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# Mantle volatiles in spring gases in the Basin and Range Province on the west of Beijing, China: Constraints from helium and carbon isotopes

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ABSTRACT

The mantle degassing observed at the Earth surface demonstrates both a provenance of fluids in the mantle and a pathway to the surface. Quantities of this process are discovered on the plate boundaries, where there are plenty of active volcanoes and active faults, releasing plenty of mantle volatiles. However, in intraplate tectonic settings without obvious mantle plume, the work for mantle degassing observed in spring gasses seems comparatively limited. We selected the Basin and Range Province on the west of Beijing, an area in the inner part of North China Craton, to discuss the mantle degassing based on the helium and carbon isotopes of spring gasses, and the previous works on seismic tomography and fault slip rate. The spring gas helium and carbon ($CO_2$) isotopes indicate the mixture of crustal and mantle materials. The helium ratios (reported as $R_C/R_A$, air-corrected $^3He/^4He$ ratio, $R_A = 1.4 \times 10^{-6}$; $R_A$ is the air ratio) vary in the range of 0.33–2.08. The calculated mantle helium contributes 4% ~ 26% of helium in spring gasses, and the remaining is generated in the crust by radiogenic decay of U–Th series with tiny air mixture. $CO_2$ acquires analytical $\delta^{13}C_{V\text{-}PDB}$ values in the range from −20.3‰ to −10.2‰, affected by carbonate precipitation. The unaffected values are calculated to be −8.5 ~ 5.1 ‰ by temperature-dependent isotope fractionation, indicating the mixture of mantle and crustal (limestone) materials. The mantle volatiles are possibly generated in the upwelling asthenosphere, in that, the $^3He/^4He$ ratio corresponds well with the negative anomaly of P-wave velocity at the depth of 70 km imaged by seismic tomography. The $^3He/^4He$ ratio also correlates with time-averaged fault slip rate, suggesting higher slip rate renders more permeable mantle vent. These consequences help to construct a conceptual model for intraplate mantle degassing, that the mantle volatiles generate in the upwelling asthenosphere and uprise through faults and fractures whose permeabilities are controlled by slip rates.



## 1. Introduction

Mantle rocks contain volatile components in crystal interior or at grain boundaries (Hiraga et al., 2004; Burnard et al., 2015). The degassing of these primordial volatiles from the mantle to the surface is generally considered to be coupled with mantle partial melting and early magma ocean (Zhang, 2014 and references therein). The gasses released from the mantle move upward through faults and fractures and can be finally expressed as free or dissolved geothermal gasses. The mantle degassing process facilitated by spring gasses has been deduced by helium and carbon isotopes in plate boundaries where there are plenty of active magmatism and active faults, such as Iceland, Central America convergent margin, circum-Pacific volcanic arcs (e.g. Lupton, 1983; Poreda and Craig, 1989; Sano and Wakita, 1985; Sano and Marty, 1995; Hilton, 1996; Hilton et al., 1998; Shaw et al., 2003; Füri et al., 2010; Horiguchi and Matsuda, 2013). In the intraplate setting, significant mantle volatiles could also be identified in areas with high heat flow, thin crust, and active faults, while the active magmatism is not necessary (e.g., Kennedy and van Soest, 2007; Brauer et al, 2009; Burnard et al, 2012). The association of higher $^3He/^4He$ ratios with lower P-wave velocity has been found in the west USA, implying a provenance of mantle volatiles in the upwelling asthenosphere (Newell et al., 2005; Crossey et al., 2009; Karlstrom et al, 2013). For the fluid percolation in the west USA, higher mantle helium with higher strain rate suggests that the permeability of the ductile crust increases with strain rate (Kennedy and van Soest, 2007).

Several hot springs are scattered in the active fault zones along the Basin and Range Province on the west of Beijing (BRPWB). In this area, the fractured crust with fluids and the upwelling asthenosphere toward the depth of 60 km have been detected by seismic tomography (Huang and Zhao, 2004; Tian et al., 2009). Therefore, the BRPWB can serve as host of mantle volatiles for their generating and uprising. The mantle helium has been identified in spring gasses (Wang et al, 2005)

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and soil gasses (Li et al., 2009) in the Yanqing–Huailai Basin, part of the BRPWB. However, the spring gas provenances and mechanisms controlling gas transport are still poorly understood in this area.

In this paper, we discussed the mantle degassing process in the middle of a continental plate using helium and carbon isotopes in spring gasses. And we proposed a conceptual model for the generation and transport of mantle volatiles in an intraplate tectonic setting, the BRPWB.

## 2. Geological setting

The BRPWB is located on the north end of the Shanxi Rift System, which belongs to the Trans-North China Orogen. The BRPWB has experienced quantities of tectonic events and is characterized by not only the unique topography of the basins alternated with ranges but also the geological setting with active faults stretching along the range roots or in the inner parts of those basins. Since the Paleogene, the counterclockwise motion of the two sub-blocks of North China Craton, Eastern Block and Western Block, endows the Trans-North China Orogen with basins located between ranges (Fig. 1-a) (Xu and Ma, 1992). Due to its location on the north end of the S-shaped rift system, the BRPWB is characterized by NEE-SWW active normal faults with dextral strike slip component (Fig. 1-b). Furthermore, the basement rocks outcrop as the ranges stretching in NEE-SWW. Those rocks consist of Precambrian TTG (tonalite–trondhjemite–granodiorite) gneisses, suprarcrustal metamorphic rocks, syn- or post-tectonic granites (Lu et al., 2008), together with limestones and sandstones, acting as sources of Quaternary unconsolidated sediments in the basins. The Cenozoic basalts containing abundant mantle xenoliths outcrop in Yangyuan and Datong Basin of the research area (Xu et al., 2005; Xu

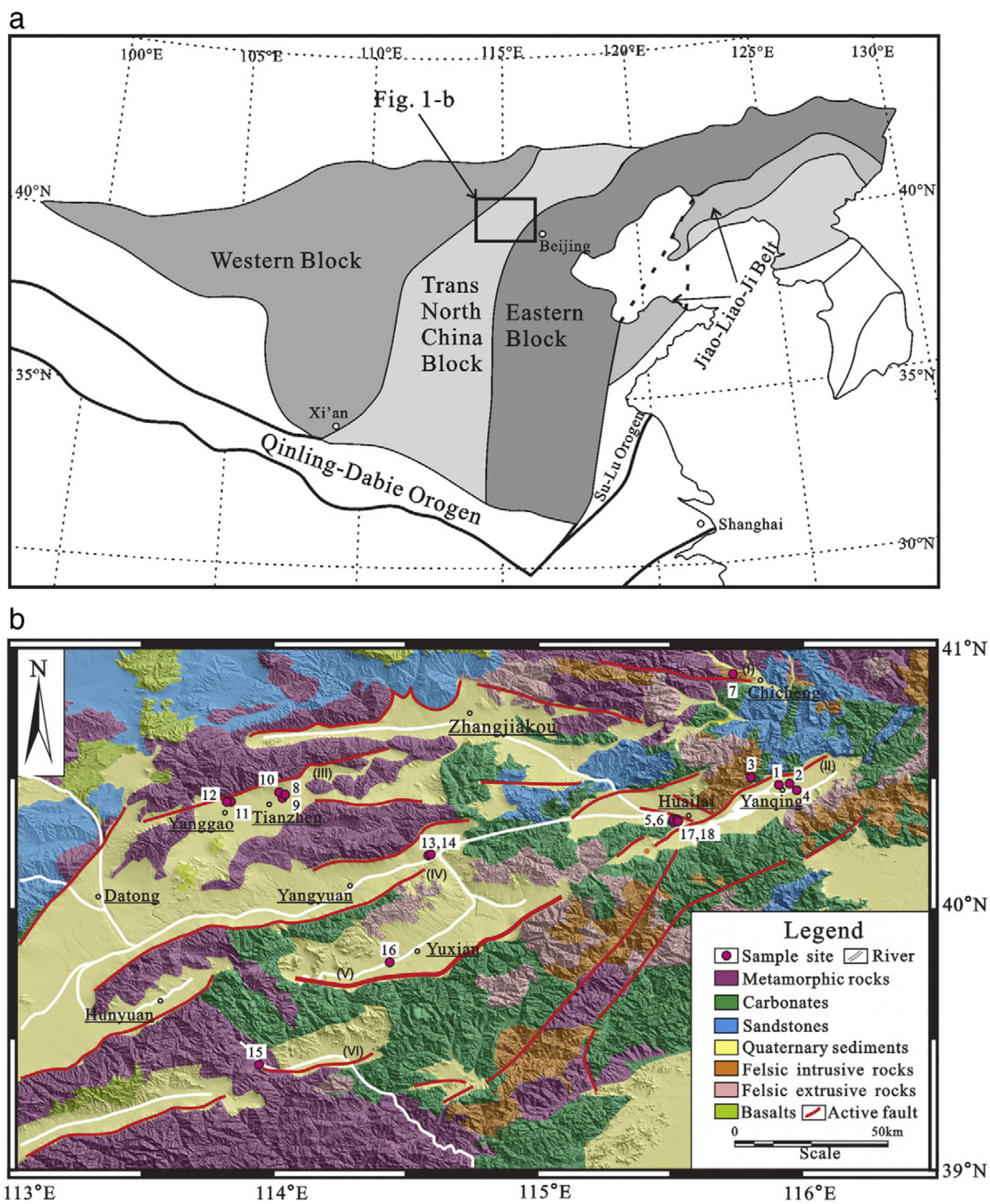


**Fig. 1.** Schematic geologic map the research area ( a, the sub-zones of North China Craton, was modified after Zhao et al, 2001; b, the geological map of the Basin and Range Province on the west of Beijing, combining geological units with topography). Active faults: (I) Shangyi–Chicheng Fault; (II) Fault of North Yanqing–Fanshan Basin; (III) Yanggao–Tianzhen Fault; (IV) Fault of North Root of Liulengshan Mountain; (V) Fault of Yuxian South Mountain; (VI) Fault of South Lingqiu Basin.