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Attenuation tomography in West Bohemia/Vogtland

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ABSTRACT

We present a three-dimensional (3-D) *P*-wave attenuation (Qp) model for the geodynamically active swarm earthquake area of West Bohemia/Vogtland in the Czech/German border region. Path-averaged attenuation t^* is calculated from amplitude spectra of time windows around the *P*-wave arrivals of local earthquakes. Average t/t^* value or Qp for stations close to Nový Kostel are very low (<150) compared to that of stations located further away from the focal zone (increases up to 500 within 80 km distance). The SIMUL2000 tomography scheme is used to invert the t^* for *P*-wave attenuation perturbation. Analysis of resolution shows that our model is well-resolved in the vicinity of earthquake swarm hypocenters. The prominent features of the model are located around Nový Kostel focal zone and its northern vicinity. Beneath Nový Kostel a vertically stretched (down to depth of 11 km) and a highly attenuating body is observed. We believe that this is due to fracturing and high density of cracks inside the weak earthquake swarm zone in conjunction with presence of free gas/fluid. Further north of Nový Kostel two highly attenuating bodies are imaged which could represent fluid channels toward the surface. The eastern anomaly shows a good correlation with the fluid accumulation area which was suggested in 9HR seismic profile.

1. Introduction

The West Bohemia/Vogtland region is located at the border of Czech Republic and Germany. It is of great interest as it exhibits ongoing geodynamical activities. Main activities in West Bohemia are related to diffuse CO_2 degassing in the form of CO_2-rich mineral waters or wet and dry mofettes (e.g., Bräuer et al., 2003; Geissler et al., 2005), Quaternary volcanoes and earthquake swarms (Fischer et al., 2014). Although fluids rising from deep crustal root zones are considered as the main reason for inducing earthquake swarm activities (e.g., Špičak and Horálek, 2001, Weinlich et al., 1998; Heinicke and Koch, 2000; Weise et al., 2001; Bräuer et al., 2005, 2009; Kämpf et al., 2013), the relation between earthquake swarms and CO_2 degassing is still a matter of debate (Babuška et al., 2016). The main tectonic features of West Bohemia including Cheb basin, Eger rift and Mariánské Lázně fault zone (MLF) as well as main mofettes (Soos, Bublák and Hartoušov), gas vents and Quaternary volcanoes (KomorníHůrka, ŽeleznáHůrka and Mýtina) are shown on the map in Fig. 1.

This study focuses on seismic attenuation in the West Bohemian massif and thus complements previous geophysical investigations. Seismic attenuation is the loss of energy of seismic waves passing through a medium (e.g., Aki and Richards, 1980) and is the inverse of the quality factor Q. Many studies have shown that seismic attenuation is a parameter sensitive to fluid content and some significant rock properties which do not have large impact on seismic velocities (e.g., Karato, 1993; Jackson et al., 2002; Faul and Jackson, 2005; Aizawa et al., 2008), thus it sheds new lights on our existing models of *P*- and *S*-wave velocities (Mousavi et al., 2015). Seismic waves are attenuated due to anelastic and elastic processes. Geometrical spreading, multipathing and scattering are elastic processes in which energy is attenuated along the propagation path. In contrast, during anelastic processes the energy of a propagating wave converts into heat (e.g., Stein and Wysession, 2003) or permanent deformation. Theoretical and experimental studies have shown that a combination of both, intrinsic (anelastic) and scattering (elastic) attenuation is responsible for the total seismic attenuation but it is often difficult to identify the dominant mechanism (Arevalo et al., 2003).

Intrinsic attenuation is considered to be caused by a variety of mechanisms. It is mainly a result of movement along minerals, frictional sliding on grain boundaries in a fluid-saturated elastic solid, vibration of dislocations, and viscous damping from local pore fluid motion (Berryman and Wang, 2000; Winkler and Murphy, 1995). The attenuation effect of these factors is different. Intrinsic attenuation of minerals has a relatively small effect whereas viscous dissipation (Mavko et al., 1979; Walsh, 1995), the presence of water, temperature and frictional

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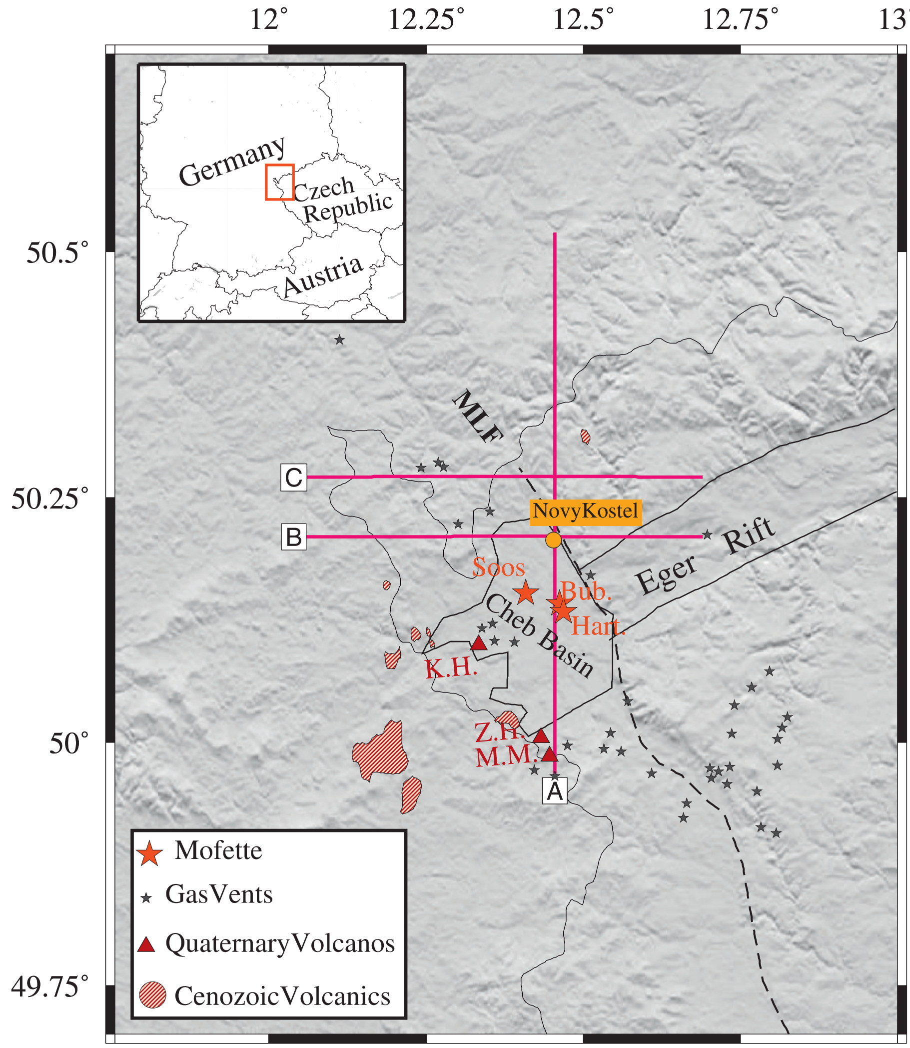

Fig. 1. Map of the study area showing the W-Bohemia/Vogtland region in the western part of Czech Republic, close to the German border. Grey background shading represents topography. Eger Rift, Cheb basin, Márianské Lázně Fault (MLF), mofettes, gas vents, Cenozoic volcanic zones, Quaternary volcanoes including KomorníHůrka (KH), ŽeleznáHůrka (ZH) and Mýtina (MM) and Main mofette fields inside Cheb basin including Hartoušov mofette (Hart.) and Bublák mofette (Bub.) and Soos (marked by red stars) are shown in the map. Location of three vertical tomographic sections A, B and C are shown with pink lines.

sliding between grains, are considered to have higher impact on attenuation (e.g., O'Connell and Budiansky, 1974, Johnston et al., 1979; Sato et al., 1989; Peacock et al., 1994; Winkler and Murphy, 1995). Thus, the intrinsic attenuation is strongly dependent on the permeability (Biot, 1956a,b). Intrinsic attenuation of seismic waves could even be caused by a very small amount of fluid (Mavko and Nur, 1979) which does not show up in high electrical conductivity. Intrinsic attenuation is often directly related to crack density and the presence of a small percentage of free gas in the medium (e.g., Trehu and Flueh, 2001).

In a recent study, Gaebler et al. (2015a) estimated the quality factor for elastic *S*-wave attenuation in West Bohemia around 700. Later, Gaebler et al. (2015b) determined scattering and absorption parameters for West Bohemia by inversion of envelopes with radiative transfer theory. They found that intrinsic attenuation dominates over scattering attenuation in this region for frequency bands from 3 to 24 Hz. Bachura and Fischer (2016) determined Qc (coda attenuation) and measured the amount of intrinsic and scattering attenuation. They also concluded that intrinsic attenuation is dominant in the frequency range 1–18 Hz, and that intrinsic attenuation in West Bohemia is higher than that of neighbouring areas in Germany. In this paper, we present the first detailed 3-D *P*-wave attenuation model around the swarm quake region in West Bohemia. Attenuation tomography provides independent constraints on derived anomalies in seismic velocities and Vp/Vs ratios (Mousavi et al., 2015). As such, using seismic attenuation as an imaging tool identifies spatial variations in fluid behaviour in Nový Kostel and provides further insight into the earthquake swarm focal zone.

2. Method

The source and attenuation parameters for an individual ray path from earthquake swarm to receiver can be determined by relating the observed spectrum of each station to its attenuation, source parameters, geometrical spreading, and site response (e.g., Sanders, 1993) as:

$$A_{i,j}(f) = S_j(f) I_i(f) R_i(f) G_{i,j}\, exp\left(-\pi f t^*_{i,j}\right) \quad (1)$$

where $A_{i,j}$ is the observed body wave spectrum of the jth earthquake recorded at the ith station, f is frequency, S_j is the source spectrum, I_i is the instrument response, R_i is the receiver site effect, $G_{i,j}$ is the geometrical spreading, $t^*_{i,j}$ is the path-averaged attenuation value. Geometrical spreading is considered to be independent from frequency and only depends on the distance between the source and the receiver.