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Research paper

Spatial variations in gas and stable isotope compositions of thermal fluids around Lake Van: Implications for crust–mantle dynamics in eastern Turkey

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ABSTRACT

We investigate the helium ($^3He/^4He$) and carbon ($\delta^{13}C$) isotope compositions and relative abundance ratios ($CO_2/^3He$) of gas samples together with the stable isotope compositions of dissolved carbon and sulfur and the oxygen and hydrogen isotopic compositions of the associated water phase from a number of geothermal fields located around Lake Van in eastern Anatolia, Turkey. The mantle-derived helium component, which is likely transferred to the crust beneath eastern Turkey by recent magmatism, is found to constitute up to 96% (e.g. Nemrut Caldera) of the total He content in fluids. As regards the spatial distribution of He, samples collected from areas of Pliocene–Quaternary volcanics are characterized by a wide and generally higher range of R/R_A ratios (0.93 to 7.76 R_A) compared to those of non-volcanic regions (0.85 to 1.0 R_A). $CO_2/^3He$ ratios vary over a wide range (2.4×10^5–3.8×10^{13}) but are mostly higher than that of the nominal upper mantle (~2×10^9). Oxygen–hydrogen isotope values of the waters are conformable with the Global Meteoric Water Line and indicate a local meteoric origin. Sulfate in waters is most probably derived from dissolution of marine carbonates and terrestrial evaporite units. Temperatures calculated by SO_4–H_2O isotope geothermometry lie between 40 and 199 °C, and are in poor agreement with reservoir temperatures estimated from silica geothermometers. Discordant temperatures may be due to either the relatively slow rate of isotopic equilibrium between water and sulfate or mixing of geothermal water with sulfate-bearing shallow waters which may modify the $\delta^{18}O$ value. The $\delta^{13}C$ (CO_2) values of gas samples are consistently lower than those of their water counterparts, consistent with loss of CO_2 from waters by degassing. Mixing between mantle and various crustal C-sources appears to be the main control on the C-isotope composition. The principal origin of CO_2 in all samples is crustal lithologies, mainly limestone (~85 to 98% of the total carbon inventory): thus, the crustal carbon flux is at least 10 times that from the mantle. There is a broad correlation between high $^3He/^4He$ values and thinner crust in the western part of the Lake Van region, where several historically-active volcanoes are located. This observation indicates that localized volcanic and magmatic activity exerts the primary control on the balance between mantle and crustally-derived volatiles in the region.

1. Introduction

Eastern Anatolia in Turkey is characterized by post-collisional tectonics and widespread Neogene–Quaternary volcanism which has resulted in a moderately high regional geothermal gradient (Mıhçakan and Öcal, 2000). Indeed, one of the key features of the region is the occurrence of several recently-active volcanoes (Yilmaz et al., 1998). Paradoxically, however, reservoir temperatures, estimated using chemical geothermometry on geothermal waters, together with bottom-hole temperatures recorded in thermal wells, are generally low—a feature attributed to the lack of deep fault systems (and hence deep hydrothermal circulation) (Mutlu and Güleç, 1998). Therefore, eastern Anatolia provides a potentially rewarding locality to examine the relationship between active tectonic and magmatic activity and to gain insight into the nature of crust–mantle interactions in a collision setting characterized by three decades of intense research activity (e.g., Şengör et al., 2008 and references therein).

One of the key approaches to record the effects of crust–mantle interaction—particularly in regions characterized by abundant geothermal activity such as eastern Anatolia—is through use of coupled He–CO_2 variations as both volatiles possess isotopic and/or

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abundance features diagnostic of crustal and mantle derivation (e.g., O'Nions and Oxburgh, 1988). An additional advantage of this approach is that both tracers are sensitive to changes in the balance between crustal and mantle provenance in any resultant mixture so that seismically-active regions can be targeted for monitoring studies (e.g., Hilton, 1996; Italiano et al., 2001; de Leeuw et al., 2010). To date, these two features of the He–CO_2 system have been combined in studies of the North Anatolia Fault Zone and adjacent areas of western Anatolia (Güleç et al., 2002; Mutlu et al., 2008; de Leeuw et al., 2010): however, similar studies in eastern Anatolia have exploited He isotope variations alone (e.g., Nagao et al., 1989; Kipfer et al., 1994; Ercan et al., 1995). In this study, we present new data on the CO_2 and He systematics (isotopes and relative abundances) of geothermal fluid gasses together with stable isotope variations of the associated water phase ($\delta^{18}O$, δD, $\delta^{34}S$–$\delta^{18}O$ (SO_4) and $\delta^{13}C$) from 18 sites in eastern Anatolia. Helium isotope compositions and the relative abundances of helium and carbon in these fluids are used to assess volatile/fluid provenance in the region along with the extent of crust–mantle interaction. Stable isotope variations provide additional constraints on fluid provenance as well as on processes associated with host geothermal reservoirs. Taken together, this multi-tracer approach is presented in the context of the complex tectonomagmatic evolution of eastern Anatolia.

2. Geologic outline

The geologic framework of eastern Anatolia, as well as much of Turkey, has been defined by the collision between the Arabian Plate and Eurasia (Şengör and Yılmaz, 1981). Although the collision terminated in the Middle Miocene (Şengör and Kidd, 1979; Dewey et al., 1986), the ongoing convergence along the Bitlis–Zagros Thrust Zone (Fig. 1) has given rise to uplift of the Turkish–Iranian Plateau (Şengör and Kidd, 1979), which attains an average elevation of about 2 km above sea level. The nature of the tectonic regime in the region seems to have changed from compressional–contractional (post-collisional convergence) in the Middle Miocene-Early Pliocene to compressional–extensional (tectonic escape) in Early Pliocene—Recent times (Koçyiğit et al., 2001). The recent M = 7.2 Van earthquake of 23 October 2011 is the latest manifestation of active tectonism in the region.

The basement of the Turkish–Iranian Plateau is comprised of several microcontinents separated from one another by suture zones and accretionary complexes. Based on a summary/synthesis of previous studies (Şengör, 1990; Yılmaz et al., 1997; Karapetian et al., 2001; Şengör et al., 2003; Topuz et al., 2004), the geologic framework of eastern Anatolia can be described by recognizing the presence of five different tectonic blocks in the region: the Eastern Rhodope–Pontide fragment, Northwestern Iranian fragment, Eastern Anatolian Accretionary Complex (EAAC), Bitlis–Pötürge Massif, and the Arabian foreland (Keskin, 2007) (Fig. 1).

The Eastern Rhodope–Pontide fragment comprises the northernmost part of the region. It is represented by metamorphic basement consisting of granulite facies rocks (Topuz et al., 2004) and overlying volcano–sedimentary sequences which are considered part of a south-facing magmatic arc resulting from northward subduction under Eurasia (Yılmaz et al., 1997). The Northwestern Iranian fragment consists of

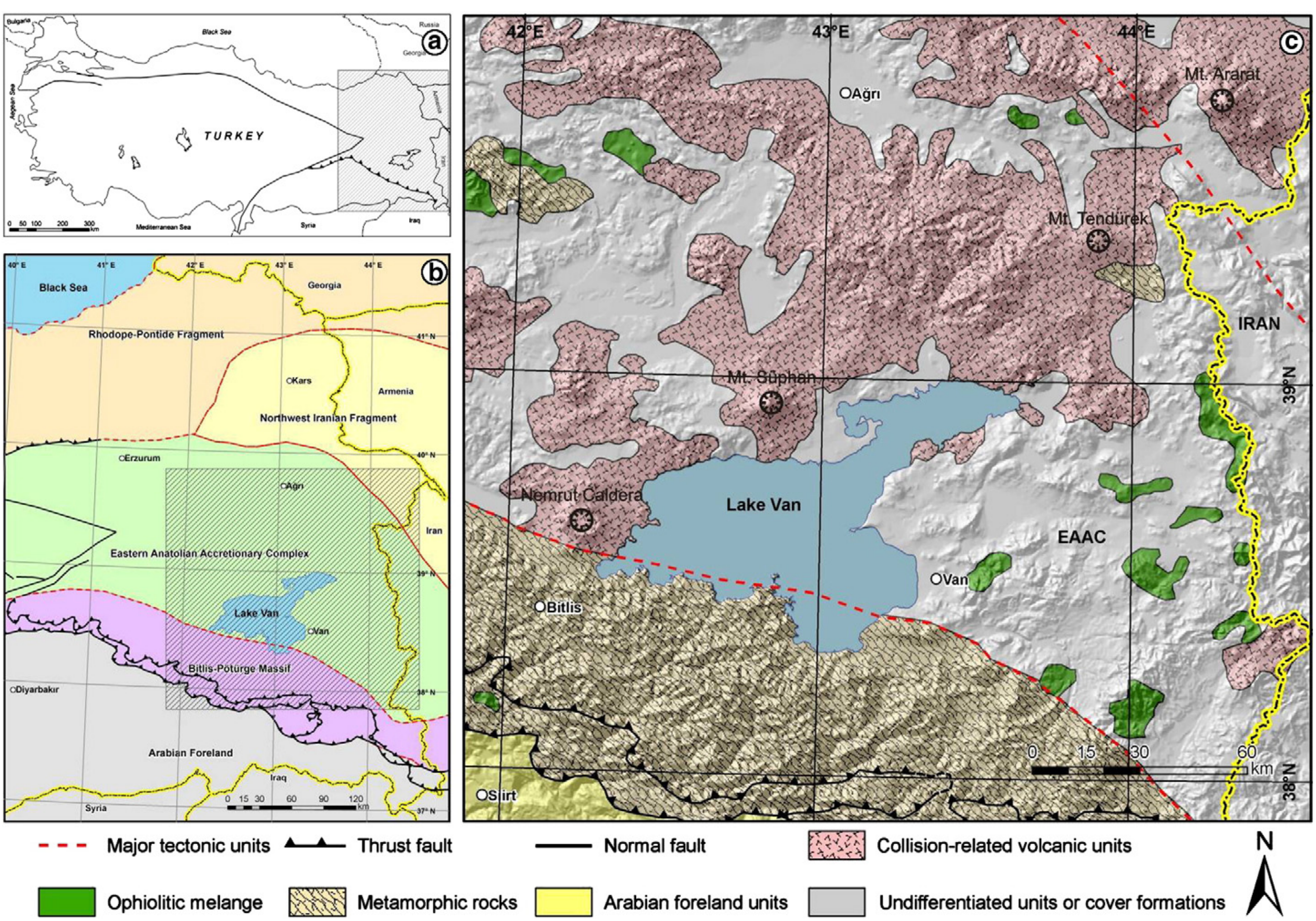

Fig. 1. Maps showing a) the location, b) major tectonic units and c) geology of eastern Anatolia. From Keskin, 2007.