Tectonic heat flow modelling for basin maturation: method and applications

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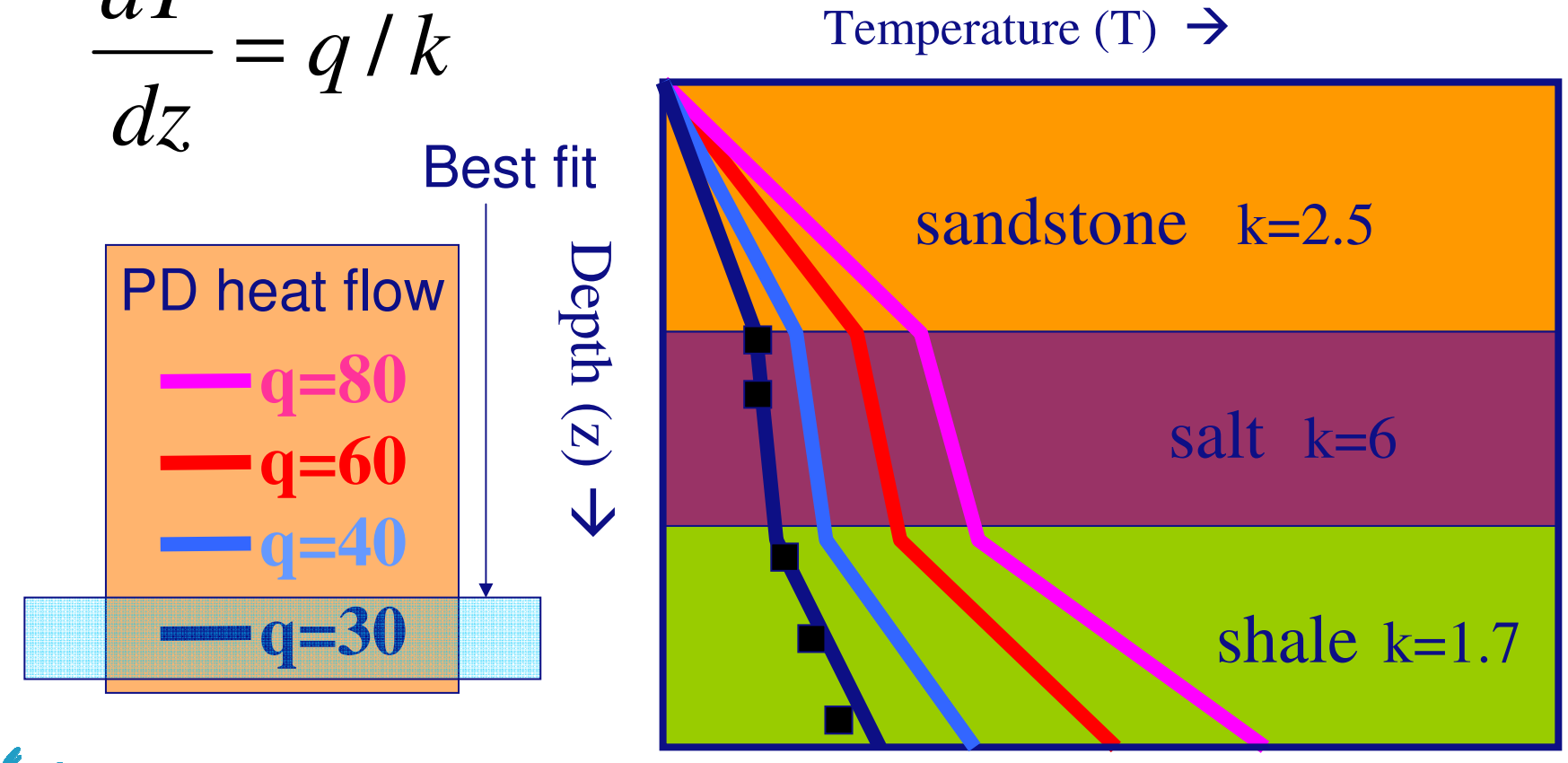
Content

- Definition of tectonic heat flow
- Workflow
- Added value of tectonic heat flow

- Tectonic models for the Netherlands
  - West Netherlands Basin
  - Netherlands Antilles
  - Terschelling Basin
  - Variscan Foreland evolution

Heat flow (**q**) relates to the temperature gradient. Present day (PD) Temperature data (■) in wells can be directly related to (**q**)

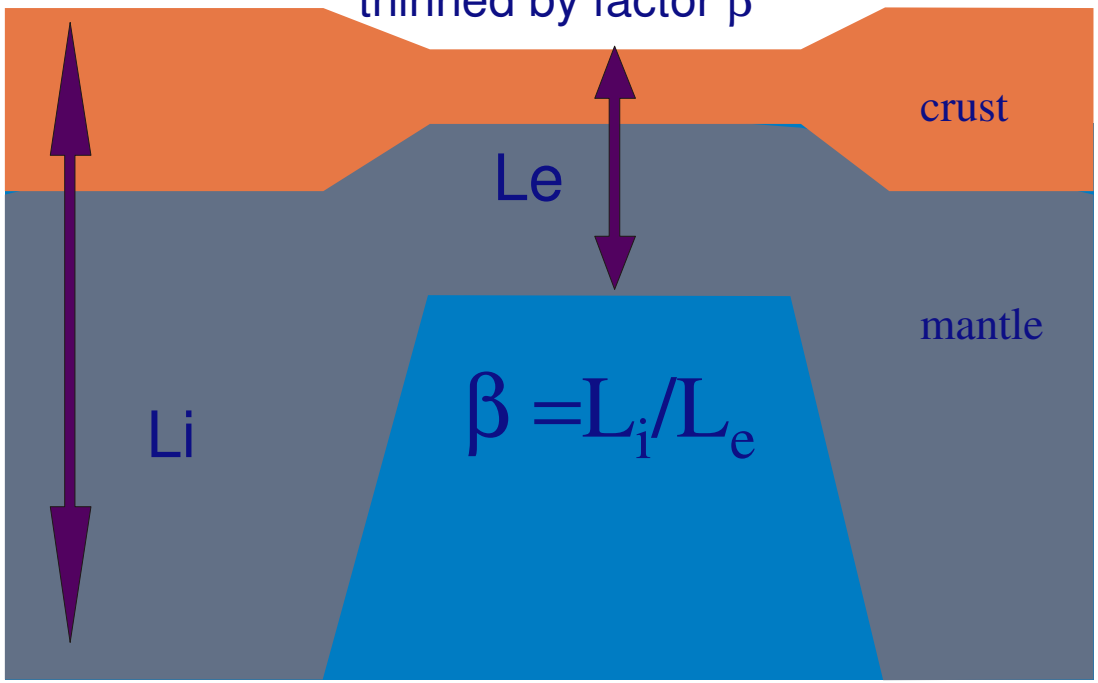
$$\frac{dT}{dz} = q / k$$

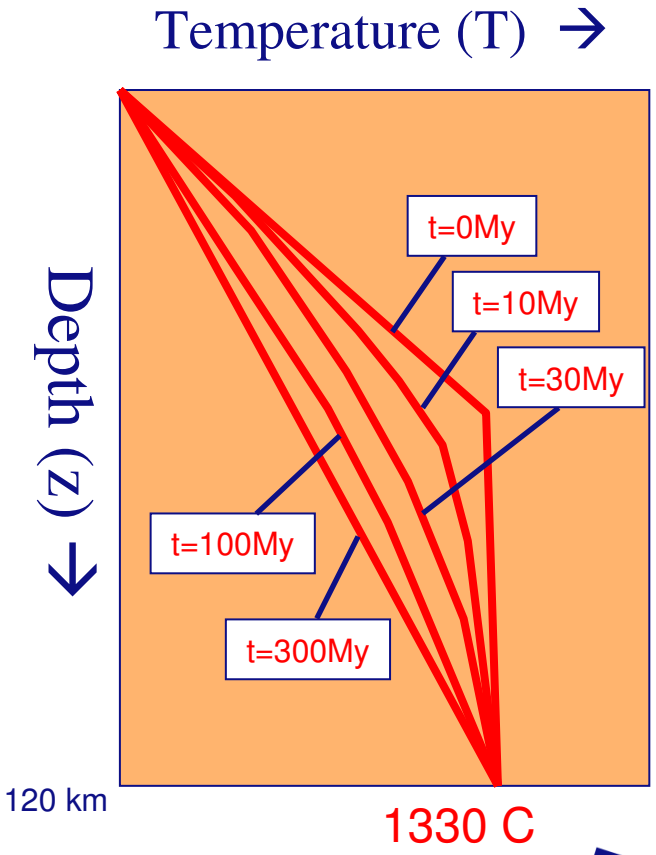


tectonic heat flow is calculated from the temperature gradient in the top of the numerical kinematic models, which predict temperature effects of lithosphere deformation.

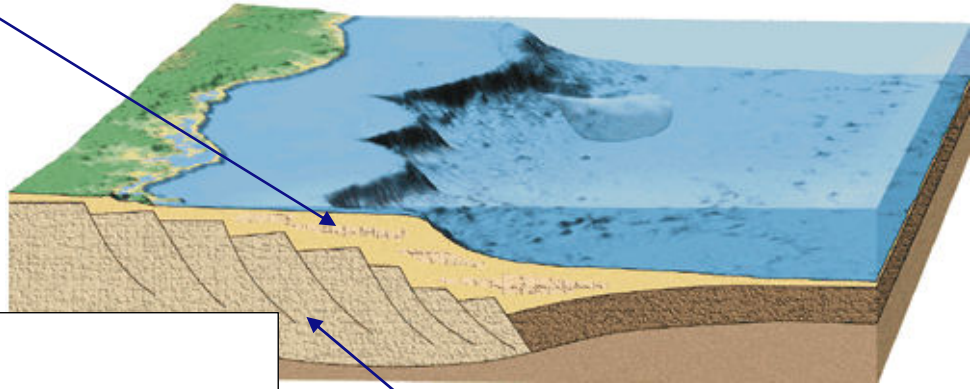
The 1D McKenzie Model (1978) is a classic for continental lithosphere extension (rifting)

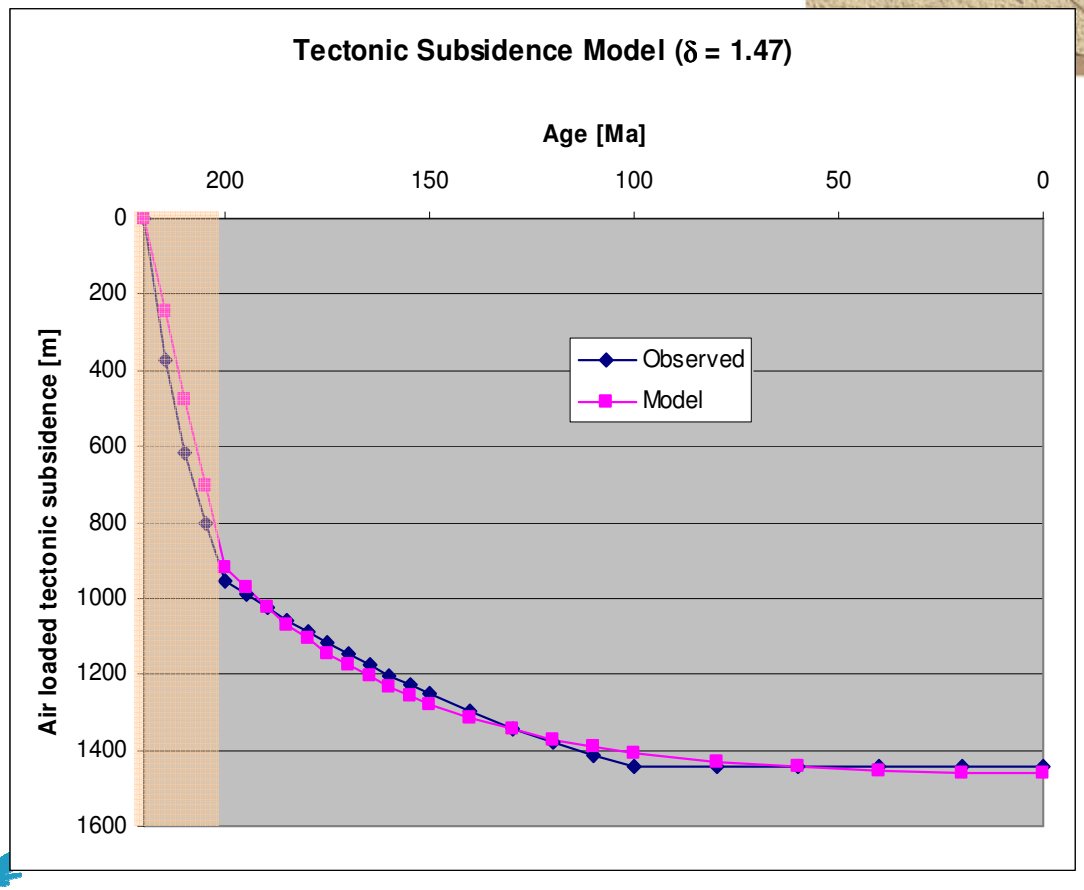
McKenzie model: lithosphere (Li) is instantaneously thinned by factor β





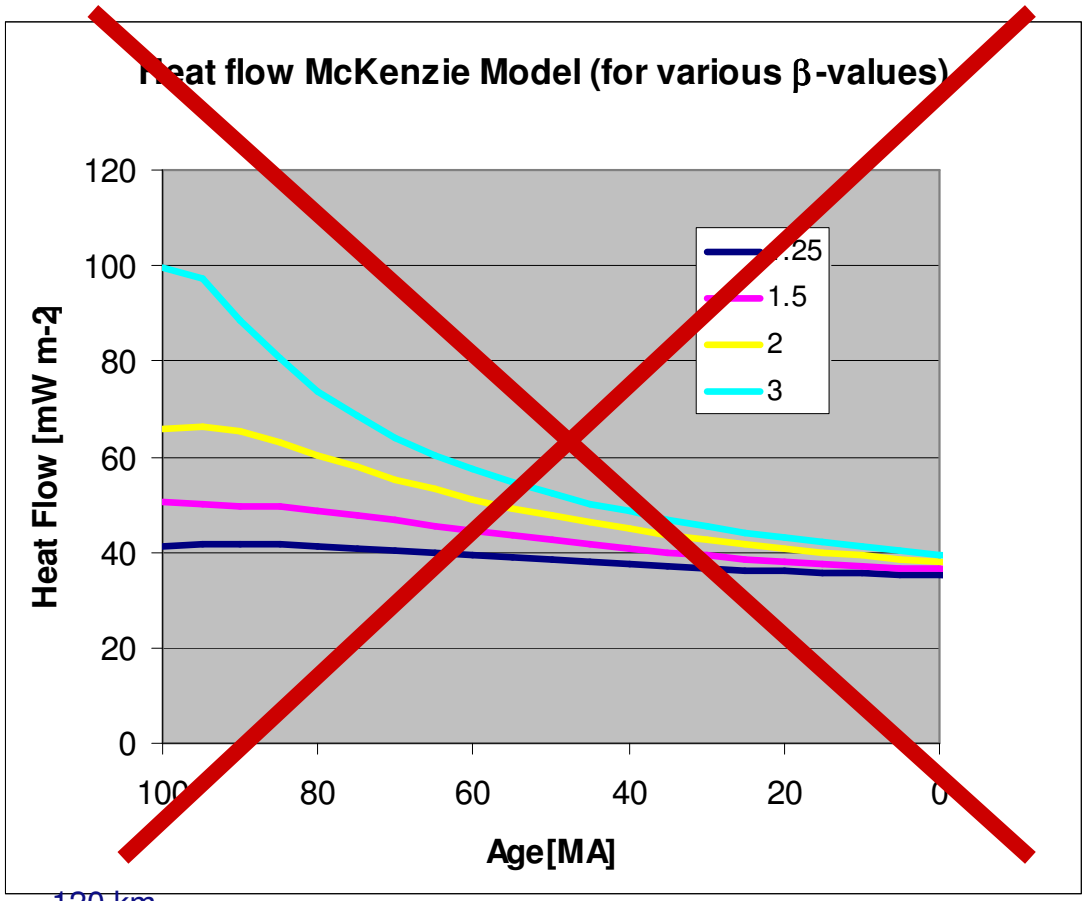
Sediment record:
Burial history-
observed mass deficit





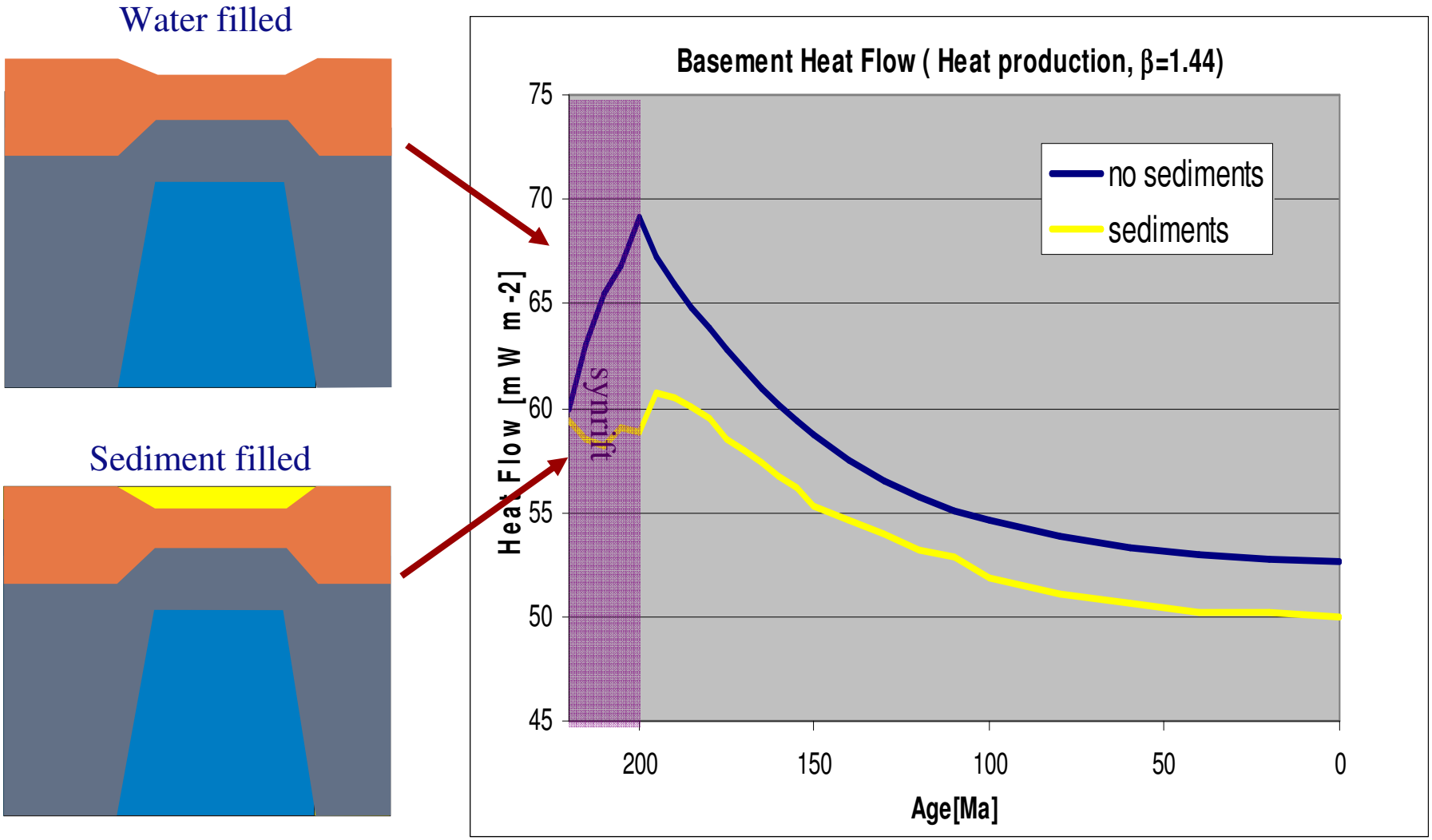
Tectonics:
Lithosphere extension –
Predicted Mass surplus

For the McKenzie model a very simple analytical solution for the heat flow exist (McKenzie, 1978)



McKenzie heat flow
No Good:

- No crustal heat production
- No sediment infill



Heat Flow Model, stretching (β=1.44)

Van Wees and Beekman, 2000

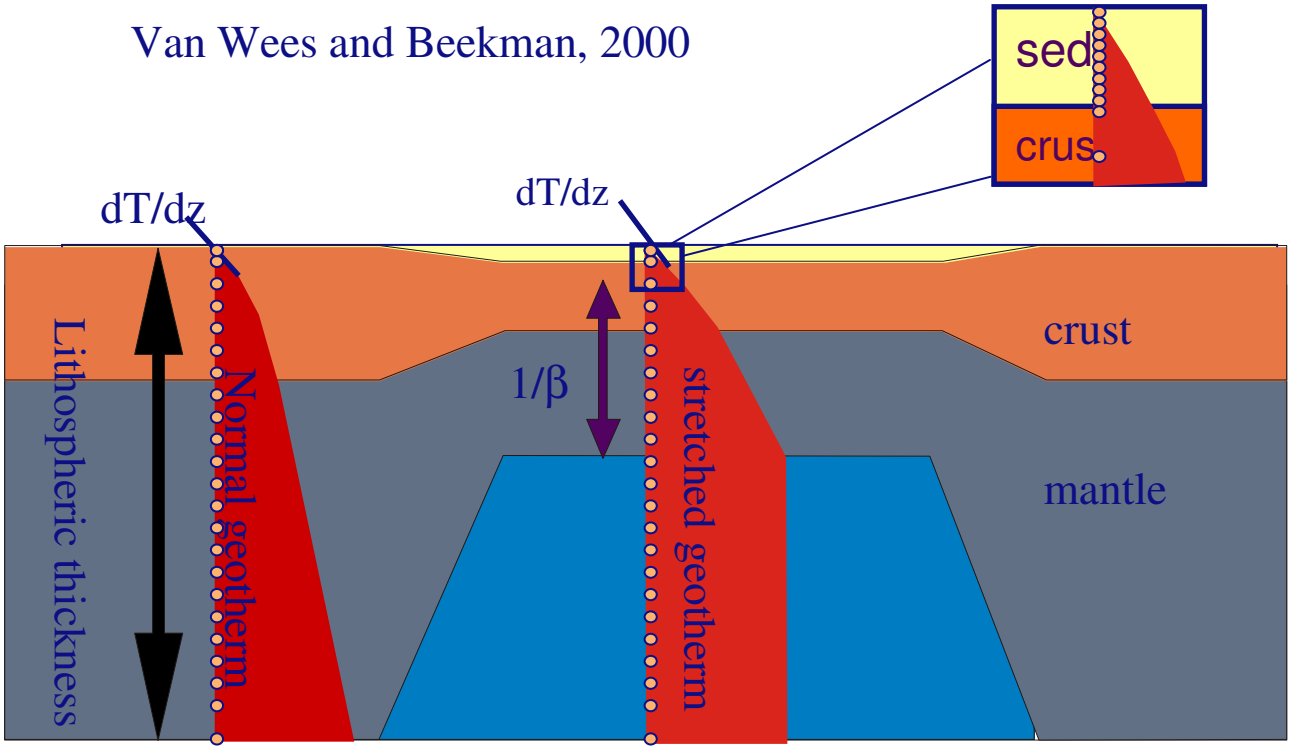
Subsidence Inversion
– tectonic heat flow

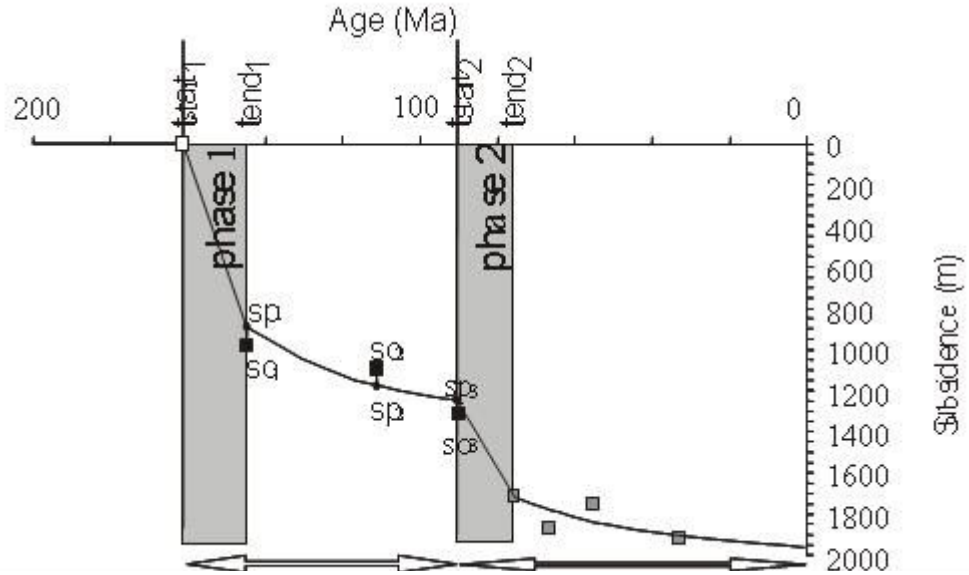
Tectonic Subsidence curve

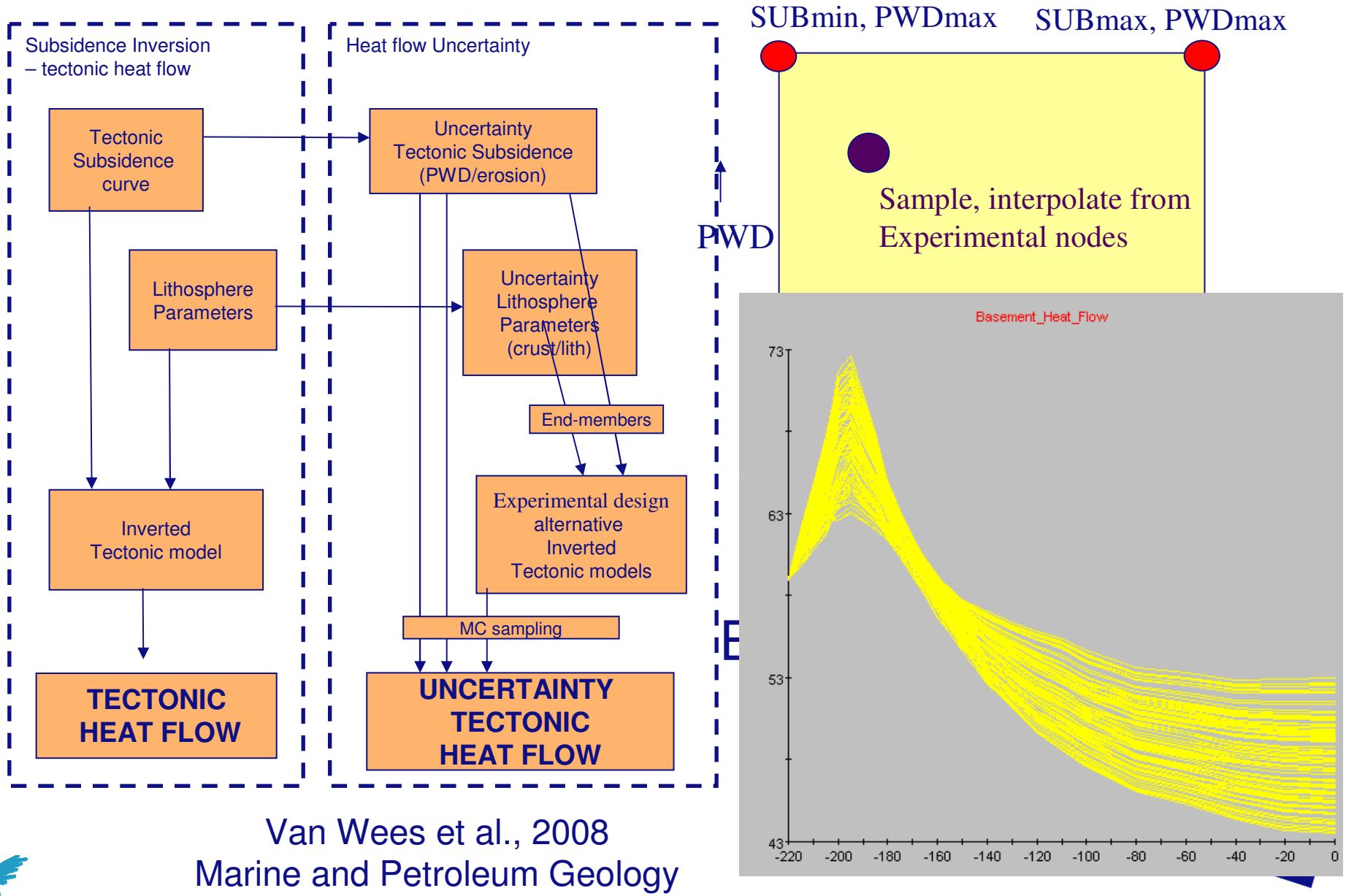
Lithosphere Parameters

Inverted Tectonic model

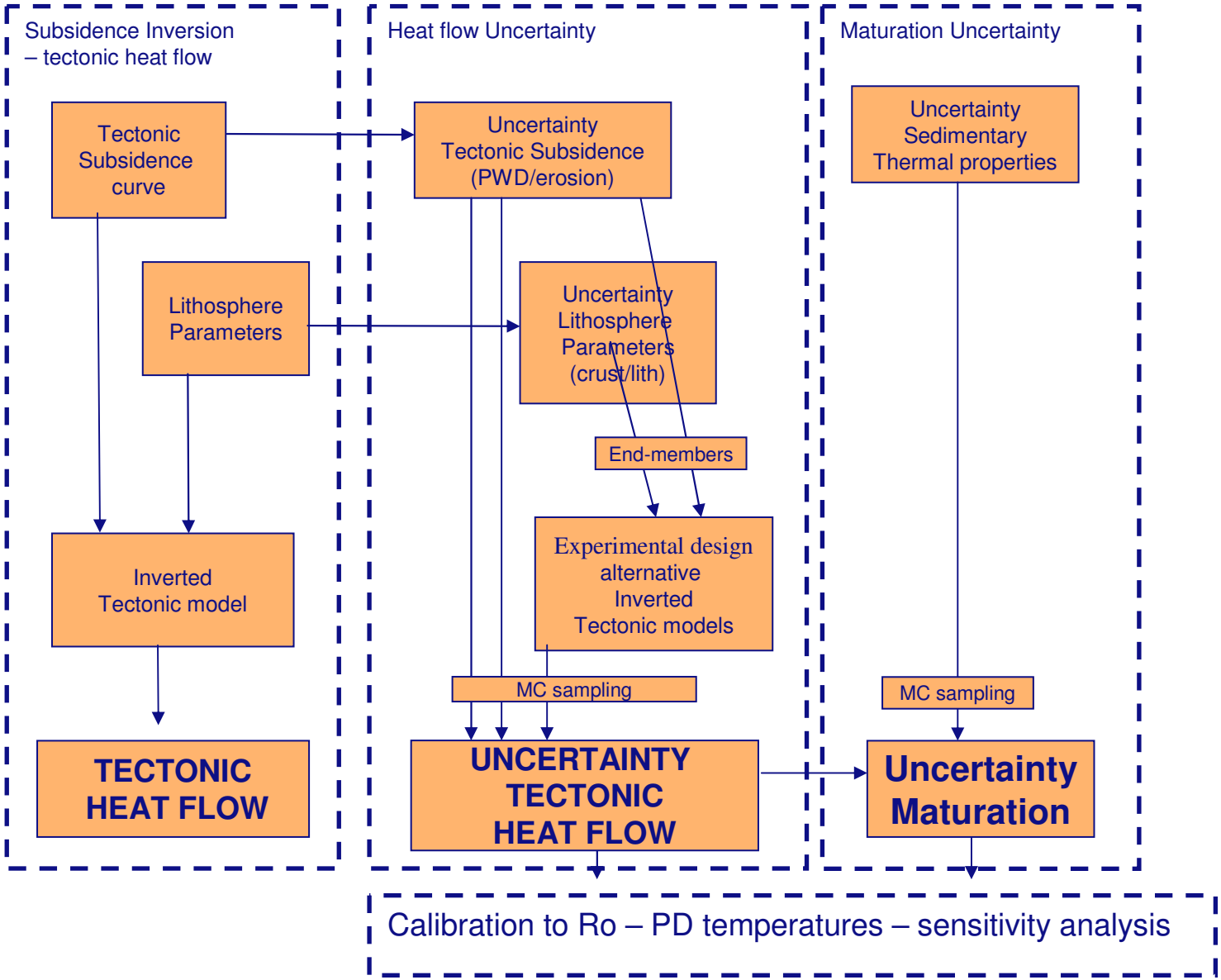
TECTONIC HEAT FLOW



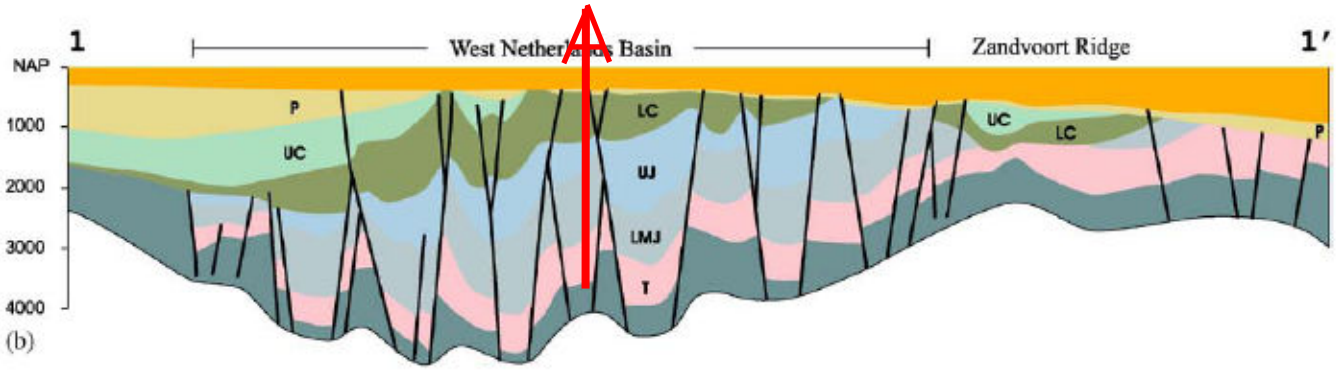




Van Wees et al., 2008
Marine and Petroleum Geology


Subsidence Inversion
– tectonic heat flow
Tectonic Subsidence curve
Lithosphere Parameters
Inverted Tectonic model
TECTONIC HEAT FLOW
Heat flow Uncertainty
Uncertainty Tectonic Subsidence (PWD/erosion)
Uncertainty Lithosphere Parameters (crust/lith)
End-members
Experimental design alternative Inverted Tectonic models
MC sampling
UNCERTAINTY TECTONIC HEAT FLOW
Maturation Uncertainty
Uncertainty Sedimentary Thermal properties
MC sampling
Uncertainty Maturation
Calibration to Ro – PD temperatures – sensitivity analysis

West Netherlands Basin – WAS-2



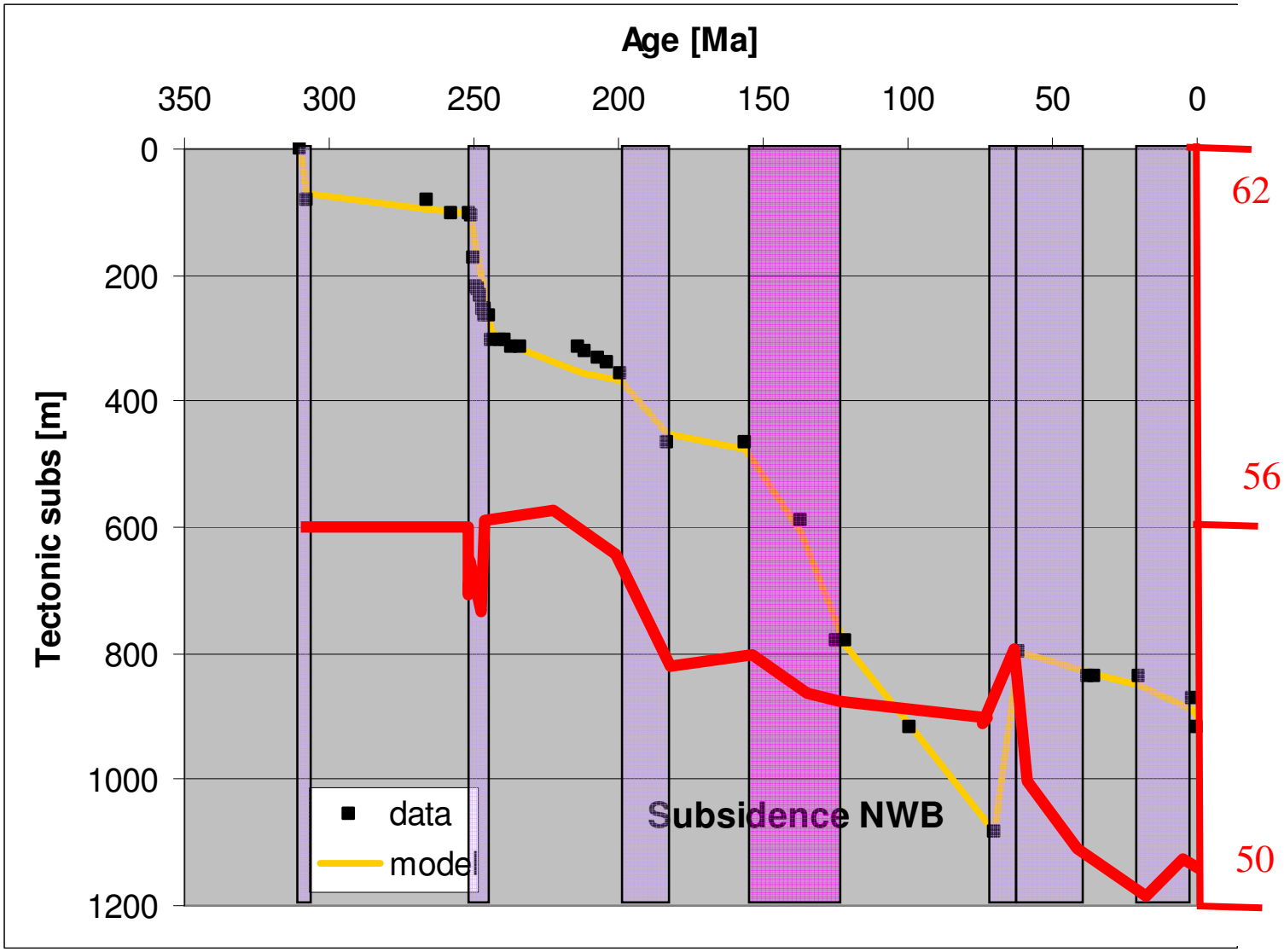
A priori Uncertainty

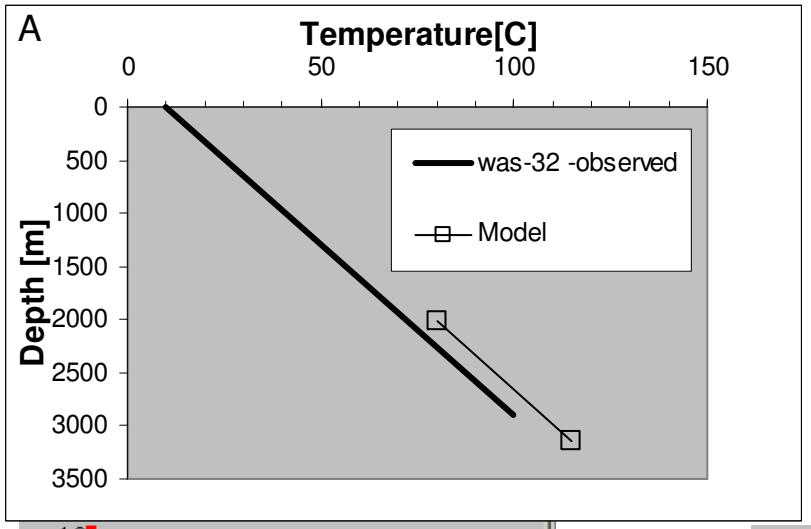
- **Lithospheric thickness 90-130 km**
- **Erosion during Late Cretaceous Inversion 500-1500 m**
- **Porosity depth curves → sediment conductivity**

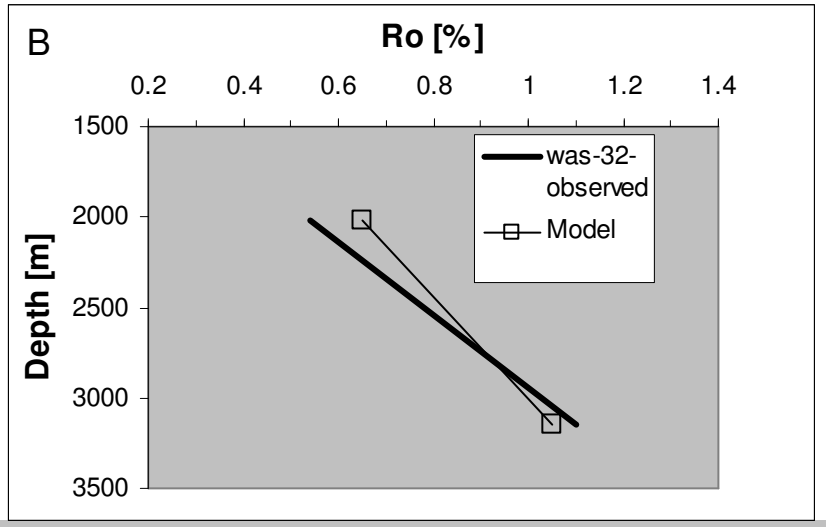
Calibration

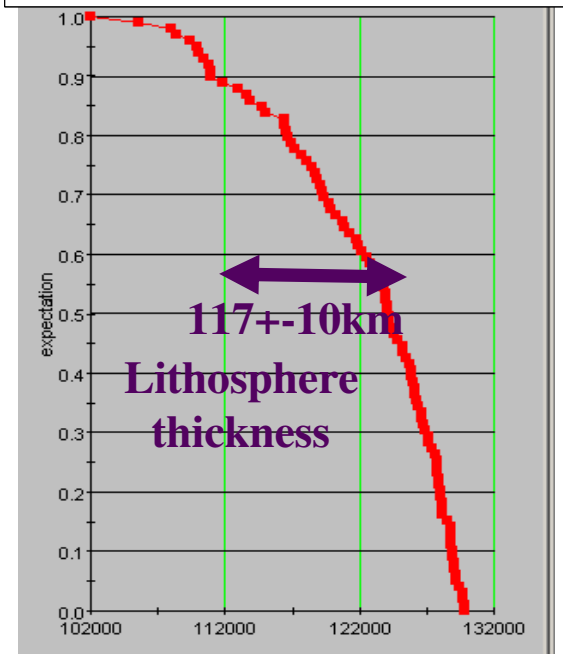
- **Ro depth trend**
- **PD temperature gradient**

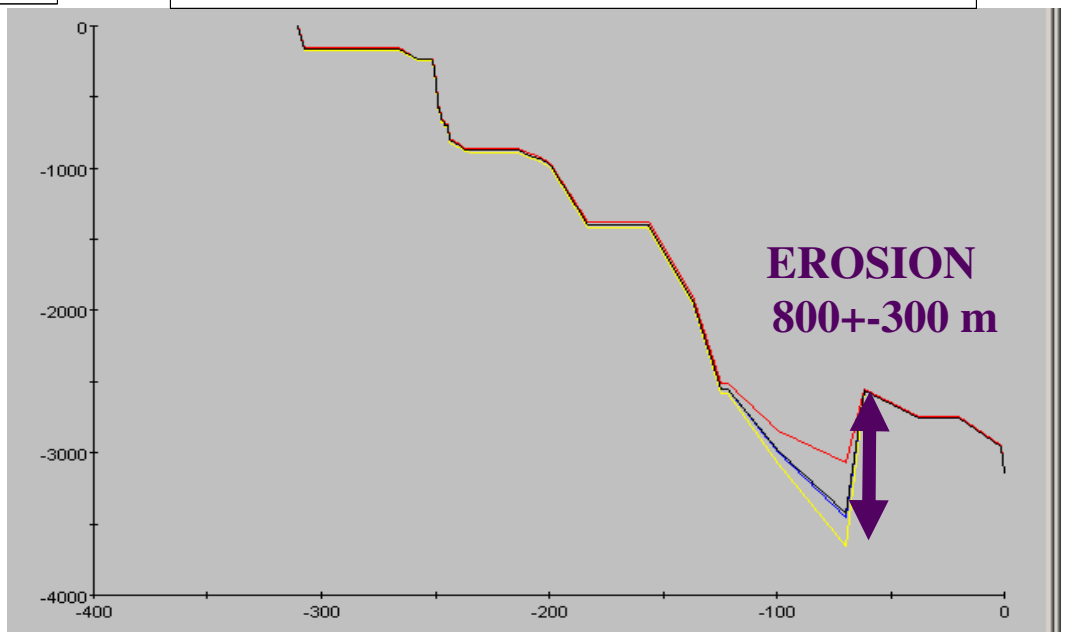
-

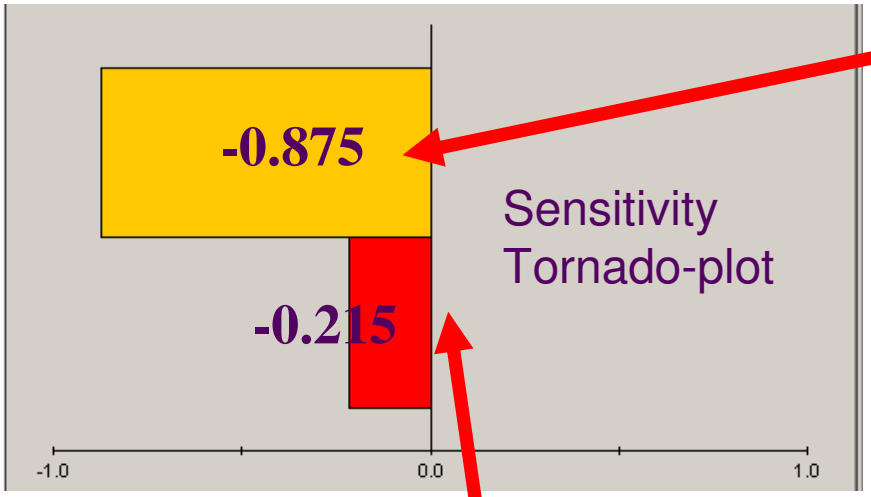

Age [Ma]
350
300
250
200
150
100
50
0
Tectonic subs [m]
0
200
400
600
800
1000
1200
data
mode
Subsidence NWB
62
56
50


A
Temperature[C]
0
50
100
150
0
500
1000
1500
2000
2500
3000
3500
Depth [m]
was-32 -observed
Model

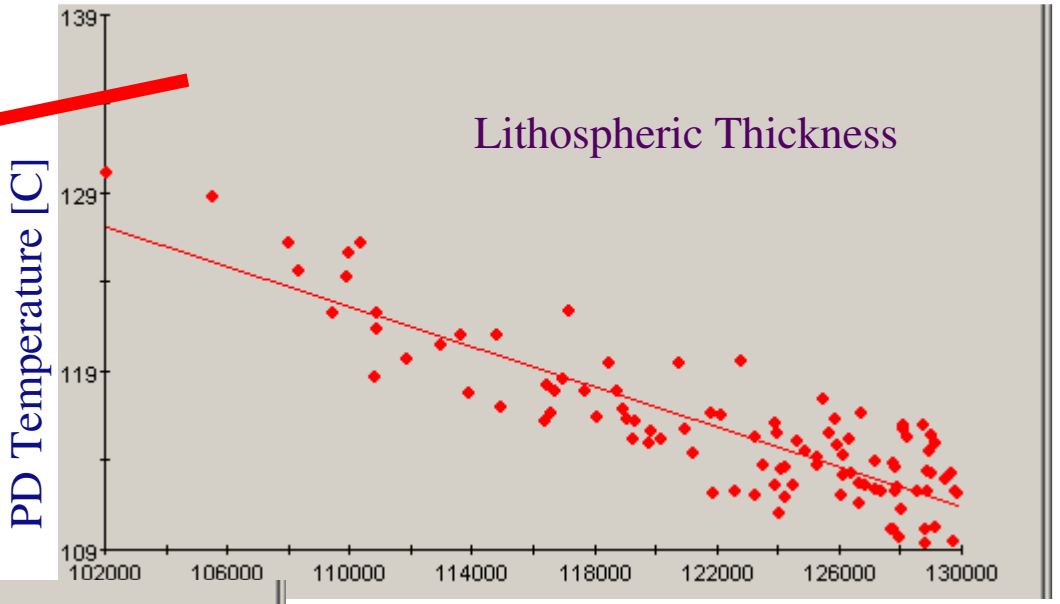

B
Ro [%]
0.2
0.4
0.6
0.8
1
1.2
1.4
1500
2000
2500
3000
3500
Depth [m]
was-32-observed
Model


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
expectation
102000
112000
122000
132000
117+-10km
Lithosphere
thickness

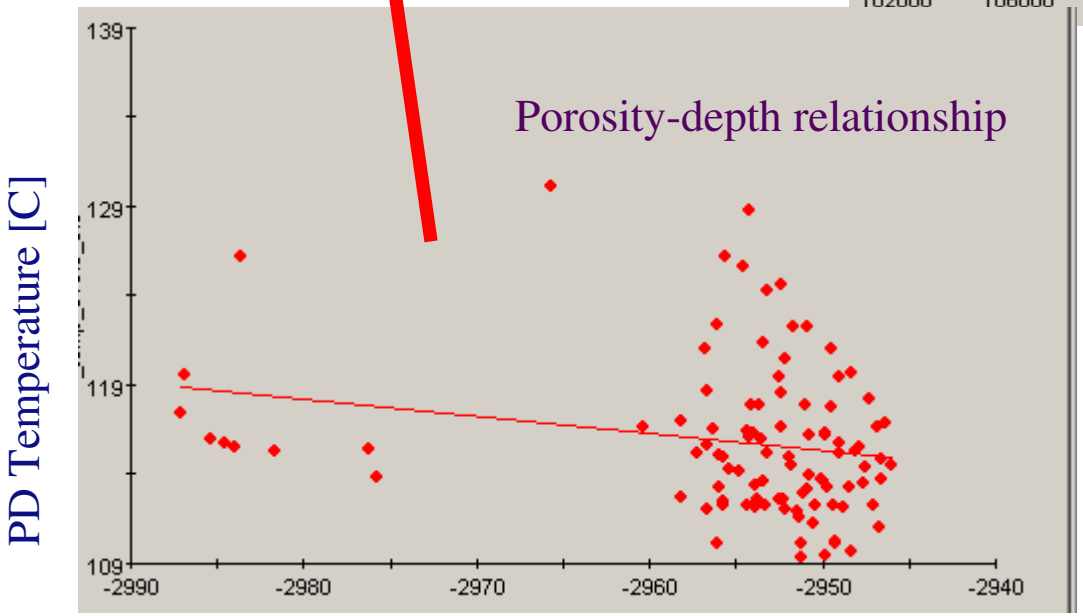

0
-1000
-2000
-3000
-4000
-400
-300
-200
-100
0
EROSION
800+-300 m



Sensitivity Tornado-plot



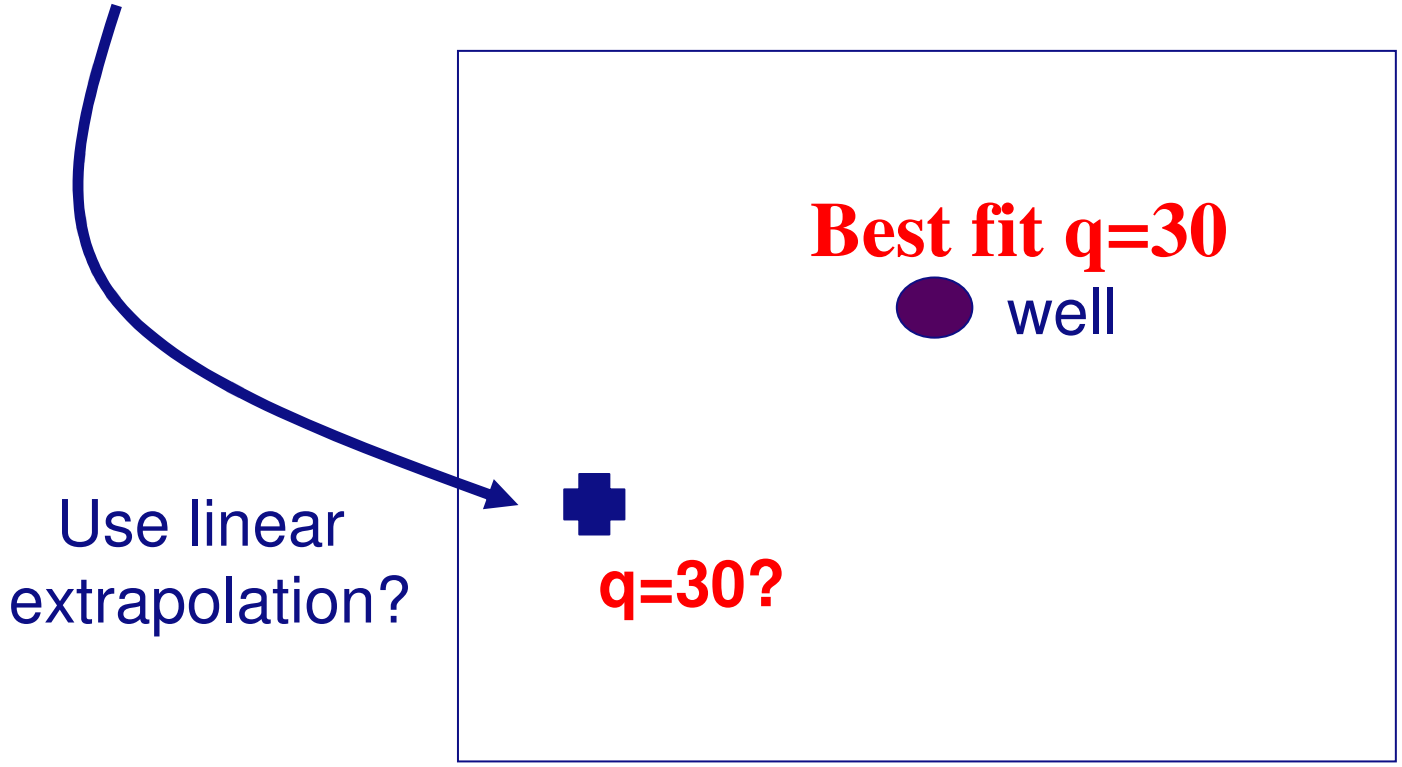
Lithospheric thickness [m]



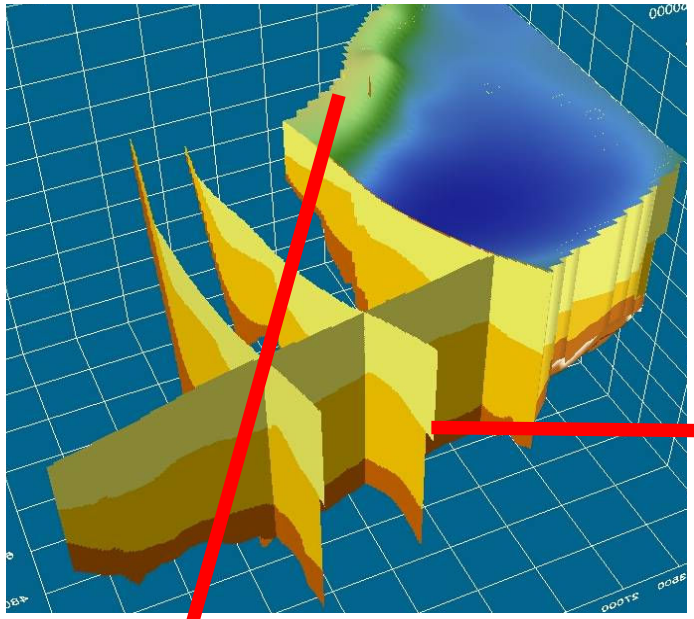
Porosity-depth / subsidence 1.7 Ma [m]

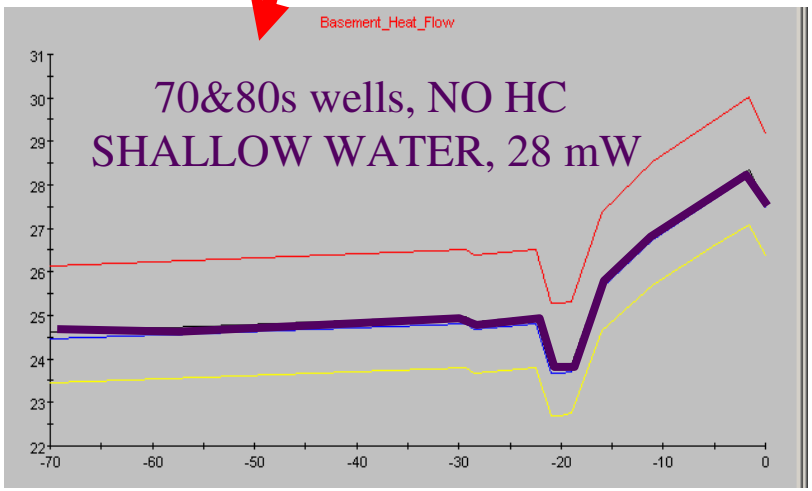
Added value of tectonic heat flow modeling

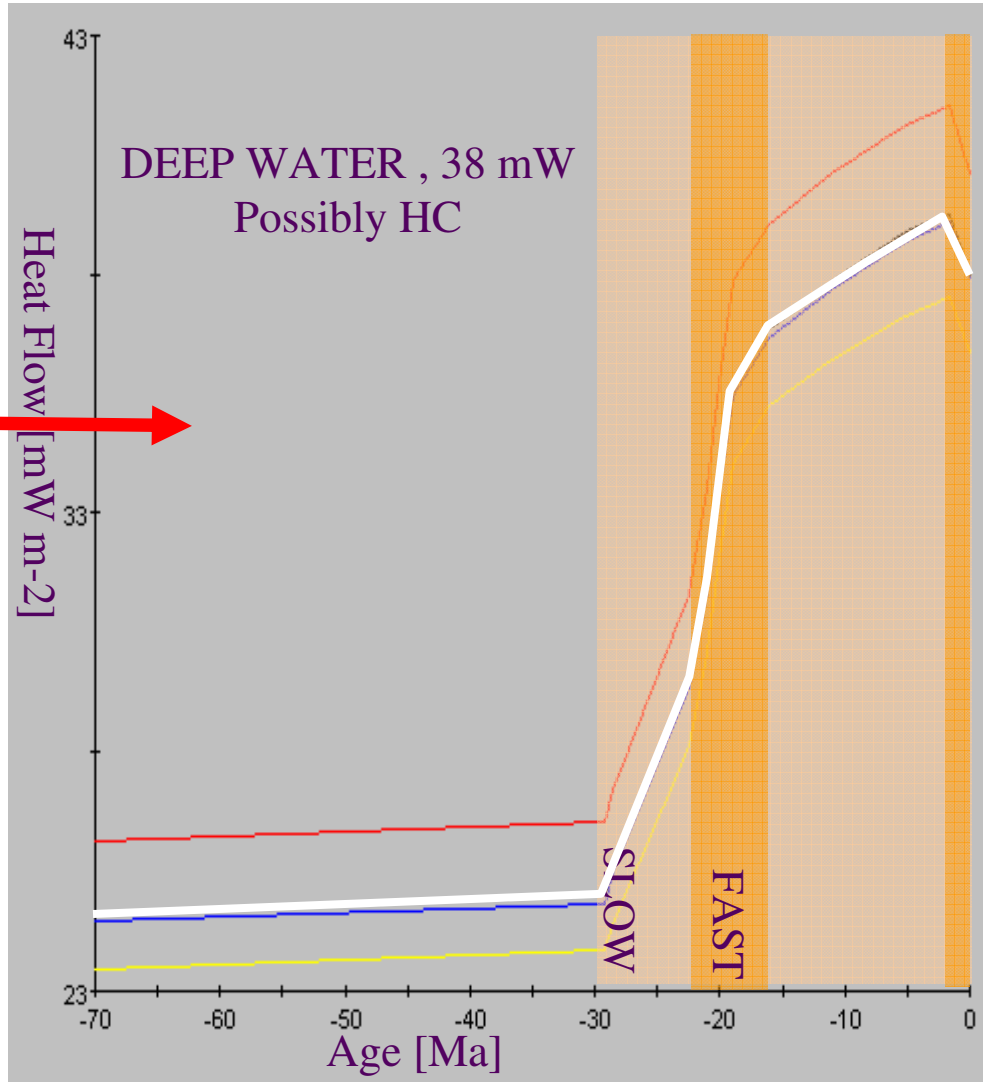
- 3D Basin Modeling: How to predict heat flow away from wells?



Netherlands Antilles



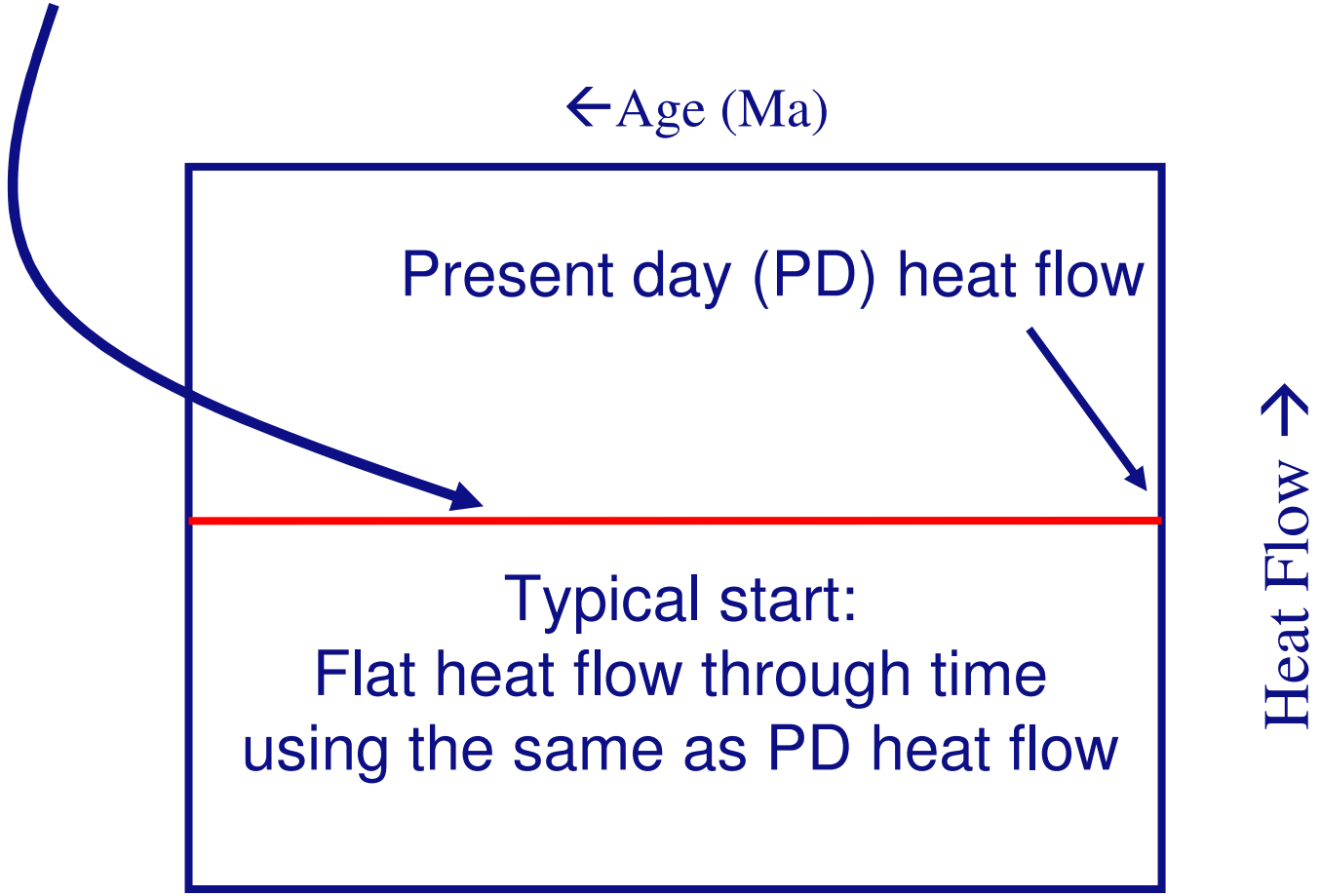




Van Wees et al., 2008 – Marine and Petroleum Geology

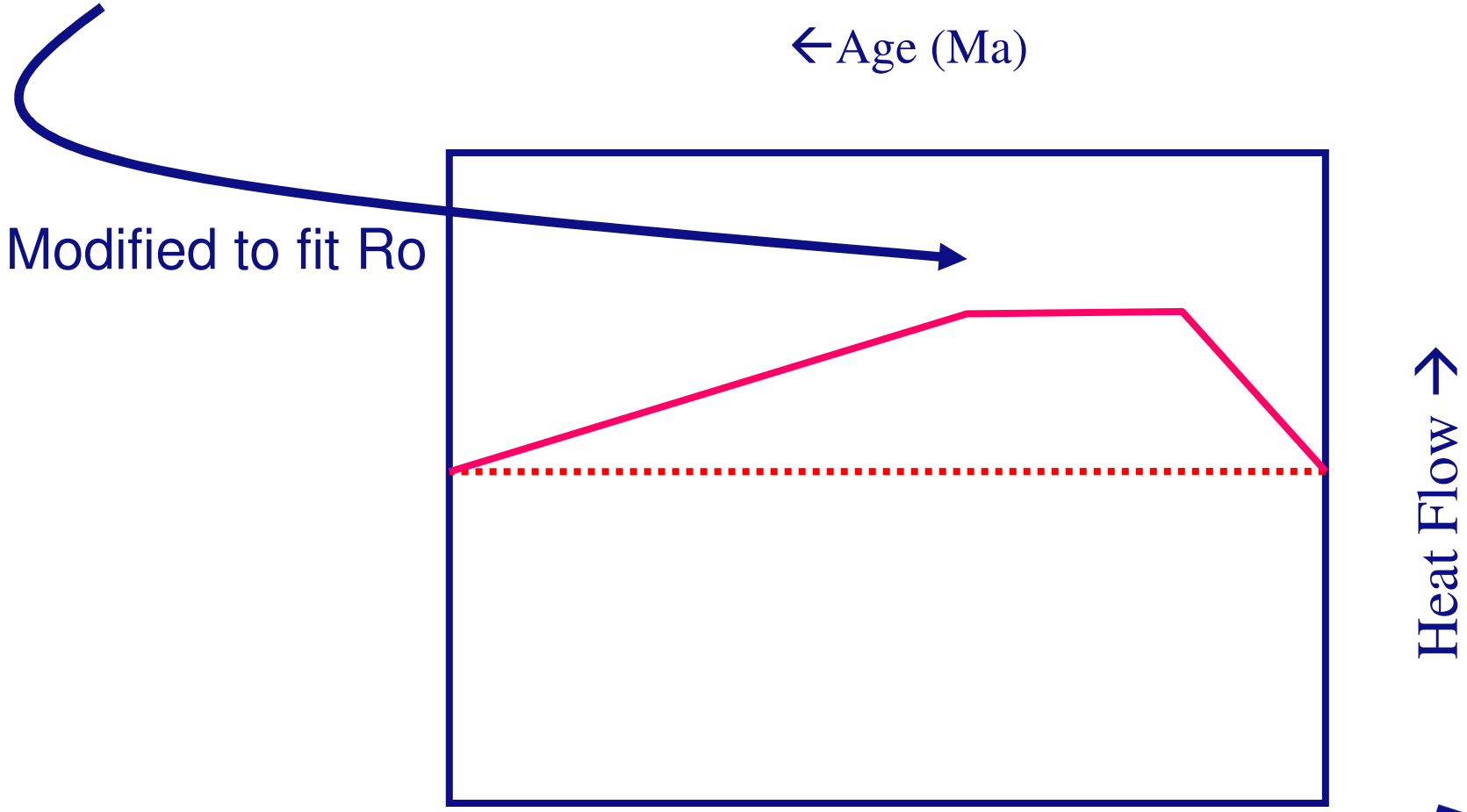
Added value of tectonic heat flow modeling

- Basin Modeling: How to find heat flow in the past

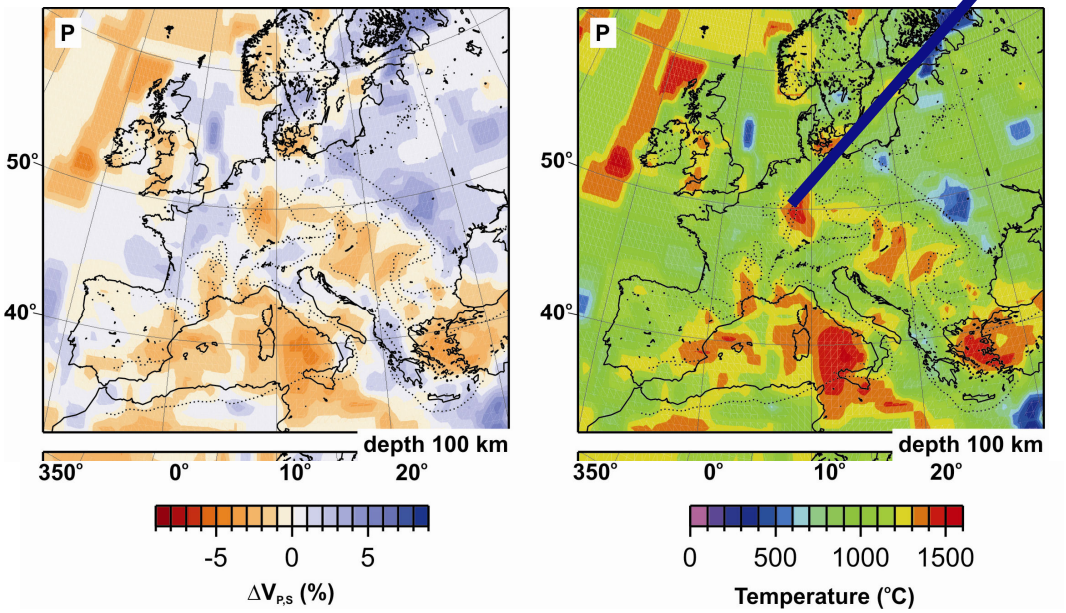


Added value of tectonic heat flow modeling

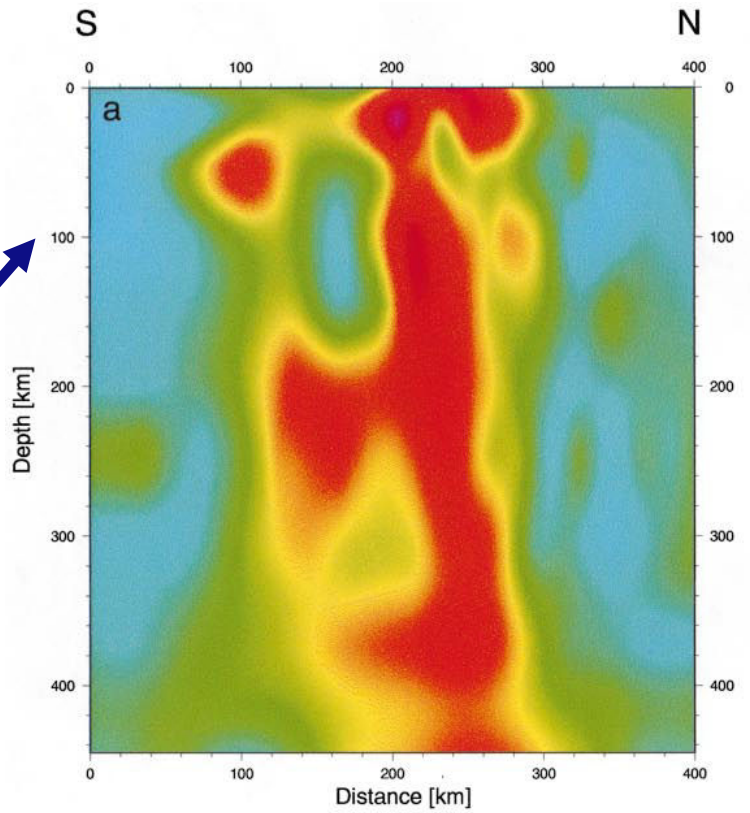
- Basin Modeling: How to find better heat flow in the past



Seismic tomography demonstrates mantle plumes acting as heat advection channels in the deep lithosphere

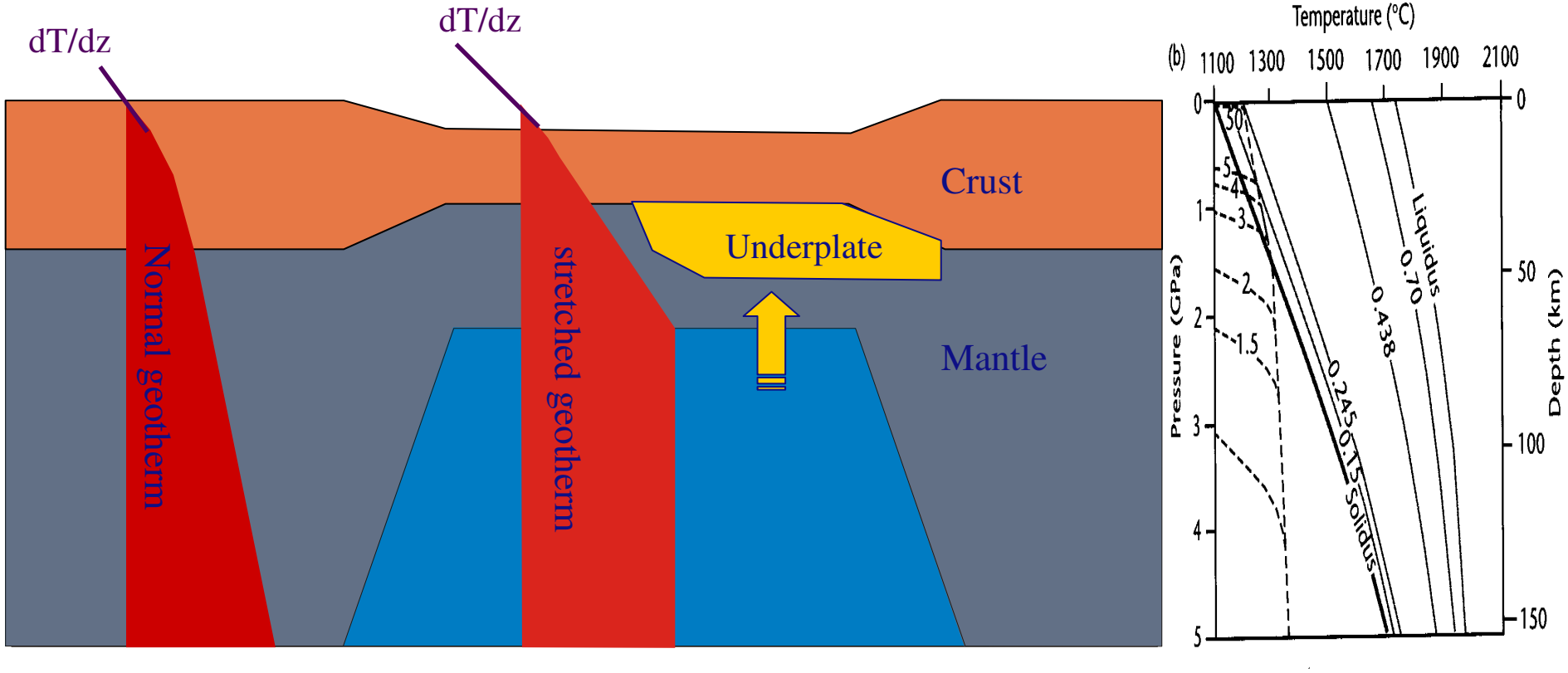


Goes et al., 2000

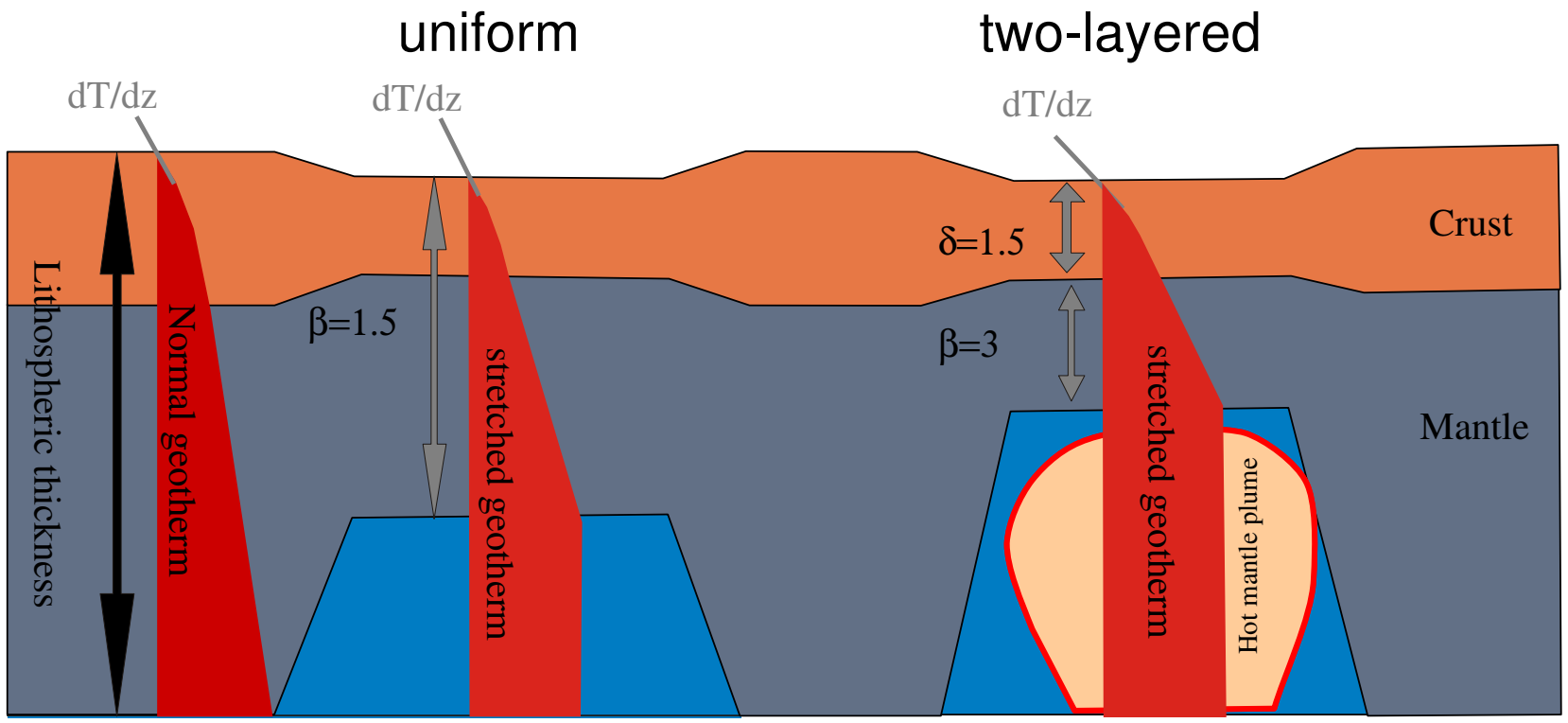


Ritter et al., 2001

Extension models – melts and underplates can arise from hot mantle (plumes) which result in accentuated heat advection and heat flow, relative to default extension

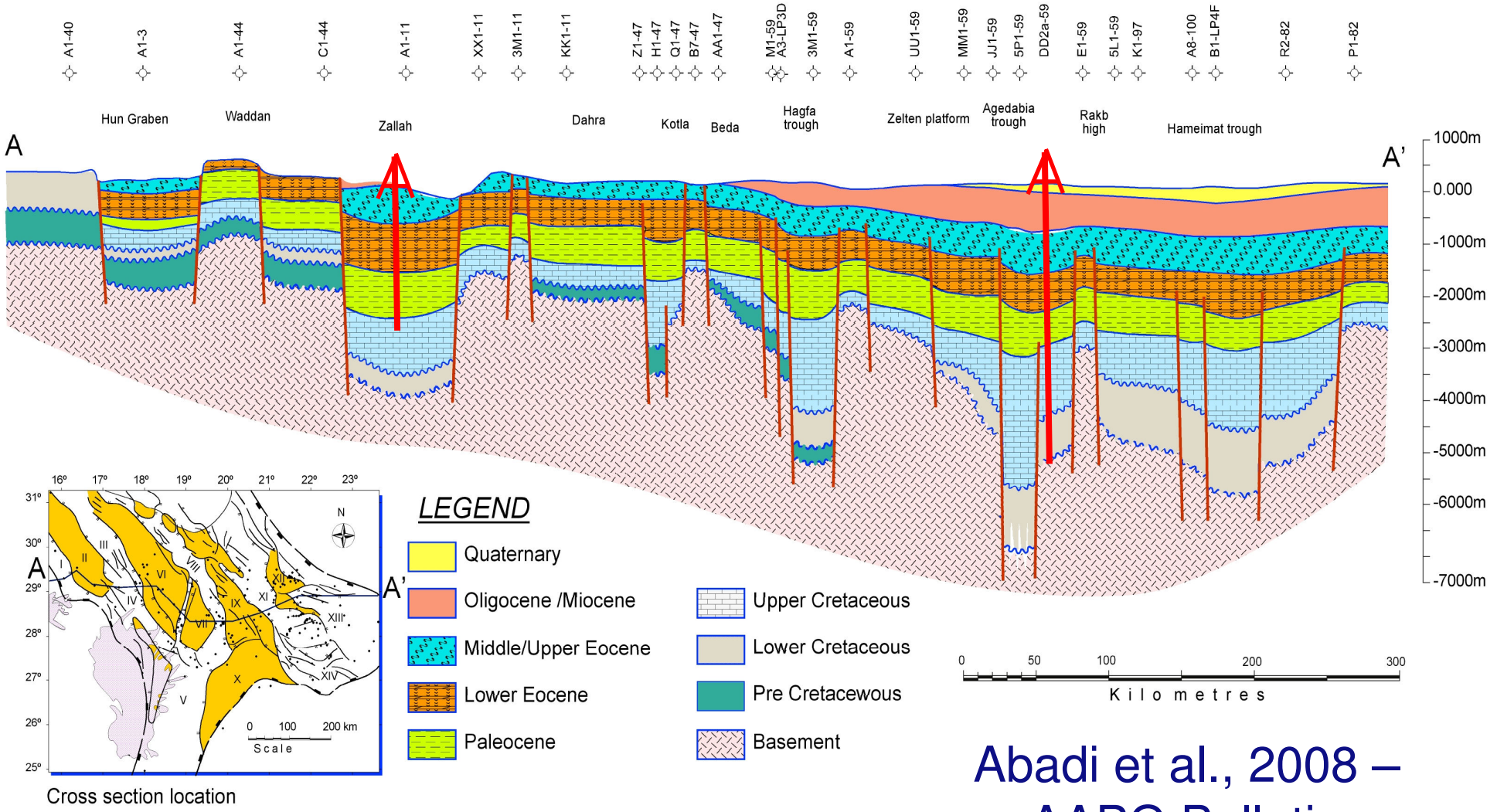


http://www.mantleplumes.org/



Van Wees et al., 2000- – Marine and Petroleum Geology
Ziegler et al., 1998 - Tectonophysics

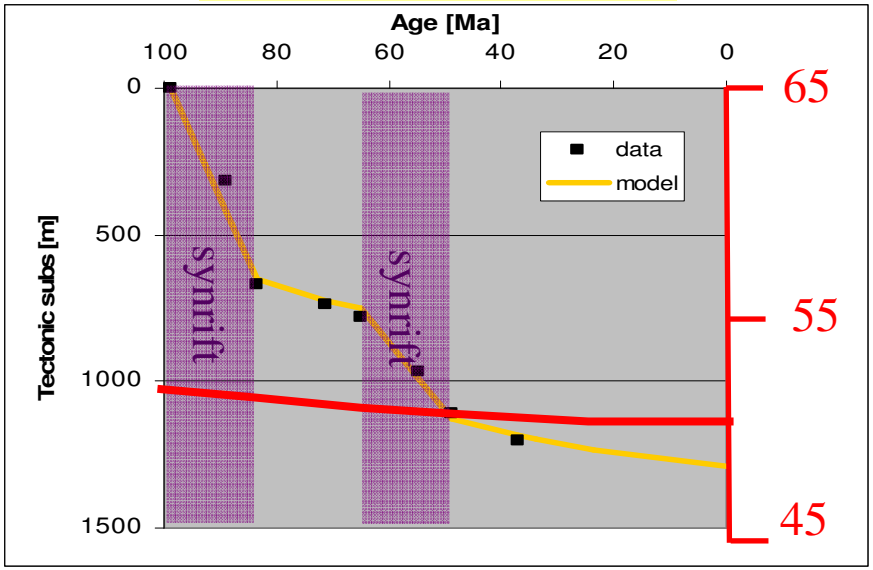
Sirt Basin



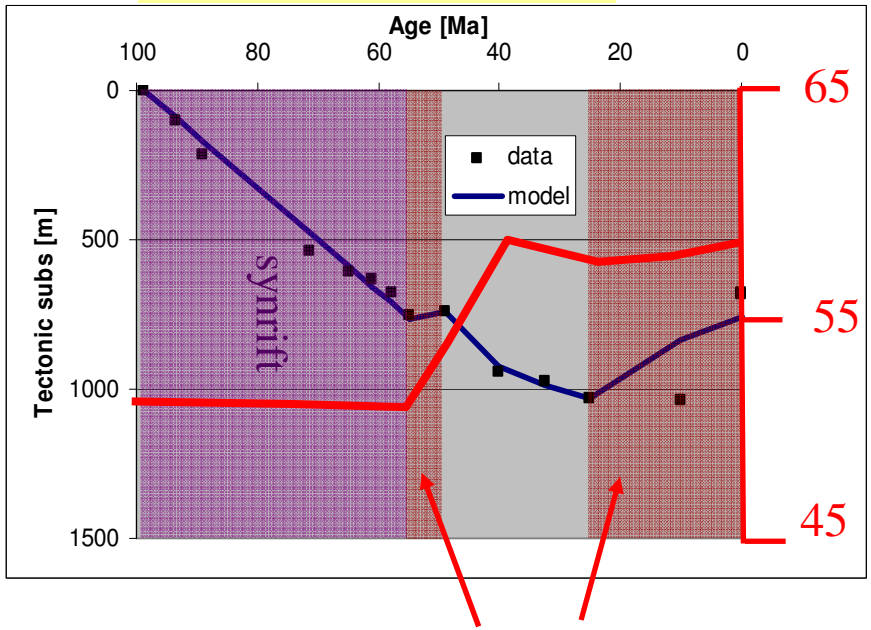
Cross section location

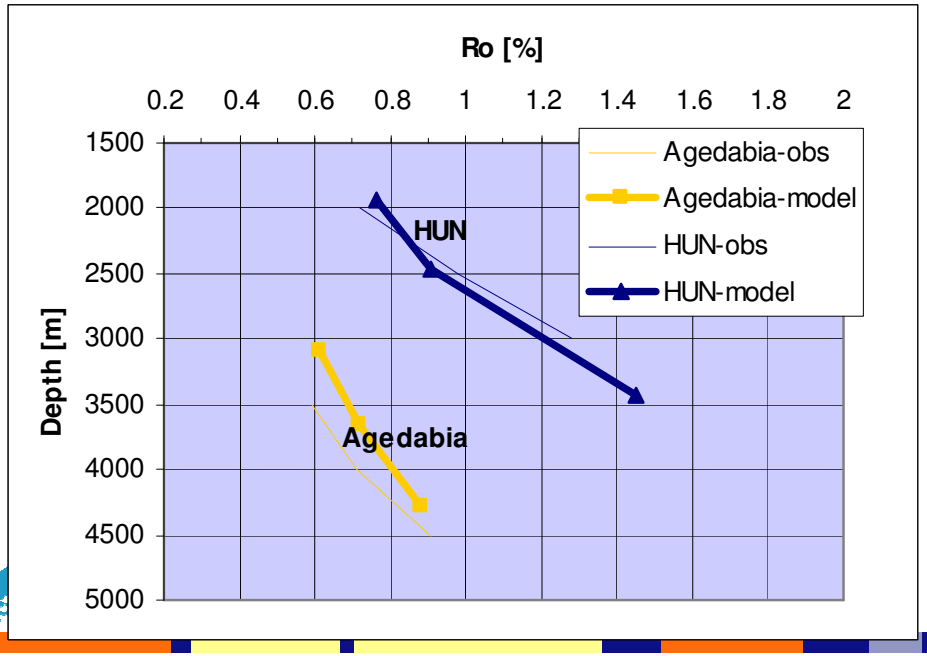
Abadi et al., 2008 – AAPG Bulletin

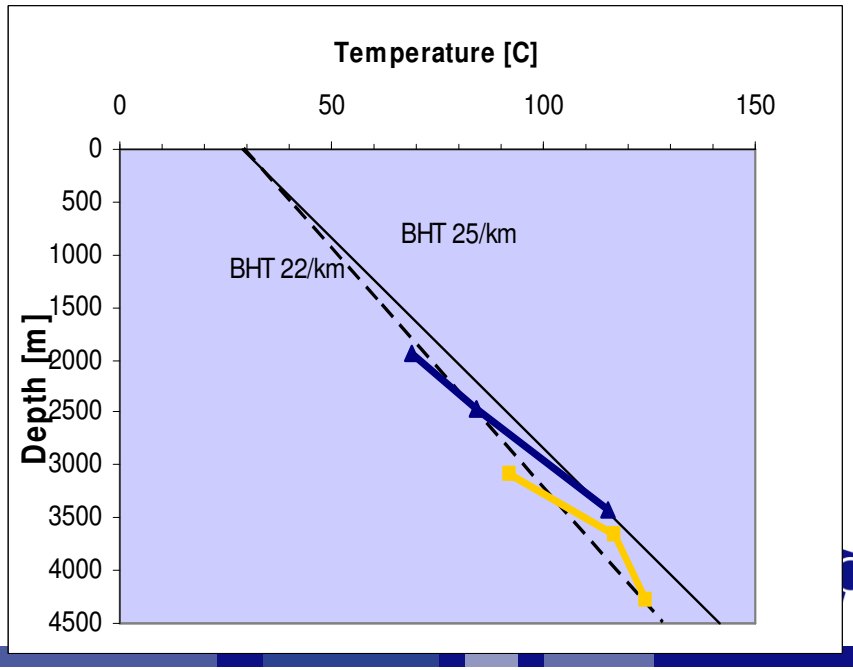
EAST SIRT- Agedabia



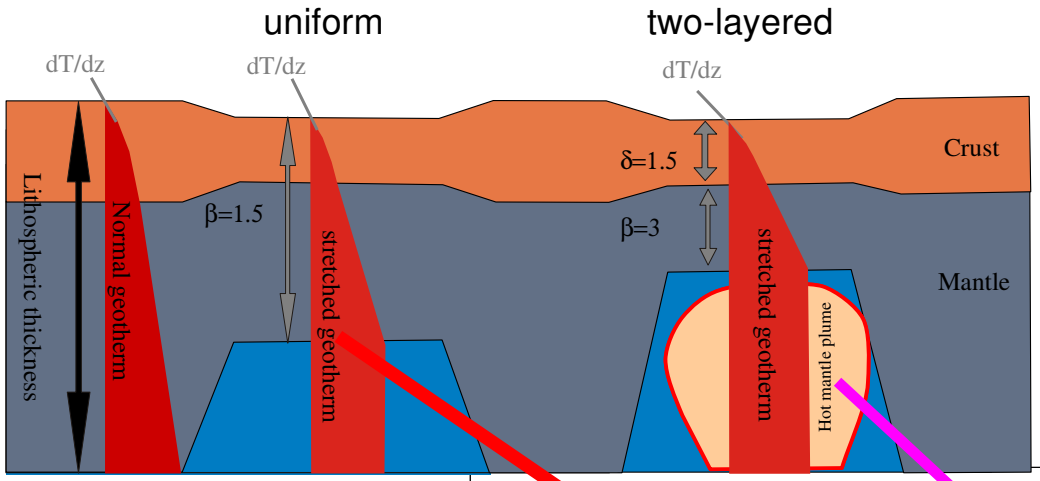
WEST SIRT- Hun

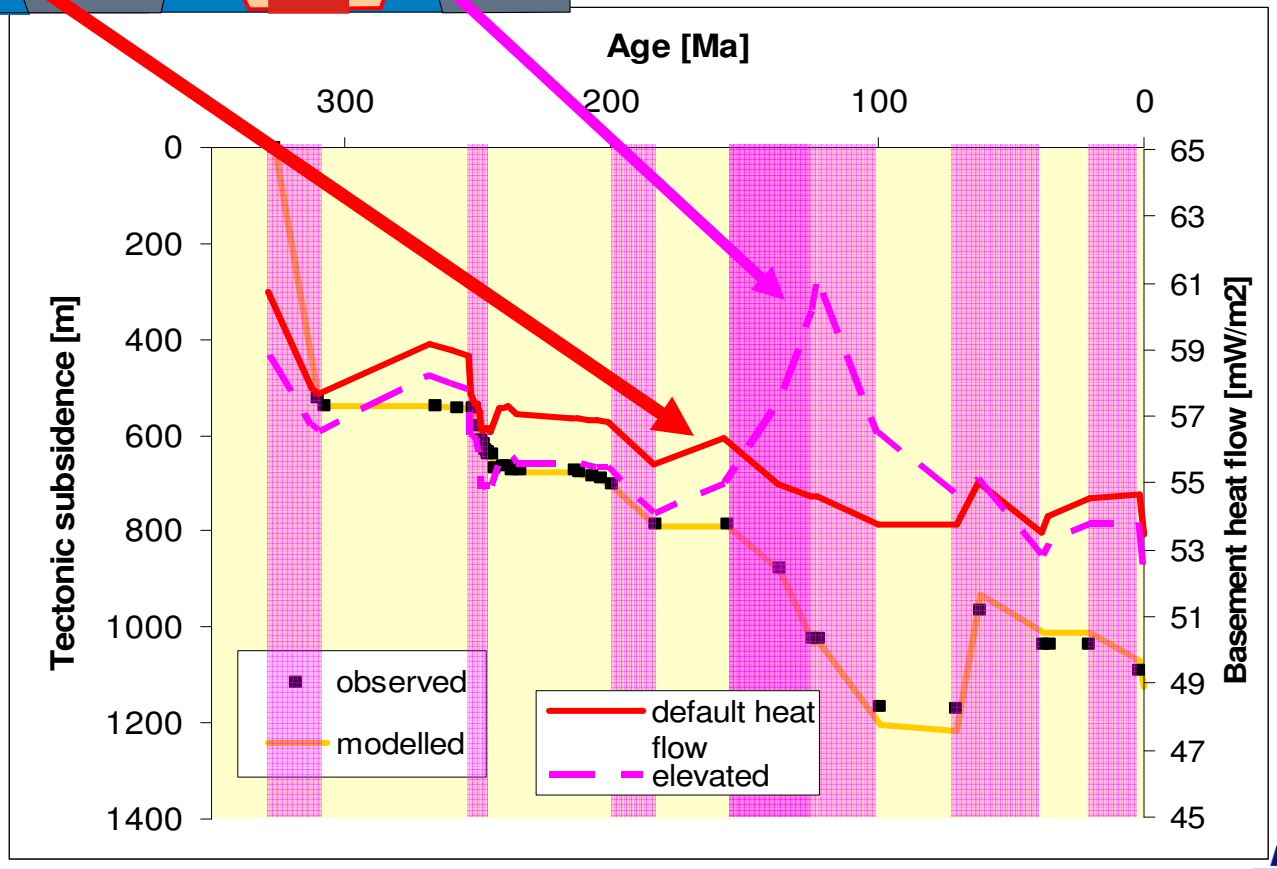






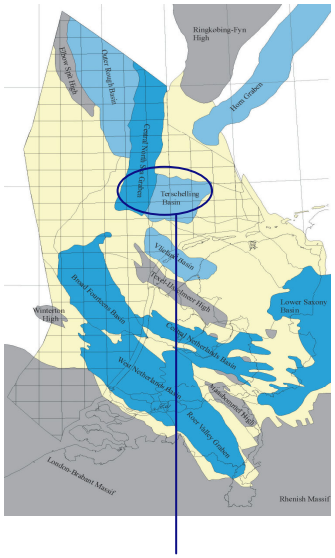
West Netherlands Basin

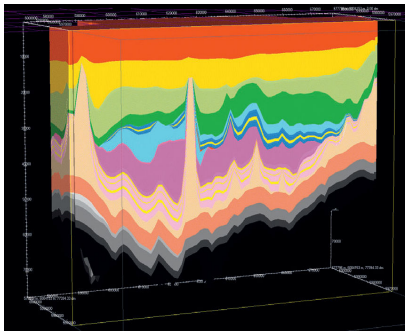


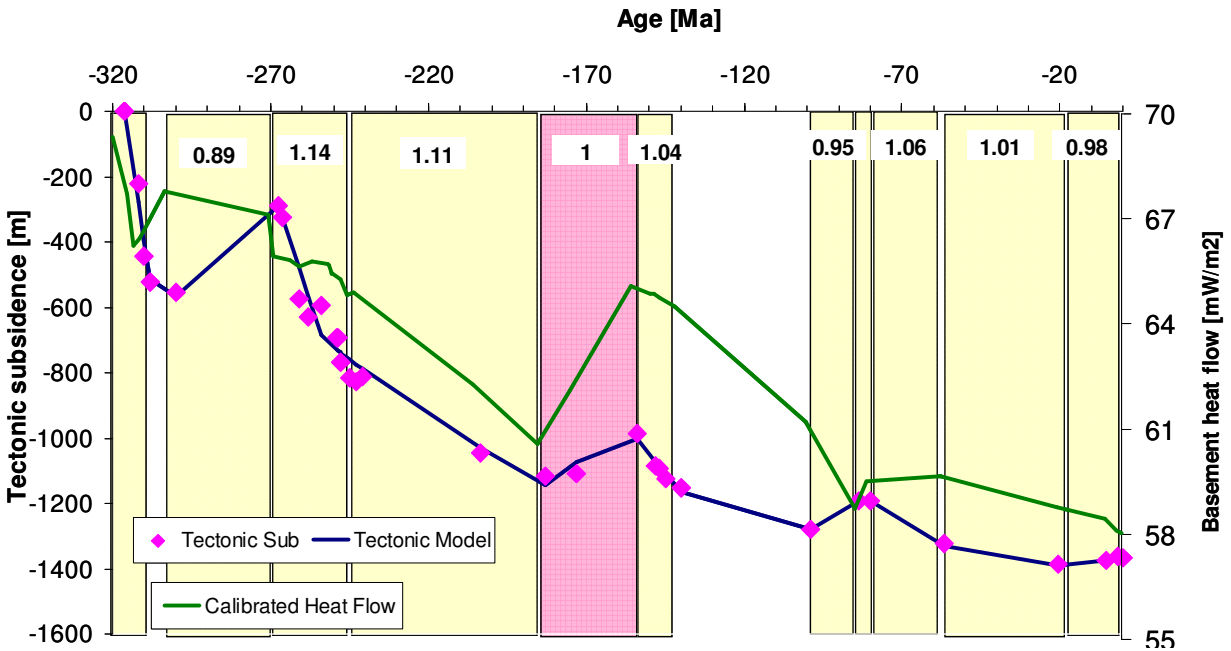


Van Wees et al., 2008 – Marine and Petroleum Geology

Model building: Boundary conditions



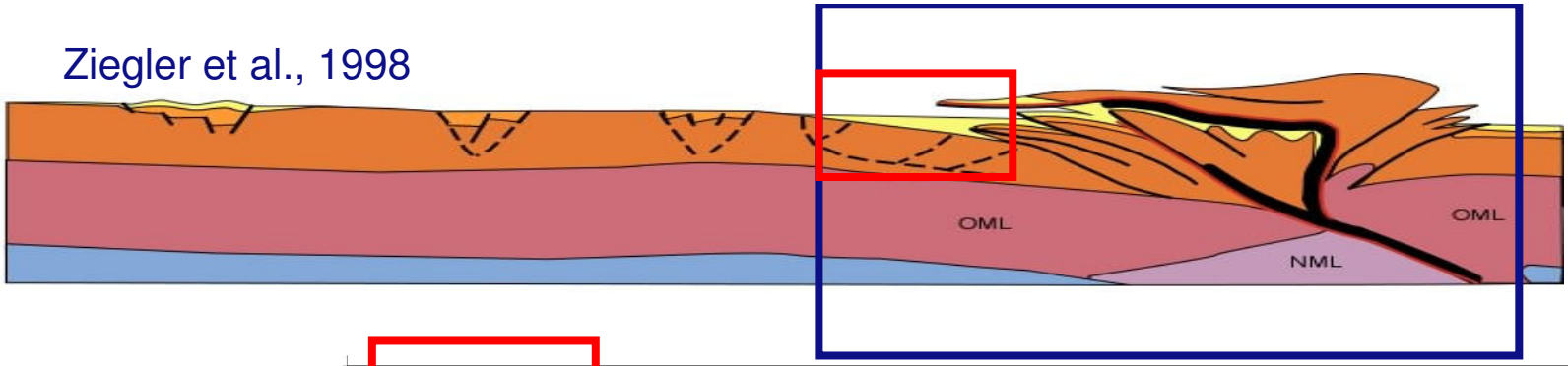


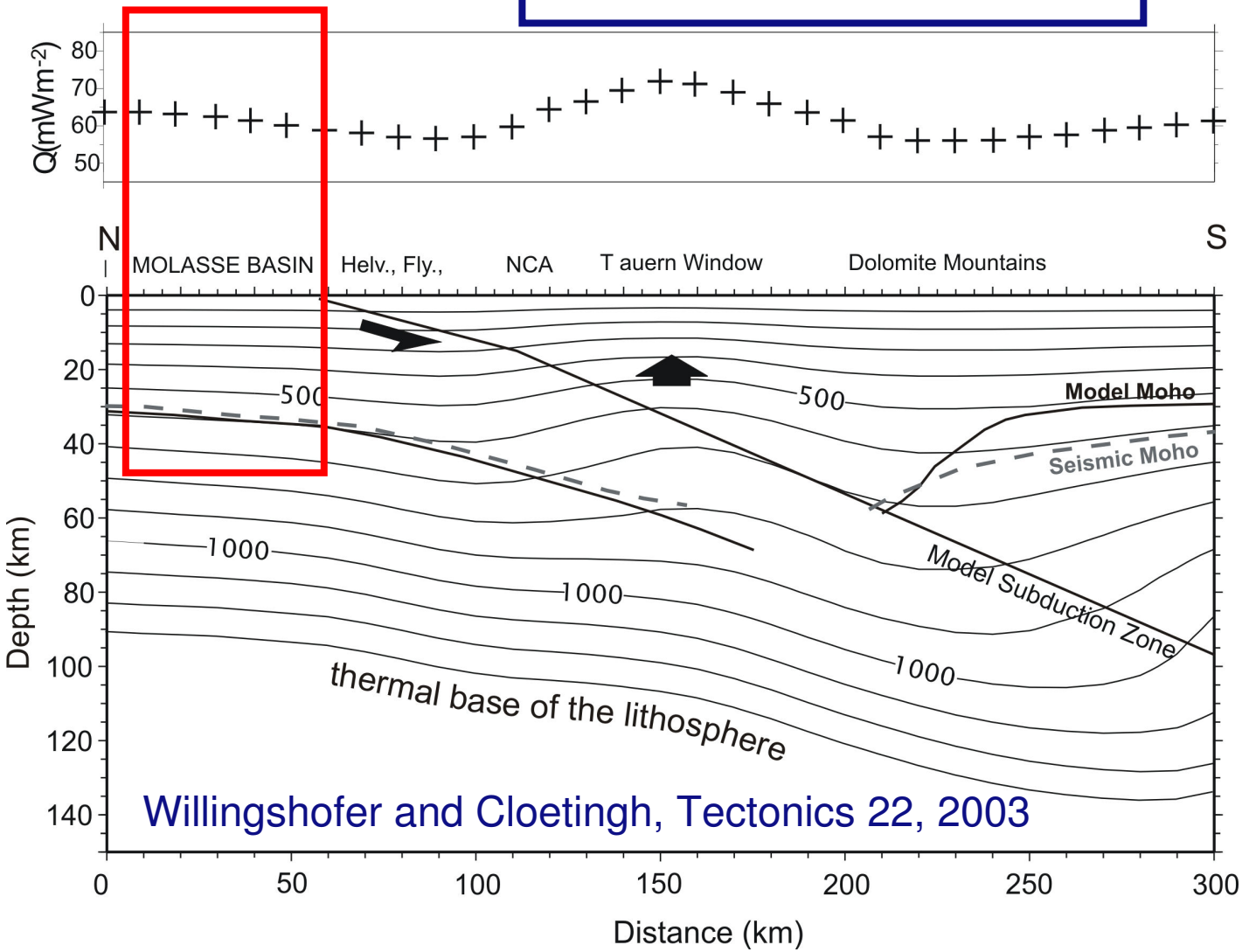


33 heat flow maps

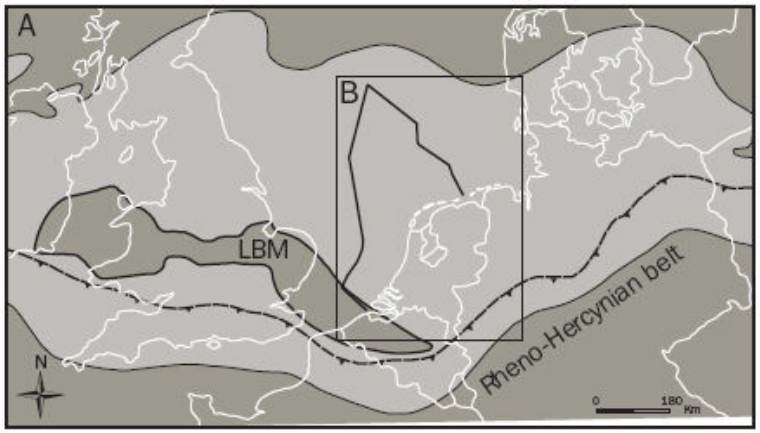
Basal heat flow history reconstructed from tectonic modelling (Petroprob) (Rader Abdul Fattah et al 2008)

Ziegler et al., 1998

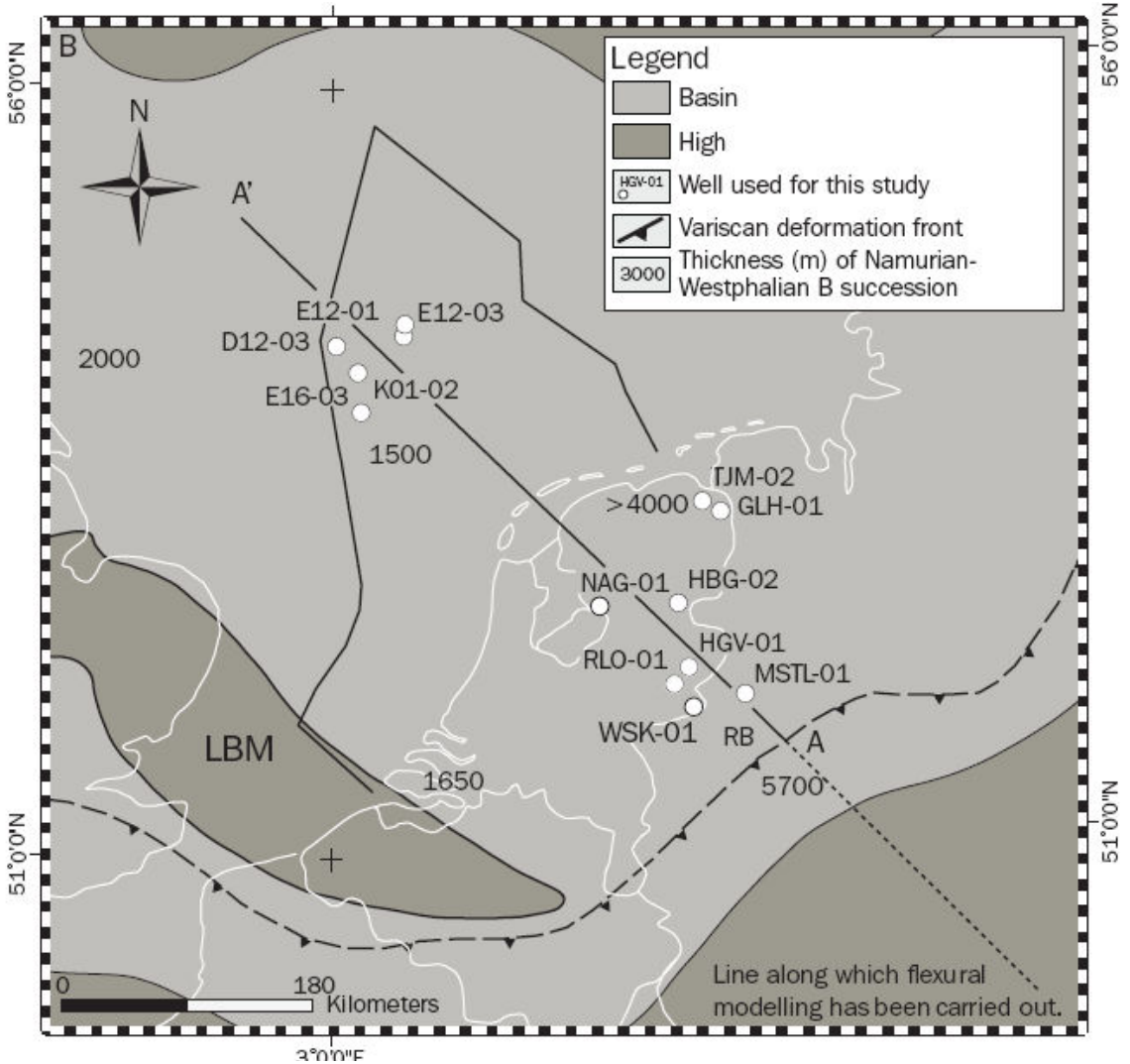




Willingshofer and Cloetingh, Tectonics 22, 2003

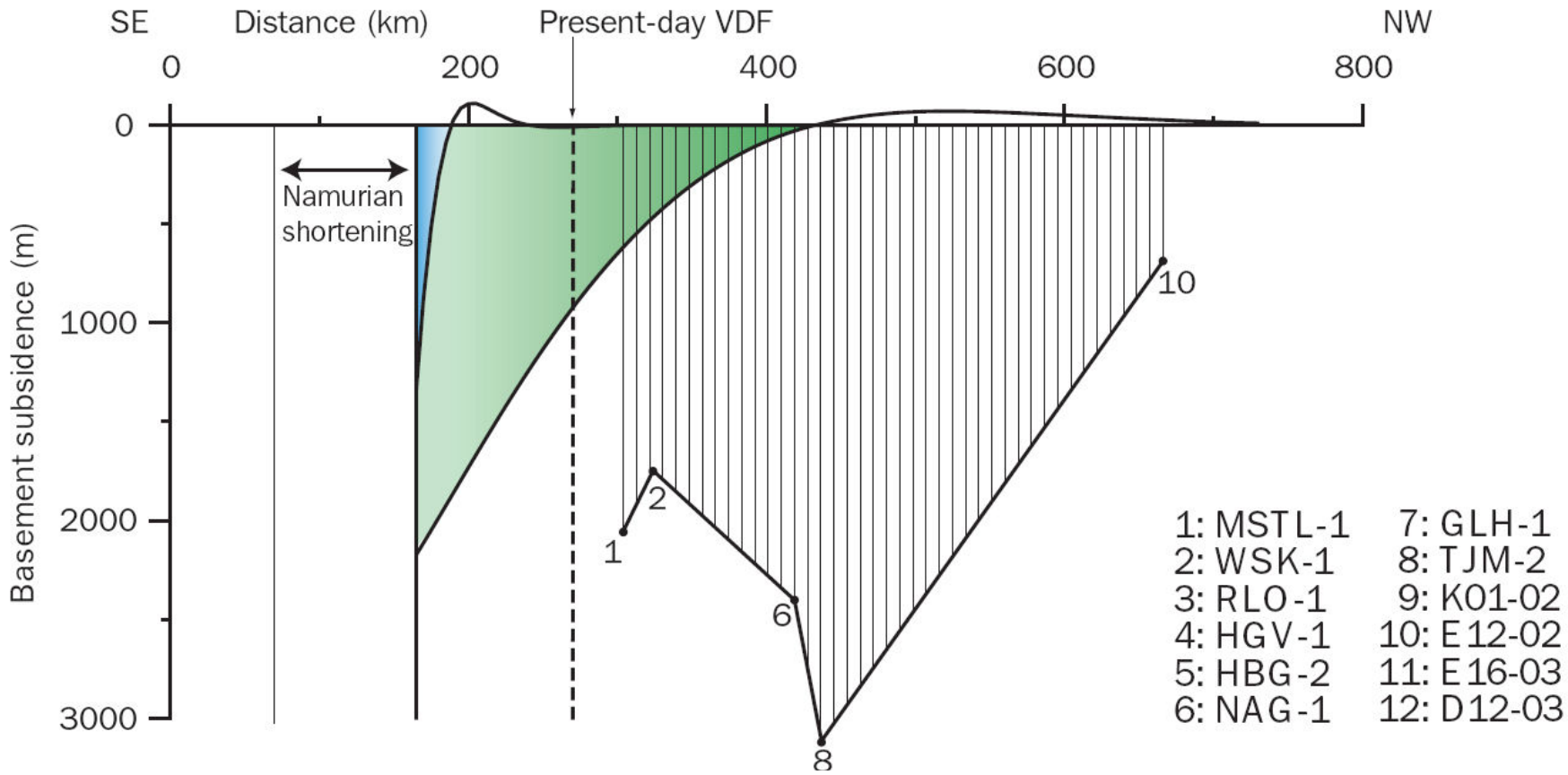


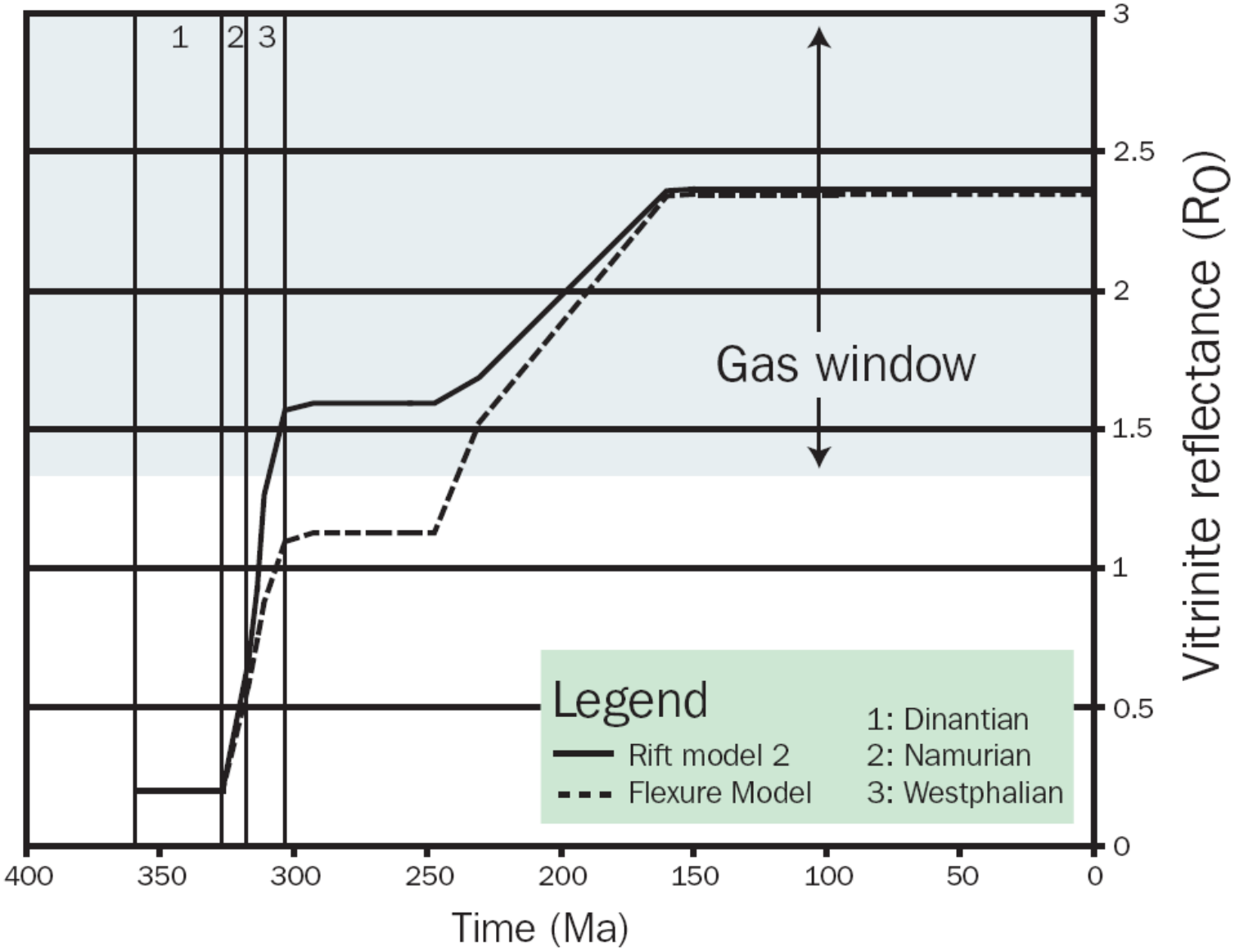
C	Stage	Age (Ma) Menning et al (2006)	Western Europe (used in this study)		Sequences	
Carboniferous	Kasimovian	305	Stephanian		UK	GE
	Moscovian	308	Westphalian	D	Inver-sion	
		311		C		?
	Bashkirian	313.5		B	Thermal-sag	Molasse
		316.5		A		
	Serpukhovian		Namurian			
	Visean	326.4	Dinantian		Syn-rift	Flysch
	Tournaisian					
	Devonian	358	Devonian			



Kombrink et al., 2008 (Basin Research)

A Basement subsidence Namurian




1
2
3
Gas window
Legend
Rift model 2
Flexure Model
1: Dinantian
2: Namurian
3: Westphalian
Vitrinite reflectance (Ro)
Time (Ma)
400
350
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0

Conclusions

- Tectonic heat flow models aid in predicting heat flow for basin modelling beyond well control
  - Mature basins - Heat flow through time
  - Frontier basins – spatial variability
- Tectonic heat flow models should include effects of crustal heat production and sediment infill/erosion
- The Netherlands
  - Average heat flow values today
  - Considerable variation through time:
    - Elevated at mantle plume/underplating phase
    - Depressed during foreland formation