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Endowed Hydrogeology Chair and Foundation

Comparison of 2D simulated flow pattern and measured hydraulic data for a confined aquifer to reveal the influence of gravity and heat on flow pattern

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Motivation and goals

- *Title of the session: Verification of conceptual patterns and expected natural effects of regional groundwater flow ……..*
  organized by Regional Groundwater Flow Commission of IAH

- Understanding the hydrodynamic behaviour of confined carbonate aquifers is especially important: the role of different driving forces such as buoyancy and gravity are not well known.
- The fluid pattern influences hypogenic karstification and fluids are the source of geothermal utilization and hydrocarbon exploration

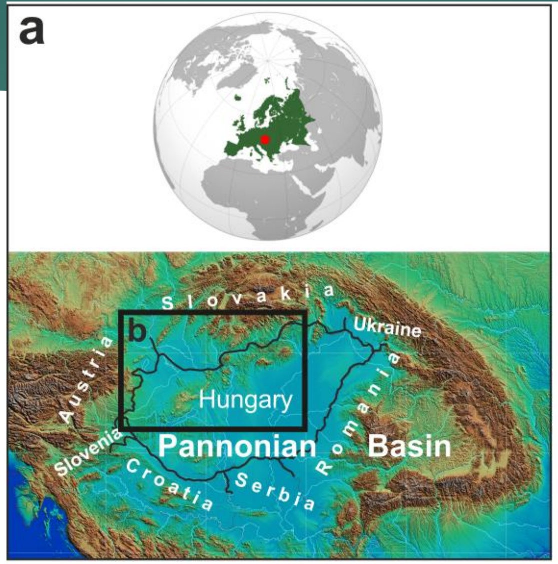
Goals: Verification of real flow and temperature simulations by the measured hydrodynamic parameters and semi-synthetical simulations

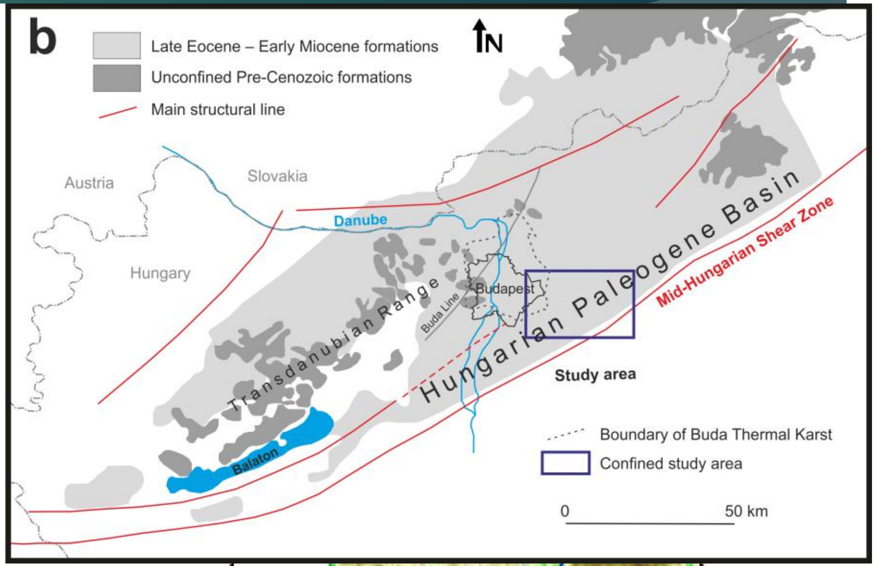
Proposed Approach and Outline

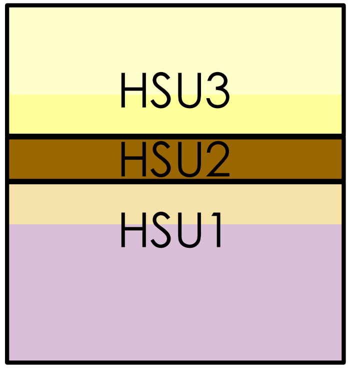
- (1) Evaluation of measured hydrodynamic parameters for the confined carbonate aquifer of the Paleogene basin, Hungary
- (2) Semi-synthetical simulations for the understanding of the role of gravity and buoyancy as driving forces for a confined carbonate aquifer in 2D (Comsol Multiphysics, Zimmerman 2006)
- (3) Real flow pattern and temperature simulations for the study area (Comsol Multiphysics, Zimmerman 2006)
- (4) Conclusions

Study area: confined carbonate aquifer of the Paleogene Basin, Hungary

- The study area is part of the Pannonian Basin, Hungary
- The basement of the Paleogene Basin is characterized by mainly Mesozoic carbonate formations, divided by ENE-WSW strike slip faults (Haas et al. 2010; Fodor et al. 2005).
- The depth of the carbonates is > -2000 m asl
- The upper sequence (HSU3) is exposed in the NW-SE trending elevated Gödöllő Hills.





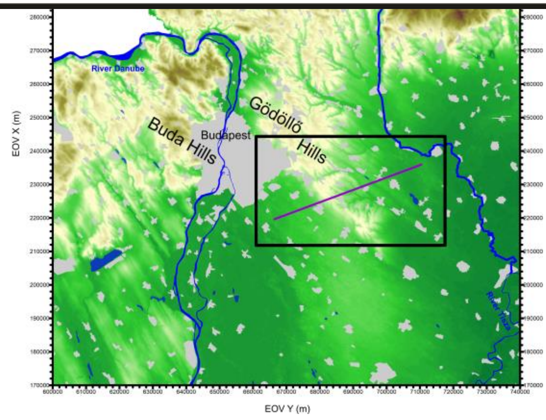


Miocene-Pliocene-
-Quaternary siliciclastic
aquifer-aquitard

Paleogene Shale aquitard

Mesozoic-Eocene
Carbonate
aquifer

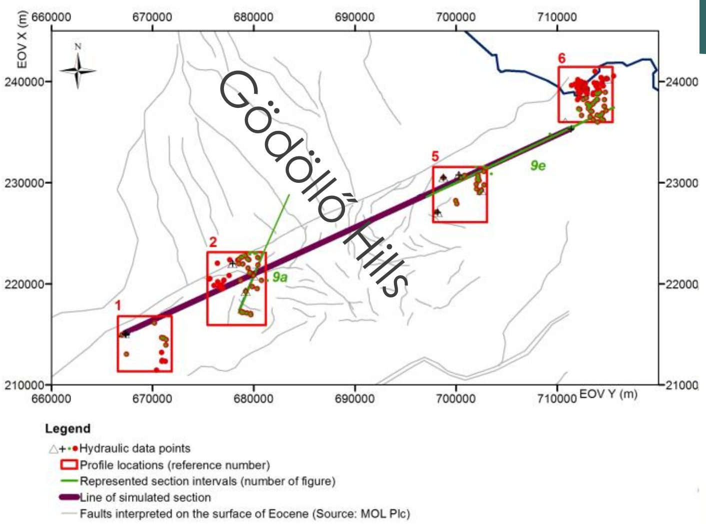
Dominant hydrostratigraphic units



(modified after Mádl-Szőnyi et al. 2016 under review)

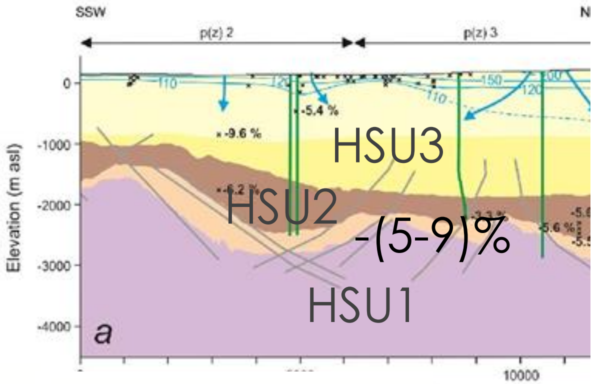
(1) Evaluation of measured hydrodynamic parameters

(modified after Mádl-Szőnyi et al. 2016 iunder review)

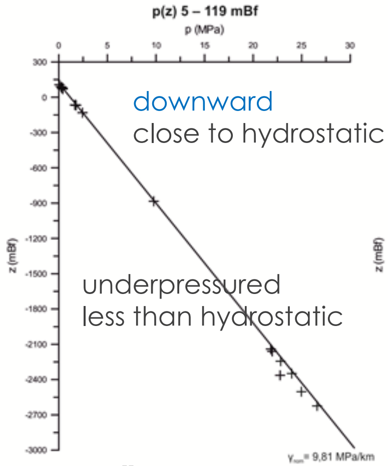


- These related to *dominantly gravity-driven flow.*
- *Underpressure* exists under the uplifted Gödöllő-region.
- It can be (1) due to the pressure disequilibrium in the flow domain (Mádl-Szőnyi et al. 2015) or (2) the consequence of buoyancy as driving force.

Gödöllő Hills



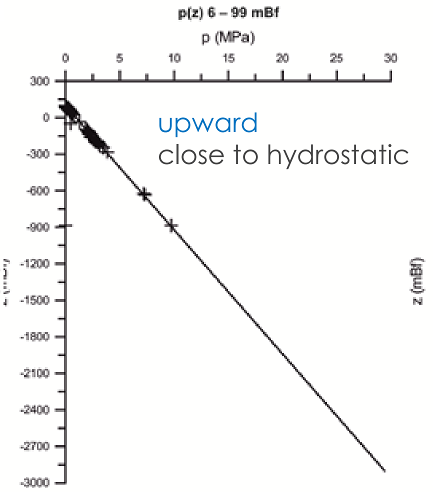
p(z) 5 – 119 mBf



downward
close to hydrostatic

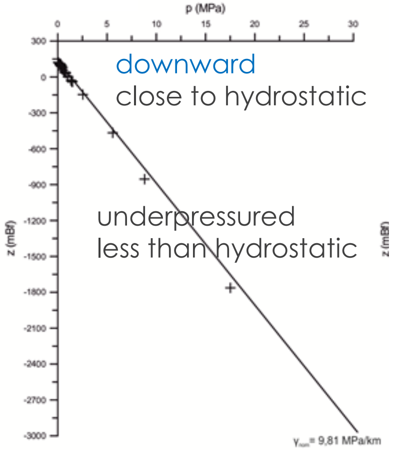
underpressured
less than hydrostatic

p(z) 6 – 99 mBf



upward
close to hydrostatic

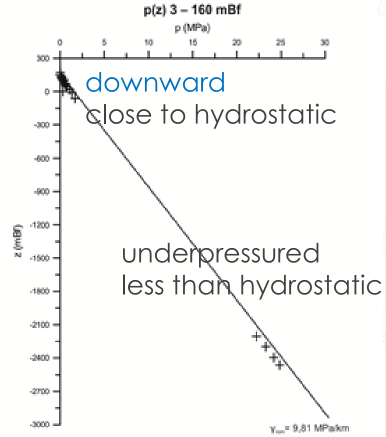
p(z) 2 – 131 mBf



downward
close to hydrostatic

underpressured
less than hydrostatic

p(z) 3 – 160 mBf

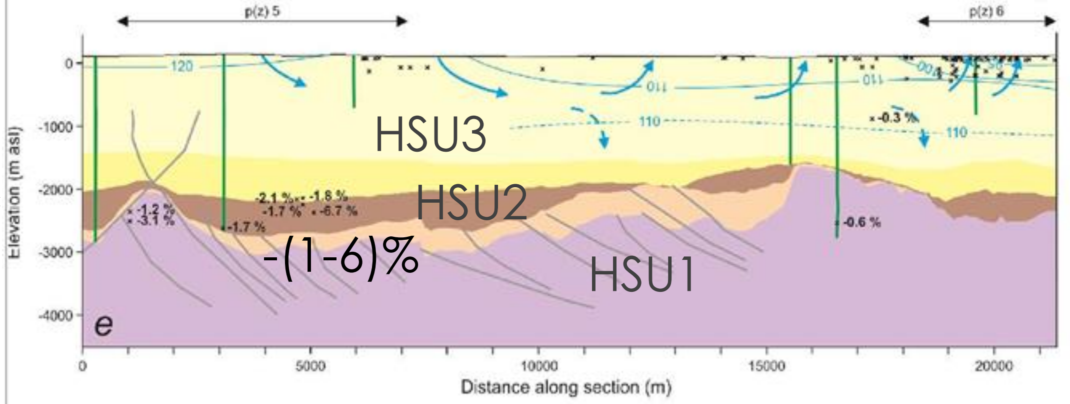


downward
close to hydrostatic

underpressured
less than hydrostatic

GödöllőHills

Edge of the Hills



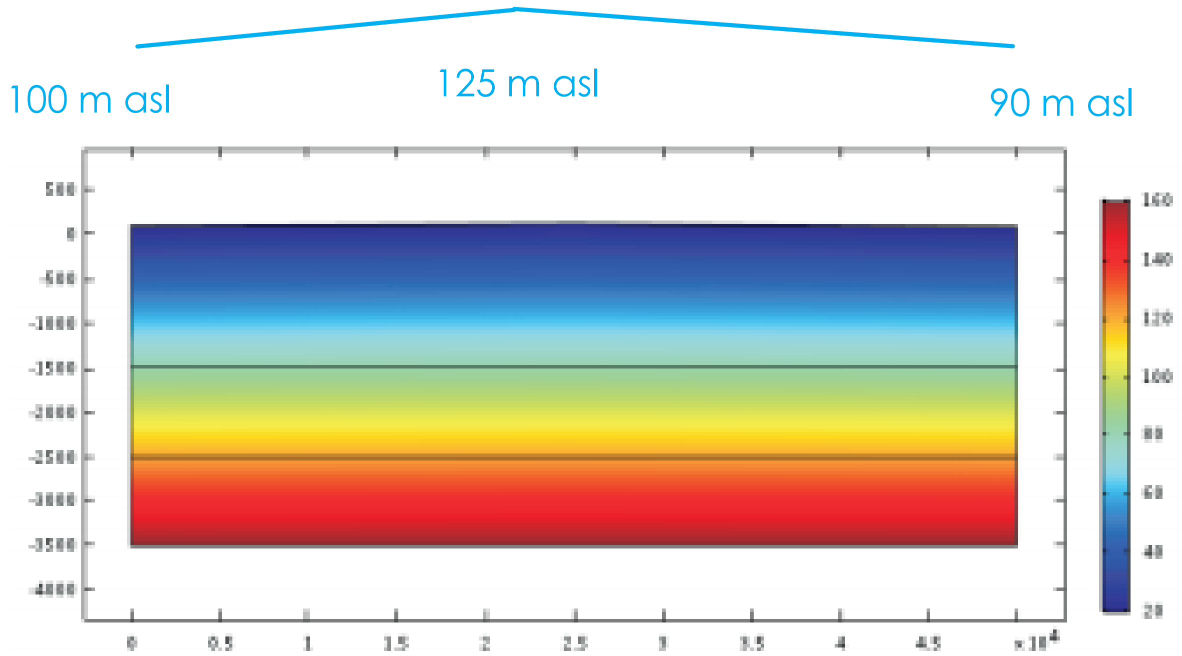
(2)Semi-synthetical simulations in 2D

Parameters of the simulations, conductive model domain

- Goal: analyse the potential role of the gravity and buoyancy as driving forces for a very simple flow domain (HSU1-3) similar to the real situation.
- Parameters of the model were derived from the real situation, but in a very simplified form: Basin with: 5X10^4m; Basin depth: 3500m and 3 HSU.

Darcy's Law		
Left wall	n ·u=0	No flow
Right wall	n ·u=0	No flow
Surface	H_0=y	Hydraulic head
Bottom	n ·u=0	No flow
Heat Transfer in Porous Media		
Left wall	n ·q=0	Thermal insulation
Right wall	n ·q=0	Thermal insulation
Surface	T_s=20 °C	Temperature
Bottom	T_b=160 °C	Temperature

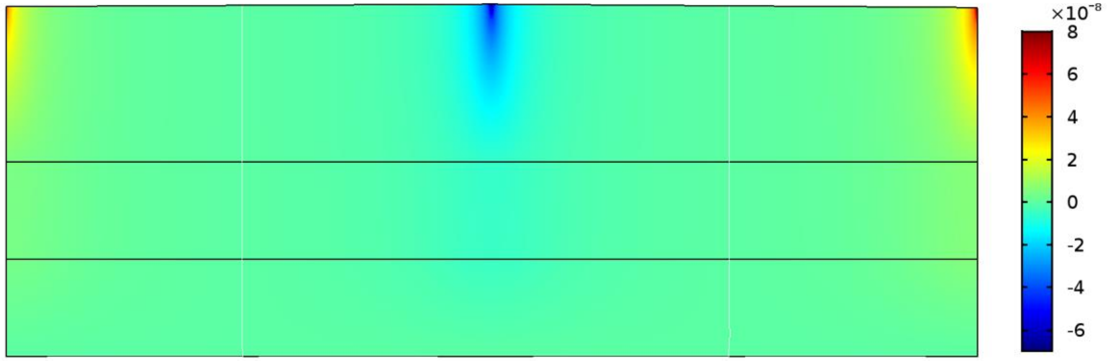
Description	Value	Unit	Symbol
Water density	1000	kg/m^3	rho0_f
Matrix density	2600	kg/m^3	rho_p
Gravitational acceleration	9.8067	m/s^2	g_const
Heat expansion coefficient	0, 10^{-5}, $3.5 \cdot 10^{-5}$	1/K	alpha
Surface temperature	20	°C	T_s
Bottom temperature	160	°C	T_b
Permeability	$10^{-12}/10^{-13}/10^{-12}$	m^2	k
Thermal conductivity of water	0.6	W/(mK)	K_f
Thermal conductivity of matrix	3.6	W/(mK)	K_p
Porosity	0.2	1	phi
Specific heat of water	4200	J/(kgK)	cp_f
Specific heat of matrix	900	J/(kgK)	cp_p



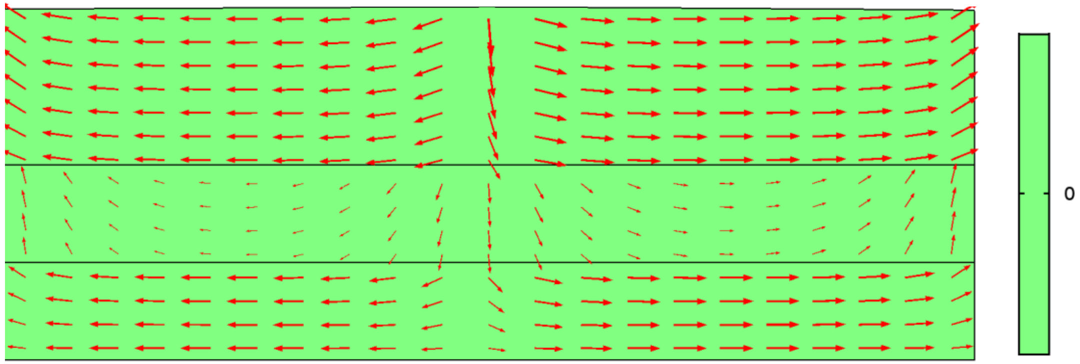
(2) Semi-synthetical simulations in 2D

Single effect of gravity-driven flow

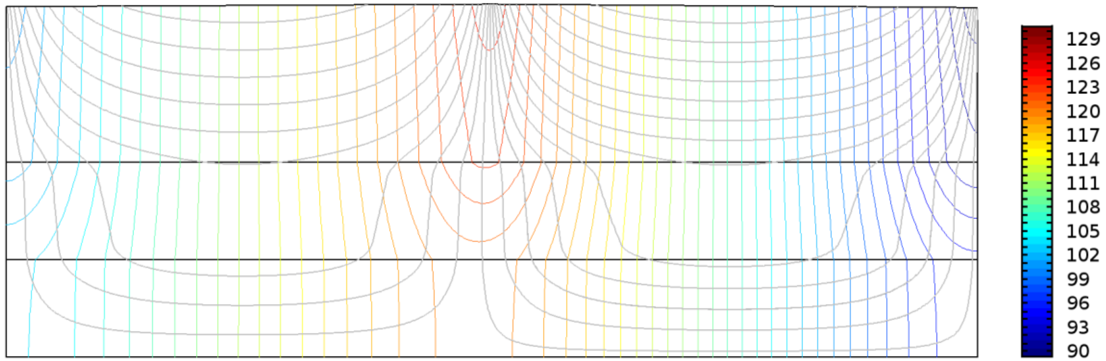
Vertical component of Darcy's velocity, ms^{-1}



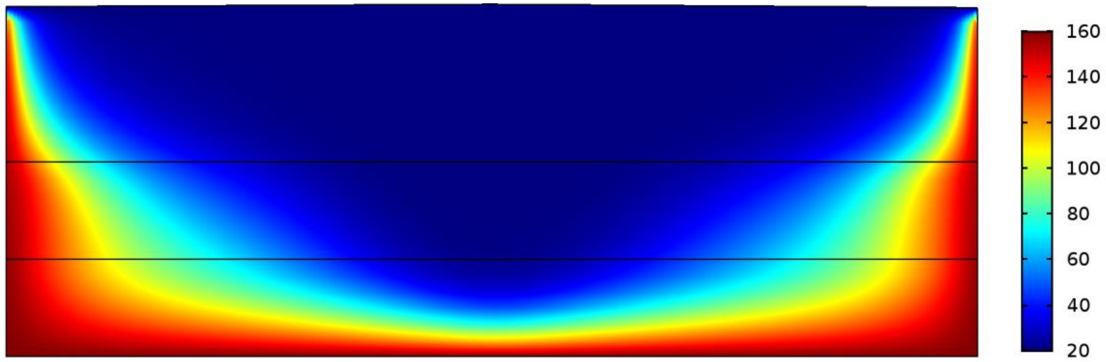
Thermal buoyancy force Nm^{-3} and logaritmically scaled Darcy's velocity field



Hydraulic head contours, masl
and streamlines of Darcy's velocity field



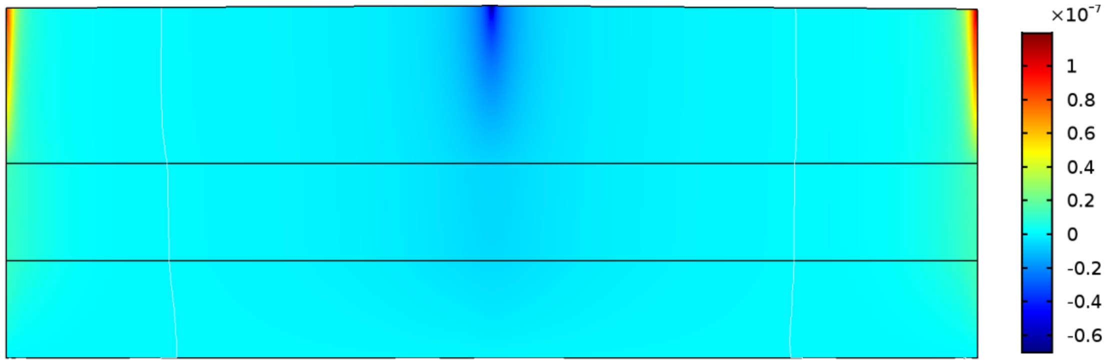
Temperature °C,



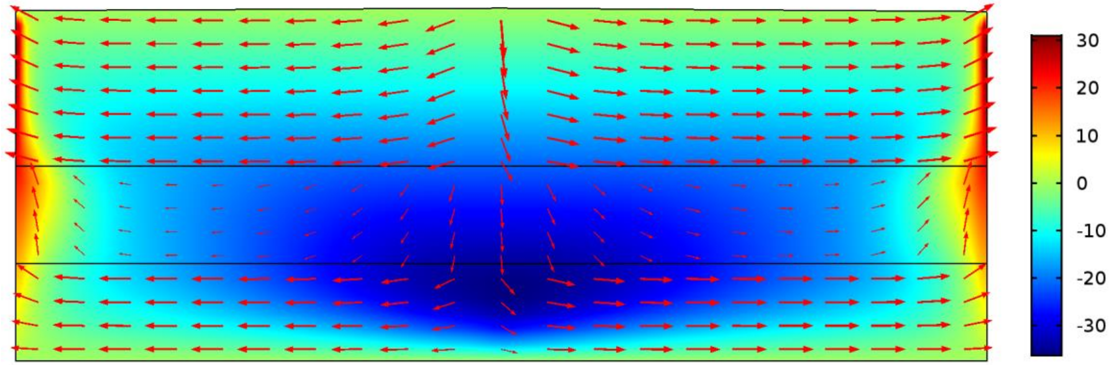
(2) Semi-synthetical simulations in 2D

Coupled effect of gravity-driven flow and buoyancy (α=3,5X10^{-5} K^{-1})

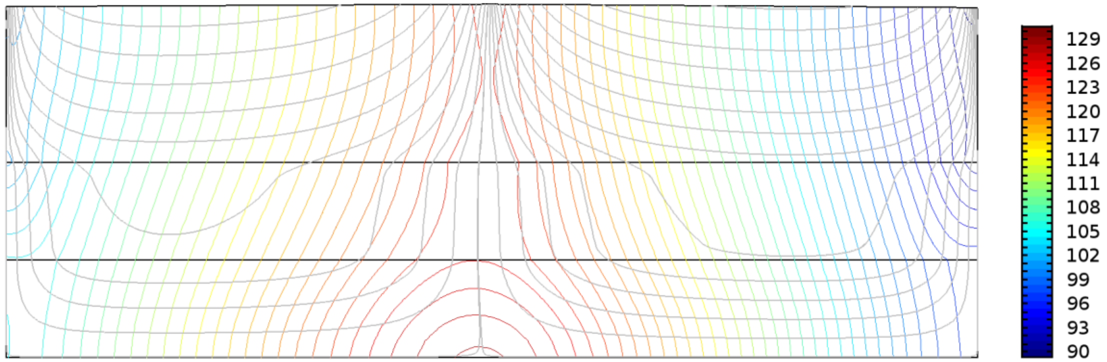
Vertical component of Darcy's velocity, ms^{-1}



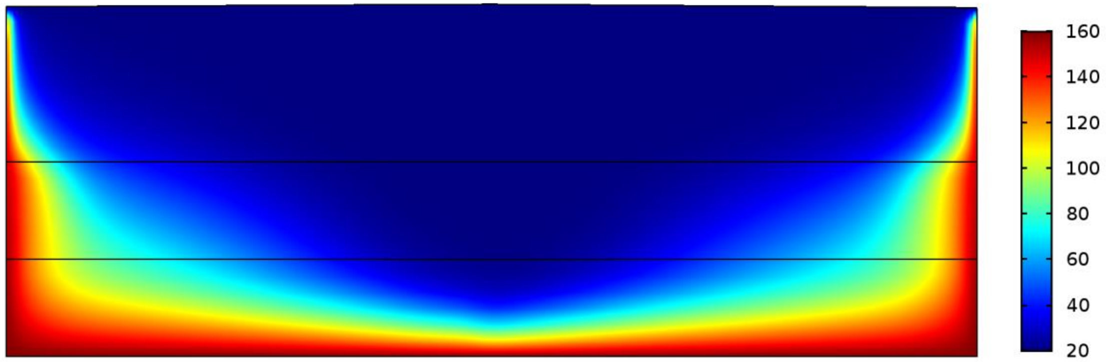
Thermal buoyancy force Nm^{-3} and
logaritmically scaled Darcy's velocity field



Hydraulic head contours, masl
and streamlines of Darcy's velocity field

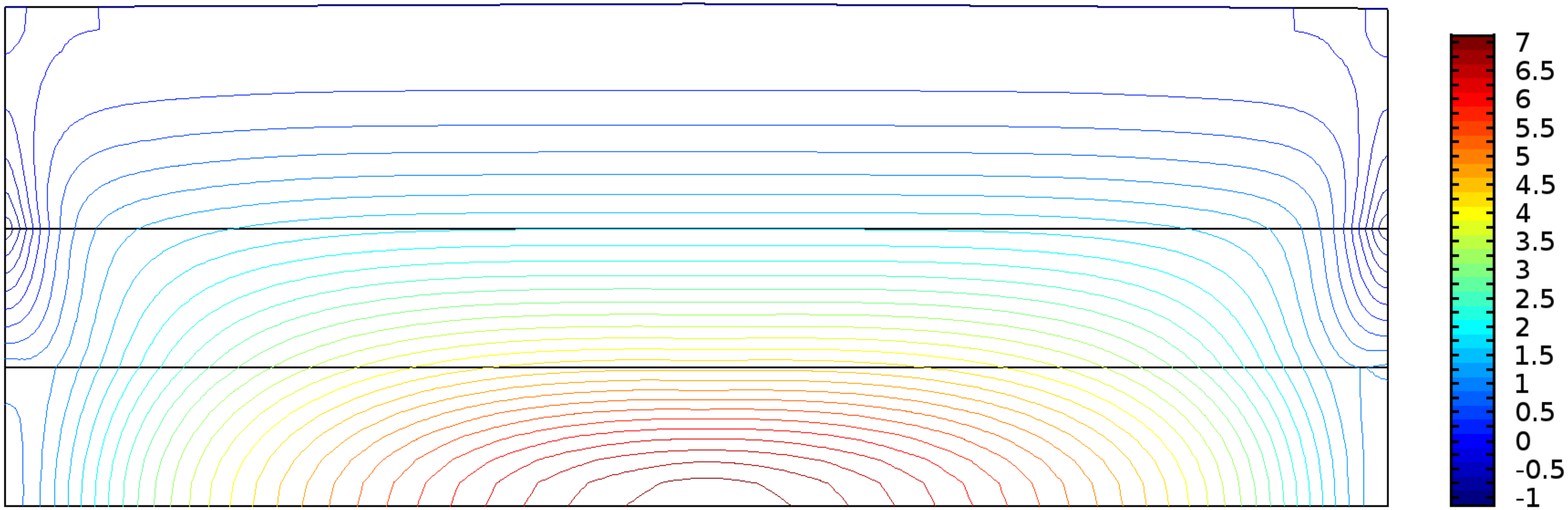


Temperature °C



(2) Semi-synthetical simulations in 2D

Coupled effect of gravity-driven flow and buoyancy



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- Buoyancy increases the intensity of flow and modify the advective temperature field.

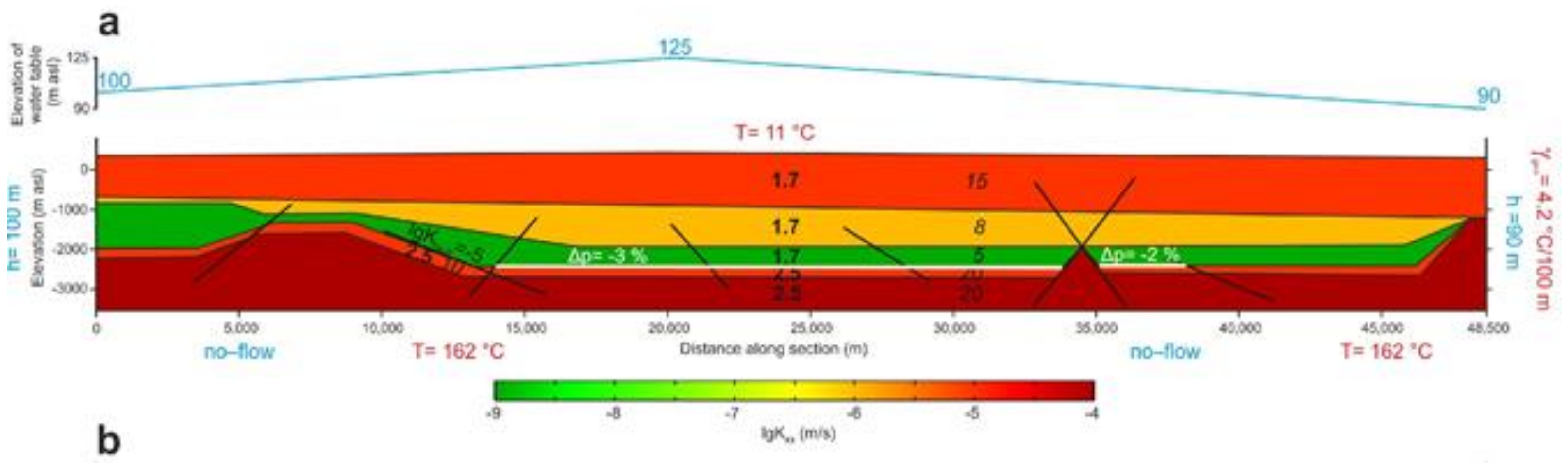
In real flow and temperature simulations the effect of **gravity driven-flow** was taken into account with **underpressure** in low permeability HSU2.

(3) Real flow and temperature simulations for the study area in 2D

- Boundary conditions: water table: 100m asl; 125m asl; 90 masl, lateral boundary: fixed head, low boundary. no-flow
- Hydrostratigraphy: the real sequence was further divided into 5 HSUs in accordance with the original HSU1-3. The most imortant faults were involved with one order higher K values.
- Underpressure was defined by 2-3% values in the low permeability HSU2.

(Mádl-Szőnyi et al. 2016 under review)

Gödöllő Hills

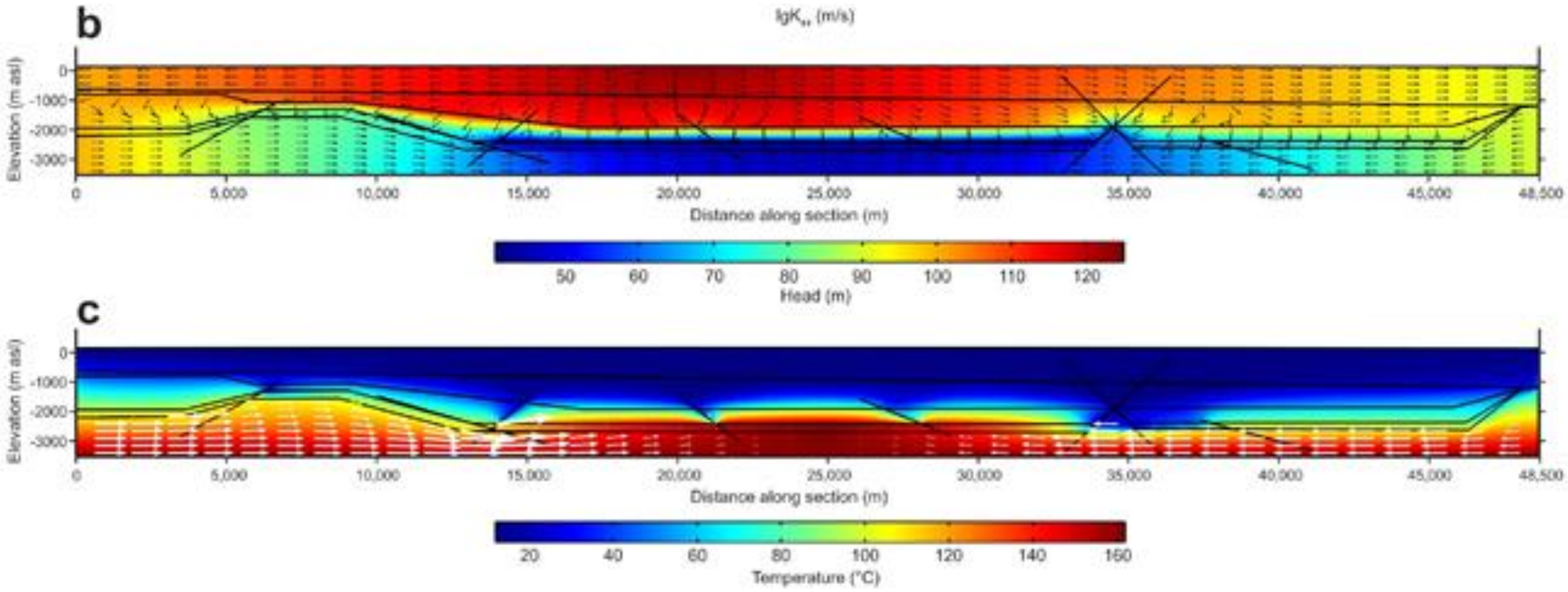


- Horizontal logK values in $ms^{-1}K$ indicated by colours.
- Porosity in % *in italics*, heat conductivity in $Wm^{-1}K^{-1}$ in **bold**, complemented by structural elements (with 10-5 ms-1)
- The temperature along the base: was chosen as 162°C; at the surface as 11 °C. Temperature values at the lateral boundaries were defined based on the geothermal gradient of 4.2 °C/100m.

(3) Real flow and temperature simulations for for the study area in 2D

- (b) Flow distribution, heads (m), streamlines and Darcy's velocity vectors (normalized) based on flow simulations
- (c) Temperature distribution (°C), with Darcy's vectors (magnitude control) based on flow and heat transport simulations

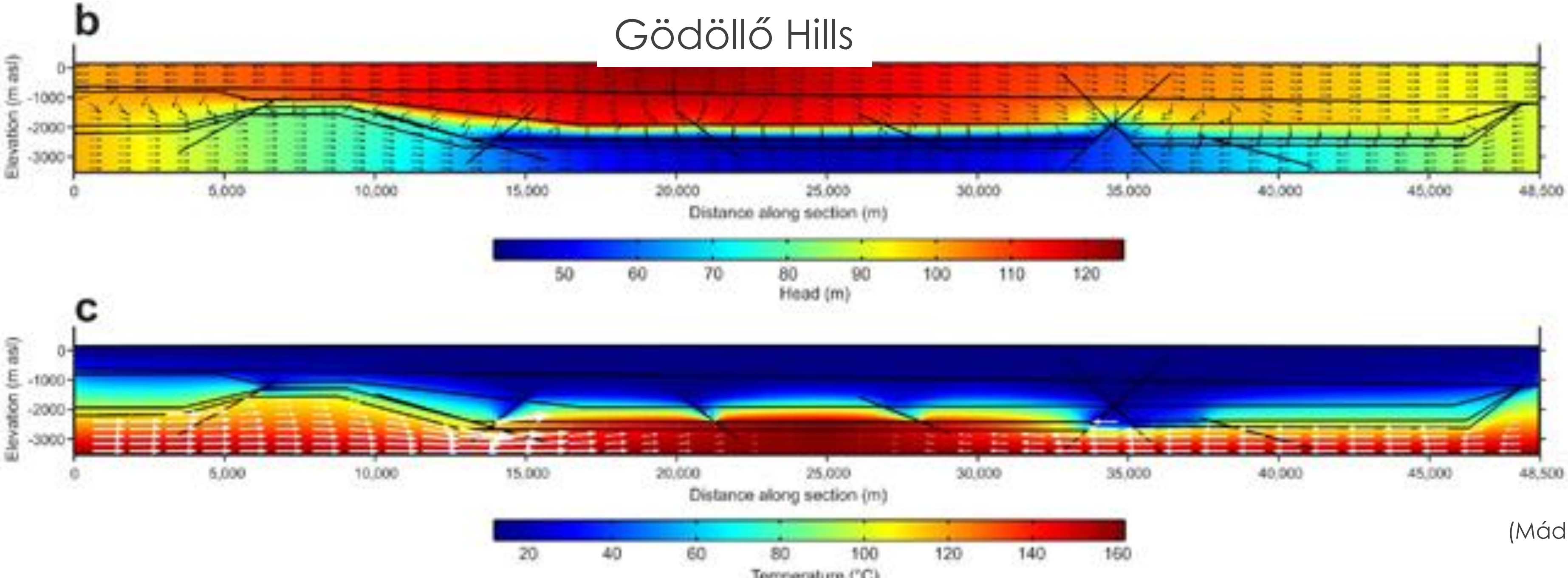
Gödöllő Hills



(Mádl-Szőnyi et al. 2016 under review)

(3) Real flow and temperature simulations for for the study area in 2D

- In the carbonate (HSU1) aquifer an intense flow is generated toward the centre of the section (due to underpressure in HSU2) and resulting in the highest temperature here.
- The fluxes in the upper hydrostratigraphic units (HSU3) are limited. Below the Gödöllő Hills but the flow is directed downward and dominantly goes toward the edges. The structures also influence flow.
- In the low permeability HSU2 the flow has significant vertical (upward and downward) component along structures and the temperature field is influenced by this vertical downward water movement under the Hills.


Gödöllő Hills

(Mádl-Szőnyi et al. 2016 under review)

(4) Conclusions

In confined (carbonate) systems not only the buoyancy but also the gravity has to be taken into account as driving force.

- The measured hydrodynamic data analyses led to the recognition of the effect of gravity as the driving force and the underpressure in the low permeability unit (HSU2) and in the basement carbonates (HSU1).
- The semi-synthetical simulations could display the significant effect of gravity with modifying influence of buoyancy as driving force.
- The real numerical flow and temperature simulations were set up based on the results of preliminary hydrodynamic data analyses and semi-synthetical simulations. In the first step the effect of gravity-driven flow were evaluated with the implementation of underpressure.

Proposed approach: verification of real flow and heat transport simulations by the **measured hydrodynamic parameters** of regional groundwater flow and **semi-synthetical simulations** to better understand deep hydrodynamic processes.

Thank you for your kind attention. Questions?

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