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A multidisciplinary approach to the study of the relationships between shallow and deep circulation of geofluids: the Equi Terme (NW Tuscany, Italy) example.

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A multidisciplinary, integrated approach -using structural geology, hydrogeology, magnetotelluric, electric resitivity tomography as well as hydrogeochemical data - have been used to get insights into circulation patterns of geothermal fluids at the NW edge of the Alpi Apuane Metamorphic Complex - Equi Terme area. The low temperature geothermal system under study is drained by some springs and a single water well located along the left side of the *Catenelle River* at *Equi Terme* village (NW Apuan Alps - Tuscany). The main spring has a flow rate of about 10-20 L/s and it is exploited for thermal spa treatments.

At first, a detailed mapping and a structural analysis have been performed in order to better characterise the kinematics of the Equi Terme main fault system. The geological-structural field survey has encompassed a wide area across this structure also to reconstruct the kinematical and geometrical relationships between the differently trending fault families characterising the studied area and most likely related to the thermal occurrence.

Chemical and isotopic ($^{18}O/^{16}O$, $^{3}H/H$ and $^{13}C/^{12}C_{DIC}$) analyses were carried out on thermal water and cold springs (located at different altitudes in the zone). Samples were repeatedly collected in the different seasons, measuring temperature, conductivity and pH at the tapping point. The thermal waters are of the Na/Cl type and the cold springs are of the Ca/HCO_3 type. Despite their Na/Cl composition, the thermal waters show significant amounts of SO_4 and Ca, which suggest water interaction with Triassic evaporitic formations found at the bottom of the carbonate sequence. The maximum temperature (27 ˚C) and ion concentrations (TDS, Cl and SO_4= 4900, 2100 and 800 mg/L respectively) are measured at the end of the dry season, whereas a consistent dilution of the chemical values (lowest TDS, Cl and SO_4, respectively 3800, 1700 and 600 mg/L) and temperature decrease (lowest value 21 ˚C) are observed during the rainy period (from autumn to spring). This is the results of a mixing between the cold, low-salinity $Ca\text{-}HCO_3$ waters (TDS 250-350 mg/L; temperature 10-12 ˚C), flowing at shallow depth within the carbonate formations of the Apuan Alps, and the deeper thermal component. Apart from a single value of -7.2, tied to a storm event, the $^{18}O/^{16}O$ data are in the range -7.6/-7.5. As no significant isotopic content variations with time are observed, the recharge areas for the two components can be supposed to have very similar elevation and should be mainly represented by the SE reliefs (M. Pisanino-M. Grondilice zone). $^{3}H/H$ values suggest relatively short circulation time and $^{13}C/^{12}C_{DIC}$ definitely indicates interaction between water and carbonate rocks.

Furthermore, a geophysical survey has been carried out in order to get insights into the resistivity distribution at depth. The geophysical approach used two different kinds of methodologies: MagnetoTelluric (MT) and Electrical Resistivity Tomography (ERT). The former has allowed us to obtain information on the distribution of resistivity in the deeper part of the system; the latter has been very useful to gain insights about the resistivity distribution concerning the shallower, near-surface, level. MagnetoTelluric data have been collected at 10 sites in the frequency range 10^5-0.1 Hz. ERT data have been acquired along two 1 km long profiles, with an effective investigation depth of about 250 meters depending on the array used and on the geological setting.

The analysis of ERT data has provided a 3D model of the distribution of resistivity around thermal springs, where the two profiles are closer. Moreover, MT and ERT data show anomalies of resistivity that are correlated with geological units and with zones of higher permeability and fluid content representing possible fluid pathways.

This multidisciplinary approach has been proved to be a powerful tool, since it unravels the high complexity of this natural geothermal system and allows us to reconstruct in detail the complex fluid circulation pattern feeding the Equi Terme thermal spring.