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Anomalously deep crustal earthquakes in the northern Alpine foreland - driven by the lithosphere slab-roll back beneath the Central Alps?

Julia Singer (1), Tobias Diehl (2), Stephan Husen (2), and Edi Kissling (1)

(1) Institute of Geophysics, Swiss Federal Institute of Technology, ETH Zurich, Switzerland
, (2) Swiss Seismological Service, Swiss Federal Institute of Technology, ETH Zurich, Switzerland

Beneath the northern foreland of the Central Alps deep crustal earthquakes up to magnitude 4 regularly occur in the continental European lithosphere. At 20 km to 30 km depths, where most of these earthquakes are located, temperatures above 450°C are expected and thus a ductile rheology rather than brittle behavior. To better understand occurrence and underlying processes of these unusual earthquakes, we homogenize and improve hypocenter locations of events in the period 1984 to 2012 using a high-precision multi-phase earthquake location method in combination with a reliable three-dimensional P-wave velocity model of the crust and uppermost mantle. With the new approach, the average uncertainty in focal depth of well-locatable earthquakes is less than ± 1 km. The homogeneously relocated hypocenters suggest a relatively uniform depth distribution throughout the lower crust. In agreement with previous studies, seismicity is entirely restricted to the crust and no evidence for seismicity in the mantle lithosphere beneath the northern Central Alpine foreland was found. The geographical distribution of lower crustal earthquakes in the foreland correlates remarkably well with the lateral extent of the European slab beneath the Central Alps where it is still attached to the European plate. In addition, the directions of extensional axes derived from focal mechanisms of the deep crustal earthquakes are predominantly parallel to the Alpine front. This consistency of extensional axes can be interpreted as the result of bending forces in the subducting European lithosphere with a strong dynamic coupling between the foreland and the gently to steeply dipping European slab beneath the Central Alps. Existing 2-D thermo-mechanical models predict such elastic bending and stress transfer to the foreland causing an enhanced regional stress field in the lithosphere. The presence of high-pressure fluids in the lower European crust seems likely and in combination with a high-strength lithology network plastic instabilities might be enhanced causing brittle failure. Nevertheless, the driving forces for the occurrence of the anomalously deep crustal seismicity seems to be the stress transfer from the European slab into the foreland.