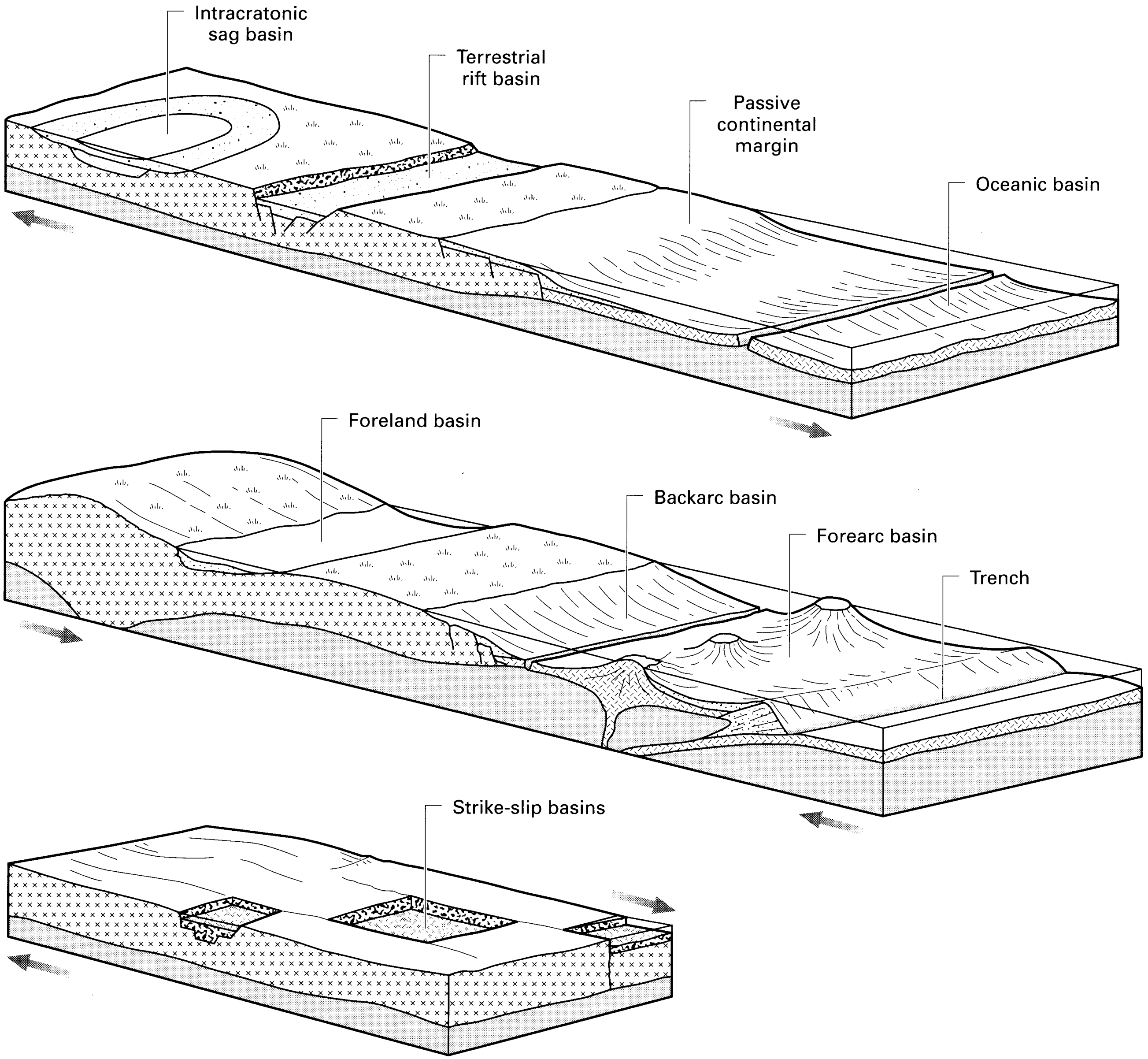
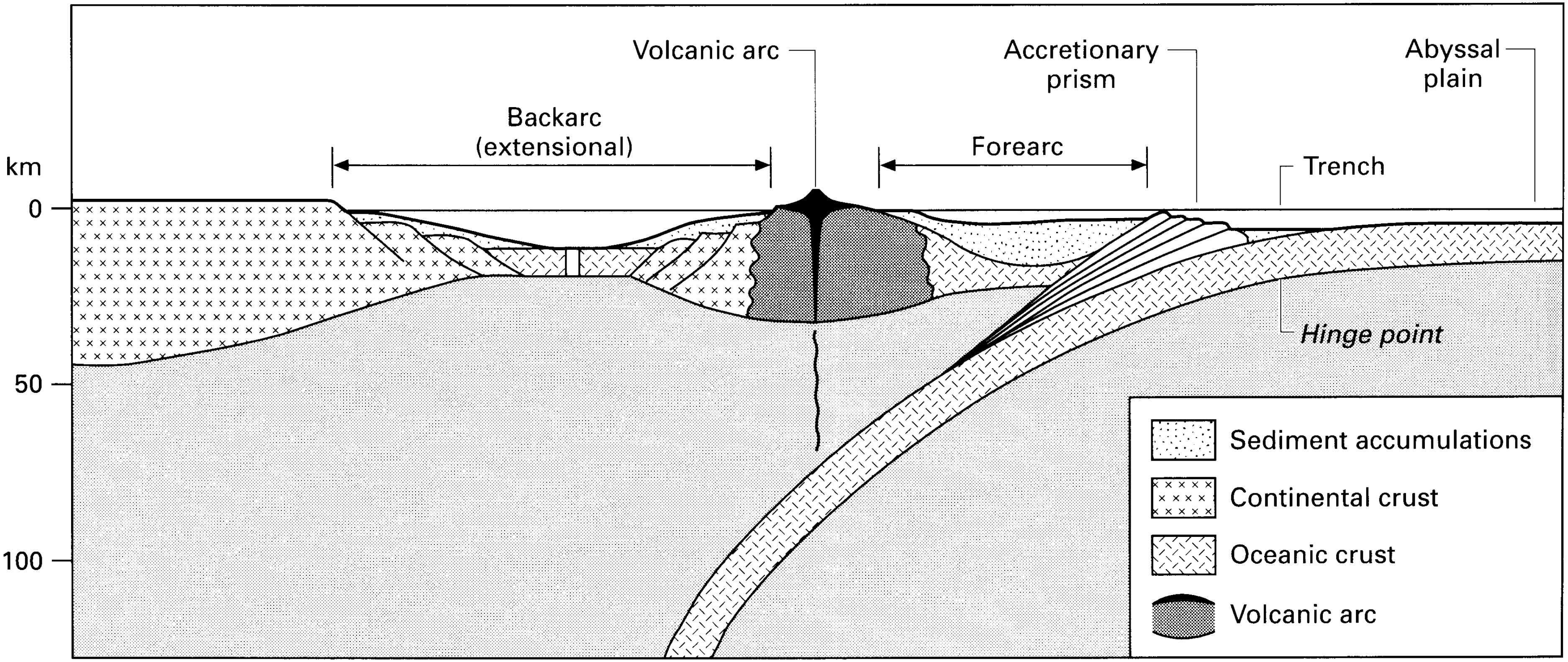
Basin classification

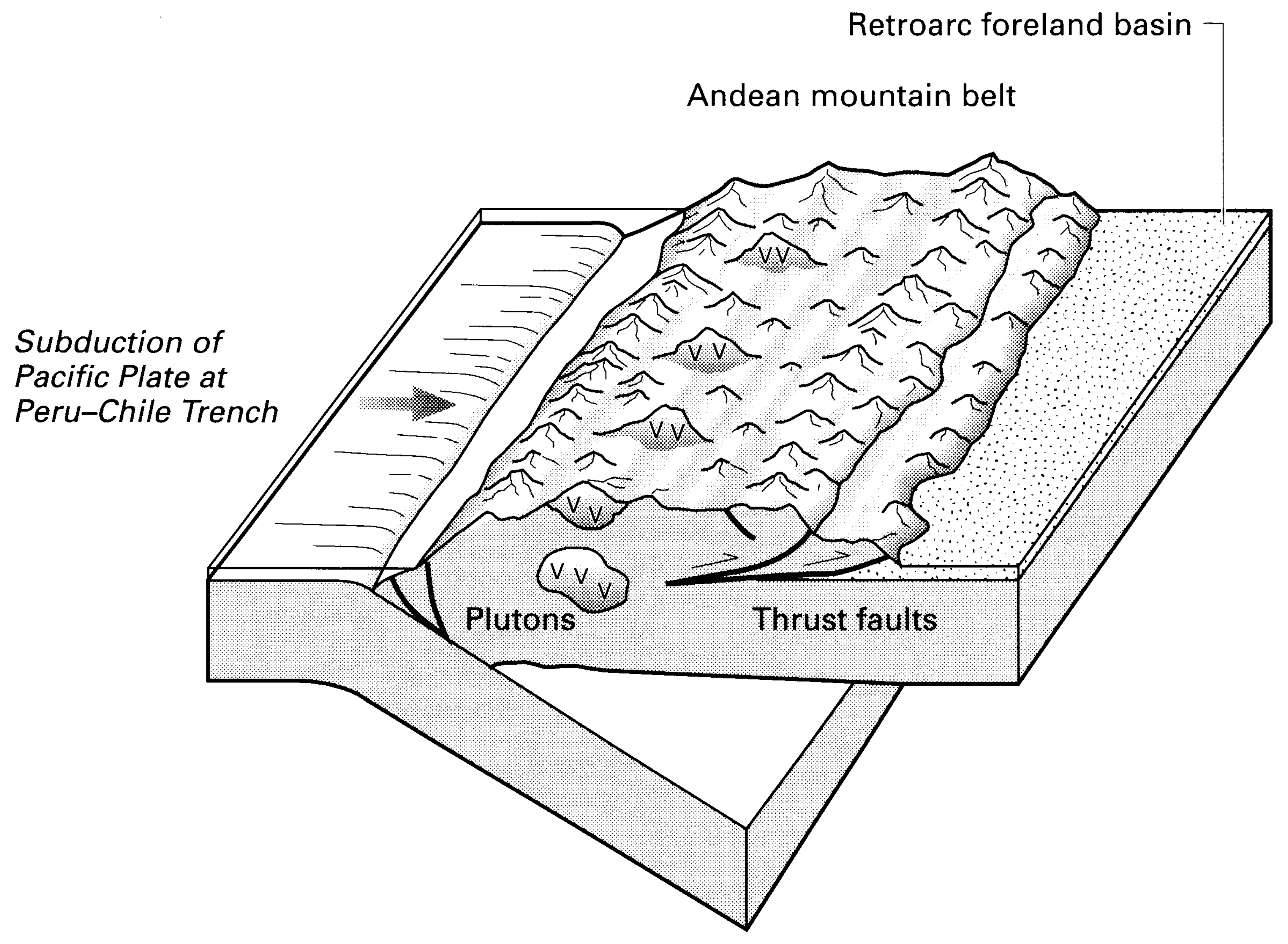
Basins are classified according to either their position within a plate, or according to their structural/ tectonic origin.



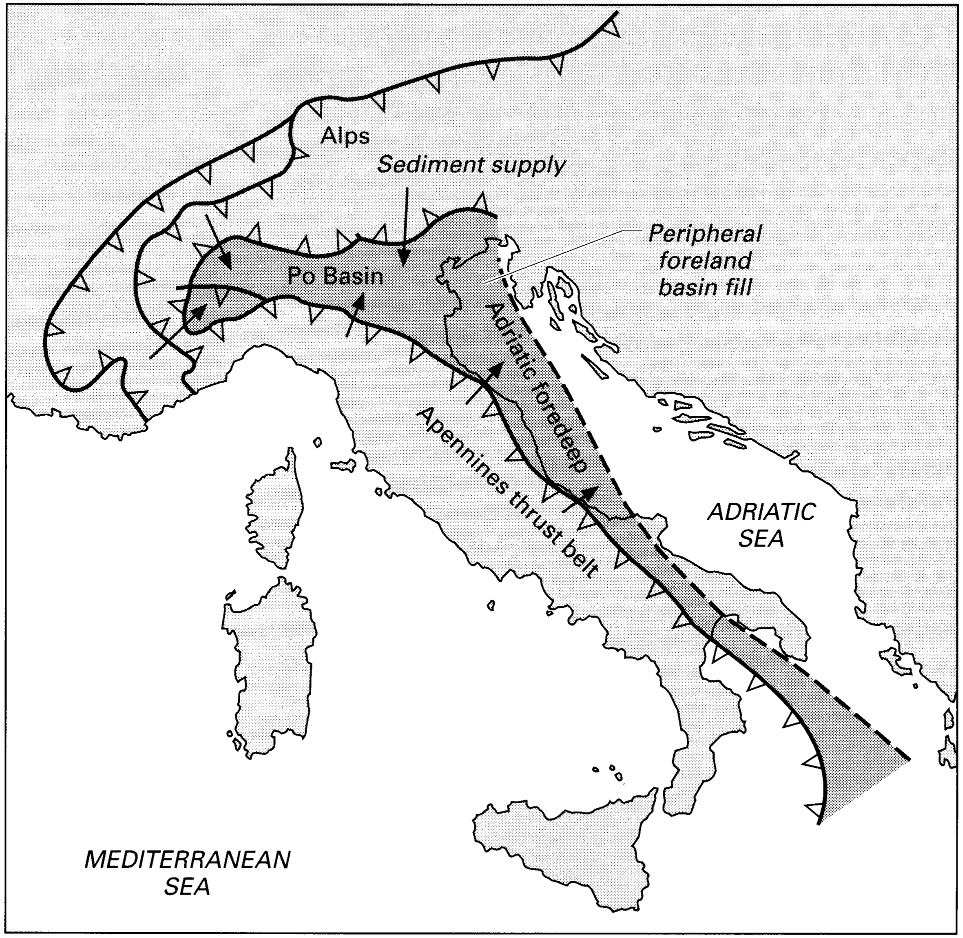
Basins on an active margin

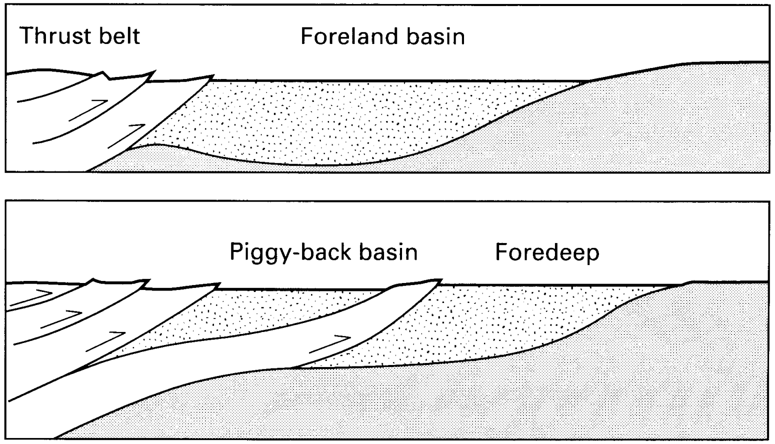


Andean-type active margin



Foredeep basin





Schematic cross-sections across foreland basins

Alpine foredeep basin, Austria (Molasse basin)

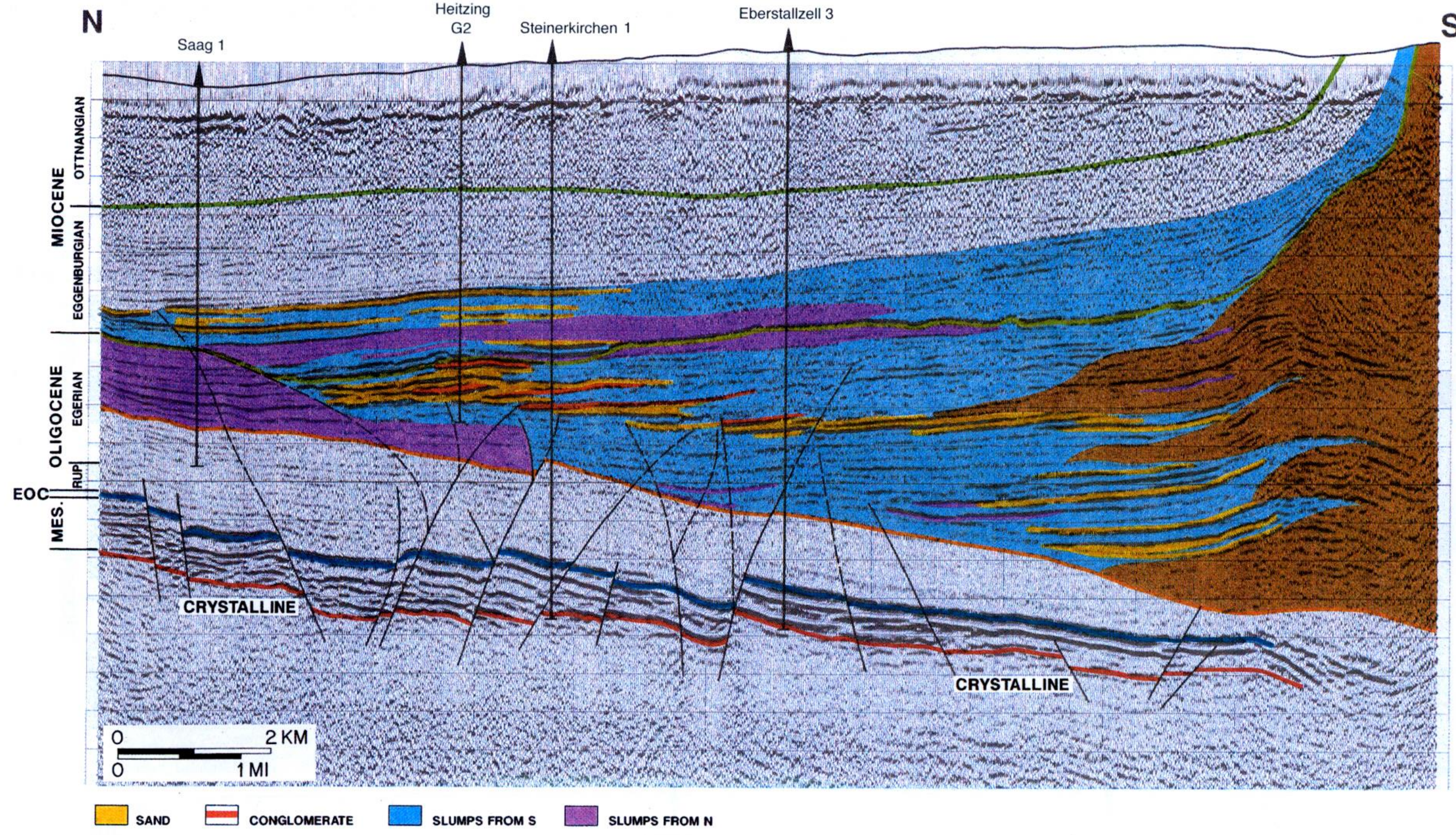
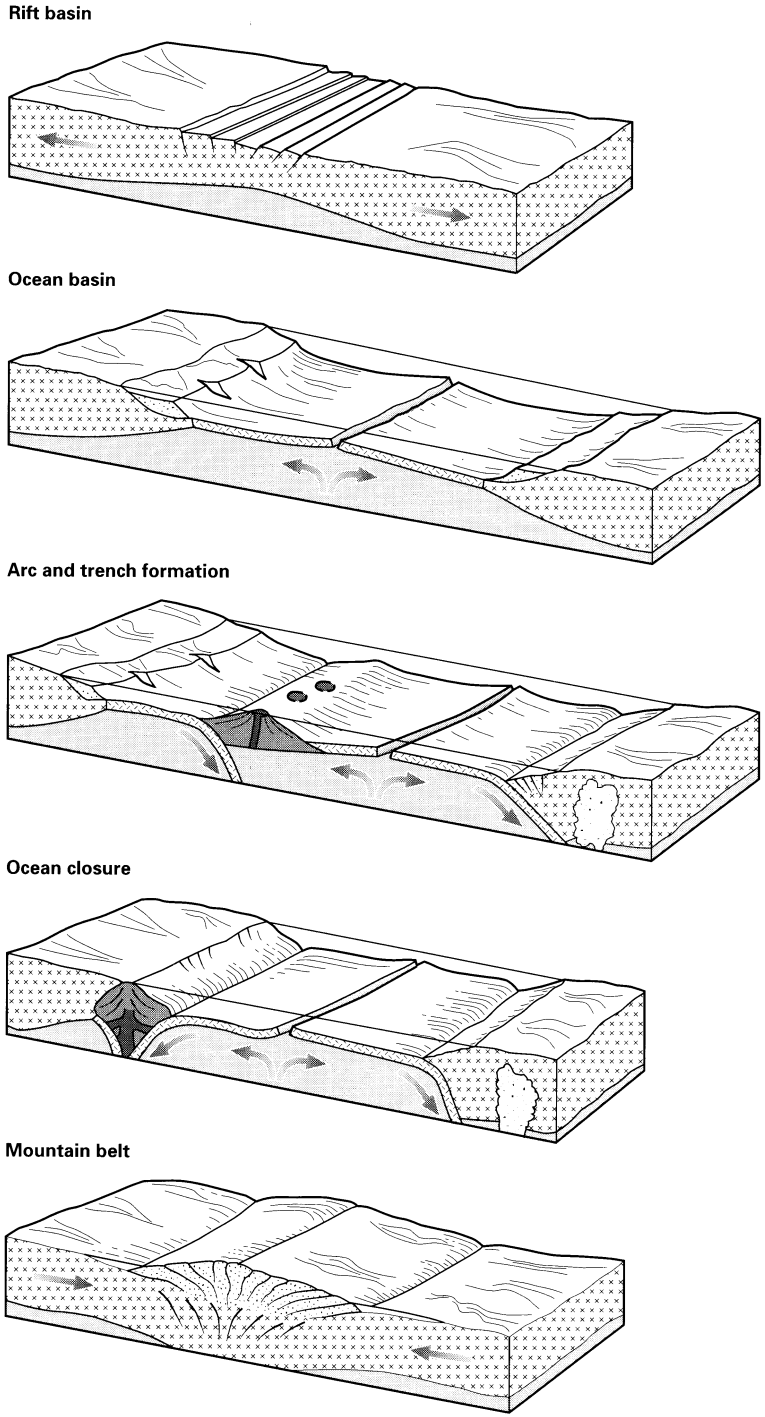


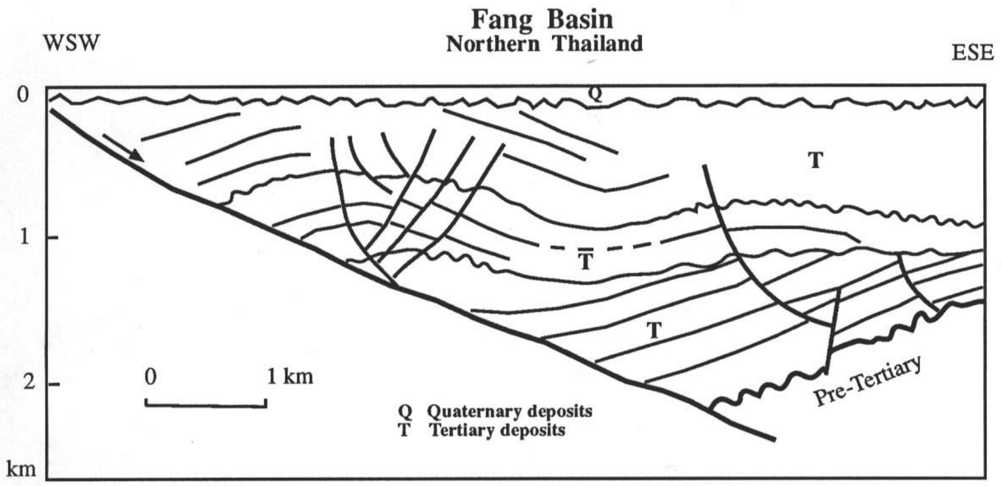
Fig. 14. N–S seismic line through the Upper Austrian Molasse Basin.

Wilson (orogenic) cycle

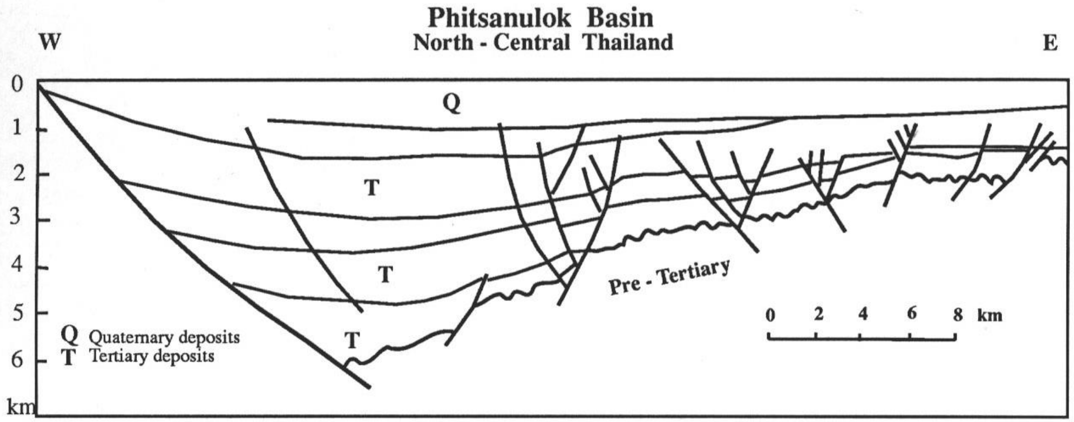
As a region evolves tectonically many areas of sedimentation occur under different tectonic settings. Hence many basins have a polyphase history.



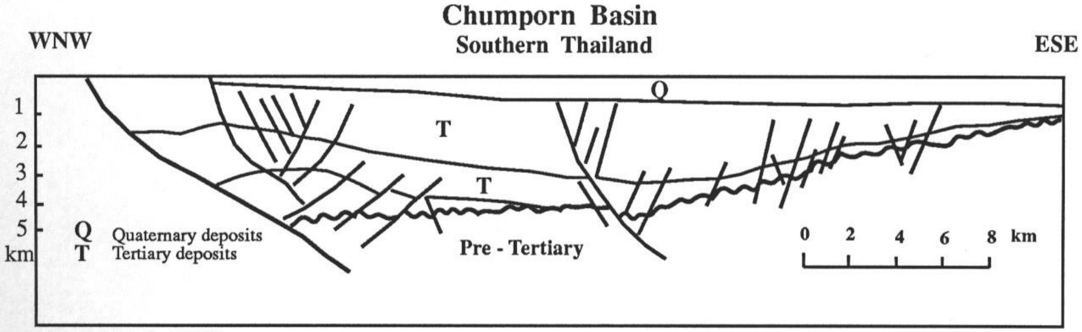
Rift basins, Thailand


Fang Basin
Northern Thailand

(From Settakul et al, 1990)


Phitsanulok Basin
North - Central Thailand

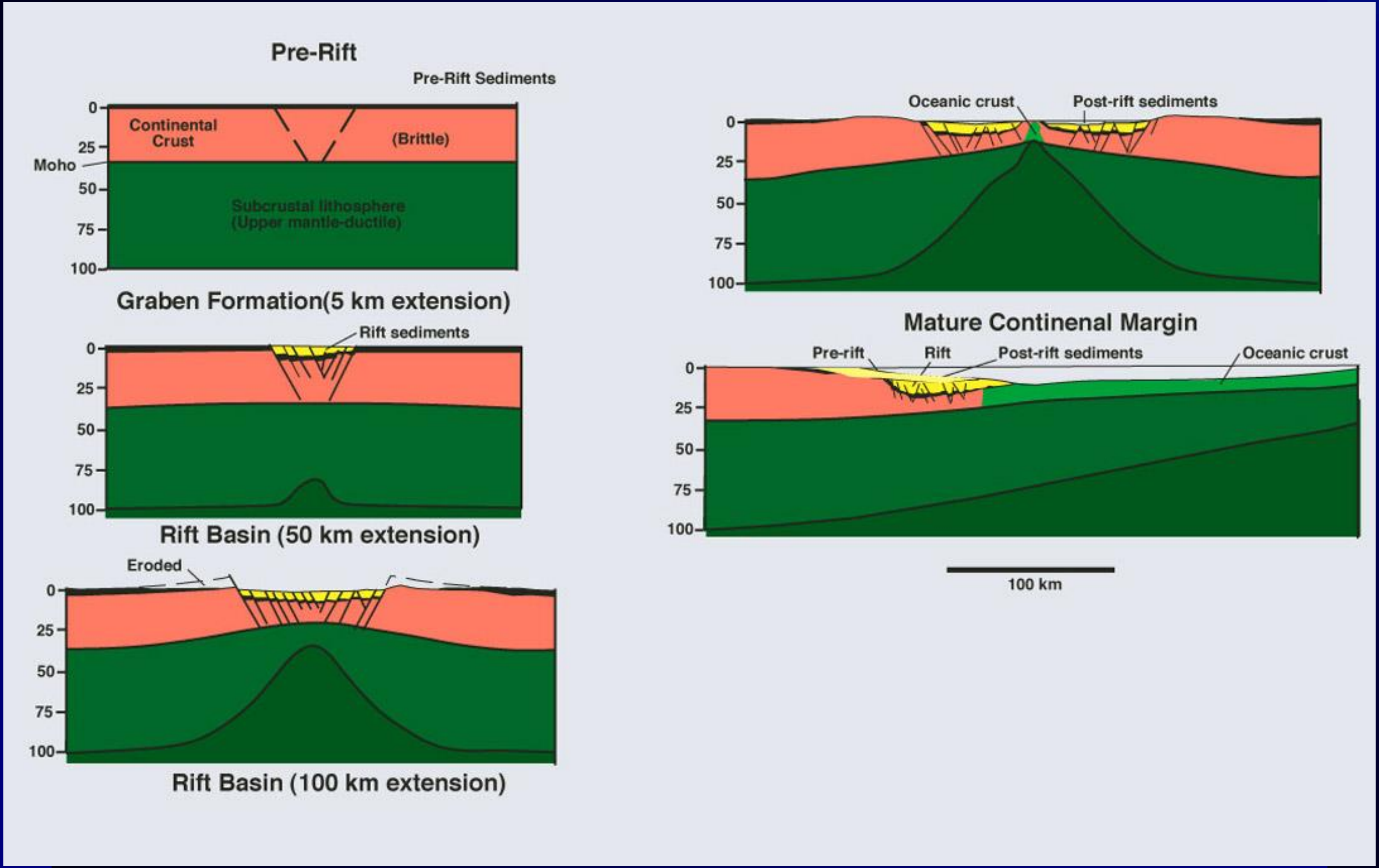
(From Burri, 1989)


Chumporn Basin
Southern Thailand

(From Burri, 1989)

W.Uttamo 97

Evolution from continental rift to passive margin



Pre-Rift

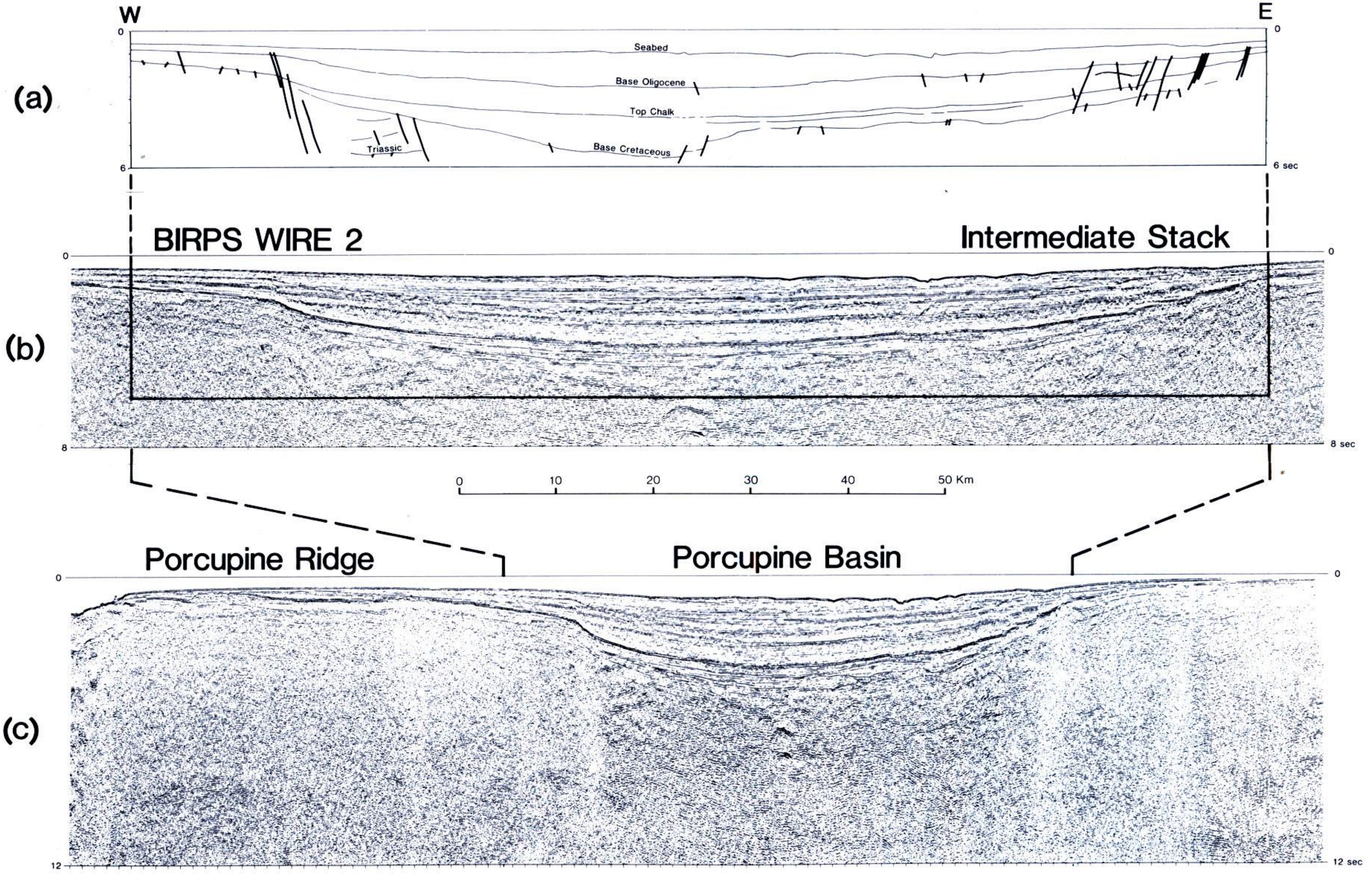
Graben Formation(5 km extension)

Rift Basin (50 km extension)

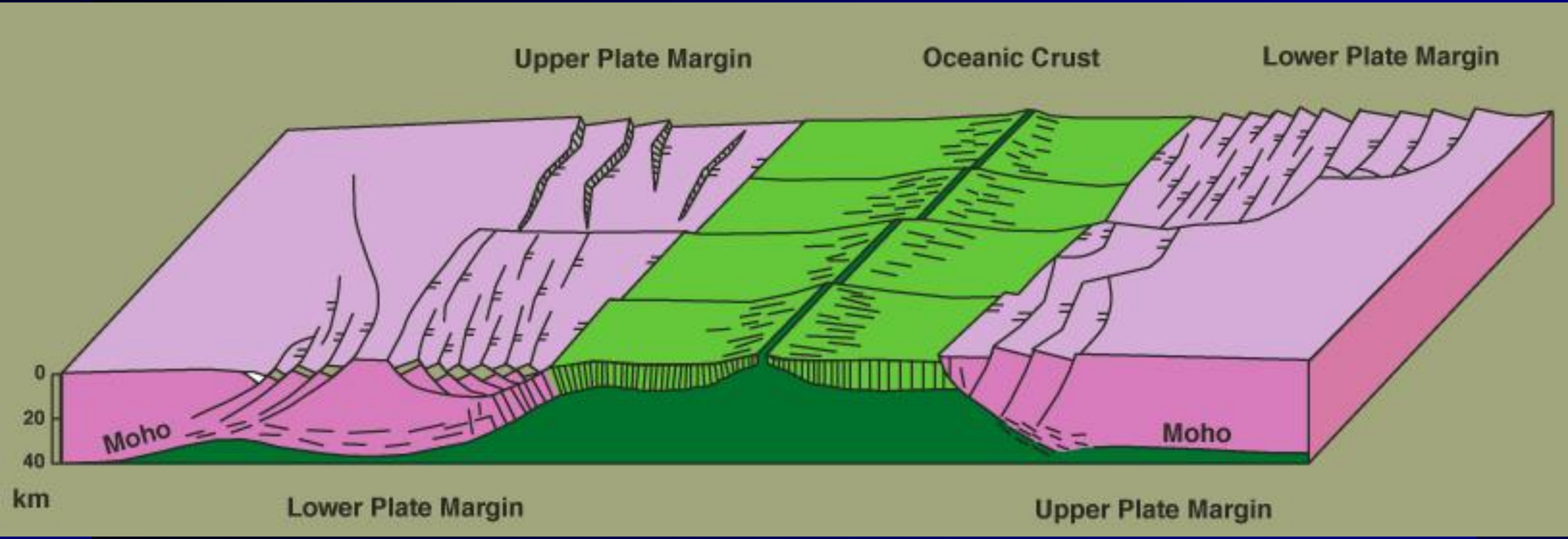
Rift Basin (100 km extension)

Mature Continenal Margin

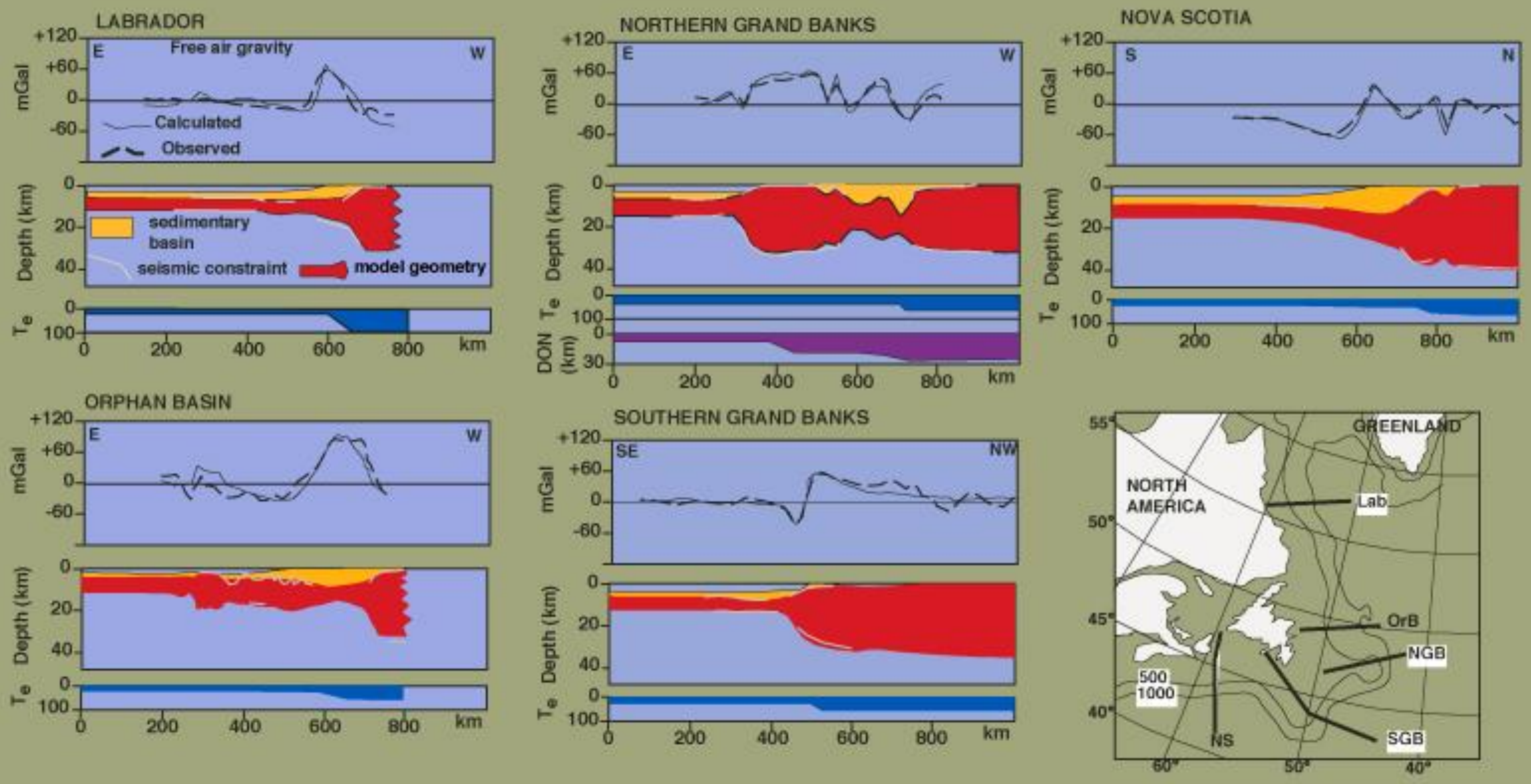
Thermal sag basin over rift basin



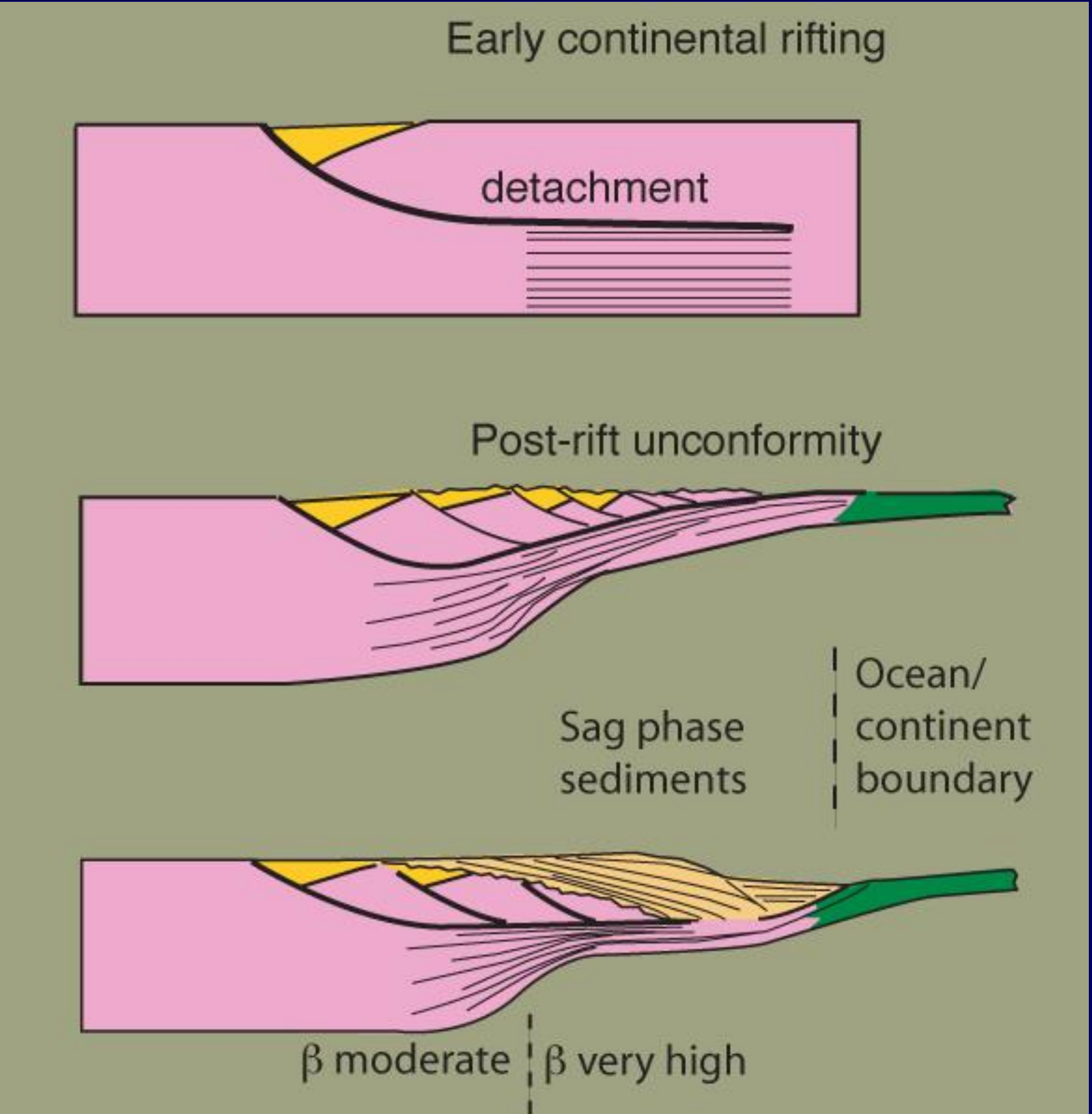
Passive margin geometry

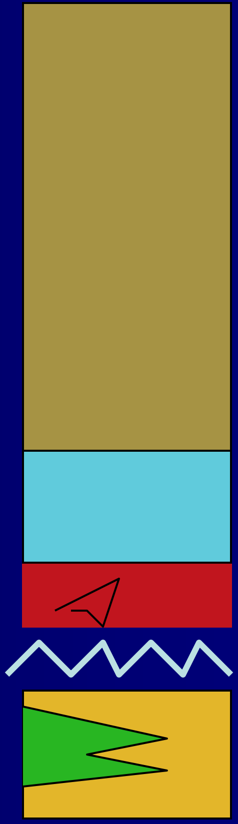


Stretching geometries of N Atlantic margin



Passive margin evolution





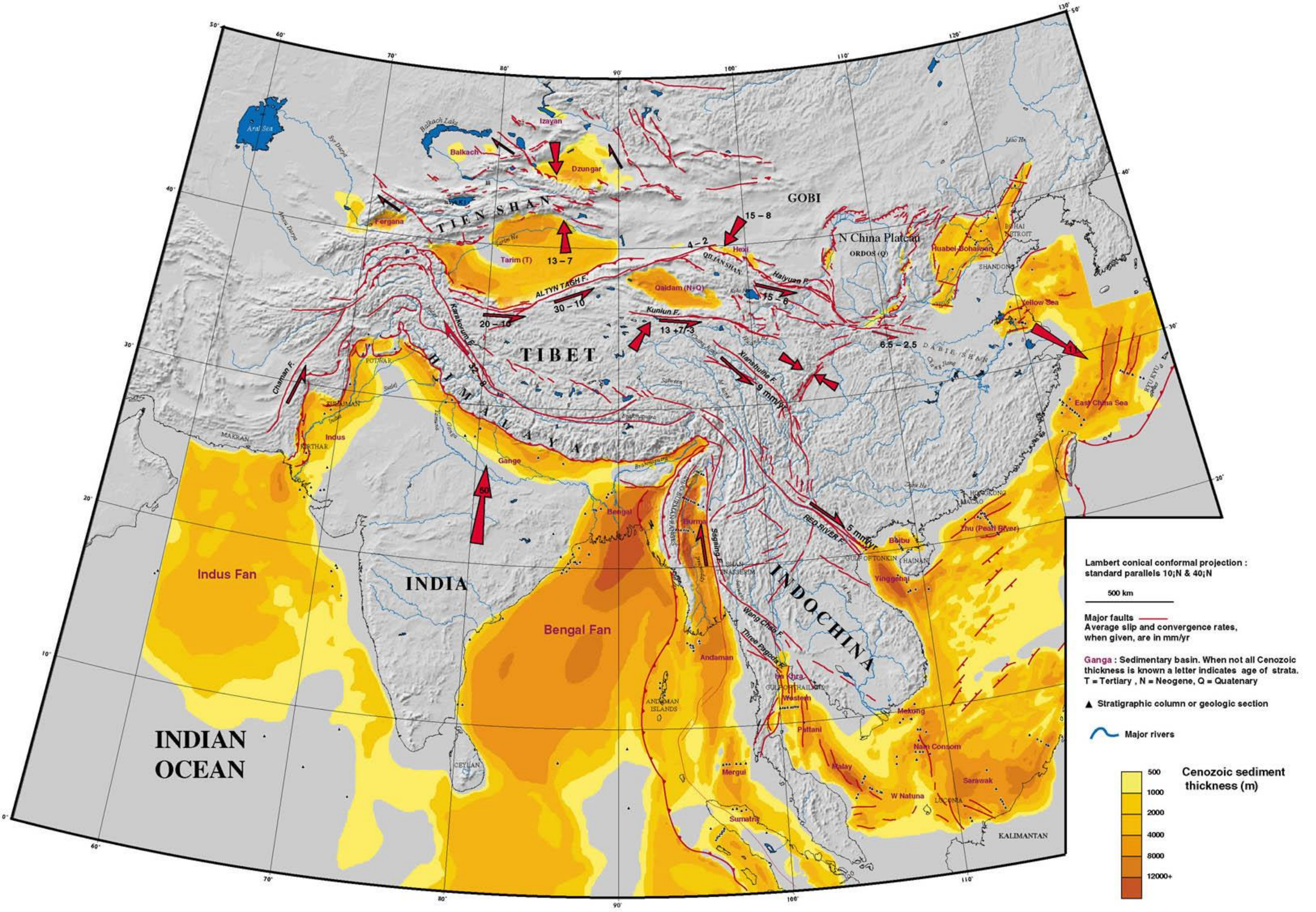
Marine clastics

Carbonates

Evaporites

Breakup UC

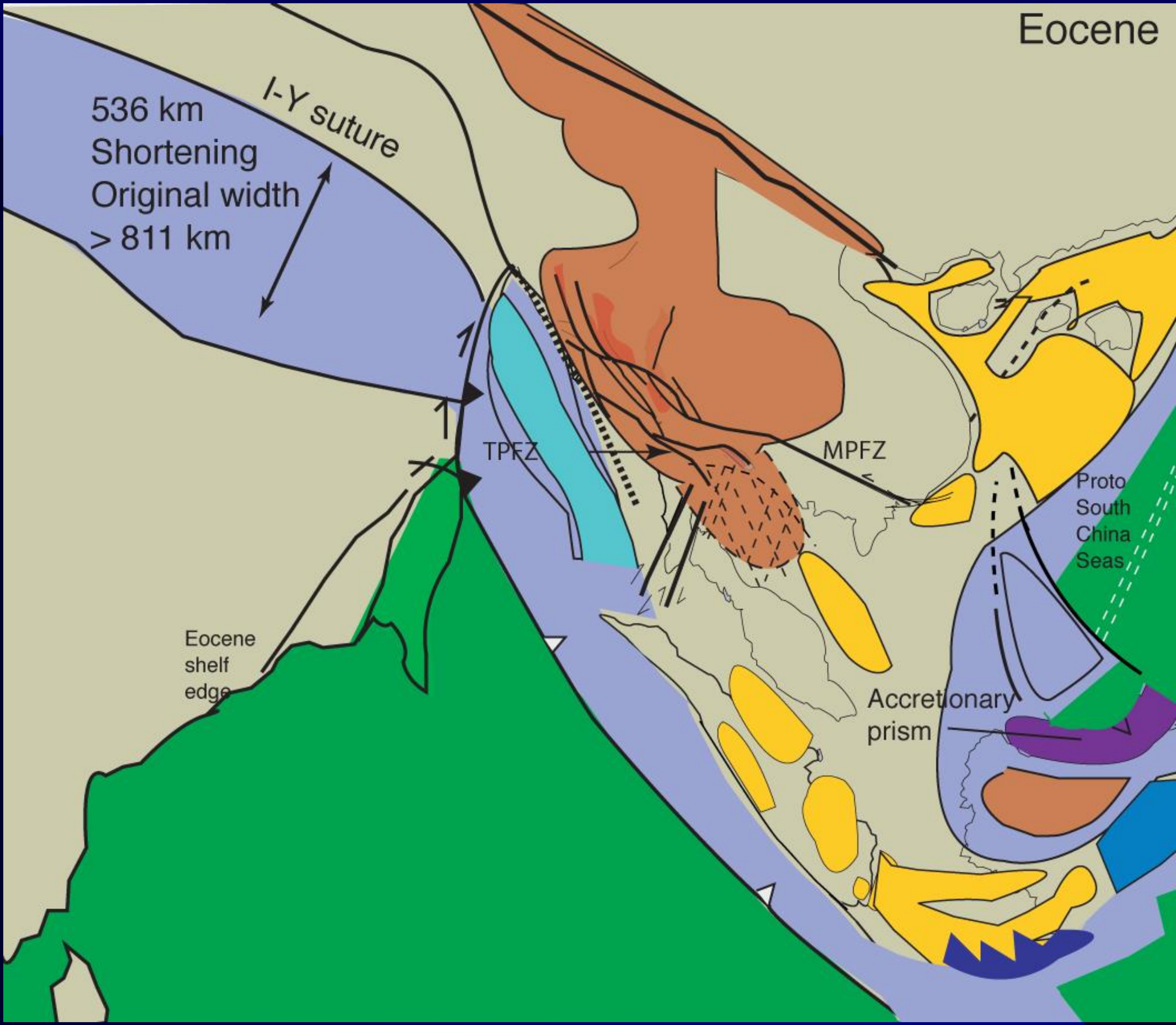
Continental Sands and shales


Aral Sea
Syr Darya
Amou Darya
Balkach Lake
Balkach
Izayan
Dzungar
Ili
Issyk Kul
Fergana
TIEN SHAN
Tarim He
Tarim (T)
13 – 7
GOBI
15 – 8
4 – 2
Hexi
QILIAN SHAN
N China Plateau
ORDOS (Q)
Huabei-Bohaiwan
BOHAI
DETROIT
SHANDONG
Yellow Sea
ALTYN TAGH F.
30 – 10
Qaidam (N+Q)
Haiyuan F.
Koko Nor
15 – 6
Kunlun F.
13 +7/-3
20 – 10
Karakorum F.
32 – 8
TIBET
Xianshuihe F.
9 mm/yr
6.5 – 2.5
DABIE SHAN
Chang Jiang
11
East China Sea
RYUKYU
Chaman F.
POTWAR
SULAIMAN
Sutlej
Indus
MAKRAN
KIRTHAR
HIMALAYA
Yamuna
Ganga
Gange
Brahmaputra
Salween
Bengal
50
INDO-BURMAN RANGES
Burma
Irrawaddy
Sagaing F.
SHAN
TENASSERIM
RED RIVER F.
5 mm/yr
Zhu He
HONGKONG
MACAO
Zhu (Pearl River)
Beibu
GULF OF TONKIN
HAINAN
Yinggehai
INDOCHINA
Wang Chao F.
Three Pagoda F.
Kra
GULF OF THAILAND
Western
Mekong
Pattani
Nam Consom
Malay
W Natuna
LUCONIA
Sarawak
KALIMANTAN
INDIA
Indus Fan
Bengal Fan
Andaman
ANDAMAN ISLANDS
Mergui
Sumatra
CEYLAN
INDIAN OCEAN
50°
60°
70°
80°
90°
100°
110°
120°
130°
40°
30°
20°
10°
0°
Lambert conical conformal projection : standard parallels 10¡N & 40¡N
500 km
Major faults
Average slip and convergence rates, when given, are in mm/yr
Ganga : Sedimentary basin. When not all Cenozoic thickness is known a letter indicates age of strata. T = Tertiary , N = Neogene, Q = Quatenary
▲ Stratigraphic column or geologic section
Major rivers
500
1000
2000
4000
8000
12000+
Cenozoic sediment thickness (m)

Orogenic belt between Red River Fault zone and Myanmar

Predominantly continental rifts

Mae Ping and Three Pagodas Fault zones active (not main Tibetan collision)



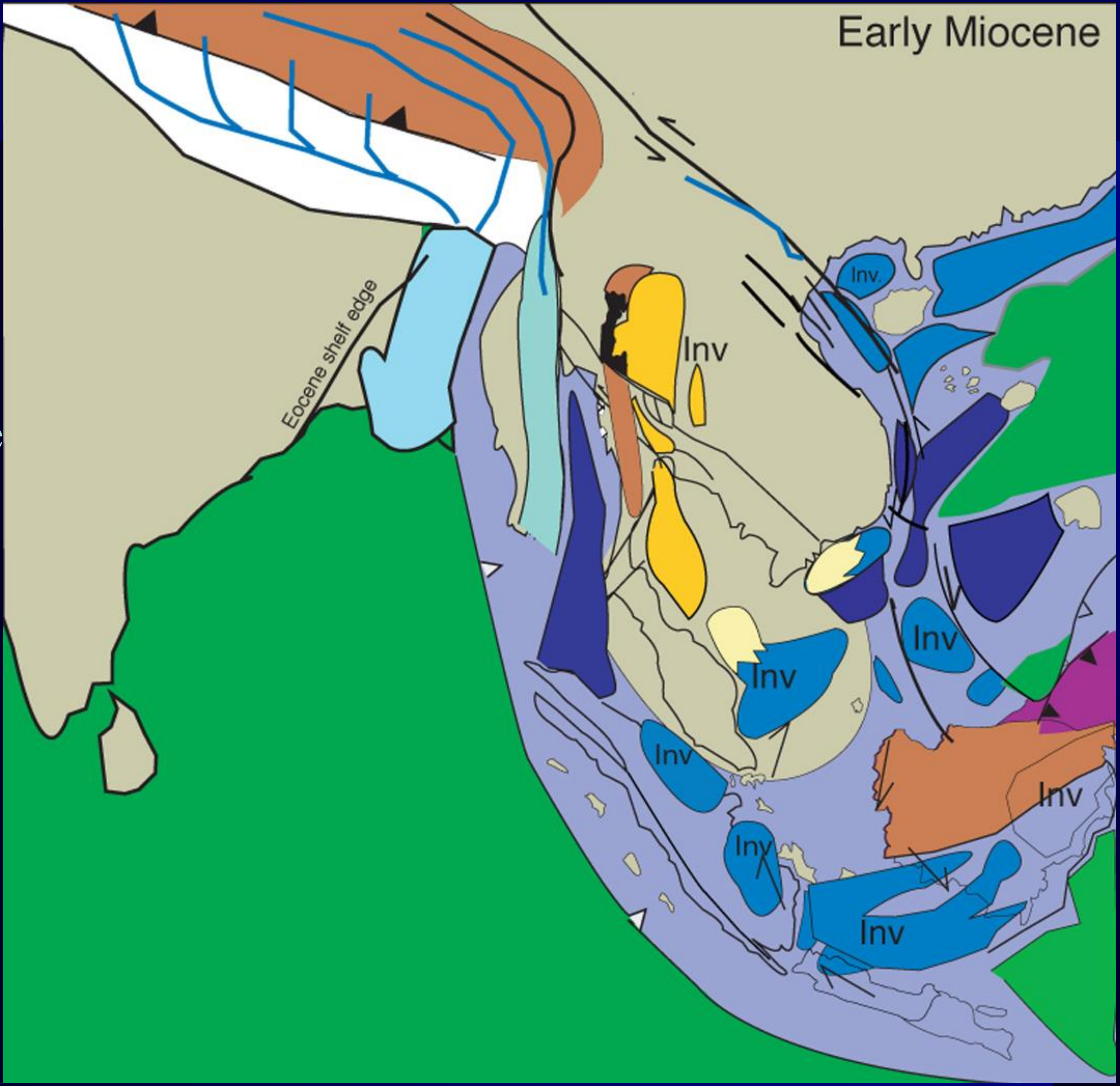
Modified from Lee and Lawver, 1995, Hall, 1995 and Morley 2002)

Thermal subsidence in southern Sundaland

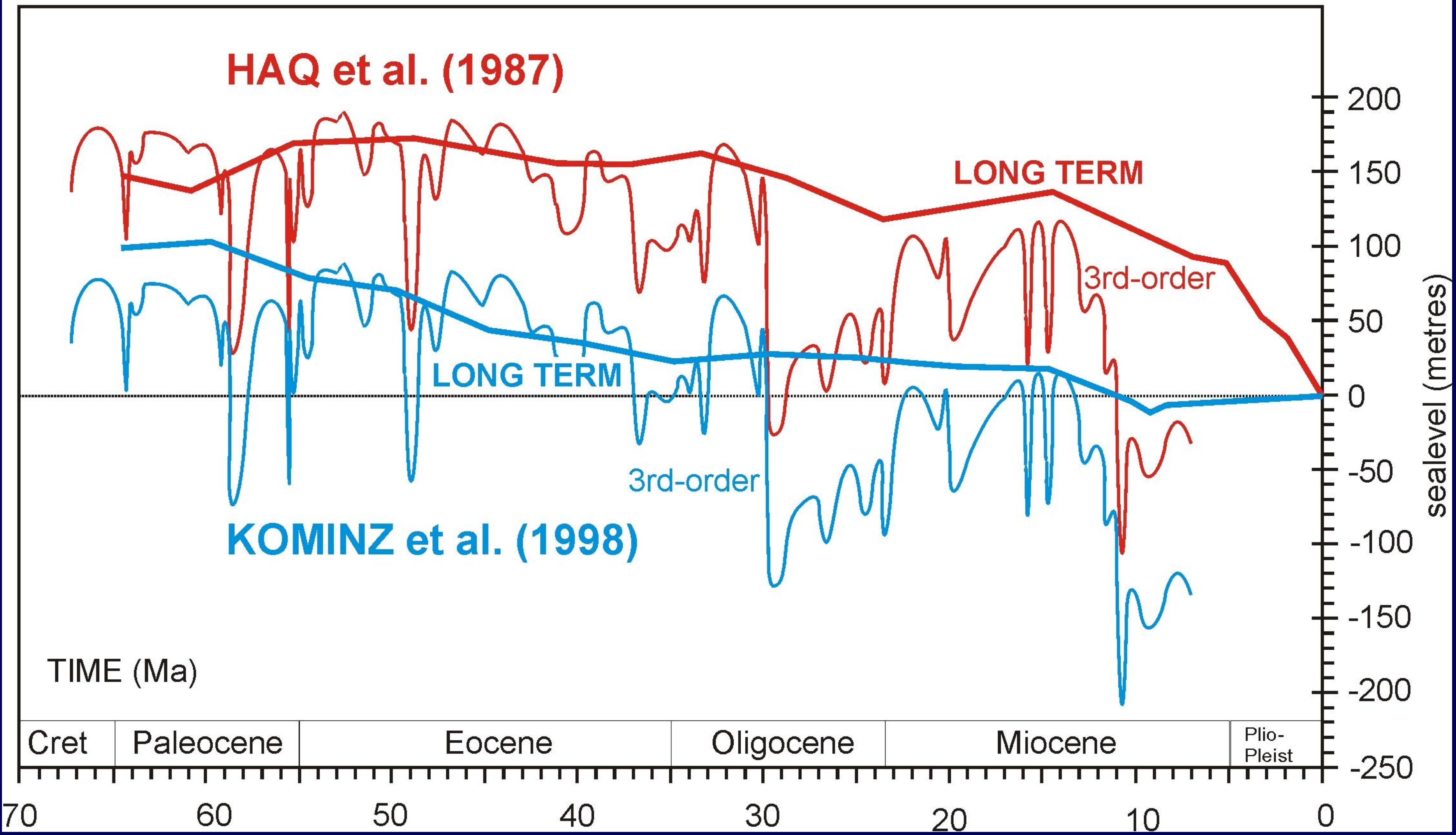
Extensive marine conditions

Uplift in west Thailand

Widespread inversion



CENOZOIC SEA-LEVEL CHANGE

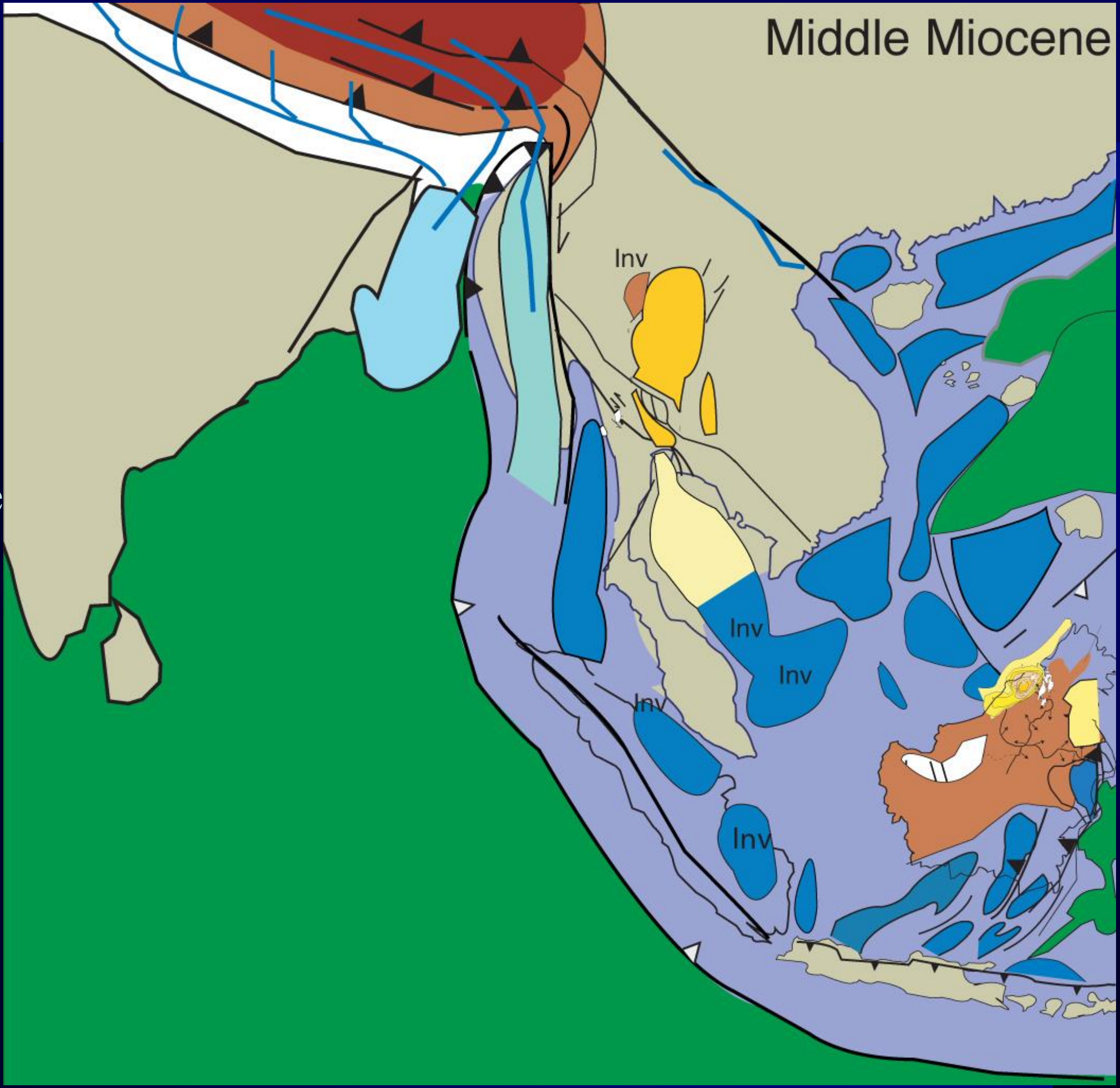


Thermal subsidence everywhere except onshore Thailand

Extensive marine conditions

Uplift west of Chiang Mai

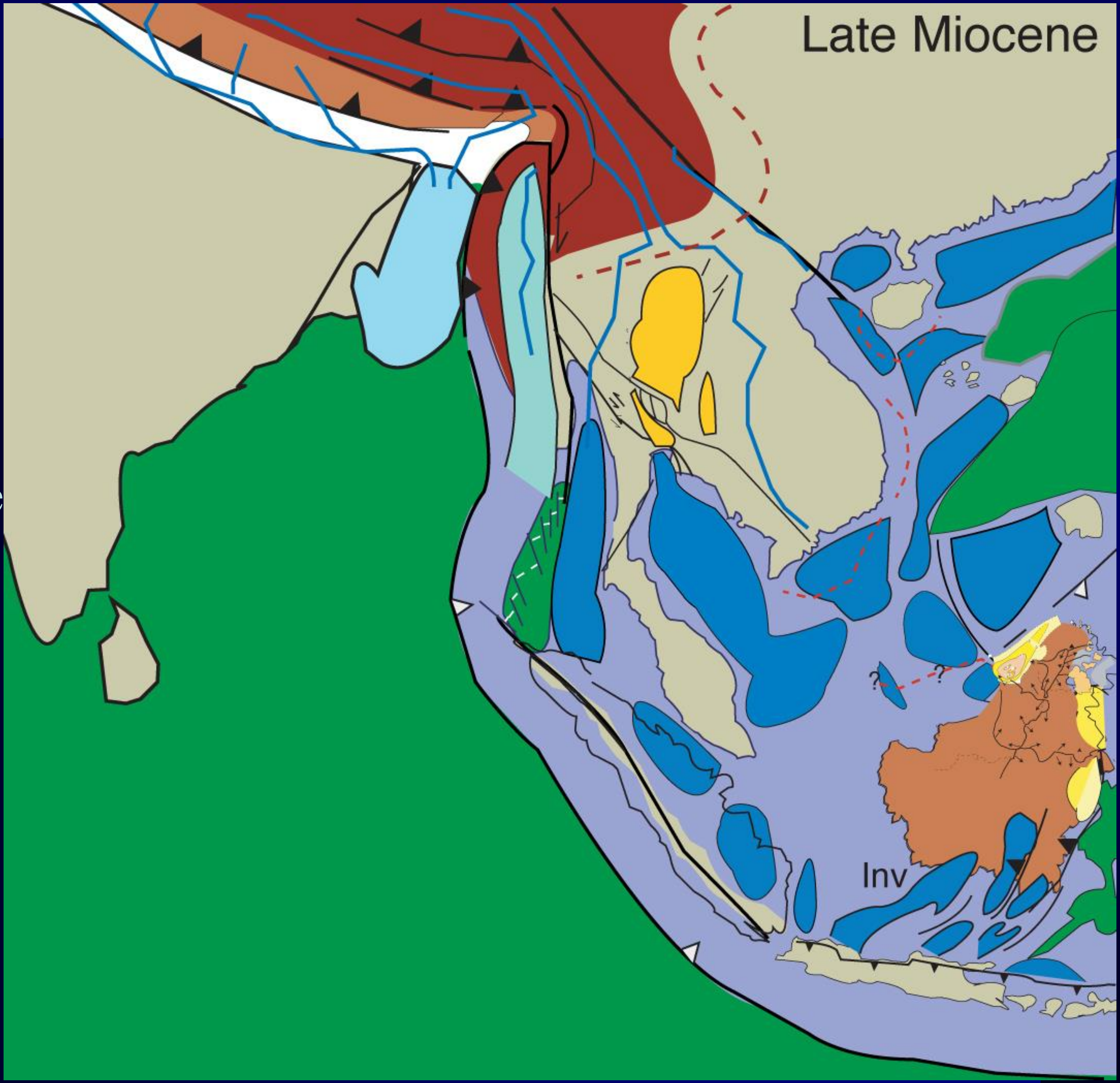
Widespread inversion



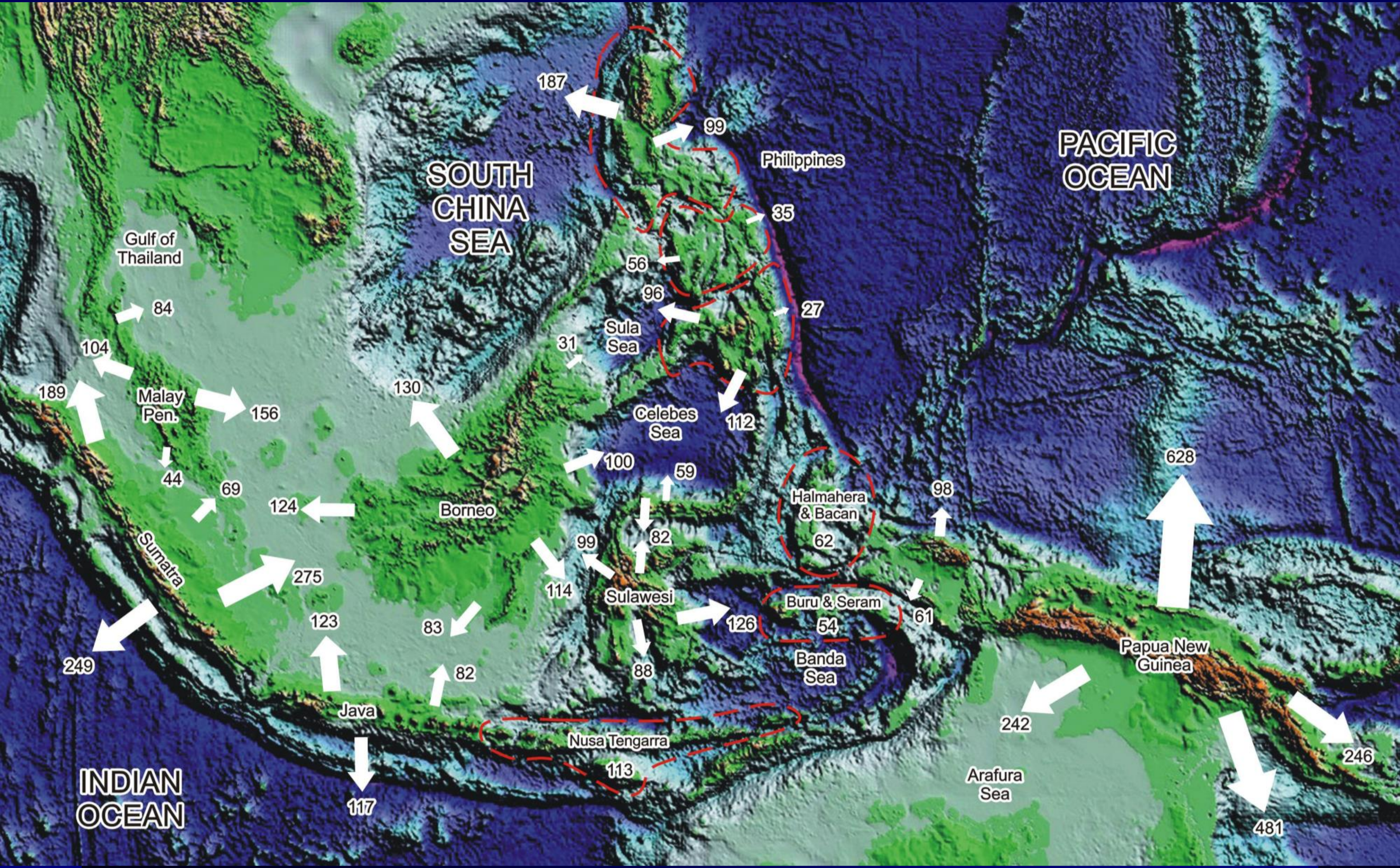
Thermal subsidence everywhere except onshore Thailand

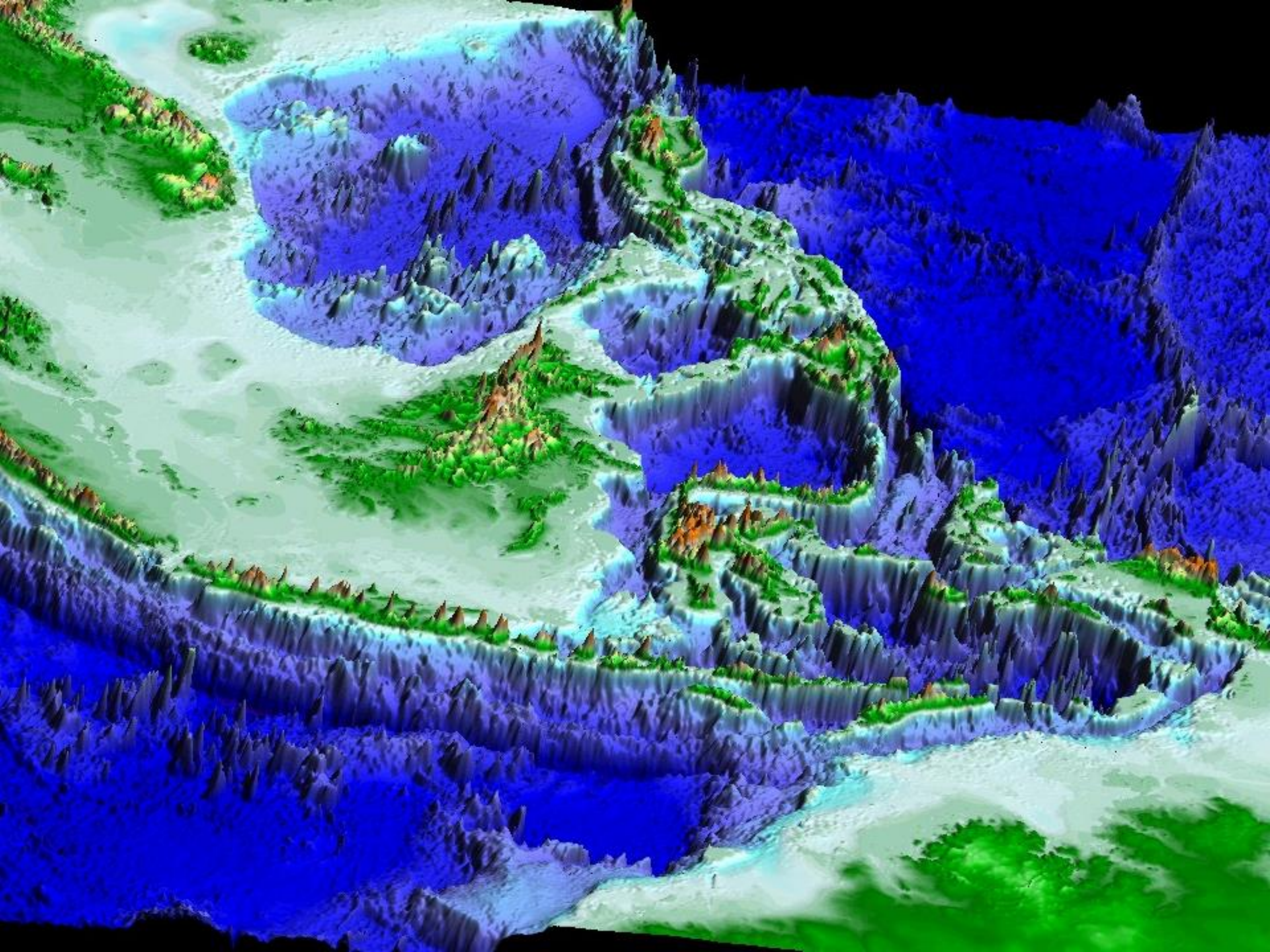
Extensive marine conditions

Start of Mekong and Salween rivers having headwaters in the Tibetan Plateau?

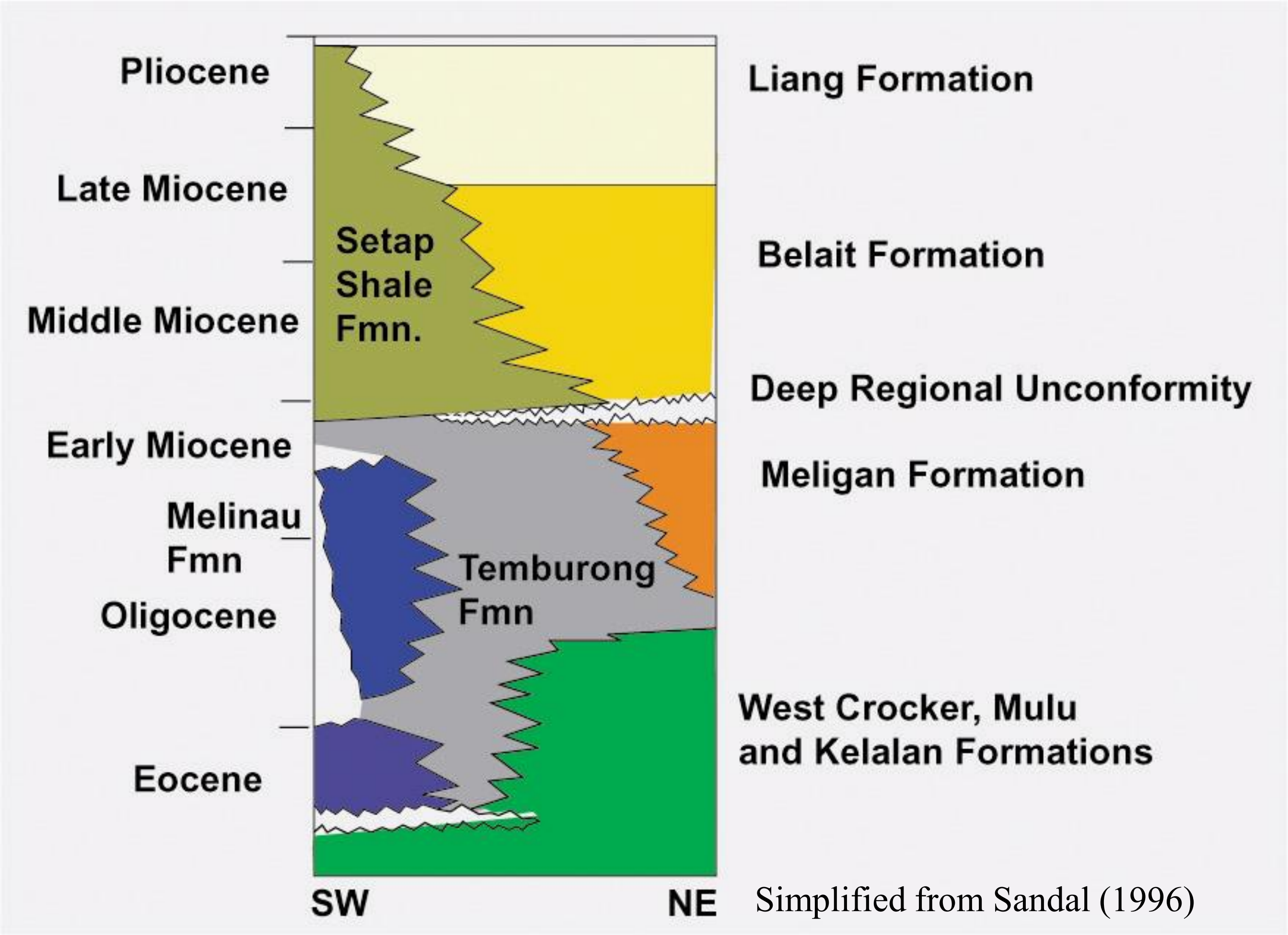


Regional setting: DEM





Tertiary stratigraphy of Brunei and Sarawak



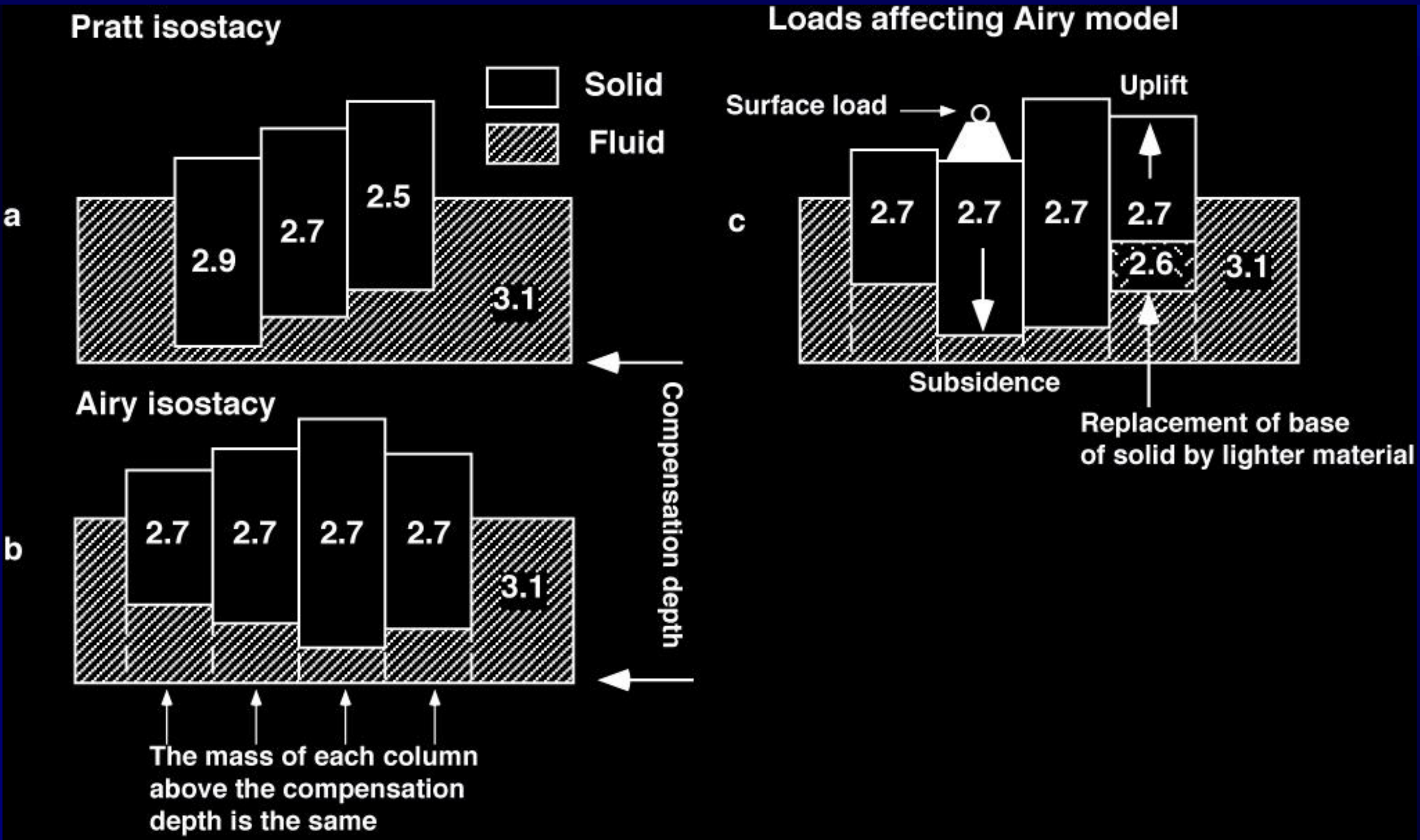
Simplified from Sandal (1996)

Uplift of accretionary prism, massive erosion

Jamming of Subduction zone Slow emergence of Islands within accretionary prism

Accretionary prism

Models for local isostasy



Basic principals of local isotasy

The sum of masses of different rock units in the columns must be equal:

1

$$t_w\rho_w + t_{ps}\rho_{ps} + t_c\rho_c + t_m\rho_m = \text{constant}$$

t is thickness and ρ is density of *w* water, *ps* sediment *c* crust *m* mantle.

If deposition adds material to the column the mass of a compensated column before sediments (ρ_s) are deposited is:

2a

$$t_w\rho_w + t_{ps}\rho_{ps} + t_c\rho_c + \left[D_c - \left(t_c + t_{ps} + t_w\right)\right]\rho_m$$

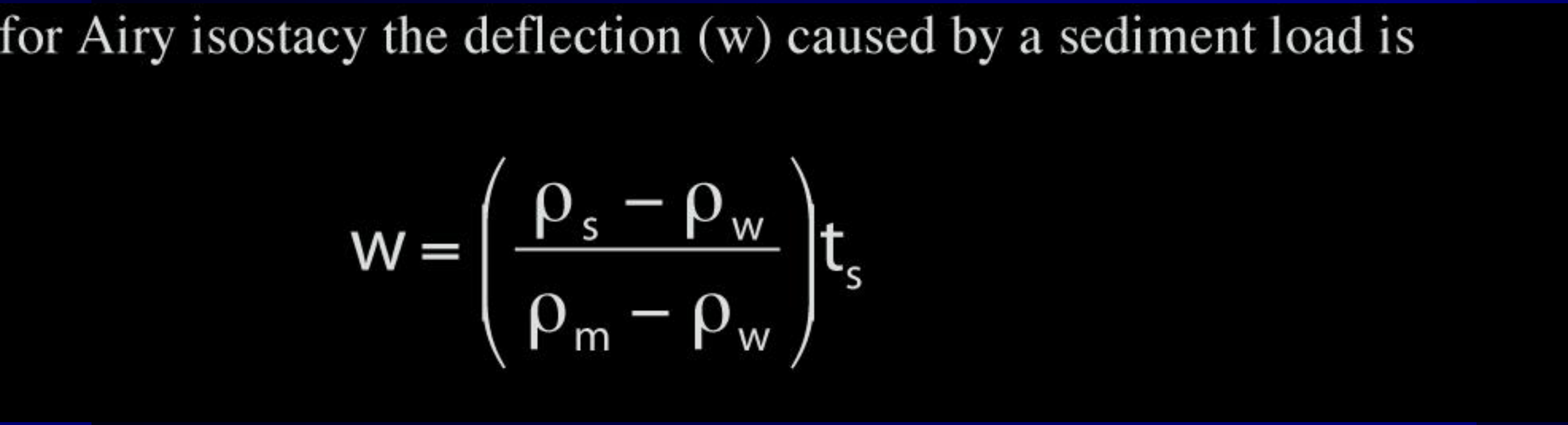
Where D_c = compensation depth, and ρ_{ps} is the density of sediments deposited prior to the episode of sedimentation that caused the loading.

After sediment deposition it becomes:

2b

$$\left(t_w + w - t_s\right)\rho_w + t_s\rho_s + t_{ps}\rho_{ps} + t_c\rho_c + \left[D_c - \left(t_c + t_{ps} + w + t_w\right)\right]\rho_m$$

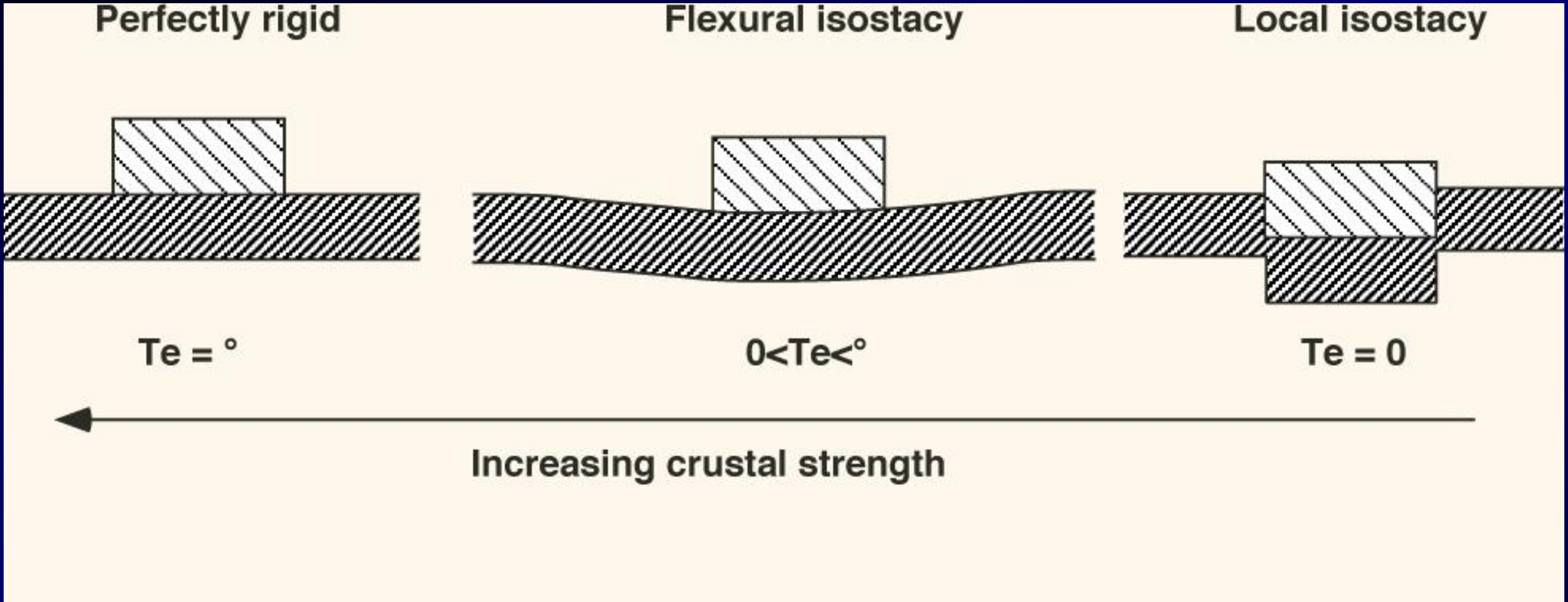
Key assumption in Airy isostasy - no change in crust thickness

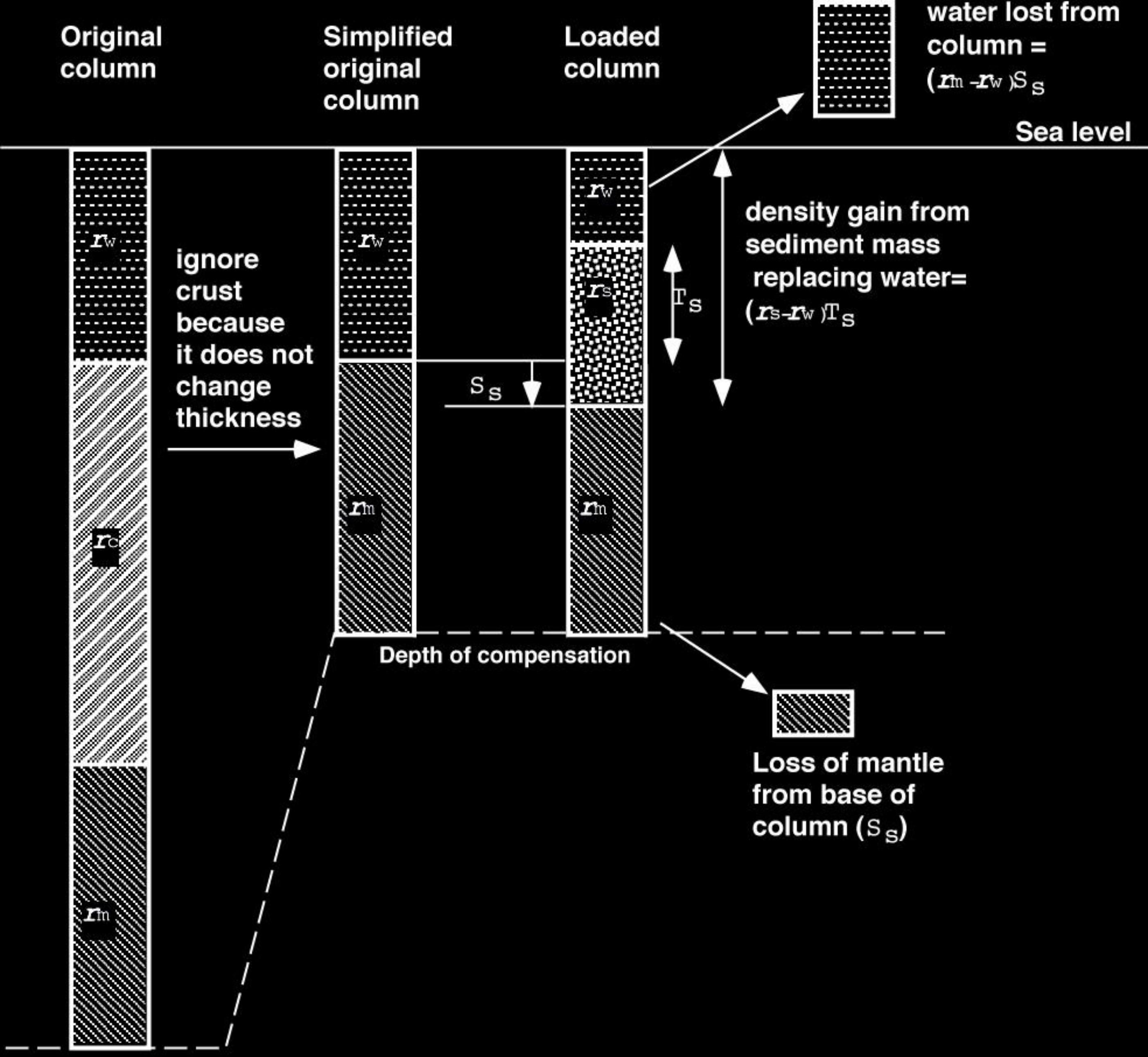


for Airy isostacy the deflection (w) caused by a sediment load is

$$w = \left(\frac{\rho_s - \rho_w}{\rho_m - \rho_w} \right) t_s$$

Basic modes of load support





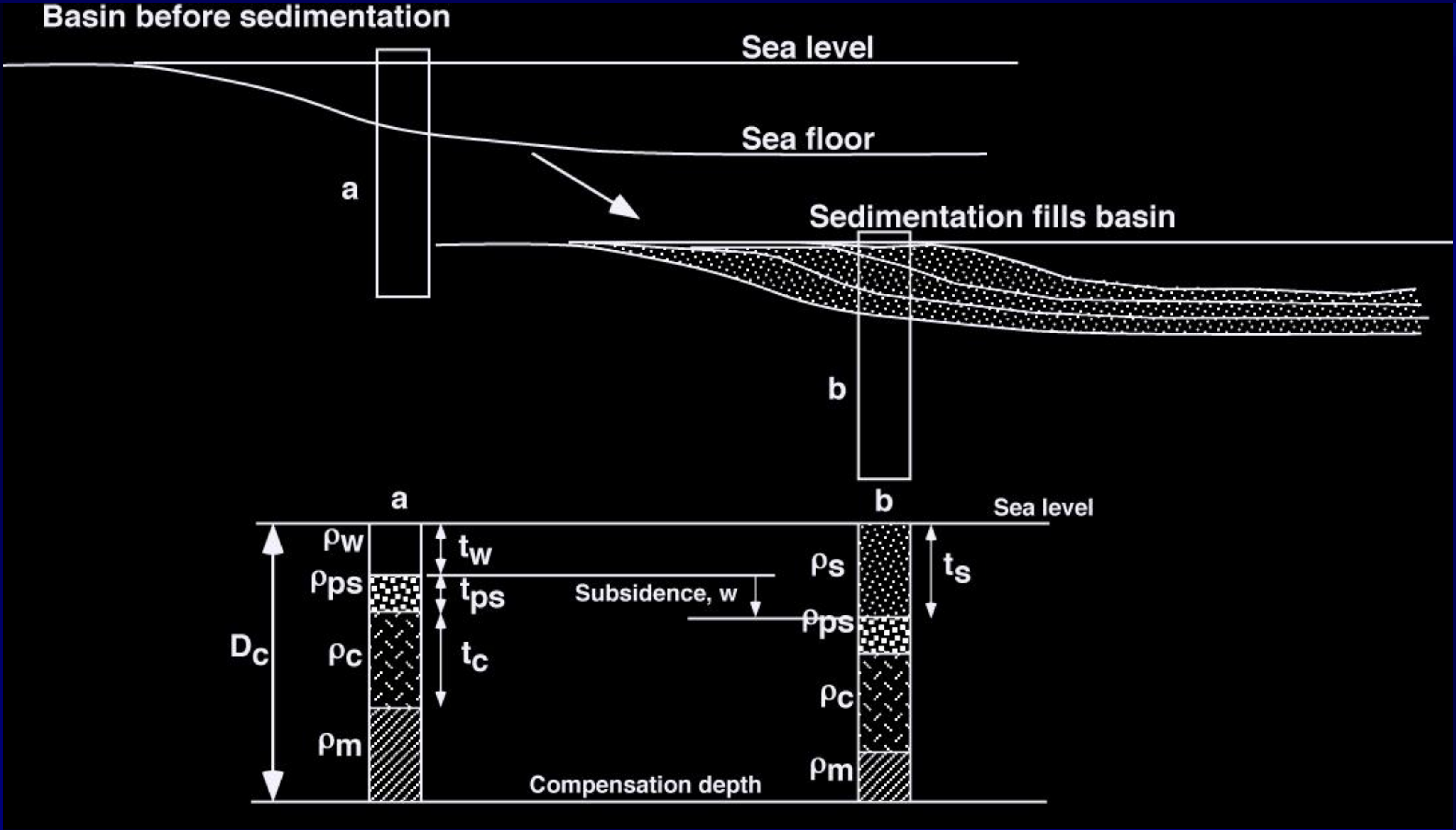
ignore crust because it does not change thickness

water lost from column = $(\rho_m - \rho_w)S_s$

density gain from sediment mass replacing water= $(\rho_s - \rho_w)T_s$

Loss of mantle from base of column (S_s)

Sediment loading

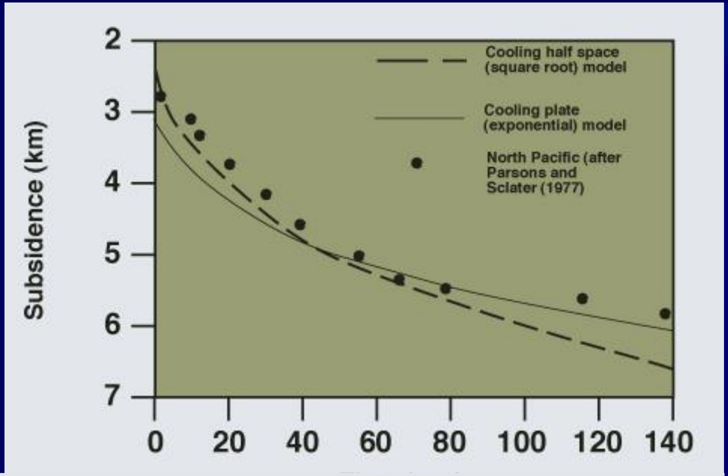


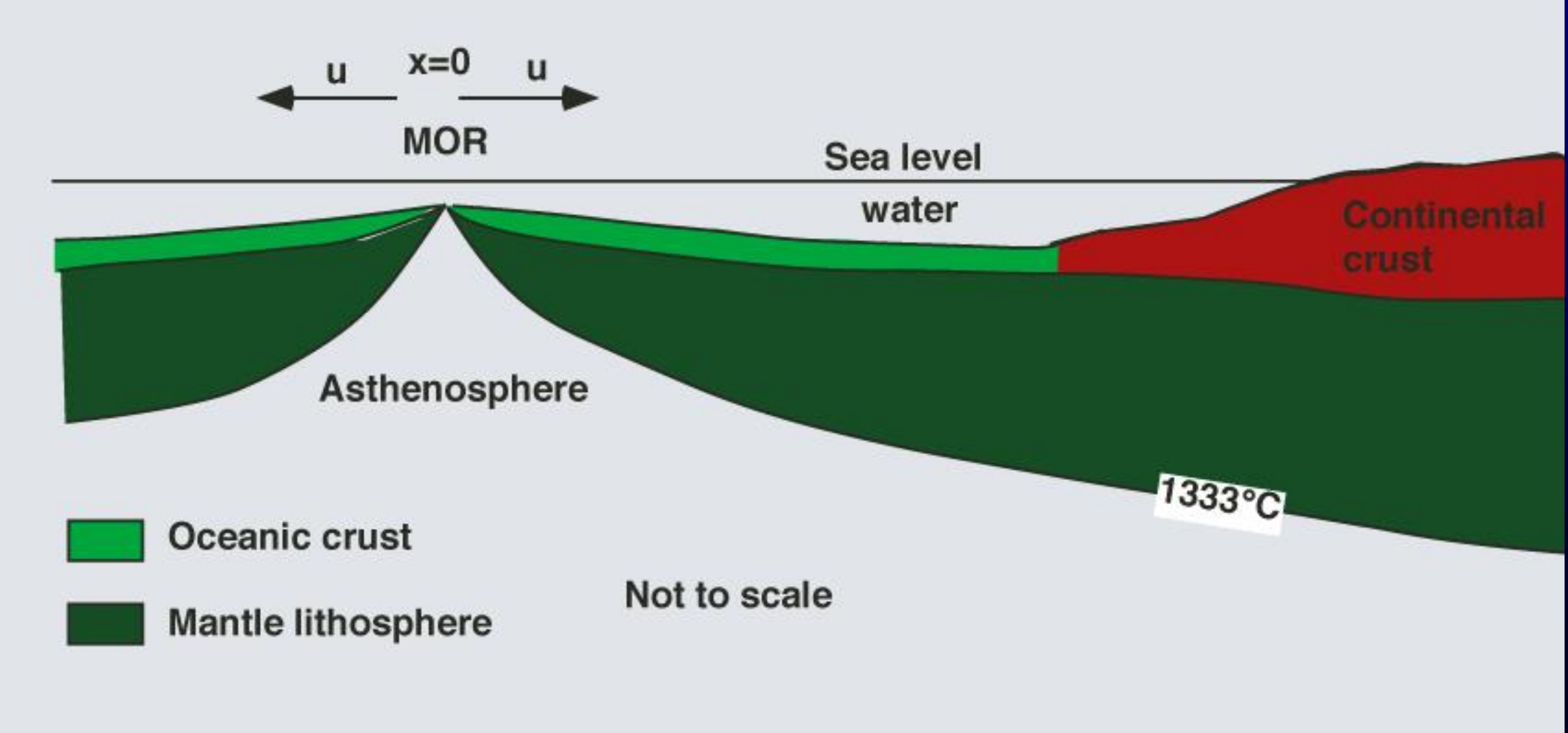
The basics of thermal subsidence

Thermal subsidence is the isostatic result of heating the crust during extension, and the subsequent cooling of the thermal anomaly post-rifting

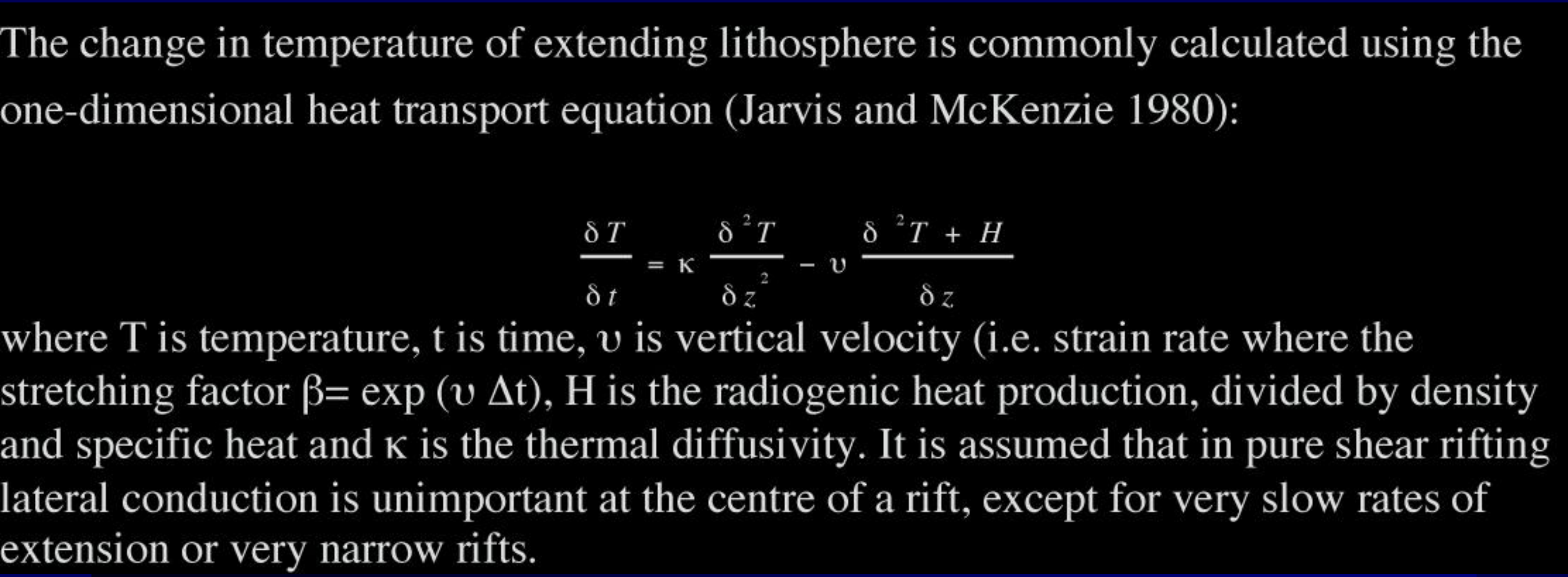
The models for the continental crust were based on cooling of the oceanic crust as it moved away from mid oceanic ridges

Cooling of oceanic crust is exponential





Rifting causes change in thermal structure of lithosphere

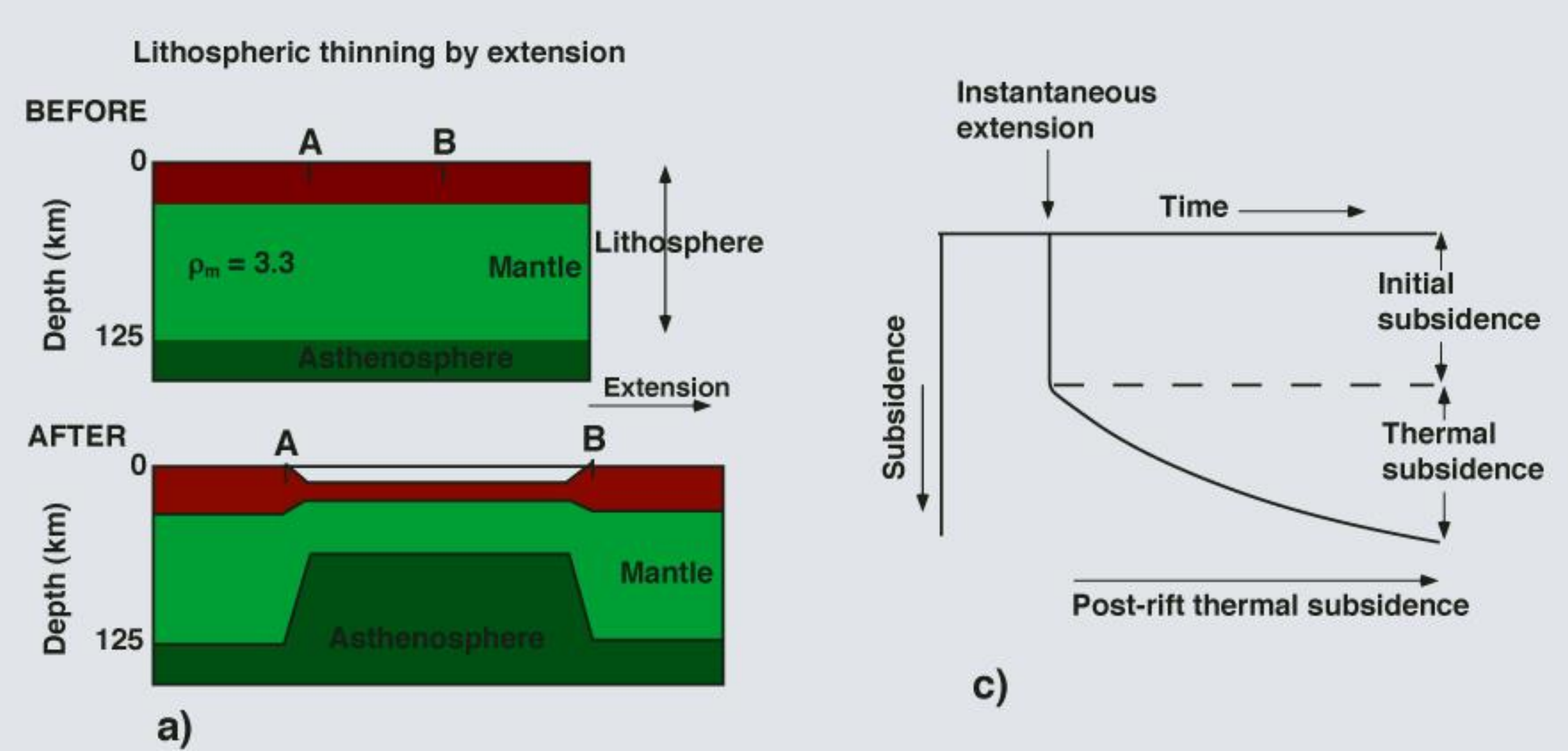


The change in temperature of extending lithosphere is commonly calculated using the one-dimensional heat transport equation (Jarvis and McKenzie 1980):

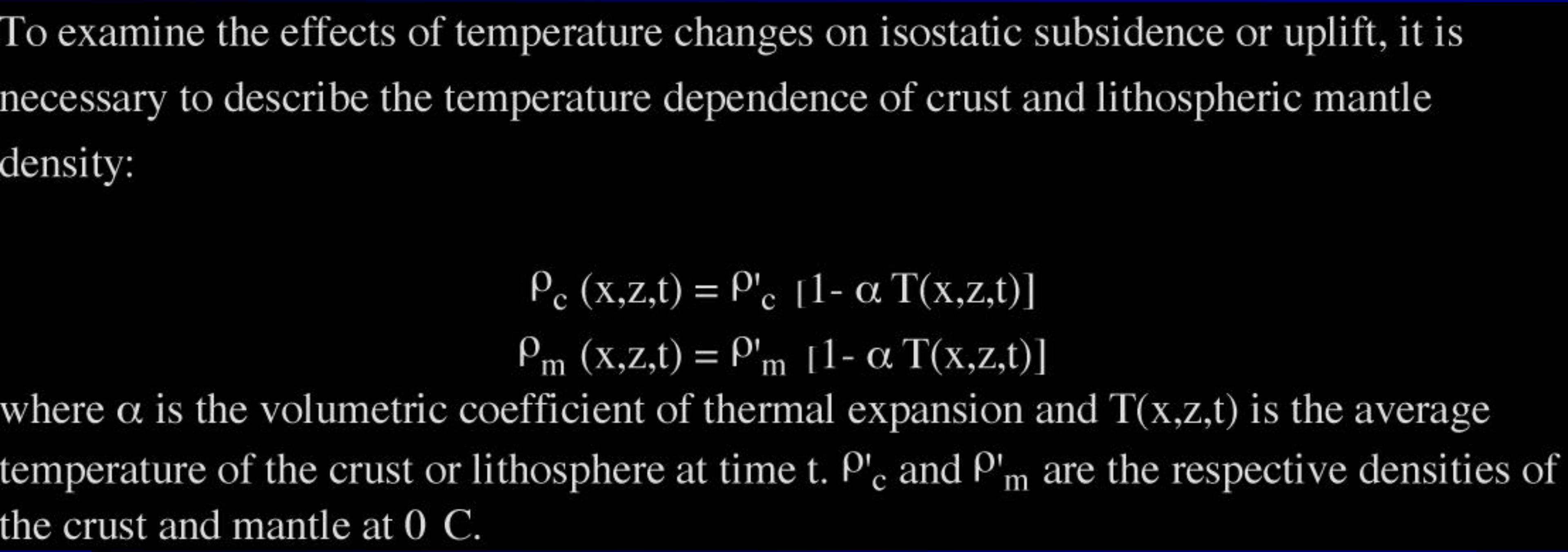
$$\frac{\delta T}{\delta t} = \kappa \frac{\delta^{2} T}{\delta z^{2}} - \upsilon \frac{\delta^{2} T + H}{\delta z}$$

where T is temperature, t is time, υ is vertical velocity (i.e. strain rate where the stretching factor $\beta = \exp(\upsilon \Delta t)$, H is the radiogenic heat production, divided by density and specific heat and κ is the thermal diffusivity. It is assumed that in pure shear rifting lateral conduction is unimportant at the centre of a rift, except for very slow rates of extension or very narrow rifts.

McKenzie model for passive extension



Temperature dependence of lithosphere density on temperature



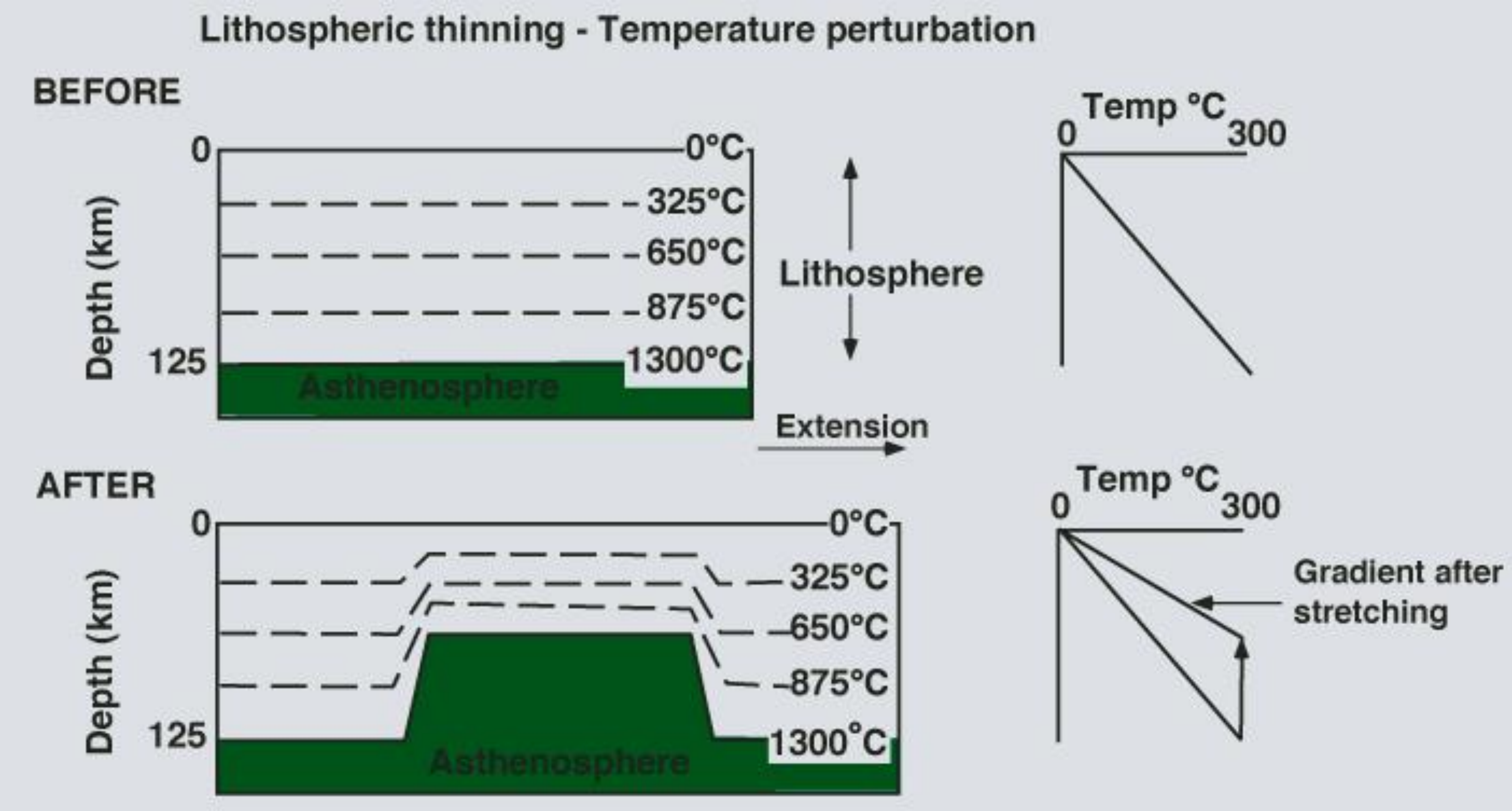
To examine the effects of temperature changes on isostatic subsidence or uplift, it is necessary to describe the temperature dependence of crust and lithospheric mantle density:

$$\rho_c\ (x,z,t) = \rho'_c\ [1 - \alpha\, T(x,z,t)]$$

$$\rho_m\ (x,z,t) = \rho'_m\ [1 - \alpha\, T(x,z,t)]$$

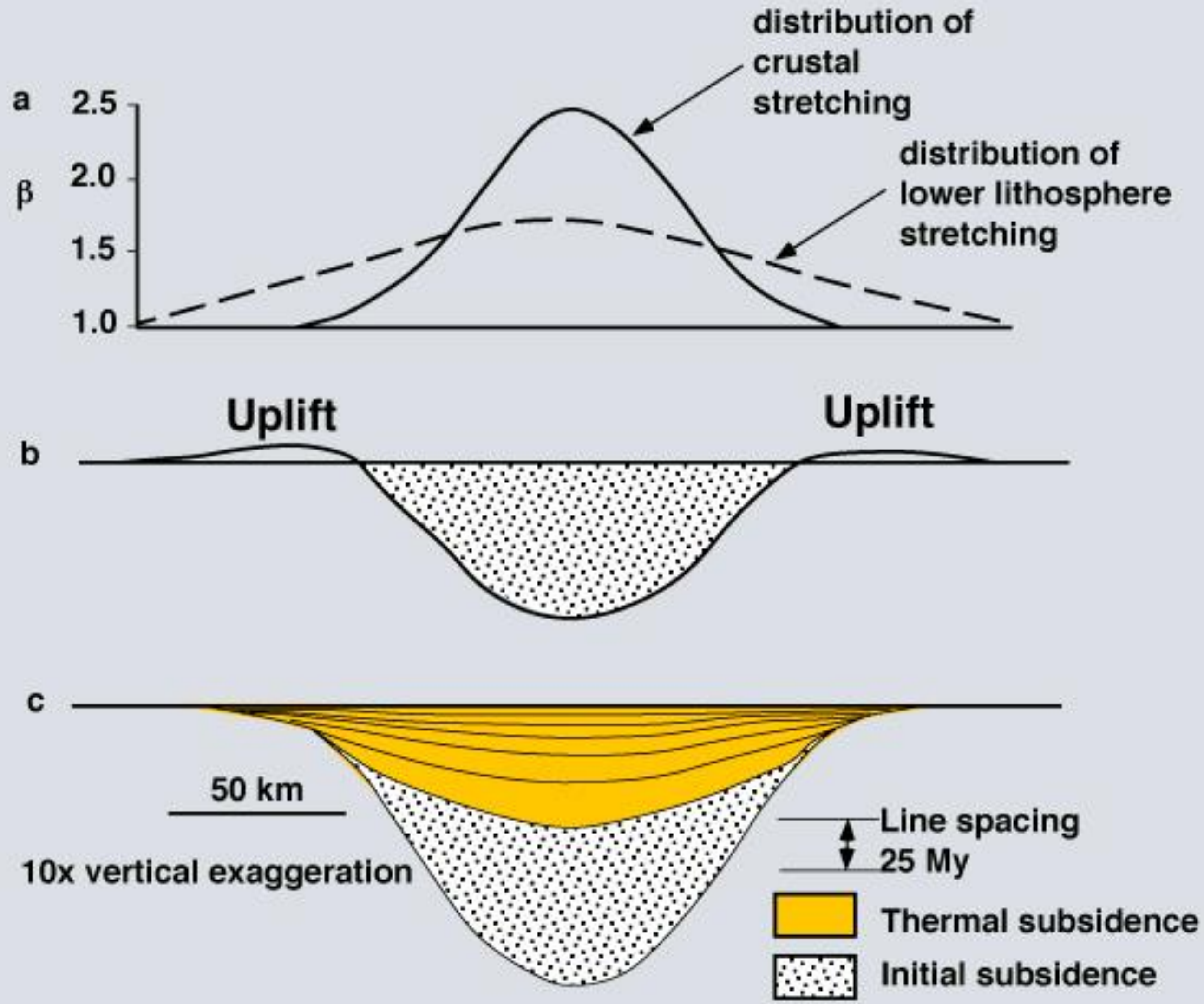
where α is the volumetric coefficient of thermal expansion and T(x,z,t) is the average temperature of the crust or lithosphere at time t. ρ'_c and ρ'_m are the respective densities of the crust and mantle at 0 C.

Thermal consequences of passive rifting

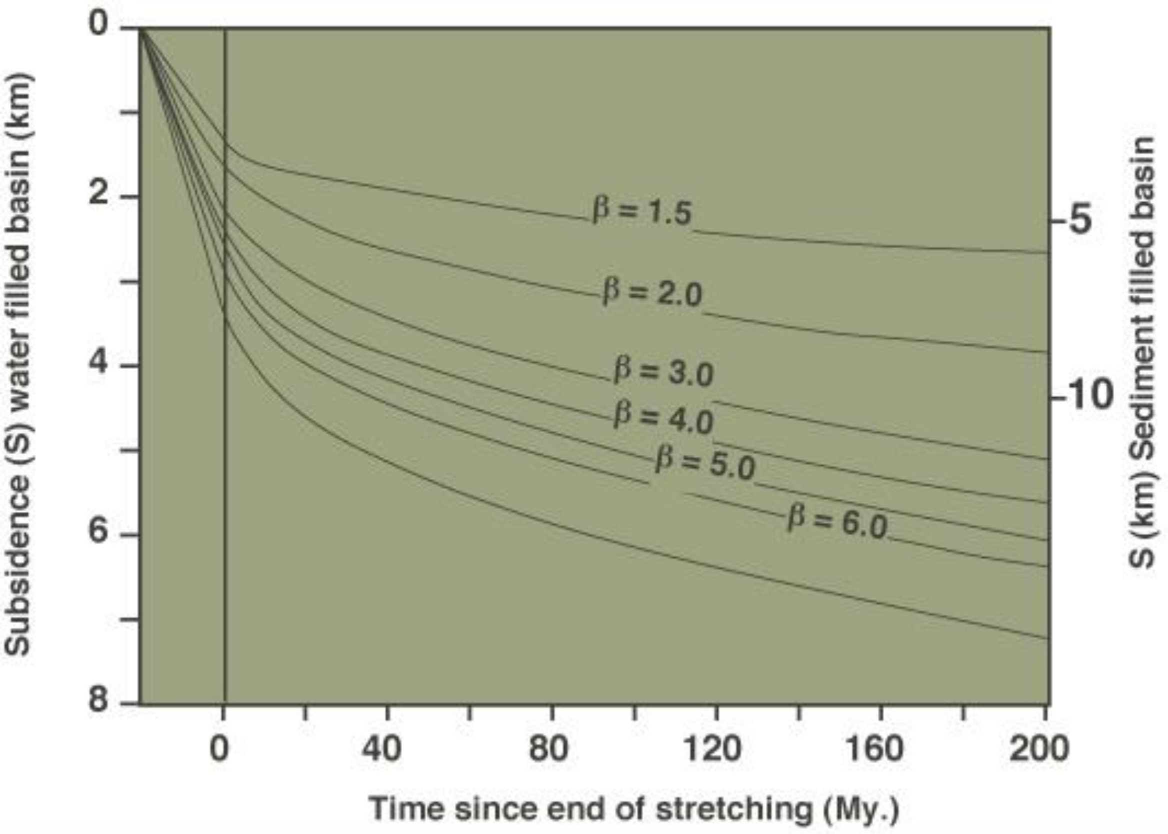


McKenzie model extension followed by thermal subsidence

Maximum subsidence at start of post-rift basin which decreases upwards

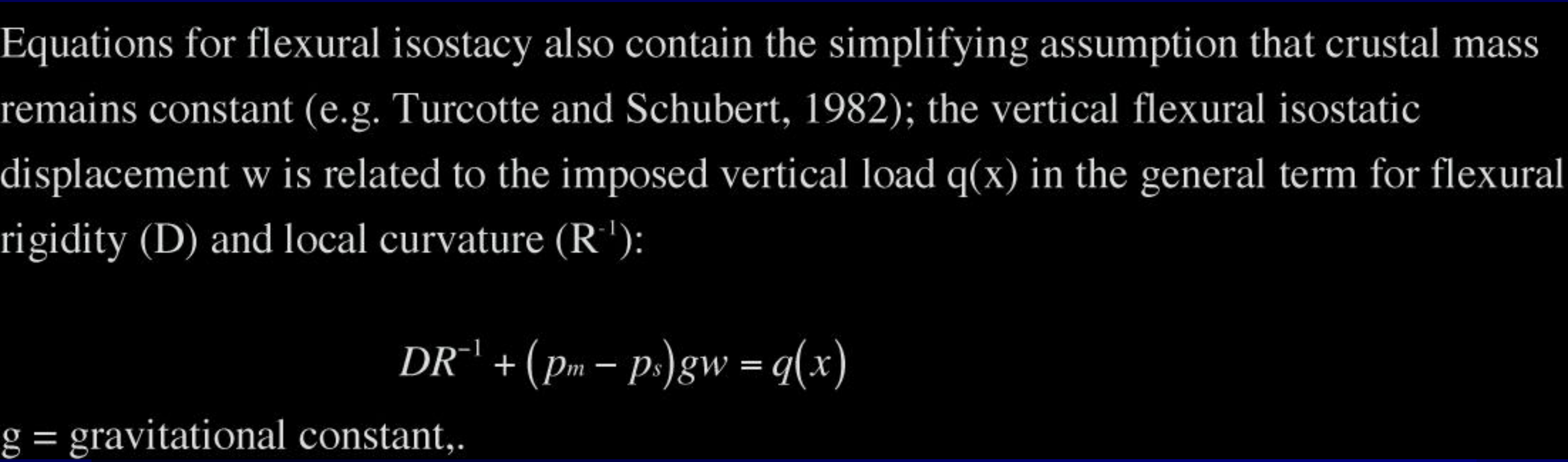


Relationship between syn-rift extension (β) and post-rift subsidence (passive rifting)



The contribution by sediment loading cannot be fully predicted by the model

Basic flexural isostasy equation

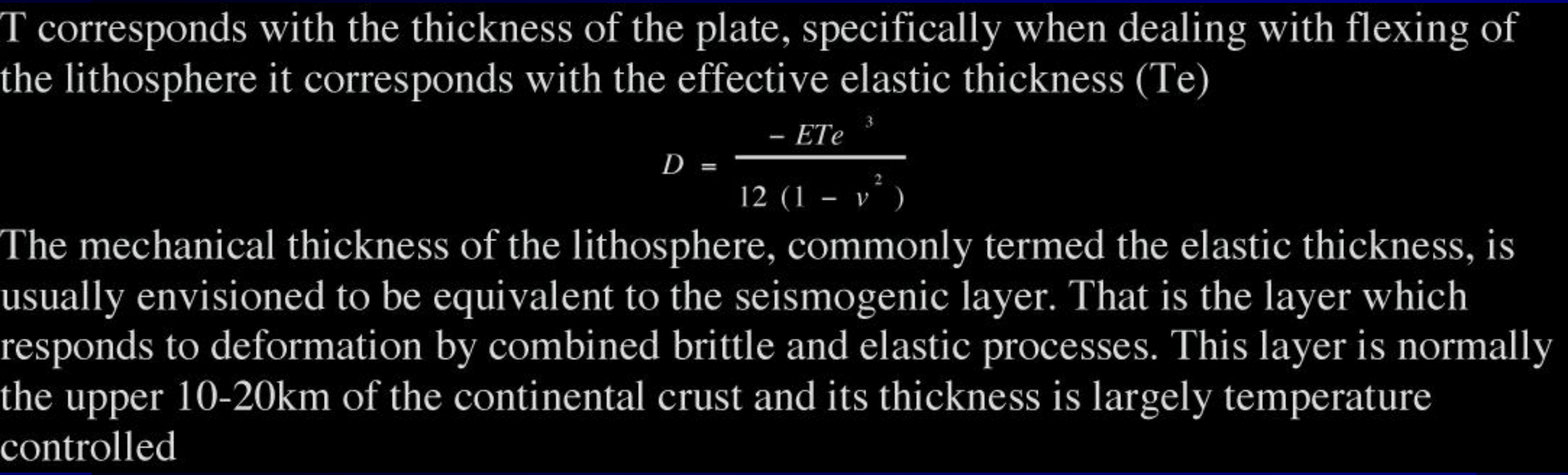


Equations for flexural isostacy also contain the simplifying assumption that crustal mass remains constant (e.g. Turcotte and Schubert, 1982); the vertical flexural isostatic displacement w is related to the imposed vertical load q(x) in the general term for flexural rigidity (D) and local curvature (R^{-1}):

$$DR^{-1} + (p_m - p_s)gw = q(x)$$

g = gravitational constant,.

The importance of elastic thickness to flexural behaviour

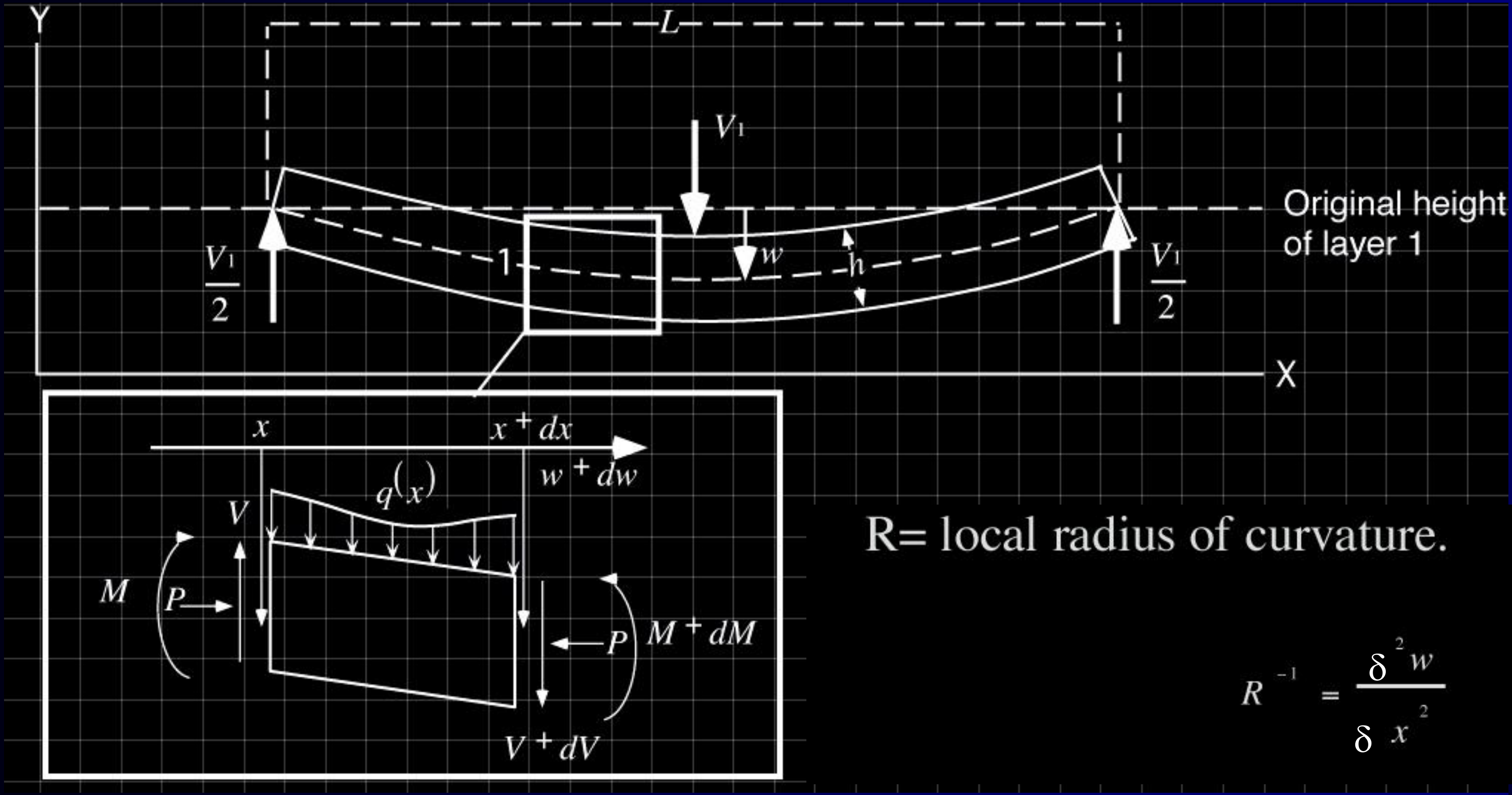


T corresponds with the thickness of the plate, specifically when dealing with flexing of the lithosphere it corresponds with the effective elastic thickness (Te)

$$D = \frac{-ETe^{3}}{12(1 - v^{2})}$$

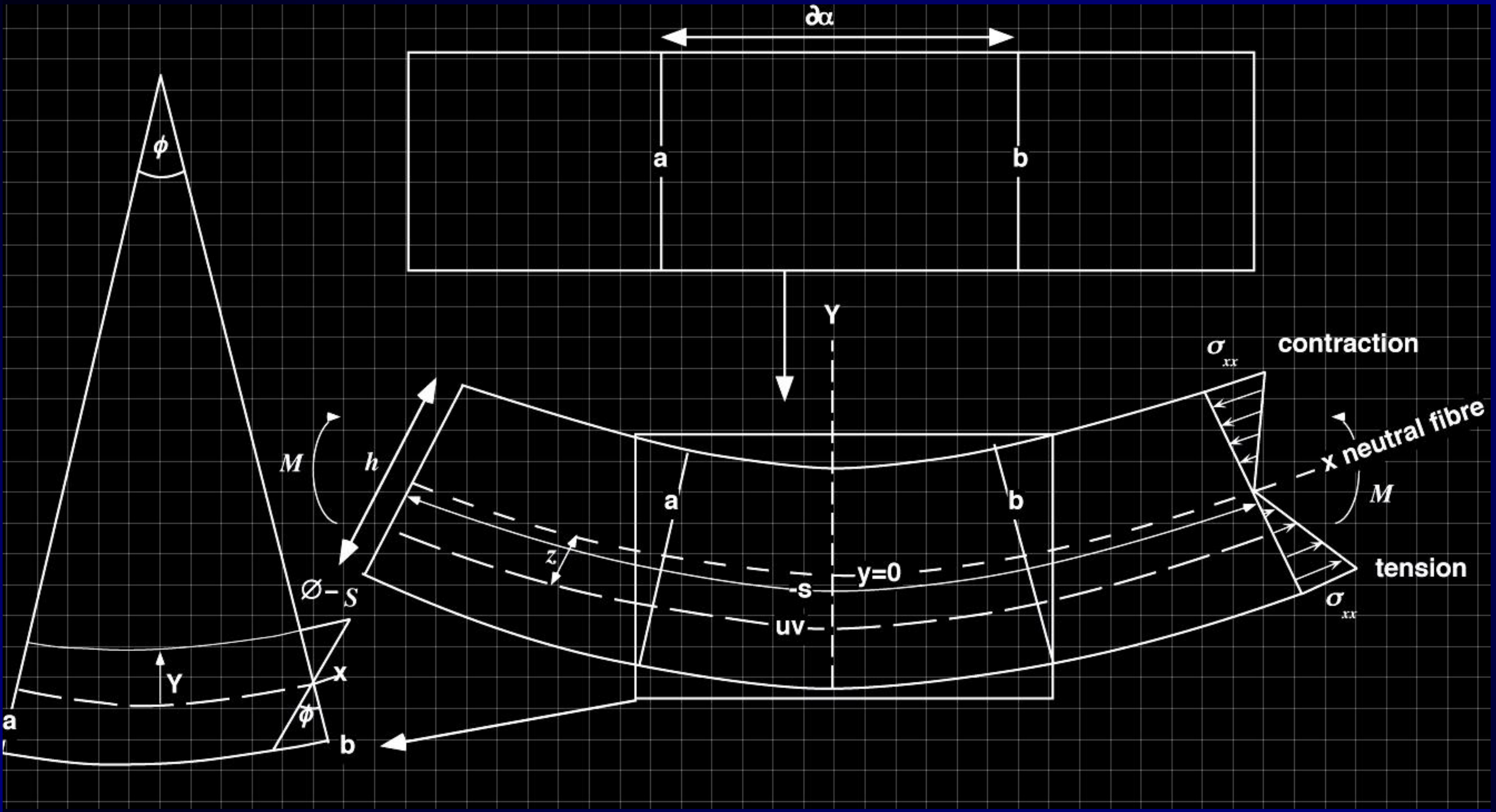
The mechanical thickness of the lithosphere, commonly termed the elastic thickness, is usually envisioned to be equivalent to the seismogenic layer. That is the layer which responds to deformation by combined brittle and elastic processes. This layer is normally the upper 10-20km of the continental crust and its thickness is largely temperature controlled

Bending of a beam

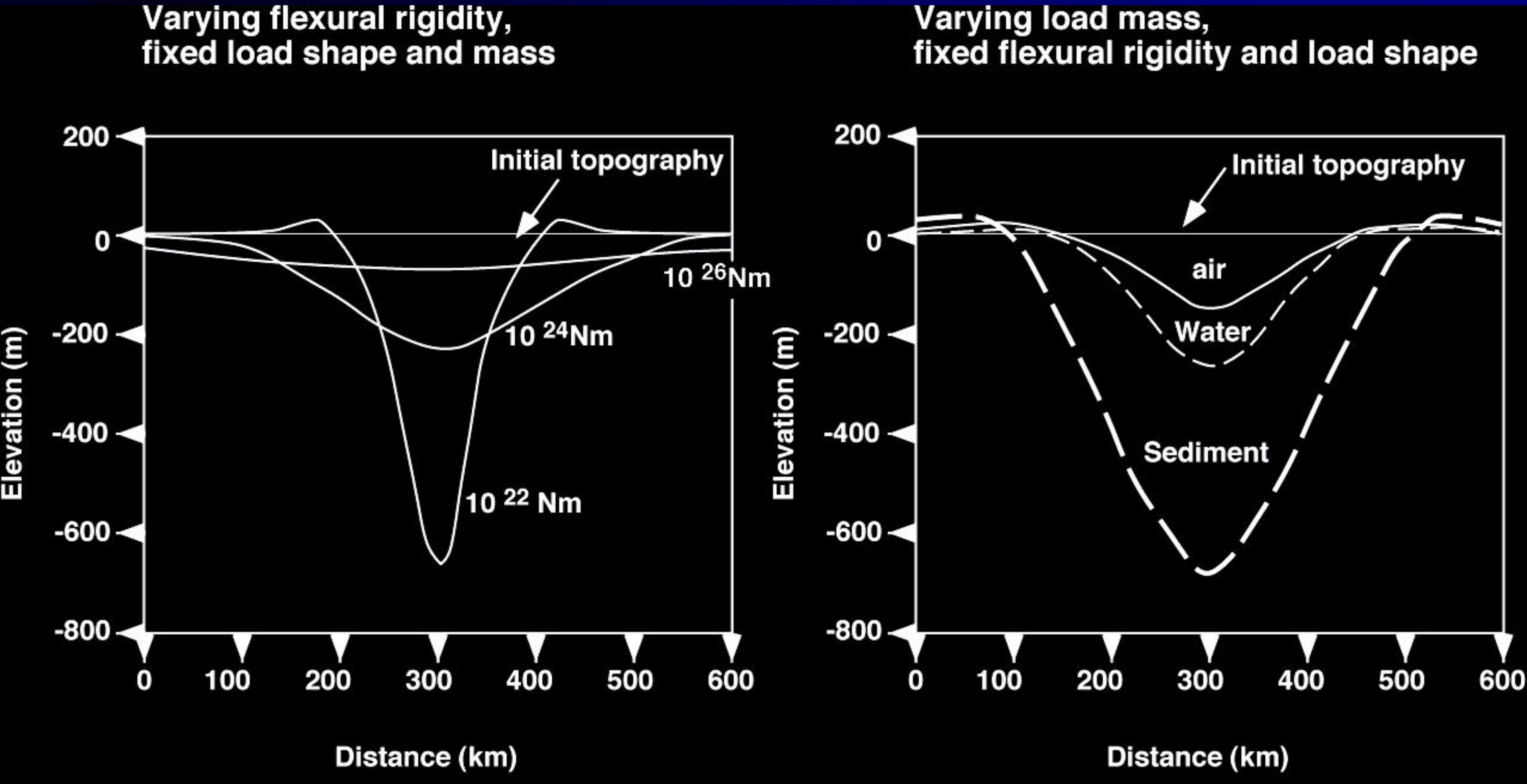


R= local radius of curvature.

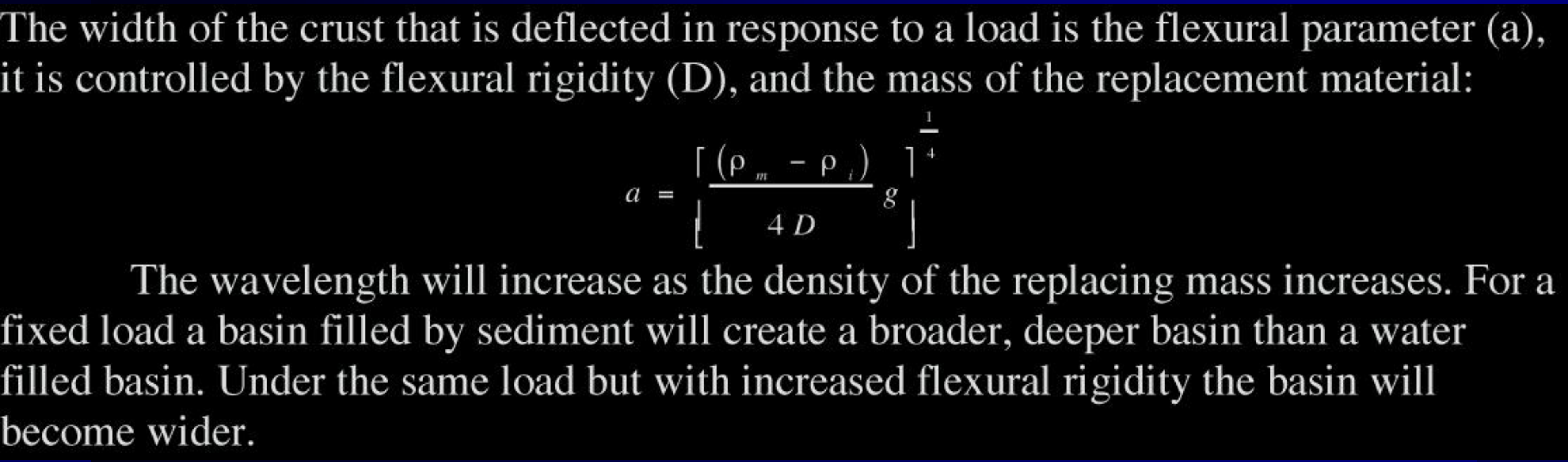
$$R^{-1} = \frac{\delta^2 w}{\delta x^2}$$


∂α
a
b
φ
M
h
Y
σ_xx
contraction
x neutral fibre
M
a
b
z
y=0
s
uv
tension
σ_xx
∅ - S
Y
x
φ
a
b

Effects of varying Te and load mass on basin geometry



Wavelength of crustal deflection in response to a load

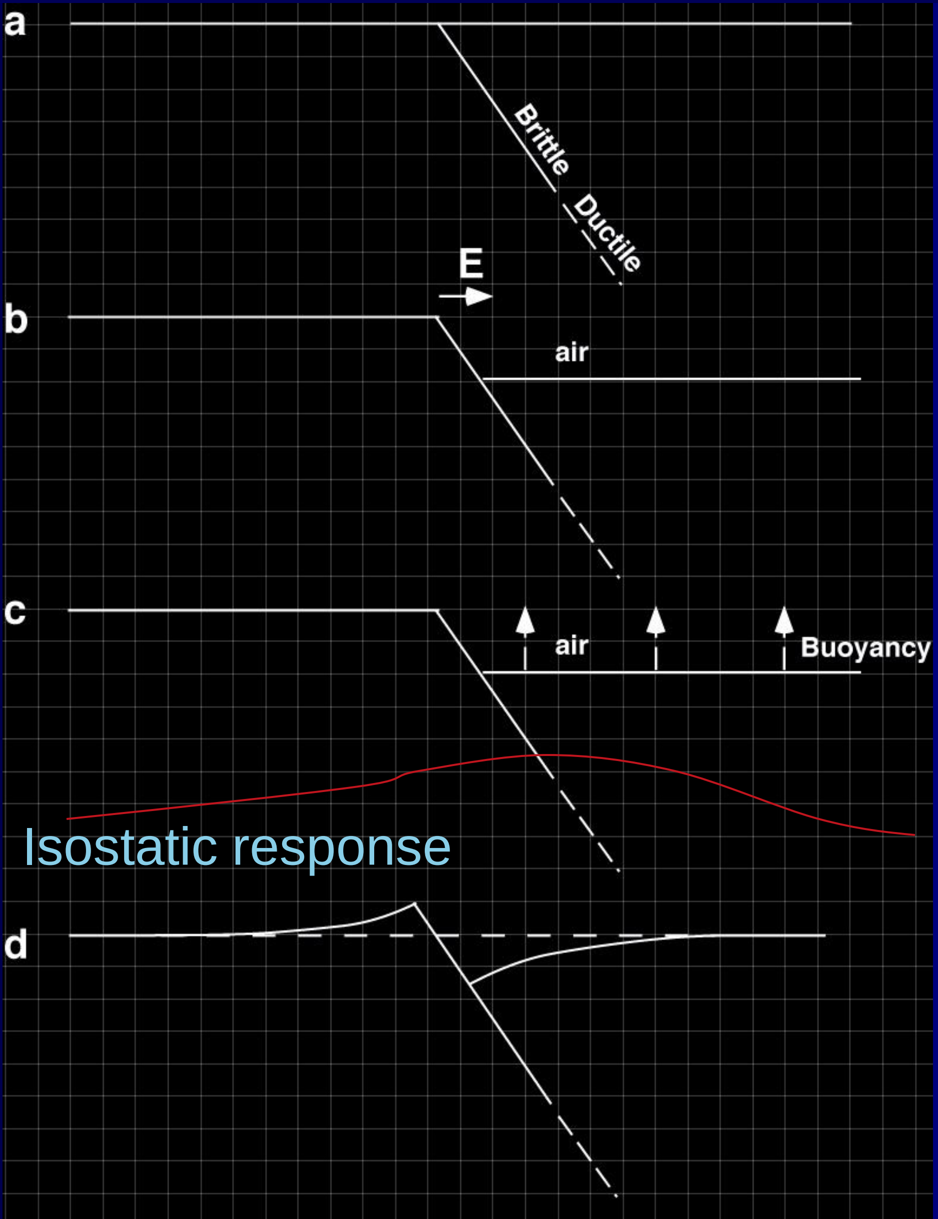


The width of the crust that is deflected in response to a load is the flexural parameter (a), it is controlled by the flexural rigidity (D), and the mass of the replacement material:

$$a = \left[\frac{(\rho_m - \rho_i)}{4D} g\right]^{\frac{1}{4}}$$

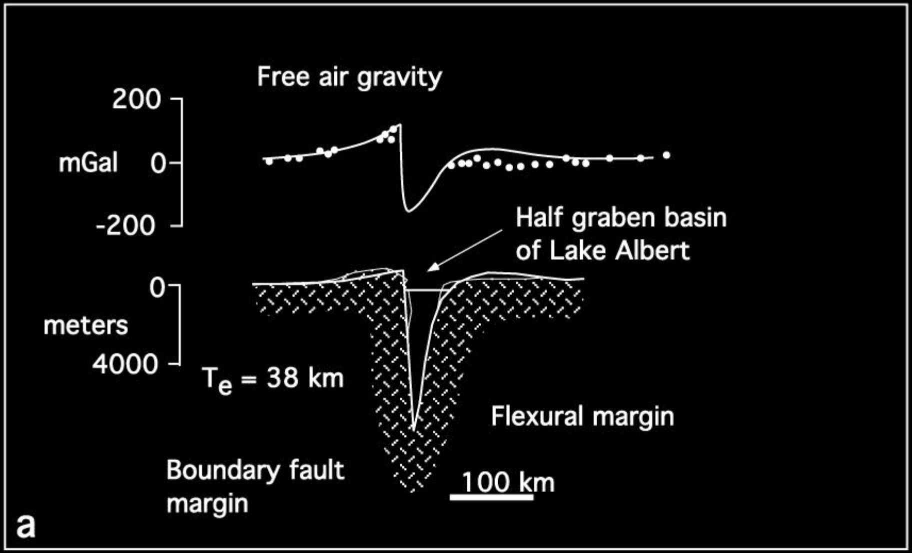
The wavelength will increase as the density of the replacing mass increases. For a fixed load a basin filled by sediment will create a broader, deeper basin than a water filled basin. Under the same load but with increased flexural rigidity the basin will become wider.

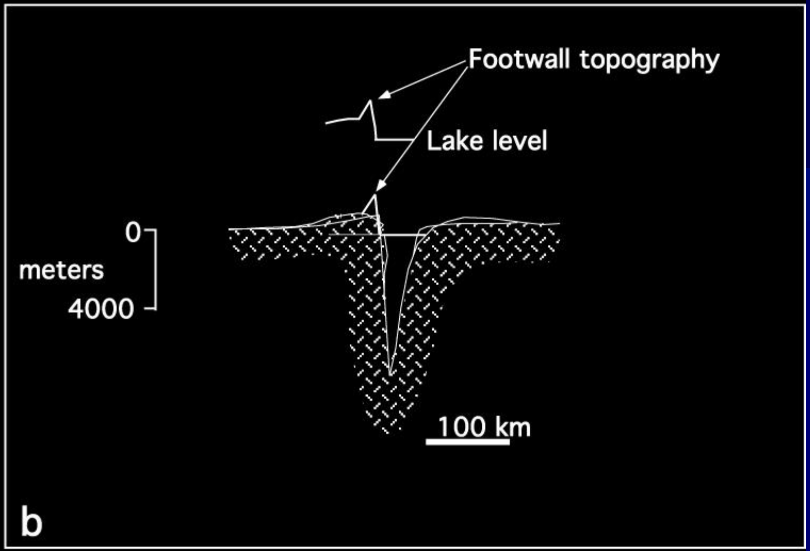
Flexural response to faulting



Isostatic response

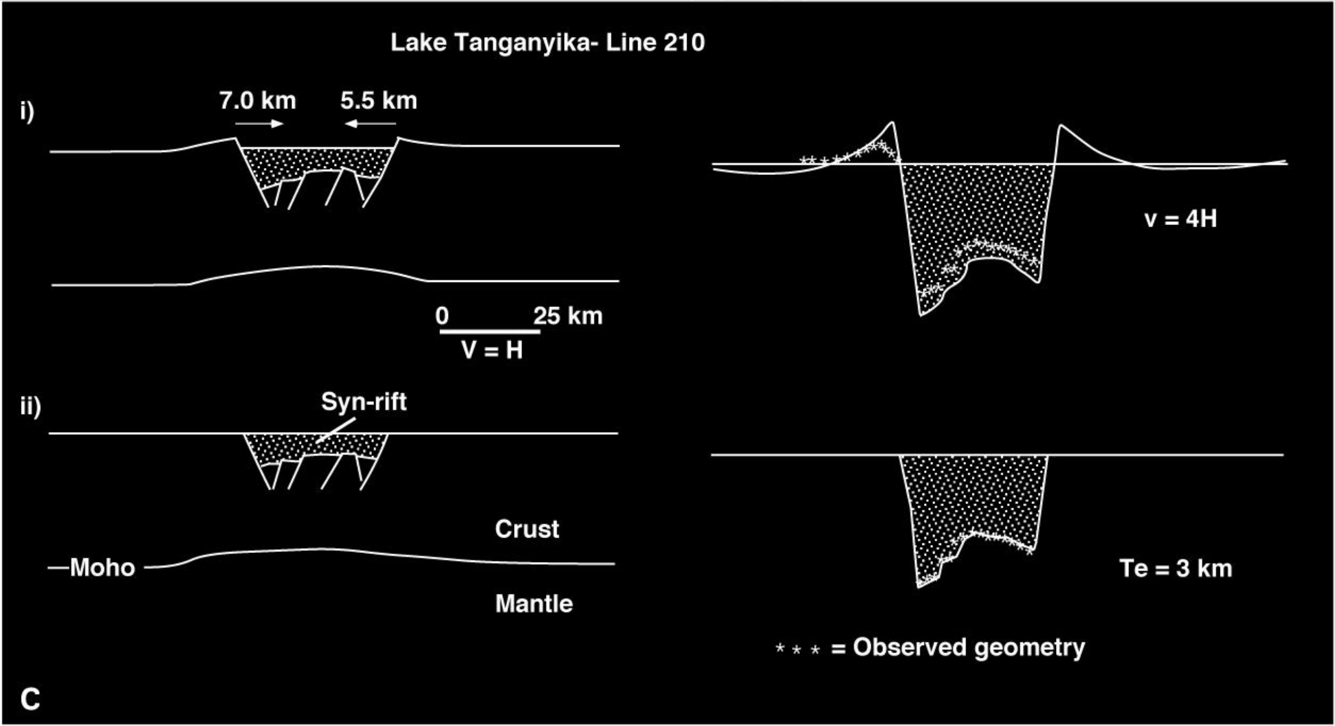
Detachment model

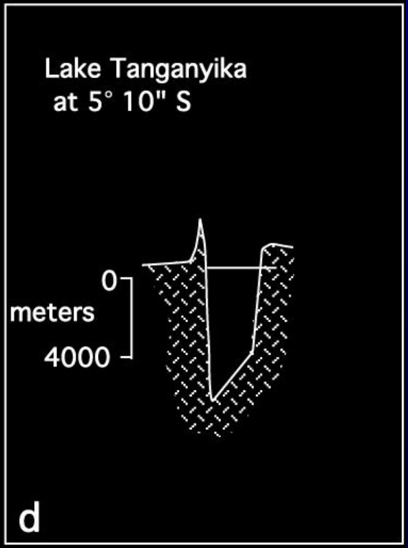


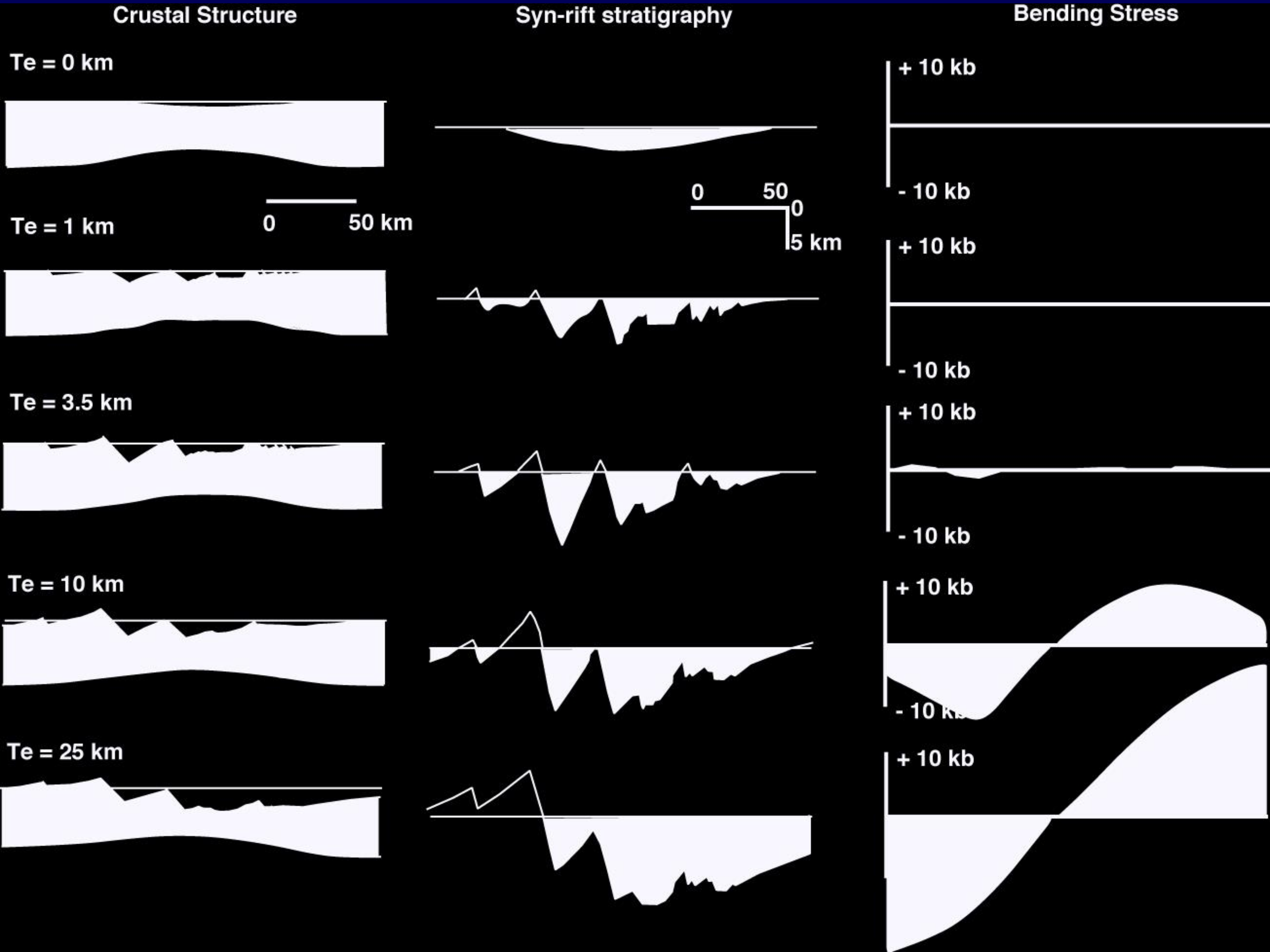


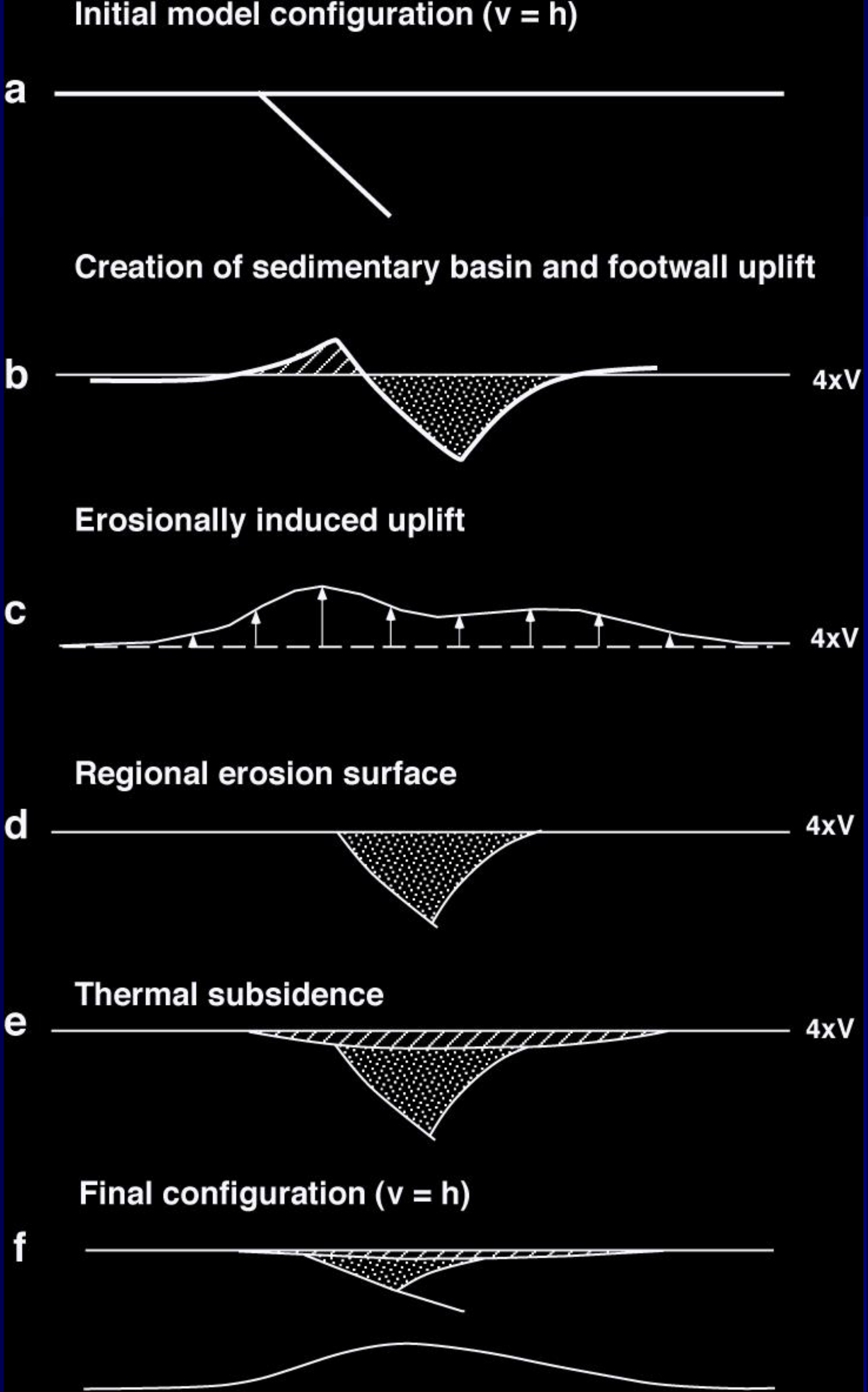
Flexural cantilever model

Lake Albert

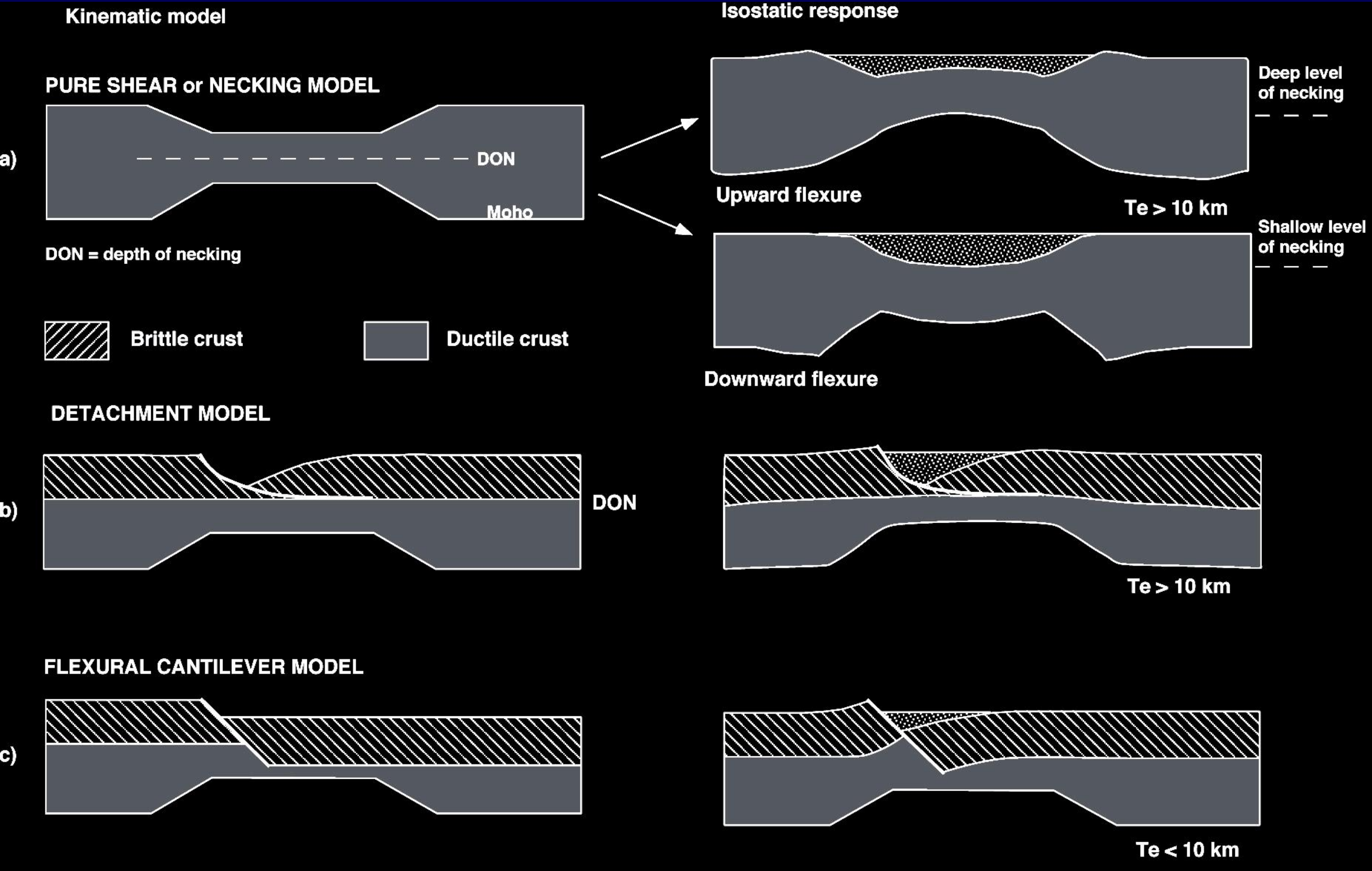




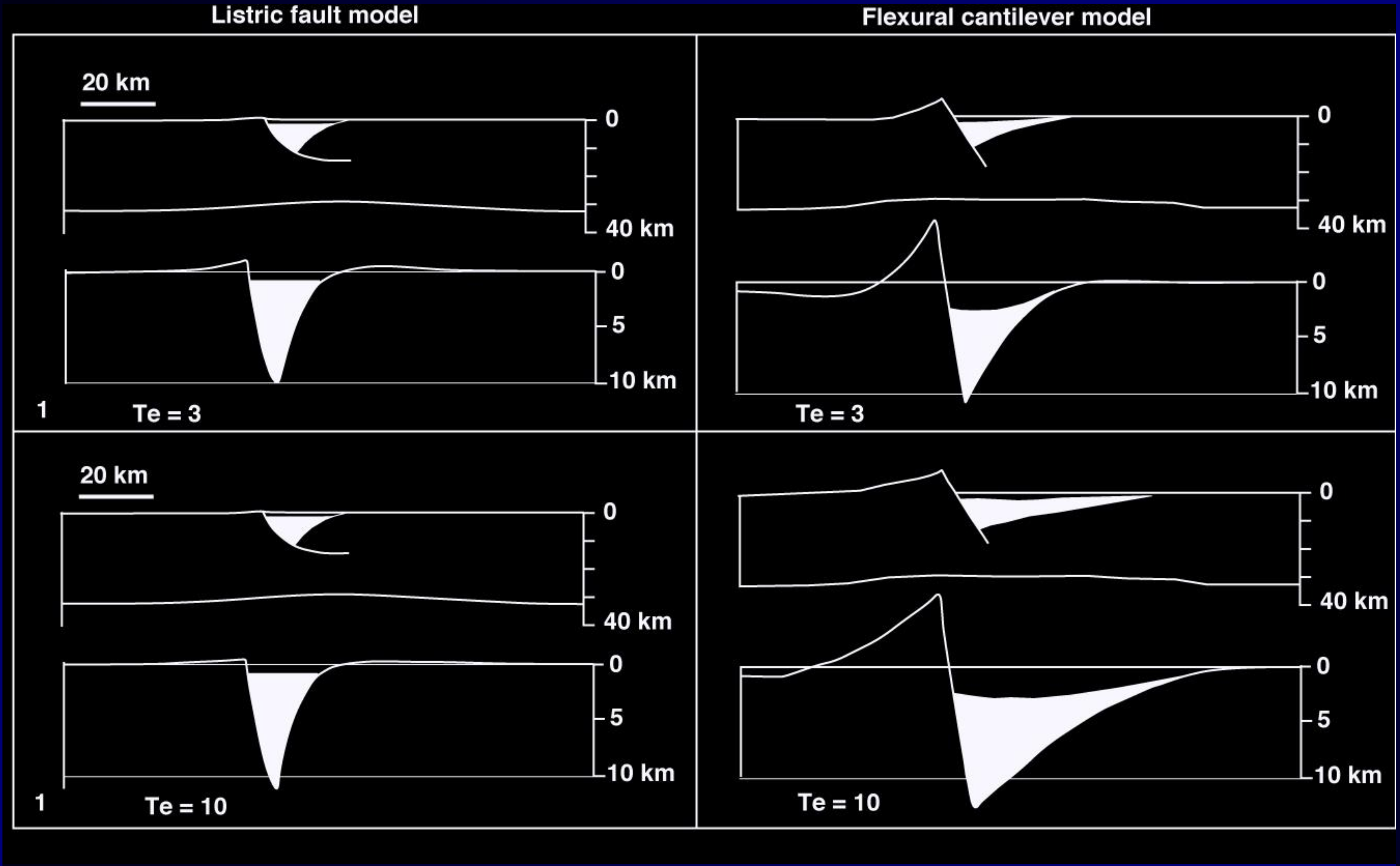

Crustal Structure
Syn-rift stratigraphy
Bending Stress
Te = 0 km
Te = 1 km
Te = 3.5 km
Te = 10 km
Te = 25 km
0
50 km
0
50
0
5 km
+ 10 kb
- 10 kb
+ 10 kb
- 10 kb
+ 10 kb
- 10 kb
+ 10 kb
- 10 kb
+ 10 kb


Initial model configuration (v = h)
a
Creation of sedimentary basin and footwall uplift
b
4xV
Erosionally induced uplift
c
4xV
Regional erosion surface
d
4xV
Thermal subsidence
e
4xV
Final configuration (v = h)
f

Airy and flexural models of rifts



Unbroken beam and broken beam (flexural cantilever) flexural models



Badleys

http://www.badleys.co.uk

Java Stretch and Flex Decomp

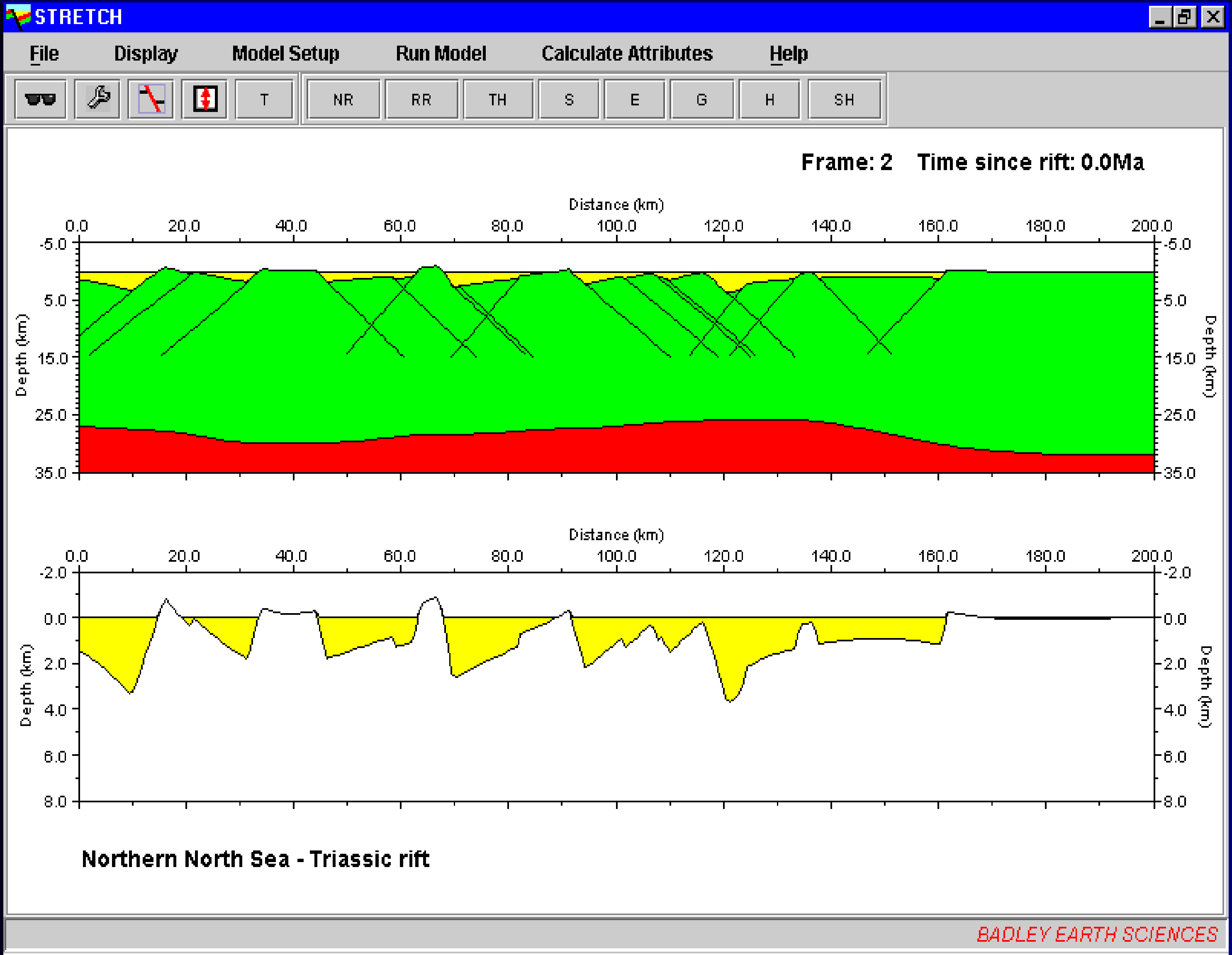
Worked examples from the Northern North Sea multiple-rift basin

Stretch forward model

- Triassic syn-rift at 250Ma (early Triassic)
- Thermal subsidence for 100Myr
- Re-rift at 150 Ma (late Jurassic)
- Thermal subsidence to present-day

Stretch: Triassic syn-rift basin at 250Ma

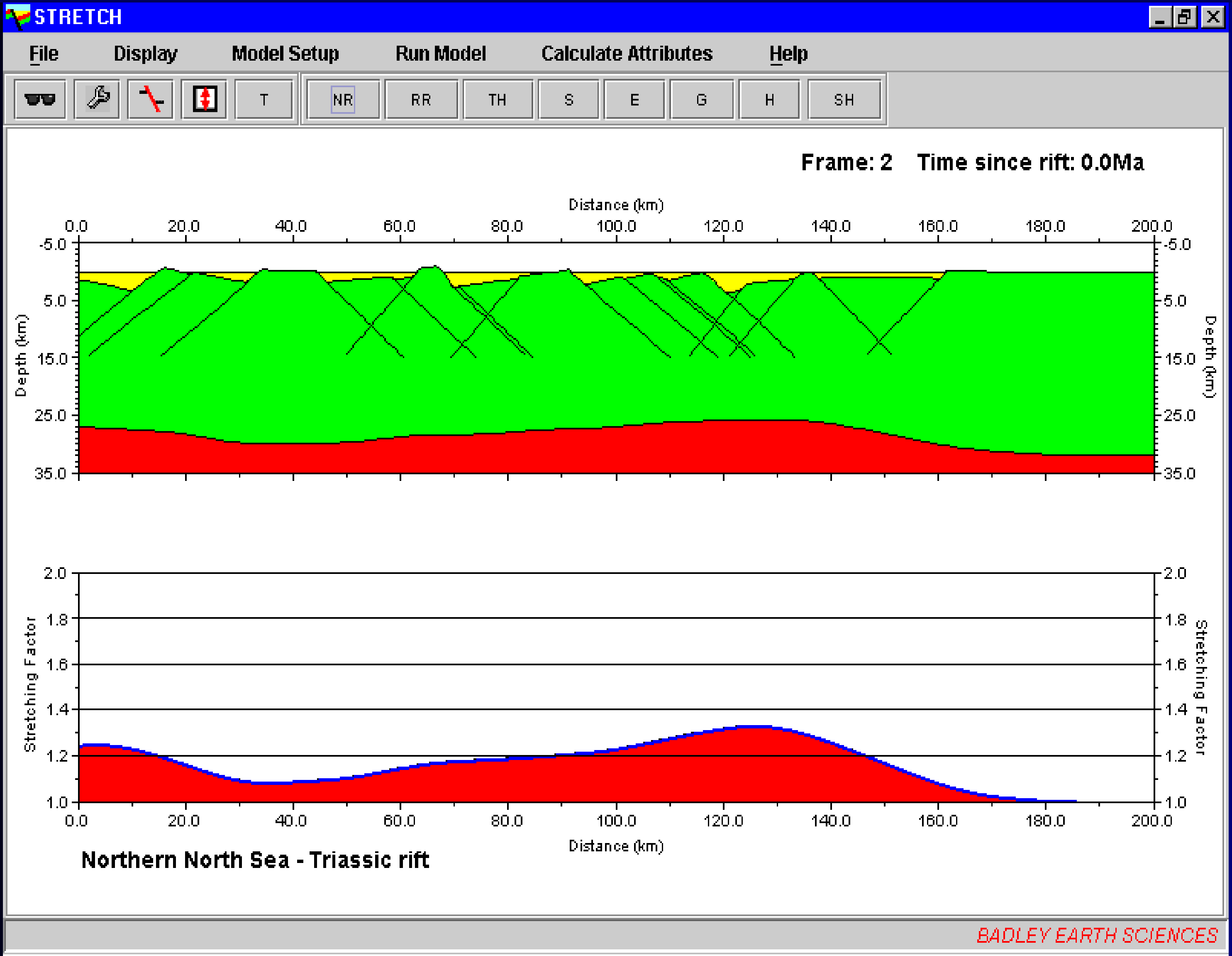
Dominantly fluvial with emergent footwalls



Frame: 2 Time since rift: 0.0Ma

Northern North Sea - Triassic rift

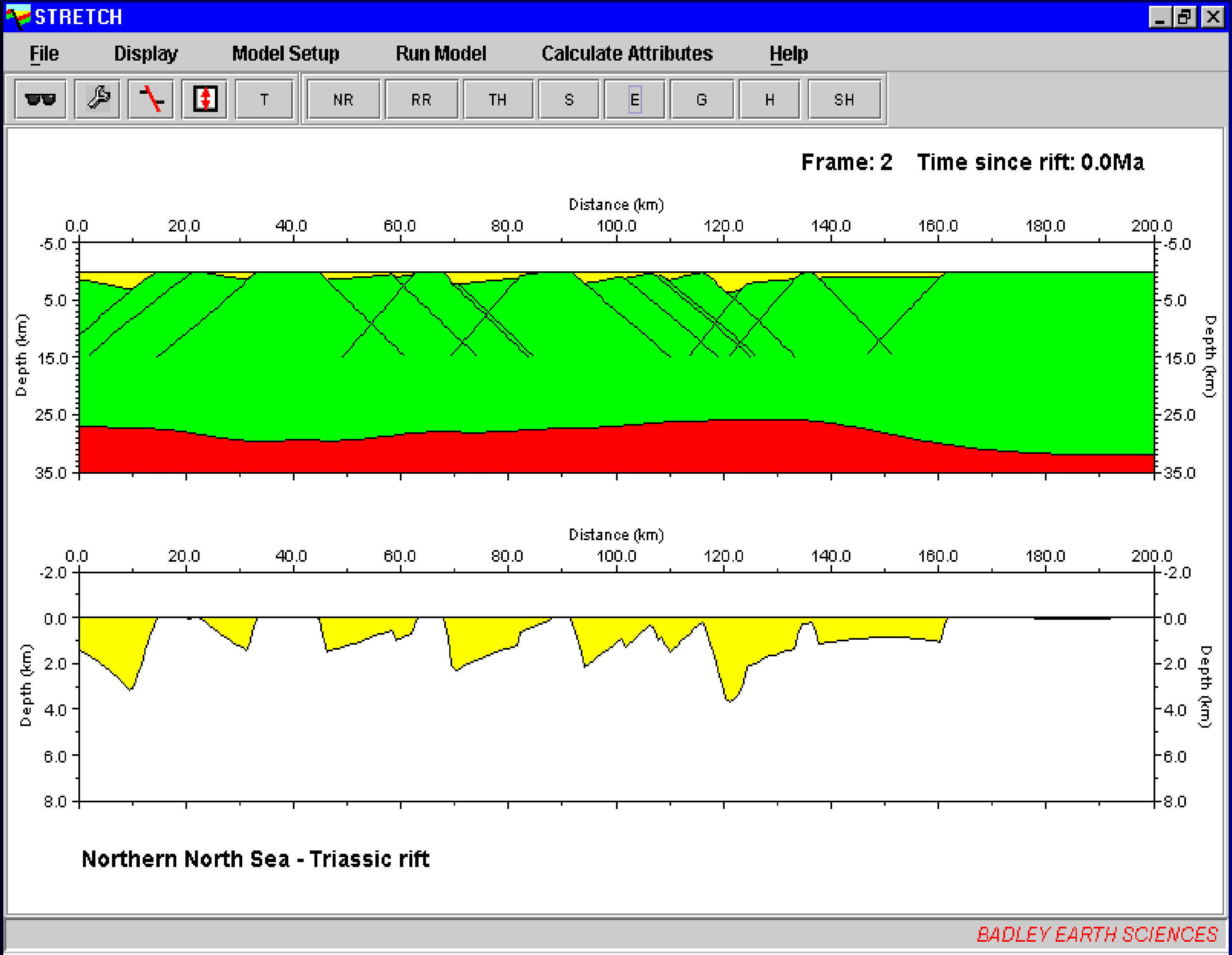
Stretch: Triassic rift and beta profile



Frame: 2 Time since rift: 0.0Ma

Northern North Sea - Triassic rift

Stretch: Erode syn-rift topography

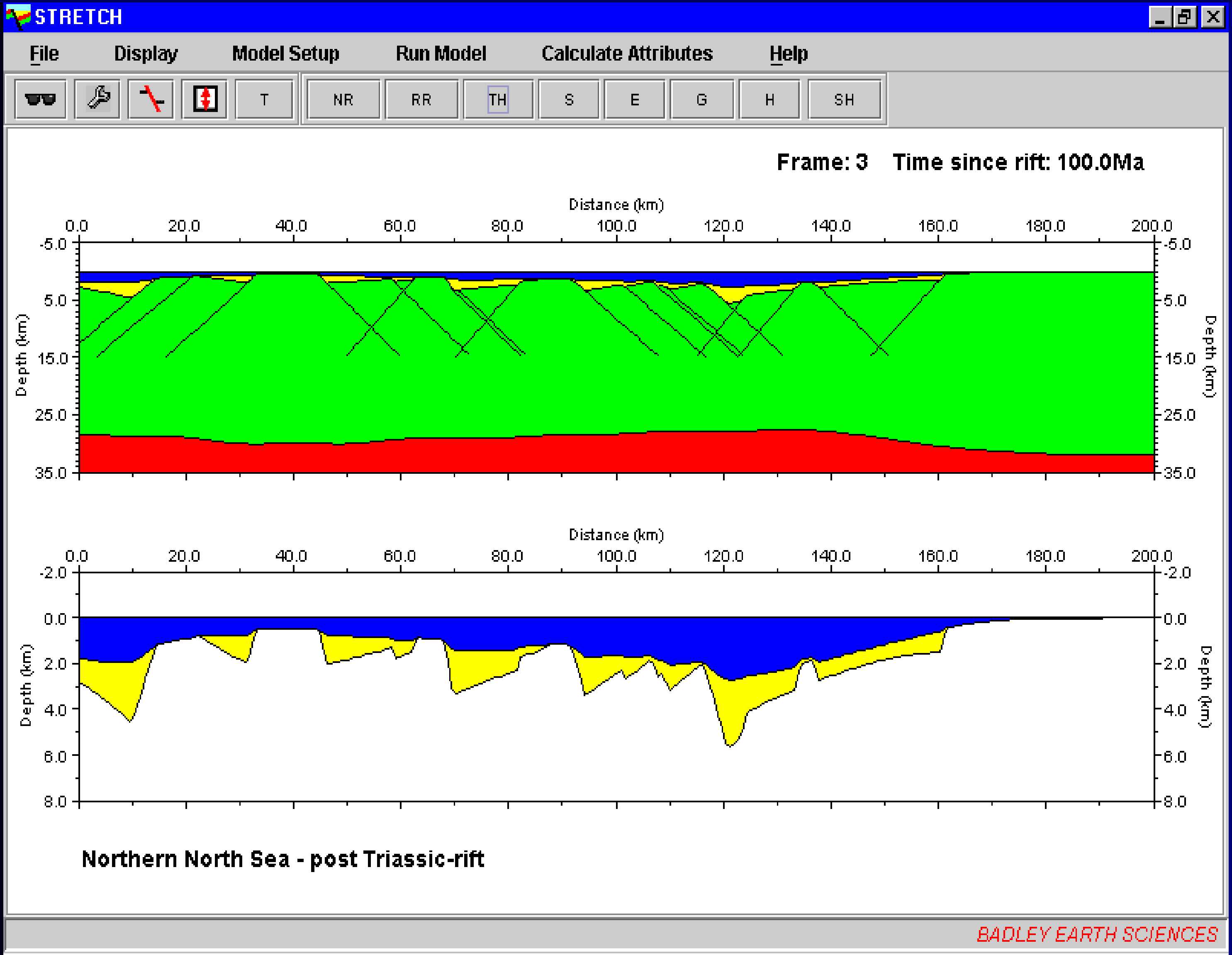


Frame: 2 Time since rift: 0.0Ma

Northern North Sea - Triassic rift

Stretch: 100Myr thermal subsidence

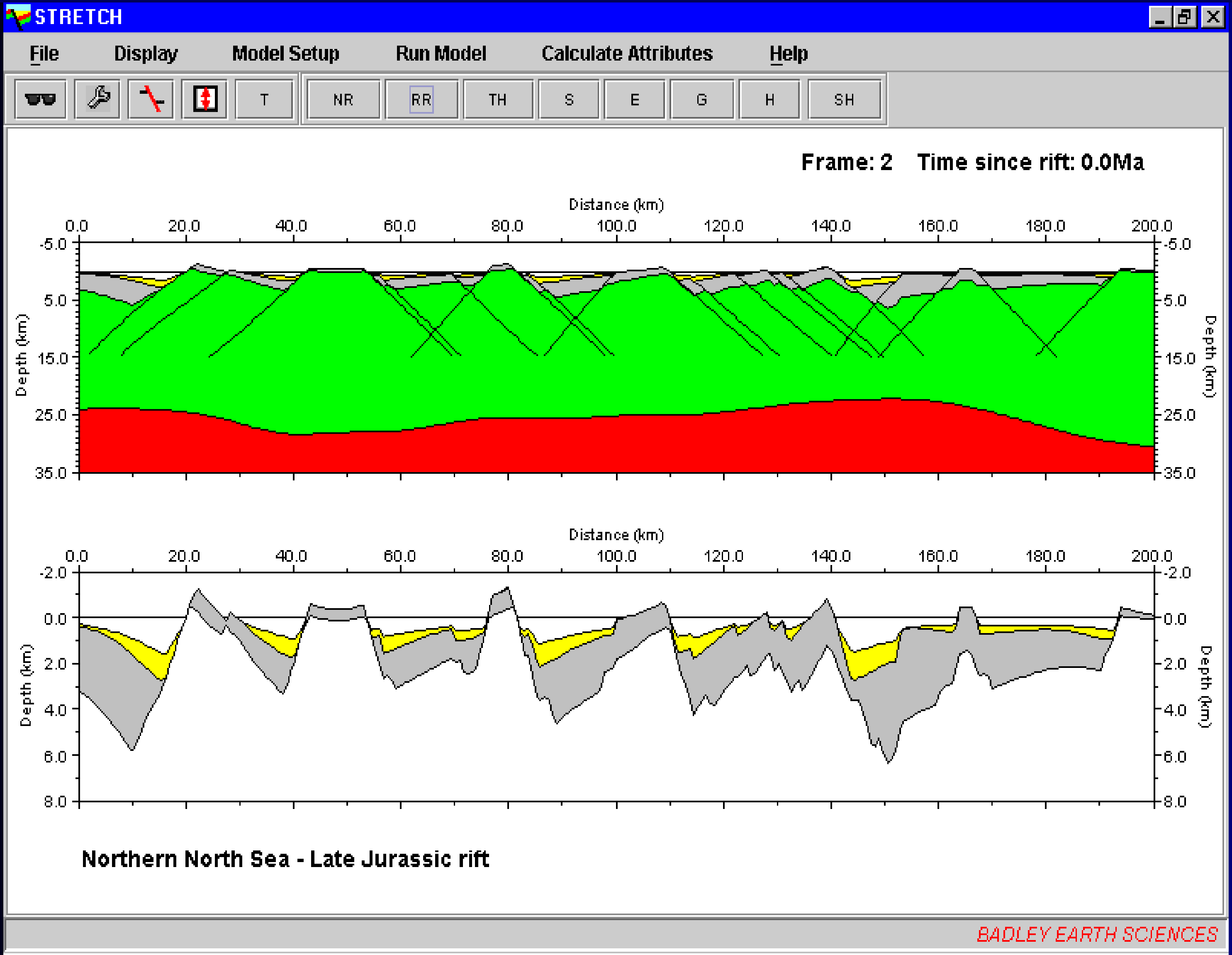
Jurassic delta plain at 150Ma



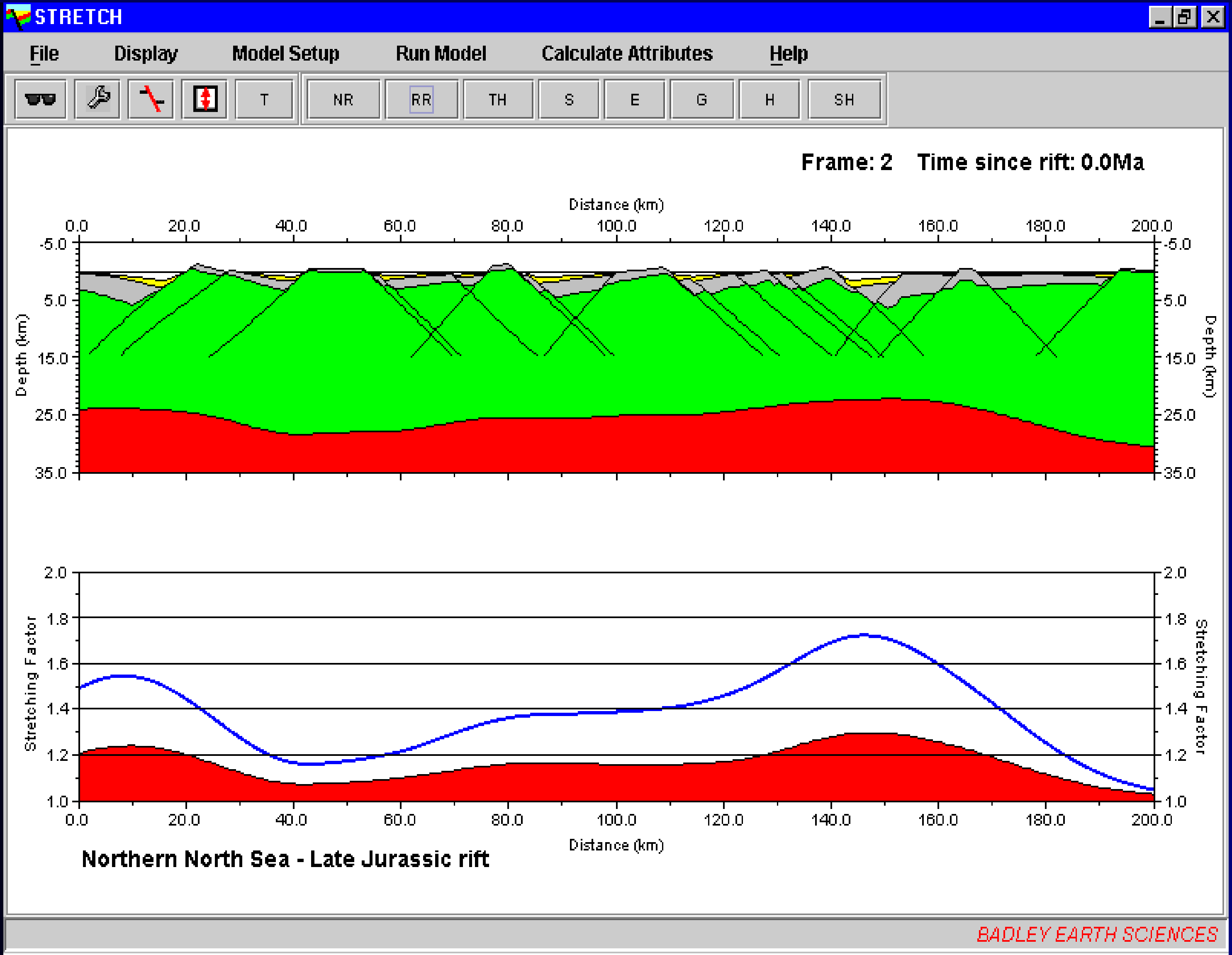
Northern North Sea - post Triassic-rift

Stretch: Re-rift in the late Jurassic

Marine basin with island archipelago



Stretch: 2nd-rift & composite beta profiles

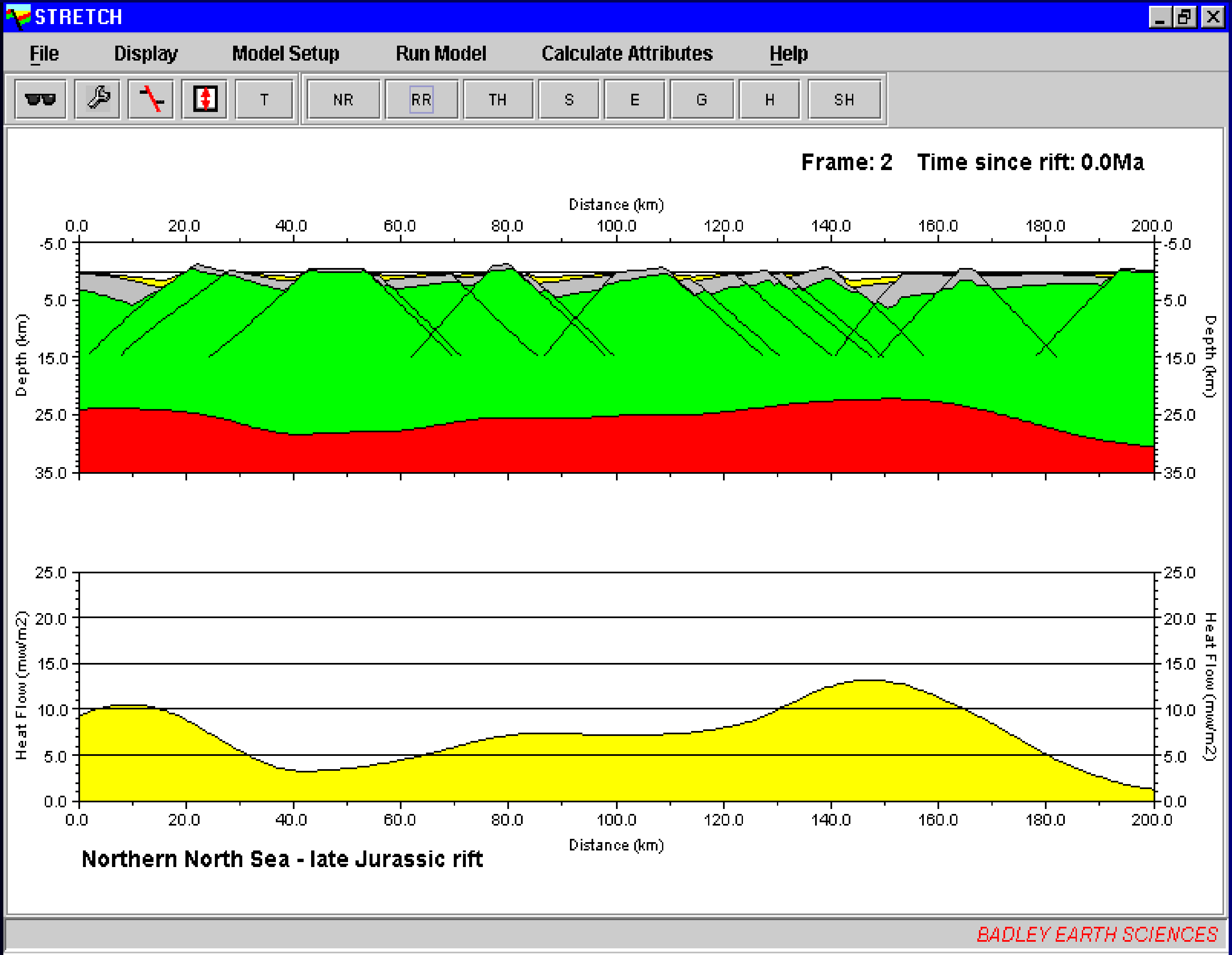


Frame: 2 Time since rift: 0.0Ma

Northern North Sea - Late Jurassic rift

Stretch: Late Jurassic heat-flow anomaly

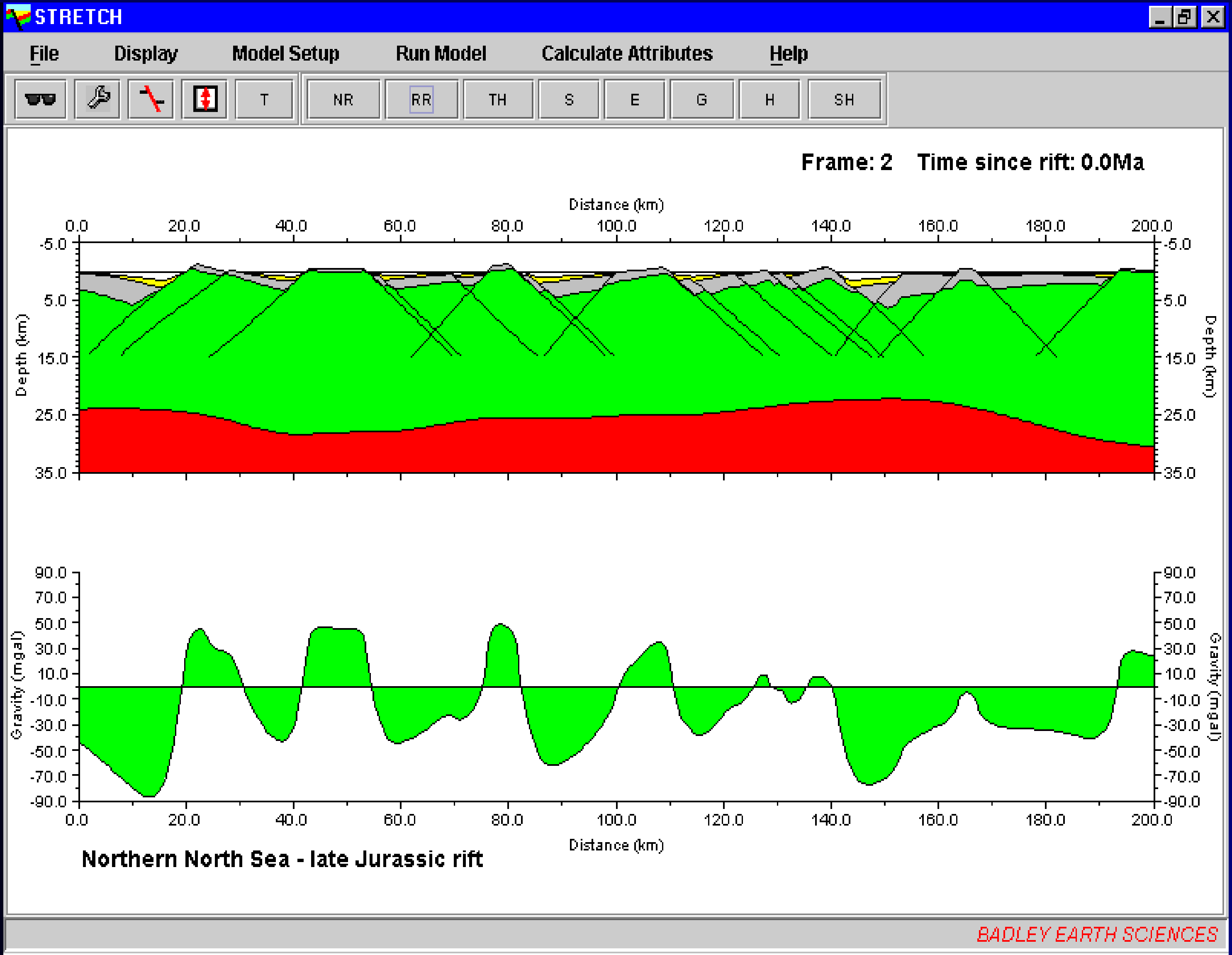
Composite anomaly from both rifts



Frame: 2 Time since rift: 0.0Ma

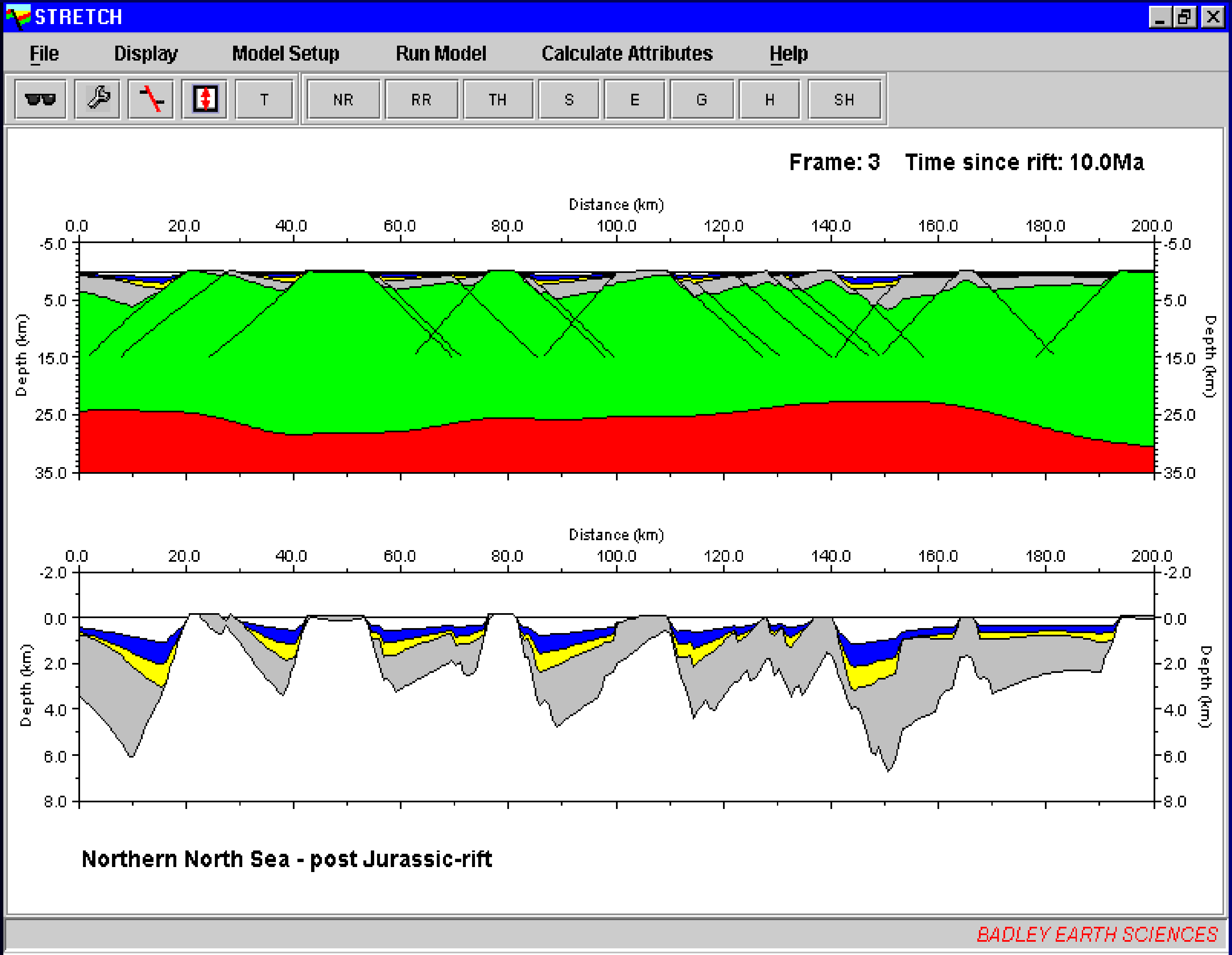
Northern North Sea - late Jurassic rift

Stretch: Jurassic syn-rift gravity anomaly



Stretch: 10Myr post-rift and erosion

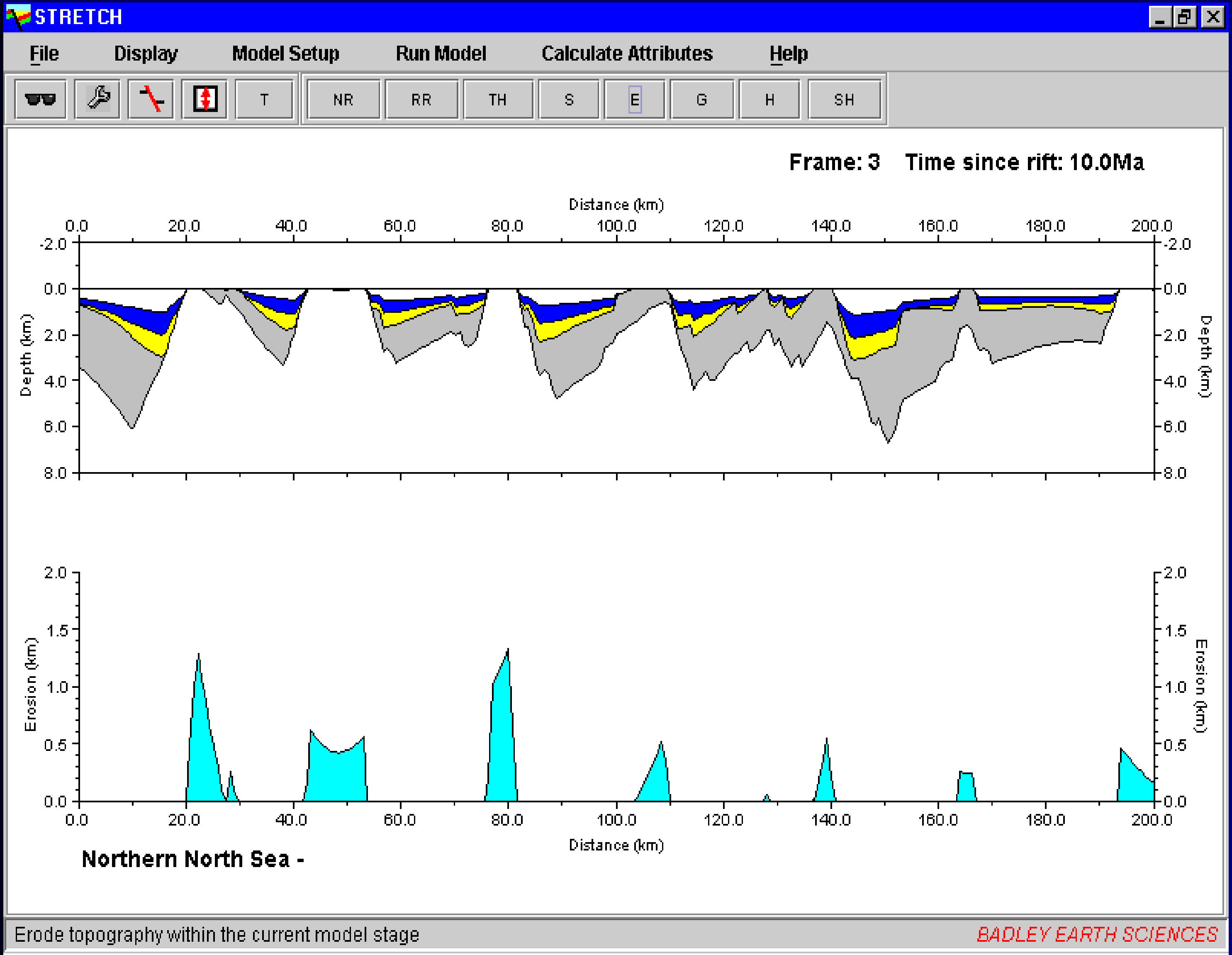
Base Cretaceous seismic marker at 140Ma



Frame: 3 Time since rift: 10.0Ma

Northern North Sea - post Jurassic-rift

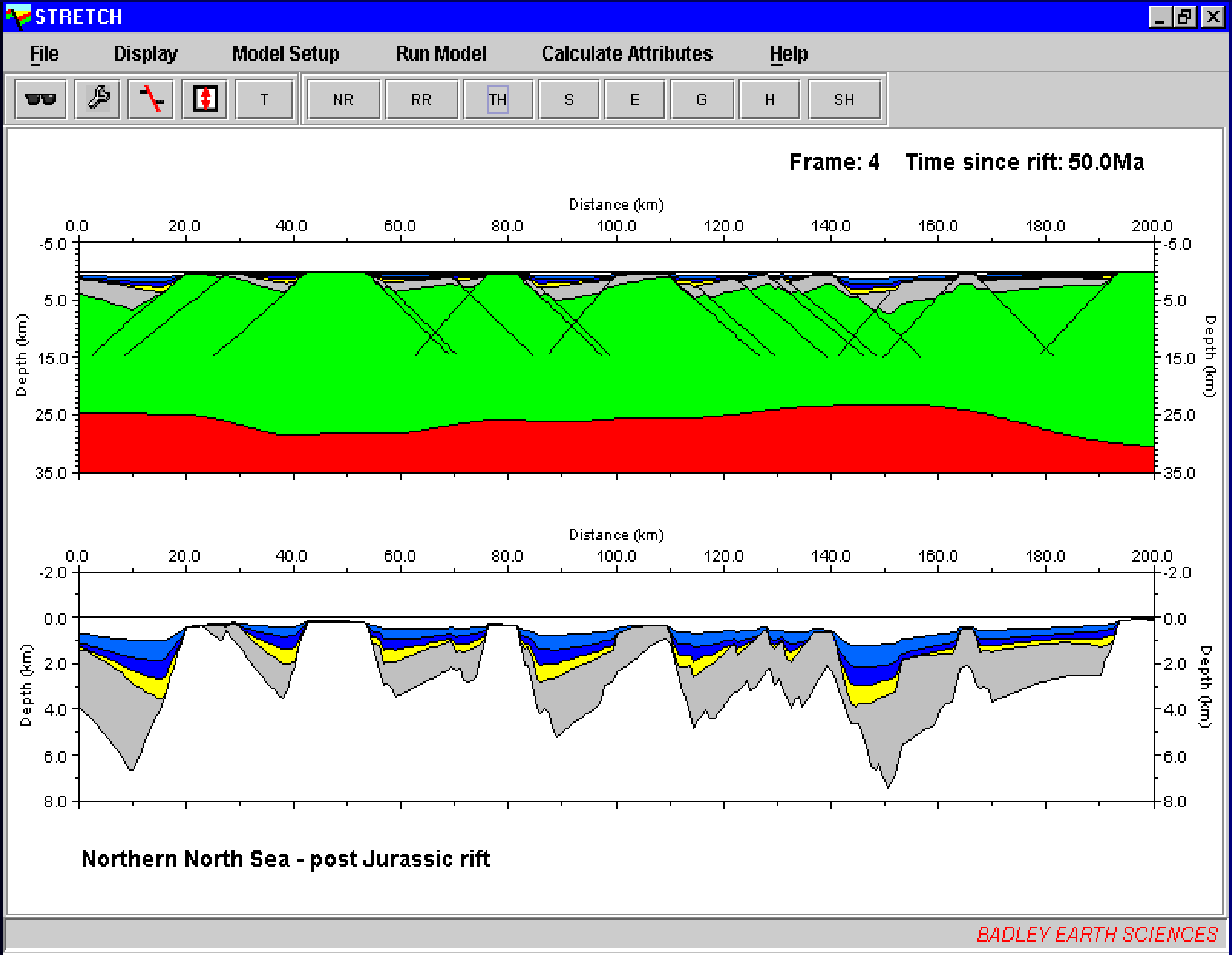
Stretch: Base Cret erosion at sea-level



Erode topography within the current model stage

Stretch: 50Myr post-rift subsidence

Marine basin at end Early Cretaceous, 100Ma

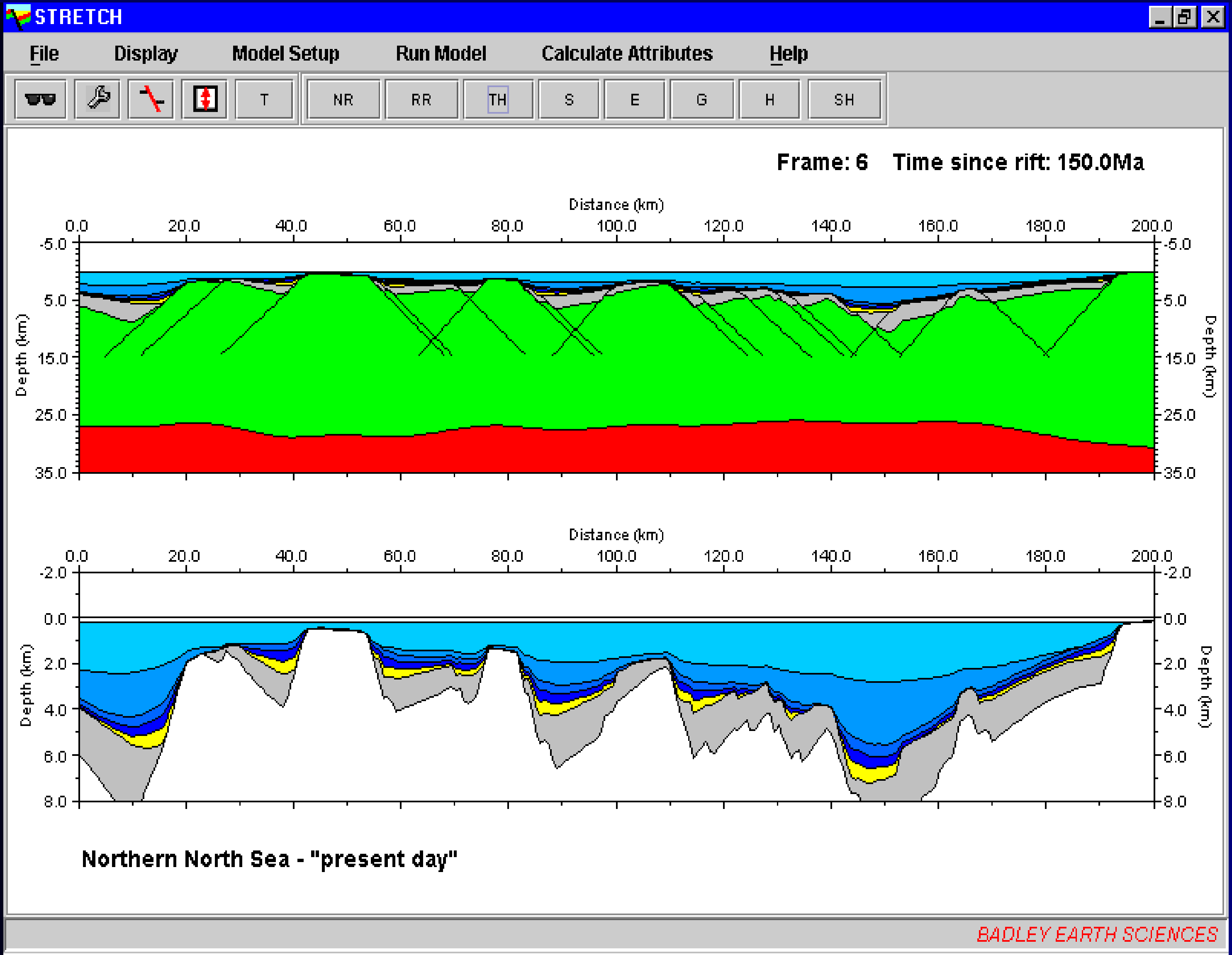


Frame: 4 Time since rift: 50.0Ma

Northern North Sea - post Jurassic rift

Stretch: 150Myr post-rift subsidence

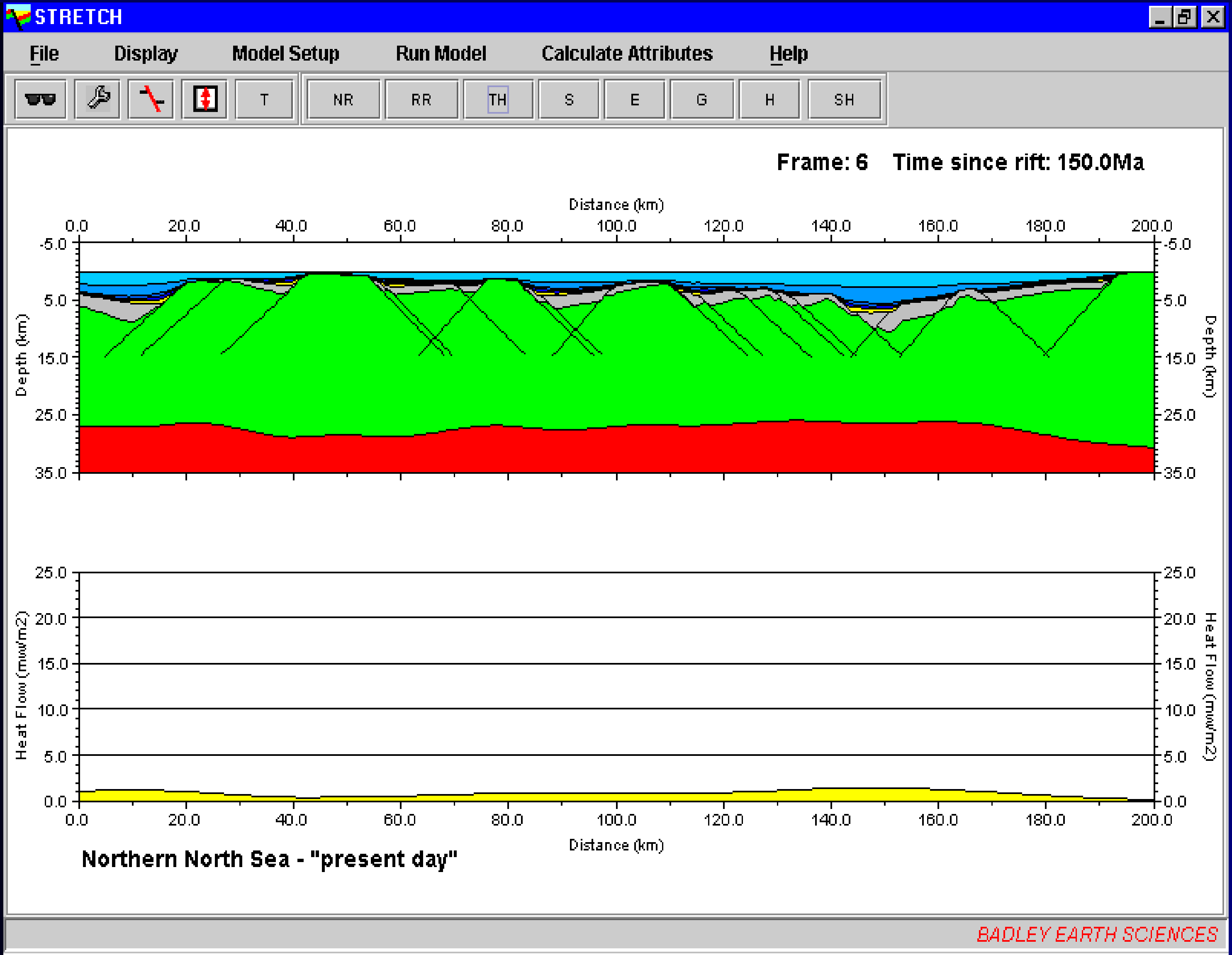
The “present-day” multiple rift model



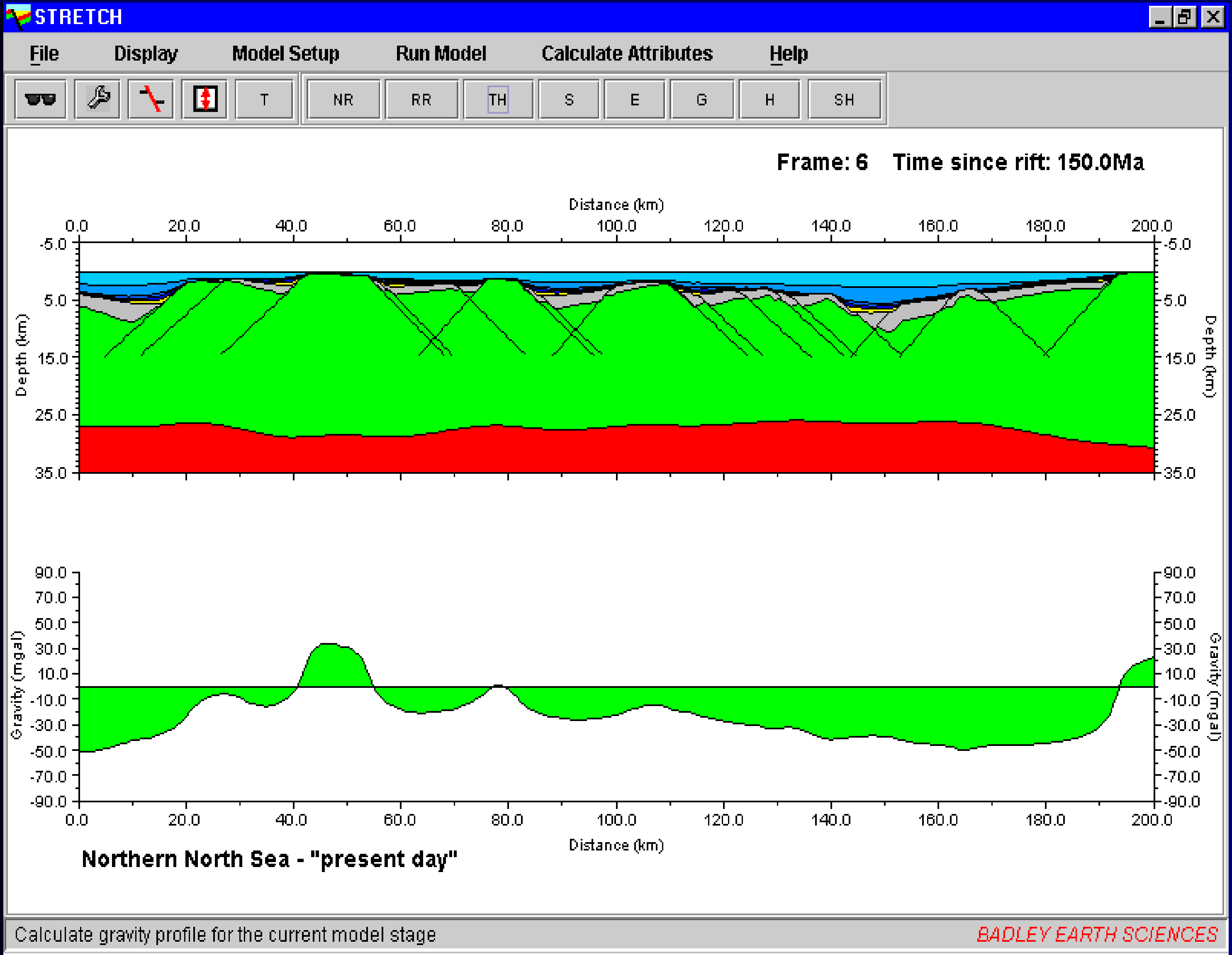
Frame: 6 Time since rift: 150.0Ma

Northern North Sea - "present day"

Stretch: Present-day heat-flow anomaly



Stretch: Gravity anomaly for present-day model



Frame: 6 Time since rift: 150.0Ma

Northern North Sea - "present day"

Calculate gravity profile for the current model stage

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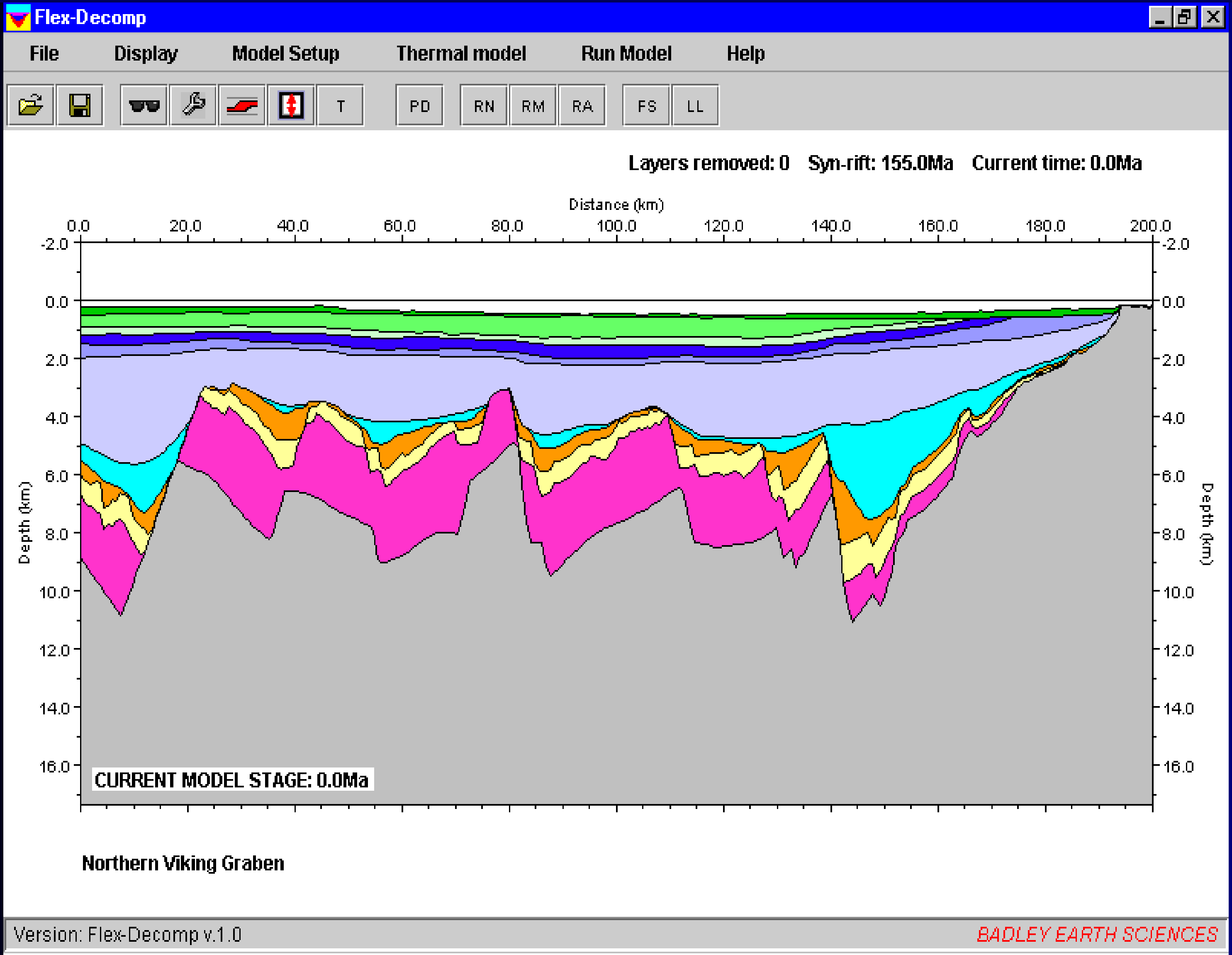
Flexural Decompaction backstripped model

- **Backstrip from present to near syn-rift**
- **Acknowledge two rift events**
- **Jurassic (150Ma) beta profile from Stretch**
- **Constant value for Triassic (250Ma) beta**
- **Allow for Palaeocene uplift by Iceland plume**

Flex Decomp: Present-day cross-section



Layers removed: 0 Syn-rift: 155.0Ma Current time: 0.0Ma

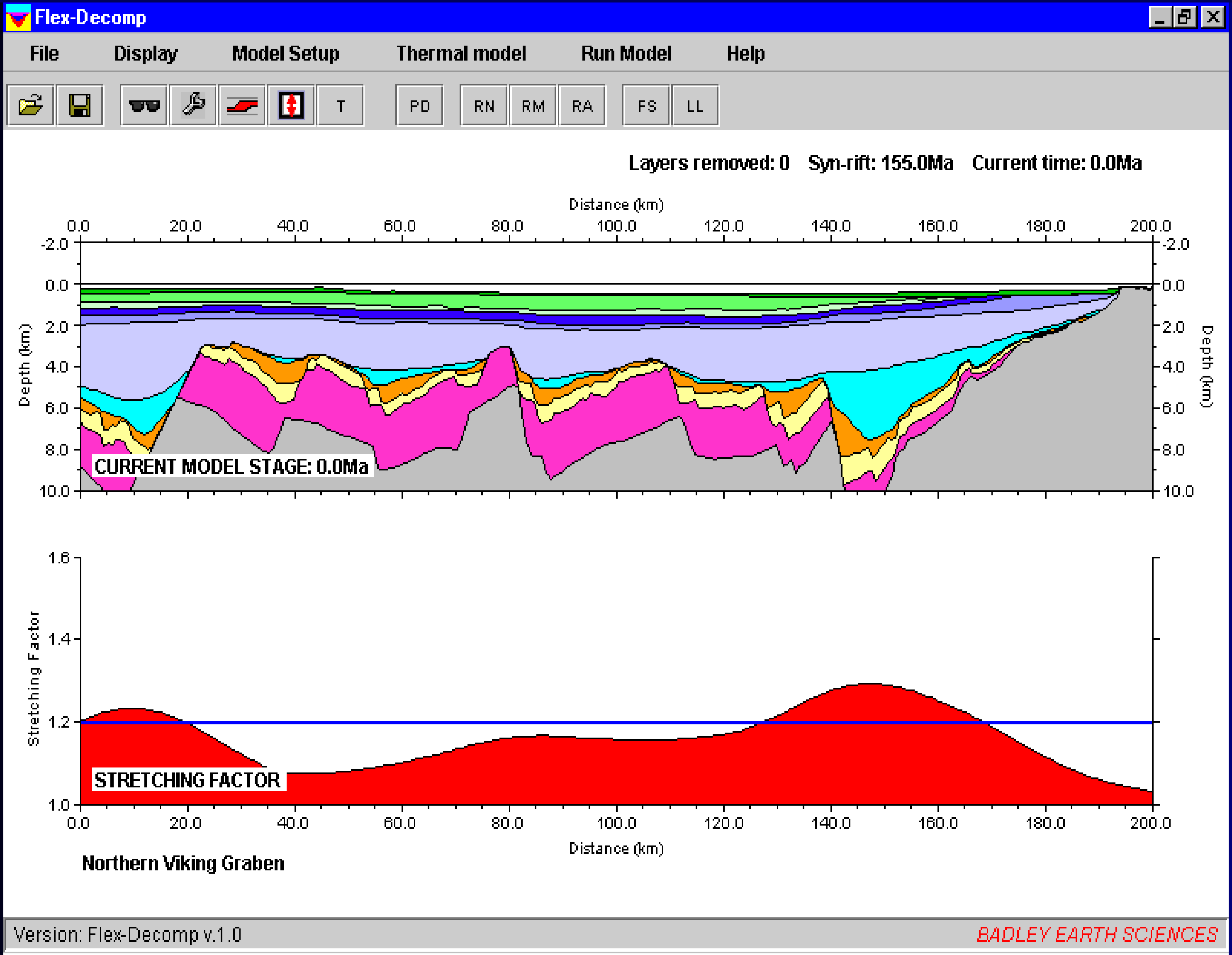
CURRENT MODEL STAGE: 0.0Ma

Northern Viking Graben

Version: Flex-Decomp v.1.0

BADLEY EARTH SCIENCES

Flex: Present section and beta profiles



Layers removed: 0 Syn-rift: 155.0Ma Current time: 0.0Ma

CURRENT MODEL STAGE: 0.0Ma

STRETCHING FACTOR

Northern Viking Graben

Version: Flex-Decomp v.1.0

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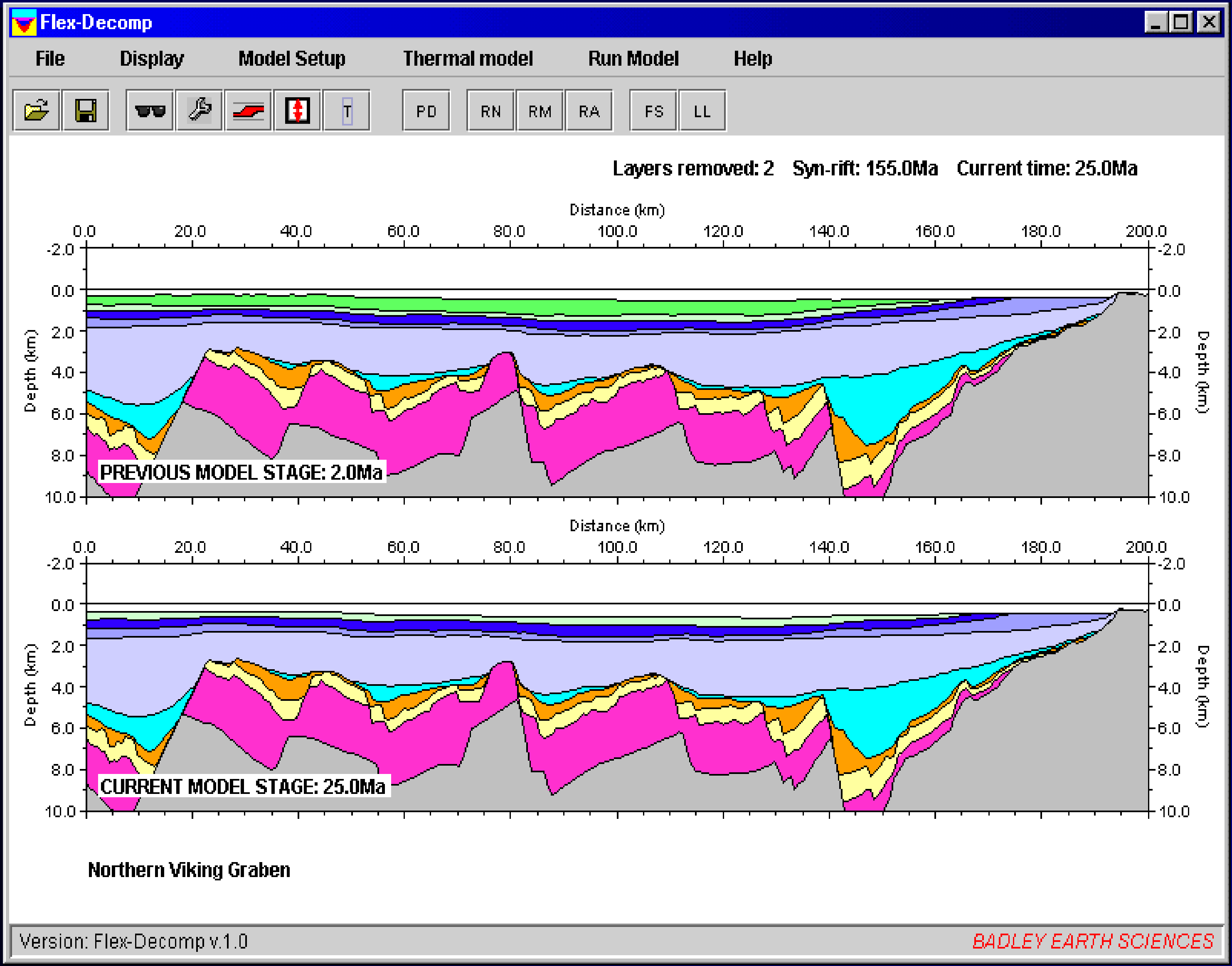
Flex Decomp: Layers 1 and 2 removed



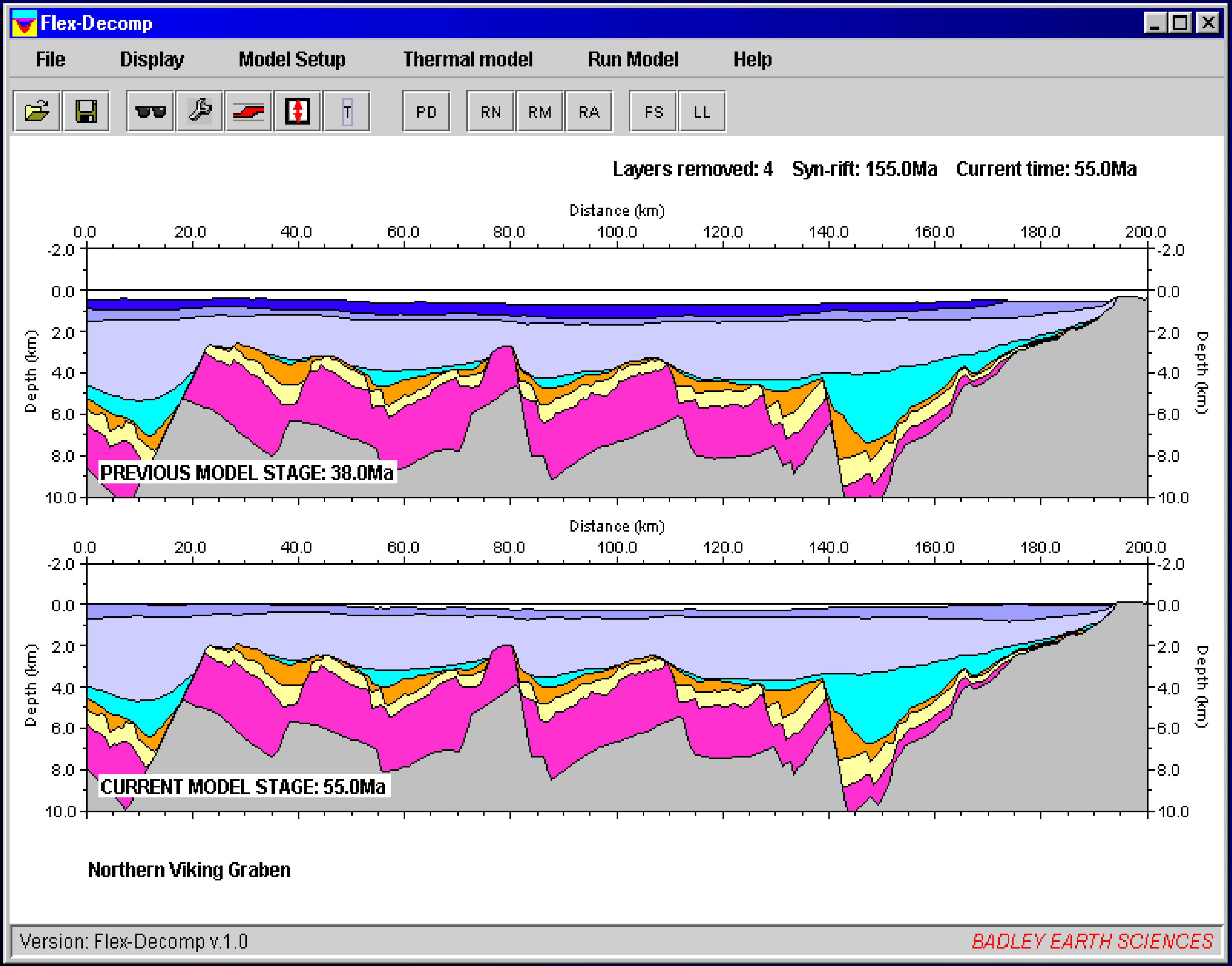
Layers removed: 2 Syn-rift: 155.0Ma Current time: 25.0Ma

Northern Viking Graben

Version: Flex-Decomp v.1.0

Flex Decomp: Layers 3 and 4 removed

460m Iceland Plume support applied at 55Ma



Layers removed: 4 Syn-rift: 155.0Ma Current time: 55.0Ma

PREVIOUS MODEL STAGE: 38.0Ma

CURRENT MODEL STAGE: 55.0Ma

Northern Viking Graben

Version: Flex-Decomp v.1.0

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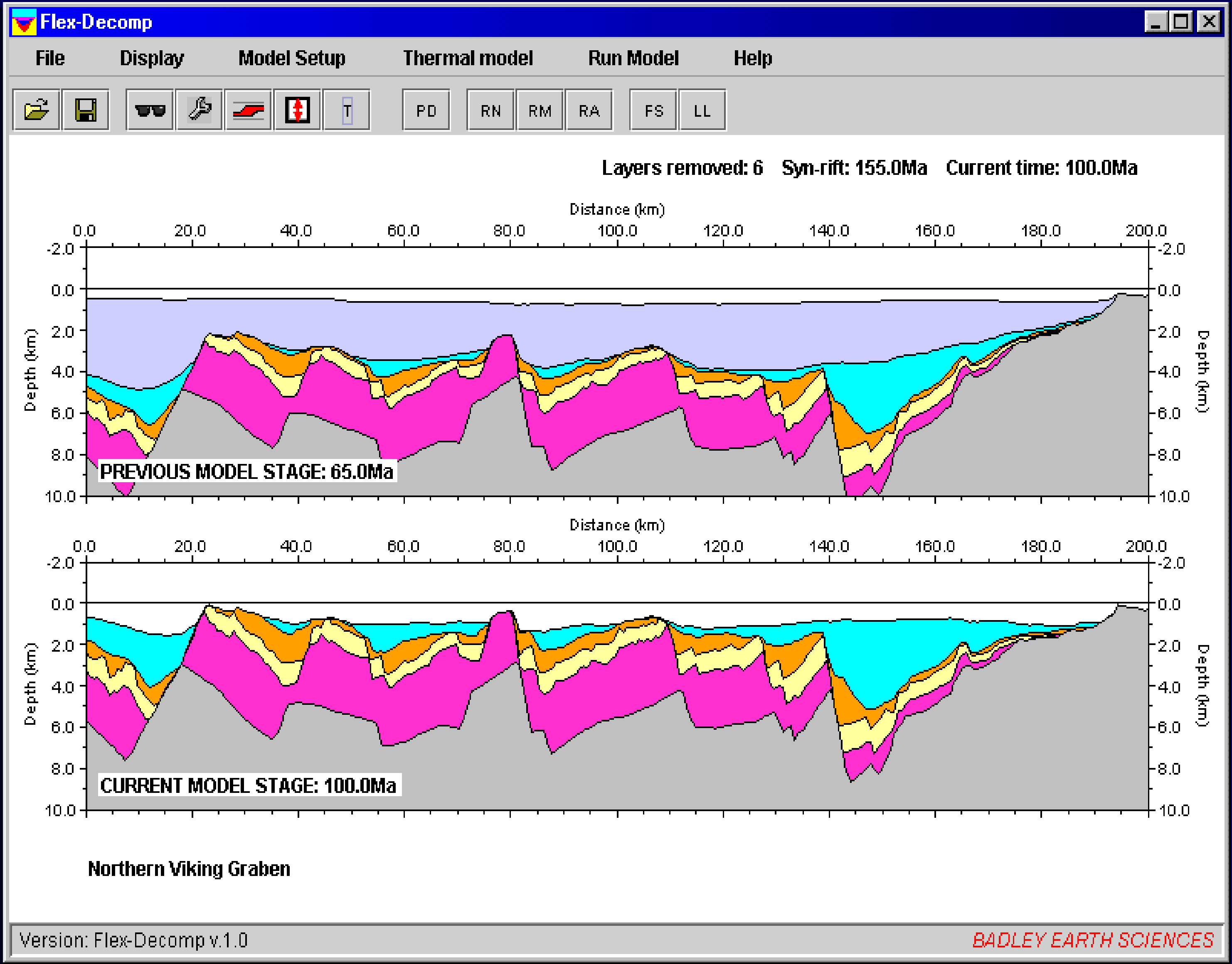
Flex Decomp: Layers 5 and 6 removed



Layers removed: 6 Syn-rift: 155.0Ma Current time: 100.0Ma

PREVIOUS MODEL STAGE: 65.0Ma

CURRENT MODEL STAGE: 100.0Ma

Northern Viking Graben

Version: Flex-Decomp v.1.0

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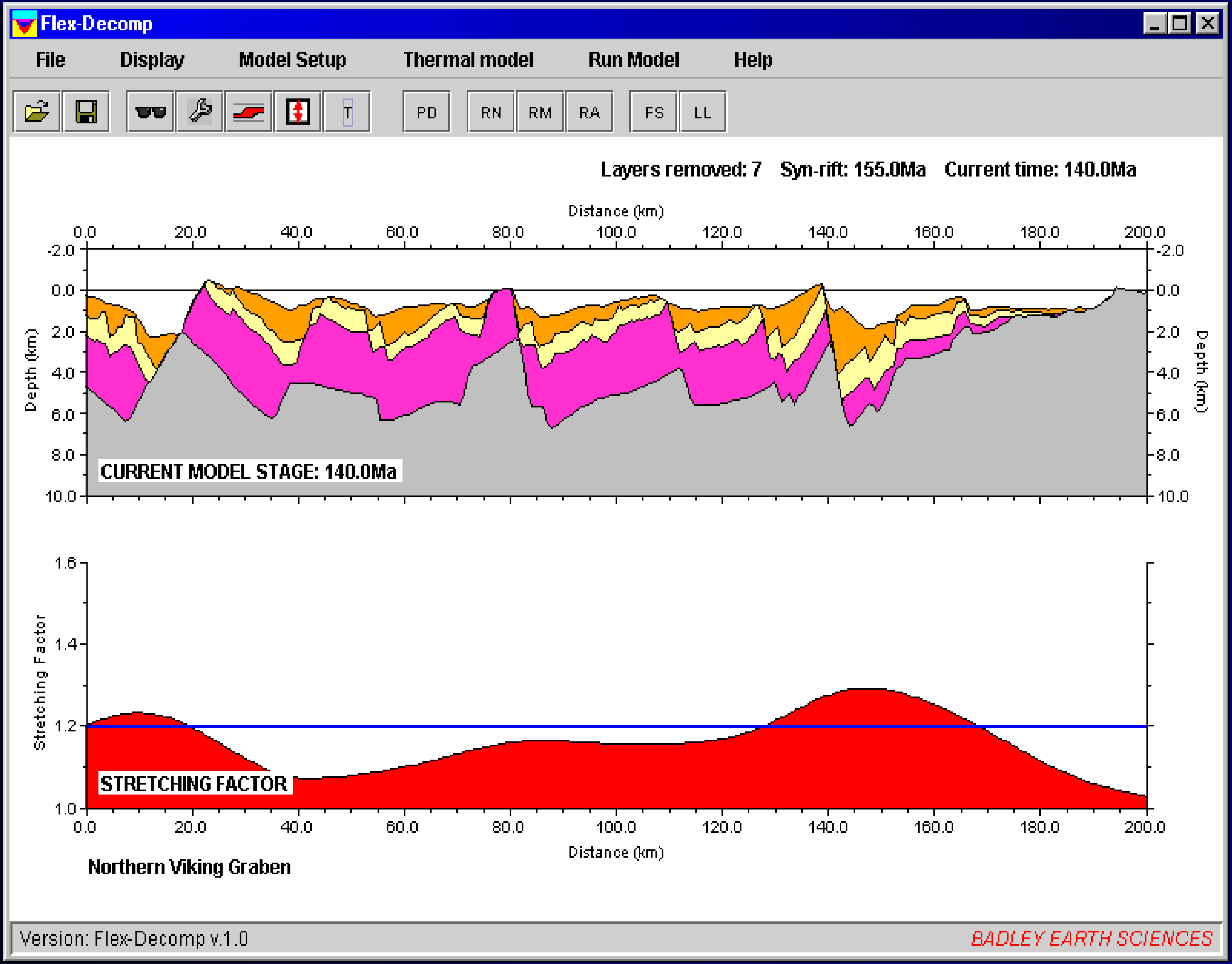
Flex Decomp: Layer 7 removed

Base Cretaceous at 140Ma close to syn-rift



Layers removed: 7 Syn-rift: 155.0Ma Current time: 140.0Ma

CURRENT MODEL STAGE: 140.0Ma

STRETCHING FACTOR

Northern Viking Graben

Version: Flex-Decomp v.1.0

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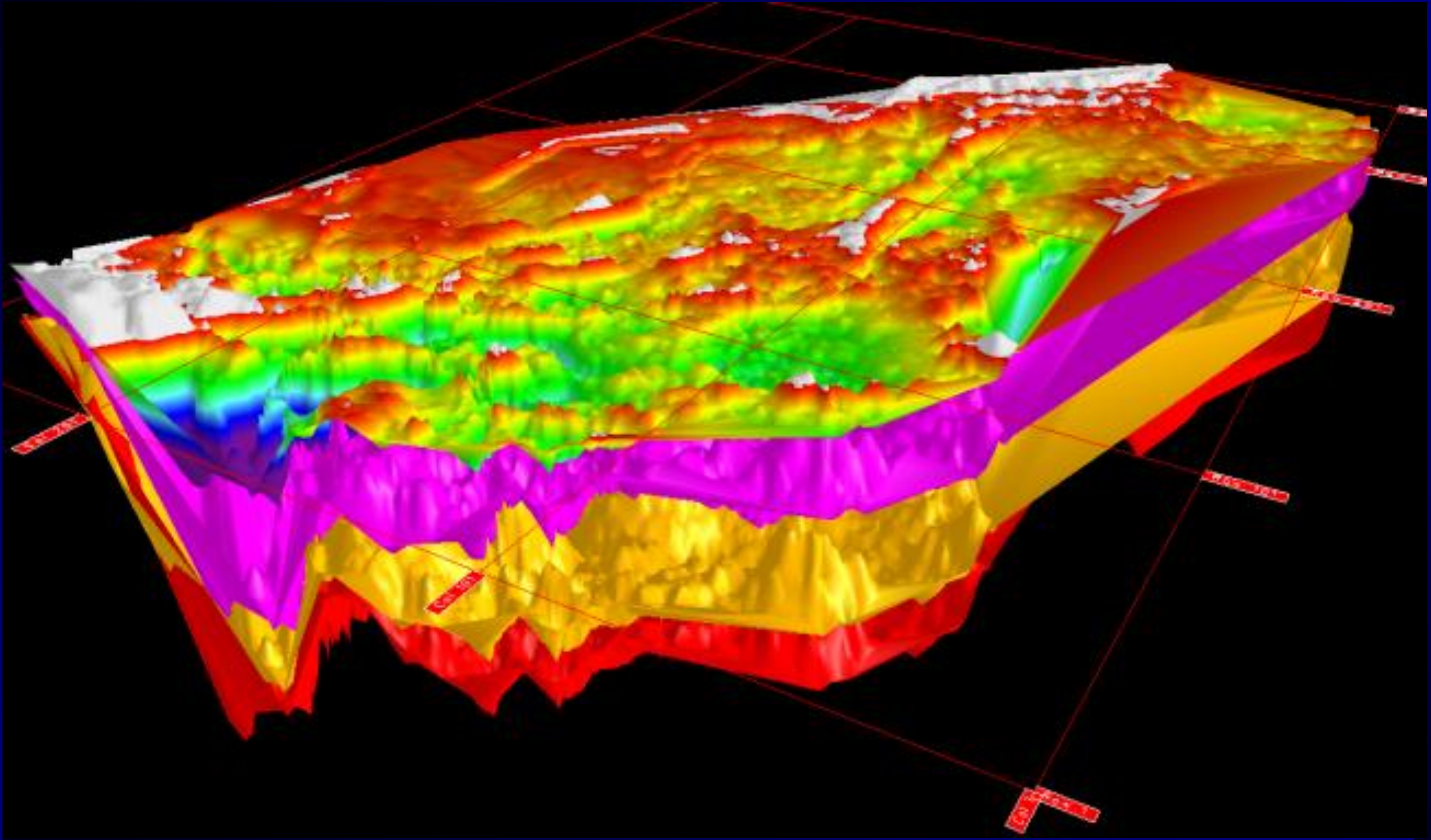
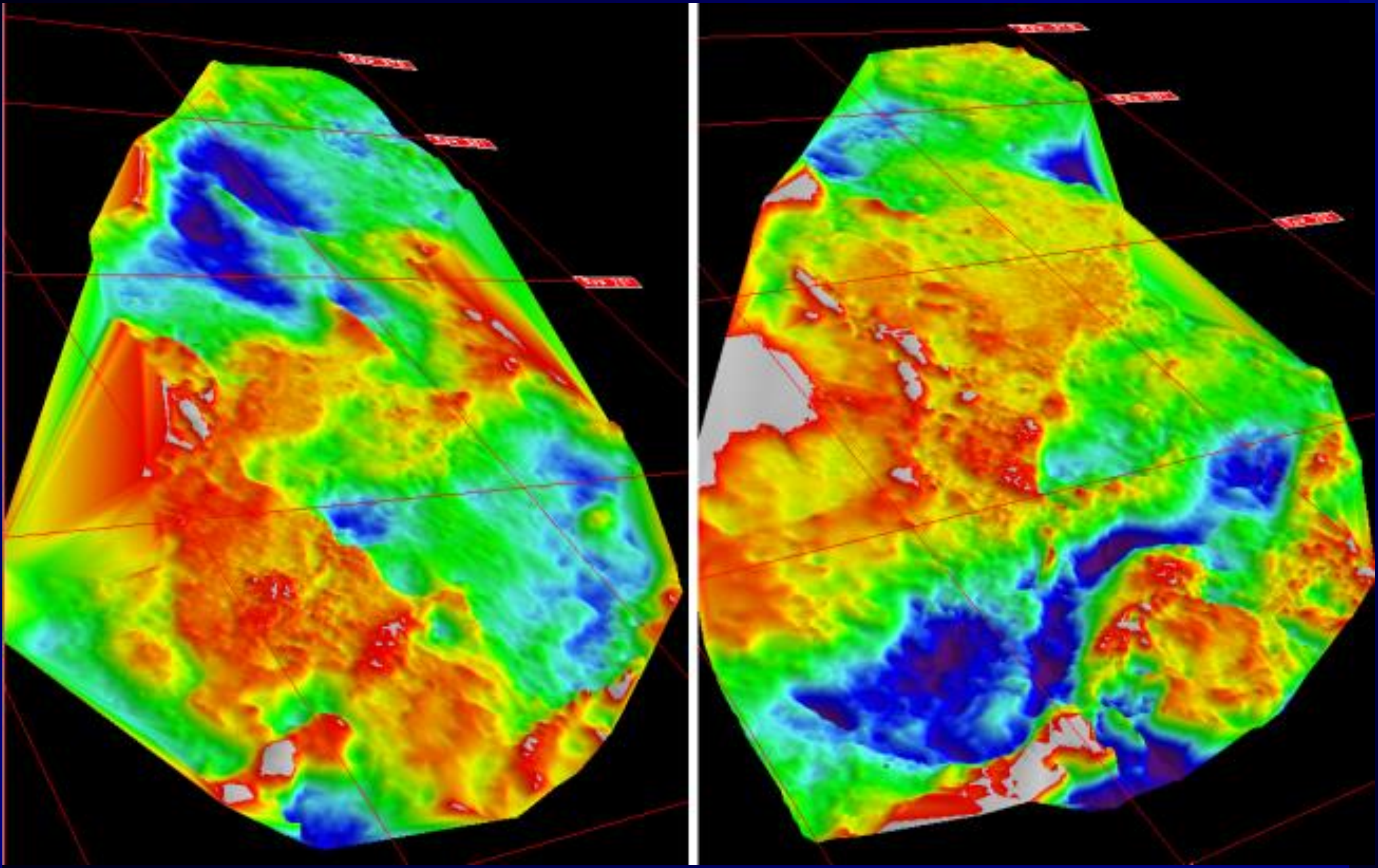
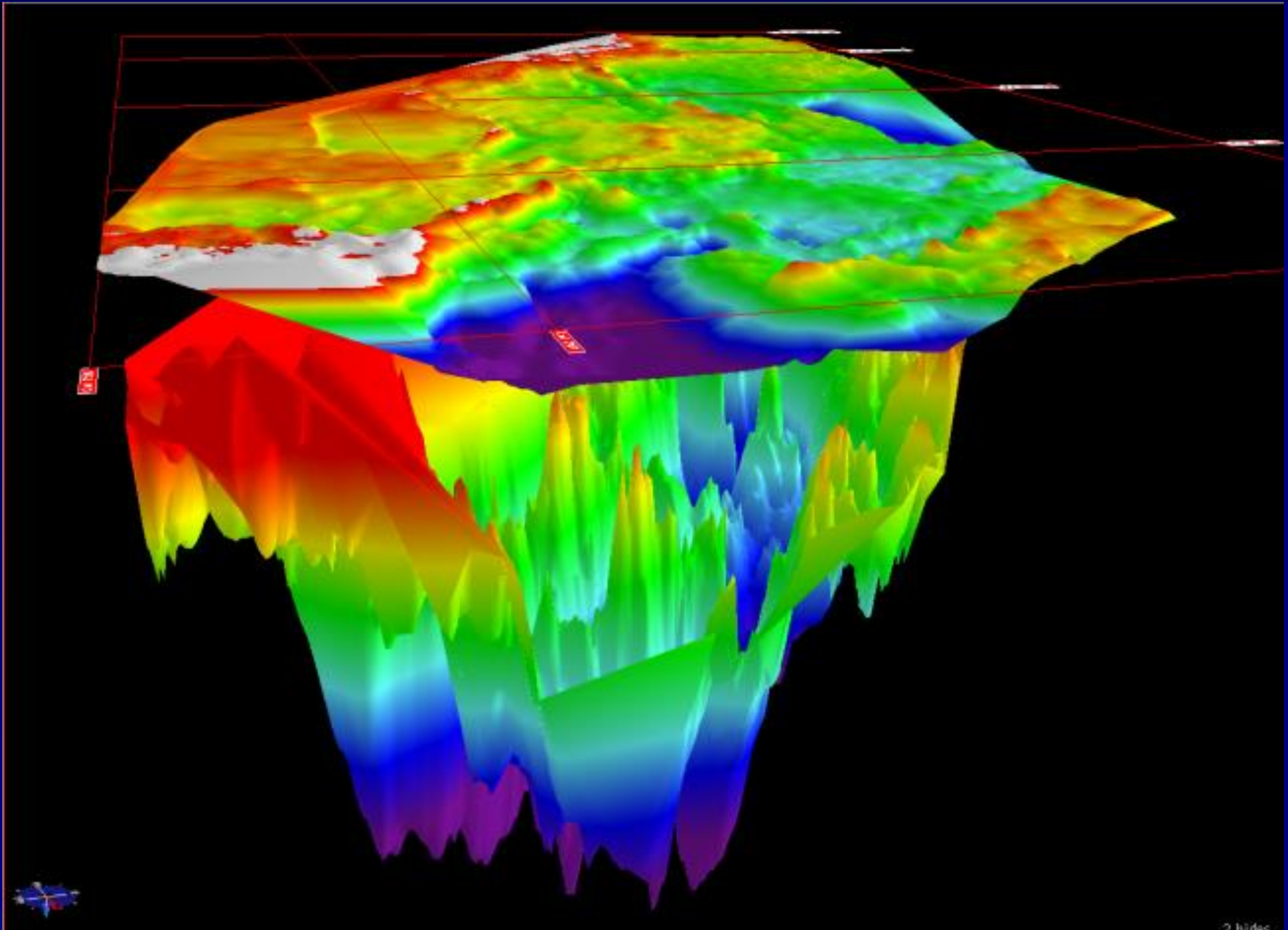
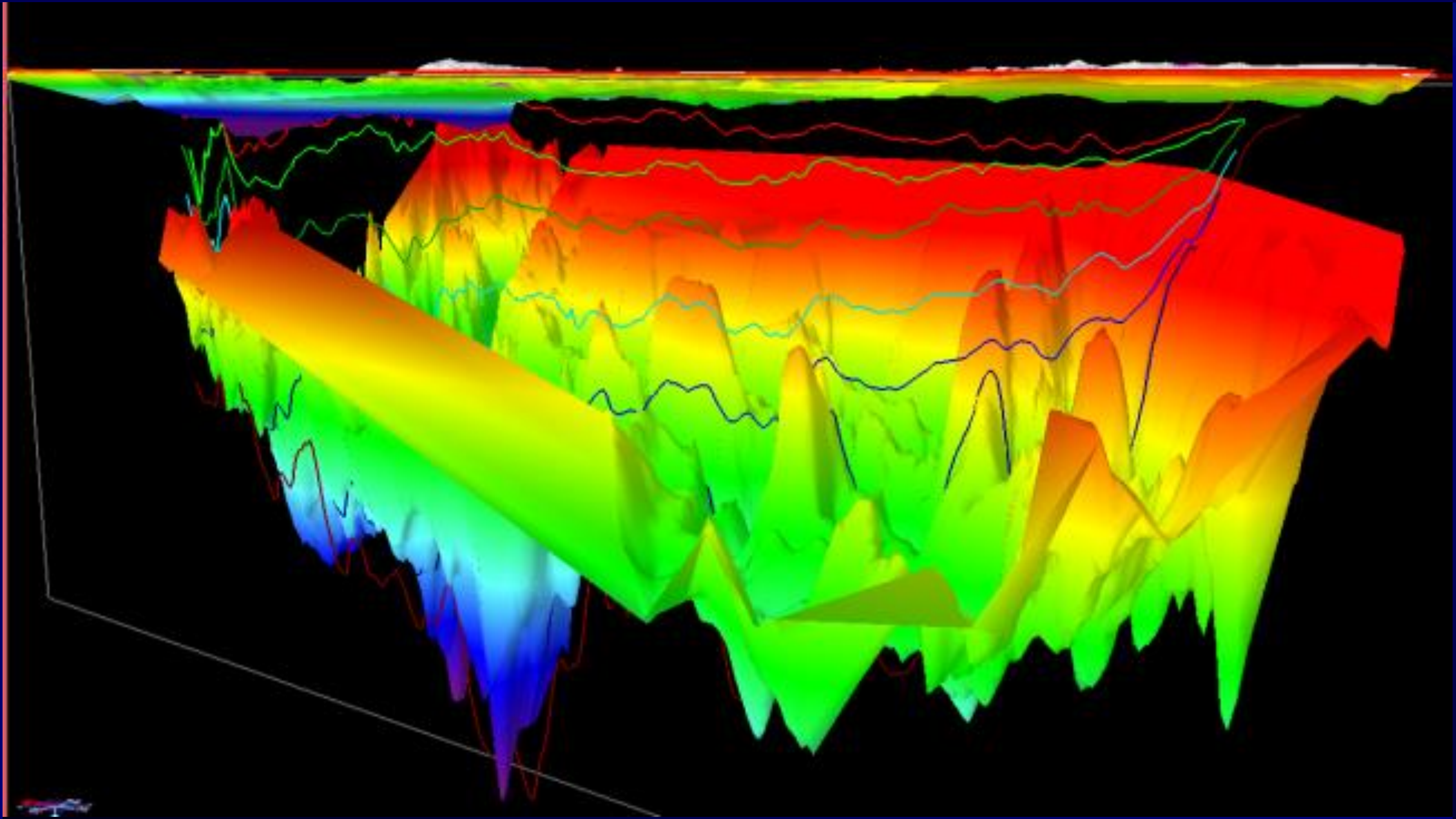
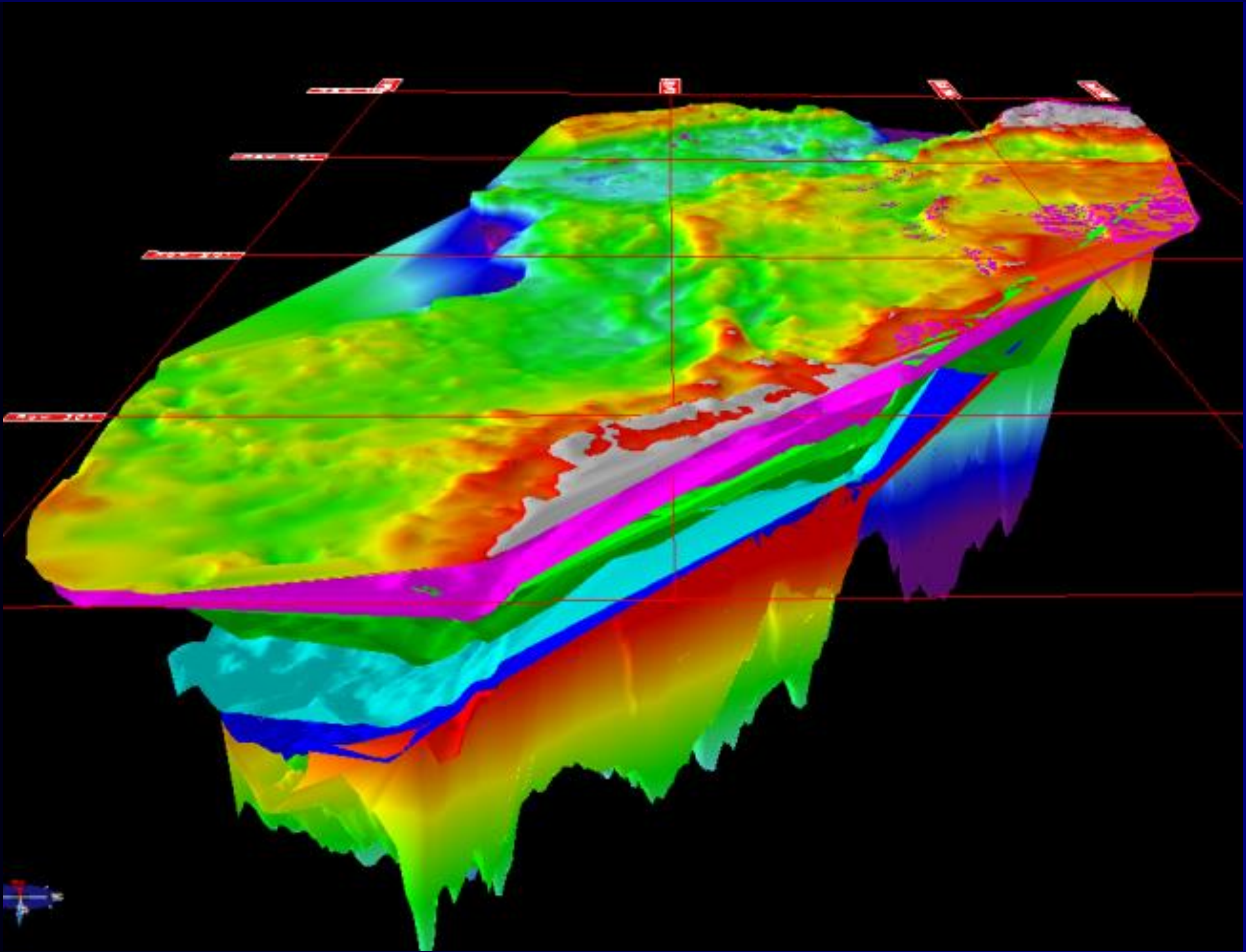
Flexural backstripping in 3D:Base Tertiary sequence, N Sea











Variations in timing and subsidence amount of post-rift basins

How does the syn-rift to post-rift transition occur?

How much variation in subsidence is there between rifts of similar upper crustal extension amount

Evolution of post-rift basins- single rifting events, combination events

Lateral variations in onset of post-rift subsidence

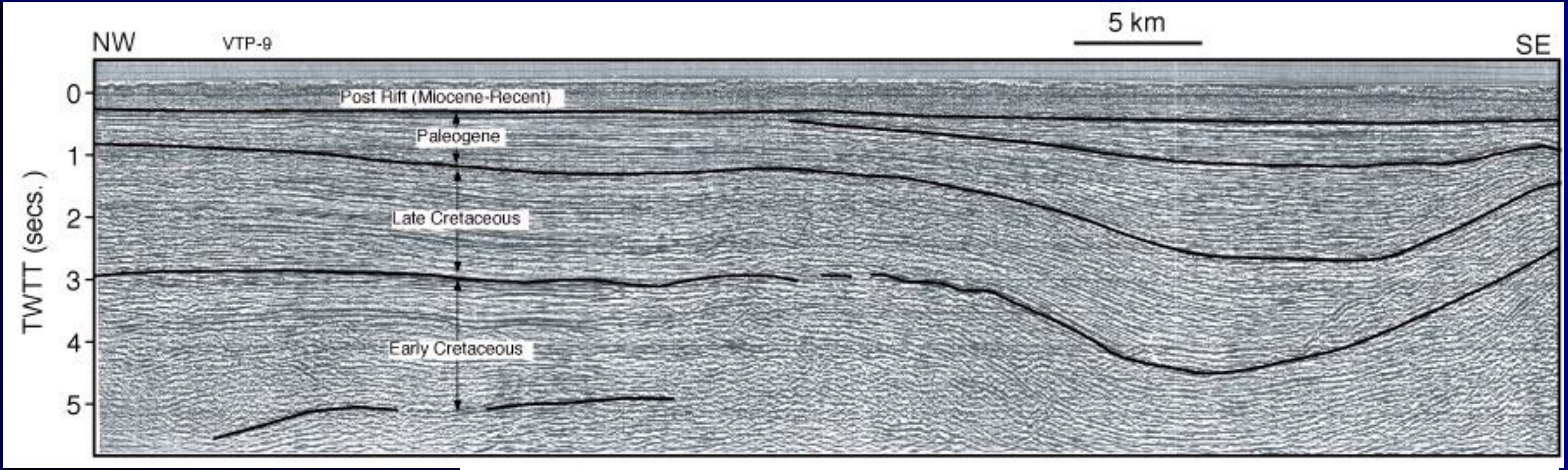
How to explain the discrepancy between back-stripped subsidence and observed upper crustal extension?

- Non-uniform stretching - extension increases downwards in the lithosphere
- Numerous seismically invisible faults contributing to upper crustal extension
- Active mantle processes (e.g. plume)
- Errors in calculation (e.g. water loads)
- Important heat source within sedimentary basin

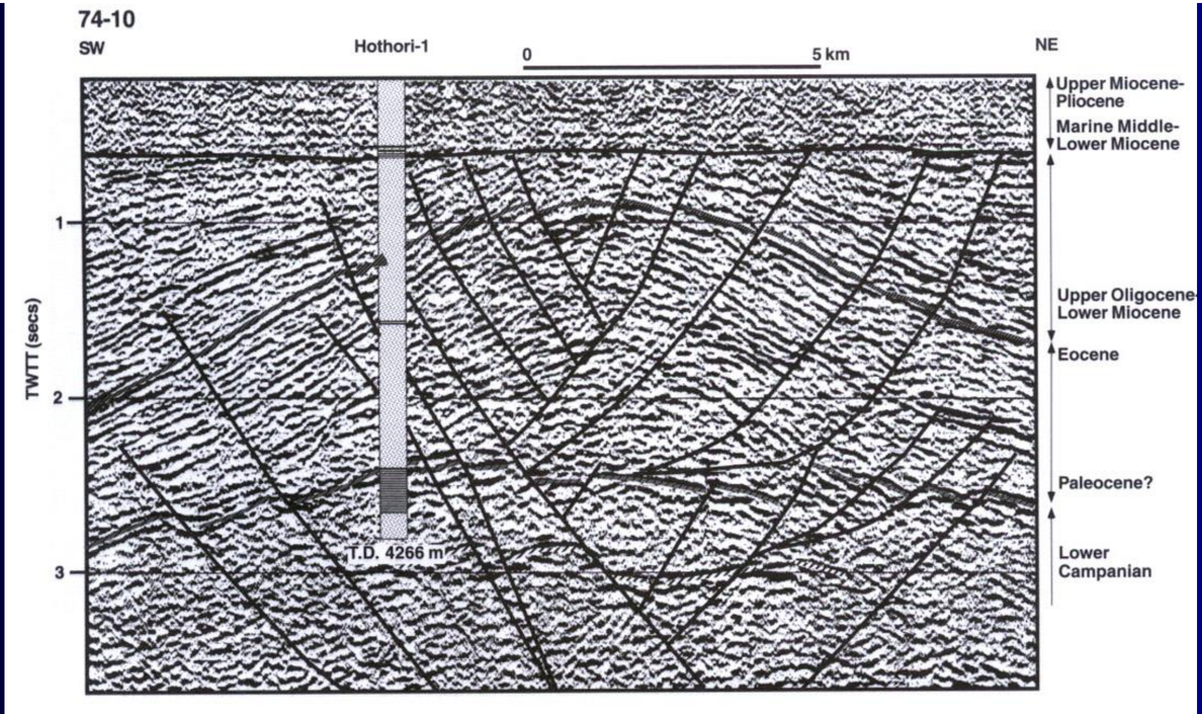
Onset of thermal subsidence in marine vs continental depositional settings

Typically the syn-rift post-rift unconformity in continental filled rifts is planar, and the syn-rift topography largely infilled and eroded flat

Thermal subsidence in the Anza graben



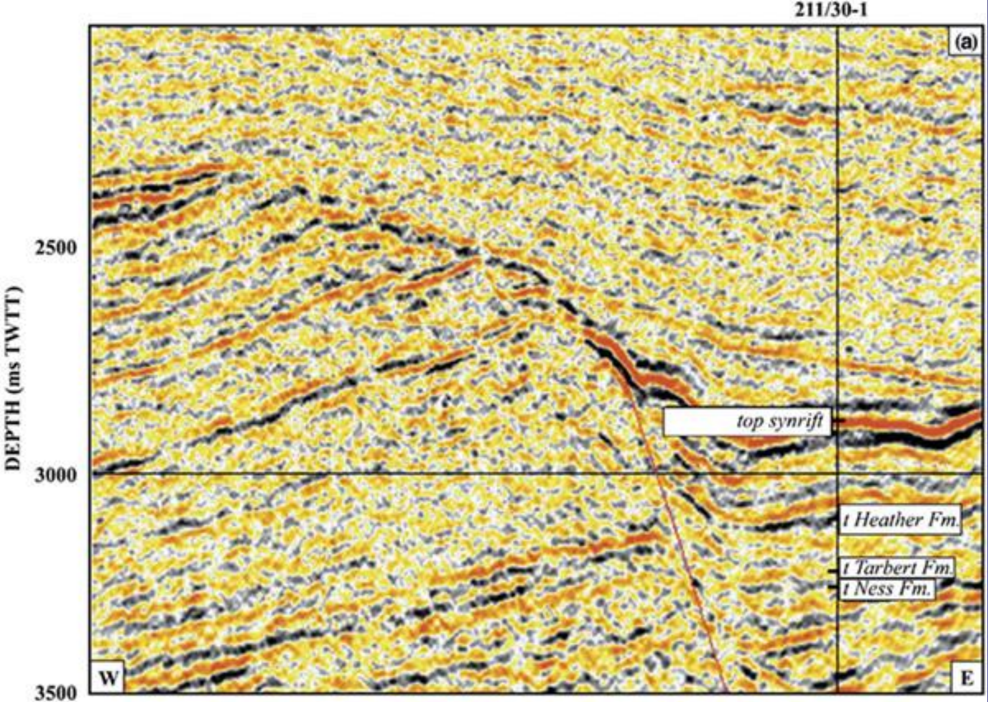
In continental filled rifts the post-rift unconformity tends to be an almost peneplaned surface



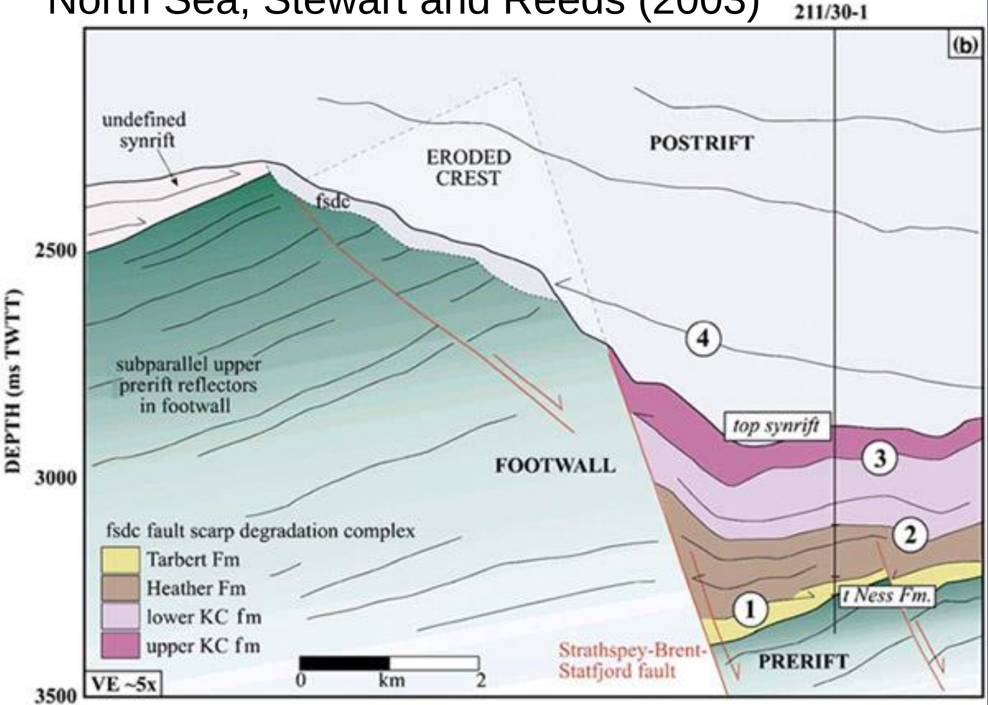
Marine rifts

- In deep marine rifts such as the North Sea substantial submarine syn-rift topography is preserved into the post-rift phase.

- Infill of the marine topography by post-rift sediments is effectively infilling of accommodation space created by syn-rift not post-rift processes. Hence inclusion of the section that onlaps topography will create an over-estimate of the thermal anomaly and hence overestimate the beta factor.

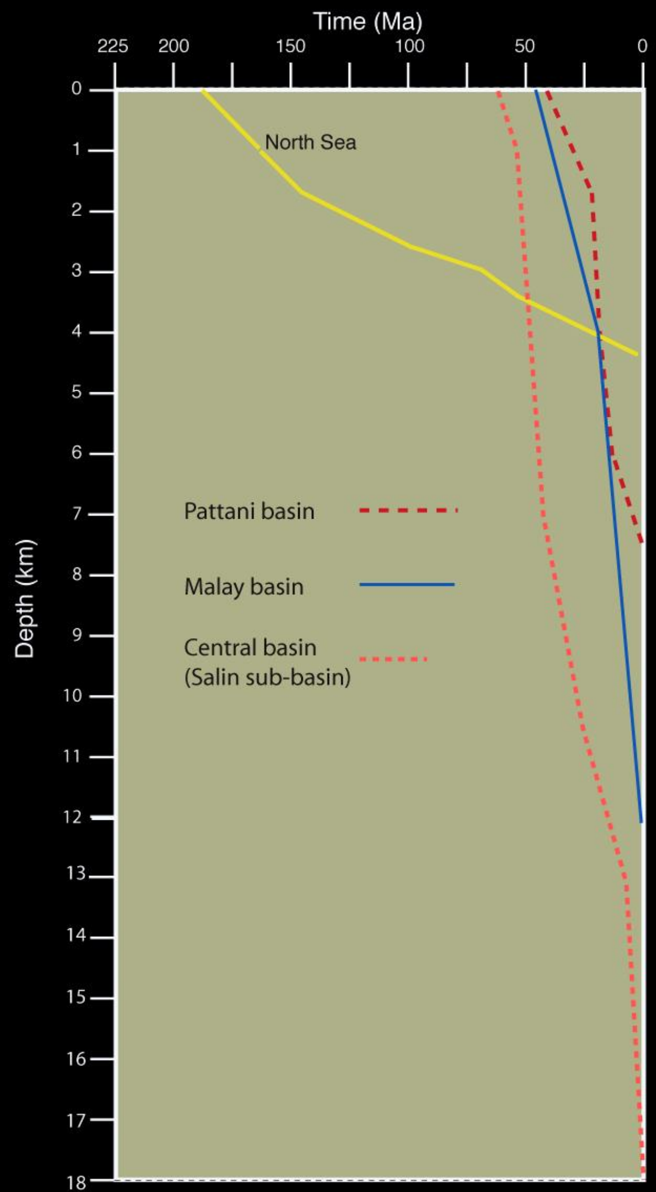


North Sea, Stewart and Reeds (2003)

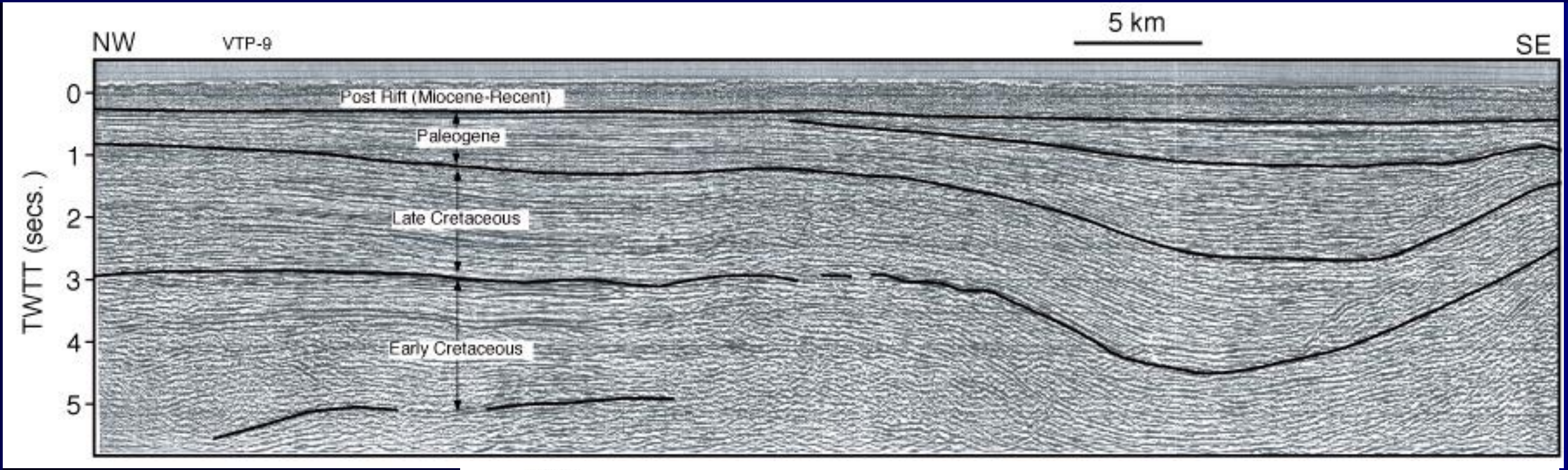


Subsidence rates for the North Sea and SE Asian basins

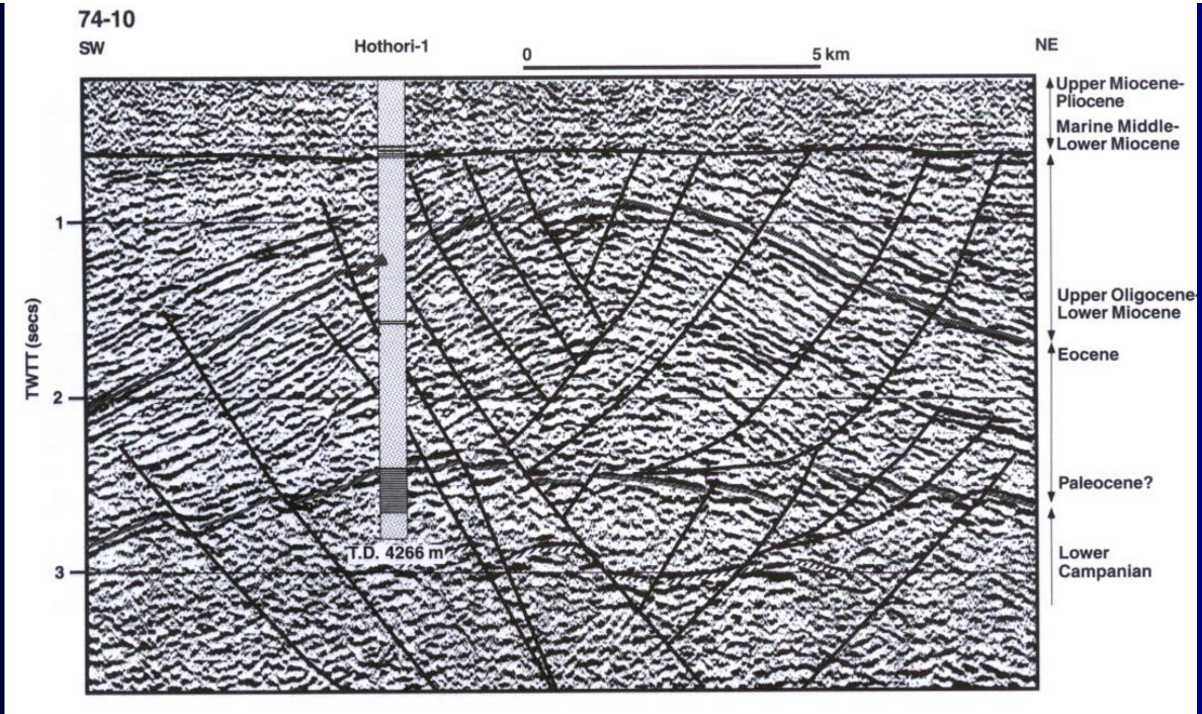
There is almost an order of magnitude difference in subsidence rates between post-rift subsidence in the North Sea and that of the Malay and Pattani basins, yet the three rifts all display upper crustal extension of $\beta < 1.5$



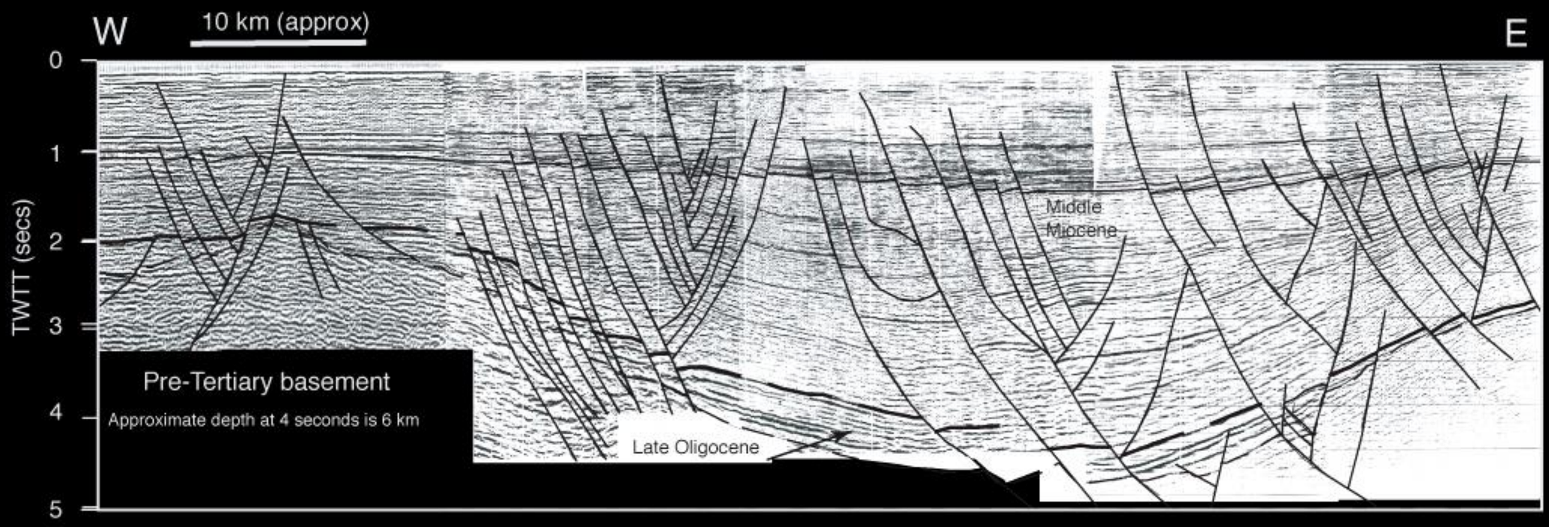
Thermal subsidence in the Anza graben



Miocene-Recent thermal subsidence in the southern Anza Graben is only about 700 m

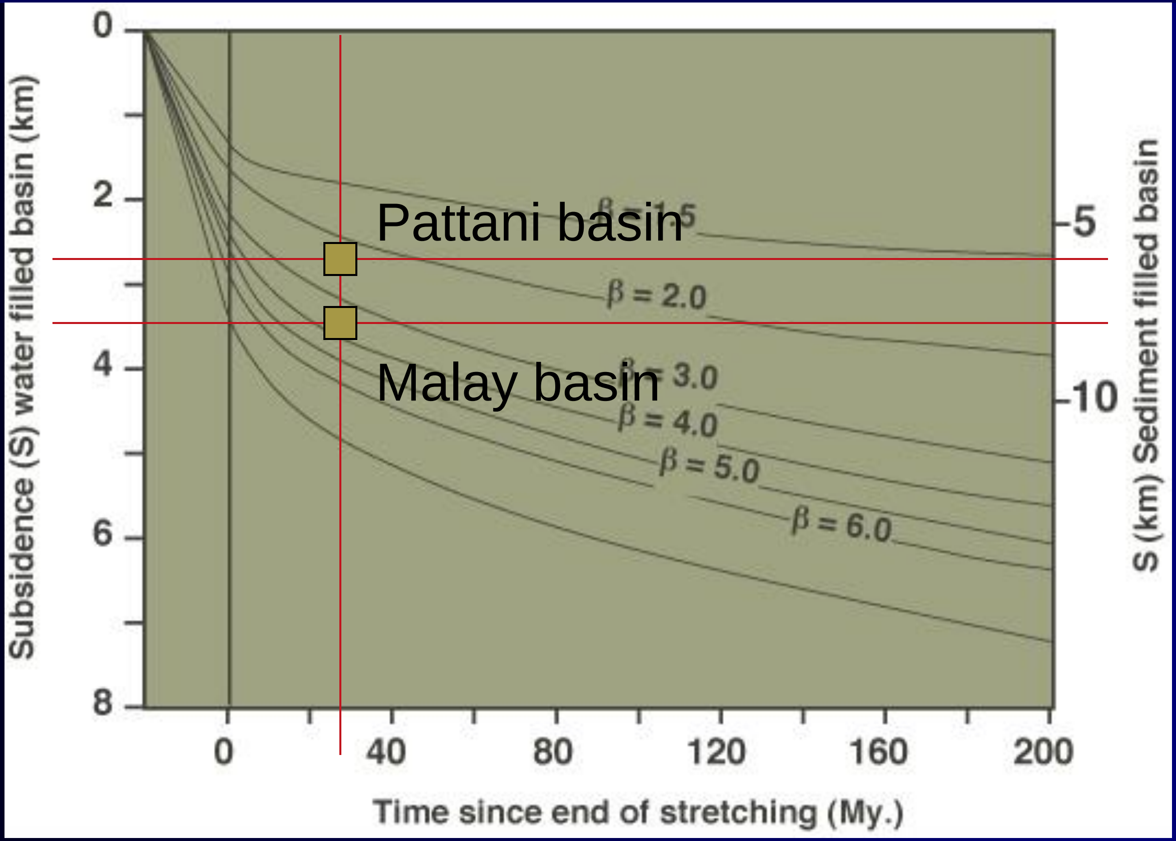


Thermal subsidence in the Pattani basin



Miocene-Recent post-rift fill in the Pattani basin is 5-6 km thick

Relationship between syn-rift extension (β) and post-rift subsidence (passive rifting)



The backstripped extension for the Pattani and Malay basins is considerably greater (β 2-3) than the upper crustal extension estimated from seismic lines (β < 1.5)

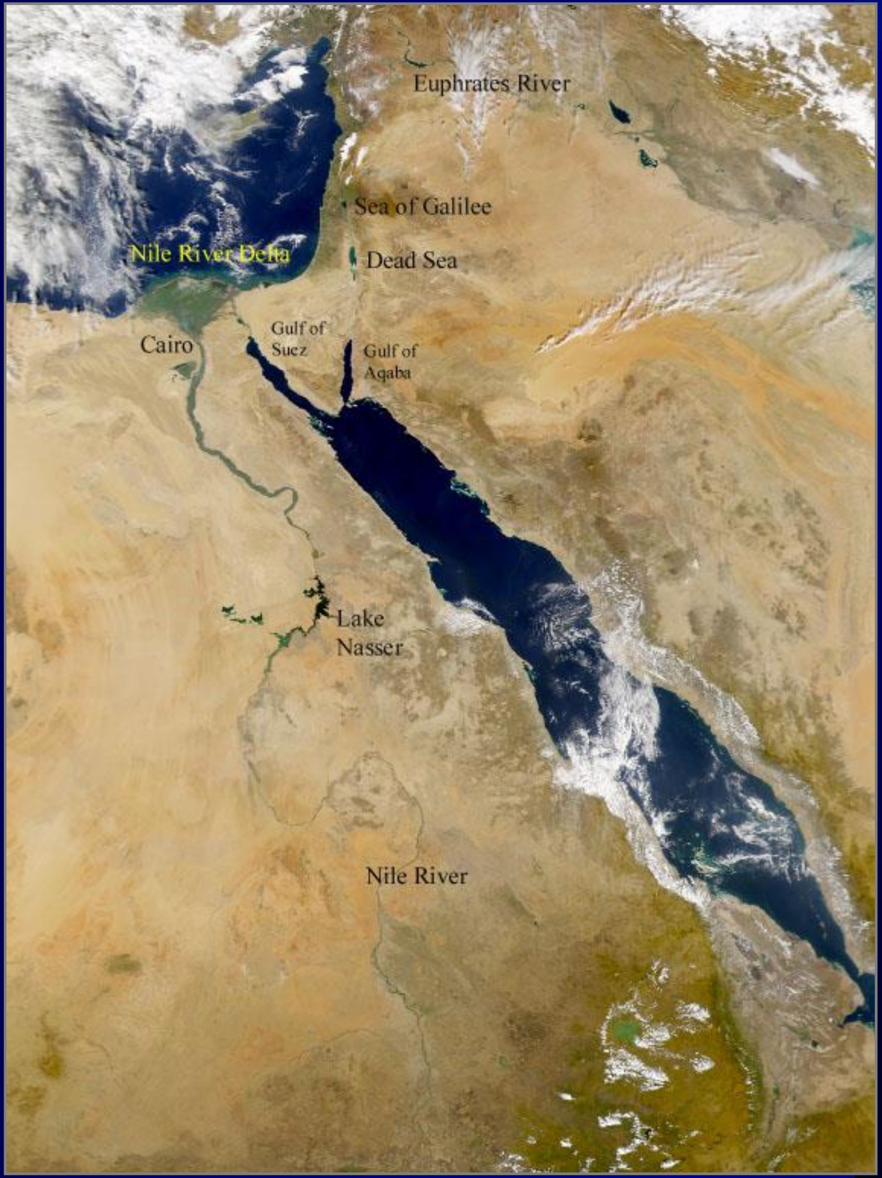
Timing of onset of post-rift: Gulf of Suez

Just when did post-rift subsidence begin?

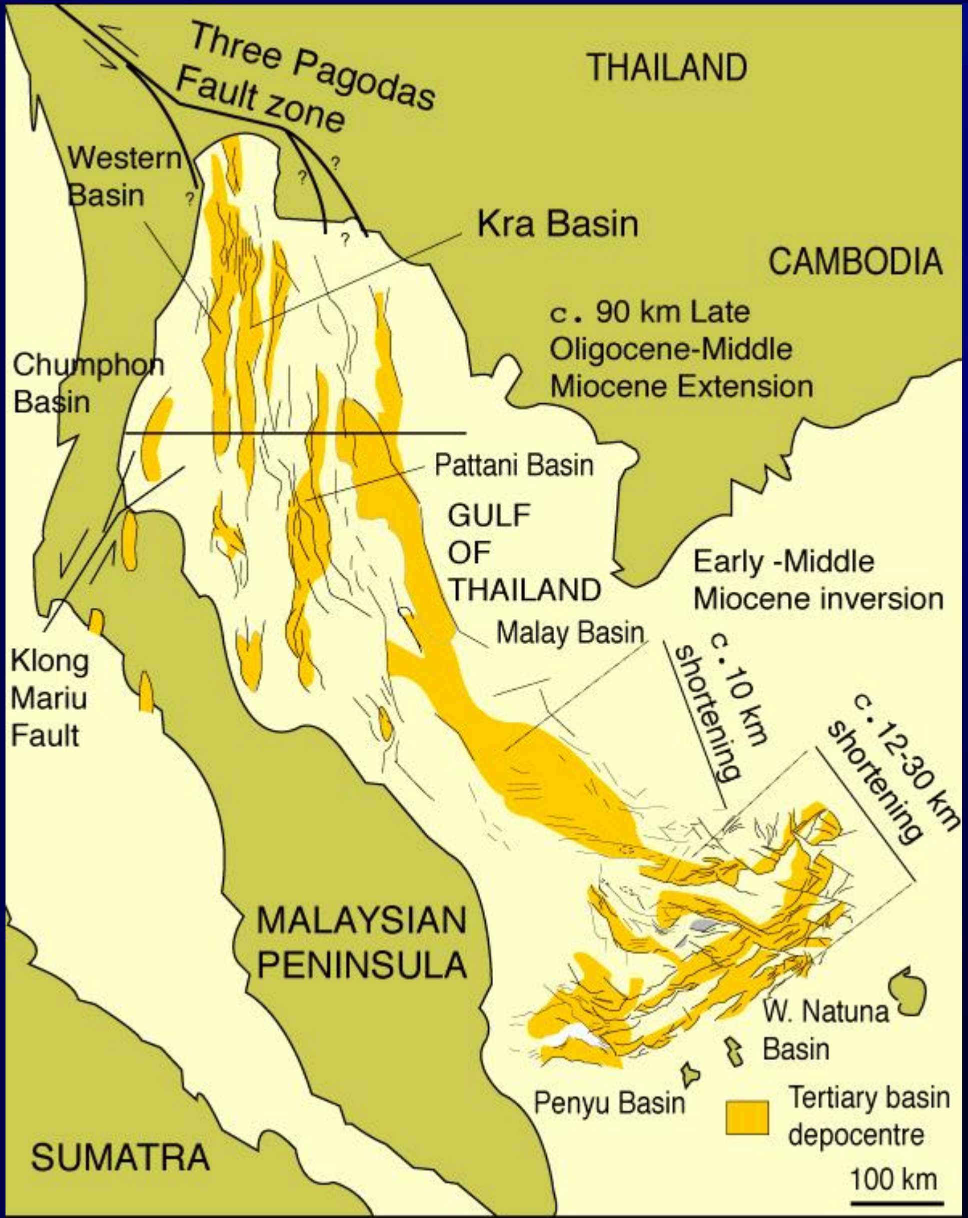
Middle Miocene mid Rudeis event - Wescott et al. (1998), - onset Aqaba-Dead Sea shear zone

3 Ma later - Top Kareem - marked unconformity, slowing of subsidence, onset evaporites - Patton et al. (1994)

Period of tectonic quiescence for ~7 ma, but Late Miocene-Present extension has occurred. McClay et al. (1998) Oligocene-Recent is syn-rift



Gulf of Thailand Tertiary basins

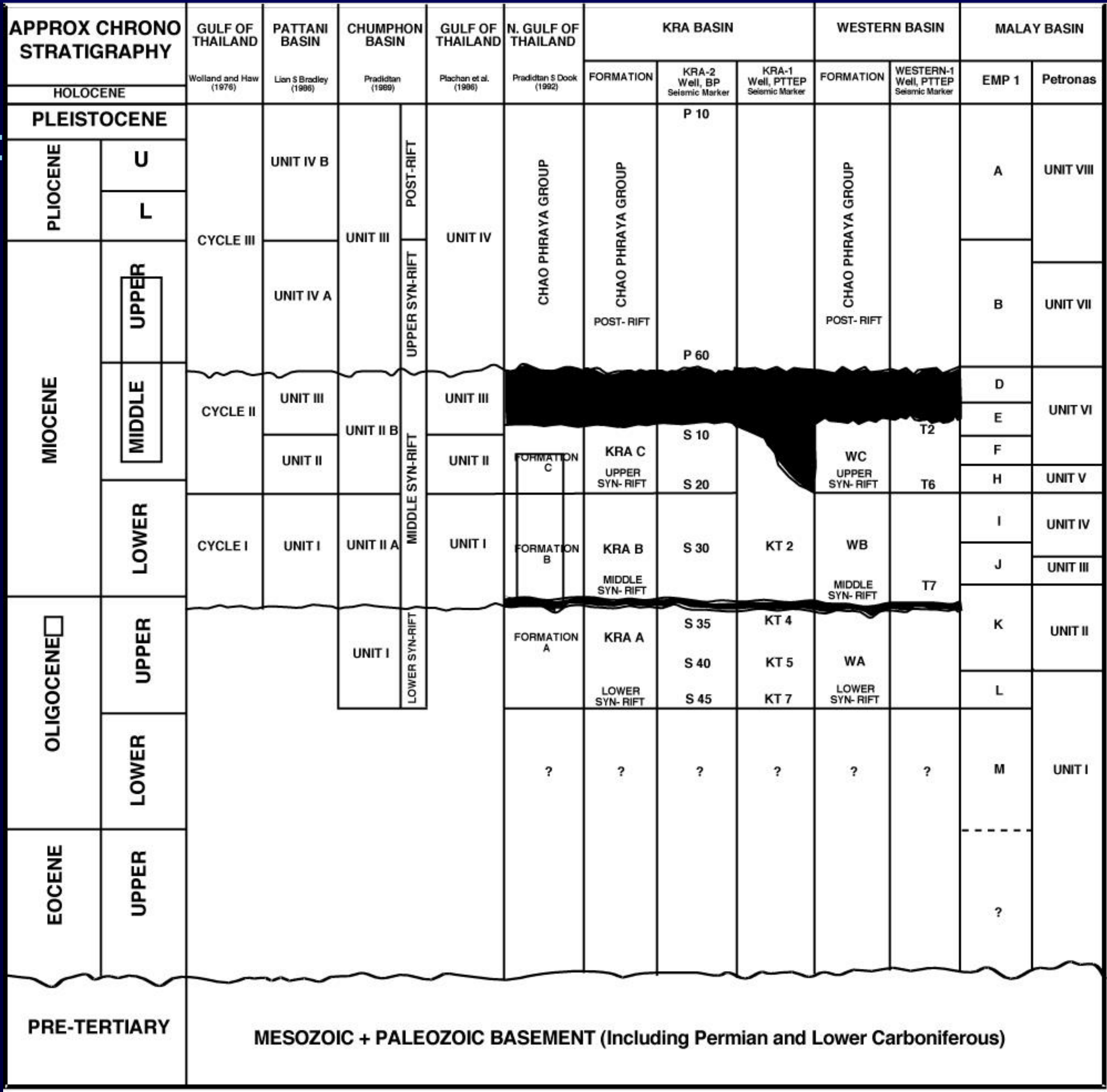


An older stratigraphic scheme for the GOT (*c.*1997)

Application of perceived wisdom for a region:

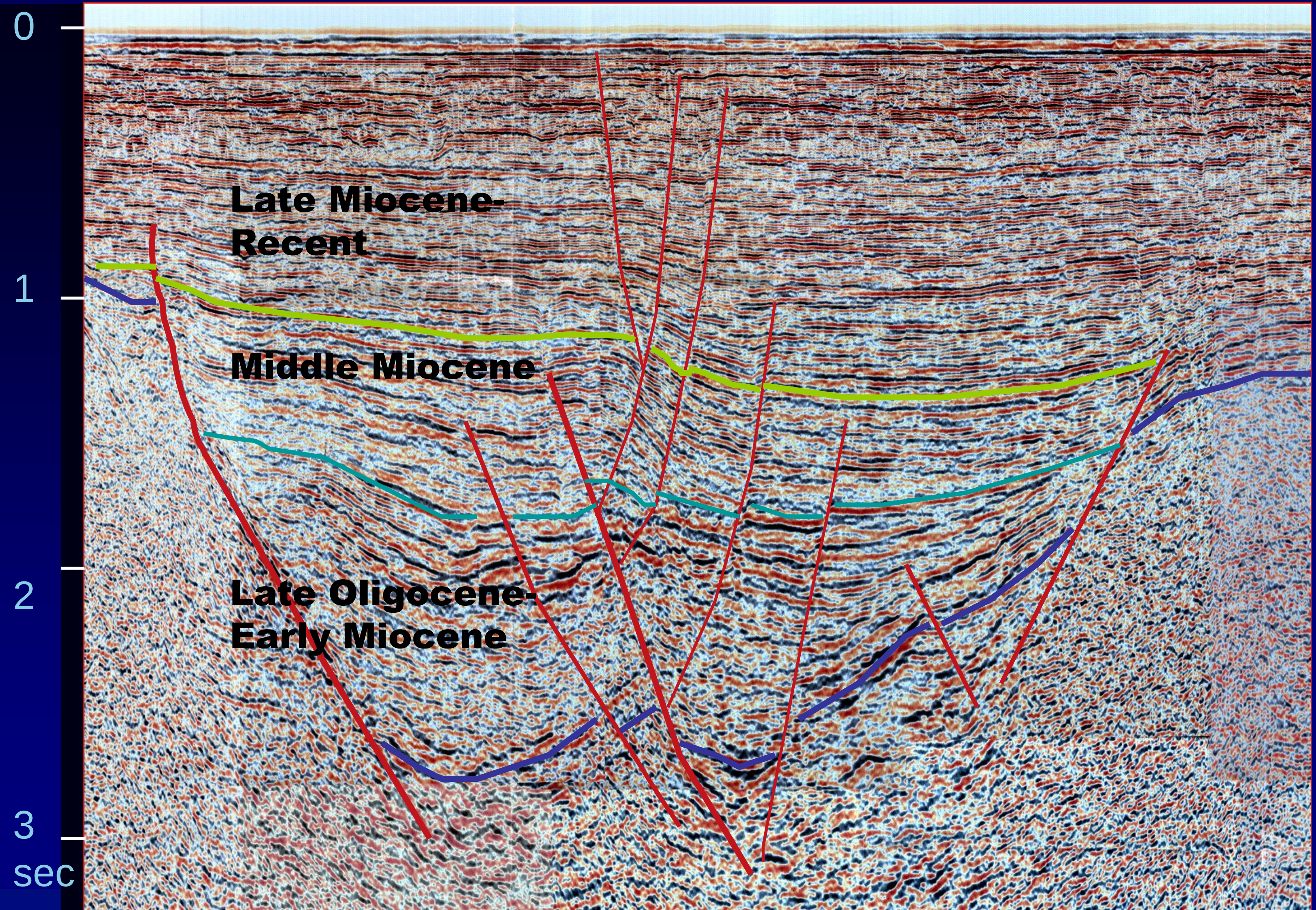
1) Assumption regionally all basins have a similar history

2) Onset of thermal subsidence regionally uniform

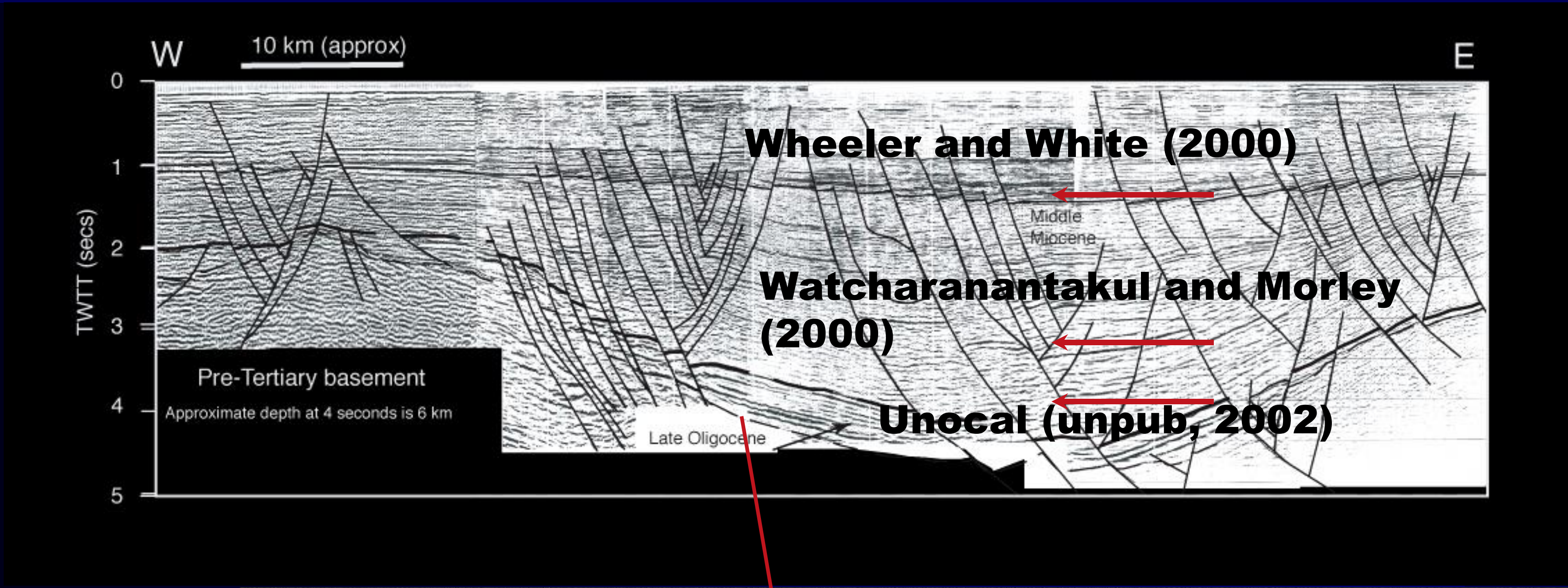


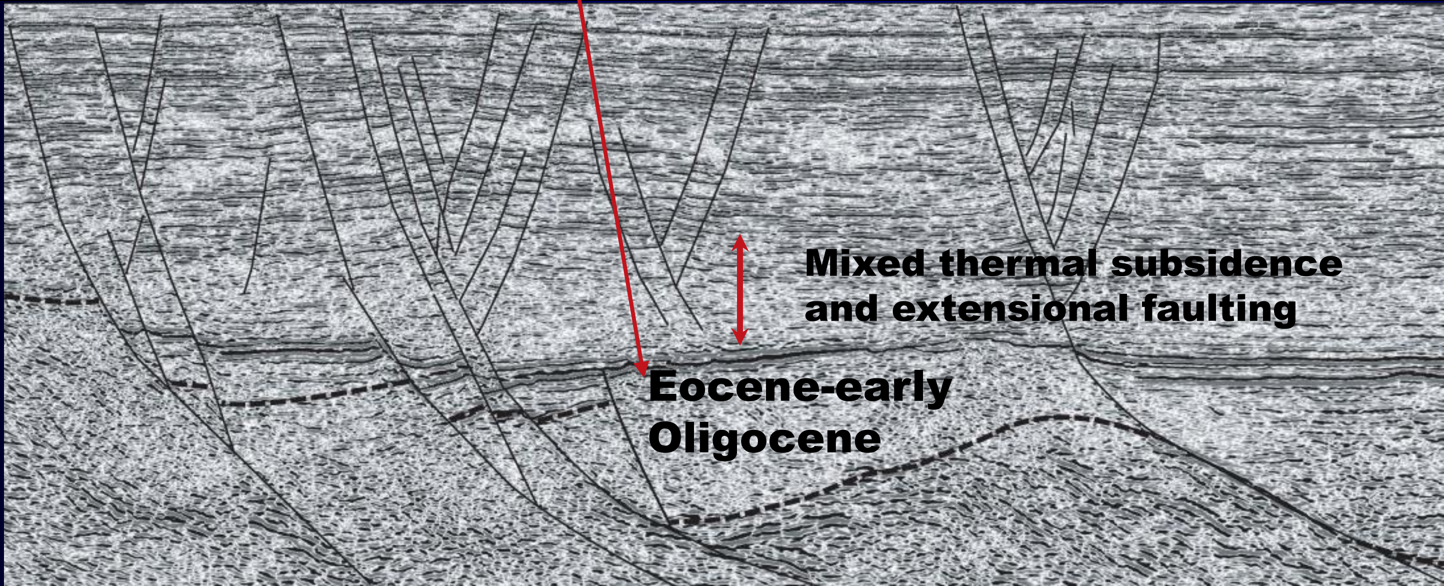
APPROX CHRONO STRATIGRAPHY		GULF OF THAILAND Wolland and Haw (1976)	PATTANI BASIN Lian & Bradley (1986)	CHUMPHON BASIN Pradidtan (1989)		GULF OF THAILAND Plachan et al. (1986)	N. GULF OF THAILAND Pradidtan & Dook (1992)	KRA BASIN FORMATION	KRA BASIN KRA-2 Well, BP Seismic Marker	KRA BASIN KRA-1 Well, PTTEP Seismic Marker	WESTERN BASIN FORMATION	WESTERN BASIN WESTERN-1 Well, PTTEP Seismic Marker	MALAY BASIN EMP 1	MALAY BASIN Petronas
HOLOCENE														
PLEISTOCENE		CYCLE III			POST-RIFT		CHAO PHRAYA GROUP	CHAO PHRAYA GROUP POST- RIFT	P 10		CHAO PHRAYA GROUP POST- RIFT		A	UNIT VIII
PLIOCENE	U		UNIT IV B											
	L			UNIT III		UNIT IV								
MIOCENE	UPPER		UNIT IV A		UPPER SYN-RIFT				P 60				B	UNIT VII
	MIDDLE	CYCLE II	UNIT III UNIT II	UNIT II B		UNIT III UNIT II	FORMATION C	KRA C UPPER SYN- RIFT	S 10 S 20		WC UPPER SYN- RIFT	T2 T6	D E F H	UNIT VI UNIT V
	LOWER	CYCLE I	UNIT I	UNIT II A	MIDDLE SYN-RIFT	UNIT I	FORMATION B	KRA B MIDDLE SYN- RIFT	S 30	KT 2	WB MIDDLE SYN- RIFT	T7	I J	UNIT IV UNIT III
OLIGOCENE	UPPER			UNIT I	LOWER SYN-RIFT		FORMATION A	KRA A LOWER SYN- RIFT	S 35 S 40 S 45	KT 4 KT 5 KT 7	WA LOWER SYN- RIFT		K L	UNIT II
	LOWER						?	?	?	?	?	?	M	UNIT I
EOCENE	UPPER												?	
PRE-TERTIARY		MESOZOIC + PALEOZOIC BASEMENT (Including Permian and Lower Carboniferous)												

Half graben geometry in western Gulf of Thailand



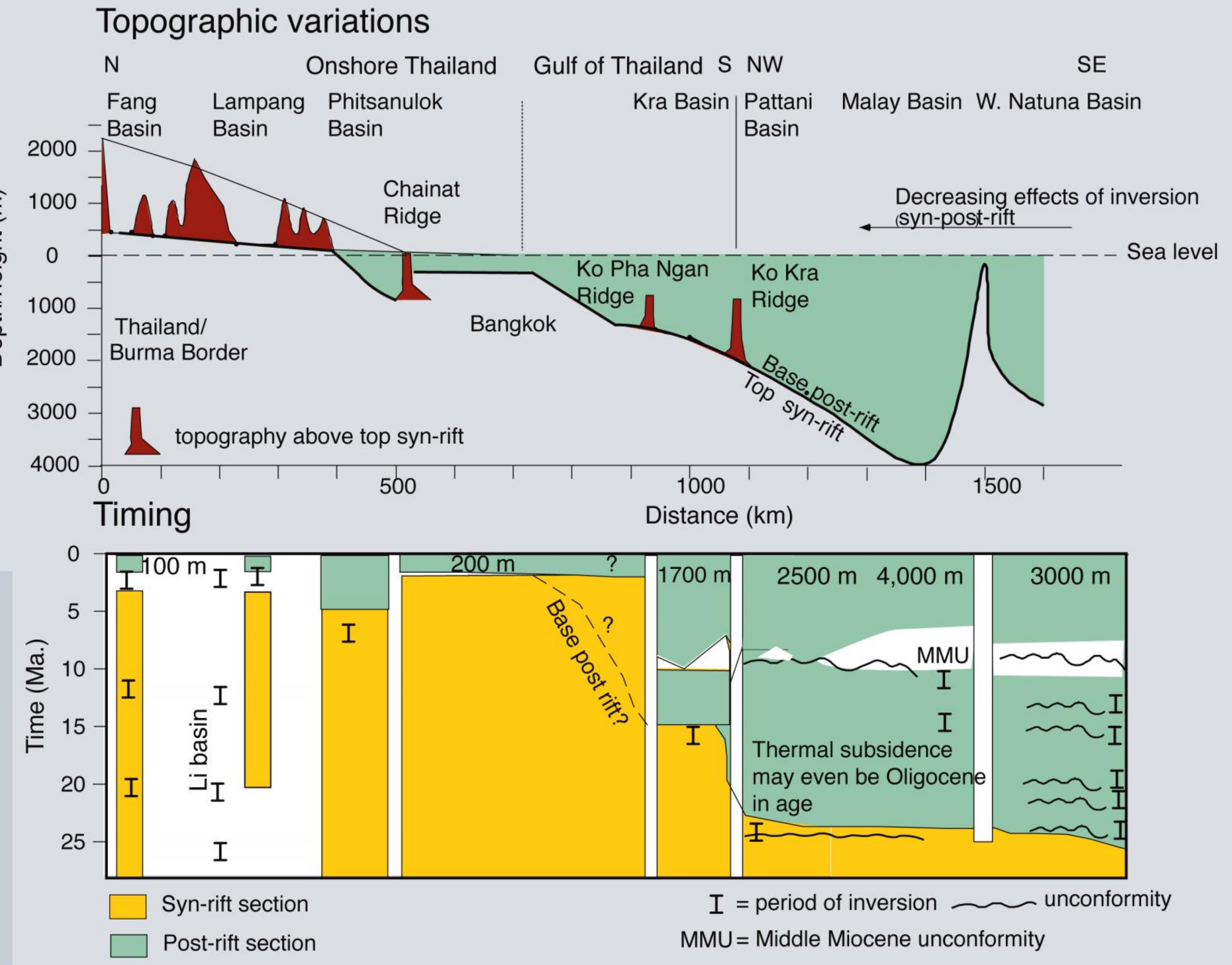
Thermal subsidence in the Pattani basin

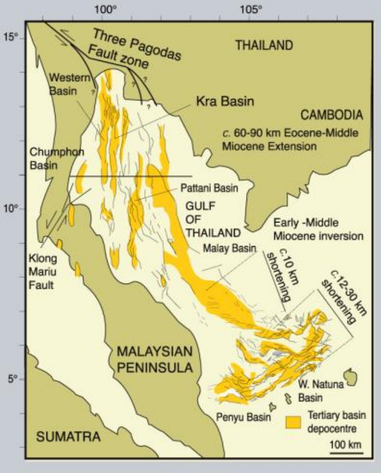




Miocene-Recent post-rift fill in the Pattani basin is 5-6 km thick

Lateral variations in timing of post-rift subsidence, W. Natuna basin to N. Thailand

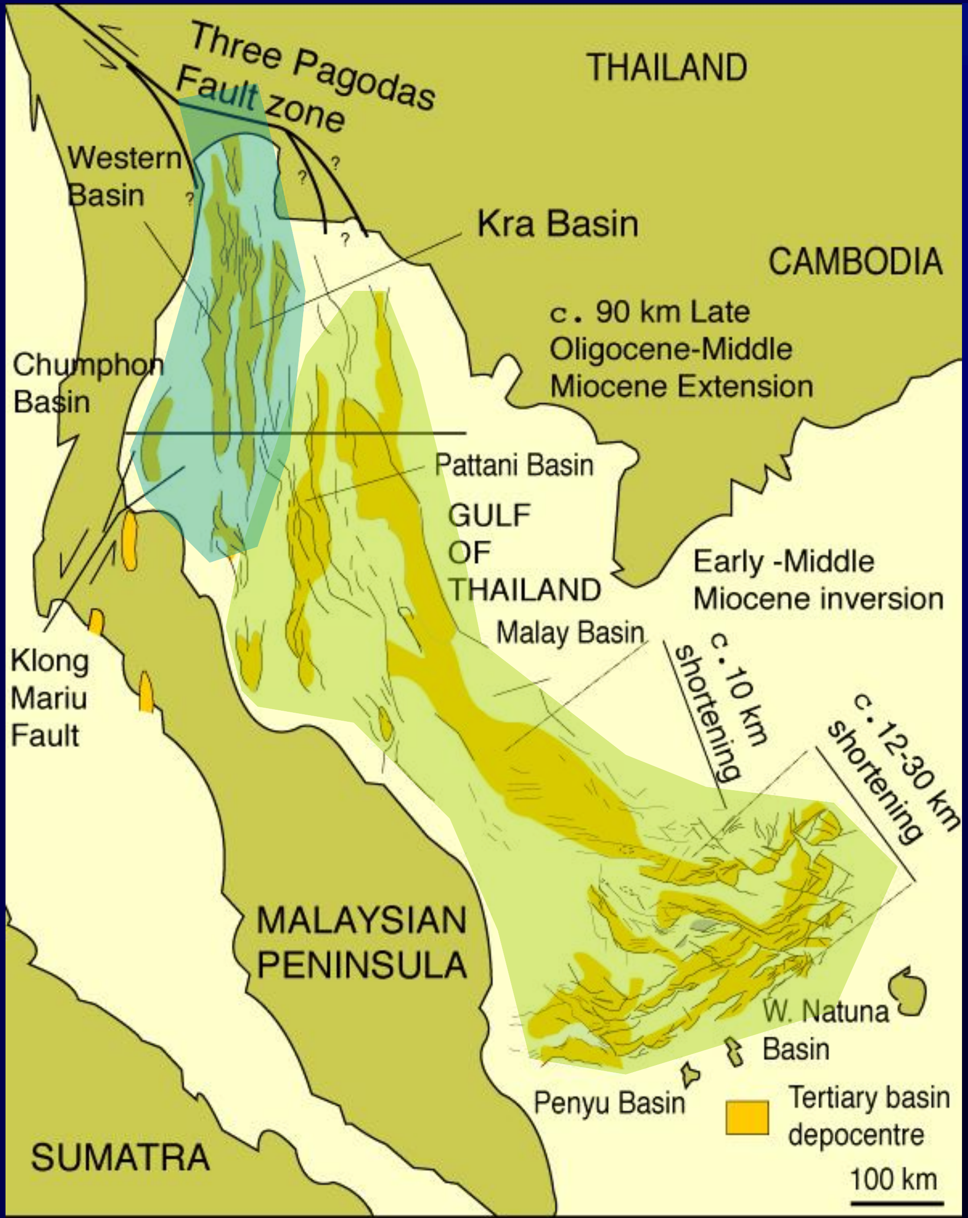




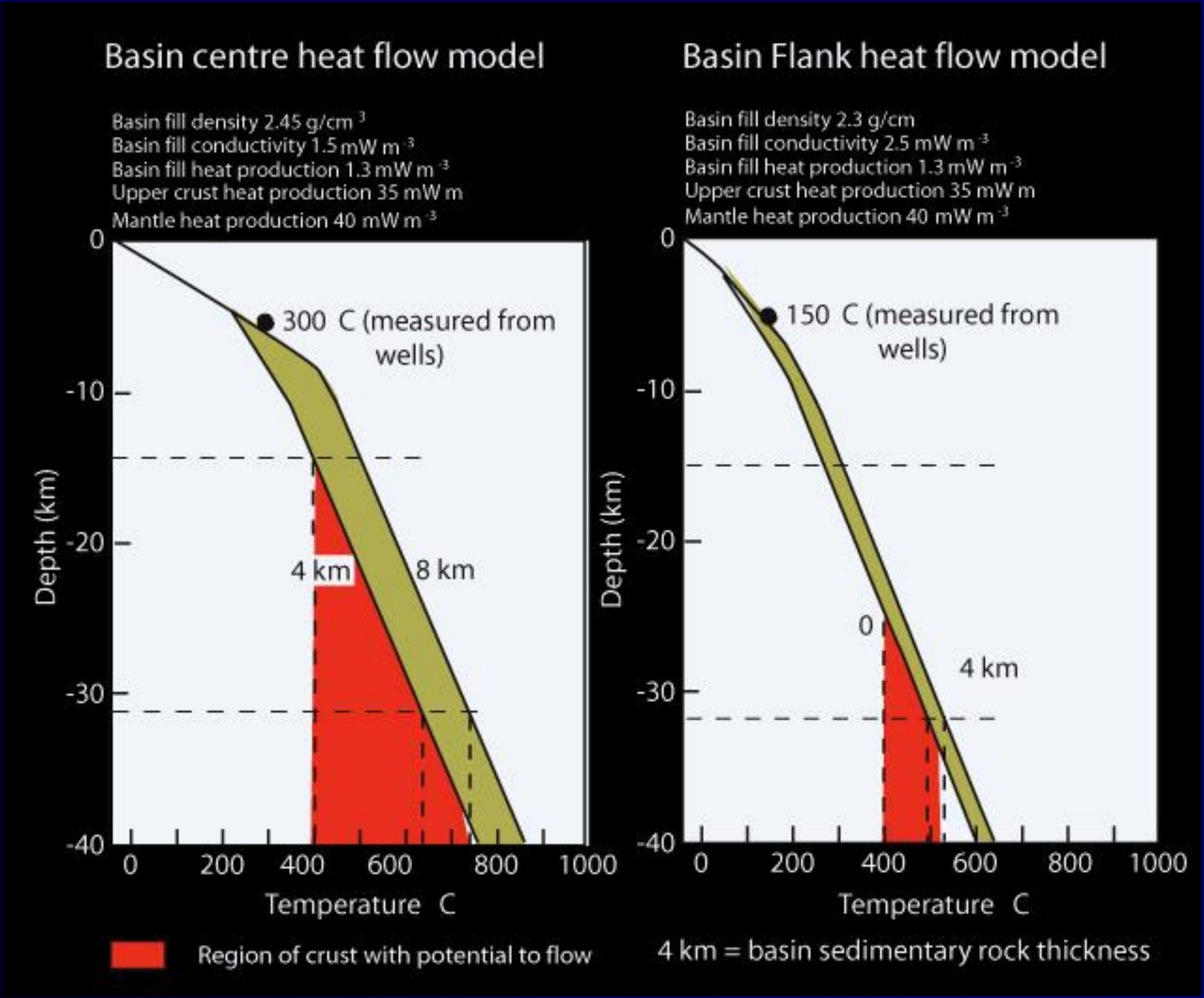
Gulf of Thailand Tertiary basins

Oligocene -Middle Miocene extension
Middle-Late Miocene thermal subsidence

Eocene-Oligocene major extension,
Mixed Oligocene-Early Miocene thermal subsidence and extension
Middle-Late Miocene thermal subsidence, conjugate faulting,
Or in the southern half Miocene inversion during thermal subsidence



Modelling of heat flow in the Pattani basin



Inhibition of cooling in the Pattani and Malay basins

Possible causes:

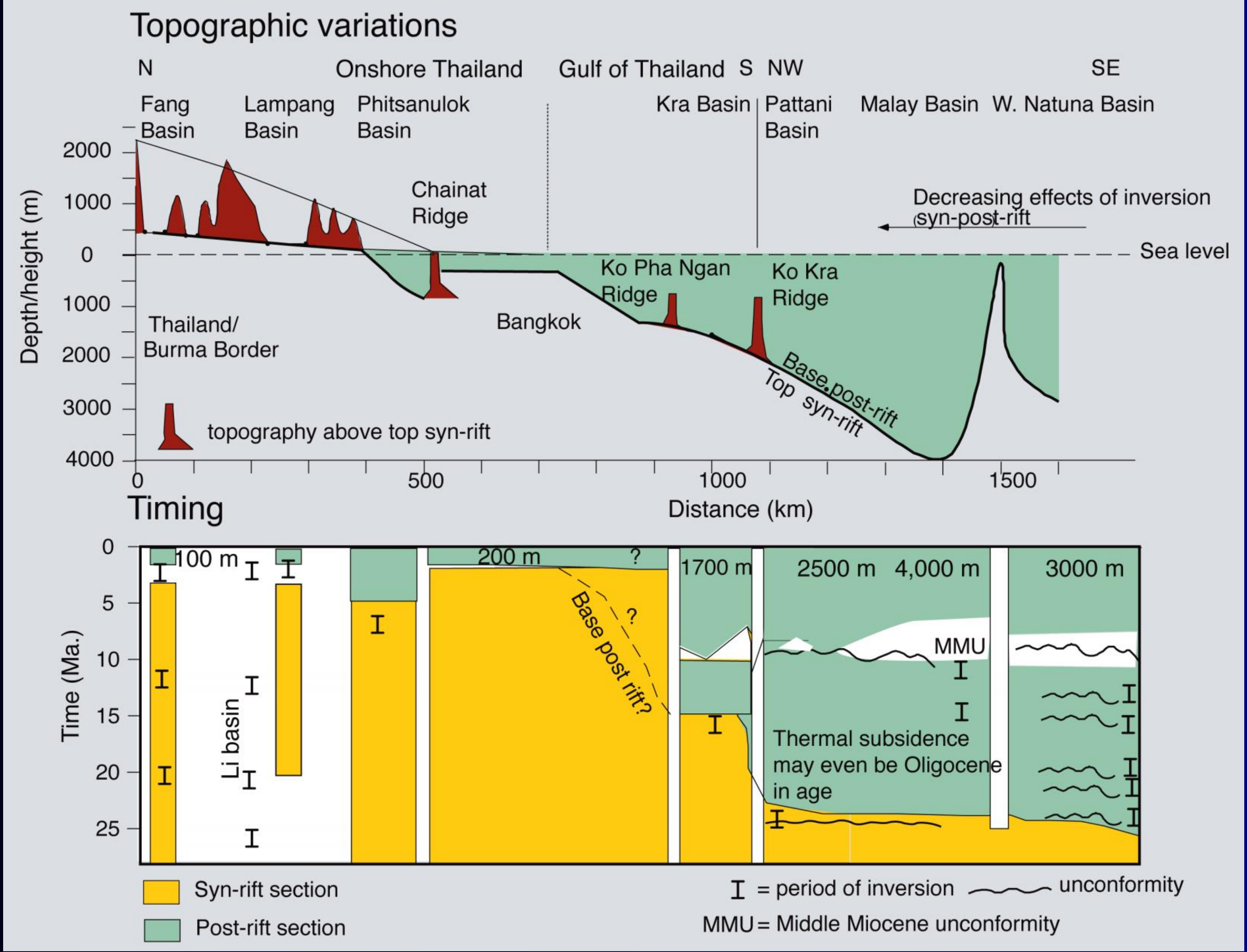
Insulation by shale sequences within the thick basinal sequences

Erosion of radiogenic sediment source areas (granites)

Fluids appear to have redistributed some of the radiogenic material - high gamma ray readings are sometimes associated with calcite cemented layers

Diagenetic history of high temperature dickite formation prior to hydrocarbon generation indicates temperatures have been high for a long period, not just a short, late episode

N-S variations in timing of thermal subsidence W Natuna basin-North Thailand



Summary

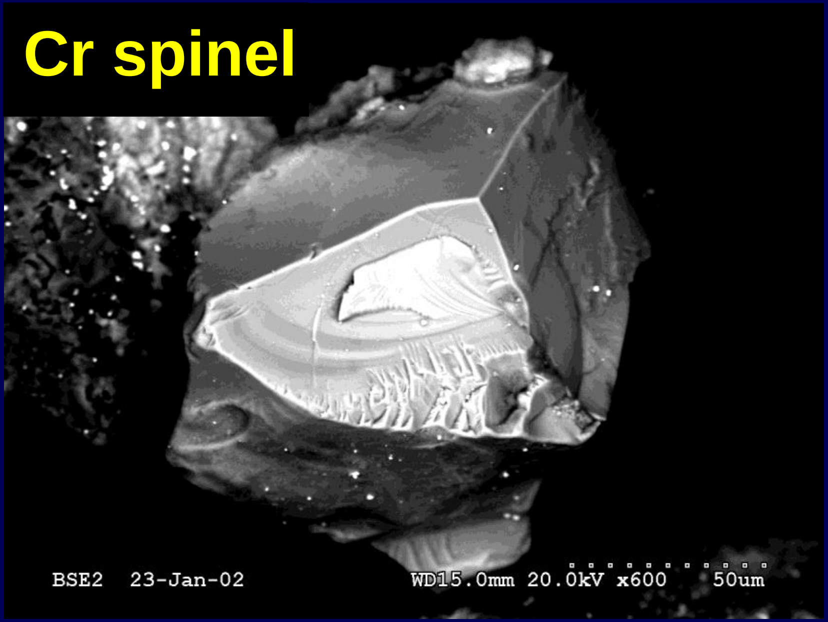
Commonly in rifts the observed upper crustal extension amount does not match the amount of lithospheric thinning predicted by backstripping of the post-rift basin

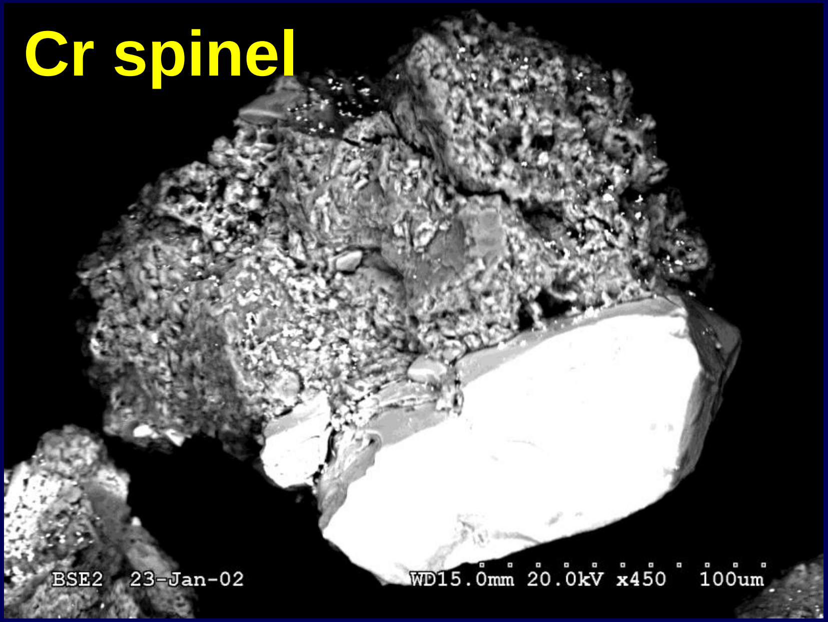
The onset of post-rift subsidence is commonly regarded as a simple event to define

Consequently confusion in basin terminology can arise as there are attempts to force a simple model on areas where the simple model is inappropriate

There are a number of factors that can make the onset of subsidence difficult to define, and post rift subsidence difficult to model, these factors include:

1) Continental vs marine depositional setting
2) Tectonic setting (e.g. propagating tip of spreading centre, GOS)
3) Duration of extension
4) Radiogenic sediment source


Cr spinel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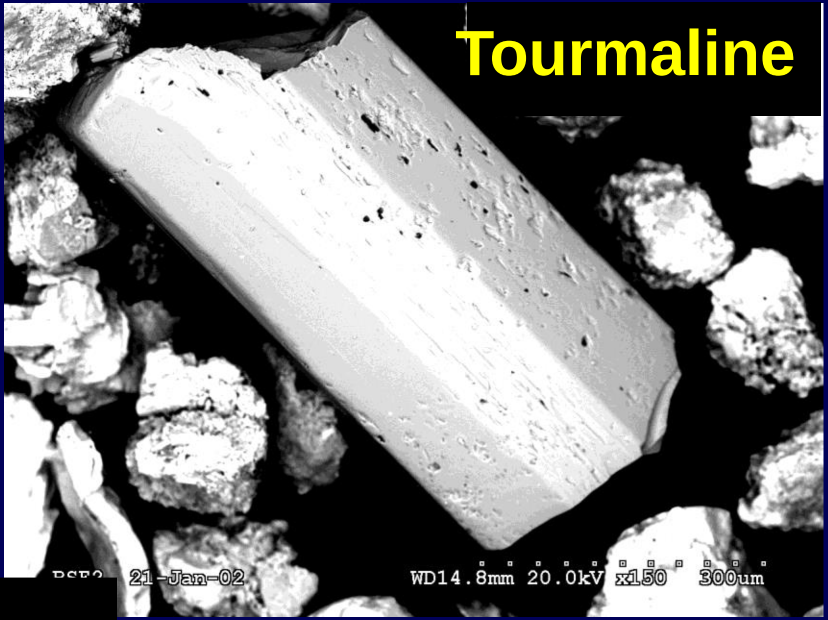
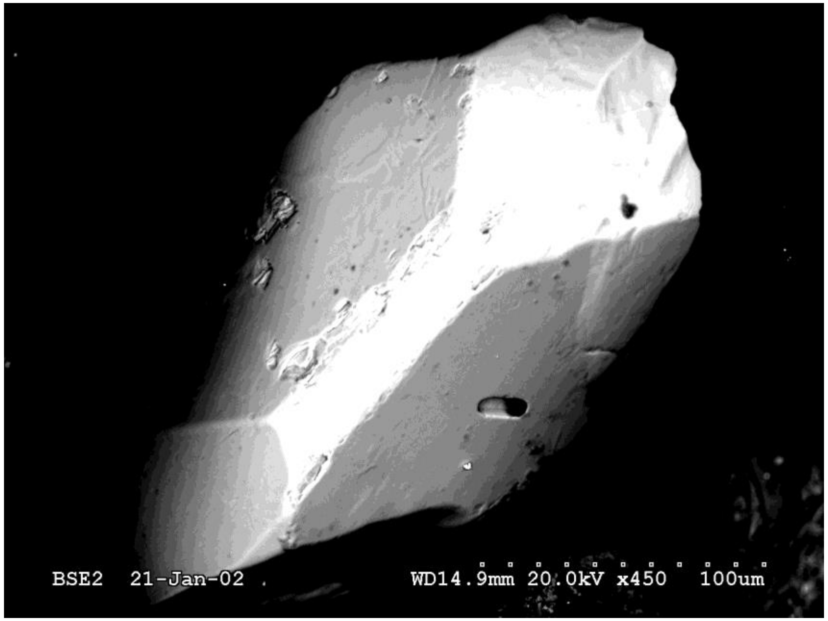

Tourmaline

[redacted]


Kyanite

Zircons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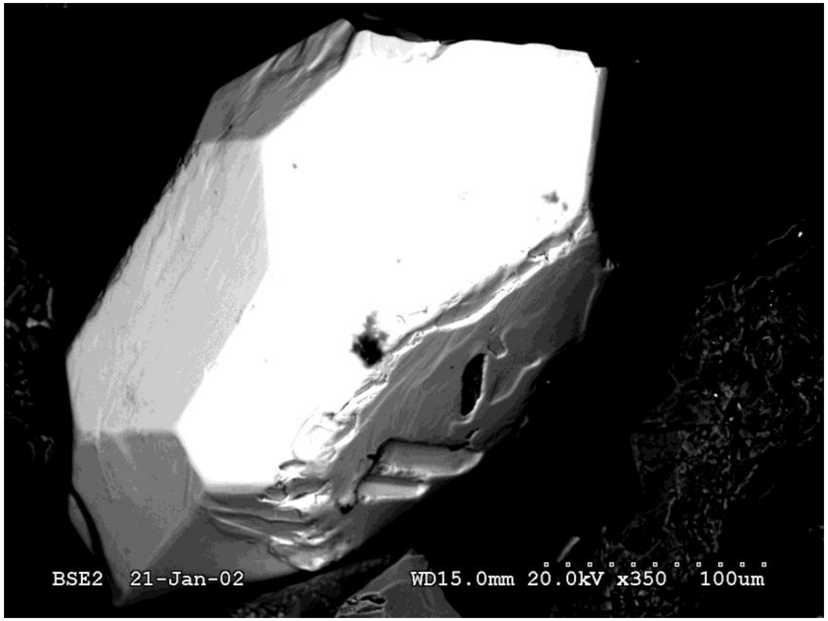
WD14.9mm 20.0kV x450 100um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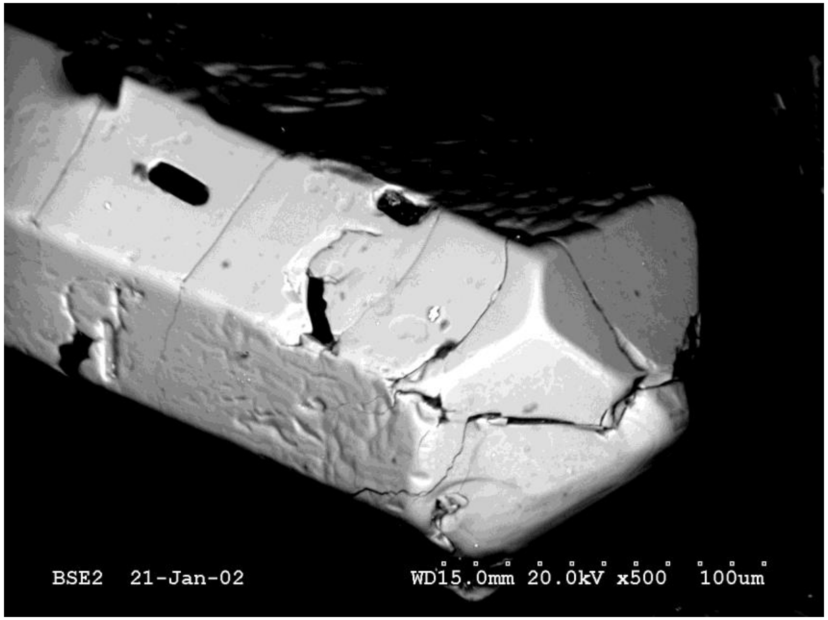
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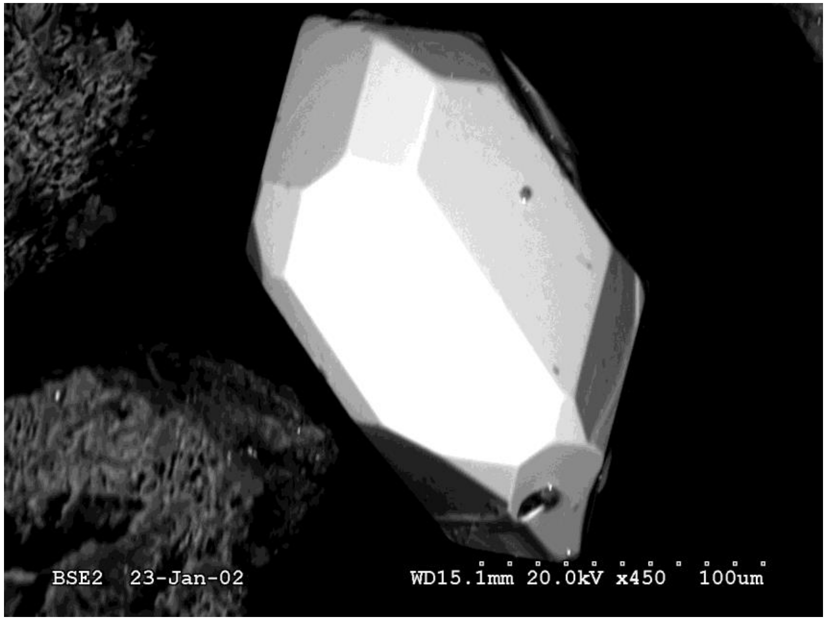
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WD15.1mm 20.0kV x450 100um

Post-rift subsidence can be split into different components