# Static Source Parameters of the West Bohemia/Vogtland Earthquake Swarms

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## Introduction

The static source parameters like seismic moment, stress drop and size of the fault plane are important quantities in assessing the earthquake effects. We study earthquake swarms in West Bohemia/Vogtland (WB) region where the deformation energy is released in a large number of small events (see Fig. 1 and Table 1 for details). The area is continuously monitored since 1990 by WEBNET seismic network which nowadays consists of 13 permanent stations and similar amount of temporary stations. Our aim is to evaluate individual earthquakes in swarms to get characteristics typical for this area. In this study we present results obtained from spectral analysis of seismograms in the frequency domain and focused on the swarm 2000.

The West Bohemia is the most seismically active region in the Czech Republic and about 80% of the energy is released in the epicentral area near the station NKC. The main fault plane is steeply dipping towards west at 80° and striking 171° to the south. Hypocentral distances to the stations ranges between 6 - 30 km. For details see e.g. *Fischer et al. (2010)*.

| Swarm year | $M_{L\,max}$ | # events ($M_L$>0) |
|---|---|---|
| 1997 | 3.0 | ~ 620 |
| 2000 | 3.2 | ~ 6 000 |
| 2008 | 3.8 | ~ 8 000 |
| 2011 | 3.6 | ~ 8 000 (not complete) |

*Table 1: Major earthquake swarms in West Bohemia/Vogtland*

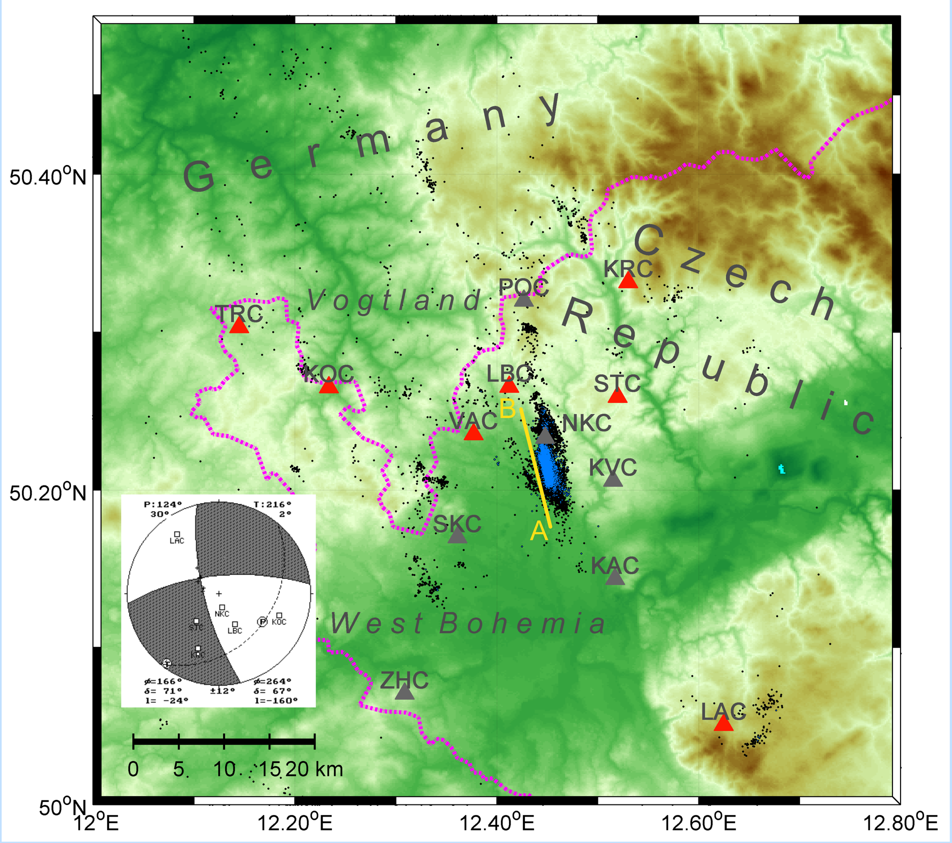


*Fig.1. Map of epicenters 1997-2009 (black dots) and WEBNET stations (triangles). Stations used for this study are red, epicenters of earthquake swarm 2000 are blue. Topography based on SRTM data from USGS.*

## Data

In this study **we analyzed 39 events from the 2000 swarm**. All the events are evenly distributed along the main focal zone covering approximately **6 km²** (Fig. 2). We selected only events ($M_L$= 0.3 - 3.0) with **clear and simple P-pulse** to eliminate multiple or complicated rupture processes. Because of the azimuthal coverage and only seven stations were suitable for analysis. Seismograms are analyzed in **1-80 Hz frequency range** (SP seismographs), sampling frequency is 250 sps.

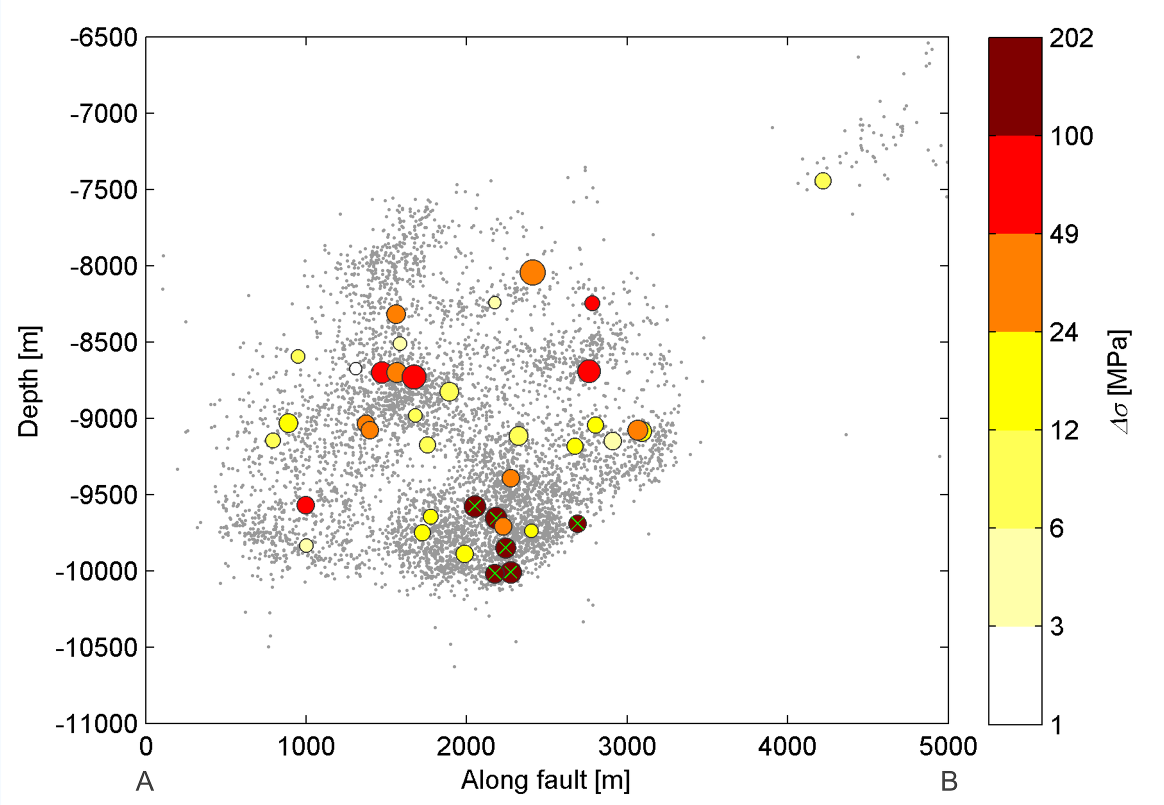


*Fig.2. Depth section along the strike 171° (line A-B in Fig. 1) for the 2000 swarm. Analyzed events are highlighted - size correspond to obtained seismic moment and color to the obtained stress drop. Green crosses highlight events with stress drops > 100 MPa.*

## Effects of attenuation

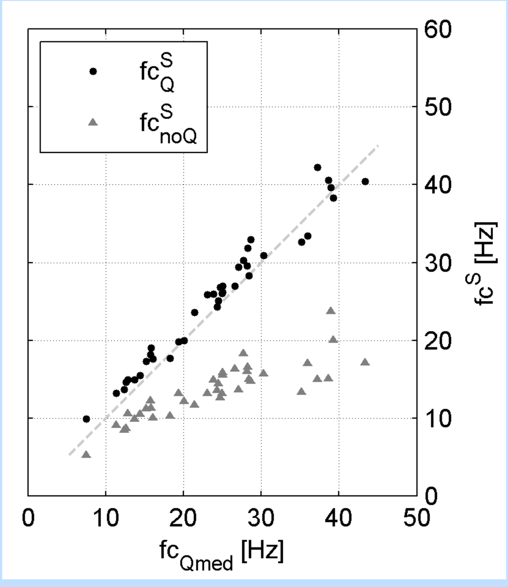


*Fig. 6. Comparison $f_c$ obtained by two approaches and effect of attenuation.*

In our analysis we assumed the Q factor to be frequency independent. The **median *Q*** values at stations are quite stable mostly in range of **200-350** (Fig. 4). Another indication that our attenuation correction is correct is comparison of $f_c$ obtained by inversion and by Snoke´s approach (Fig. 6). After the correction for attenuation the corner frequencies are almost the same. Possible error in fitting the spectra can arise from $f_{max}$ (high frequency attenuation) visible in Fig. 5 for $f_c$ > 40 Hz.

## Methods and models

We used an absolute spectral approach similar to *Abercrombie (1995)*, slightly modified. We analyzed **P-wave displacement amplitude spectra on vertical components** following these steps:

**1.** Find one **corner frequency $f_c$** and N values of **attenuation factors *Q*** for each station

**2.** Fix ***Q* factor** to its median value at each station from previous step and find the **corner frequency $f_c$** again - this $f_c$ is used for further analysis

**3.** As an additional approach for $f_c$ dermination we used method of **Snoke (1987),** equation below. ***J*** is integral of the square of the ground velocity spectrum.

**Assumptions:**

- ***Q*-factor** is constant for each station (source area is small, similar rays)
- no directivity in source
- similar focal mechanisms

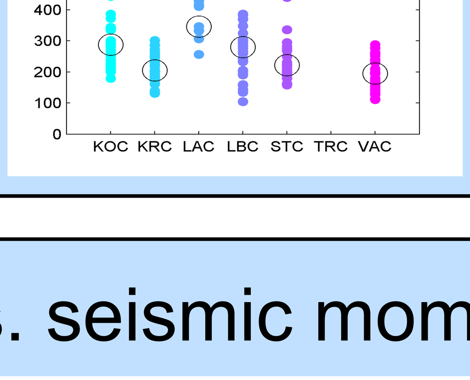


*Fig. 4. Attenuation factors Q obtained at individual stations and their median values marked by empty circles.*

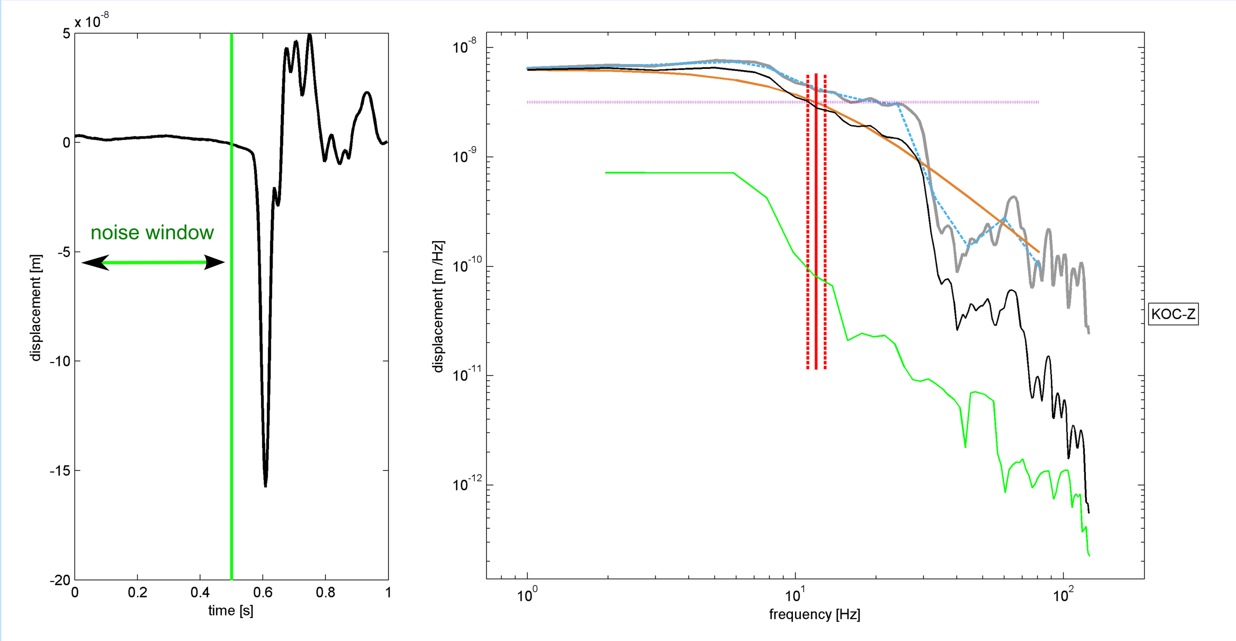


*Fig. 3. Example of frequency analysis of event $M_L$= 1.4 (ID: P1479A) at station KOC. Left is time window, right is spectrum with fitted $f_c$ (vertical solid red line). Observed spectrum of the signal is black, noise spectrum is green. Smoothed observed spectrum (blue), model (orange) and observed spectrum (gray) are all corrected for Q. The violet horizonal line is half value of low frequency amplitude. The $f_c$ with resolution estimate (5% flatness of misfit function) are vertical red.*

**Source model**

$$\Omega(f)=\frac{\Omega_0 \exp(-\pi f t/Q)}{1+\left(\frac{f}{f_c}\right)^2}$$

**Snoke´s $f_c$**

$$f_c=\left[\frac{J}{2\pi^3\Omega_0^2}\right]^{\frac{1}{3}}$$

## Stress drop

Both inversion and Snoke´s methods show significant correlation (0.73 and 0.83, respectively) which points to non-constant stress drop. The high stress drop (>100 MPa) occure for stronger events ($M_L$ > 2) in the beginning of the swarm in the deepest part of the fault zone (green crosses in Fig. 2).

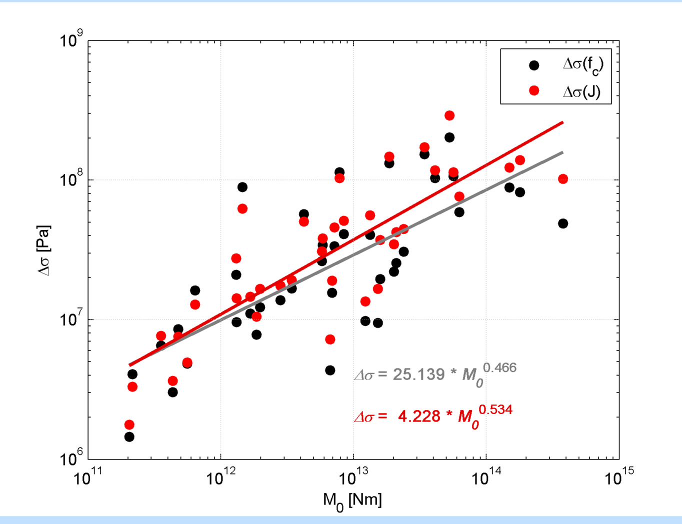


*Fig. 7. Stress drop shows significant dependence on $M_0$. Note the high stress drop for events with $M_0$ > 3E13 Nm only.*

## Source radius vs. seismic moment

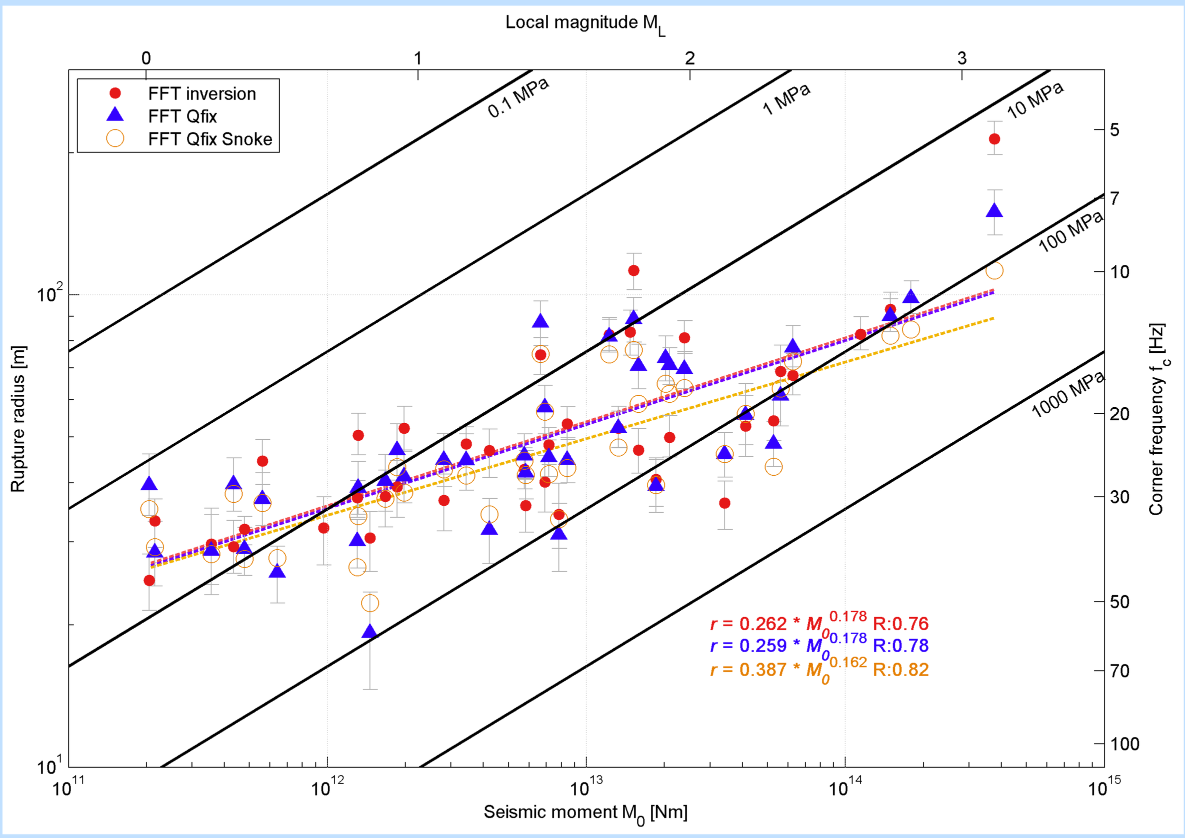


*Fig. 5. Comparison of three approaches for retrieving $f_c$ as described in section Methods. Black lines - constant stress drop. Error bars shows the uncertainity of radius derived from the 5% flatness of the misfit function.*

The **source radius** is calculated according to formula

$$r=\frac{k_P v_S}{f_c} \quad \text{where } k_P = 0.32 \text{ and } v_S=\frac{v_P}{\sqrt{3}}=3.5 \text{ km/s.}$$

**Seismic moment** is derived using

$$M_0=\frac{4\pi\rho v_P^3 R\,\Omega_0}{\Re_{\Theta,\Phi}F}$$

where $\rho$ = 2.7 g/cm³, R is hypocentral distance, $\Re_{\Theta,\Phi}$ is radiation pattern correction term and *F* correction for incidence angle at free surface (assumed value of 2). The source is assumed to be **circular rupture** after *Brune (1970)* and using the constant $k_P$ from *Madariaga (1976)*.

The question whether the stress drop is changing with decreasing moment or not can not be clearly answered based on this small amount of events we processed. We observe that the **stress drop varies between 3 - 300 MPa** and is decreasing with moment as well as the source size. The relation $r \sim M_0^{1/3}$ which is expected for the constant stress drop we do not observe and in our data we found $\boldsymbol{r \sim M_0^{0.18}}$ instead. The **source radius range between 20-200 m** but this is strongly model dependent as well as the seismic moment.

## Conclusions

- We found **frequency analysis** suitable for evaluating EQ source parameters in the West Bohemia region. Further study on bigger data set should be done to provide reliable results
- **Correction for attenuation** is crucial step in this analysis. **Q-factor** is stable, values are mostly between **200-350** at individual stations
- **Source radius** (**20-200 m**) is decreasing with moment. We found relation $\boldsymbol{r = 0.26\, M_0^{0.18}}$ for events in magnitude range $M_L$ 0.3-3.0
- **Stress drop** of swarm earthquakes with 2E11< $M_0$ <3E14 Nm range between **3 - 300 MPa**; the small events show smaller stress drops; the dependence on $M_0$ is significant but not very well constrained

## Acknowledgements

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