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Regional fluid flow and heat distribution over geological time scales at the margin of unconfined and confined carbonate sequences

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Understanding the main hydrogeological processes within thick carbonate deposits is challenging. A particularly interesting situation arises at the margin of confined and unconfined carbonate sequences, which could develop from partial uplift of fully confined carbonate systems and subsequent erosion of cover layers. This situation has occurred in the case of the broader area of the Buda Thermal Karst system (Hungary).

Several groundwater flow and heat transport process-related questions arise from this geological evolution, namely: i) what are the main characteristics of these carbonate systems with decreasing cover thicknesses at one ridge, ii) what are the main effects of the low-permeability confining formations overlying the permeable carbonate system; in addition to iii) what is the relative importance of gravity and buoyancy as driving forces in the different geological evolutionary stages with different confining layer thicknesses.

Since the study focuses on regional groundwater flow and heat transport processes rather than on more detailed, local predictions of flow directions or rates, an equivalent porous medium (EPM) approach was applied, which integrates the effects of matrix, fracture and channel flow (Abusaada and Sauter, 2013). The applicability of the gravity-driven regional groundwater flow concept for such systems was justified by Mádl-Szőnyi and Tóth (2015), from which we develop the initial conditions for the model.

Scenario modelling of three cases from the fully-confined carbonate stage through to partly and completely unconfined conditions over the western block was carried out in a 2D vertical plane using the Heatflow-Smoker finite element model (Molson and Frind 2015). The preliminary results highlight the critical role of confining formations on flow patterns as well as on heat distribution and dissipation.

The first fully-confined scenario led to the development of thermal convection cells due to the insulating role of the low permeability confining formation, which facilitates buoyancy-driven flow by restricting the dissipation of heat. Over geological time, these cells were gradually overprinted by gravity-driven flow and thermal advection due to the uplift of the western part of the system. The limited thickness of the cover along the western block allowed efficient water infiltration into the system, which leads to an increased cooling effect. Further uplifting of the western part leads to a change of the main character of the flow patterns, with gravity-driven groundwater flow dominating over the effect of buoyancy–driven flow. Although cooling of the system has significantly progressed, conditions over the confined part of the system are still favorable for the development of thermal convection cells, and leads to significant heat accumulation under the confined sub-basin.

The flow and heat transport simulations have helped to derive the main evolutionary characteristics of groundwater flow and heat transport patterns for the unconfined and confined parts of the region. The result is flow convergence toward the discharge zone from different sources over geological time scales. This is decisive for heat accumulation as well as for the development of a deep geothermal energy potential in confined carbonates.

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