WP5:
Earthquake source mechanisms and stress analysis

Starting time of WP5 – July 2021

Taks 5.1:

• Retrieval of the earthquake source mechanisms in the moment-tensor description

1. P- and S-wave amplitudes
2. Full waveform inversion
3. Empirical Green's functions.

• Analysis of earthquake source mechanisms:
stability, robustness, errors, evaluation of nonshear components - construction of confidence regions

• Categorisation of earthquake source mechanism in space and time. correlation of source mechanism angles with fault geometry and surface fractures (input from WP4, Task 4.2.)

Taks 5.2:

• Local stress analyses
Inversion of earthquake source mechanisms (double-couple components) for principal stress components (σ1 σ2 σ3) and shape ratio (*subject of the PhD thesis on Veronika Turjakova*)

P- and S-wave amplitude inversion used previously to retrieve full moment tensors of the W-Bohemia swarm earthquakes and earthquakes triggered by fluid injection HDR site Soultz-sous-Forˆets (Alsace) in 2003

Geophysical Journal International

Geophys. J. Int. (2013) **194,** 979–999
Advance Access publication 2013 May 15

doi: 10.1093/gji/ggt138

Source mechanisms of the 2000 earthquake swarm in the West Bohemia/Vogtland region (Central Europe)

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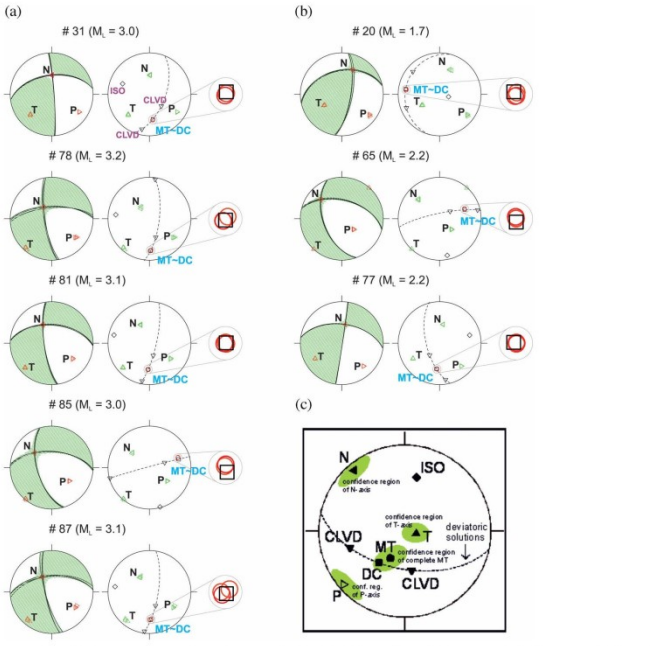
Accepted 2013 April 8. Received 2013 April 5; in original form 2011 June 23

SUMMARY

An earthquake swarm of magnitudes up to $M_L = 3.2$ occurred in the region of West Bohemia/Vogtland (border area between Czech Republic and Germany) in autumn 2000. This swarm consisted of nine episodic phases and lasted 4 months. We retrieved source mechanisms of 102 earthquakes with magnitudes between $M_L = 1.6$ and 3.2 applying inversion of the peak amplitudes of direct *P* and *SH* waves, which were determined from ground motion seismograms. The investigated events cover the whole swarm activity in both time and space. We use data from permanent stations of seismic network WEBNET and from temporal stations, which were deployed in the epicentral area during the swarm; the number of stations varied from 7 to 18. The unconstrained moment tensor (MT) expression of the mechanism, which describes a general system of dipoles, that is both double-couple (DC) and non-DC sources, was applied. MTs of each earthquake were estimated by inversion of three different sets of data: *P*-wave amplitudes only, *P*- and *SH*-wave amplitudes and *P*-wave amplitudes along with the *SH*-wave amplitudes from *a priori* selected four 'base' WEBNET stations, the respective MT solutions are nearly identical for each event investigated. The resultant mechanisms of all events are dominantly DCs with only insignificant non-DC components mostly not exceeding 10 per cent. We checked reliability of the MTs in jackknife trials eliminating some data; we simulated the mislocation of hypocentre or contaminated the *P*- and *SH*-wave amplitudes by accidental errors. These tests proved stable and well constrained MT solutions. The massive dominance of the DC in all investigated events implies that the 2000 swarm consisted of a large number of pure shears along a fault plane. The focal mechanisms indicate both oblique-normal and oblique-thrust faulting, however, the oblique-normal faulting prevails. The predominant strikes and dips of the oblique-normal events fit well the geometry of the main fault plane Nový Kostel (NK) and also match the strike, dip and rake of the largest $M_L = 4.6$ earthquake of a strong swarm in 1985/86. On the contrary, the 2000 source mechanisms differ substantially from those of the 1997-swarm (which took place in two fault segments at the edge of the main NK fault plane) in both the faulting and the content of non-DC components. Further, we found that the scalar seismic moment M_0 is related to the local magnitude M_L used by WEBNET as $M_0 \propto 10^{1.12M_L}$, which differs from the scaling law using moment magnitude M_w, that is $M_0 \propto 10^{1.5M_w}$.



Geophysical Journal International

Geophys. J. Int. (2010) **181,** 1547–1565 doi: 10.1111/j.1365-246X.2010.04506.x

Source mechanisms of micro-earthquakes induced in a fluid injection experiment at the HDR site Soultz-sous-Forêts (Alsace) in 2003 and their temporal and spatial variations

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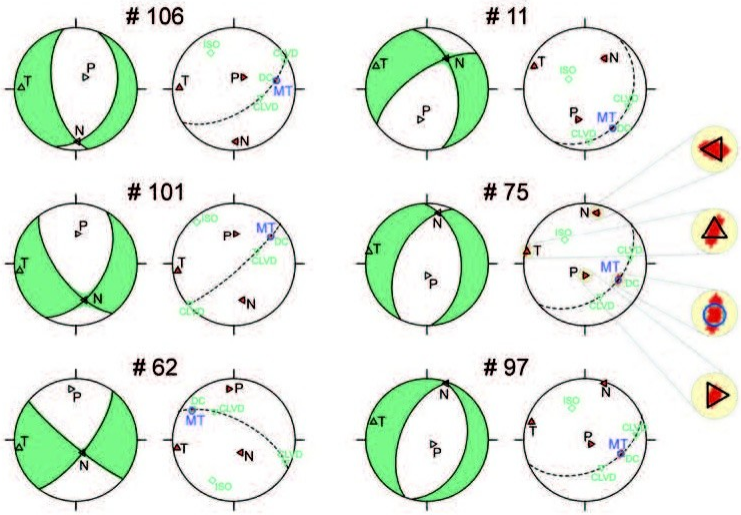
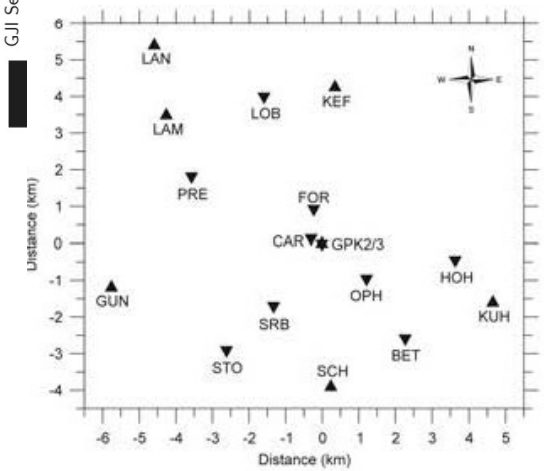
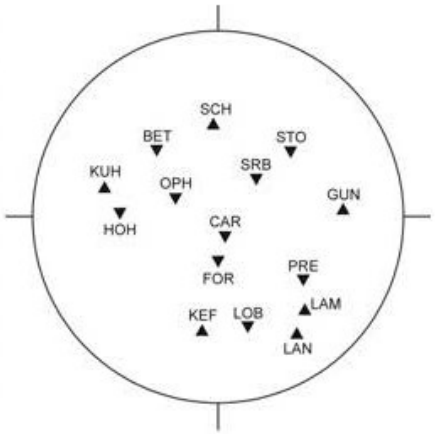
Accepted 2010 January 6. Received 2010 January 6; in original form 2008 December 30

SUMMARY

We have inverted the peak amplitudes of direct *P* waves of 45 micro-earthquakes with magnitudes between $M = 1.4$ and 2.9, which occurred during and after the 2003 massive fluid injection in the GPK3 borehole of the Soultz-sous-Forêts Hot Dry Rock facility. These events were recorded by a surface seismic network of 15 stations operated by the Ecole et Observatoire des Sciences de la Terre, University of Strasbourg. The unconstrained moment tensor (MT) expression of the mechanism was applied, allowing the description of a general system of dipoles, that is, both double-couple (DC) and non-DC sources, as tensile fractures. The mechanisms of all but one event are dominantly DCs with a few per cent additional components at the most. We have checked carefully the reliability of the MT retrieval in bootstrap trials eliminating some data, by simulating the mislocation of the hypocentre and by applying simplified velocity models of the area in constructing Green's functions. In some of the trials non-DC components amounting to several tens of per cent appear, but the *F*-test classifies them as insignificant. Even the only micro-earthquake with an exceptionally high non-DC mechanism cannot be classified unambiguously—the *F*-test assigns similar significance to the pure DC solution. The massive dominance of the DC indicates the shear-slip as the mechanism of the micro-earthquakes investigated. The mechanisms display large variability and are of normal dip-slip, oblique normal to strike-slip types. The *T*-axes are fairly stable, being concentrated subhorizontally roughly in the E–W direction. On the contrary, the *P*-axes are ill constrained varying in the N–S direction from nearly vertical to nearly horizontal, which points to heterogeneous stress in the Soultz injected volume. This is in agreement with the stress pattern from *in situ* measurements: the minimum stress axis is well constrained to E–W, whereas the maximum and intermediate stress values are close to one another, enabling the ambiguity of the *P*-axis direction. We found no significant dependence of source mechanisms either on magnitudes or depths. The time–space distribution of the events analysed suggests that the injection activated two segments of the natural faults existing in the area (I and II in our notation) showing different source mechanism patterns. The dip-slip regime is characteristic of fault segment I where the seismicity occurred during and also after injection, whereas the strike-slip regime prevails in segment II where the seismicity was triggered only after the injection shut in. This indicates that the tensile fractures, which are assumed to be created during injection, may have occurred on a smaller scale than the pure shear micro-earthquakes investigated.







Necessary preconditions:

1) sufficient coverage of the focal sphere by stations

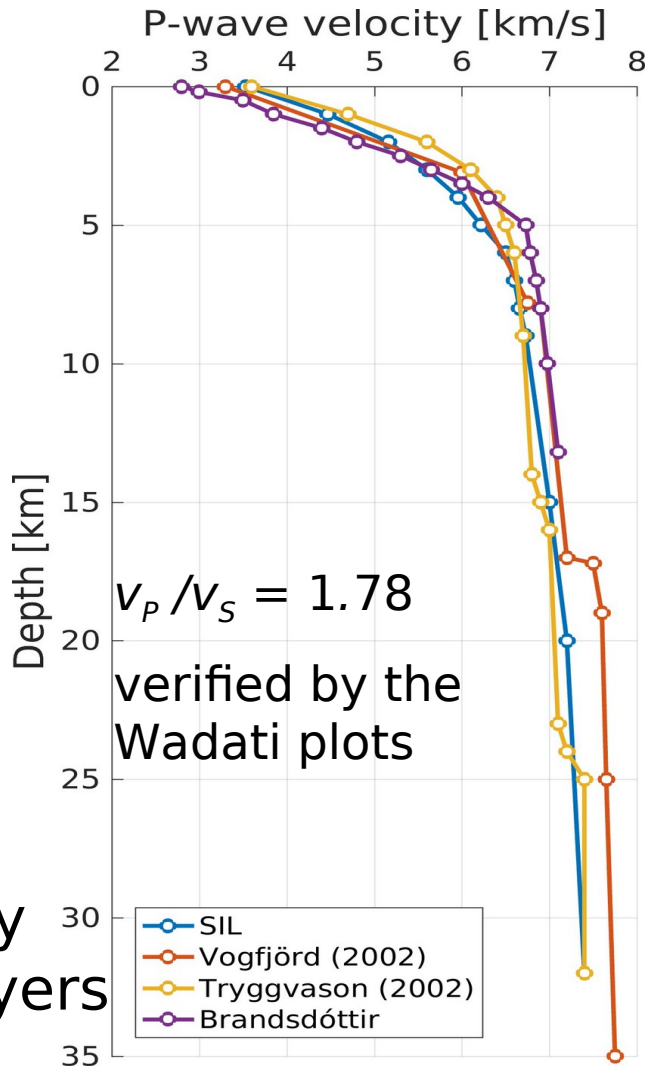
2) reliable amplitudes of the direct P- and S-waves

3) reliable Green's functions (response of the medium to elementary dipole excitation)

Two major problems:

1) REYKJANET is not dense enough for proper sufficient coverage of the focal sphere

2) Unreliable 1D P- and S-wave velocity model for the Reykjanes Peninsula



SIL - systematically greater depths by cca 700m

Tryggvason et al. (2002) - significantly higher P- wave velocities in the upper layers

Brandsdóttir (University of Iceland) – significantly lover velocities down to ~ 4.5 km, significantly higher velocities at depths > 5.0 km