The thermal regime of continental margins

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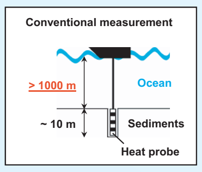
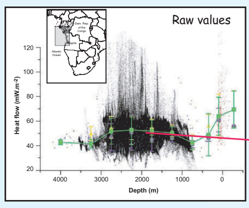
1) Introduction

Conventional measurements of heat flow at sea using a short probe cannot be performed in shallow waters, consequently few measurements exist on continental margins

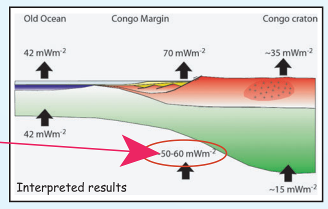


Sparse evidence of "anomalous" thermal regime on some margins:

For example on the Congo margin:



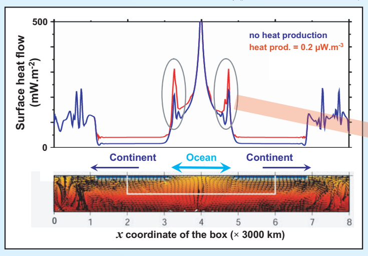
from Lucazeau et al. (2004)



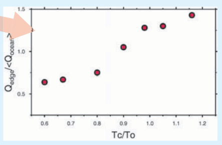
Locally high mantle heat flow on margin!

Numerical simulations of mantle convection including continental roots

from Claire Perry (personnal communication, 2004)



Apparition of an anomaly depending on the contrast of temperature between ocean and continent, at the base of the continental root:



More data are needed...

Oil wells are **deep enough** to reach zones undisturbed by seasonal variations of temperature

Oil exploration is or has been active on numerous margins

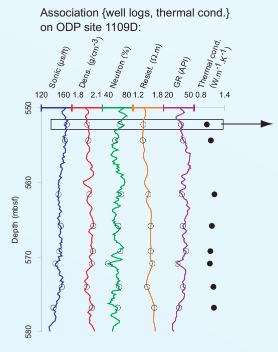
Results from deep offshore wells can be compared to conventional measurements

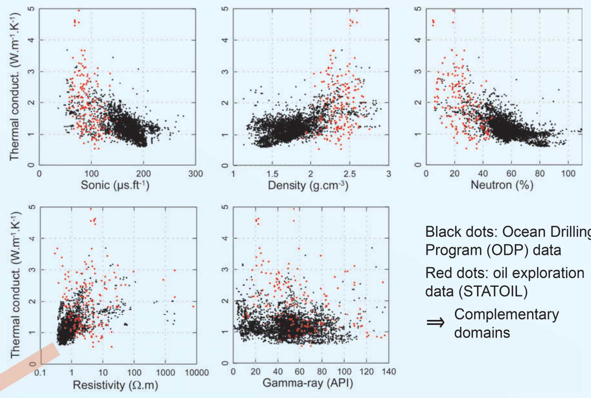
⟹ Let's see more about thermal conductivity and temperatures from oil exploration data

2) Thermal conductivity from geophysical well logs (Goutorbe et al., 2006)

Construction of a comprehensive data set of {well logs, thermal conductivity measurement}

Association {well logs, thermal cond.} on ODP site 1109D:





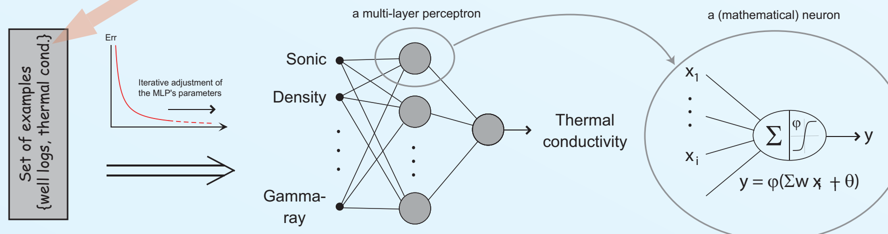
Black dots: Ocean Drilling Program (ODP) data

Red dots: oil exploration data (STATOIL)

⟹ Complementary domains

4700 examples {well logs, thermal conductivity} from 90 ODP sites + 65 oil exploration boreholes, covering numerous lithological contexts

Using neural networks to predict thermal conductivity from geophysical well logs



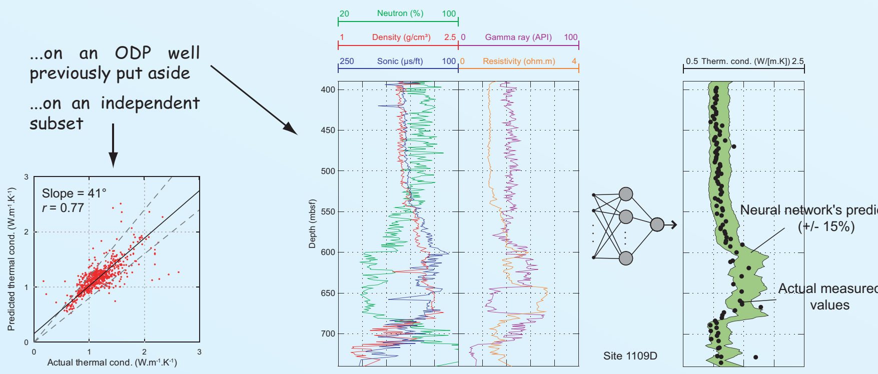
used to train a multi-layer perceptron (MLP)... (special type of neural network)

...because MLP are universal approximators (Cybenko, 1989).

Predictions' performances of the neural network...

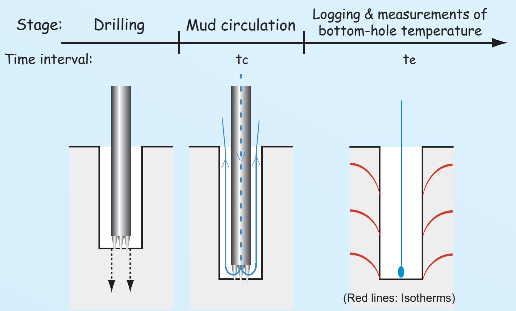
...on an ODP well previously put aside

...on an independent subset

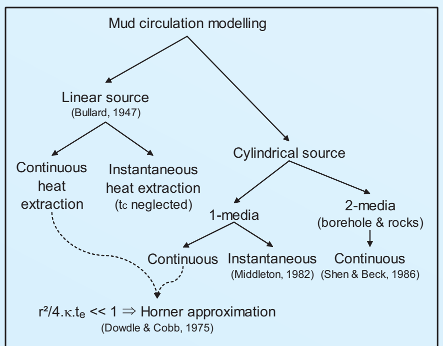


A ~15% level of confidence can be expected from the neural networks' predictions

3) Insights into temperature corrections



⟹ Temperature measurements must be corrected from the cooling effect of mud circulation:



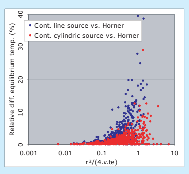
Correction is possible if at least 2 bottom-hole temperatures have been measured at different times te.

There are several ways to model the effect of mud circulation:

- radius can be neglected (linear source) or not (cylindrical source)
- circulation time tc can be neglected (instantaneous heat extraction) or not (continuous heat extraction)
- contrast of thermal properties borehole's mud / rocks can be neglected (1-media) or not (2-media)
- and finally the well-known Horner correction is a first order development of the "continuous" corrections

➡ Comparison of corrections... we had the opportunity to compare the corrections on a very large Australian data set (~500 boreholes, 2600 temperatures)

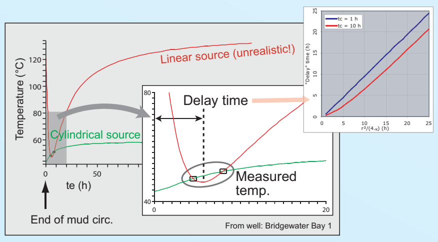
As expected, the extrapolations of the Horner correction and its parent models diverge as $r^2/4\kappa t_e$ approaches 1



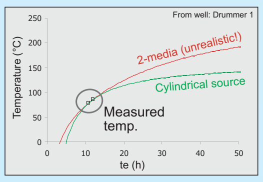
Linear source models can lead to unrealistic results because of a 'delay time' t_d after the end of mud circulation.

The correction fails when a temperature has $t_e < t_d$. As $t_d \sim r^2/4\kappa$, linear source models cannot be applied for $r^2/4\kappa t_e > 1$.

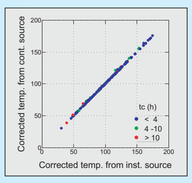
This means that linear source models don't necessarily have a wider application domain than the Horner correction.



2-media models are not robust on low-quality data:



Instantaneous and continuous models give similar results:



Our preferred model is the cylindrical source, 1-media model

The instantaneous version (Middleton, 1982) is simpler, and gives the same results as the continuous version

4) Application to South Africa and Australia

South Africa

Acquisition of well logs and well completion reports (WCR) from Petroleum Agency of South Africa

Thermal conductivity: application of neural networks on well logs

Temperatures: already corrected in WCR

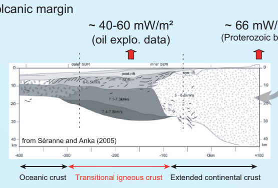
Western margin (Orange basin)

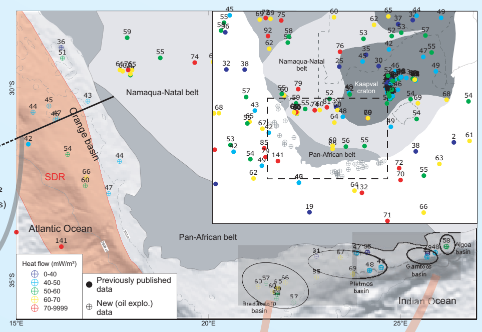
Extension Late Jurassic - early Cret.
Oldest magnetic anomaly: M4 (127 Ma)
Volcanic margin

Heat flow = 40-60 mW/m²

Most of the wells are located on (or near) the transitional igneous crust domain

Thermal regime is perhaps representative of old oceanic lithosphere





Southern margin

Few studies of the deep crustal structure
Complex structure
Basement uplifted and arched (?)

High values on the western part: 60-70 mW/m²

Low values on the eastern part: 40-50 mW/m²

...more information on the nature of the crust, the deep structure of the margin, etc., are needed for correct interpretation (variations in mantle heat flow, in crustal or sediments heat production, heat refraction...).

Australia

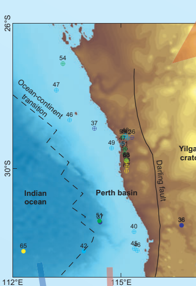
Acquisition of well logs and temperatures from Wiltshire Geological Survey

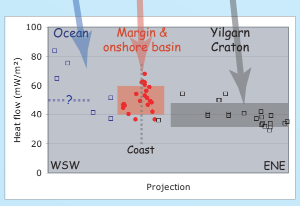
Thermal conductivity: from well logs

Temperatures: corrected using the Middleton (1982) model

Western margin (Perth Basin)

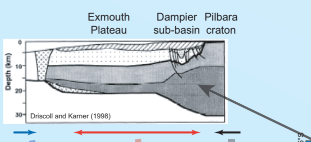
Extensions from Permian to Early Cret.
Breakup during Valanginian (135 Ma)
Crustal stretching factor β?



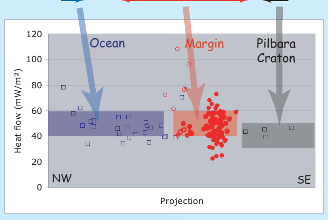


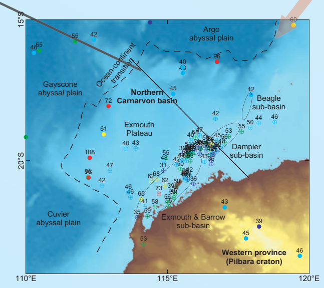
Western Province: 40 ± 8 mW/m²
Western margin: 50 ± 10 mW/m²

Northwestern margin (Nortern Carnarvon Basin)



Extensions from Late Permian to Early Cret.
Breakup 150-130 Ma
Volcanic margin
β ~ 1.5 (shelf) to 3 (OCT)

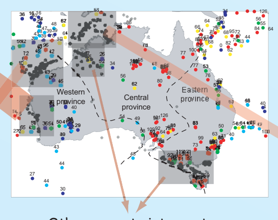




Western Province: 40 ± 8 mW/m²
Northwestern margin: 50 ± 10 mW/m²
Ocean: 50 ± 10 mW/m²

Thermal regime of the passive margins bordering the Western (Archean) province:

- old ocean regime? But it is a continental domain...!
- extended crust -> if identical crustal heat production, heat flow should be less than on craton!
-> radiogenic elements in sediments?
-> or higher mantle heat flow?

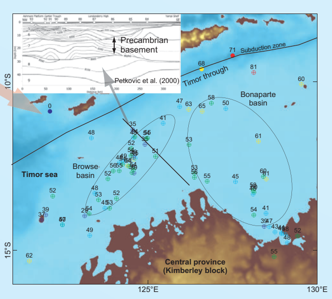


Other areas to interpret...

Margins from different contexts have, on the average, surprisingly similar heat flow.

On the other hand, we haven't studied local variations in detail.

Southern margin (Browse, Bonaparte basins)



NW-SW extension from Late Devonian to Carboniferous (-> Bonaparte basin)

NW-SE extension from Early Permian to Late Jurassic (-> Browse basin)

Breakup ~155 Ma

5-6Ma: collision Australia-Eurasia, subduction

β ~2.6

Heat flow decrease from 80 20 mW/m² on the Central province to 40-60 mW/m² on the margin

-> explained by decrease in radogenic contribution due to crustal thinning?

Conclusion and perspectives

- A method for estimating thermal conductivity from well logs has been set up
- Several models for bottom-hole temperatures' correction have been analyzed
- ➡ Oil exploration data are being processed to quantify the thermal regime of several continental margins
- Heat flow has been found to be ~ 40-60 mW/m² on a number of diferent margins
- Interpretations should be made in the frame of the geological framework, as well as the particular transitional situation of continental margins
- Numerical simulations of mantle convection with continental roots to be performed

References