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EVOLUTION OF REGIONAL GROUNDWATER FLOW AND HEAT DISTRIBUTION OVER GEOLOGICAL TIME SCALE AT THE MARGIN OF UNCONFINED AND CONFINED CARBONATE SEQUENCES

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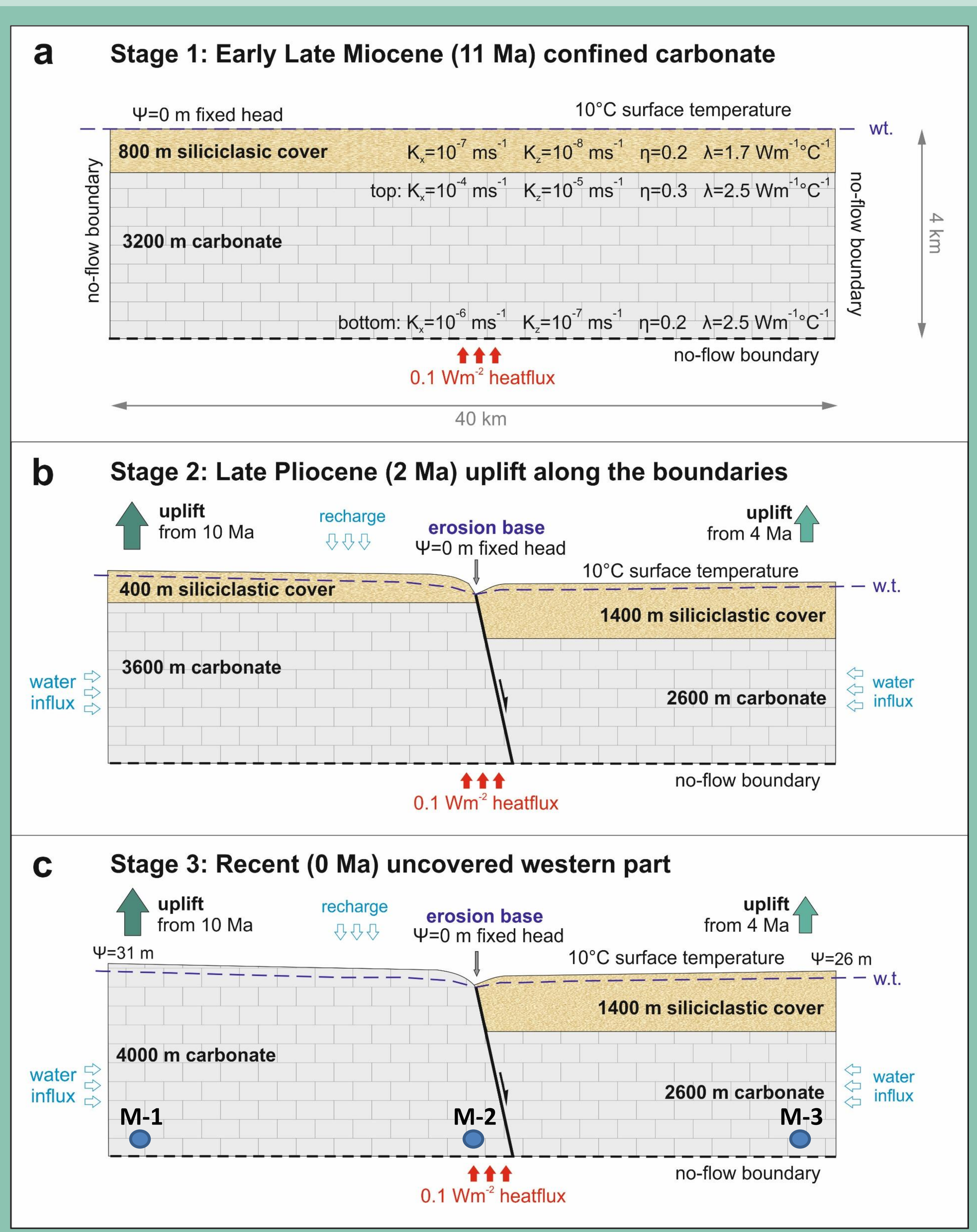
1. INTRODUCTION

Hydrogeological processes acting at the margins of confined and unconfined thick carbonate sequences are particularly interesting due to a complex system evolution including partial uplift of fully confined carbonate systems and subsequent erosion of cover layers. We provide insights into this evolution by simulating coupled density-dependent fluid flow and heat thermal transport based on the Buda Thermal Karst (BTK) system (Hungary) in a 2D vertical plane.

2. QUESTIONS TO BE ANSWERED

1. What are the main characteristics of the flow in these carbonate systems with decreasing cover thicknesses at one ridge during geological evolution?
2. What are the main effects of the low-permeability confining formations overlying the permeable carbonate system on fluid flow and heat distribution?
3. What is the relative importance of gravity and buoyancy as driving forces in the different geological evolutionary stages?

3. CONCEPTUAL MODELS OF THE EVOLUTION



Initially, the whole BTK was confined (Stage 1). From the Late Miocene, inversion of the Pannonian Basin began which contributed to the uplift of the western block (Stage 2). Uplift of the eastern part of the BTK system has been ongoing for 4 million years (Stage 3).

Fig. 1. Conceptual models of the numerically investigated geological evolutionary stages (Ψ: equivalent freshwater head, wt: water table, M-1, M-2 and M-3: monitor points)

4. METHOD

For the basin scale simulation an equivalent porous medium approach was applied, which integrates the effects of matrix, fracture and channel flow. The semi-synthetic snapshot models were simulated using the Heatflow-Smoker finite element model (Molson and Frind 2015) which couples density-dependent groundwater flow and heat transport.

5. RESULTS

STAGE 1

Flow pattern within the carbonate is dominated by buoyancy, and can be attributed to the insulating role of the low conductivity confining formation, which resctricts the dissipation of heat along the upper boundary.

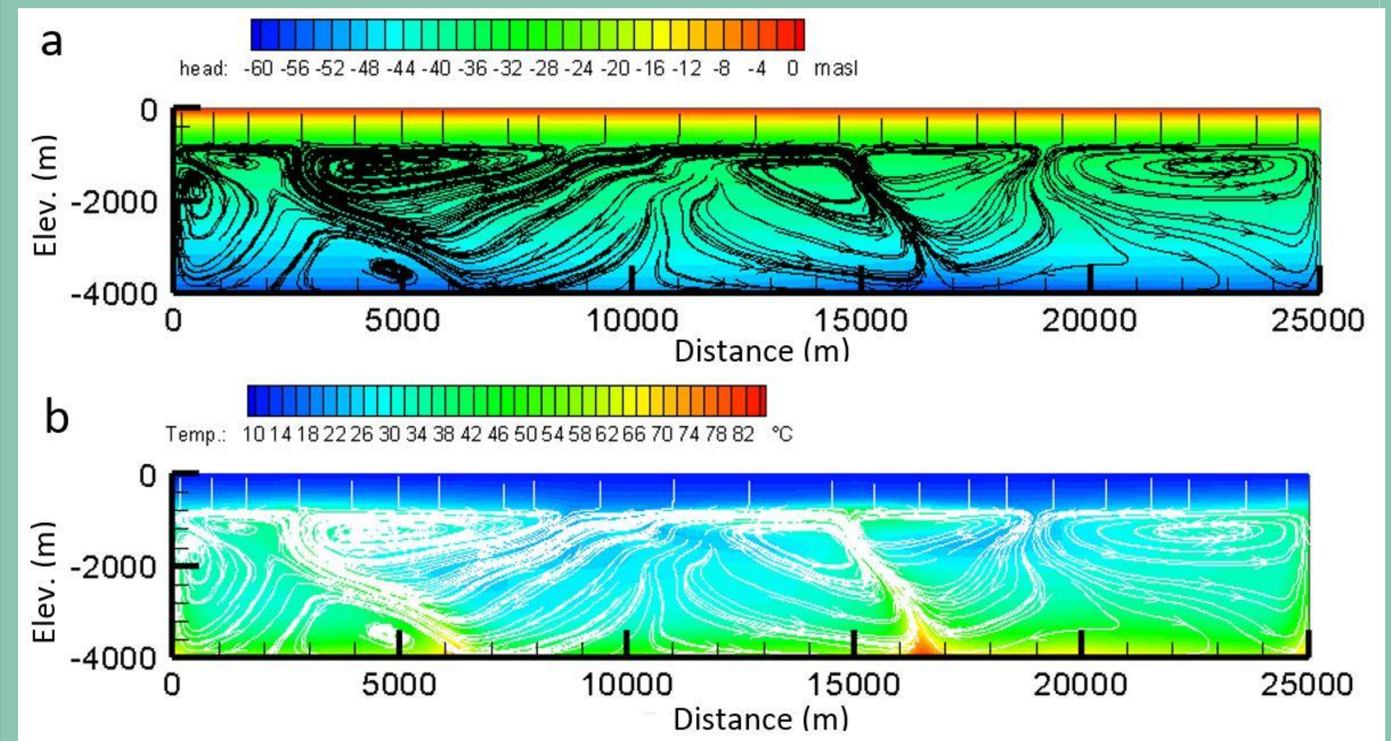


Fig. 2. (a) Hydraulic head distribution and flow pattern as well as (b) temperature field and flow pattern of Stage-1 generated by buoyancy

TEMPERATURE VARIATION

Period of cyclic temperature variations decreases during system evolution, which could be attributed to the increasing flow velocities caused by more efficient meteoric water infiltration through the reduced thickness of the left cover, which leads to the developement of a more dynamic flow system (Fig. 5).

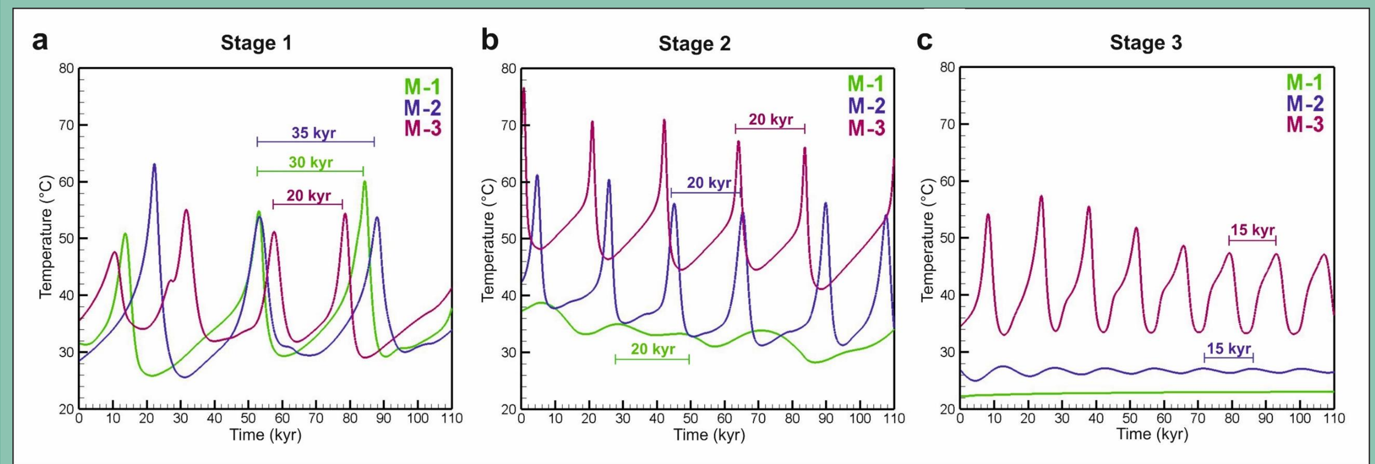


Fig. 5. Temperature variations over the 110 kyr simulation at three monitor points (locations of the monitor points indicated on Fig. 1c)

STAGE 2

Due to uplift of the western part, head differences evolved in the water table, which facilitated the development of gravity-driven groundwater flow. Taking into account the modifying effect of heat, the generated flow pattern is considerably changed, which reflects even the dominance of buoyancy as the driving force. However, the reduced thickness of the cover along the left side has facilitated fresh water infiltration into the system. It leads to increased cooling within the left block. Convection cells could therefore not easily build up in this part and shifted towards the eastern part of the system (Fig. 3).

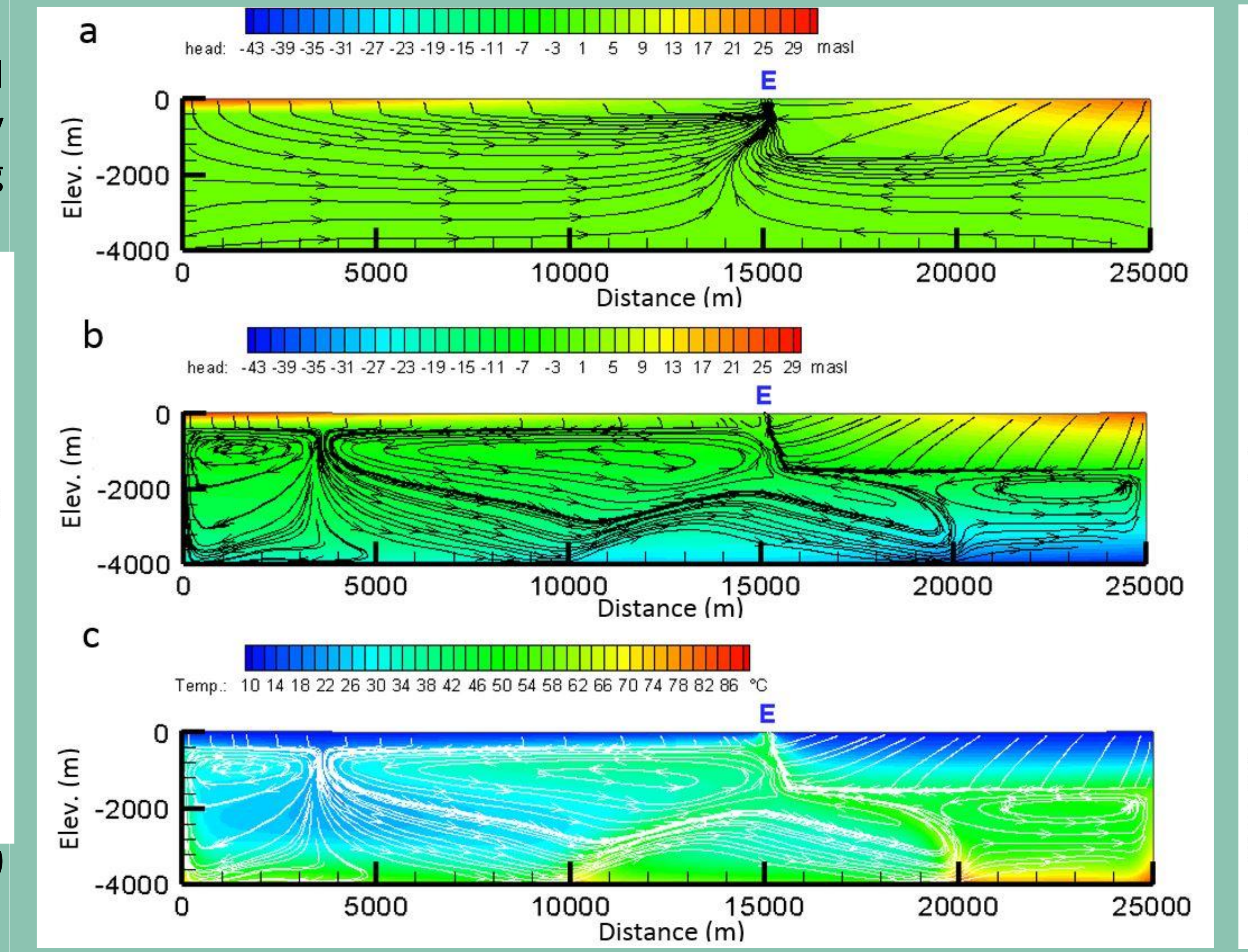


Fig. 3. (a) Hydraulic head distribution and flow pattern generated only by gravity, (b) by gravity and buoyancy, and (c) temperature field and flow pattern generated by gravity and buoyancy of Stage 2

STAGE 3

Further uplifting of the western part leads to a change of the main character of the flow pattern, gravity-driven groundwater flow dominating over the effect of buoyancy–driven flow. Moreover, the cooling of the system has significantly progressed. However, conditions over the confined part of the system are still favourable for the development of convection cells. An asymmetric flow pattern is also the consequence of more intense meteoric recharge. This condition and the insulating role of the cover formations leads to significant heat accumulation under the confined subbasin (Fig. 4).

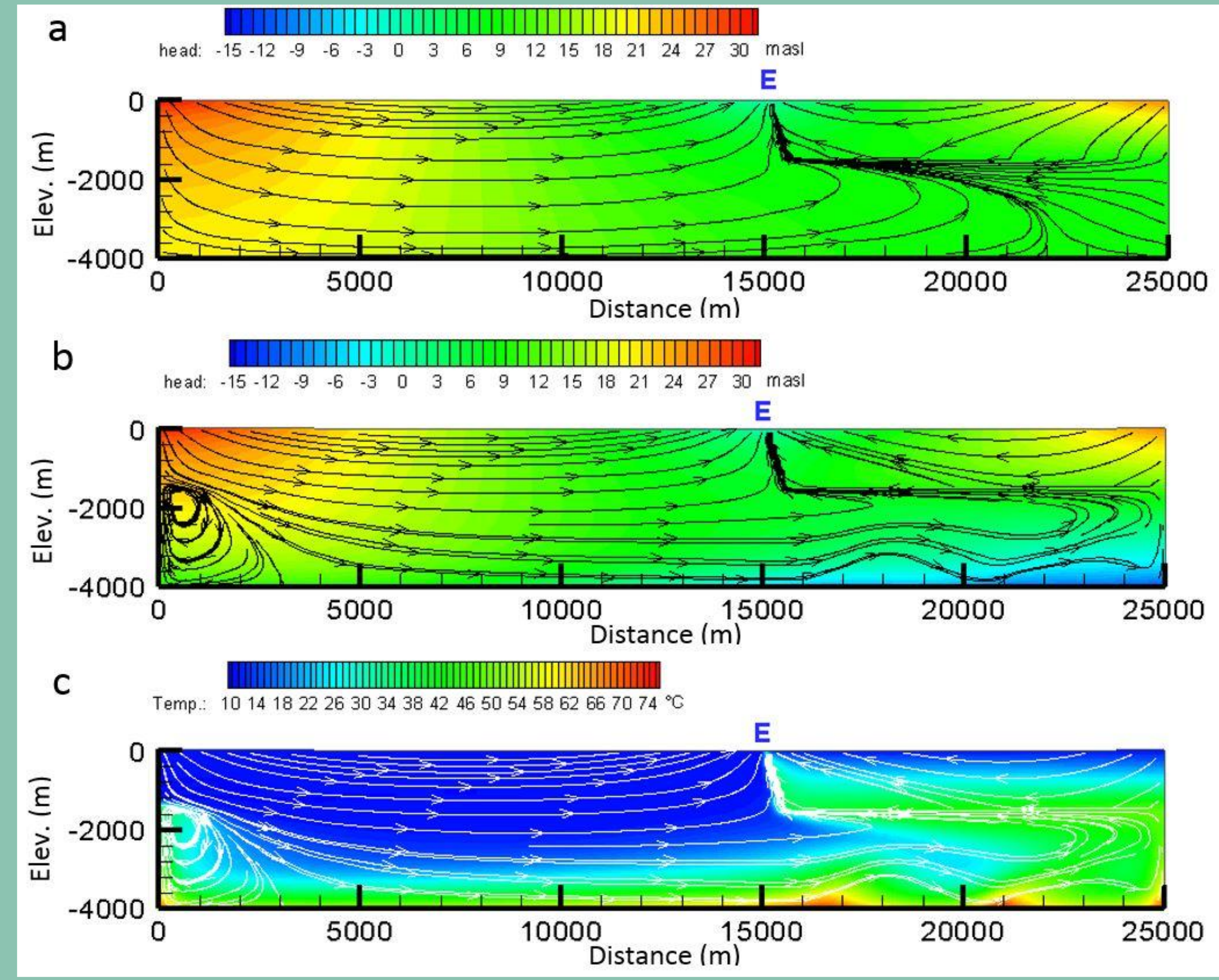


Fig. 4. (a) Hydraulic head distribution and flow pattern generated only by gravity, (b) by gravity and buoyancy, and (c) temperature field and flow pattern generated by gravity and buoyancy of Stage 3

6. CONCLUSIONS

The results highlight the effects of paleo-recharge and confining formations, as well as the role of an evolving hydrodynamic system on heat distribution and dissipation. Differential uplift led to large-scale changes in the importance of different fluid driving forces, therefore leading to changes in flow patterns and heat distribution. Numerical simulations have provided new insights into the processes controlling fluid flow and heat transport at the margin of unconfined and confined carbonates during their geological evolution. The simulations covered the range from fully confined conditions to the development of unconfined conditions. The simulations can help identify the geothermal and hydrocarbon resource potential of deep carbonate systems.

REFERENCES

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