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Fluids along the North Anatolian Fault, Niksar basin, north central Turkey: Insight from stable isotopic and geochemical analysis of calcite veins

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ABSTRACT

Six limestone assemblages along the North Anatolian Fault (NAF) Niksar pull-apart basin in northern Turkey were analyzed for $\delta^{18}O_{PDB}$ and $\delta^{13}C_{PDB}$ using bulk isotope ratio mass spectrometry (IRMS). Matrix-vein differences in $\delta^{18}O_{PDB}$ (−2.1 to 6.3‰) and $\delta^{13}C_{PDB}$ (−0.9 to 4.6‰) suggest a closed fluid system and rock buffering. Veins in one travertine and two limestone assemblages were further subjected to cathodoluminescence, trace element (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) and $\delta^{18}O_{PDB}$ (Secondary Ion Mass Spectrometry, SIMS) analyses. Fluid inclusions in one limestone sample yield T_h of 83.8 ± 7.3 °C ($\pm 1\sigma$, mean average). SIMS $\delta^{18}O_{PDB}$ values across veins show fine-scale variations interpreted as evolving thermal conditions during growth and limited rock buffering seen at a higher-resolution than IRMS. Rare earth element data suggest calcite veins precipitated from seawater, whereas the travertine has a hydrothermal source. The $\delta^{18}O_{SMOW\text{-}fluid}$ for the mineralizing fluid that reproduces T_h is +2‰, in range of Cretaceous brines, as opposed to negative $\delta^{18}O_{SMOW\text{-}fluid}$ from meteoric, groundwater, and geothermal sites in the region and highly positive $\delta^{18}O_{SMOW\text{-}fluid}$ expected for mantle-derived fluids. Calcite veins at this location do not record evidence for deeply-sourced metamorphic and magmatic fluids, an observation that differs from what is reported for the NAF elsewhere along strike.

1. Introduction

Fluid pressure has a significant effect on earthquake rupturing and fault slip behavior (e.g., Sibson et al., 1975; Bredehoeft and Ingebritsen, 1990; Rice, 1992; Byerlee, 1993; Sibson, 1996; Chiodini et al., 2004; Miller et al., 2004; De Leeuw et al., 2010). Increased permeability as a direct result of faulting is assumed in many of these cases, but fracture networks can also form impermeable barriers or combined permeable and impermeable zones (e.g., Caine et al., 1996; Frima et al., 2005; Olierook et al., 2014; Ran et al., 2014). Passive and dynamic open-mode fracturing occurs in transtensional settings, each having differing implications for the nature of fluids recorded in rock fractures (e.g. Sample, 2010; Uysal et al., 2011; Nuriel et al., 2012a, 2012b). Dynamic fractures open episodically due to seismic events, and fluids are mobilized to form veins (e.g., Hilgers and Urai, 2002; Nuriel et al., 2012a). Vein mineralization in passive fractures may occur over short timescales after earthquake activity, with distinct episodes of mineral deposition mediated via the influx of fluids (Moore et al., 2000). Thus veins have the potential to directly record information regarding fluid composition and the permeability of fracture networks after seismic activity (Verhaert et al., 2003, 2004).

Here we seek to understand the nature, source, and extent of

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fluids recorded by fracture networks along the seismically-active North Anatolian Fault (NAF) in north central Turkey, in portions of the fault system that displace Upper Jurassic to Lower Cretaceous carbonate assemblages at the surface (Fig. 1). Geochemical signatures for deep crustal- or mantle-derived fluids may exist within fault rock calcite veins, and such evidence would indicate that NAF deformation results in vertically permeable fracture networks accessing deep, over-pressured fluids (e.g., Pili et al., 2002, 2011). Alternatively, diagenetic processes may dominate, and calcite veins record only precipitation or mineralization during previous events related to the closure of the Tethyan oceans with no evidence of more recent activity. Discerning the processes responsible for the formation of calcite veins in rocks displaced by the NAF is possible by employing multiple geochemical and isotopic tracers.

Geochemical evidence for fluid sources tapped by NAF fracture systems potentially exists within calcite veins in limestone rocks collected directly from fault planes or fault-related fractures (e.g., Janssen et al., 1997, 2009; De Leeuw et al., 2010; Crémiére et al., 2012). The rocks displaced by the NAF have experienced a multistage history, thus discriminating veins that result from mineral precipitation due to pressure changes and fluid unmixing after earthquake rupture (e.g., Uysal et al., 2011) from those associated with diagenesis (e.g., Morad et al., 2010) or previous metamorphic cycles associated with the closure of Tethyan oceans (e.g., Bektaş et al., 2001; Yilmaz, 2006) remains unknown. In strike slip systems and within the NAF, the extent of vertical fluid flow in fault zones is unclear as a number of controls influence migration (e.g., Peacock and Anderson, 2012; Ritz et al., 2015). The results reported here have implications for understanding the nature of regional-scale fluid-flow within the NAF and the use of isotopic data from calcite veins as recorders of seismic activity (Roberts, 1994; Uysal et al., 2011; Dabi et al., 2013).

Ample evidence exists for deep crustal and magmatic fluid migrating vertically through the NAF and related deformation zones at specific locations along strike. For example, contributions of mantle helium in hydrothermal fluids from areas along the NAF associated with seismic activity have increased after seismic events (Doğan et al., 2009; De Leeuw et al., 2010; Burnard et al., 2012). Magnetotelluric studies show increased conductivity in deformed crust beneath the NAF trace (Türkoğlu et al., 2015), and seismic tomography indicates a pervasive low-velocity zone that extends into the mantle, interpreted to be a zone of deformation associated with the NAF (Fichtner et al., 2013). Clay minerals from NAF planes have δ^{18}O and δD values consistent with deeply sourced metamorphic and magmatic fluids that have migrated as a result of fault activity (Uysal et al., 2006).

This study is the first to present $\delta^{18}O_{PDB}$ Secondary Ion Mass Spectrometry (SIMS) data from NAF calcite veins, which shows promise for deciphering small-scale variations in larger veins and discriminating among different smaller fracture generations (Sample, 2010). The results are further informed by bulk isotope ratio mass spectrometry (IRMS), fluid inclusion analyses, cathodoluminescence (CL) images, and petrography. The data provide insight regarding changes in fluid source and temperature, and are used to infer chemical processes occurring during crystallization.

2. Geologic background

The North Anatolian Fault (NAF) (Fig. 1) is a 1200 km-long dextral strike-slip fault which extends from the town of Karliova in northeastern Turkey, paralleling the coast of the Black Sea, across the Northern Aegean Sea, central and mainland Greece, eventually linking with the Hellenic subduction zone (e.g. Barka, 1992; Barka, 1996; Barka et al., 2000; Şengör et al., 2005). The structure is part of a larger zone of deformation called the North Anatolian Shear Zone (NASZ) (Şengör et al., 1985, 2005), which lies along the boundary between the Eurasian plate to the north and the Anatolian microplate to the south. Its dextral slip accommodates the counterclockwise rotation and westward escape due to the collision between the Arabian and Anatolian plates (Barka and Hancock, 1984; Piper et al., 2010).

The focus of this study is the Erbaa-Niksar basin in the Tokat Massif of NE Turkey. The basin is considered one of the widest (12–13 km) active pull-apart basins along the NAF (Figs. 1 and 2) (Barka et al., 2000; Ozden et al., 2002; Bektaş et al., 2001). The strike of the NAF between the towns of Erzincan and Erbaa is approximately 105°, whereas adjacent segments are 120°-125° (Fig. 1). A zone of convergent, N-S directed, E-W trending strain intersects with ideal strike-slip motion on the eastern part of the NAF, and is responsible for the origin of the Erbaa-Niksar basin (Şengör et al., 1985). It is Z-shaped, bounded to the north by the Niksar-Kaleköy fault segment which ruptured in 1942 ($M_s = 7.1$) and 1943 ($M_s = 7.4$) and to the south by the Erzincan or Ezine Pazarı fault which ruptured in 1939 (Ms 7.8) (e.g., Mann et al., 1983; Ambraseys and Jackson, 1998; Tatar et al., 2007; Gürsoy et al., 2013; Demir et al., 2015). The southern boundary is part of a series of faults at a major NAF step over (Barka et al., 2000; Zabci et al., 2011). The Erbaa-Niksar basin has been a key component used to model NAF evolution and slip history (Barka and Hancock, 1984; Tatar et al., 1995; Barka et al., 2000; Gokten et al., 2013), and is also termed separately Niksar and Erbaa-Taşova (e.g., Hempton and Dunne, 1984; Barka et al., 2000).

Mammal fossils from the Erbaa-Taşova portion of the basin place a minimum age for its formation in Early Pliocene, with initiation of the fault zone in this area in Late Miocene to Early Pliocene (Barka et al., 2000; Erol and Topal, 2013). Assuming that Erbaa-Taşova basin length and total fault displacement are directly related suggests a total displacement of 65 km for this part of the NAF. The Niksar basin (Fig. 2) is shorter in length (~15 km), and thus accommodates less displacement, making its age 0.5–1 Ma when extrapolating from slip rate estimates of 15–20 mm/yr (Barka et al., 2000; Hubert-Ferrari et al., 2002). Sedimentary units comprising the Niksar basin are younger than the Erbaa-Taşova (primarily Quaternary) and contain evidence of Quaternary volcanism (Adiyaman et al., 2001; Tatar et al., 2007).

Basement rocks of the Erbaa-Niksar basin are part of the Tokat Massif (Rojay, 1995; Yilmaz and Yilmaz, 2004; Catlos et al., 2013) and are separated by regional unconformities (Yilmaz et al., 1997; Yilmaz and Yilmaz, 2004). The basement units are: (1) Triassic metamorphic rocks of the Karakaya accretionary complex, (2) Liassic to Mid-Cretaceous carbonates, clastic sediments and volcanic rocks, (3) Upper Cretaceous limestones, volcanic rocks and ophiolites, and (4) Eocene volcanic and sedimentary rocks (Yilmaz et al., 1997; Yilmaz and Yilmaz, 2004; Erturac and Tüysüz, 2012). These units are exposed along the western boundary of the Niksar basin and along the principal displacement zone along the Erbaa-Taşova basin (Fig. 1) (Barka et al., 2000; Erturac and Tüysüz, 2012).

3. Methods

3.1. Sampling and analytical strategy

Our approach is to apply a combination of bulk (IRMS) and high-resolution (laser ablation inductively coupled plasma mass spectrometry, LA-ICP-MS and SIMS) geochemical tools to six fractured limestone assemblages collected from exposures of the NAF and within the Erbaa-Niksar basin in north-central Turkey (Fig. 1). Calcite matrix (the rock material surrounding the vein) and vein fill were characterized petrologically and analyzed using IRMS for oxygen and carbon ($\delta^{18}O_{PDB}$, $\delta^{13}C_{PDB}$). Based on petrography, IRMS