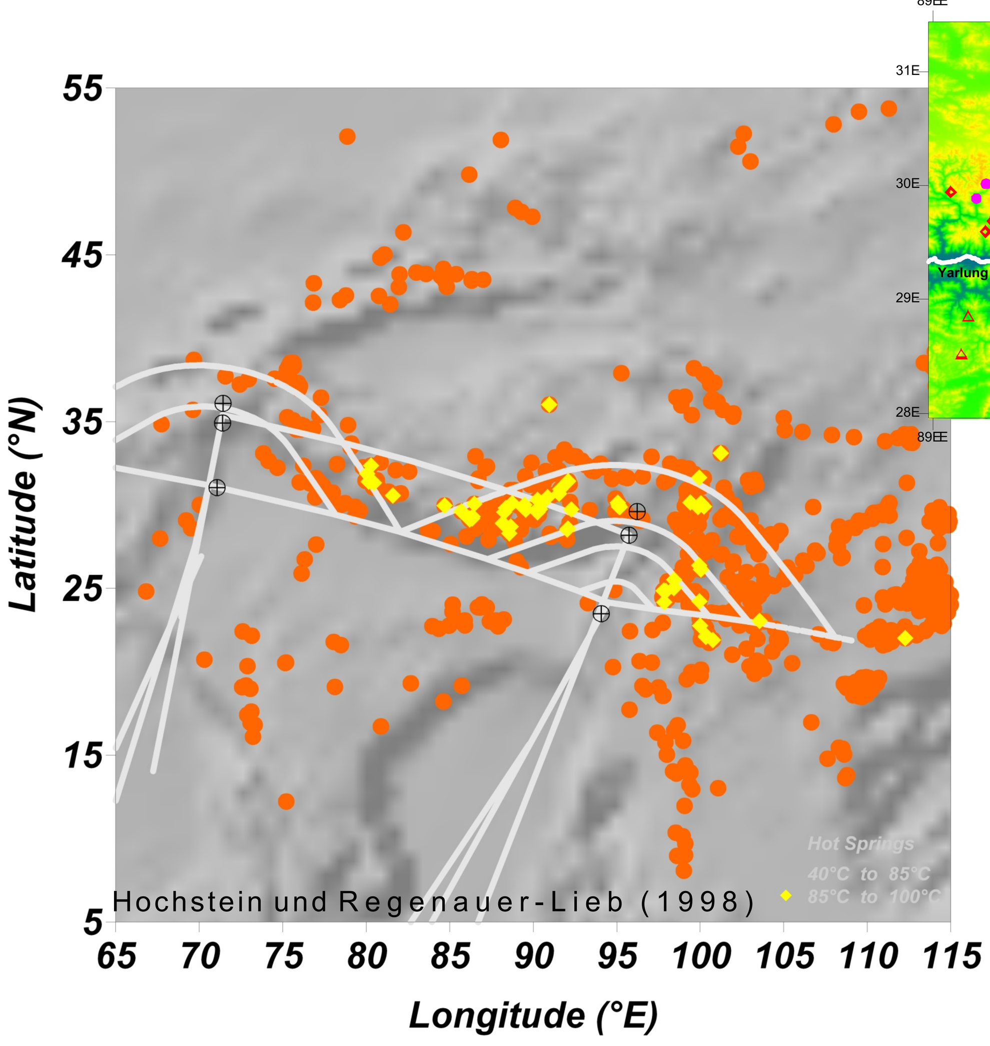
Geothermal resources in central Europe: A geodynamic view

E. Schill, F. Wellmann, K. Regenauer-Lieb

The largest geothermal resources in the world are coupled with active plate boundaries (e.g. Japan, New Zealand) and areas of extension and rift development such as the African rift. In central Europe largest surface heat flux (>120mW/m^2) and highest temperatures (>150°C in depth of 2000m) are observed in the Upper Rhine valley in France and Germany . The Upper Rhine valley is a tectonic graben structure belonging to the European Cenoyoic Rift System, which is probably active since 45Myr (Ziegler et al., 2004). It evolved under a change in direction of the central European stress field with a maximum horizontal compressional stress direction changing from approximately N-S to NW-SE. This stress field is controlled by the opening of the Mediterranean sea, the related rotation of the Italy-Adria indenter in the South and the North Variscian deformation front in the North.

Another tectonic scenario controlled by indentation of a rigid plate into a deformable continent is the collision between India and Eurasia. In this area the heat anomalies observed on the Tibetan plateau have been related to the so-called near-field indentation mode calculated from elasto-plastic solid mechanics contact theory (Fig. 1, Hochstein and Regenauer-Lieb, 1998). The near-field indentation mode predicts co-focal shear zones around the corners of the Indian indenter.

The far-field cutting mode predicted from the same contact mechanic theory applied to the indentation of Adria into Eurasia describes shear zones cutting through the European continent between the Adriatic indenter and the North Variscian deformation front (Fig. 2). In this study, we verify the far-field cutting field in the larger Alpine foreland by the investigation of the present deformation patterns deduced from geomorphological investigations and stress observations. We also show the possible influence of such major structures on the stimulation experiments in Soultz-sous-Forets (Fig. 3)



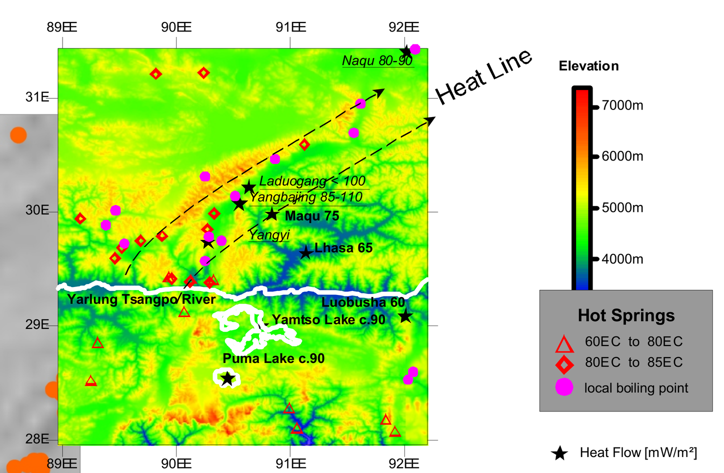


Figure 1
(a) Distribution of hot (orange) and boiling (yellow) springs on the Tibetan plateau. The grey lines show the calculated Indian indenter for 3 and 10 Ma before present and the slip lines of the near-field indentation mode representing the active shear zones along which heat of granite intrusi ons is released.
(b) Detailed distribution of boiling springs.

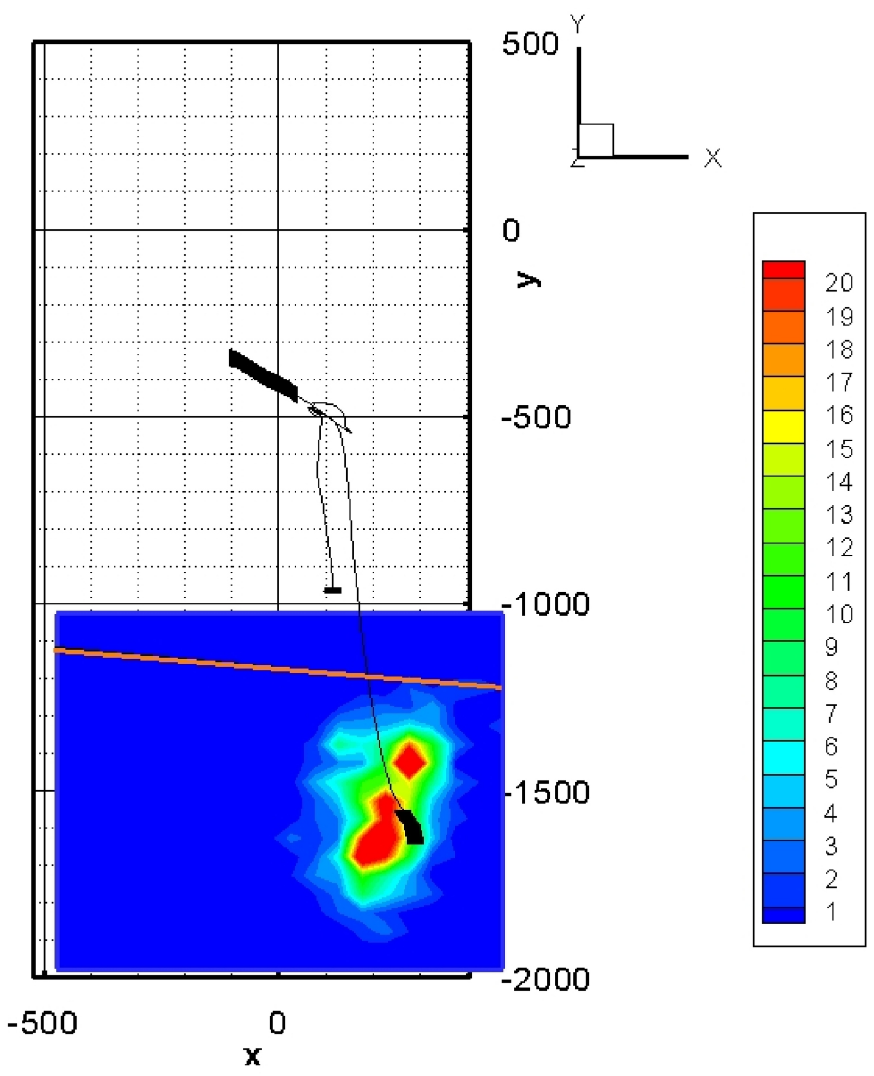
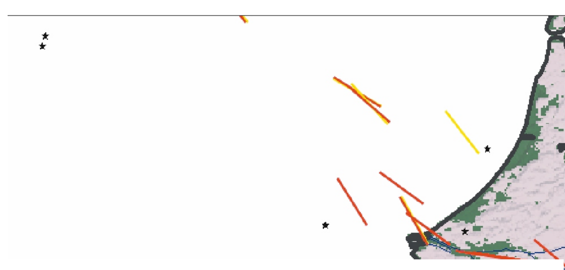


Figure 3
The distribution of seismicity during hydraulic stimulation at the Soultz geothermal site reveals an aseismic zone between GPK3 and GPK4 (Kohl et al., 2006). Starting from the local minimum of seismicity a plane orientation was calculated that minimizes the number of seismic events located closer than a distance d=25m. Two scenarios for the hydraulic conditions of this zone have been put forward. Theoretically, both no-flow boundaries or drainage systems could produce such an aseismic zone.
The correlation of the orientation of the plane with the present slip line field supports the hypothesis of a high conductive zone, which is part of the recent pattern of shear zones cutting through the European continent.



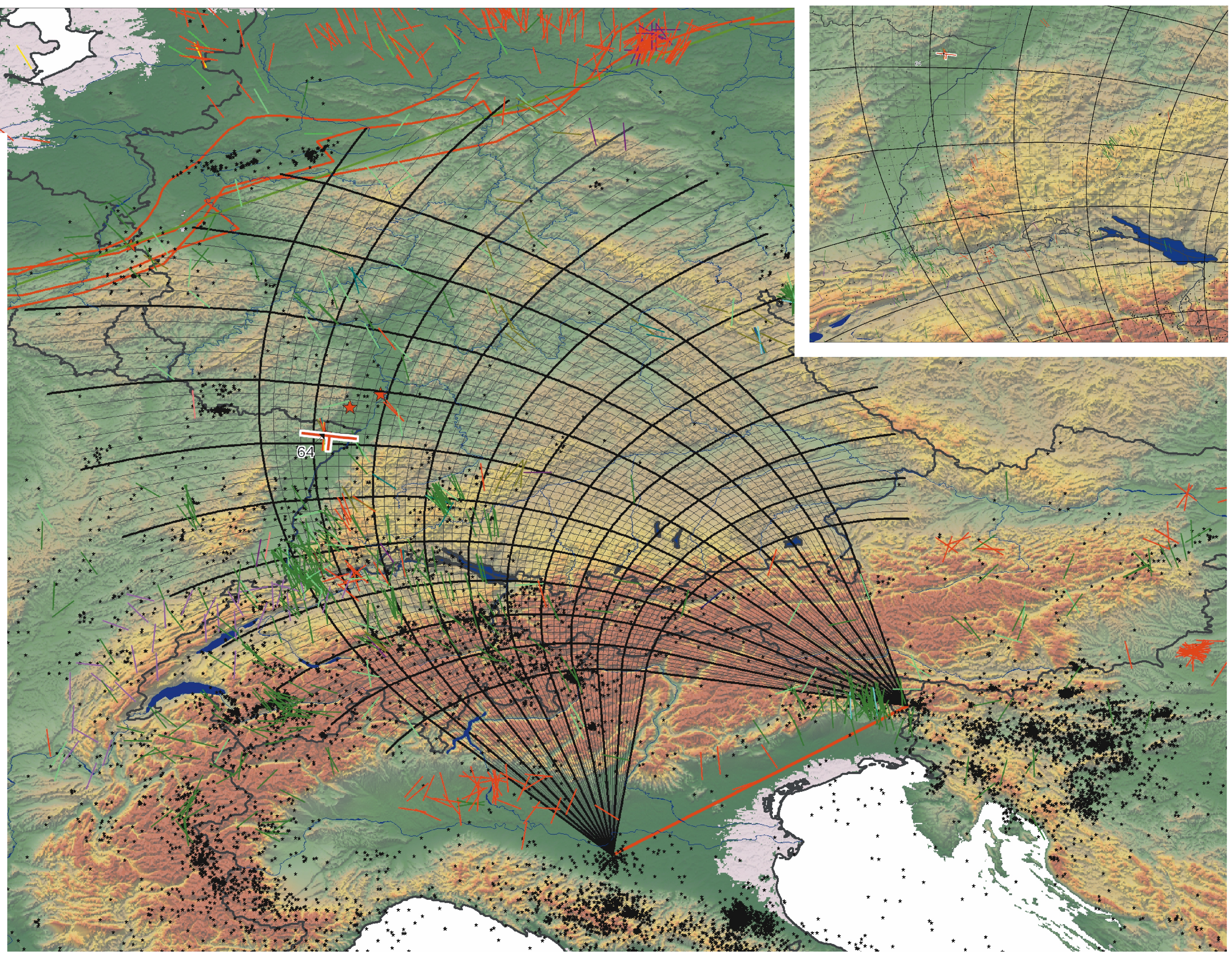


Figure 2
The field of slip lines for the far-field cutting mode (black lines) has been calculated according to elasto-plastic solid mechanic contact theory. The frequency of earthquakes (black stars) was used as an indication for the limits of the Adriatic indenter and the North Variscan deformation front (red lines) as the close boundary to the North. The slip lines indicate lines of possible dextral shearing to the W and sinistral to the E cutting the European continent. The slip line field fits the distribution of the present stress field indicated by the maximum compressional stress direction (green lines from borehole break out and red lines from fault plane solutions of recent earthquakes).
Analysing the active geomorphological structures mainly in the young basins (e.g. the Upper Rhine valley and the Molasse basin), a large number of recent structures fits the calculated slip lines. One example are the rivers flowing into the Danube river in SE Bavaria. Another striking correlation of active structures with the calculated slip line field is observed between the E-W striking youngest tectonic structures at the Western flank of the Upper Rhine graben (see inlet). The present stress field in Soultz (located in this area), however, does neither represent the regional stress distribution, nor the calculated slip lines. This leads to the assumption that in the area of Soultz a strong influence of local structures dominates the stress in the reservoir.