Aachen Institute for Advanced Study in Computational Engineering Science
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Computational Modelling of Coupled Heat Transport between the Heterogeneous Earth and an Overlying Ice Sheet

Computational Geoscience
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

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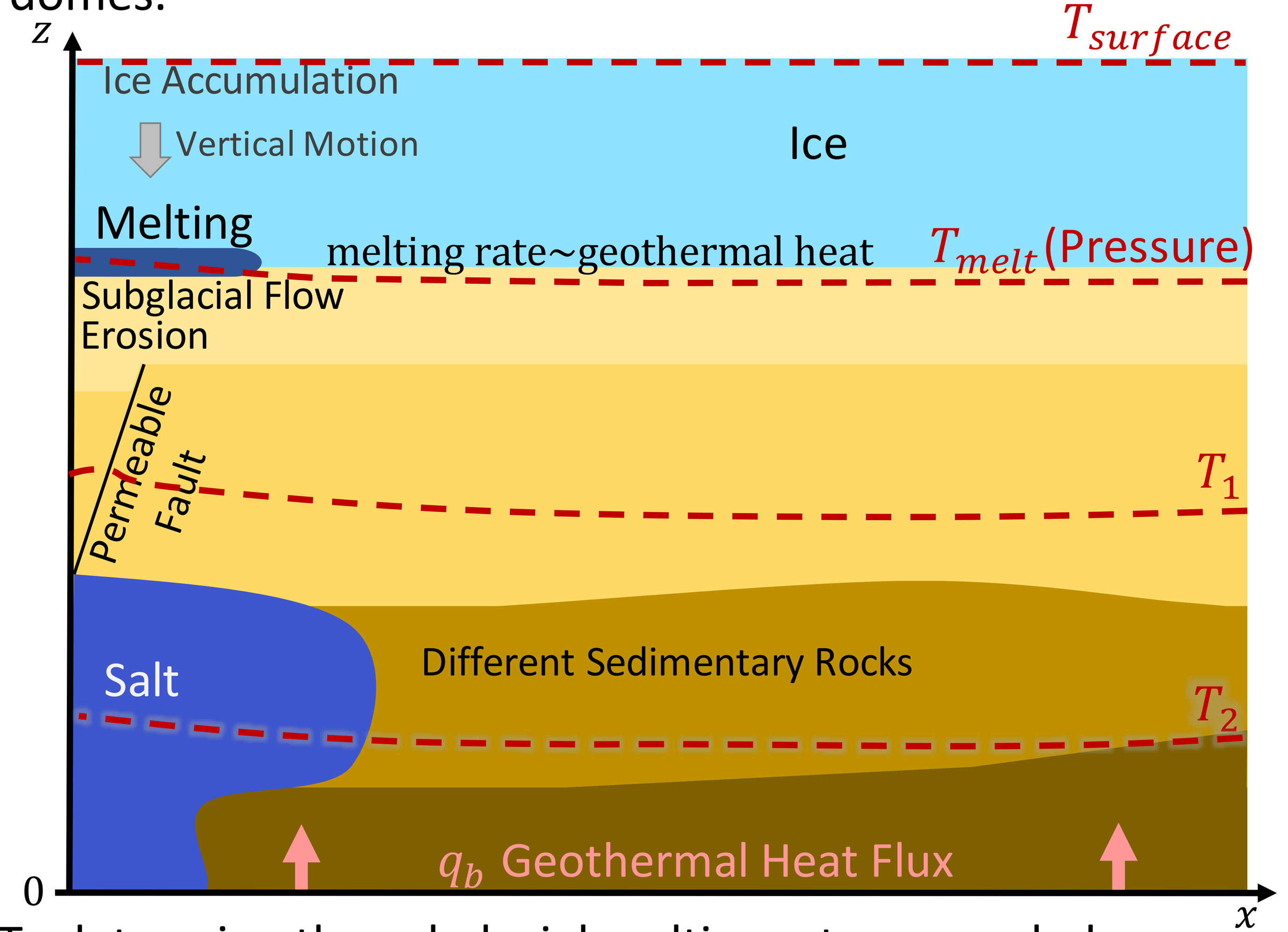
Tunnel valleys are a wide-spread phenomenon in the North German Basin. They can be more than 400 m deep, 100 km long and 4 km wide (Ó Cofaigh, 1996). Wenau and Alves (2020) study a mechanical relation between crestal faults, which usually overlie salt domes, and the formation of tunnel valleys. We investigate the additional role of the expected increase of the geothermal heat flux above salt domes.



To determine the subglacial melting rate, a coupled computational model comprising the heterogeneous subsurface, an overlying ice sheet and phase change processes at their interface is needed. The software SHEMAT-Suite (see Keller et al. (2020)) is used. The finite difference code originally developed by Clauser (2003) was expanded by Mottaghy and Rath (2006) with the apparent heat capacity method.

Heat.equation: $(\rho c)_a\, \partial_t T = \nabla \cdot (\lambda \nabla T - \rho\, c\, T\, v)$

Subglacial energy balance: $-\lambda_{ice}\, \nabla\, T|_{ice} = q_b + \rho_f\, L\, v$

T	Temperature	[K]
v	Velocity	[m / s]
q_z	Heat flux	[W / m²]
$(\rho c)_a$	Apparent heat capacity	[J / m³ K]

λ	Thermal conductivity	[W / (m K)]
ρ	Density	[kg / m³]
c	Heat capacity	[J / (kg K)]
L	Latent heat	[J / kg]

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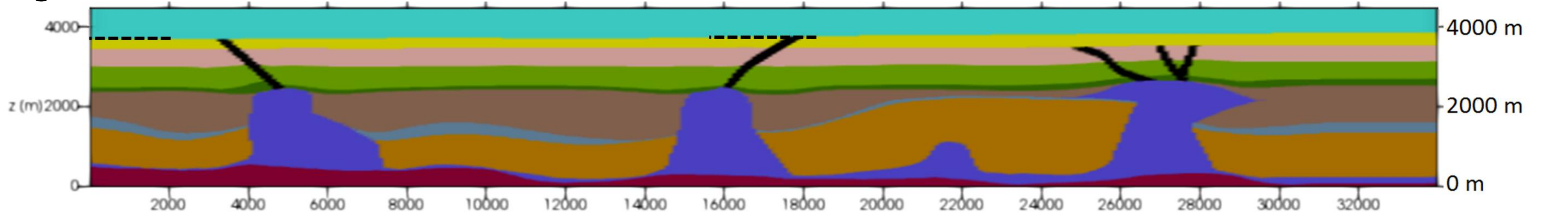
Case study: Southern North Sea

In the southern North Sea are three salt structures overlain by two tunnel valleys (indicated by stippled lines). To model the state during their formation before the Quaternary glaciations, the Quaternary strata are replaced by thicker Paleocene to Miocene strata. Following Magri et al. (2010), faults are modelled as equivalent porous media with thicknesses of 200 m. The temperature and the vertical heat flux through the subsurface-ice interface are slightly increased leading to a slightly higher melting rate.

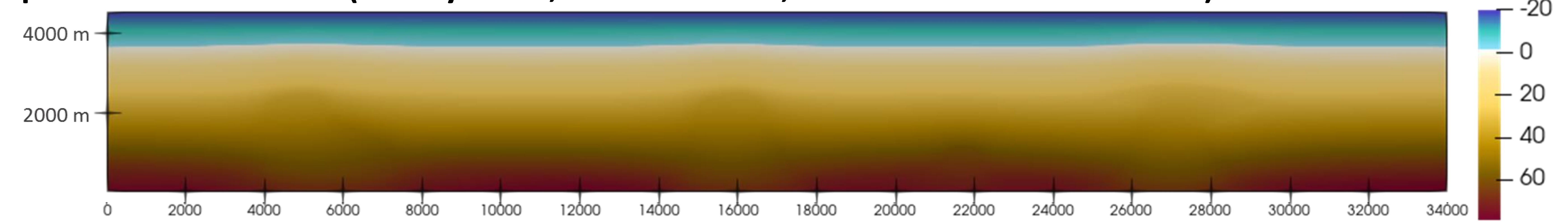
Geological model



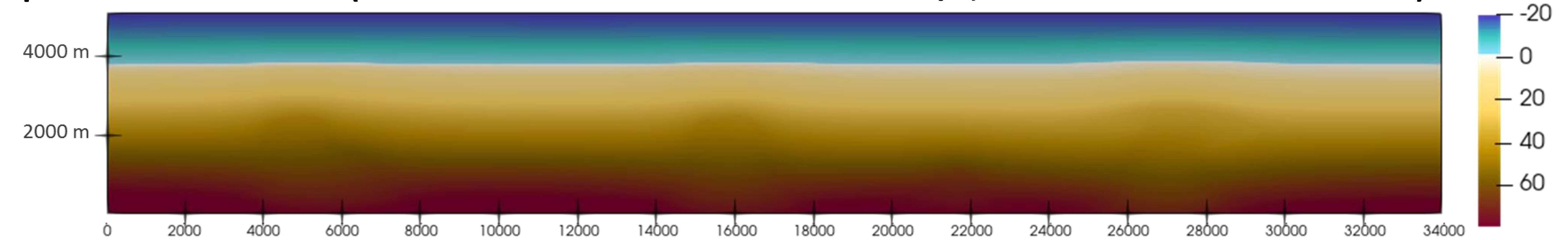
Unit	Ice Sheet	Fault Zones	Miocene	Tertiary	Upper Cretaceous	Lower Cretaceous	Triassic Keuper	Triassic Muschelkalk	Triassic Buntsandstein	Permian Zechstein-Salt	Pre-Zechstein
Porosity	100 %	4 %	0.1 %	0.1 %	6 %	6 %	10^{-7} %	10^{-7} %	4 %	10^{-7} %	3 %
λ [W/(mK)]	2.3	2.4	2.2	2.9	2.1	2.1	2.3	2.3	2.4	4.9	3.3

Thermal parameters adapted from Beha et al. (2008) and Evans (1977)

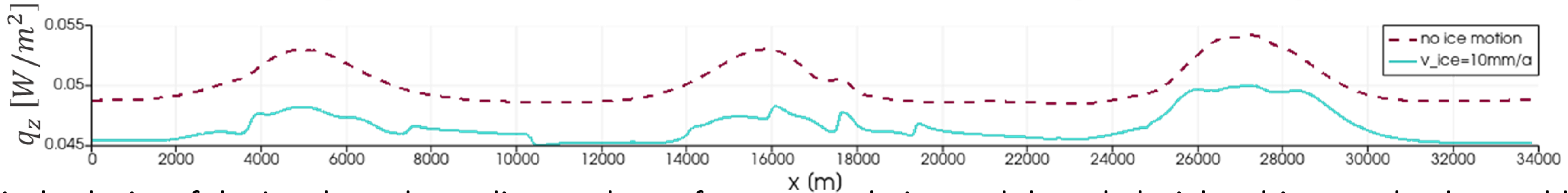
Temperature Distribution (Steady-State, No Ice Motion, Ice Sheet Thickness 680 m)



Temperature Distribution (Constant Vertical Ice Motion of 10 mm/a, Ice Sheet Thickness 1220 m)



Vertical Heat Flux Through the Subsurface-Ice Interface Above the Subglacial Melting (0 mm/a or 10 mm/a)



A vertical velocity of the ice sheet depending on the surface accumulation and the subglacial melting rate leads to colder temperatures within the ice sheet. As the ice sheet is obviously molten at some places, we assume the lower boundary of the ice sheet to be at melting temperature and adapt the ice sheet thickness accordingly. The surface temperature is constantly -20°C and the geothermal heat flux at the bottom 50 $\mathrm{mW/m^2}$. Right now, the ice motion (in the second model a constant vertical velocity of 10 mm/a) is still independently from the geothermal heat flux, but it will be coupled in a future step.

Summary and Outlook

We observe slightly increased geothermal heat fluxes above salt structures allowing to derive a local increase of melting rates. In the investigated scenarios (with and without idealized ice motion), this process not solely causes, but reinforces tunnel valley erosion. In a future study, we will include transient effects, investigate the hydrothermal convection and couple the melting rates to the computed heat fluxes.

Description	Characteristic Scales	Reference
Cycle length of ice ages	100 000 a (interglacials of 10 000 a)	Bick, 2006
Half life time of a thermal adaption to a change of $T_{surface}$	~12 000 a (in 1000 m depth)	-
Ice sheet thickness	300 – 1700 m	Sachse and Littke, 2018
Surface air temperature (winter)	-40 – -30 °C	Colleoni et al., 2009
Surface air temperature (summer)	-10 – -2°C	Colleoni et al., 2009
Mean annual accumulation at surface	300 – 800 mm/a	Colleoni et al., 2009
Peclet number of ice	< 40	-
Meltwater to erode tunnel valleys	~10^8 m³/a	Beaud et al., 2018

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