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High-resolution fault image from accurate locations and focal mechanisms of the 2008 swarm earthquakes in West Bohemia, Czech Republic

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ABSTRACT

We have analyzed 463 micro-earthquakes in the magnitude range from 0.5 to 3.8 that occurred during the 2008 earthquake swarm in West Bohemia, Czech Republic, in order to screen the detailed structure of the focal zone situated at depths between 7 and 11 km. The double-difference location method was applied to records of 22 local seismic stations with an epicentral distance of less than 25 km in order to retrieve highly accurate locations of hypocenters with an accuracy of less than 20 m. The hypocenters are well-clustered and distinctly map the system of activated faults. The fault system has a complex geometry being composed of several fault segments with different orientations. Some of the segments intersect each other. The orientations of the segments coincide well with the focal mechanisms. We have introduced and evaluated the so-called fault instability of the individual fault segments. The fault instability ranges from 0 (most stable faults) to 1 (most unstable faults) and measures the susceptibility of the fault to be activated under specified stress. In the West Bohemia focal zone, two fault segments are optimally oriented with respect to the tectonic stress being characterized by an instability value higher than 0.9. Tractions on these fault segments are concentrated in the Mohr's diagram in the area of validity of the Mohr–Coulomb failure criterion and the associated micro-earthquakes are mainly shear. The other fault segments are slightly misoriented with instability values between 0.7 and 0.9, and the shear traction is significantly lower. These earthquakes are probably more tensile and activated most likely by the local redistribution of Coulomb stress during swarm activity.

1. Introduction

The West Bohemia/Vogtland region is the border area between the Czech Republic and Germany (Fig. 1) and the most seismically active region in the Bohemian Massif (Babuška et al., 2007). Active tectonics in this geothermal area is expressed by the presence of Tertiary or Quaternary volcanism, mineral springs, emanations of CO_2, and by pertinent seismic activity in the form of earthquake swarms. The most prominent earthquake swarms occurred recently in 1985/86, 1997, 2000 and in 2008 in the same epicentral area called the Nový Kostel zone (e.g., Fischer and Horálek, 2003; Fischer et al., 2010; Vavryčuk, 2002, 2011a, 2011b). Their duration was from 2 weeks to 2 months and the activity was located typically at depths ranging from 7 to 12 km.

One of the strongest earthquake swarms occurred in October 2008 (Fischer et al., 2010). This swarm lasted for about four weeks and involved more than 25,000 micro-earthquakes with magnitudes higher than −0.5. The magnitude of the strongest earthquake reached 3.8. The hypocenters were located at depths of 7.5–11 km. The micro-earthquakes were recorded by 22 three-component short-period West Bohemia Network (WEBNET) stations installed in the area and surrounding the swarm epicenters with epicentral distances of less than 25 km (Fig. 1). The sampling frequency of the velocity records was 250 Hz, the frequency response being flat at least between 1 and 60 Hz. The configuration of the network guarantees high-quality recording and a good focal sphere coverage of the studied earthquakes.

The tectonic structure of the area is characterized by two main fault systems well expressed on the surface: the Sudeten NW–SE fault system and the Eger–Rift WSW–ENE fault system. The NW–SE fault is probably a continuation of the Mariánské Lázně fault (see Fig. 1). The recently active fault systems are, however, different. The most active is the left-lateral strike-slip fault running N–S with a strike of N169°E. During some periods, the seismicity is associated also with the right-lateral strike-slip fault in the WNW direction with a strike of N304°E (Bankwitz et al., 2003; Vavryčuk, 2011a). The maximum compressive stress, determined through an inversion of focal mechanisms, has an azimuth of N146°E (Vavryčuk, 2011a). This direction is close to the average direction of N144°E of the maximum compression in Western Europe (Heidbach et al., 2008).

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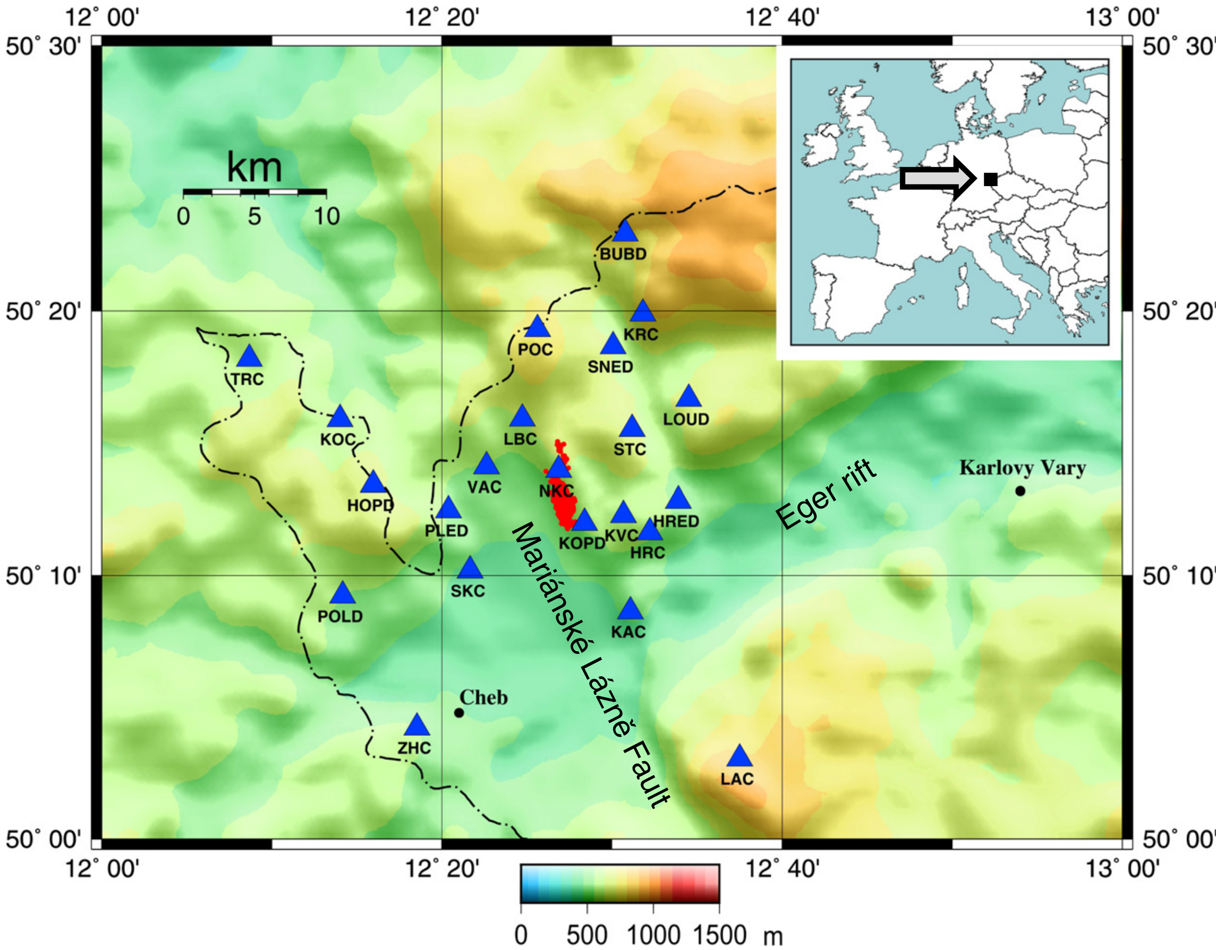

Fig. 1. Topographic map of the West Bohemia/Vogtland region. The epicenters of the 2008 swarm earthquakes are marked by red dots. The WEBNET stations are marked by blue triangles. The dashed-dotted line shows the border between the Czech Republic and Germany.

Interestingly, the σ_3 axis is horizontal, but the σ_1 and σ_2 axes are inclined by about 45° (Vavryčuk, 2011a).

2. Locations and focal mechanisms

2.1. Double-difference locations

We located 463 microearthquakes of the 2008 West Bohemia earthquake swarm recorded at all WEBNET stations in order to depict the detailed structure of the focal zone. The initial locations were calculated by the FASTHYPO code (Hermann, 1979) in a layered velocity model (see Table 1) obtained by refining the model of Málek et al. (2000) and using the P and S arrival times. The location accuracy is affected mostly by two factors: first, by uncertainties in the velocity model, and second, by errors in picking the arrival times. By minimizing the effects of these errors, the location accuracy can be significantly increased and the fault imaging improved. To do this, we apply the double-difference relocation method of Waldhauser and Ellsworth (2000). Based on the initial hypocenter locations, we use hypocenter pairs with a separation of less than 0.7 km. Each hypocenter had to be connected to a minimum of 10 other neighbors. The catalog of differential times is calculated from manually picked P and S wave arrivals, respectively. Additionally, we use the cross-correlation differential times computed in the band-pass from 3 to 10 Hz. We considered only data with a normalized correlation coefficient higher than 0.8. The same P-wave velocity model as for the initial locations (Table 1) was used for relocations and the same ratio between the P and S wave velocities, Vp/Vs = 1.70, was retained. The relative accuracy of the foci within the foci cluster is estimated to be less than 20 m (Bouchaala et al., 2013). This value was obtained by repeating the locations of arrival times perturbed by random errors of up to ±4 ms for the P waves and of up to ±8 ms for the S waves. The high relative precision of the locations was achieved because: (1) an extensive data set of micro-earthquakes observed at many local seismic stations was located, (2) the foci are concentrated in a small focal zone and they allow for creating a large number of foci pairs, and (3) the cross-correlation differential times are determined with a high accuracy. The absolute position of the cluster is about 100 m in the horizontal plane and 350 m in depth being mainly affected

Table 1
The West Bohemia velocity model.

Layer number	Depth (km)	P-wave velocity (km/s)
1	0.0	4.30
2	0.2	5.06
3	0.5	5.33
4	1.0	5.60
5	2.0	5.87
6	4.0	6.09
7	6.0	6.35
8	10.0	6.74
9	20.0	7.05
10	32.0	7.25

The P to S velocity ratio is 1.70.