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Review Article

Intra-continental earthquake swarms in West-Bohemia and Vogtland: A review

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ABSTRACT

Earthquake swarms and high CO_2 flow of mantle origin are the characteristic features of West Bohemia/Vogtland (Central Europe). At present, the highest concentration of earthquake activity and CO_2 degassing occurs in the area of the Cheb Basin at the intersection of the Eger Rift and Regensburg–Leipzig–Rostock Zone with three Quaternary active volcanoes. We review about 140 studies on structure, tectonics, volcanism, seismicity, earthquake source, triggering mechanisms, and gas-isotope geochemistry focused on the earthquake swarms from this area with the aim to build a complex image of the ongoing processes and find a possible link between activity of the mantle-derived fluids and the earthquake swarms. The so far unpublished data on the 2011 swarm and little known data on the 1824 swarm are presented, as well, showing that earthquake swarms activate a complex fault system and display long-term migration that differs from the occurrence of CO_2 escapes. The activity of individual swarms is consistent with models involving high-pressure fluids; the isotopic signature of the rising gas proves its origin at depths below the hypocenters. We show that the earthquake swarms and degassing of CO_2 of magmatic origin represent common result of the geodynamic activity of the area. Nevertheless, current knowledge does not preclude processes other than fluid-induced failure in triggering swarm seismicity.

Contents

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1. Introduction

The West Bohemia/Vogtland earthquake swarm region is one of the unique European intra-continental areas that display present activity of geodynamic processes, in particular, degassing of CO_2 and persistent seismic activity. The degassing of CO_2 of deep origin occurs in the form of CO_2-rich mineral waters and in the form of wet and dry mofettes in several degassing fields. The former represents the basis for multiple spa resorts distributed along the neighboring regions of the Czech Republic and Germany. The high $^3He/^4He$ ratios point to the mantle origin of the ascending gases. Seismicity is dominated by periodically occurring earthquake swarms with seismic magnitudes not exceeding M_L 5; a culmination of seismicity is observed within the last 30 years when a single M_L 4+ swarm and multiple M_L 3+ swarms occurred. These processes have been intensively studied by many authors and from various viewpoints, which resulted in a common opinion that the seismic activity stems from the whole geodynamic activity in the region; though the triggering factors still remain undisclosed.

In this review we summarize the seismological, structural and gas-emission studies carried out in West Bohemia and Vogtland with the aim to critically evaluate possible relations between seismic swarm activity and deep geodynamic processes. The paper is organized according to the individual disciplines and each section is concluded by a short summary outlining the key results that contribute to build up a comprehensive view of the present geodynamic processes in this unique European natural laboratory.

2. Tectonic setting

The Bohemian Massif is one of the largest stable outcrops of pre-Permian rocks in Central and Western Europe. It forms the easternmost part of the Variscan orogenic belt, which developed approximately between 500 and 250 Ma during a period of large-scale crustal convergence, collision of continental plates and microplates and subduction (Matte et al., 1990). The West Bohemia/Vogtland region (Fig. 1) forms the western part of the Bohemian Massif and it is situated in the transition zone among three different Variscan structural units: the Saxothuringian in the north-west, the Teplá-Barrandian in the central region, and the Moldanubian in the south-east (Babuška et al., 2007). The Paleozoic suture between the Saxothuringian and the Teplá-Barrandian with the Moldanubian units has been reactivated since the lower Triassic. The post-orogenic extension, together with the alkaline magmatic activity during the Cenozoic led, to the evolution of the Eger Rift, a 300 km long and 50 km wide ENE–WSW trending zone as an active element of the European Cenozoic Rift System (Prodehl et al., 1995). This tectonosedimentary structure is associated with a system of Cenozoic sedimentary basins and intense intraplate alkaline volcanism (Ulrych et al, 2011).

2.1. Neotectonic activity

The area is located at the intersection of two tectonic structures: the ENE–WSW striking Eger Rift (EGR) with the Eger Graben (EG) in the center and the N–S striking Regensburg–Leipzig–Rostock Zone, (length: 700 km and width: 40 km) which is seismically active in its middle part between Mariánské Lázně/Marktredwitz and Leipzig (Bankwitz et al., 2003), Fig. 2. This zone is dominated by numerous N–S faults, which are composed of en echelon segments measuring a few kilometers. The middle part consists of a set of sub-parallel faults, which were partly detected from satellite images and from negative geomorphological forms (Krentz et al., 1996; Krull and Schmidt, 1990). The faults were observed in numerous uranium mining exposures (including boreholes and prospecting trenches), especially in W Saxony and E Thuringia, Germany (Bankwitz et al., 2003).

The Cheb–Domažlice Graben (CDG) is located in the eastern part of the Regensburg–Leipzig–Rostock Zone (Fig. 2) and to the east it is bounded by the approximately 100 km long Mariánské Lázně Fault (MLF), which is morphologically expressed by a 50–400 m high escarpment. The western flank of the graben is characterized by a more gentle topography. The formation of the Cheb Basin in the northern part of CDG was initiated by the reactivation of basement faults inherited from the Variscan orogeny during the late Oligocene–Miocene. The sedimentary fill of the Cheb Basin consists of Tertiary and Quaternary sediments up to 300 m thick, representing debris of Proterozoic and Paleozoic magmatic and metamorphic rocks of the north-western Bohemian Massif, that bound the basin (Fiala and Vejnar, 2004). Sedimentation started during the Late Eocene, was interrupted in the Lower Oligocene and continued from Late Oligocene to Miocene; after a period of erosion it was revived in the Pliocene. The normal character of the fault zone controlled the formation of the Cheb Basin since late Eocene until Pliocene (Špičáková et al., 2000). The Cheb Basin is typified by a blocky fabric with a network of faults of different orientation (trending in NNW, NW, NW, E–W and N–S directions). Among them, the NNW trending faults are dominant; these faults belong to the East Marginal Fault of the basin that forms the northern portion of the MLF. The N–S trending faults do not seem to have significantly influenced the basin fill geometry (Špičáková et al., 2000 and references therein).

The NNW–SSE striking Mariánské Lázně Fault (MLF) intersects the area close to the main seismically active zone of Nový Kostel (NK), where more than 80% of seismic energy was released within the last