphasized by the 1978 earthquake in the Suabian Alb, far away from the Rhine graben but on the main axis of the isoseismal ellipses (Fig. 2).

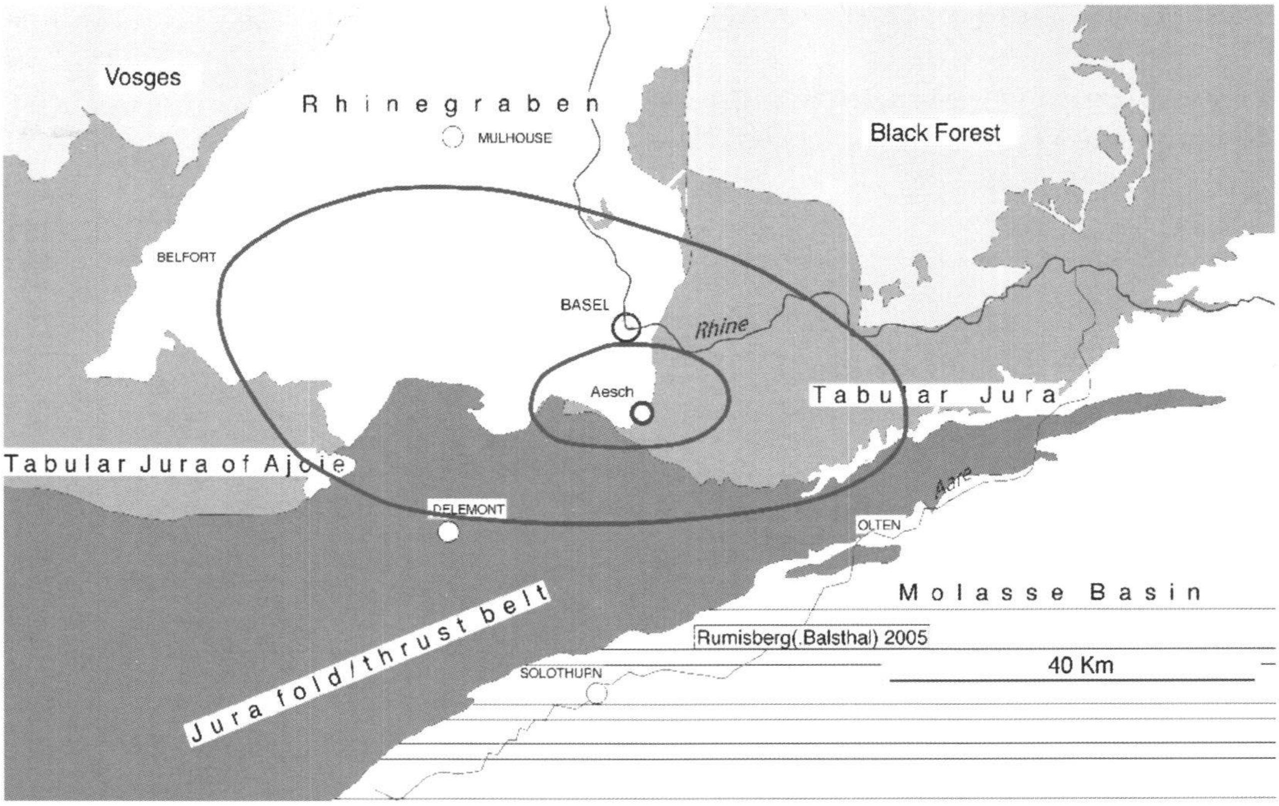

Fig. 1: The isoseismals of Meyer (2006; solid lines) superimposed on a geologic map of the Basel region (after Spicher 1980). Color code: white = Tertiary depressions; pale grey = Tertiary highs (the crystalline basement of Black Forest and Vosges), medium grey = tabular expanse of mostly Mesozoic limestones, dark grey = late Miocene fold/thrust belt of the Jura.

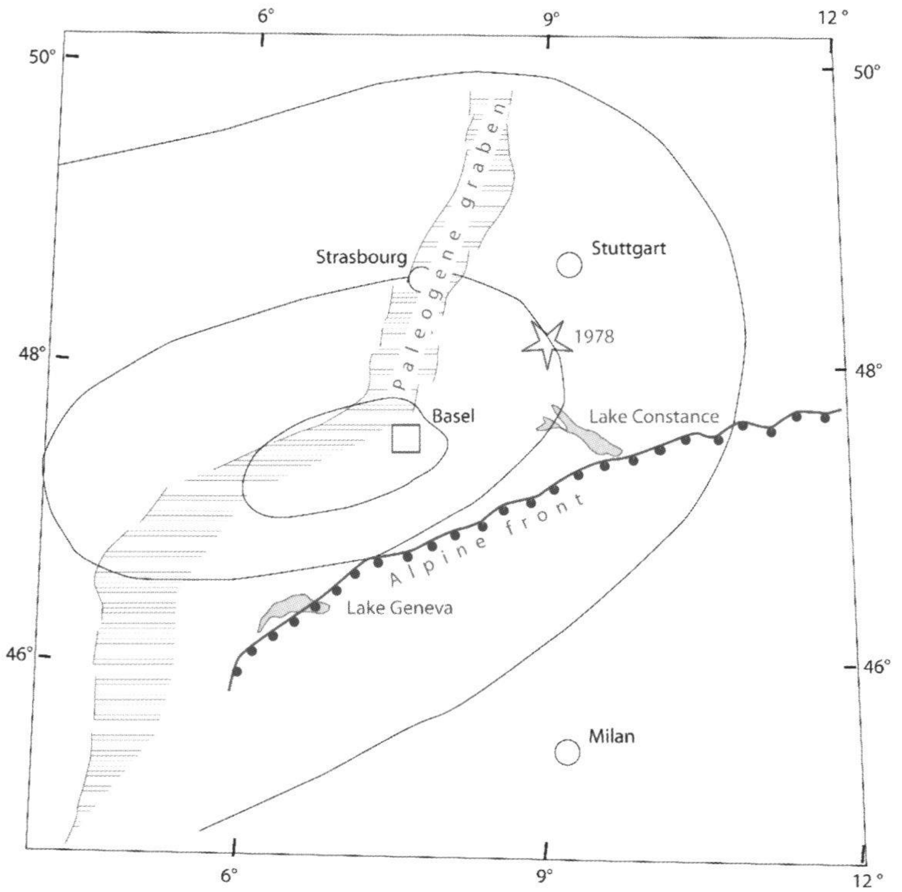

Fig. 2: The isoseismals of Mayer-Rosa & Cadiot (1979). The asterisk locates the 1978 earthquake in the Suabian Alb.

Obviously these isoseismals, though suggestive, give no clue as to an active fault that may have triggered the quake. For this we have to have recourse to a tectonic map (Fig. 3). It shows the major tectonic provinces of northwestern Switzerland and its surroundings. The heavy dark lines are the most important linear structures for the discussion at hand. All of these have been recognized as having been active in the Miocene, when compressional tectonics set in, on the basis of either direct stratigraphic evidence or analogy with the ones stratigraphically dated. Especially marked are those deemed to carry the greatest regional weight. They mark the southern and eastern borders of the Rhine graben. The southern border follows a rather complex belt of little flexures or faults from Montbéliard to Aesch. The eastern border of the Rhine graben is the well-known Rheintal flexure.

Both of these lines continue into the area beyond the Rhine graben, the southern border line into the Mandach flexure, discovered about 20 years ago during a seismic survey by Nagra (the organization entrusted with finding repositories for radiowaste; Laubscher 1986). True, there is a gap between the seismic survey and the Rhine graben, but sundry tectonic elements suggest essential continuity. The Rheintal flexure may be followed to the south all the way through the late Miocene fold belt although deformed and shoved into an allochthonous position (Laubscher, in print).

As a particularly instructive recent event I have placed the epicenter of the 2005 Rumisberg(-Balsthal) earthquake on the map, based on data amiably sent me together with other pertinent information by Beat Meier. The data, including the aftershocks, delineate a NNE trending fault break at a

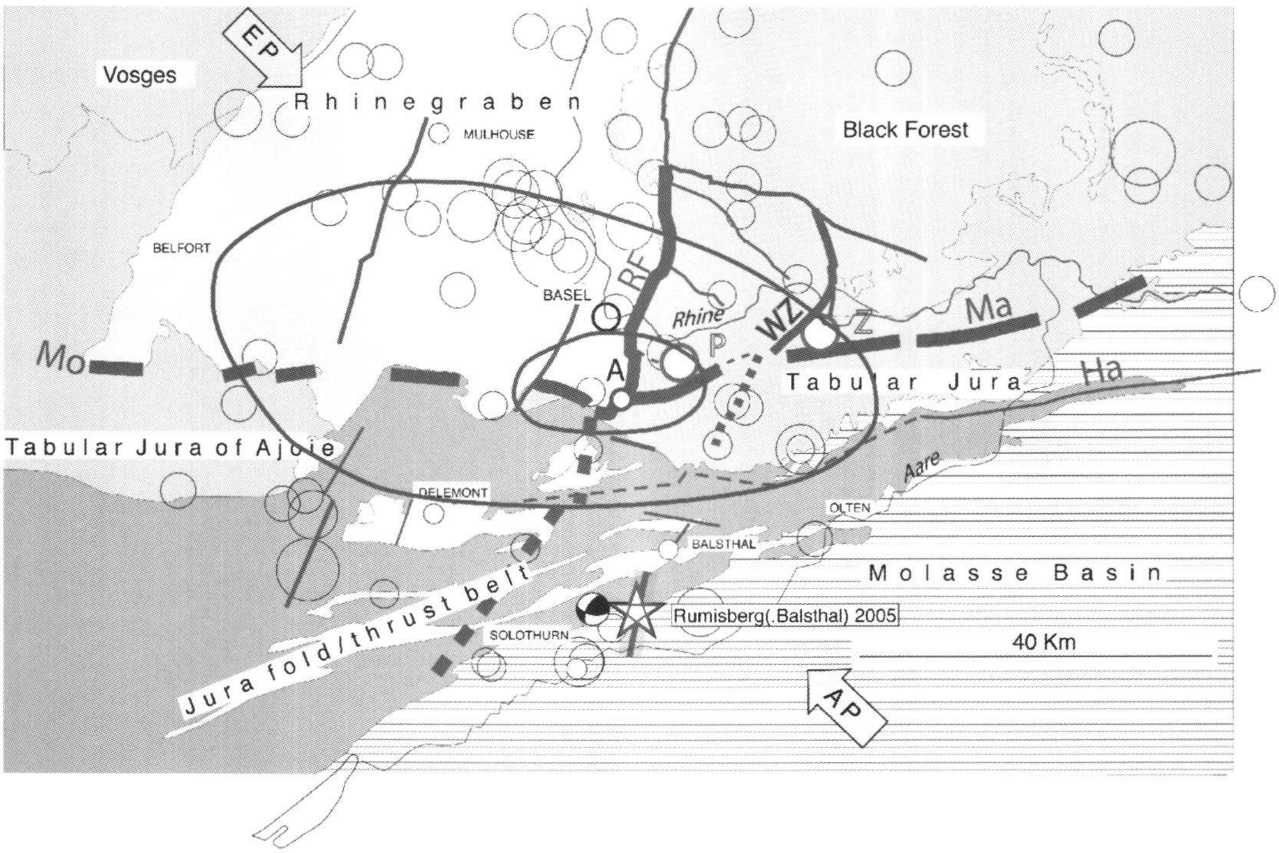

Fig. 3: The earthquake epicenters (black circles) of the period 1975-2003 according to Deichmann et al. 2004, superimposed on the map of Fig. 1. Added are the main fault lines (heavy dark lines and the Rumisberg(-Balsthal) 1905 earthquake data. Mo = Montbéliard, A = Aesch, Ma = Mandach line, Ha = Habsburg line, RF = Rheintal flexure, WZ = Wehratal-Zeiningen fault, P = Pratteln epicenter, Z = Zeiningen epicenter.

depth of about 25 km, the conjectured brittle-ductile transition layer in the region (compare Deichmann 1992). This patently is a deeply rooted autochthonous feature. Had it been active in the early Miocene, like the rest of the linear features shown in the figure, it should show traces in an allochthonous position in the Jura fold belt. And indeed, at the Schelten pass, there is a stratigraphically dated early Miocene feature that had baffled geologists for years (Laubscher, in print; compare Koch et al. 1936). Lying within the Jura fold/thrust belt it is in an allochthonous position with respect to its basement part. Restoring it to its autochthonous position makes it the surface trace of the Rumisberg(-Balsthal) fault. This fault points directly to the important Wehratal-Zeiningen fault in the northern foreland of the Jura. The focal mechanism indicates a sinistrally transpressional mode of movement, conforming with well-nigh all of the other recent earthquakes and with a NW-SE direction of plate convergence.

Fig. 3, moreover, shows epicenters of earthquakes for the period 1975 to 2003 (Deichmann et al. 2004). Emphasized are the Zeiningen earthquake of 2003 on the Zeiningen-Rumisberg lineament and the Pratteln earthquake of 1999, which lies on a very striking northwesterly trending line of particularly frequent epicenters, widely known as the Adlerhof line, although its interpretation is controversial (Laubscher 2003, Spottke et al. 2005). All of these earthquakes reveal SE-NW compression, which makes the Adlerhof line motion one of dextral strike-slip.

How does the 1356 Basel earthquake fit into this picture? In fig. 3 the isoseismals of Meyer (2006) are superimposed on the tectonic map. It is striking how the regionally most important fault lines intersect right in the center of the damage field at Aesch. It should be noted that neither Meyer nor I had any intention to manipulate this outcome, although the configuration fits almost artificially well. In view of the regional isoseismals one would be led to surmise that the active fault zone had been the Mandach-Montbéliard trend, and that the epicenter had been near the village of Aesch. One would further conjecture that the intersection of the Rheintal flexure and the Mandach-Montbéliard trend constituted a particularly severe asperity at the brittle-ductile boundary which functioned as a sort of décollement layer for the compression of the upper crust. Motion along the Mandach-Montbéliard line would have been dextrally transpressive.

This, it would appear, is as far as local and regional data, both historical and geological, will get us. True, recently efforts have been underway to define a «Reinach-Basel fault» as responsible for the 1356 earthquake (Meghraoui et al. 2001). However, as I have noted in Laubscher (2006) it is difficult to accept either the authors' presentation of data or their argumentation. Neither does the strike conform to that of the isoseismals nor does the postulated motion conform to the current stress field, among other things. Let it suffice on this occasion to say that for most geologists familiar with the area, the «Reinach fault» is a landslide.

Focusing the Basel earthquake

Finally, let's have a look at the plate-teconical position of the Basel earthquake - not only, because this turns out to be an extremely interesting problem, but also because people always want to know how the Basel area compares with the great earthquake belts.

Basel is located, regionally speaking, at the very northern edge of a wide plate boundary zone - its width is nearly 2000 kilometers from the Atlas to the Alps. Within this plate boundary zone seismically and tectonically active belts have changed position repeatedly. What is the current configuration of tectonic motions? To address this question the method of choice is GPS, the Global Positioning System. Fig. 4 is from a recent publication of our Zurich colleagues (Tesauro et al. 2005). Although the raw data have to be manipulated in various ways in order to obtain the distribution of crustal strain rates shown in fig. 4, we may accept this picture at face value for the time being.

It is quite a shocking picture. Compressive strain accumulates in the foreland of the Alps rather than in the Alps themselves: Quite on the contrary, within the Alps there are widespread extensional domains. Moreover, strain acumulates in a distinctly lobate pattern. This is quite at variance with the usual «Micky Mouse» illustrations of straightforward Africa-Europa convergence with the Alps as the focus of compressive strain accumulation. Basel lies approximately at the center of a line connecting the lobes of compressive strain accumulation. Note that the Suabian earthquake of 1978 is inside the main compressional lobe issuing from the Alps; there is no connection with any current activity of the Rhine graben.

Basel is in a similar position within the strained southern border of the Europa plate, and the 1356 earthquake is consequently a plate boundary quake. However, this plate boundary raises fundamental questions about the dynamics of plate boundaries generally (see fig. 5).

How do we reconcile the high contractive strain rates in the foreland with the extensional domains to the south? Extensional domains within plate boundary zones are commonplace and are now generally attrib-

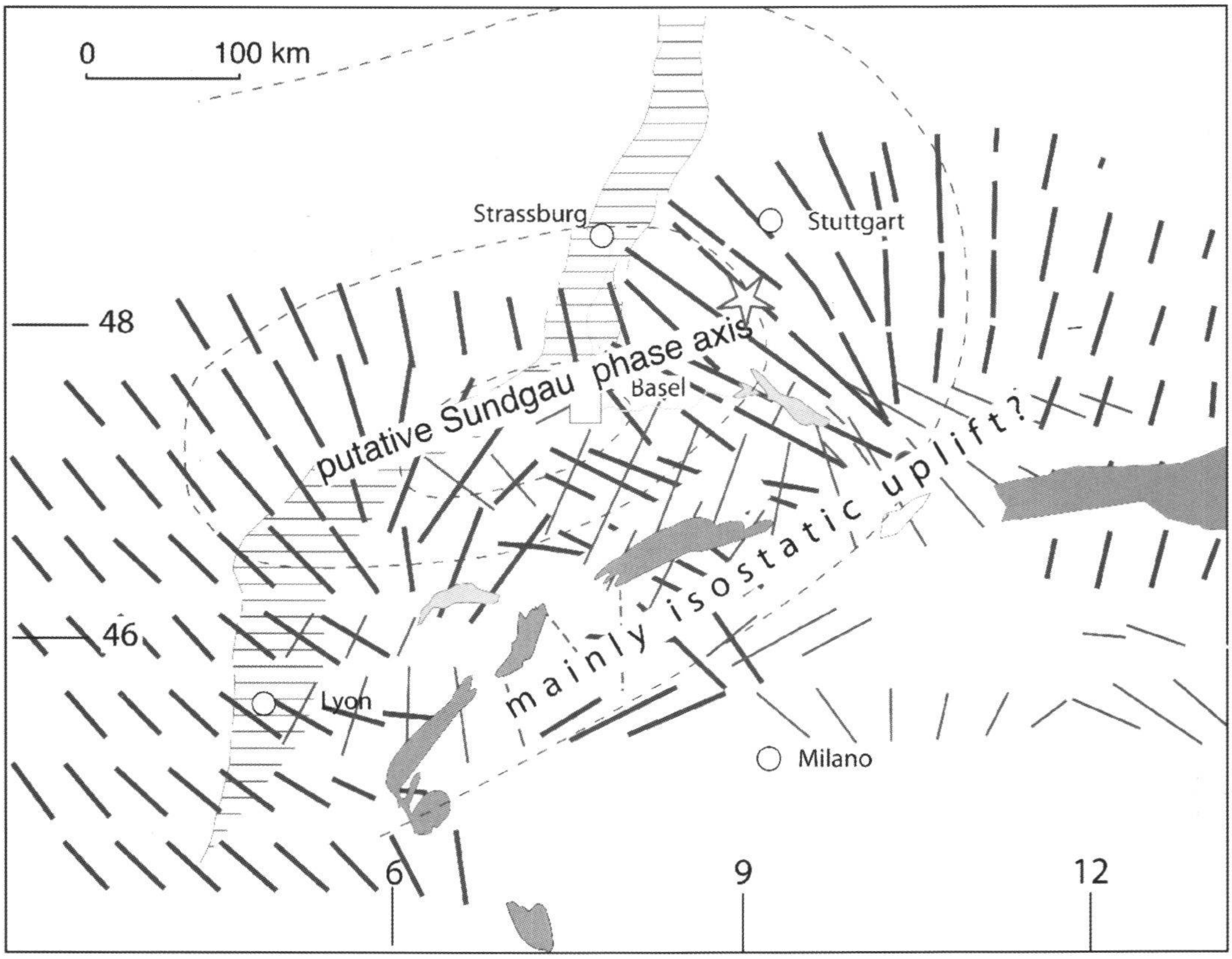

Fig. 4: The current distribution of horizontal strain rates based on GPS data (Tesauro et al. 2005), slightly simplified. Heavy dark lines: principal compressive component; thin dark lines: principal extensional component; dashed lines: isoseismals of Mayer-Rosa & Cadiot (1979); horizontal grey ruling: Rhine-Rhone graben domain; dark grey areas: belt of External Alpine Massifs; asterisk: epicenter of 1978 earthquake (compare Fig. 2).

uted to rollback of subducting slabs - a special sort of gravitational collapse. This mechanism has been proposed for the Tyrrhenian collapse and may well hold for the current extensional domains in the Alps too. The tenuous Alpine upper crustal lid (fig. 5) would, in this scenario, have to rise isostatically rather than as a consequence of horizontal compression. It would have to be detached from its underpinnings. Compression due to the Africa-Europa convergence would have to be transmitted by some lower portions of the lithosphere or by asthenospheric flow - or so it would seem. However, the arcuate shape of the Western Alps can obviously be understood only in 3D. The detached Alpine-Adriatic upper crust apparently rotates counterclockwise according to another recently published paper on GPS data. Dynamic modelers have quite a job cut out for them.

Conclusions

The currently available data are insufficient for definitive tectonic modelling of the Basel earthquake 650 years ago. However, the bulk of the data would suggest that it occurred in an area of compressive strain accumulation in the foreland of the Alps, that is, in the generalized Africa-Europa plate boundary zone. It would therefore have to be classified as a convergent plate boundary earthquake, albeit as one in a hardly understood plate boundary. The hypocenter may be expected to have been at the base of the brittle upper crust where a repeatedly reactivated WSW

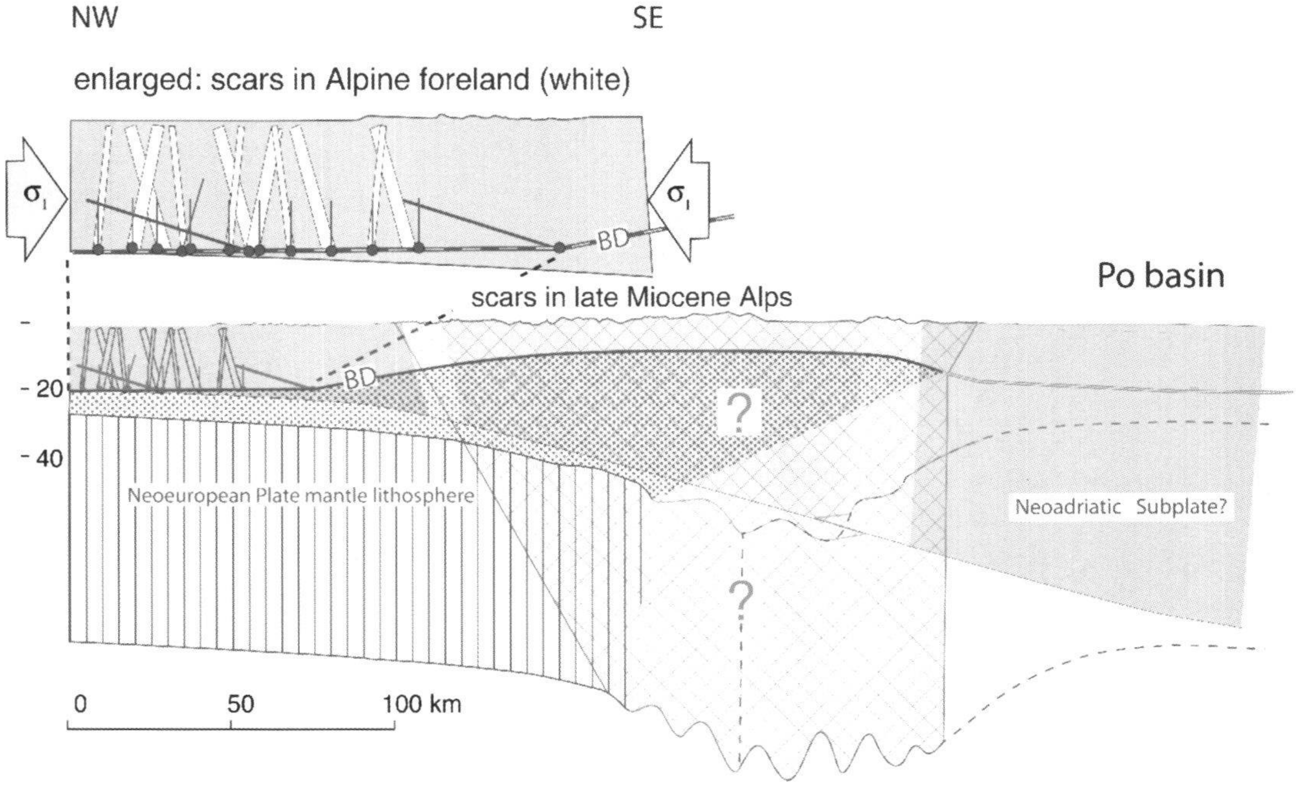

Fig. 5: Schematic cross-section through the southern plate boundary zone of the Europa plate. BD = brittle-ductile transition, located at the bottom of the seismogenic zone (= «upper crust»). Notice the extreme thinning of the seismogenic zone in the Alps (after Deichmann 1992, Deichmann & Bär 1990; compare with Fig. 5). In contrast, the ductile middle crust (dots) swells to a thick cushion. Cross-hatched: area poorly resolved by the NFP 20 deep seismic survey (Pfiffner et al. (ed.) 1997). Pale grey: putative stress transmitting Adriatic subplate - rather questionable in view of Fig. 5. White stripes in the northern foreland (Basel region): schematic old faults («scars») deemed susceptible to be reactivated (dark grey lines), particularly as asperities (dark grey dots) at the brittle-ductile transition.

striking Paleozoic fault zone (Montbéliard-Mandach line) penetrates the brittle-ductile boundary layer and there constitutes an asperity. This asperity may have been amplified by the Rheintal flexure which intersects the Montbéliard-Mandach fault line in the very center of the 1356 damage field at Aesch. From the tectonical point of view this asperity would seem to have impeded motions of the upper crust which is being pushed (relatively speaking) in a northwesterly direction on top of the ductile domain underneath. Beyond such rather vague scenarios we know hardly anything at all. However, the conventional view that the Basel earthquake is due to Rhine graben activity, still reiterated by geoscientists time and time again, should finally be abandoned.

Bibliography

Deichmann, N. 1992: Structural and rheological implications of lower-crustal earthquakes below northern Switzerland. Physics of the Earth and Planetary Interiors 69, 270-280.

Deichmann , N., & Baer, M. 1990: Earthquake focal depths below the Alps and northern Alpine foreland of Switzerland. In: Freeman et al. (ed.): The European Geotraverse - Integrated studies, 277-288. European Science Foundation, Strasbourg, France.

Deichmann, N. Baer, M., Braunmiller, J., Cornou, C., Fäh, D., Giardini, D., Gisler, M., Huber, S., Husen, S., Kästli, Ph., Kradolfer, U., Mai, M., Maraini, S., Oprsal, I., Schler, T., Schorlemmer, D., Wiemer, S., Wössner, J. & Wyss, A. 2004: Earthquakes in Switzerland and surrounding regions during 2003. Eclogae geol. Helv. 97(3). 447-458.

Koch, R., Lehner, E., Waibel, A. & Mühlberg, M.1936: Blätter Laufen, Bretzwil, Erschwil, Mümliswil. Geologischer Atlas der Schweiz, 3. Herausgegeben von der Geologischen Kommission der Schweiz. Naturf. Ges.

Laubscher, H. 1986: The eastern Jura: Relations between thin-skinned and basement tectonics, local and regional. Geol. Rundschau 73, 3, 535-553.

Laubscher, H. 2003: The Miocene dislocations in the northern foreland of the Alps: Oblique subduction and its consequences (Basel area, Switzerland-Germany). Jber. Mitt. Oberrhein. Geol. Ver., NF 85, 423-439.

Laubscher, H. 2006. Zur Geologie des Erdbebens von Basel 1356. 184. Neujahrsblatt der Ges. Für das Gute und Gemeinn. Basel, 207-230. Schwabe Verlag, Basel.

Laubscher, H.: Hundert Jahre Abschermodell für den Faltenjura: seine Beziehung zum Tafeljura aus heutiger Sicht. Jber. Mitt. Oberrhein. Geol. Ver., in print.

Mayer-Rosa, D., & Cadiot, B. 1979: A review of the 1356 Basel earthquake. Tectonophysics 53, 325-333.

Meghraoui, M., Delouis, B., Ferry, M., Giardini, D., Huggenberger, P., Spottke, I. & Granet, M. 2001: Active normal faulting in the Upper Rhine Graben and paleoseismic identification of the 1356 Basel earthquake. Science 293, 5537, 2070-2073.

Meyer, W. 2006: Da verfiele Basel überall. Das Basler Erdbeben von 1356. 184. Neujahrsblatt der Ges. für das Gute und Gemeinn. Basel. 5-205. Schwabe Verlag, Basel.

Pfiffner, O. A., Erard, P. & Stäuble, M. 1997: Two cross sections through the Swiss Molasse Basin (lines E4-E6, W1, W7-W10). In: Pfiffner, O. A., Lehner, P., Heitzmann, P., Mueller, S. & Steck, A. (Eds), Deep structure of the Swiss Alps. Results of NRP 20. Birkhäuser, pp. 64-72.

Spicher, A. 1980: Tektonische Karte der Schweiz 1:500'000. Herausgegeben von der Geologischen Kommission der Schweiz. Naturf. Ges.

Spottke, I., Zechner, E. & Huggenberger, P. 2005: The southestern border of the Upper Rhine Graben: a 3D geological model and its importance for tectonics and groundwater flow. Int. J. Earth S. (Geol. Rundsch.) 94, 580-593.

Tesauro, M., Hollenstein, Chr., Egli, R., Geiger, A. & Kahle, H.-G. 2005: Continuous GPS and broadscale deformation across the Rhine Graben and the Alps. Int. J. Earth Sci. (Geol. Rundsch.) 94, 525-537.