The effect of topography driven groundwater flow on deep subsurface temperatures in the Roer Valley Graben (southern Netherlands)

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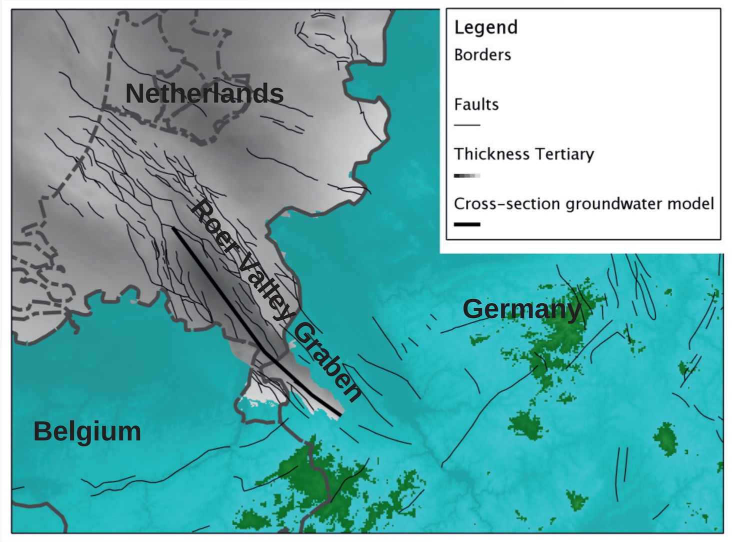
1 Introduction

- Numerous studies have documented suspected thermal effects of deep groundwater flow. However, high uncertainty and heterogeneity of permeability hampers model studies of the thermal effects of groundwater flow.

- Groundwater salinity data could offer an additional way to constrain topography driven groundwater flow systems. Availability of new temperature and salinity data indicating freshening of marine deposits in the Roer Valley Graben allowed us to quantify the extent of topography driven groundwater flow in the basin.

Location fo the Roer Valley Graben and the cross-section used for model simulations of basin-scale groundwater flow:

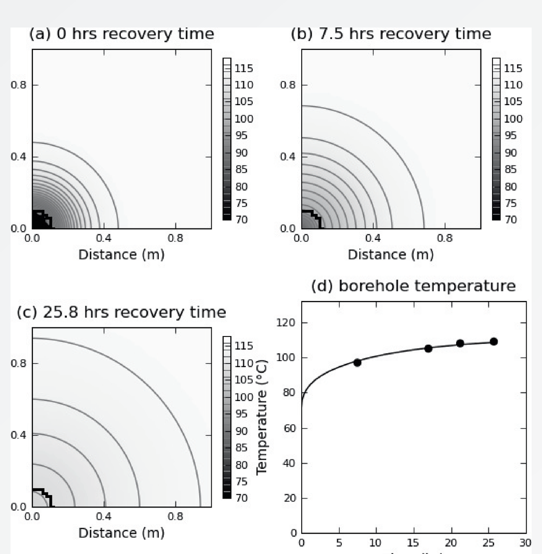


2 Heterogenous subsurface temperatures in the Roer Valley Graben

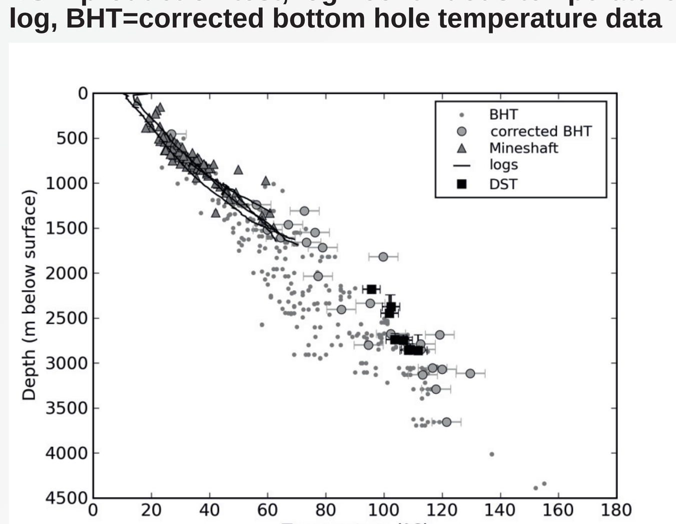
- Subsurface temperatures in the Roer Valley Graben were reconstructed using a new numerical model of the thermal recovery of wells after drilling (see figure below), resulting in relatively accurate temperature data from bottom hole temperature measurements, with an estimated uncertainty of ±5 °C

- Resulting temperatures show a heterogenous temperature field, with temperatures in wells in the northern part of the basin up to 20 °C higher than average at a depth of 1250 m.

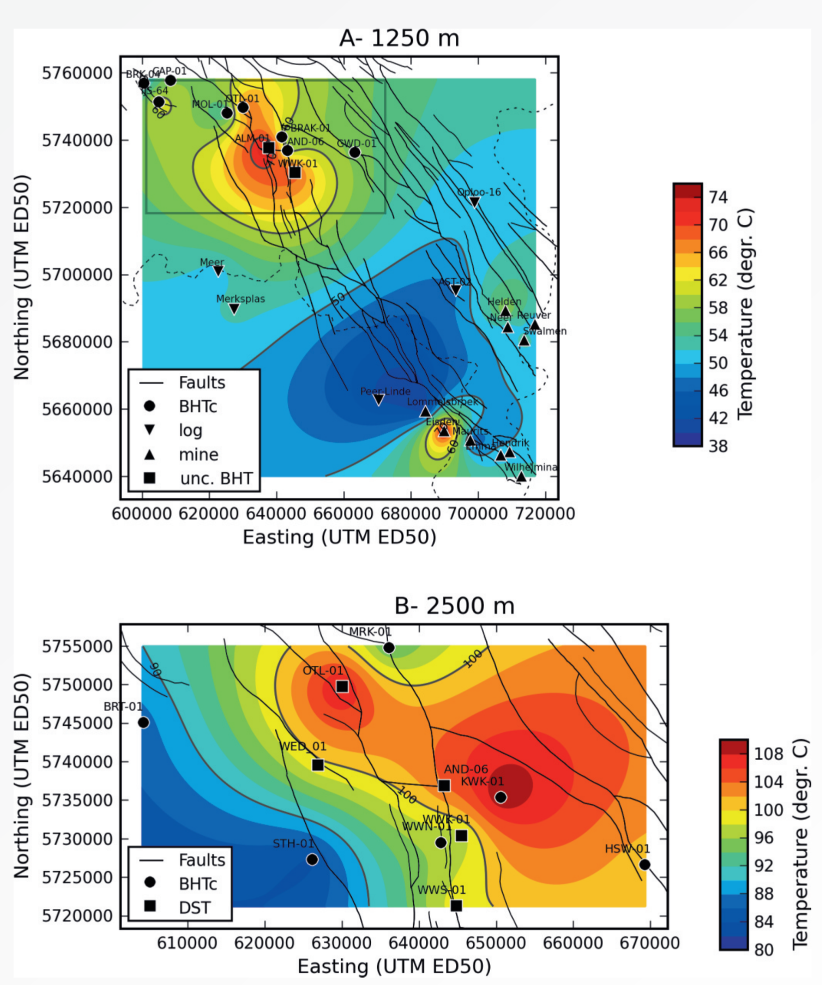
Temperature recovery model, showing the temperature field in and around a borehole at three time slices after drilling (top and left), and the corresponding temperature recovery curve in the borehole (lower right).



Reconstructed temperatures vs depth. DST=production test, log= continuous temperature log, BHT=corrected bottom hole temperature data



Temperature maps at depths of 1250 m (top) and 2500 m (bottom)



For more information see: Luijendijk et al (2010) Thermal state of the Roer Valley Graben, part of the European Cenozoic rift system. Basin Research, online early view.
The borehole thermal recovery model code PyBHT is freely available, send an email to elco.luijendijk@falw.vu.nl for a copy.

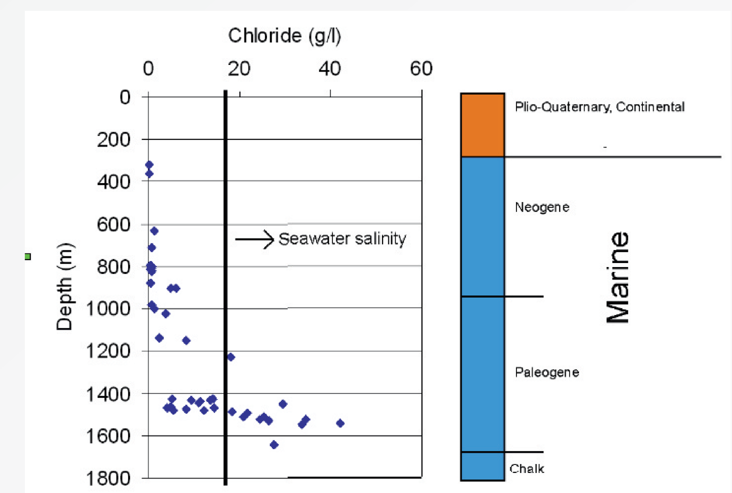
3 Freshening of marine sediments suggest topography driven groundwater flow in the upper ~1000m of the basin

- Data on groundwater salinity in the Dutch part of the Roer Valley Graben indicates freshening of marine Miocene and older sediments.

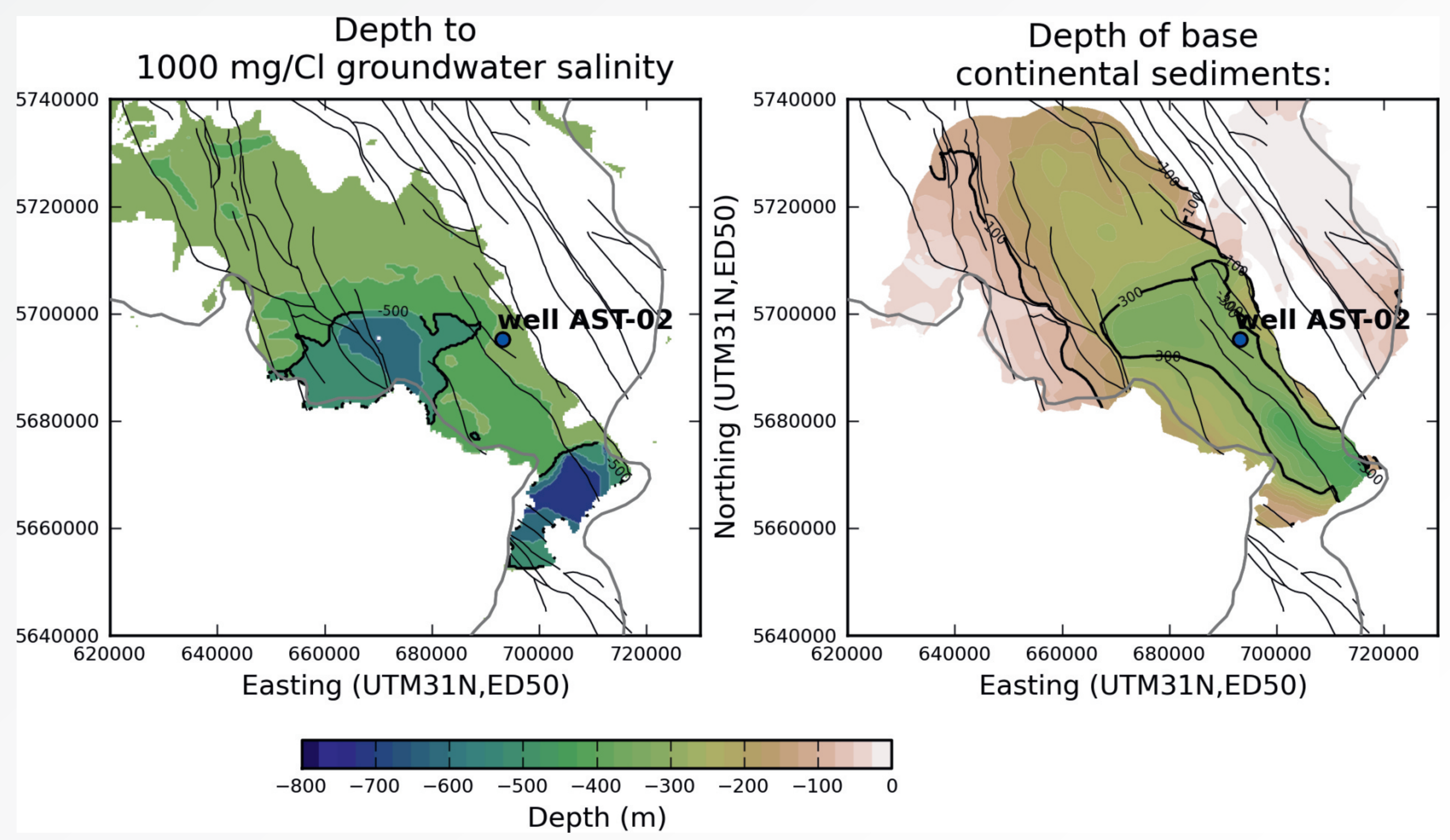
- Downward displacement of the fresh-salt water interface is strongest in the southern part of the basin, coinciding with the highest topography (up to 130 m) and thickness of relatively permeable continental deposits

- This suggests infiltration of meteoric water caused by a topography driven groundwater flow system that penetrates the upper ~1 km of the basin fill. This sytem was probably active since the Pliocene shift to continental deposition

Detailed groundwater salinity data in well AST-02 in the central part of the Roer Valley Graben shows a downward displacement of ~800 m of the fresh-salt water boundary. Salinity data from Heederik (1988)



Below: The depth of the fresh-brackish groundwater interface (left) is up to 300 m deeper than the base of (Pliocene) continental deposits (right), indicating infiltration of meteoric groundwater in underlying marine deposits.

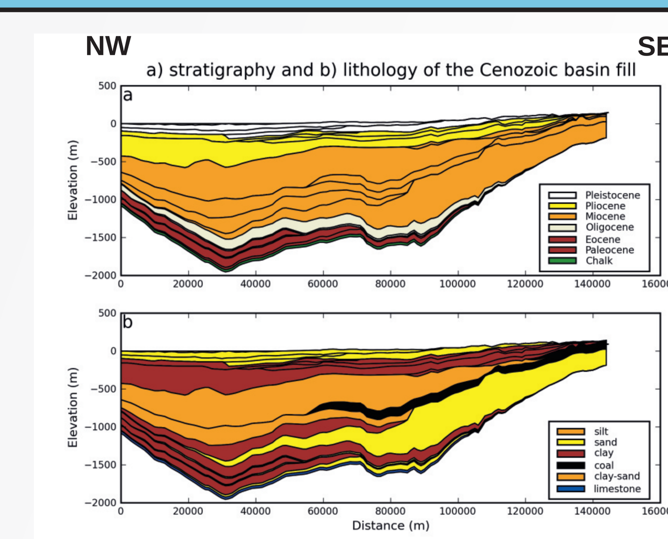


4a Numerical model of groundwater flow

- Groundwater and heat flow along a 2D NW-SE cross section were simulated using the numerical model code RIFT2D (Person et al., 2001)

- Permeability and porosity were determined using an extensive database of 2500 core plug data and pumping tests. Uncertainty of permeability was taken into account by using two end-member permeability scenarios

Right: Statigraphy and lithology of the NW-SE cross section along the axis of the Roer Valley Graben -> based on de Rooij (2000)



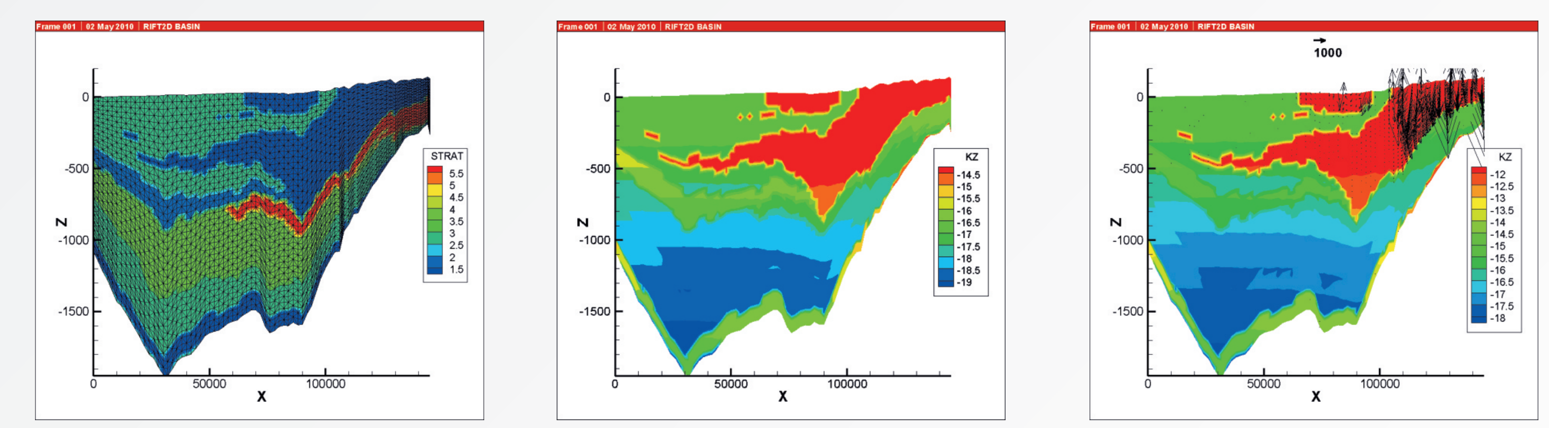
4b Preliminary model results: thermal effect of topography driven groundwater flow

- Model results suggest a strong cooling effect of topography driven flow, with maximum cooling ranging from 20 °C (low permeability scenario) to 40 °C (high permeability scenario).

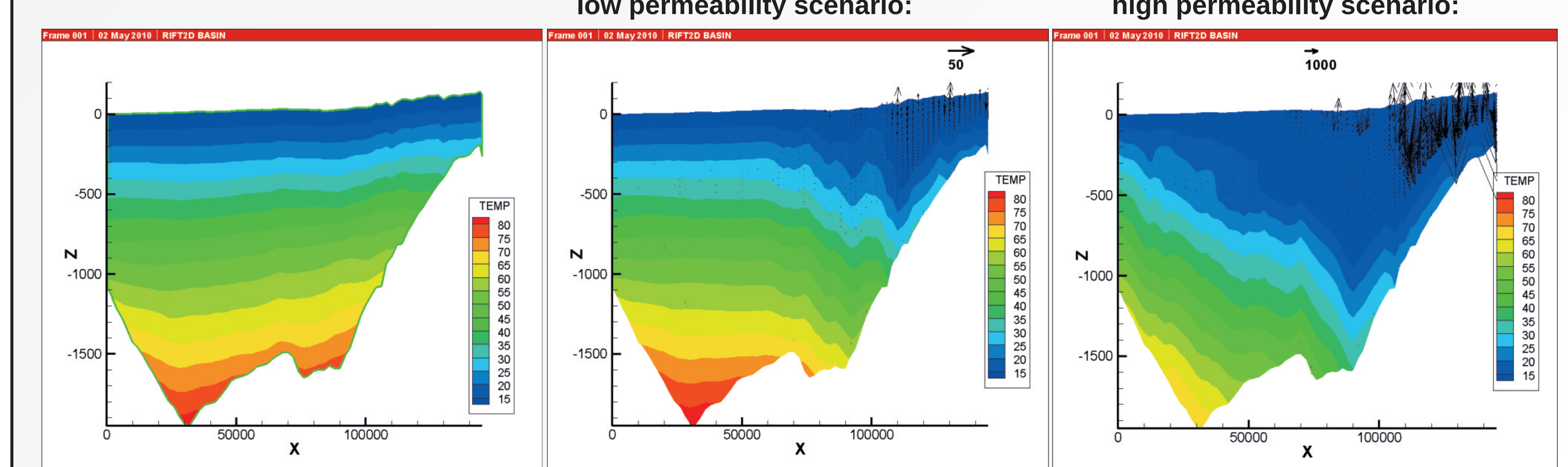
- Steady-state temperatures were reached after 75000-150000 yrs, with initial rapid cooling in the parts affected by flow within several 1000 yrs, and a slower adjustment of the deeper parts of the basin by heat conduction.

- The simulated groundwater flow system could explain the observed lower temperatures and downward displacement of salt water observed in the southern part of the Roer Valley Graben.

Model grid and permeability zones: | **Vertical permeability (log m²), low permeability scenario:** | **Vertical permeability (log m²), high permeability scenario:**



Subsurface temperatures, no flow reference case: | **Temperatures and flow velocities after 200000 yrs, low permeability scenario:** | **Temperatures and flow velocities after 200000 yrs, high permeability scenario:**



5 Conclusions

1) Subsurface temperatures show a heterogenous temperature field with variations of up to 20 °C at 1250 m depth.

2) Downward displacement of the fresh-salt water boundary in the basin indicates a topograpy-driven groundwater flow system penetrating the upper 1 km of the basin.

3) Numerical simulation of groundwater flow suggest that topography driven flow has a cooling effect of up to 20-40 °C, and could account for the observed lower temperatures and freshening of marine sediments in the southern part of the basin.

5) The fact that a thermal effect of topography driven flow was observed in a basin with a relatively low topographic gradient (130m) implies that the thermal effects of topography driven flow in basins could be more widespread than previously assumed.

References
Heederik, J.P., 1988, Geothermische Reserves Centrale Slenk, Nederland. Exploratie en evaluatie. TNO, Utrecht.
Person, M., Neuzil, C., Mailloux, B., Hsieh, P., Mendoza, C., Eadington, P., Swenson, J., and Bekele, E., 2001, RIFT2D: A finite element model for simulating two-dimensional fluid, heat, and solute mass transport in evolving sedimentary basins. US Geological Survey.
Rooij, R.D., 2000, A hydrogeological schematisation of the Roer Valley Graben: Msc thesis, Utrecht University.

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