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Monitoring of helium and carbon isotopes in the western Eger Rift area (Czech Republic): Relationships with the 2014 seismic activity and indications for recent (2000–2016) magmatic unrest

Karin Bräuer[a,*], Horst Kämpf[b], Samuel Niedermann[b], Gerhard Strauch[a]

[a] UFZ-Helmholtz Centre for Environmental Research, Germany
[b] GFZ German Research Centre for Geosciences, Germany

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ABSTRACT

We report new data of the regional distribution pattern of total gas compositions as well as He and CO_2 isotopic compositions from 25 gas exhalations in the western Eger Rift and its surroundings. Additionally, the first time-series data from gas exhalations in a clay pit within the Cheb Basin (CB) are given. At 21 degassing locations, the first data were obtained > 20 years ago. From 7 locations within the degassing center CB and from 3 degassing sites belonging to the Mariánské Lázně (ML) degassing center, neon and argon isotope compositions were determined also.

CO_2 is the major component at all degassing sites. The $\delta^{13}C$ values display a small range (−1.7 to −5.1‰) and the $^3He/^4He$ ratios vary from 1.9 to 5.9 R_a. The highest $^3He/^4He$ ratios are found at locations along the Počatky-Plesná Fault Zone, followed by the degassing site in the clay pit on the Nová Ves Fault and the locations on the ML fault at the edge of the CB. Although gas flow and CO_2 concentrations in all degassing centers are very high, the fractions of mantle-derived helium are different, with presently up to 94% (in relation to the SCLM $^3He/^4He$ of 6.32 R_a) in the CB, up to 73% in the ML and up to 35% in the Karlovy Vary degassing center. At the locations in the eastern part of the CB a clear, progressive increase of the $^3He/^4He$ ratio has been observed since the first sampling campaigns there in 1993 and 1994, whereas at the other degassing sites the helium isotope ratio remained essentially the same. The progressive increase of the $^3He/^4He$ ratio in the eastern part of the CB, together with further short-time increases up to 6.3 R_a at one location (Bublák) before both the 2000 and 2008 earthquake swarms, indicate an ongoing magmatic process beneath this area, which seems to be associated with the occurrence of seismicity. The CB is located close to the Nový Kostel focal zone where since the beginning of our investigations four strong periods of seismicity (with magnitudes > 3) occurred. The latest gas data confirm our earlier findings: time-series studies showed that in relation with seismic events, decreased $^3He/^4He$ ratios were repeatedly observed due to admixed seismically released crustal helium. Presently, the eastern part of the CB is the most active non-volcanic region in the European Cenozoic Rift System, with gas signatures similar to those found in free mantle-derived gases from the East African Rift system.

1. Introduction

The investigation area in the western Eger Rift (NW Bohemia; Fig. 1) is part of the European Cenozoic Rift System (ECRIS) (Ziegler, 1992) and is known for the recurrence of earthquake swarms (e.g. Fischer et al., 2014 and references therein). This type of seismicity is mainly known from volcanically active areas (e.g. Hill, 1977; Sigmundsson et al., 1997; Schlindwein, 2012) but also occurs in non-volcanic areas, associated with deep-reaching zones of weakness in continental rifts (Ibs-von Seht et al., 2008). In addition, the region is characterized by the presence of CO_2-rich springs and mofettes (e.g. Pačes, 1974, 1987), which are used for medical treatment in the well-known spas of Františkovy Lázně, Mariánské Lázně, and Karlovy Vary.

Such CO_2-rich degassing sites are also known from other rift (graben) structures within the ECRIS, and most of them are associated with Quaternary volcanism such as in the Eifel area, Germany (e.g. Griesshaber et al., 1992; Bräuer et al., 2013) or in the French Massif Central (e.g. Matthews et al., 1987; Aeschbach-Hertig et al., 1996; Battani et al., 2010; Bräuer et al., 2017). Likewise, seismicity occurs also in the Eifel area (e.g. Hinzen, 2003) as well as in the Massif Central (e.g. Mazabraud et al., 2005), but not as intense as in NW Bohemia.

Between 1992 and 1994, Weinlich et al. (1999) studied 74

* Corresponding author.
E-mail address: Karin.braeuer@ufz.de (K. Bräuer).

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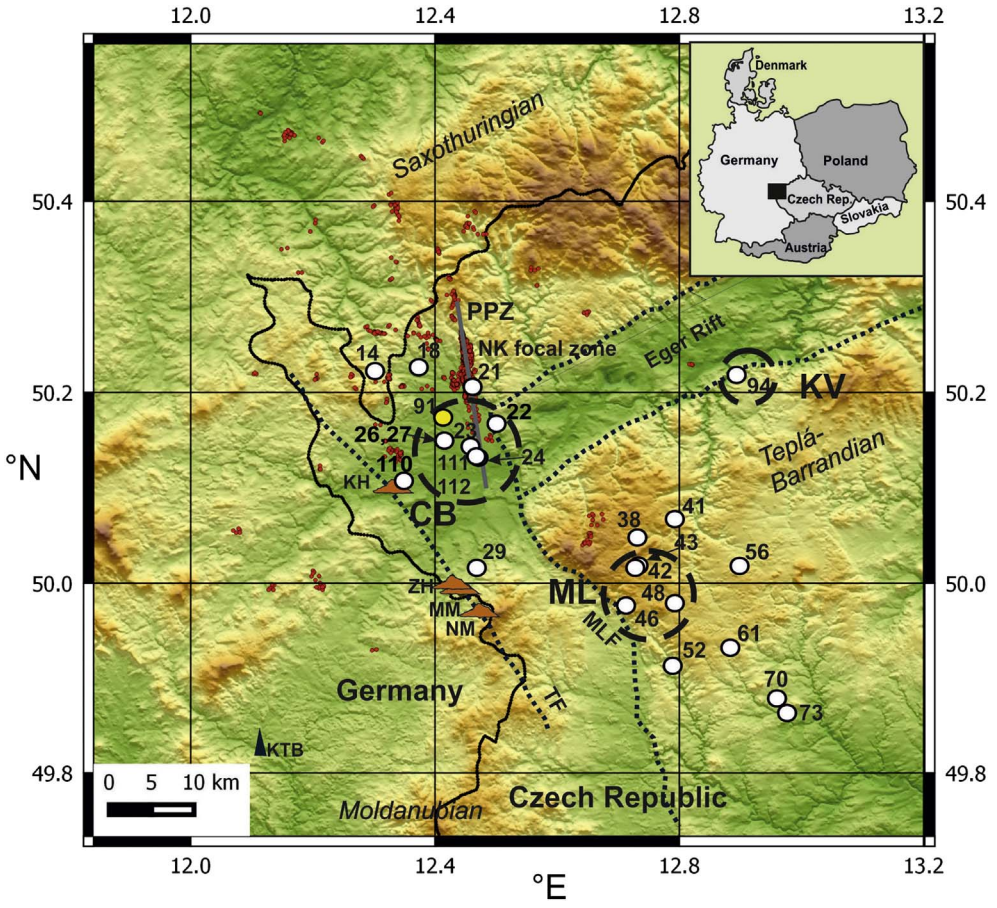

Fig. 1. Topographical map (modified after Hrubcová et al., 2017) showing the investigation area in the Czech/German border region. The white circles indicate all degassing sites which were studied (numbers according to Weinlich et al., 1999; Geissler et al., 2005). The yellow circle marks the position of the degassing site in the clay pit near Skalná, where monthly monitoring of the gas and isotopic compositions was carried out. Three degassing centers are indicated by black dashed circles (CB, Cheb Basin; ML, Mariánské Lázně; KV, Karlovy Vary). Seismic events are marked by small red dots which are concentrated in the Nový Kostel (NK) focal zone. The major fault zones Eger Rift (ER), Mariánské Lázně Fault (MLF), Tachov Fault (TF), and Počatky-Plesná Zone (PPZ) as well as four Quaternary volcanoes are indicated (KH, Komorní hůrka; ZH, Železná hůrka; MM, Mýtina Maar; NM, Neualbenreuth Maar). KTB denotes the site of the German Continental Deep Drilling Program. The inset shows the position of the investigation area in Central Europe. Numbers and names of sampling sites are listed in Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

degassing sites in the western Eger Rift area in detail by measuring the gas composition, the gas flow and the isotope ratios of CO_2 and helium. As a result, the regional distribution patterns revealed three discrete degassing centers: the Cheb Basin (CB), Mariánské Lázně and surroundings (ML), and Karlovy Vary (KV). They are all characterized by high gas flow, nearly pure CO_2 and high fractions of mantle-derived helium, therefore indicating a predominantly mantle-derived origin of both CO_2 and helium.

Geochemical fluid investigations in seismically active areas worldwide have reported anomalies of gas and isotopic compositions due to seismic unrest, pointing to seismically induced mobilization of fluids in the earth's crust and changes of fluid transport and of the permeability of migration paths (e.g. Sugisaki and Sugiura, 1986; Hilton, 1996; Sano et al., 1998; Toutain and Baubron, 1999; Caracausi et al., 2005; Chiodini et al., 2011). Seismically triggered anomalies due to several strong earthquake swarms were also recorded in NW Bohemia in the course of detailed monitoring studies of the gas and isotopic compositions (e.g. Bräuer et al., 2003, 2008, 2011). Otherwise, time-series studies to trace geochemical variations of degassing fluids or geochemical long-term studies have mainly been carried out at active volcanos (e.g. Lee et al., 2008; Martelli et al., 2008; Werner et al., 2009; Chiodini et al., 2010; Vaselli et al., 2010).

The goal of our new investigations was to reevaluate the geodynamic situation in the Eger Rift area after the occurrence of four seismically active periods (2000, 2008, 2011, and 2014) in the Nový Kostel (NK) epicentral area (Fischer et al., 2014; Hainzl et al., 2016). We present new data of the gas and isotopic compositions recorded during several sampling campaigns between 2014 and 2016 and additional monitoring data (March 2001 to August 2014) of a degassing site in a clay pit near Skalná, where monthly samples were taken from April 2010 to December 2011. As a result, we establish and/or concretize the role of the regional degassing structures.

2. Geological background

The investigation area is located within the transition zone of the Saxothuringian, the Teplá-Barrandian and the Moldanubian – a triple junction of three separated Variscan structural units (Babuška et al., 2007). In the Early Triassic, the units were reactivated, and they have presumably remained active to the present day. The evolution of the Eger Rift, which is part of the European Cenozoic Rift System (ECRIS; Ziegler, 1992), was probably associated with the occurrence of magmatic activity during the Cenozoic. Four volcanoes with Quaternary volcanic activity are known in this area (Fig. 1). The two scoria cones Železná hůrka (ZH) and Komorní hůrka (KH) are well-known. In addition, two maar structures have recently been identified: the Mýtina maar (MM; Mrlina et al., 2009) and the Neualbenreuth Maar (NM; Rohrmüller et al., 2017). All these volcanic features are located on the Tachov Fault (TF; Fig. 1).

Many seismological studies were carried out in order to search for structural discontinuities within the lithosphere beneath the investigation area. Using receiver functions, Geissler et al. (2005) and Heuer et al. (2006) found indications for crustal thinning from about 31 km to 27 km. The results of Heuer et al. (2011), who evaluated the structure of the lithosphere beneath western Bohemia, confirmed the Moho updoming there and additionally pointed to the existence of a plume-like structure beneath western Bohemia, but with only little or no imprint on the 410 km discontinuity. Further detailed active and passive seismic investigations found hints for a gradational zone over about 5 km, rather than a sharp discontinuity at the crust/mantle boundary (Hrubcová and Geissler, 2009). This interpretation of a laminated Moho structure, with a transition zone that varies between 2 and 4 km in thickness at depths ranging from 27 km to 31.5 km, was supported by Hrubcová et al. (2013).

The repeated occurrence of intraplate earthquake swarms