Insights into the deep geothermal potential from heat in place calculations of the Berlin/Brandenburg region

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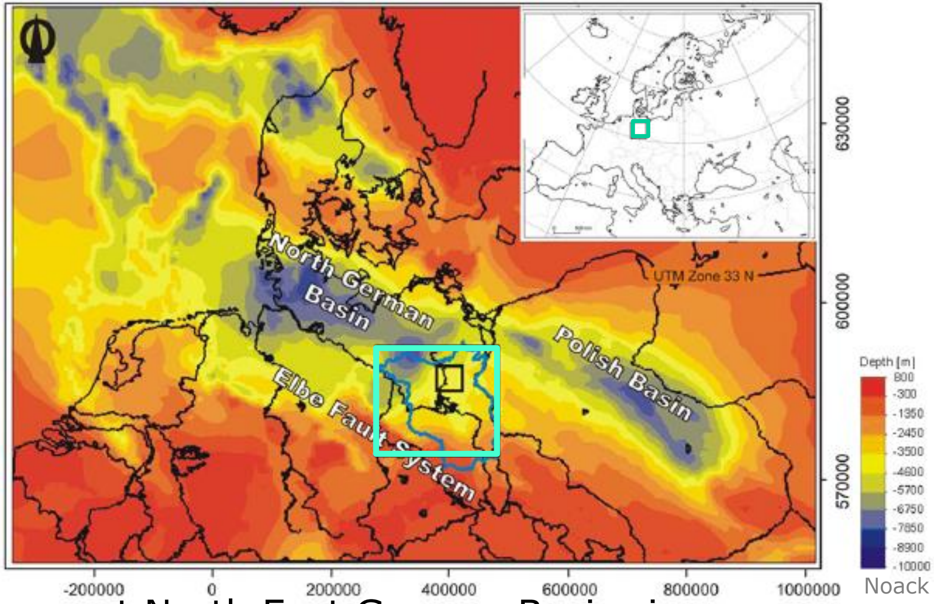
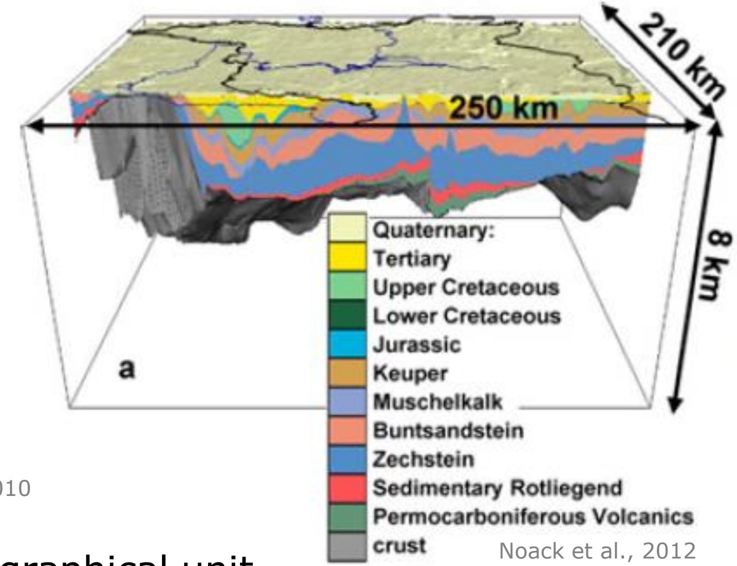
Berlin/Brandenburg as target area



Noack et al., 2010

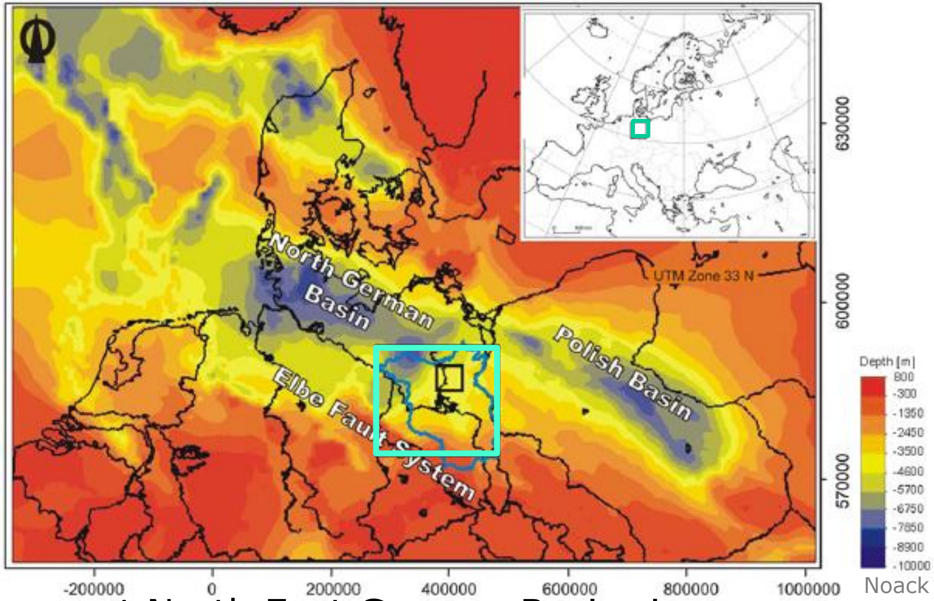


Noack et al., 2012

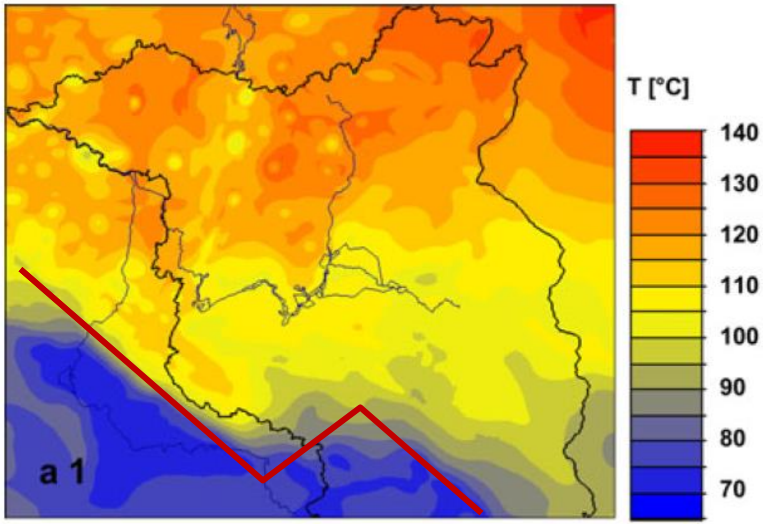
- at North East German Basin rim
- Heat in place (HIP) calculated for each litho-stratigraphical unit
- reference model includes 3D structural geological model

reference temperature model: Noack et al., 2010; Noack et al., 2012
HIP calculated for 16 litho-stratigraphical units (Tertiary divided into Post-, Pre-, Rupelian; crust divided into upper-, lower crust)

Berlin/Brandenburg as target area



Noack et al., 2010

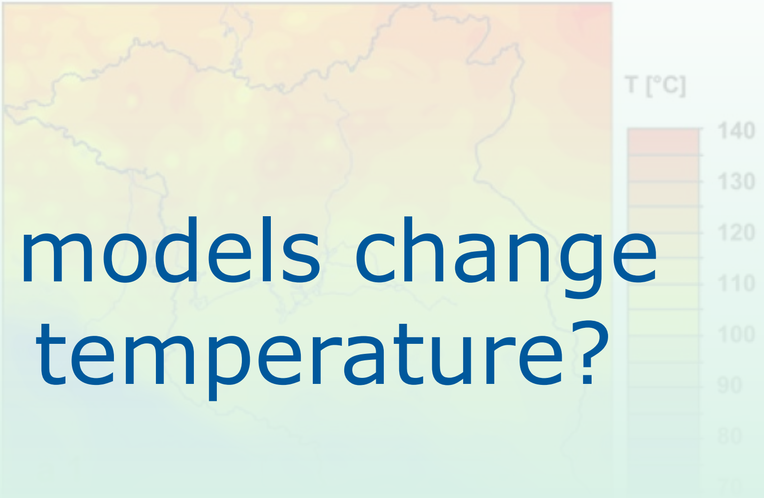


Temperature distribution at 3 km bmsl.

Noack et al., 2012

- at North East German Basin rim
- Heat in place (HIP) calculated for each litho-stratigraphical unit
- reference model includes 3D structural geological model and thermal conductive model

Berlin/Brandenburg as target area



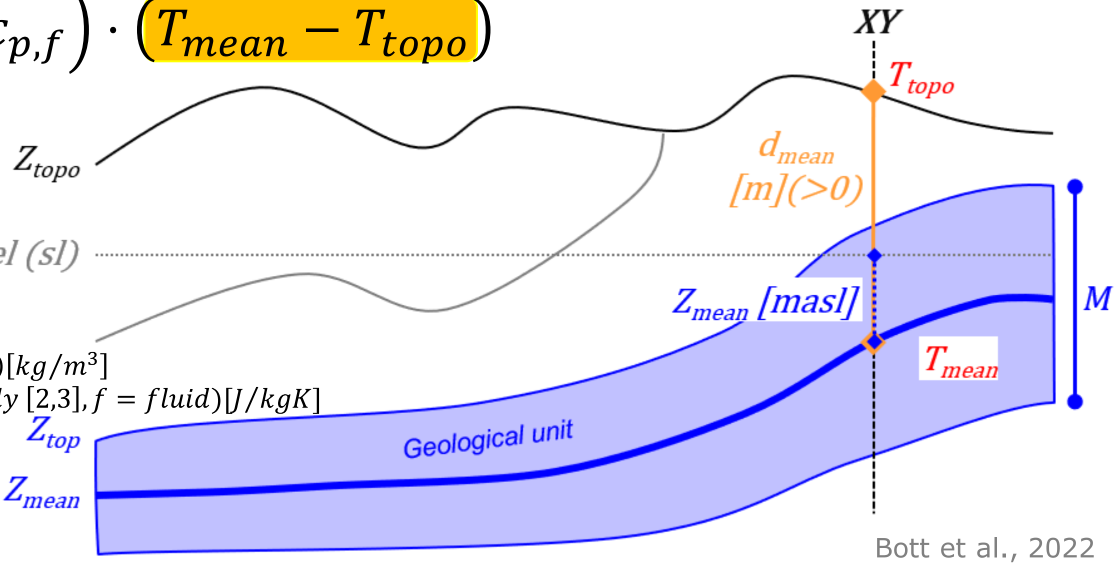
How does the value of models change with HIP additional to temperature?

HIP method for geothermal potential

$$H = \boxed{M} \cdot \left((1-\varphi)\rho_s \boxed{c_{p,s}} + \varphi \boxed{\rho_f} c_{p,f}\right) \cdot \left(\boxed{T_{mean} - T_{topo}}\right)$$

Vary in every point

H = Heat in place $[J/m^2]$
M = Reservoir thickness $[m]$
φ = porosity $[-]$
ρ = density (s = solid, f = fluid calculated empirically [1]) $[kg/m^3]$
c_p = specific heat capacity (s = solid calculated empirically [2,3], f = fluid) $[J/kgK]$
T_{mean} = mean temperature $[°C]$
T_{topo} = surface temperature $[°C]$



Bott et al., 2022

Muffler and Cataldi, 1987; [1] Batzle and Wang, 1992; [2] Bär, 2012; [3] Vosteen and Schellschmidt, 2003
Python used as programming language → "Py4HIP" Jupyter Notebook developed

HIP contributing and empirical formulas

For hydrostatic pressure:

$$p = \rho_{brine\ 0} \cdot g \cdot d_{mean} + \ 101325\ Pa$$

For mean reservoir temperature:

$$T\ at\ Z_{mean,XY} = Z_{min,XY} - \frac{M_{XY}}{2}$$

[1] Batzle and Wang, 1992

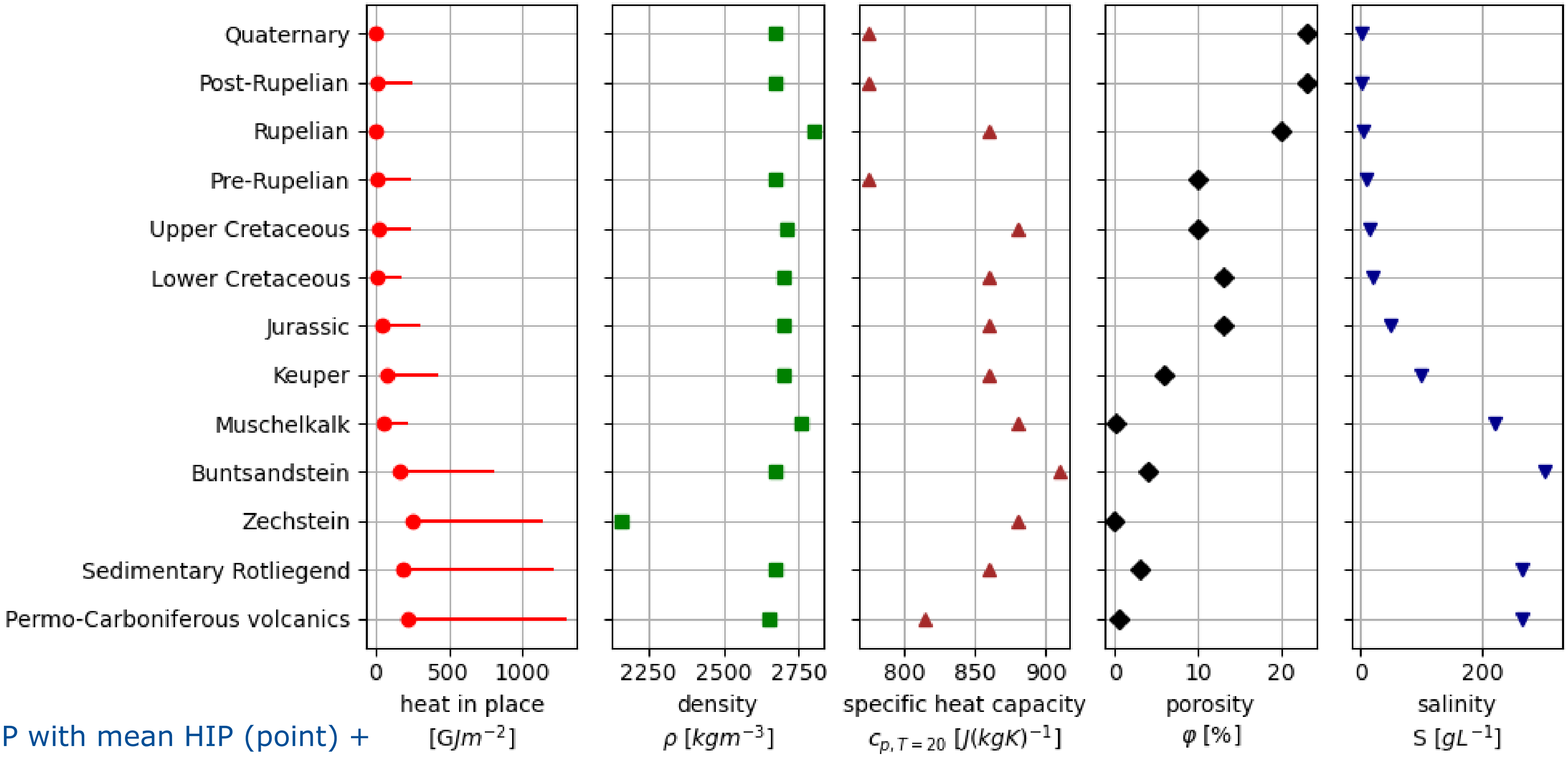
$p = hydrostatic\ pressure\ [Pa], for\ [1]\ in\ [MPa]$
$\rho_{brine\ 0} = water\ density\ at\ surface\ [kg/m^3]$
$g = gravitational\ acceleration\ [m/s^2]$
$d_{mean} = distance\ of\ water\ column\ [m]$
$T = mean\ temperature\ [°C]$
$Z_{mean,XY}, Z_{min,XY} = Z\ coordinate\ of\ point\ (X,Y)[m]$
$M_{XY} = thickness\ at\ point\ (X,Y)[m]$
$\rho_{fw}, \rho_{brine} = density\ (fw = freshwater)[g/cm^3]$
$S = salinity\ [weight\ fraction = ppm/1000000]$
$c_{p,m} = specific\ heat\ capacity\ [J/kgK]$

$$\rho_{fw} = 1 + 10^{-6} \cdot (-80T - 3.3T^2 + 1.75 \cdot 10^{-3}T^3 + 489p - 2Tp + 0.016T^2p - 1.3 \cdot 10^{-5}T^3p - 0.333p^2 - 0.002Tp^2)$$
$$\rho_{brine} = \rho_{fw} + S \cdot (0.688 - 0.44S + 10^{-6} \cdot (300p\ - 2400pS + T \cdot (80 + 3T - 3300S - 13p + 47pS)))$$

[2] Bär, 2012; [3] Vosteen and Schellschmidt, 2003 for sedimentary layers (1), and for magmatic rocks (2)

$$(1)\ c_{p,m}(T) = 6.295 \cdot 10^{-6} \cdot T^3 - 4.99 \cdot 10^{-3} \cdot T^2 + 1.71 \cdot T + c_{p,m,(T=20°C)}$$
$$(2)\ c_{p,m}(T) = 4.619 \cdot 10^{-6} \cdot T^3 - 3.945 \cdot 10^{-3} \cdot T^2 + 1.46 \cdot T + c_{p,m,(T=20°C)}$$

Lithology-dependent HIP & parameters



HIP with mean HIP (point) + error bar from min to max HIP

Parameters after: [1] Noack et al., 2010 [2] Magri 2005 [3] Blöcher et al., 2010 [4] after Noack et al., 2013 [5] Scheck 1997 [6] Waples and Waples 2004 [7] Magri et al., 2008 [8] Wolfgramm and Seibt, 2003 [9] Cherubini et al., 2013 [10] Allen and Allen 2013

All lithology-dependent HIP parameters

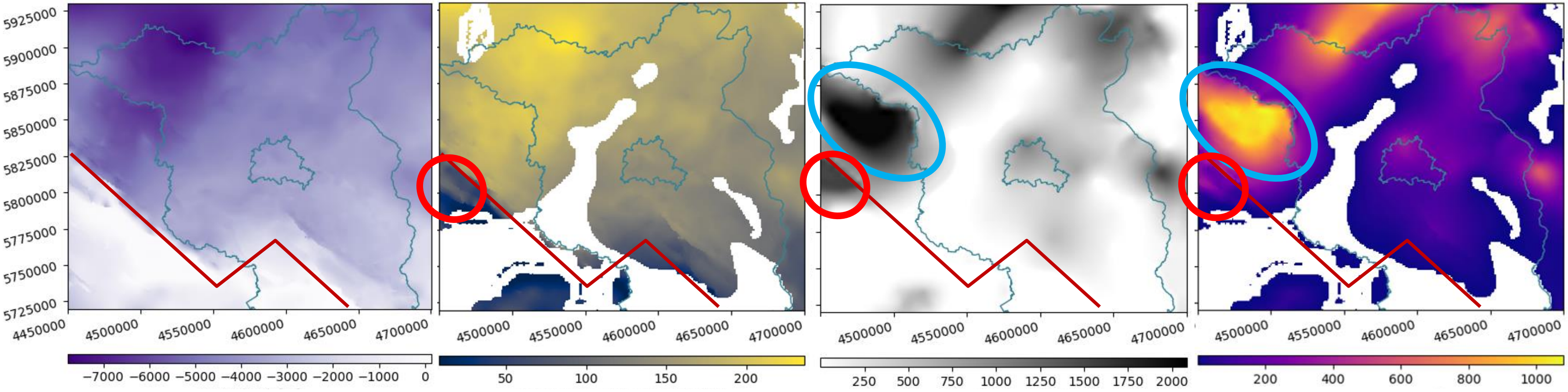
Lithology (all values for presented model)	φ **porosity** $[\%]$	ρ **density**$_{(s)}$ $[kg/m^3]$	c_p **specific heat capacity**$_{(T=20^\circ C)}$ $[J/kgK]$	**Salinity** $[g/L]$ If φ = 0 then no value
Quaternary	23 [1]	2670 [4,5]	775 [6]	2 [7]
Tertiary Post-Rupelian	23 [1]	2670 [4,5]	775 [6]	2 [7]
Tertiary Rupelian	20 [1]	2800 [4,5]	860 [6]	5 [7]
Tertiary Pre-Rupelian	10 [1]	2670 [6]	775 [6]	10 [7]
Upper Cretaceous	10 [1]	2710 [10]	880 [6]	15 [7]
Lower Cretaceous	13 [1]	2700 [4,5]	860 [6]	20 [7]
Jurassic	13 [1]	2700 [4,5]	860 [6]	50 [7]
Keuper	6 [1]	2700 [4,5]	860 [6]	100 [7]
Muschelkalk	0.1 [1]	2760 [6]	880 [6]	220 [7]
Buntsandstein	4 [1,2]	2670 [4,5]	910 [6]	300 [7]
Zechstein	0 [1]	2160 [4,5]	880 [6]	-
Sedimentary Rotliegend	3 [9]	2670 [1,5]	860 [6]	265 [8]
Permo-Carboniferous volcanics	0.5 [1,3]	2650 [1,5]	815 [6]	265 [8]
Pre-Permian	0 [1]	2700 [1,5]	850 [6]	-
Upper Crust	0 [1]	2800 [5,11]	850 [6]	-
Lower Crust	0 [1]	2800 [5,11]	850 [6]	-
Lithospheric mantle	0 [1]	3300 [5,11]	1005 [6]	-

[1] Noack et al., 2010 [2] Magri 2005 [3] Blöcher et al., 2010 [4] after Noack et al., 2013 [5] Scheck 1997 [6] Waples and Waples 2004 [7] Magri et al., 2008 [8] Wolfgramm and Seibt, 2003 [9] Cherubini et al., 2013 [10] Allen and Allen 2013 [11] Norden et al., 2008

HIP f(temperature, thickness)

Permo-Carboniferous volcanics

reference temperature model　　　　HIP



mean depth $[m]$

temperature at mean depth $[°C]$

layer thickness $[m]$

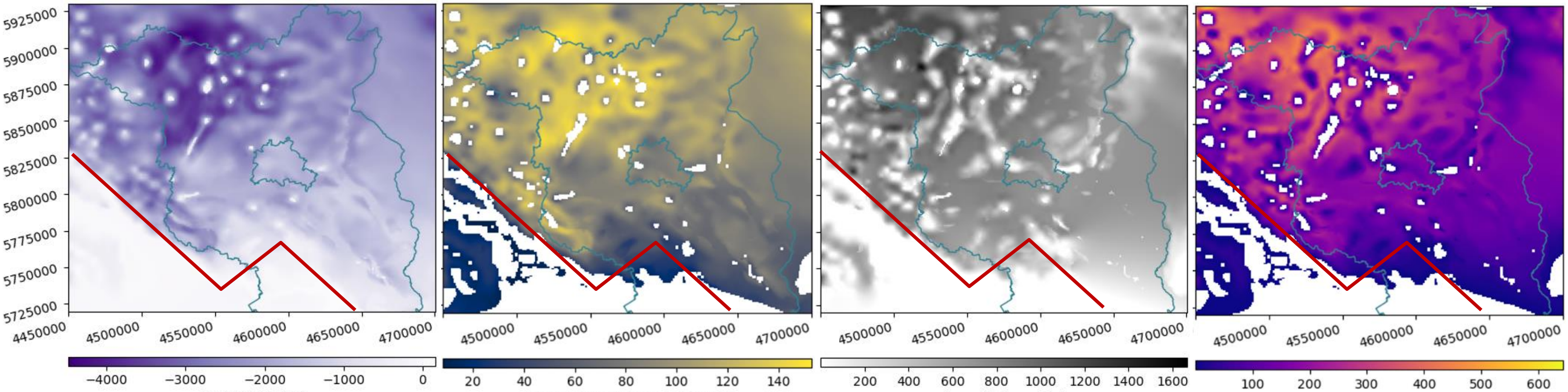
heat in place $[GJ/m^2]$

- temperature and thickness dependency shows very well in HIP maps

HIP variations due to salt

Buntsandstein

reference temperature model HIP



mean depth $[m]$

temperature at mean depth $[°C]$

layer thickness $[m]$

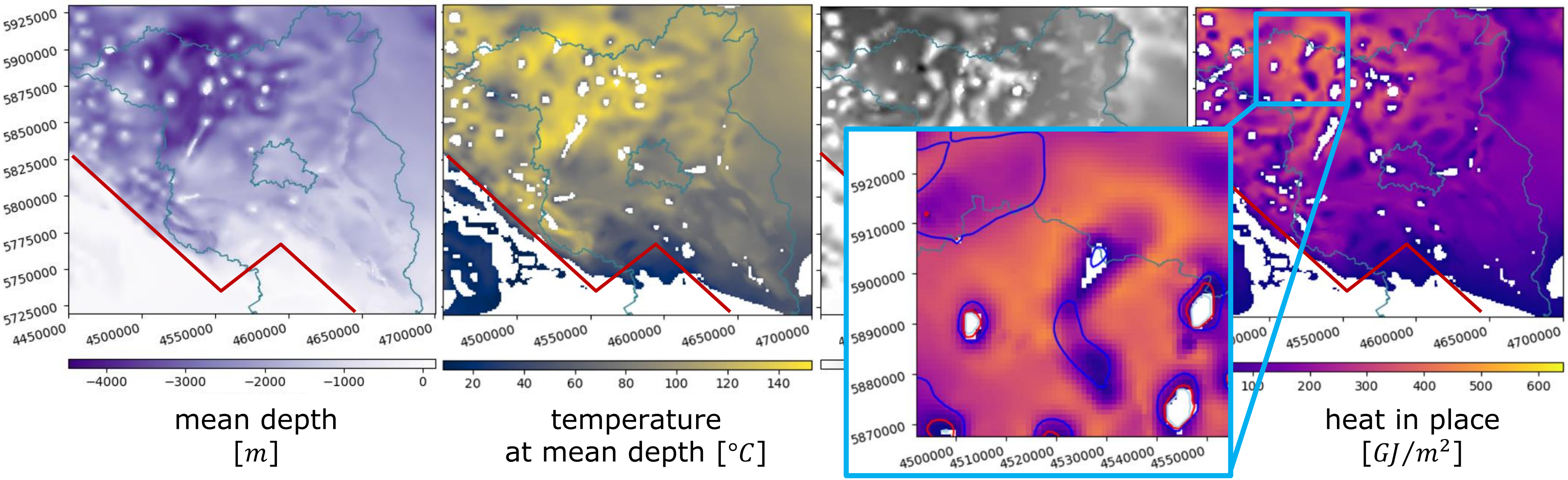
heat in place $[GJ/m^2]$

- fluctuating pattern due to salt

HIP variations due to salt

Buntsandstein

reference temperature model HIP



- fluctuating pattern due to salt

HIP with salt dome isolines (1800, 3000, 4000 m thickness)

reference temperature model modified after: Noack et al., 2010; Noack et al., 2012

Summary & outlook on HIP

- ✓ Temperature models not expressive enough! Use HIP!
- ✓ Temp & thickness dependency most influential
- ✓ Above-salt lithologies show higher inconsistency
- ✓ For drilling:
  - ✓ data-consistent geological structure, high-resolution models
- ✓ Master-thesis outlook:
  - ✓ parameter analysis
  - ✓ conductive vs. coupled thermal-hydraulic HIP

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GitLab
Basin Modelling / Python / Py4HIP
Py4HIP: Python script for heat-in-place calculations

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Use our Py4HIP tool:
https://git.gfz-potsdam.de/basin-modelling/python/py4hip

References

Allen, P. A., & Allen, J. R. (2013). Basin analysis: Principles and application to petroleum play assessment. John Wiley & Sons.

Bär, K. M. (2012). Untersuchung der tiefengeothermischen Potenziale von Hessen.

Batzle, M., & Wang, Z. (1992). Seismic properties of pore fluids. Geophysics, 57(11), 1396-1408.

Blöcher, M. G., Zimmermann, G., Moeck, I., Brandt, W., Hassanzadegan, A., Magri, F., 2010. 3D numerical modelling of hydrothermal processes during the lifetime of a deep geothermal reservoir. Geofluids. doi:10.1111/j.1468-8123.2010.00284.x.

Bott, J., Benoit, L., Koltzer, N., Anikiev, D. (2022): Py4HIP: Python tool for Heat-In-Place calculations. V. 1. GFZ Data Services, https://doi.org/10.5880/GFZ.4.5.2022.001 https://git.gfz-potsdam.de/basin-modelling/python/py4hip

Cherubini, Y., Cacace, M., Scheck-Wenderoth, M., Moeck, I., & Lewerenz, B. (2013). Controls on the deep thermal field: implications from 3-D numerical simulations for the geothermal research site Groß Schönebeck. Environmental earth sciences, 70(8), 3619-3642.

Magri, F., Bayer, U., Clausnitzer, V., Jahnke, C., Diersch, H. J., Fuhrmann, J., ... & Voigt, H. (2005). Deep reaching fluid flow close to convective instability in the NE German basin—results from water chemistry and numerical modelling. Tectonophysics, 397(1-2), 5-20.

Magri, F., Bayer, U., Tesmer, M., Möller, P., & Pekdeger, A. (2008). Salinization problems in the NEGB: results from thermohaline simulations. International Journal of Earth Sciences, 97(5), 1075-1085.

Muffler, P., & Cataldi, R. (1978). Methods for regional assessment of geothermal resources. Geothermics, 7(2-4), 53-89.

Noack, V., Cherubini, Y., Scheck-Wenderoth, M., Lewerenz, B., Höding, T., Simon, A., & Moeck, I. (2010). Assessment of the present-day thermal field (NE German Basin)—inferences from 3D modelling. *Geochemistry*, *70*, 47-62.

References

Noack, V., Scheck-Wenderoth, M., & Cacace, M. (2012). Sensitivity of 3D thermal models to the choice of boundary conditions and thermal properties: a case study for the area of Brandenburg (NE German Basin). *Environmental Earth Sciences*, *67*(6), 1695-1711.

Noack, V., Scheck-Wenderoth, M., Cacace, M., & Schneider, M. (2013). Influence of fluid flow on the regional thermal field: results from 3D numerical modelling for the area of Brandenburg (North German Basin). *Environmental earth sciences*, *70*(8), 3523-3544.

Norden, B., Förster, A., & Balling, N. (2008). Heat flow and lithospheric thermal regime in the Northeast German Basin. *Tectonophysics*, *460*(1-4), 215-229.

Scheck, M., 1997. Dreidimensionale Struckturmodellierung des Nordostdeutschen Beckens unter Einbeziehung von Krustenmodellen (Dissertation Thesis, Freie Universit¨at Berlin). Scientific Technical Report STR97/10, GeoForschungsZen- trum Potsdam, pp. 1–126.

Vosteen, H. D., & Schellschmidt, R. (2003). Influence of temperature on thermal conductivity, thermal capacity and thermal diffusivity for different types of rock. Physics and Chemistry of the Earth, Parts A/B/C, 28(9-11), 499-509.

Waples, D. W., & Waples, J. S. (2004). A review and evaluation of specific heat capacities of rocks, minerals, and subsurface fluids. Part 1: Minerals and nonporous rocks. *Natural resources research*, *13*(2), 97-122.

Wolfgramm, M., & Seibt, A. (2003). Geochemical characteristics of the formation fluid identified during stimulation tests on the Rotliegend geothermal reservoir in the NE German Basin (NEGB). In *European Geothermal Conference 2003*.

Programming languages/tools:

Python: https://www.python.org/

Jupyter Notebook: https://jupyter.org/