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Mechanisms of up-rise of the hot thermal springs of Valdieri (Argentera Massif, Maritime Alps, northwestern Italy)

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Introduction

In the Maritime Alps (north-western Italy), an intense seismic activity and the up-rise of low-enthalpy thermal waters attest to the presence of an important tectonics active in this region (Larroque et al., 2001). The thermal springs of Terme di Valdieri, emerging in the so-called Argentera Massif (mainly composed by migmatitic gneisses), make the object of a multidisciplinary study based on hydrochemical analyses, structural surveys and numerical simulations. The studied springs up-rise along a sub-vertical NW-SE striking fault zone, showing a discontinuous en-echelon distribution and evidences of right-lateral movements (Perello et al., 2001). The integration of hydrochemical and structural data provided the framework for the on-set of numerical models describing the thermal water circulation through the fault zone. These models outline both the structural features controlling the permeability properties within fault zones both the hydrodynamic and thermal conditions constraining the thermal water circulation.

Geochemistry and structural setting of thermal springs

Thermal waters of Valdieri have maximal outlet temperatures close to 70 ˚C, high pH values and are enriched in Na-SO_4. Isotopic determinations pointed out a pure meteoric origin of thermal fluids. Geothermometric determinations constrained equilibration temperatures in respect to hydrothermal phases at about 150 ˚C, which indicates that the thermal circulation would attain depths of 5-6 km in presence of geothermal gradients of 25-30 ˚C/km (Perello et al., 2001).

At the Terme di Valdieri site, the hydrothermal circulation is channelled along a sub-vertical NW-SE striking fault, 7 km long and with one tip localised at the valley bottom in proximity of thermal waters discharges. Detailed field surveys (Perello et al., 2001) allowed the reconnaissance of a peculiar permeability architecture characterising the NW-SE striking fault zone. In general, permeability increases moving from the axial part towards the borders of the fault zone. Low permeabilities in the core of faults are due to the presence of fine-grained materials (gauges and hydrothermal argilites), while high permeabilities at the boundaries of faults are due to the presence of intensively fractured domains.

Numerical simulations of fluid and heat flow

Bi- and tri-dimensional numerical models of coupled fluid and heat flow in steady regime were performed to simulate the hydrothermal circulation of the Terme di Valdieri area. It was shown that 2-D models considering the fault plane profile do not constrain adequately the conditions allowing high spring outlet temperatures. However, these models put in evidence the key-role played by the permeability distribution in affecting the heat transfer processes within faulted domains and provided an estimation of the perturbation magnitude that advective circulations bring about in the thermal state of mountainous regions. 3-D simulations considered the fault plane of Valdieri integrated within blocks of non-fractured rocks which lateral extension was arbitrarily chosen. A satisfactory fit of both hydraulic and thermal control parameters was obtained by imposing uniform hydraulic conductivities across the fault zone (K_{xx} = *1 x 10* $^{-8} m/s, K_{yy} = K_{zz}$ = *5 X 10*$^{-7} m/s$) and the country rock (*K =1 x 10* $^{-9} m/s$). Under these conditions, the required basal heat flow densities are between 80 and 100 mW/m^2. Several realisations showed that the occurrence of peak values of spring temperatures is conditioned by the presence of specific ranges of country-rocks permeabilities (about 1 x 10 $^{-16}$ m^2), in agreement with the results obtained by Forster and Smith (1989) and Lopez and Smith (1995) in similar circumstances. Furthermore, some constraining conditions allowing advective, convective and mixed heat flow regimes have been determined.

Conclusions

Finally, the used multidisciplinary approach combining hydrochemical, structural and numerical techniques may provide insights on the mechanisms driving the up-rise of hot springs through faults as well as on the thermal state of the crust in mountainous regions. An improved understanding of the interaction of groundwater flow and thermal regimes in mountain systems might constitute a major help for thermal water prospection and hazardous forecast of exploration boreholes.

References

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