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CO_2 –DRIVEN HYDROTHERMAL ERUPTIONS IN GEOTHERMAL SYSTEMS OF TURKEY

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ABSTRACT

Substantial CO_2 degassing occurs from geothermal waters in Turkey as evident from ongoing deposition of recent terrace travertines and emplacement of significant travertine vein and breccia deposits representing hydrothermal eruption products. Geochemical data indicate rapid ascent of CO_2-bearing fluids without significant interaction with basement and host rocks. High-precision U-series dates of most travertine veins coincide with times of cold/dry climate events. Late Quaternary climate variability controls the availability and quantity of geothermal waters, with relatively wet climate events (such as today) leading to CO_2 discharge and dissipation at surface through deposition of terrace-mound travertines. We hypothesise that a significant reduction in surface or near surface discharge of CO_2 by spring or geothermal waters during dry climate periods evidently promotes oversaturation of CO_2 in deep reservoirs. It is concluded that host rock fracturing in response to seismic shaking and fluid overpressure results in rapid exsolution and expansion of the dissolved gas leading to hydrothermal eruptions.

INTRODUCTION

Improving our knowledge of the physical behaviour of subsurface CO_2 is important to understanding the evolution of CO_2-rich geothermal waters in natural systems and their impact on the reservoir as well as the long term fate of CO_2 as working fluid in enhanced geothermal systems. Turkey is one of the most seismically active regions on Earth with significant associated high enthalpy geothermal systems and high CO_2 production (Güleç et al., 2002; Mutlu et al., 2008). Intense CO_2 degassing is manifested by recent deposition of travertine terraces at Pamukkale geothermal field and travertine vein and breccia deposits in fracture zones of active major fault systems (Hancock et al., 1999; Uysal et al., 2007). In order to provide some insight into the geological process that controls the behavior of CO_2 degassing in geothermal reservoirs, we investigated travertine vein and breccia deposits in the CO_2-rich Pamukkale and Kirsehir geothermal fields in western and central Turkey respectively (Fig. 1).

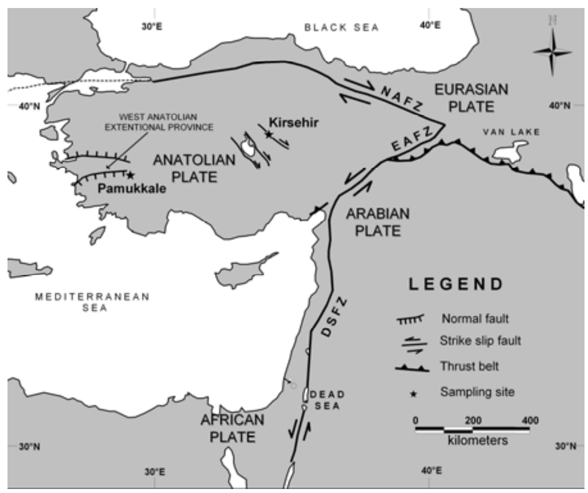
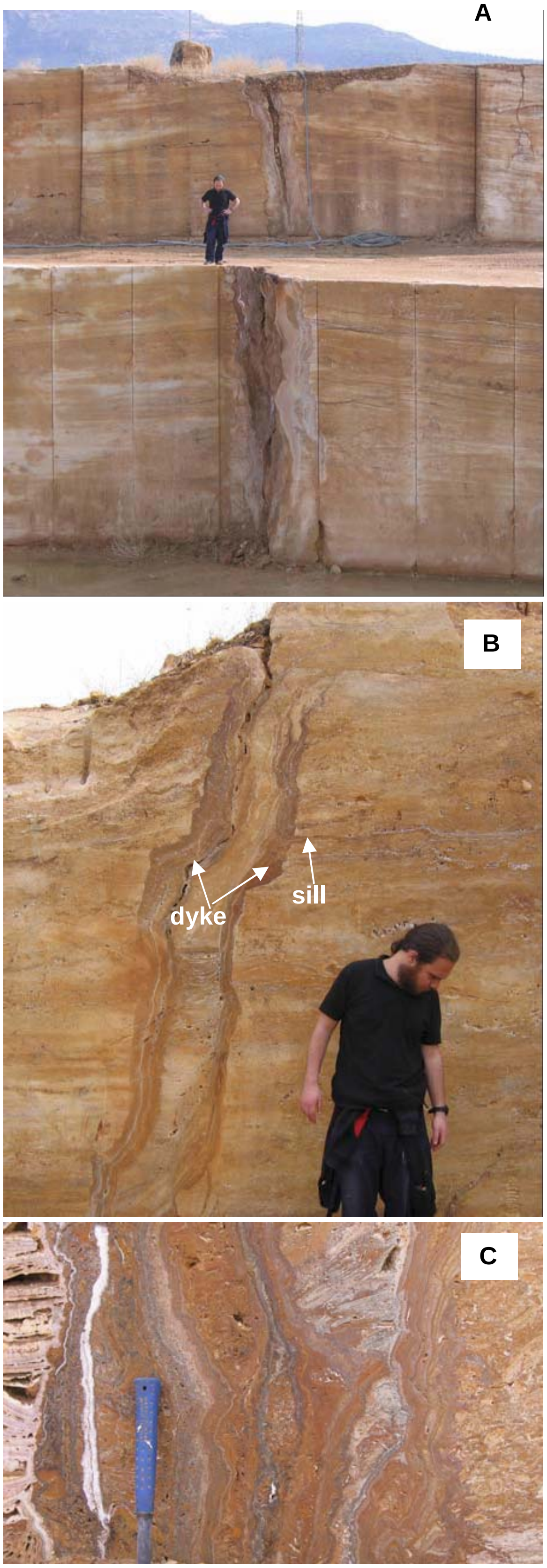


Figure 1. *Simplified tectonic map of Eastern Mediterranean region and the location of Pamukkale and Kirsehir geothermal fields. NAFZ and EAFZ: North and East Anatolian Fault Zone, respectively. DSFZ: Dead Sea Fault Zone.*

RESULTS

Field observations

The travertine veins at geothermal fields in Turkey occur as injections into basement rocks and propagated to the surface through the pre-existing horizontally bedded travertines Fig. 2A-D). The veins occur as dyke and sill systems branching towards the surface (Fig. 2B). The travertine veining is commonly associated with brecciation of wall rocks representing a “crackle” texture. At the Pamukkale geothermal field, a different breccia type also occurs commonly as dyke or poorly sorted injection deposits within the bedded travertine (Fig. 2D-E). Such breccia deposits contain clasts from both earlier deposited bedded travertine and metamorphic basement rocks.



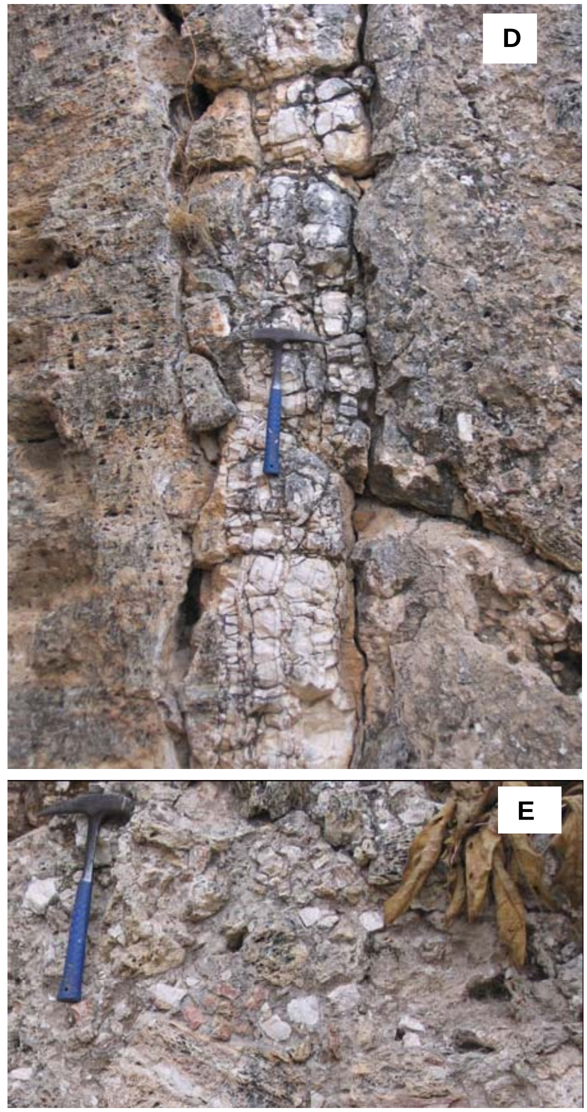


Figure 2: *Travertine vein injections into the pre-existing horizontally bedded travertines* **(A-D)**. *Veins propagating to the surface are interpreted as representing eruption vents* ***(A and D)***. *Note the breccia injection (right) juxtaposed with a pure treavertine vein (in the middle with the hammer) and the pre-existing bedded travertine representing the wall rock (left)* ***(D)***. *This breccia was cemented by the* CO_2*-rich water that reached the surface through the eruption vents* ***(E)***. *Horizontally bedded travertine was deposited earlier by similar waters at the surface.*

Geochemistry

Structural geological observations indicate that vein formation was a result of rapid upward migration of CO_2-rich fluids. However, supporting geochemical data are needed to verify this conclusion. Therefore, the application of stable isotope and trace element

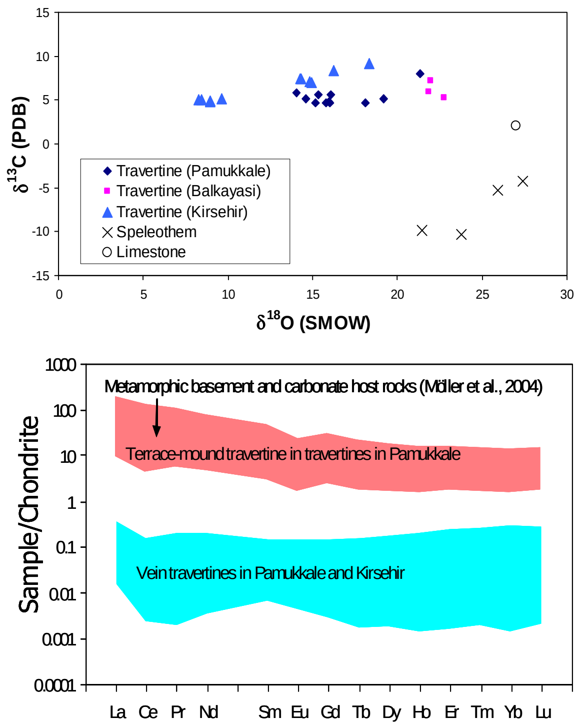


Figure 3: *Stable isotope and rare earth element geochemistry of the travertine veins. Data for samples from the Pamukkale-Balkayasi and Kirsehir geothermal field are from Uysal et al. (2007) and Uysal et al. (in preparation), respectively.*

geochemistry is important. It is evident from Fig. 3A that carbon isotope values from both Kirsehir and Pamukkale geothermal fields are significantly positive. Such positive values are characteristic of thermogene travertine where CO_2 originates from sub-surface thermal process, whereas the negative carbon isotope values for speleothem or flowstone samples from SW Turkey indicates precipitation from cold surface water. Heavy carbon isotope compositions as well as positive correlations between carbon and oxygen isotope values for samples from the Kirsehir geothermal field (Fig. 3A) is indicative of non-equilibrium isotope fractionation during intense CO_2 evasion and evaporation of hot geothermal water.

Travertine veins from both Kirsehir and Pamukkale geothermal fields have remarkably low rare earth element (REE) concentrations, in comparison to those of the metamorphic basement and the immediate carbonate host rocks (Fig. 3B). Hot geothermal waters would be expected to leach considerable amount of trace elements from the basement and host rocks during water-rock interaction; which is, however, not the case. Extremely low REE concentrations can be attributed to rapid ascent of CO_2-bearing fluids without significant interaction with basement and host rocks. On the other hand, currently precipitating terrace-mound travertines have similar REE patterns as the metamorphic basement rocks that can be explained as a result of a prolonged fluid circulation and interaction with the basement rocks.

DISCUSSIONS AND CONCLUSIONS

Travertine-filled veins and breccias represent hydrofractures, which formed as extensional mode I cracks in response to internal overpressure of CO_2-rich fluids (cf. Gudmundsson et al., 2002). The positive buoyancy of the fluids is the driving force for the propagation of hydrofractures to the surface. The vein networks and breccia deposits are analogous to hydrothermal eruption products that are characteristic of shallow parts of geothermal systems (Browne and Lawless, 2001; Hedenquist and Henley, 1985). Our previous studies have shown that travertine filled –fractures in the Pamukkale geothermal field are related to hydrothermal process associated with late Quaternary earthquake faulting (Uysal et al., 2007).

Large earthquakes have occurred throughout the ancient history in Pamukkale and Kirsehir geothermal fields; however, no CO_2-related hydrothermal eruptions or surface fracturing with associated carbonate veining events were observed during historical times (Hancock and Altunel, 1997). Therefore, another mechanism, in addition to the seismicity, must have been involved in triggering surface eruptions of CO_2-rich hydrothermal fluids. We hypothesise that late Quaternary climate variability and the associated hydrologic regime may have been responsible for the CO_2 accumulation in deep reservoirs.

To evaluate any climate effect on travertine vein formations, we correlated our high precision U-series age data for the travertine veins from Pamukkale and Kirsehir geothermal fields (Uysal et al., 2007; Uysal, in preparation) with timing of well-known global climate records extracted from Greenland ice cores and cave deposits (Hulu Cave) in China . These two climate records provide a benchmark for correlating and calibrating global climate oscillations (Wang et al., 2001). We also correlated our data with some well-dated local and regional lake-level records (Bartov et al., 2003; Landmann and Kempe, 2005). Accordingly, a large number of travertine veins dated by U-series technique coincide with times of cold/dry climate events, such as Heinrich Events 1 and 2, Last Glacial Maximum, and the immediate termination of the Younger Dryas. Such a correlation with dry climate events is in contrast with current deposition of the terrace-mound travertine in the Pamukkale geothermal field that is facilitated by relatively warm and humid eastern Mediterranean climate at present (Dilsiz et al., 2004) and also surface sinter formations from different geothermal fields that formed more frequently during wet climate periods (e.g., Sturchio et al., 1993).

We interpret significant reduction in surface discharge of CO_2 due to shutdown of the geothermal circulations during dry climate events in the late Quaternary would have promoted CO_2 oversaturation in deep reservoirs because of continuing CO_2 influx from the mantle and crustal carbonate rocks (Güleç et al., 2002; Mutlu et al., 2008). Rapid exsolution and expansion of the CO_2–oversaturated water that occur preferentially during dry climate events and triggered by seismic events may have been the driving force for fracture generation and propagation leading to hydrothermal eruptions.

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