Abstract

Understanding geothermal fluid circulation in tectonically active settings is essential for reconstructing the structural framework and for assessing deep geothermal resources. One of the principal challenges in geothermal energy production is the permeability of the reservoir, which controls both extraction and reinjection efficiency. Identifying highly permeable zones where deep fluids ascend is therefore crucial. Faults, fractures, and ongoing tectonic activity strongly influence fluid pathways and fluid-rock interactions. Assessing their geometry and behavior is fundamental as the tectonic structures may act either as barriers to fluid flow or as preferential conduits. The Acque Albule Basin (AAB) represents a key case study and one of the most prominent hydrothermal systems in central Italy. This tectonically controlled basin hosts an extensive hydrothermal discharge system, as evidenced by thick travertine deposits and numerous mineralized springs (maximum surface temperature ~23 °C). This diffuse hydrothermal activity is sustained by warm fluids circulating through a Meso-Cenozoic carbonate succession, affected by extensive dissolution and brittle deformation. The travertine deposition in the area is largely governed by fault activity. A detailed soil CO_2 survey was conducted to evaluate the role of faults in controlling hydrothermal circulation. Interpolated CO_2 flux maps reveal distinct high and low- flux anomalies aligned along N-S and NE-SW trends, indicating a clear structural control on fluid migration. $\delta^{13}C$ data further show a progressive decrease in the deep hydrothermal signal from west to east, consistent with a lateral reduction of deep fluid input. These observations highlight active degassing along the principal N-S strike-slip fault, whose southwestern segment functions as the main conduit for hydrothermal fluids. Additional minor transtensive faults in the western sector (parallel to the Collefiorito Ridge) also sustain the fluid circulation. Several transect surveys performed with an accumulation chamber around the AAB, including in the Cretone, Sant'Angelo Romano, Bagni di Tivoli, and Corcolle areas. Hydrothermal springs and soil degassing detected in the Cretone area indicate fluid migration along the northern sector of the main strike-slip system. However, no significant anomalies were identified in Sant'Angelo Romano or Corcolle, suggesting that active fluid circulation is largely confined to the AAB and to Cretone area. Other segments of the fault system (Corcolle and Sant'Angelo) appear inactive with respect to fluid flow. Furthermore, numerical modeling of the AAB shown that shallow meteoric recharge dominates the thermal structure of the system by reducing the temperature in the reservoir, while CO_2 continues to ascend along the fault zone. Gas-lift process seems to control CO_2 exsolution and upward migration, reproducing the observed coexistence of low temperatures and vigorous degassing at Regina and Colonnelle. Persistent CO_2-rich flow promotes carbonate precipitation and progressive fault sealing, suggesting a repetitive chemical sealing and fluid circulation.