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Hydrothermal fluids circulation and travertine deposition in an active tectonic setting: Insights from the Kamara geothermal area (western Anatolia, Turkey)

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ABSTRACT

Coexistence of thermal springs, travertine deposits and tectonic activity is a recurring feature for most geothermal areas. Although such a certainty, their relationships are debated mainly addressing on the role of the tectonic activity in triggering and controlling fluids flow and travertine deposition. In this paper, we present the results of an integrated study carried out in a geothermal area located in western Anatolia (Turkey), nearby the well-known Pamukkale area (Denizli Basin). Our study focused on the relationships among hydrothermal fluids circulation, travertine deposition and tectonic activity, with particular emphasis on the role of faults in controlling fluids upwelling, thermal springs location and deposition of travertine masses. New field mapping and structural/kinematics analyses allowed us to recognize two main faults systems (NW- and NE-trending), framed in the Neogene–Quaternary extensional tectonic evolution of western Anatolia. A geo-radar (GPR) prospection was also provided in a key-area, permitting us to reconstruct a buried fault zone and its relationships with the development of a fissure-ridge travertine deposit (Kamara fissure-ridge). The integration among structural and geophysical studies, fluids inclusion, geochemical, isotopic data and $^{230}Th/^{238}U$ radiometric age determination on travertine deposits, depict the characteristics of the geothermal fluids and their pathway, up to the surface. Hydrological and seismological data have been also taken in account to investigate the relation between local seismicity and fluid upwelling. As a main conclusion we found strict relationships among tectonic activity, earthquakes occurrence, and variation of the physical/chemical features of the hydrothermal fluids, presently exploited at depth, or flowing out in thermal springs. In the same way, we underline the tectonic role in controlling the travertine deposition, making travertine (mainly banded travertine) a useful proxy to reconstruct the seismological history of an area, as well as the characteristics of the parent geothermal fluids, adding an effective tool for geothermal exploration tasks.

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1. Introduction

Travertine deposits (Ford and Pedley, 1996; Capezzuoli et al., 2014) are terrestrial carbonate bodies strictly associated to thermal springs discharging mainly Ca^{2+} and HCO_3^- saline fluids, originating from a deep carbonate geothermal reservoir (Brogi et al., 2016 and references therein).

It has been documented that location of thermal springs, as well as fluids upwelling and circulation, are strictly controlled by brittle structures affecting the upper crust in areas characterized by geothermal anomalies and overall active extensional tectonics (Curewitz and Karson, 1997; Rowland and Sibson, 2004; Bense et al., 2013). Basically, travertine deposits are considered indicators of tectonic activity (Hancock et al., 1999); their study can contribute to define the

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geometry, age and kinematics of the main structure(s) to which travertine deposits are associated (Altunel and Hancock, 1993a, 1993b; Faccenna et al., 1993; Çakır, 1999; Hancock et al., 1999; Martinez-Diaz and Hernandez-Enrile, 2001; Brogi, 2004; Mesci et al., 2008; Brogi and Capezzuoli, 2009; Temiz and Eikenberg, 2011).

Furthermore, travertine is suitable for accurate dating through ^{14}C and $^{230}Th/^{238}U$ methods (Martinez-Diaz and Hernandez-Enrile, 2001, Altunel and Karabacak, 2005; Piper et al., 2007; Uysal et al., 2007; Mesci et al., 2008; Brogi et al., 2010; Temiz and Eikenberg, 2011; Nishikawa et al., 2012), and also represents key-deposit to date tectonic activities (cf. Muir-Wood, 1993; Çakır, 1999; Altunel and Karabacak, 2005; Uysal et al., 2009).

In particular, travertine fissure-ridges (Bargar, 1978) are attractive travertine bodies since their morphology and internal architecture can provide information on the geometry and kinematics of the main structure, usually hidden by the carbonate cover (Altunel, 1996; Hancock et al., 1999; Brogi et al., 2014a). Accordingly, fissure-ridge systems are considered as morpho-tectonic features useful to locate normal to transtensional faults in areas affected by recent and/or active tectonics, as it is also documented by the strict relationships between earthquakes and travertine deposition (Muir-Wood, 1993; Altunel and Hancock, 1996; Brogi and Capezzuoli, 2009; Brogi et al., 2012, 2014b; Brogi and Capezzuoli, 2014). Similarly to faults, it has also been documented that dilatational fractures (i.e., mode-I opening fracture) can have an important role in controlling the location and development of fissure-ridges (Altunel and Hancock, 1993a, 1993b; Hancock et al., 1999; Mesci et al., 2008; Temiz et al., 2009). In addition to the role of tectonics, climate fluctuations are envisaged to control travertine bodies and, in particular, fissure-ridges evolution (Faccenna et al., 2008; Uysal et al., 2009). More recently, substratum subsidence and progressive gravitational collapse of the travertine mass have been proposed as the main factors influencing fissure ridges development (De Filippis et al., 2012, 2013).

With the aim to contribute to a better understanding of the role of faults in controlling travertine deposition and in promoting the growth of travertine fissure-ridges, we studied the Kamara geothermal area (Fig. 1) by means of an integrated approach including field geology, geophysics, seismology, geochemistry and geochronology. The study area is located in the northwestern part of the Denizli Basin (Western Anatolian Extensional Province in: Bozkurt, 2001a, 2001b, 2003; Alçiçek et al., 2015), where several travertine bodies (mostly fissure-ridges), thermal springs with temperature up to 57 °C (Alçiçek et al., 2016) and seismogenic regional extensional structures (Şimşek, 1984; Sun, 1990; Westaway, 1990, 1993, 1994; Alçiçek et al., 2007, McClusky et al., 2000) have been documented. Furthermore, this area is considered as a key-example to describe the interplay between substratum subsidence and gravitational collapses, promoting and controlling the development of travertine fissure-ridges (De Filippis et al., 2012).

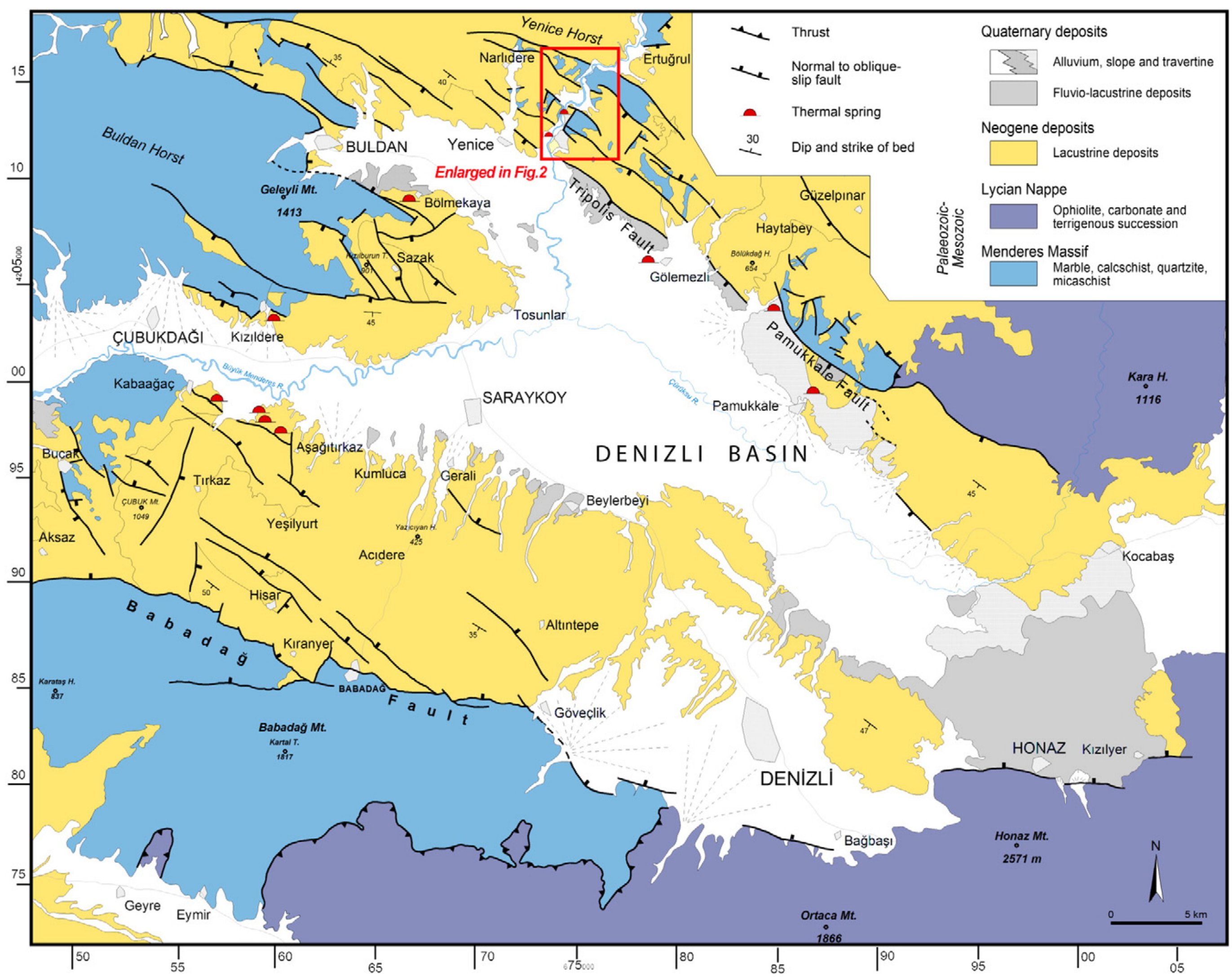

Fig. 1. Geological sketch-map of the Denizli Basin (based on Sun, 1990, after Alçiçek et al., 2007) and location of the study area.

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