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Relating thermohaline simulation of salt dissolution to land collapse at a Transylvanian salt diapir, Romania

Eric Zechner[1], Horst Dresmann[1], Marius Mocuţa[2], Alex Danchiv[2], Peter Huggenberger[1], Stefan Scheidler[1], Stefan Wiesmeier[1], Iulian Popa[2], Alexandru Zlibut[2]

1) University of Basel, Department of Environmental Sciences, Switzerland
2) University of Bucharest, Department of Geological Engineering, Romania

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Initial motivation for project

Causes for the Lake Plus collapse 22nd December 2010 in Ocna Mures.

- ➢ to quantify role of groundwater in hazard evaluation
- ➢ to use numerical model scenarios to increase process knowledge
- ➢ to estimate possible hazard for future collapses.

photo: ocnamuresonline.ro

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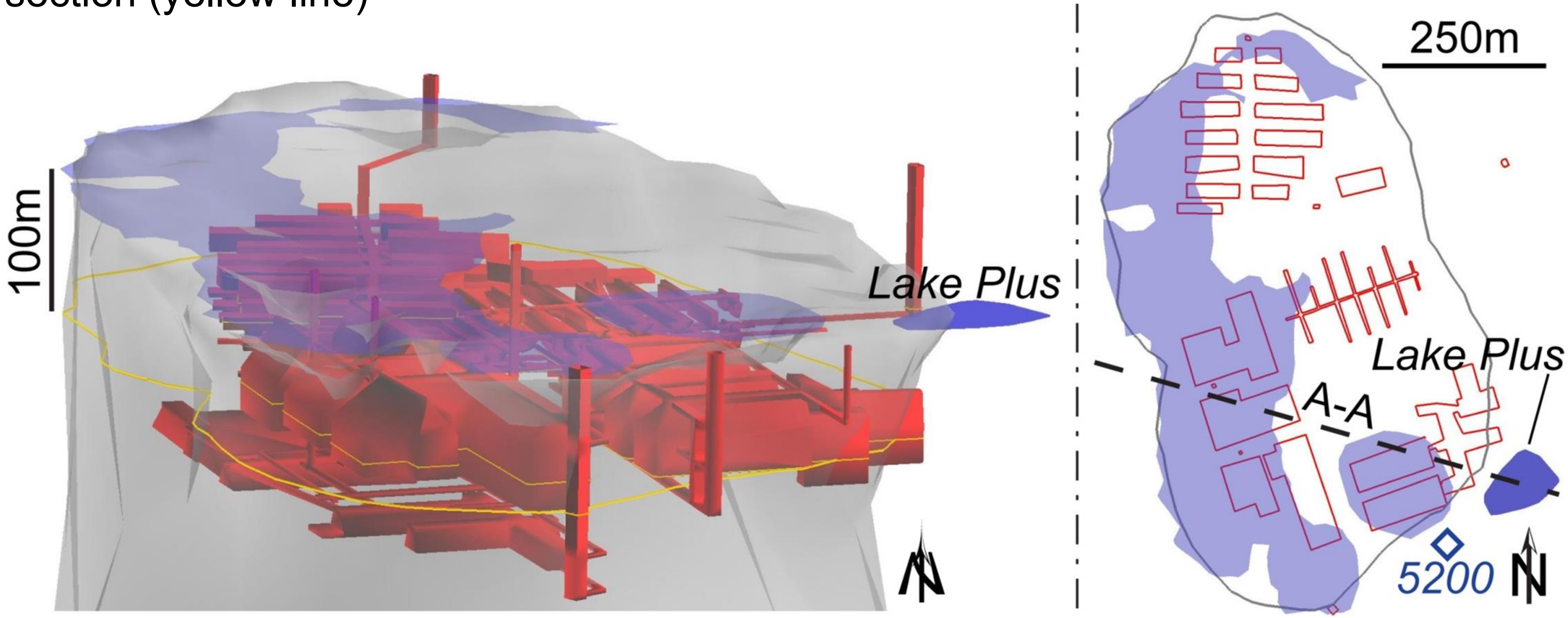
3D model view of the upper part of the Ocna Mures salt dome, the up to 150 years old mining galleries, the lakes and the traces of the 2D horizontal cross section (yellow line)



Zechner, E., Dresmann, H., Mocuţa, M., Danchiv, A., Huggenberger, P., Scheidler, S., Wiesmeier, S., Popa, I., Zlibut, A. (2019): Salt dissolution potential estimated from two-dimensional vertical thermohaline flow and transport modeling along a Transylvanian salt diapir, Romania, Hydrogeol. J., 27, 1245-1256, https://doi.org/10.1007/s10040-018-1912-1.

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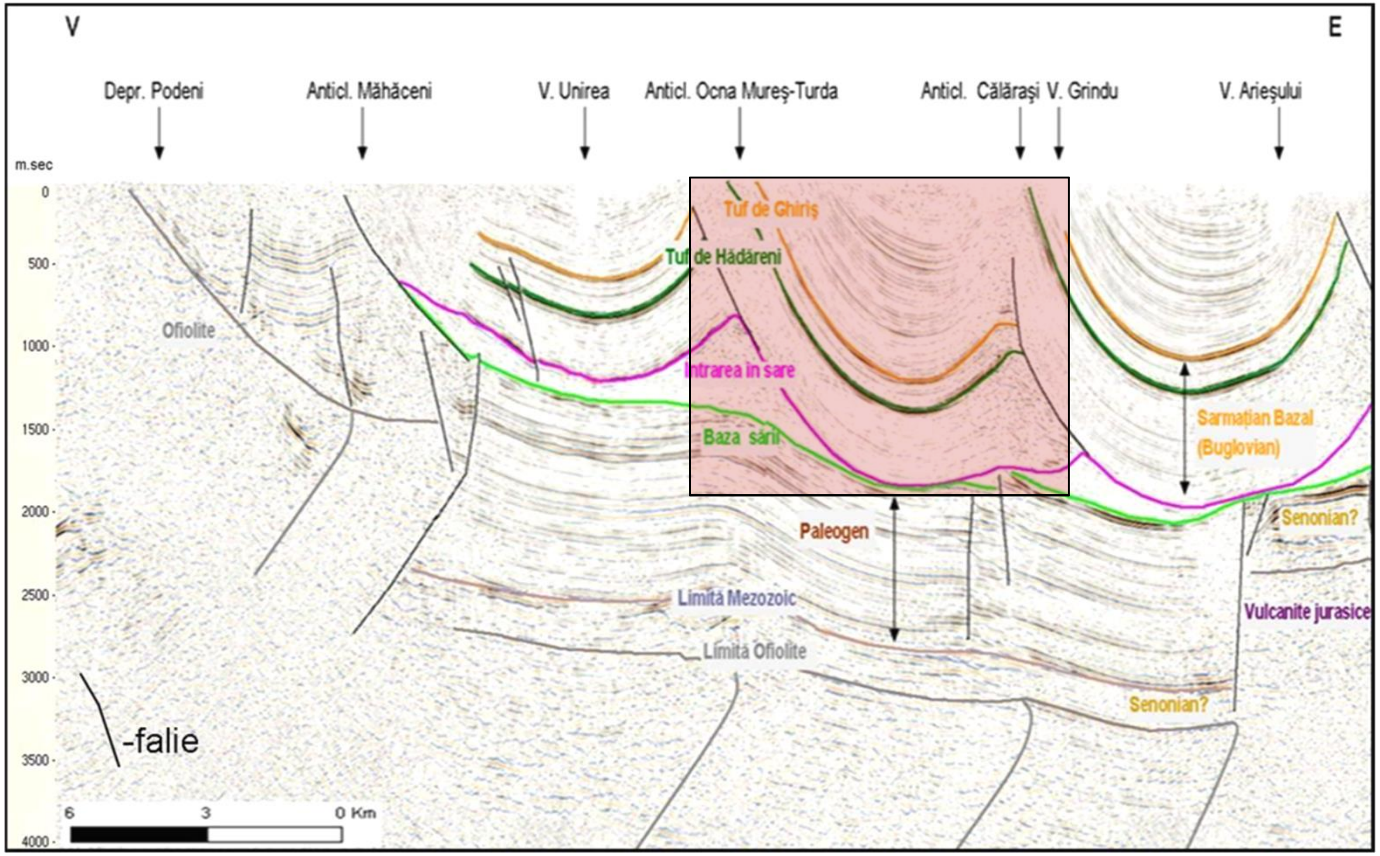
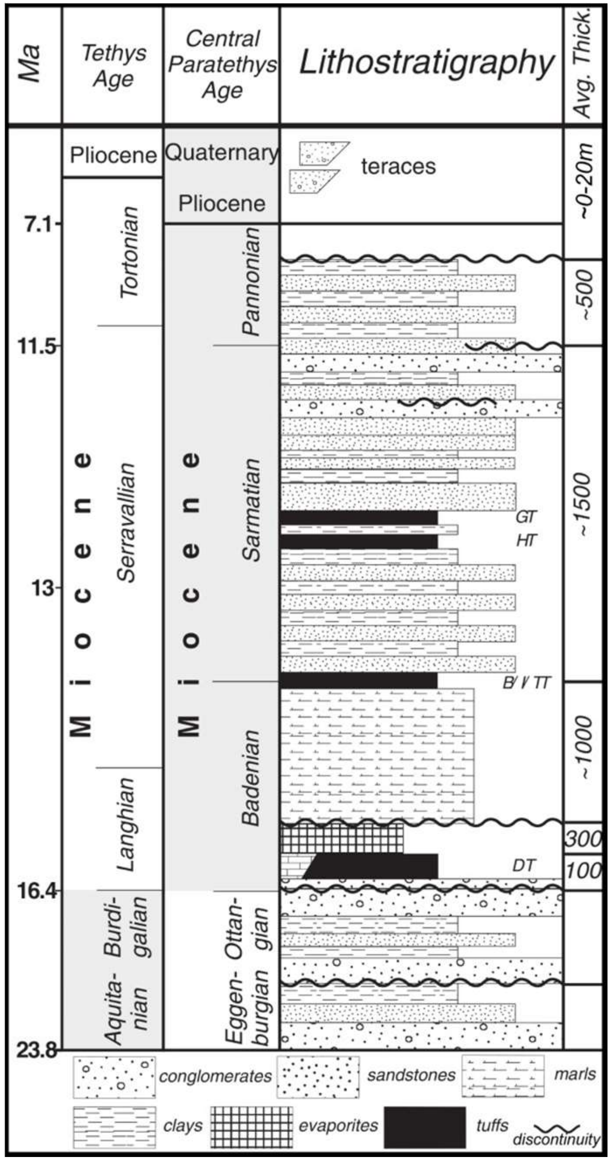
Seismic section north of Ocna Mures (Onac, 2010)

Lithostratigraphy of the Transylvanian Basin (after Tiliţă et al. 2013)





Onac BI (2010) Podişul Măhăceni: Studiu Geomorfologic [Măhăceni Plateau: geomorphological study]. PhD Thesis, BBabeş - Bolyai^ University of Cluj-Napoca, Romania, 57 pp.

Tiliţă M, Matenco L, Dinu C, Ionescu L, Cloetingh S (2013) Understanding the kinematic evolution and genesis of a back-arc continental Bsag^ basin: the Neogene evolution of the Transylvanian Basin. Tectonophysics 602:237–258.

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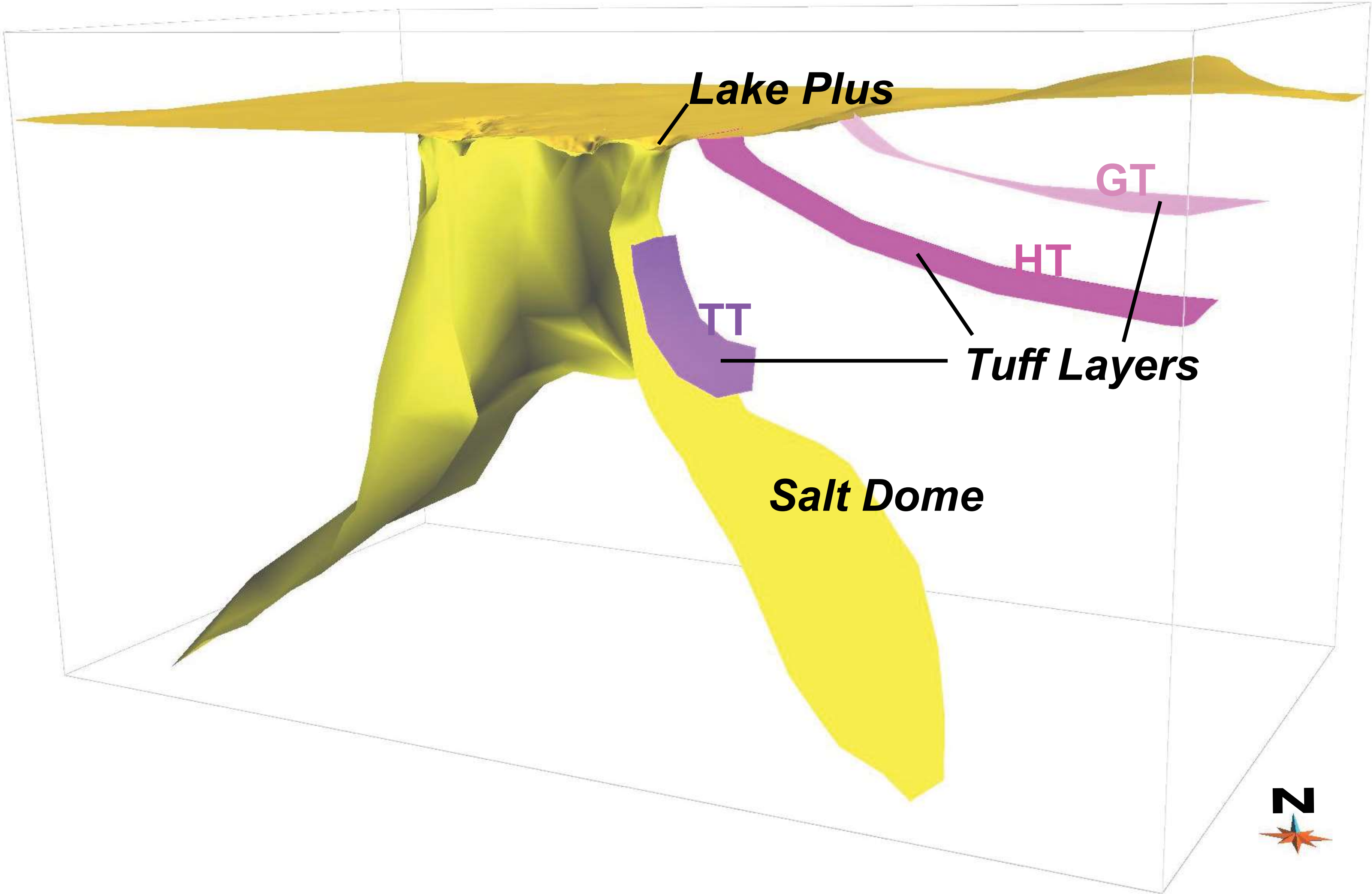
3D Model Miocene Tuff layers East of Salt Dome



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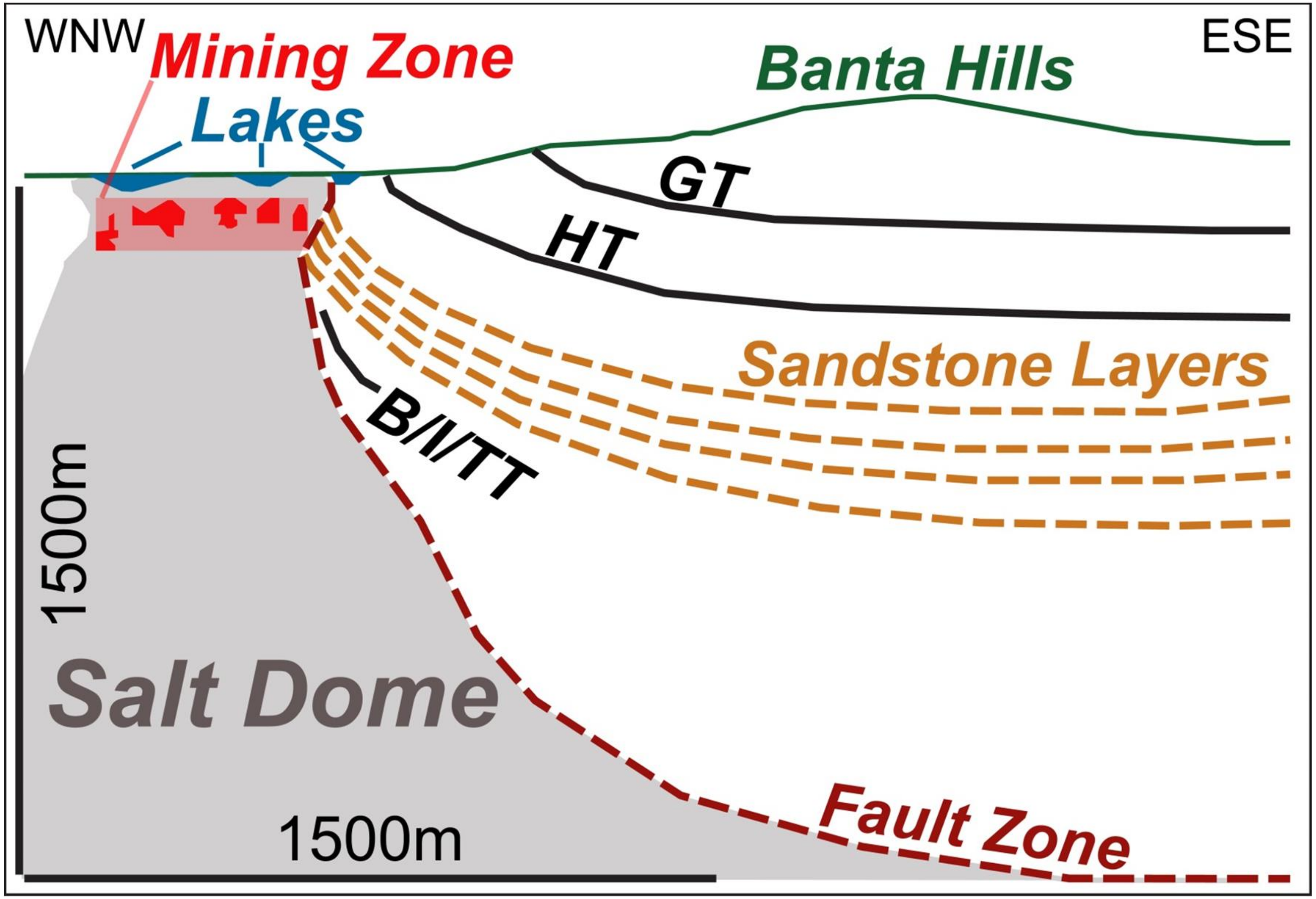
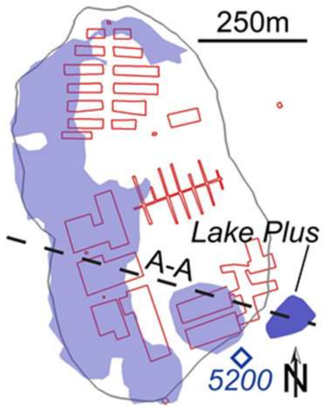
2D cross section ESE of salt diapir into Banta Hills





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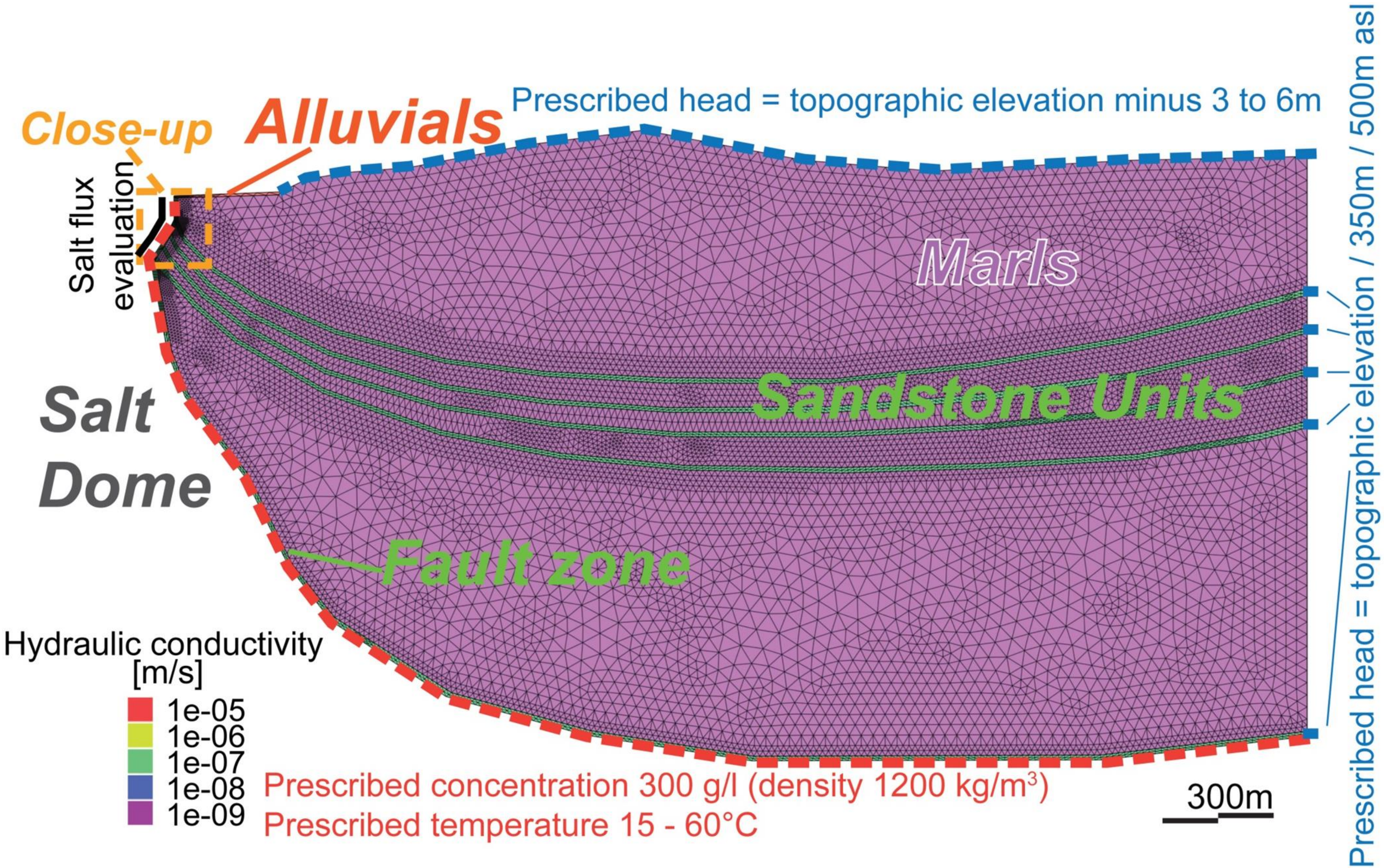
2D numerical model concept for density-dependent groundwater flow and transport



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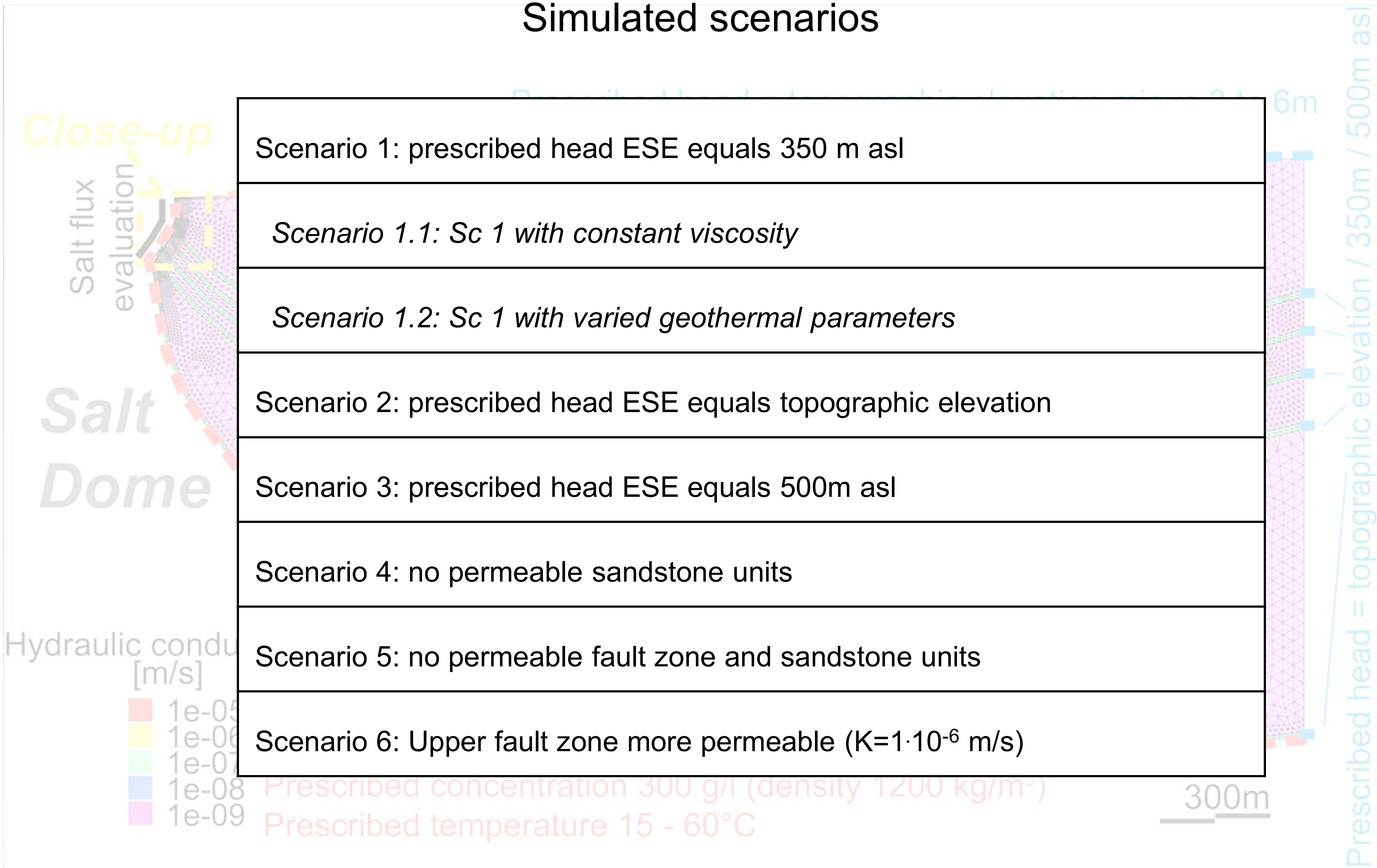
2D numerical model concept for density-dependent groundwater flow and transport
Simulated scenarios



Scenario 1: prescribed head ESE equals 350 m asl
Scenario 1.1: Sc 1 with constant viscosity
Scenario 1.2: Sc 1 with varied geothermal parameters
Scenario 2: prescribed head ESE equals topographic elevation
Scenario 3: prescribed head ESE equals 500m asl
Scenario 4: no permeable sandstone units
Scenario 5: no permeable fault zone and sandstone units
Scenario 6: Upper fault zone more permeable ($K=1 \cdot 10^{-6}$ m/s)

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2D numerical model concept for density-dependent groundwater flow and transport
Physical rock parameters

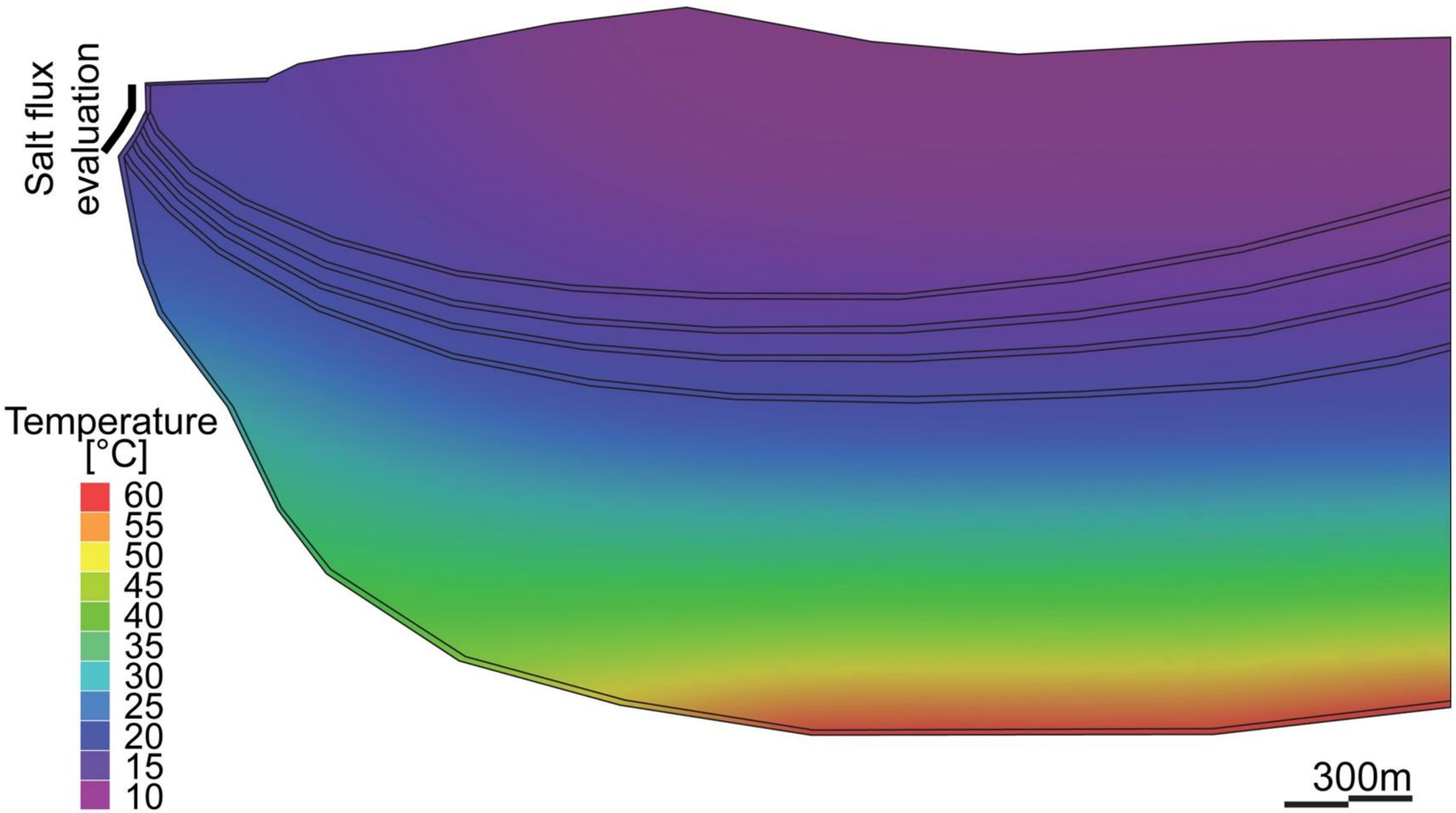
Geological feature	Hydraulic conductivity [m/s]	Porosity [−]	Volumetric heat capacity [10^6 Jm^{-3} K^{-1}]	Thermal conductivity [Wm^{-1} K^{-1}]
Quaternary alluvial foothill sediments	1.0×10^{-5}	0.1	3 (except for scenario 1.2, where it equals 2)	2 (except for scenario 1.2, where it equals 1.33)
Miocene sandstones[a]	1.0×10^{-7}			
Miocene marls	1.0×10^{-9}			
Fault zone unit[b]	1.0×10^{-7}			
Upper part fault zone unit in scenario 6	1.0×10^{-6}			

[a] Not represented in scenarios 4 and 5

[b] Not represented in scenario 5

Results 2D density-dependent groundwater flow and transport after 10’000 years: Simulated temperature values Scenario 1

Scenario 1: prescribed head ESE equals 350 m asl



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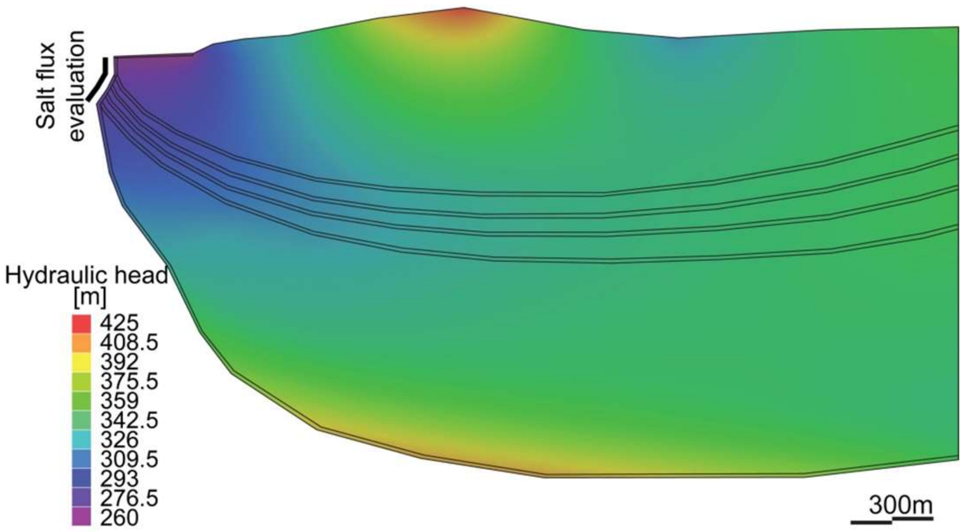
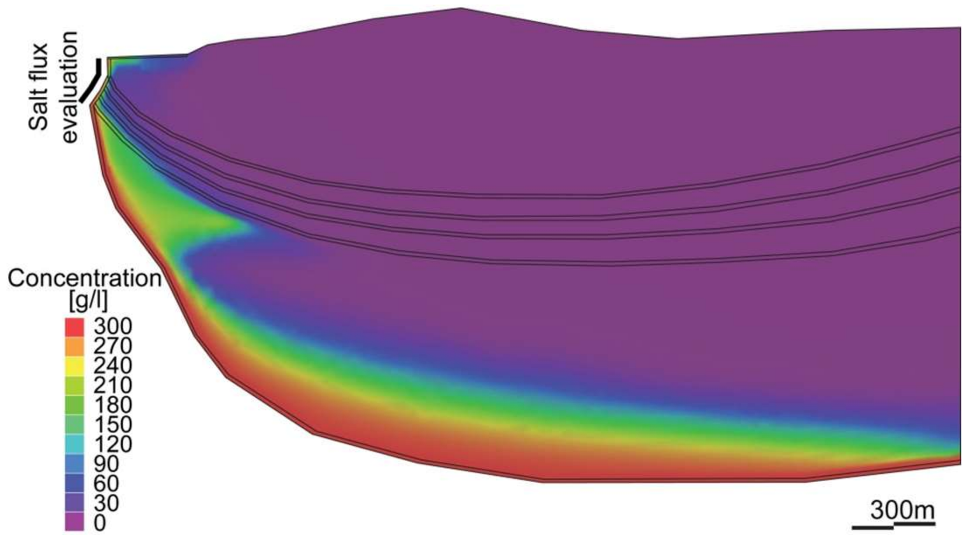
Results 2D density-dependent groundwater flow and transport after 10'000 years: Hydraulic head values and salt concentration Scenario 1

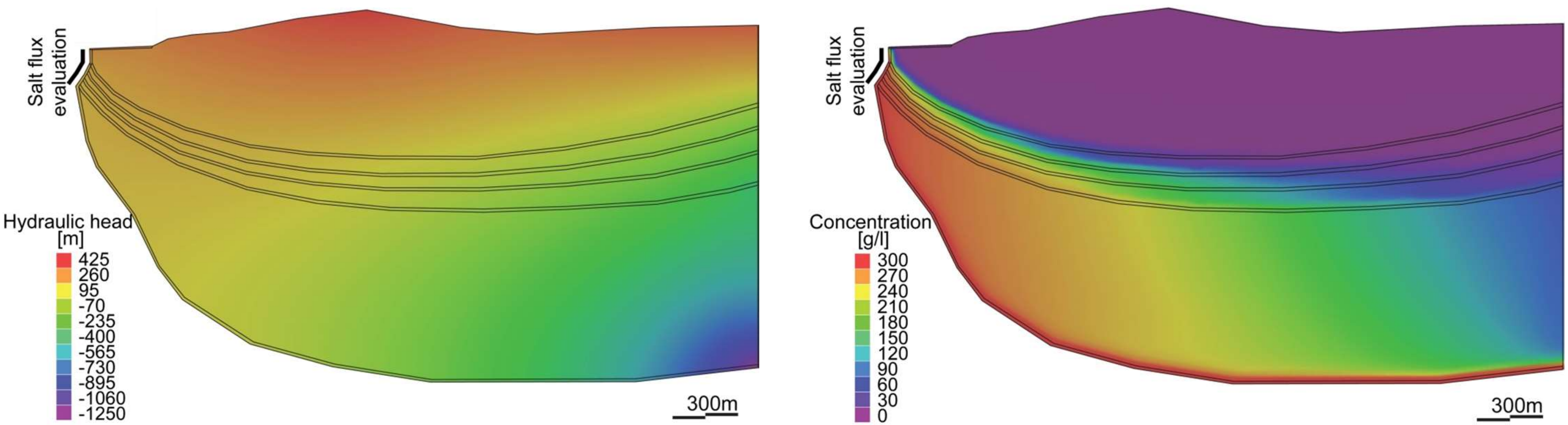
Scenario 1: prescribed head ESE equals 350 m asl





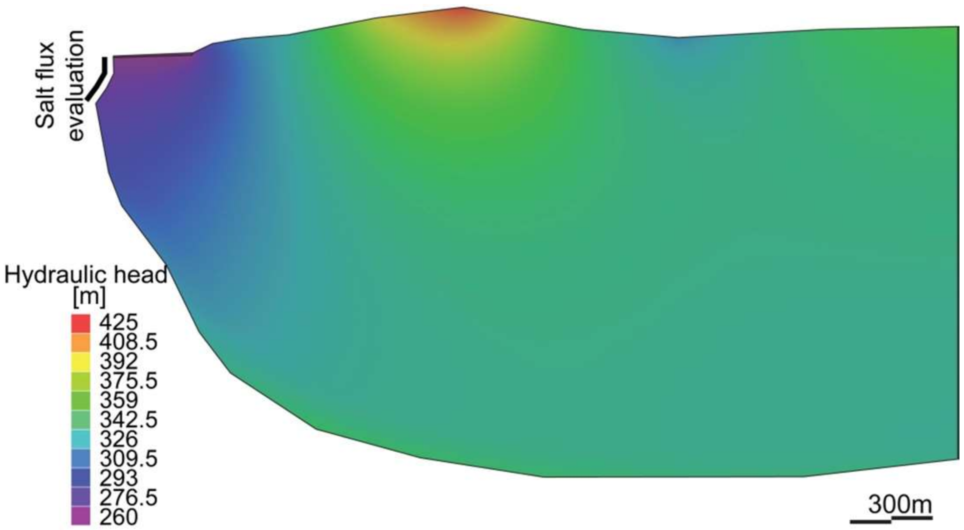
Results 2D density-dependent groundwater flow and transport after 10’000 years: Hydraulic head values and salt concentration Scenario 2

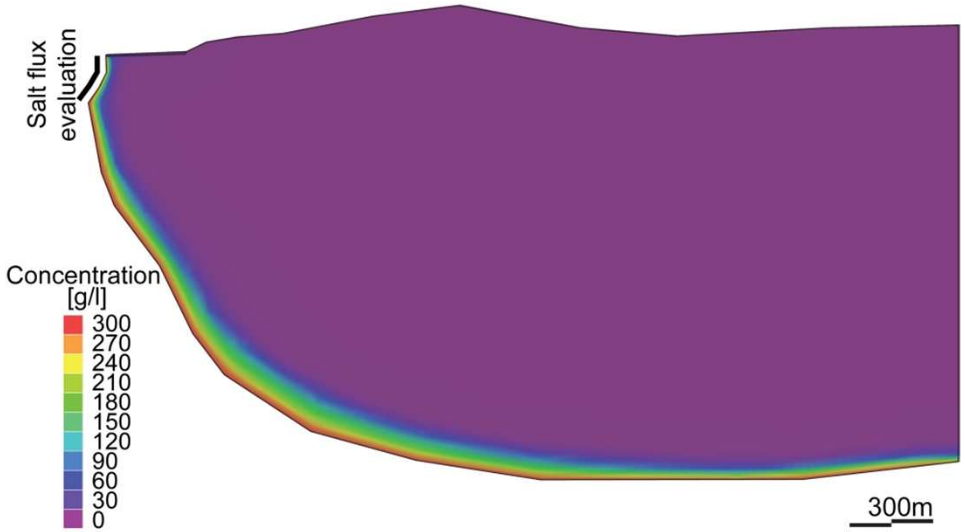
Scenario 2: prescribed head ESE equals topographic elevation



Results 2D density-dependent groundwater flow and transport after 10'000 years: Hydraulic head values and salt concentration Scenario 5

Scenario 5: no permeable fault zone and sandstone units





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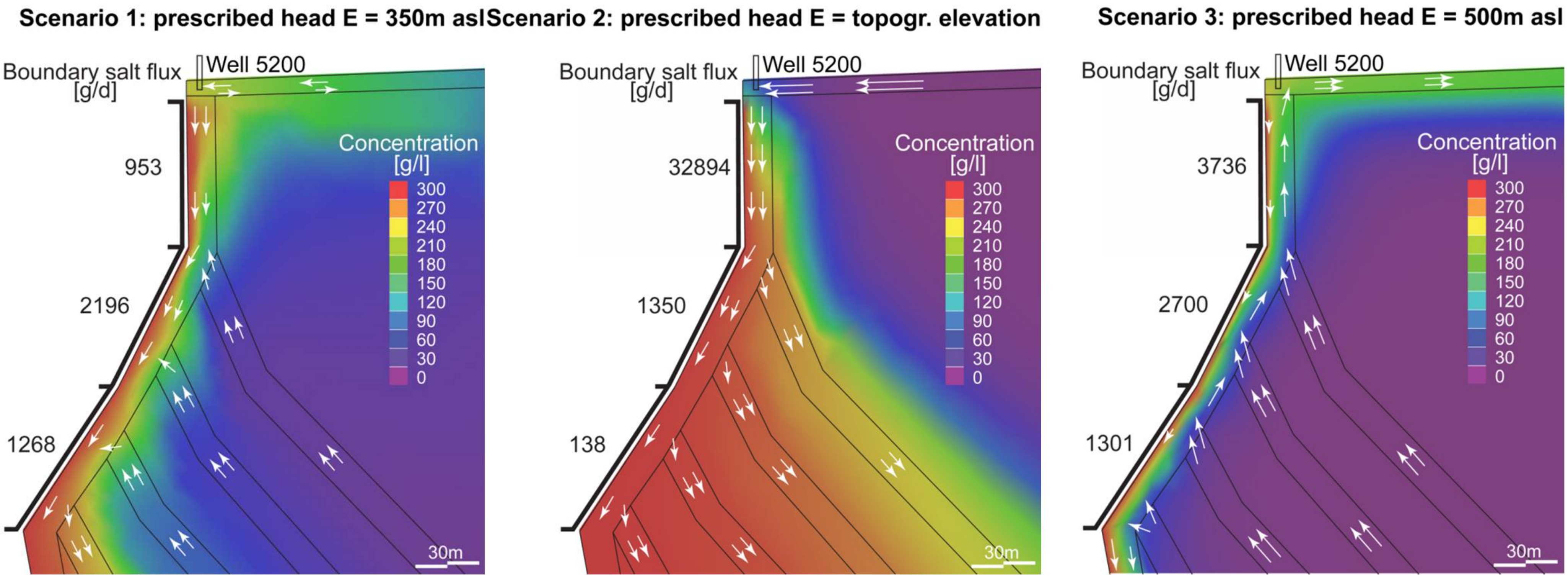
Close-up on the concentration values towards the upper 200 m of the diapir for scenarios 1–3, the predominant flow directions within the more permeable units, the projected location of well 5200 and the integrated boundary salt fluxes in g/day along the Upper, Middle, and Lower parts after 10,000 years simulation:



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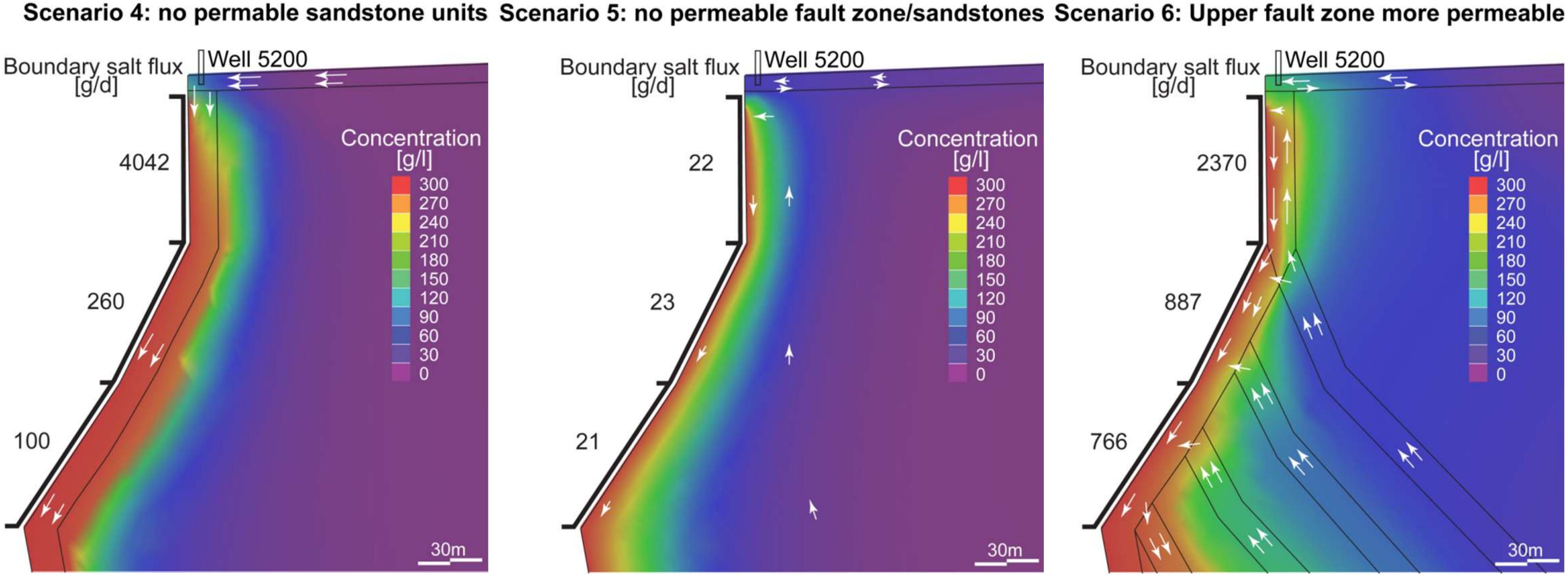
Close-up on the concentration values towards the upper 200 m of the diapir for scenarios 4–6, the predominant flow directions within the more permeable units (if represented), the projected location of well 5200 and the integrated boundary salt fluxes in g/day along the Upper, Middle, and Lower parts after 10,000 years simulation:



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Results 2D density-dependent groundwater flow and transport after 10’000 years: Salt flux, and potential dissolution rates along upper 180m

Table 2 Integrated salt fluxes in g/day and corresponding potential subrosion rates of the salt boundary in mm/year over the three parts—Upper (0–65 m), Middle (65–130 m) and Lower (130–180 m) of the top 180 m of the diapir for the different scenarios 1–6

	Upper		Middle		Lower	
	[g/day]	[mm/year]	[g/day]	[mm/year]	[g/day]	[mm/year]
Scenario 1: prescribed head ESE equals 350 m asl	953	2.5	2,196	5.7	1,268	4.3
Scenario 1.1: Sc 1 with constant viscosity	531	1.4	1,388	3.6	626	2.1
Scenario 1.2: Sc 1 with varied geothermal parameters	837	2.2	2,240	5.8	1,517	5.1
Scenario 2: prescribed head ESE equals topographic elevation	32,894	85.1	1,350	3.5	138	0.5
Scenario 3: prescribed head ESE equals 500 m asl	3,736	9.7	2,700	7.0	1,301	4.4
Scenario 4: no permeable sandstone units	4,042	10.5	260	0.7	100	0.3
Scenario 5: no permeable fault zone and sandstone units	20	0.1	23	0.1	21	0.1
Scenario 6: upper fault zone more permeable ($K = 1 \times 10^{-6}$ m/s)	2,370	6.1	887	2.3	766	2.6

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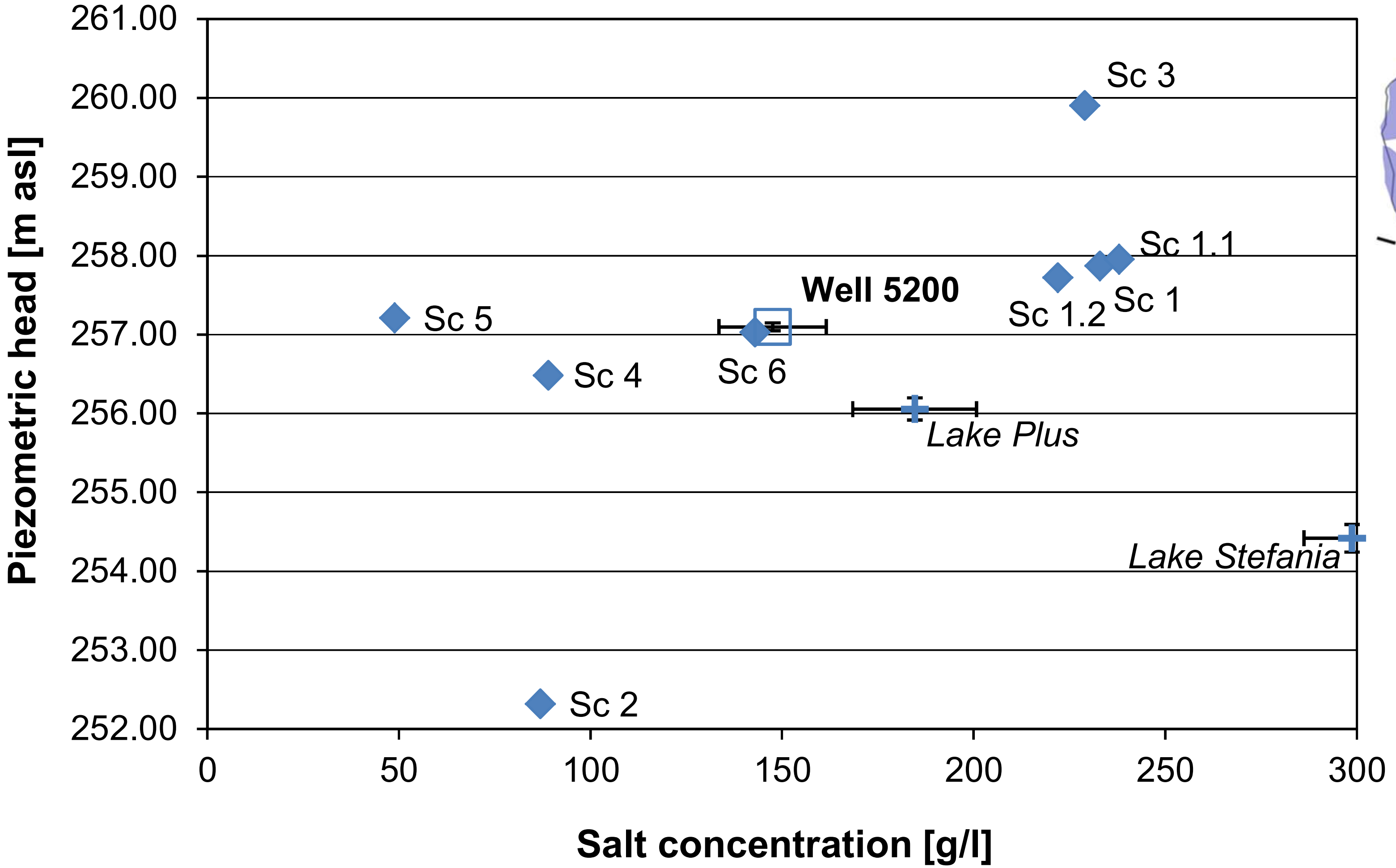
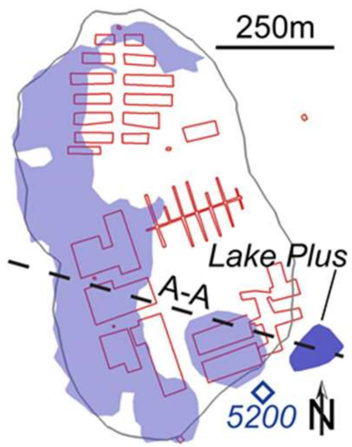
Measured piezometric heads and salt concentrations (at well bottom, 4–5 m depth) in well 5200. Measured lake stages and salt concentrations (at 5 m depth) are from nearby Lake Plus NE of well 5200, and Lake Stefania W of well 5200. Measurements are averaged over years 2014–2015, including standard deviations. Compared simulated piezometric heads and salt concentrations from scenarios 1 to 6 are from the Quaternary sediments unit above the fault zone corresponding to a depth of approx. 4 m.





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Results of the simulations show, that the following factors increase the salt dissolution capacity along the upper 180 m of the diapir:

- the presence of more permeable Quaternary alluvial sediments in connection with a fault zone of higher permeability along the diapir;
- the presence of more permeable sandstone units within the Miocene sediments in the east of the diapir, which provide freshwater access to the upper parts of the diapir.
- larger overpressure in the sandstone units, or larger hydraulic conductivities in the Upper part of the fault zone lead to partly upward flow of freshwater in the fault zone, and, therefore also to a stronger increase of salt dissolution in this Upper part;
  - thermohaline simulation with viscosity variation of the fluid, instead of a constant viscosity, influences the resulting salt fluxes by up to 50% within studied temperature ranges of 10 to 60°C in the model domain.

The range of simulated dissolution rates along the upper 180 m of the diapir supports the hypothesis that cavern collapse is more likely to occur where cavern side walls have already been mined to almost no remaining side walls of rock salt, which is the case in the southeastern part of the diapir.