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The effect of density-driven convection on temperature logs – detection, differentiation and pitfalls

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Density-driven (free) convection can cause significant transport of heat and mass in the water column of boreholes and wells. Consequently, temperatures and concentrations measured in boreholes or monitoring wells may depart significantly from the ones in the surrounding rock. Moreover, density-driven convection can also affect the surrounding rock thermally and geochemically. Understanding convective flow is thus crucial for analyses based on borehole geophysical measurements or sampling campaigns, like hydrogeological and geothermal investigations. In these cases, the water column should be examined according to the occurrence of falsifying effects of vertical transport processes.

In a water column several convection-affected sections can exist, that can exhibit different forms of density-driven flows. Some of these density-driven flows lead to equalization (overturning convection) and others to reinforcement of a vertical temperature/density contrast (double-diffusion).

By means of the so-called Synthetic Convection Log - a computational algorithm that enables in-situ detection and differentiation of various density-driven transport processes in the water column - it could be shown, that density-driven convection appears widespread in groundwater monitoring wells and boreholes. Numerous measurements in a large number of different survey areas showed, that density-driven convective transport is rather the rule than the exception. In particular, near surface zones of the water column are significantly affected by the high temperature gradients in the shallow subsoil. Deep groundwater monitoring wells and boreholes with a seasonally constant geothermally induced temperature gradient are often likewise affected, due to the considerably low threshold for the onset of the convection. The induced flow velocities are in the order of several meters per day and increase with temperature/density gradient. The convective flow velocity in wells or boreholes can consequently exceed the velocity of the horizontal natural groundwater (through) flow.

Density-driven convection causes anomalies and patterns in temperature and water quality logs. These include e.g., stratification and staircase structures or oscillations caused by convection cells. Overturning thermal, solutale or thermosolutale convection leads to spatially and temporarily oscillations in the otherwise smooth temperature log. The affected water column acts as a mixing reactor. Due to the high velocity of the revolving convection, this mixing is very effective. The so-called double-diffusion is accompanied by the formation of typical step structures in temperature logs which originate from the change from convective to well mixed layers with intervening diffusive transitional layers. The layers of convective transport are characterized by relatively steady values and the layers by diffusive transport are characterized by jump-like changes in temperature, forming the staircase structures.

These anomalies and patterns can be qualitatively evaluated (e.g., by the Synthetic Convection Log) to assess falsifying effects on temperature logs due to mixture, heat and mass transport.