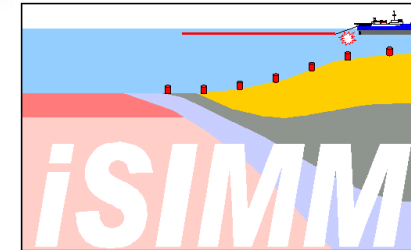




NERC/DTI Ocean Margins Thematic Programme

iSIMM
(integrated Seismic Imaging & Modelling of Margins)



PIs - **Nick Kuszniir & Bob White** - Liverpool University, Cambridge University
Co-PIs - **Phil Christie & Alan Roberts** - Schlumberger Cambridge Research, Badley Geoscience

iSIMM Team Members

Cambridge - **Roman Spitzer, Zoë Lunnon, Craig Parkin, Alan W. Roberts, Lindsey Smith, Jennifer Eccles**

Liverpool - **Dave Healy, Neil Hurst, Vijay Tymms, Rosie Fletcher, Alex Chappell**

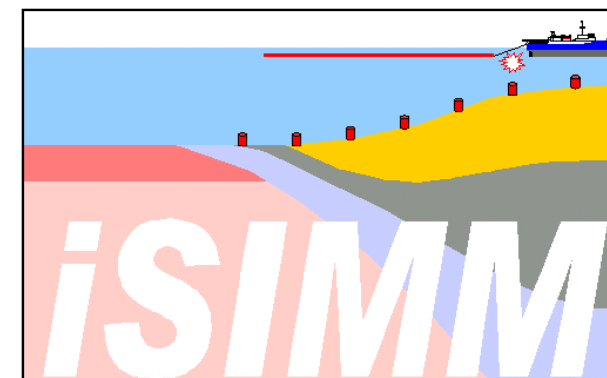
Industry Partners



A Kinematic Fluid-flow Model of Sea-floor Spreading Initiation and Rifted Continental Margin Formation

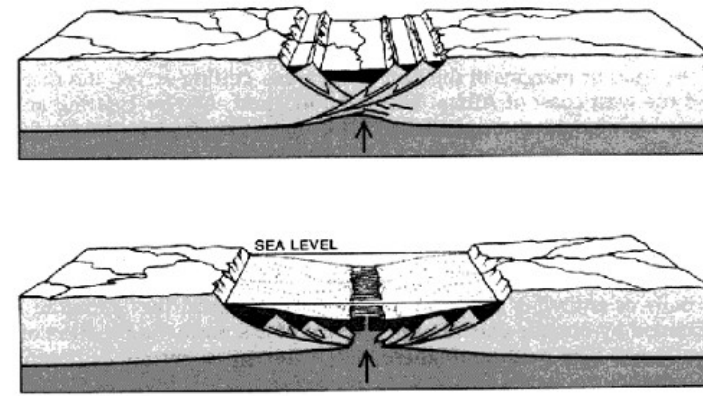
Nick Kusznir* & the iSIMM Team

*Department of Earth & Ocean Sciences,
University of Liverpool, Liverpool, UK*
Email: n.kusznir@liverpool.ac.uk

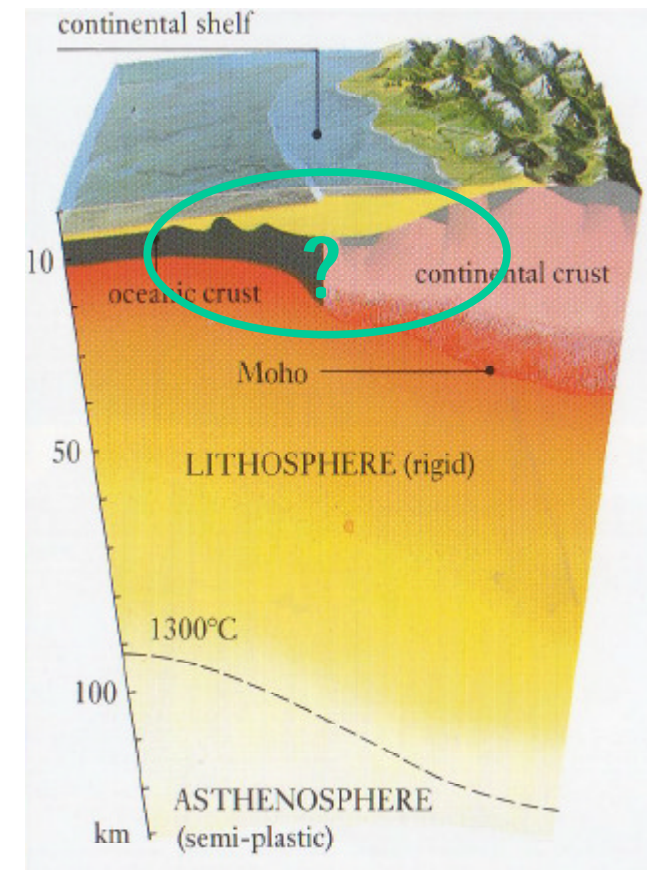


Rifted Continental Margin Formation

Is the process the same as that which forms intra-continental rift basins?



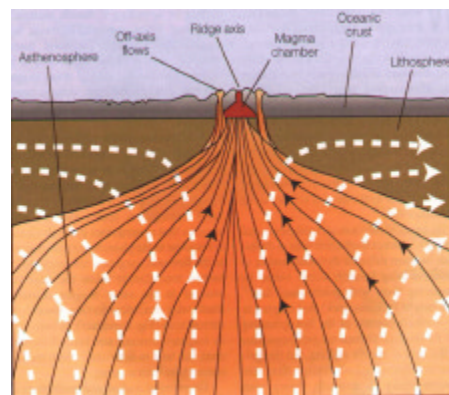
- Do we just stretch the continental lithosphere by infinity to form a rifted margin?
- Recent discoveries at rifted margins
 - *Depth Dependent Stretching*
 - *Mantle Exhumation*
- These cannot be explained by existing rift basin formation models
- New rifted margin formation model is needed



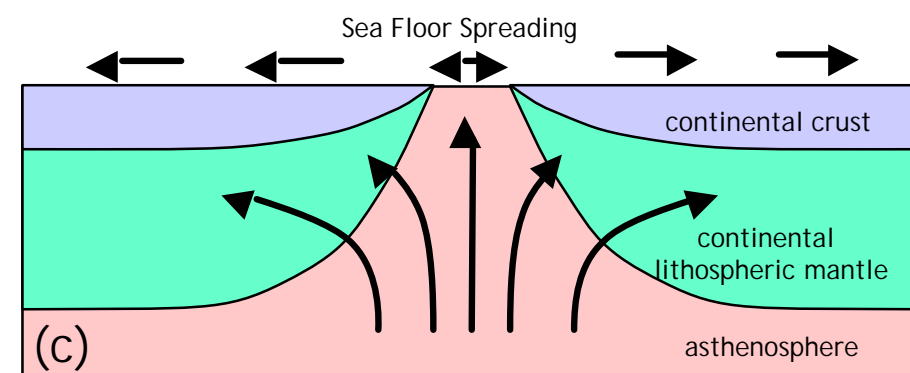
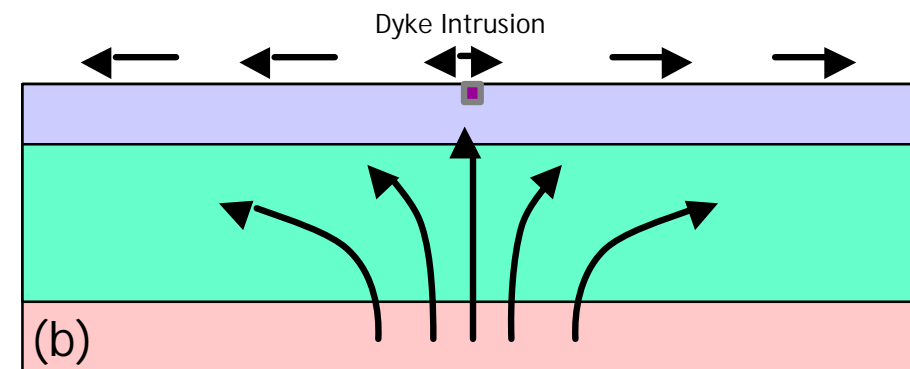
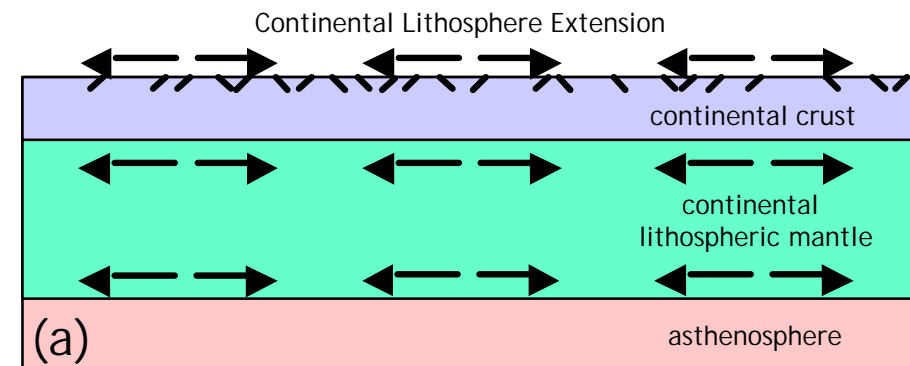
New Model of Rifted Margin Formation

Assume dominant process for thinning continental margin lithosphere leading to breakup is -

- Upwelling & divergent flow within continental lithosphere & asthenosphere
- Not depth-uniform intra-continental extension



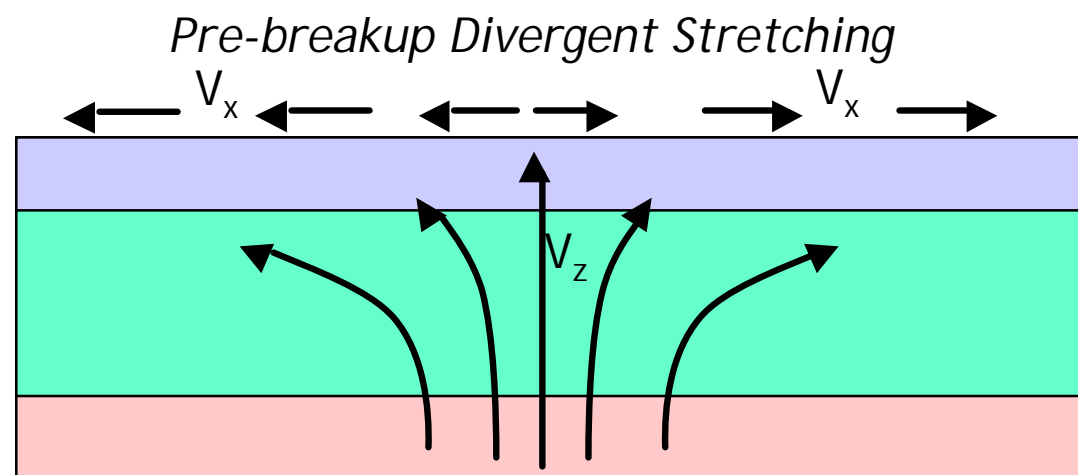
- Model sea-floor spreading initiation



Modelling the establishment of divergent flow-fields leading to breakup

Corner-flow model

- Isoviscous stream-function solution (Batchelor 1967)
- Kinematic - define divergent & upwelling velocities
 - Define V_x (divergent half-rate velocity)
 - Define V_z (upwelling velocity)

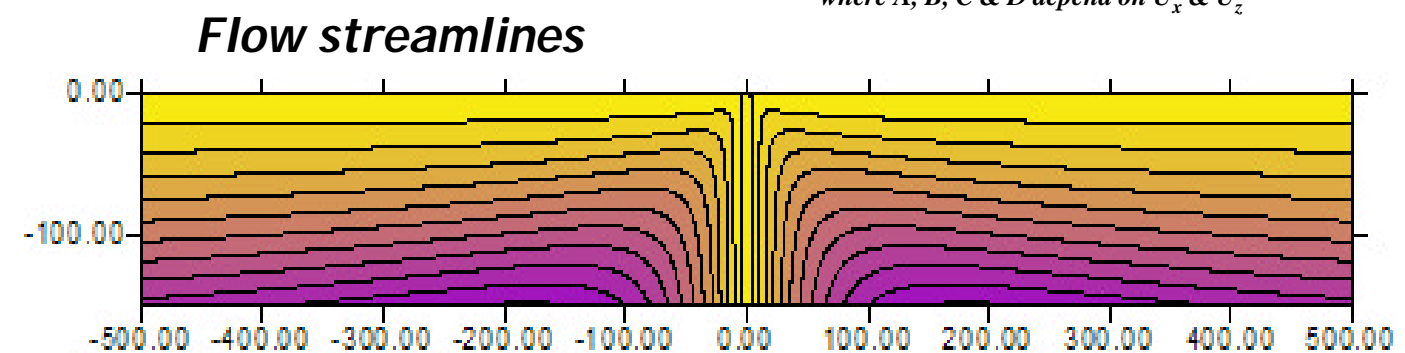


$$\Psi = (Ax + Bz) + (Cx + Dz) \tan^{-1}\left(\frac{z}{x}\right)$$

$$U_x = -B - D \tan^{-1}\left(\frac{z}{x}\right) + (Cx + Dz) \left(\frac{-x}{x^2 + z^2}\right)$$

$$U_z = A + C \tan^{-1}\left(\frac{z}{x}\right) + (Cx + Dz) \left(\frac{-y}{x^2 + z^2}\right)$$

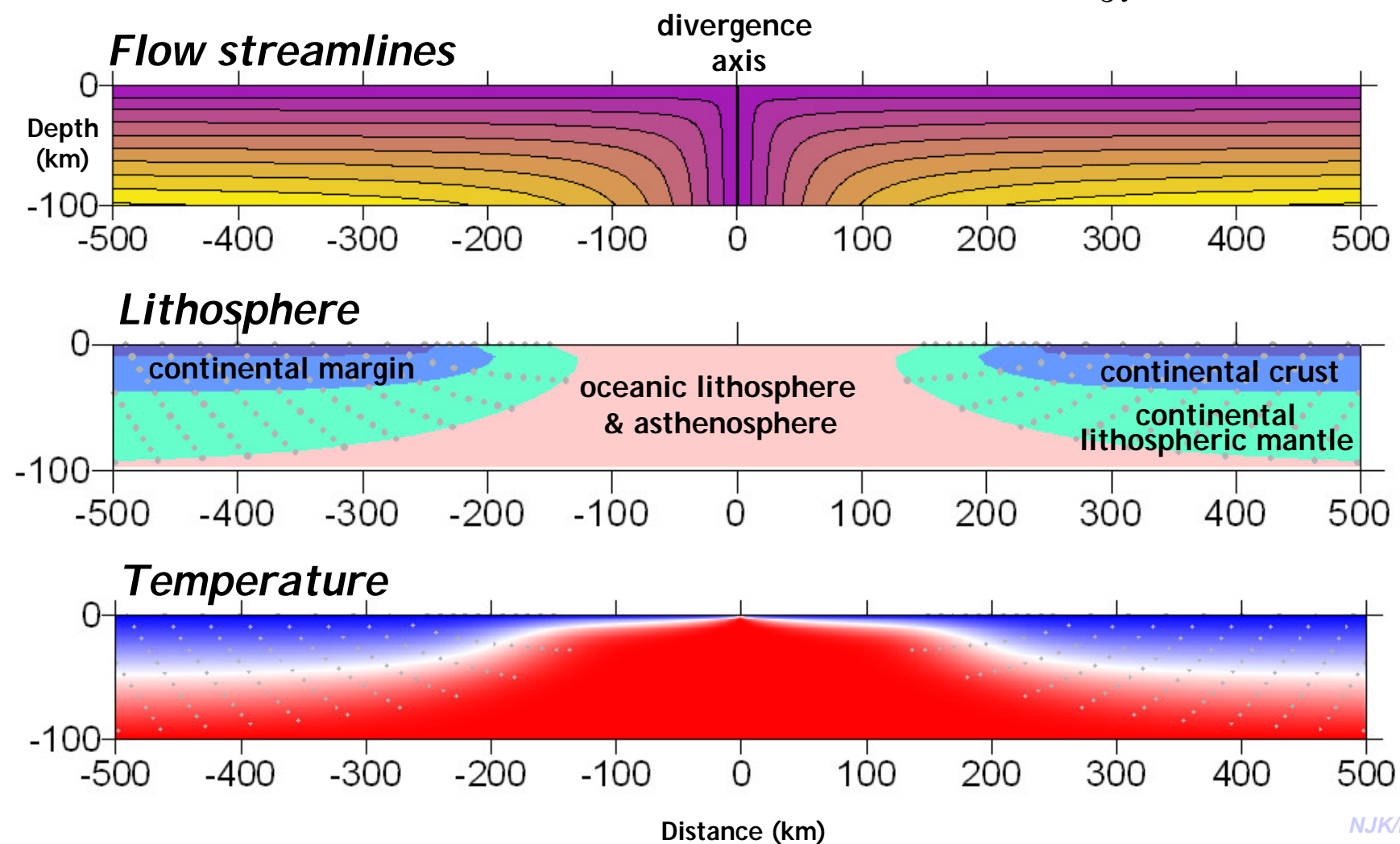
where A, B, C & D depend on U_x & U_z



NJK/Nov2004

Modelling the establishment of divergent flow-fields leading to breakup

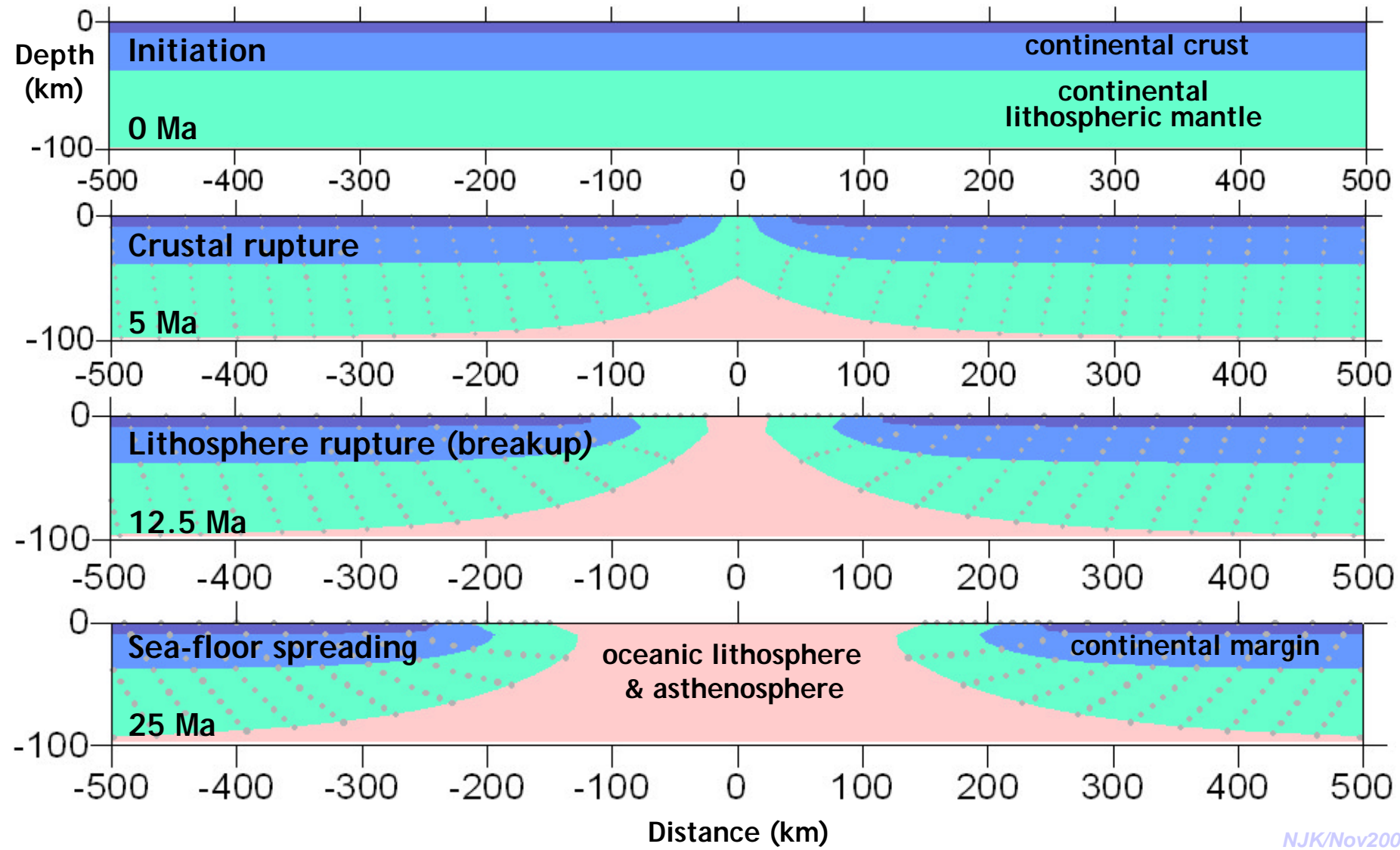
- Derive flow-field
- Advect continental lithosphere material
- Use coupled thermal diffusion & advection solution $\frac{\partial T}{\partial t} = \mathbf{k}\nabla^2 T - \bar{\mathbf{u}} \cdot \nabla T$



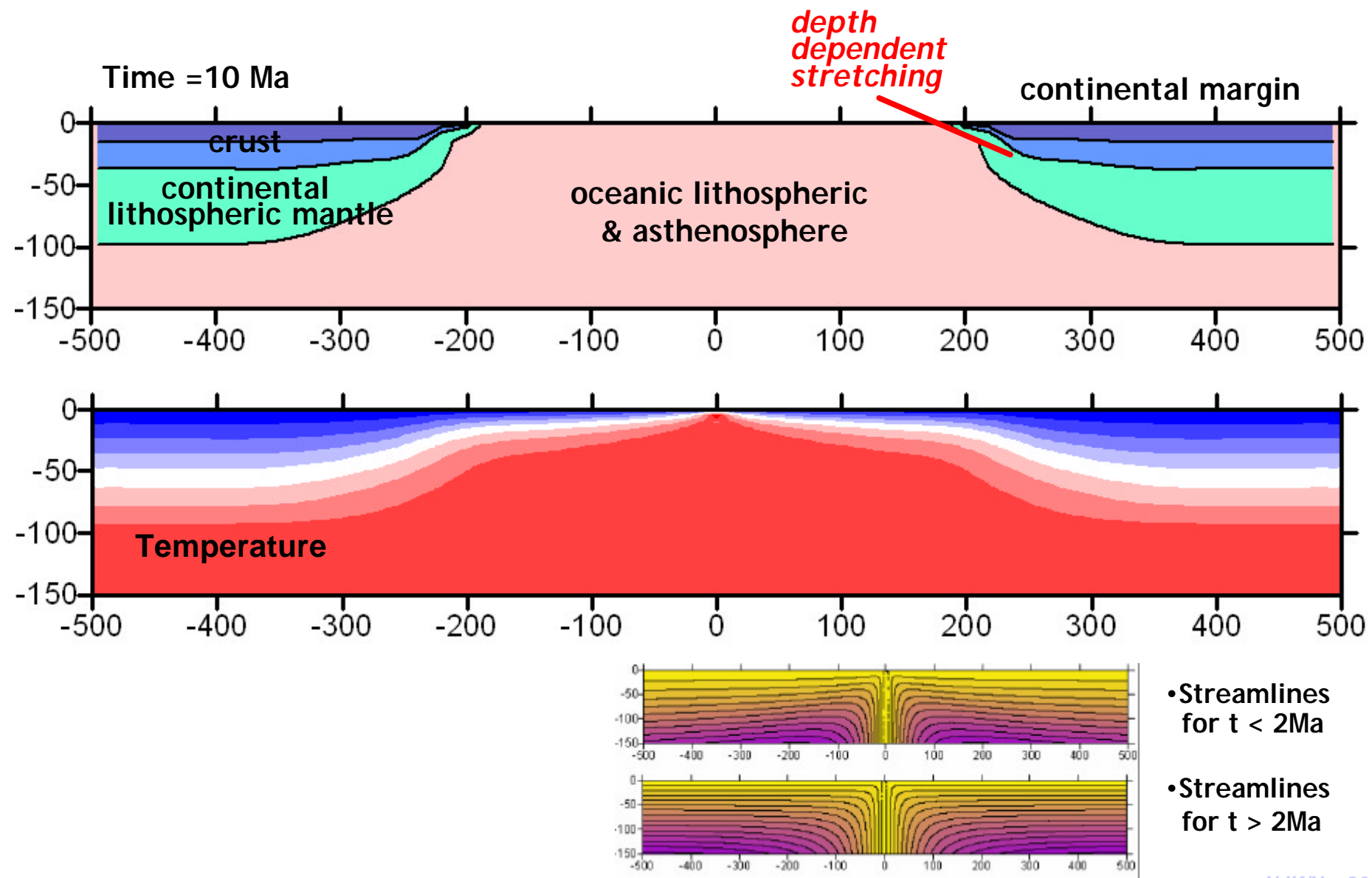
Modelling Rifted Margin Formation

Time Evolution

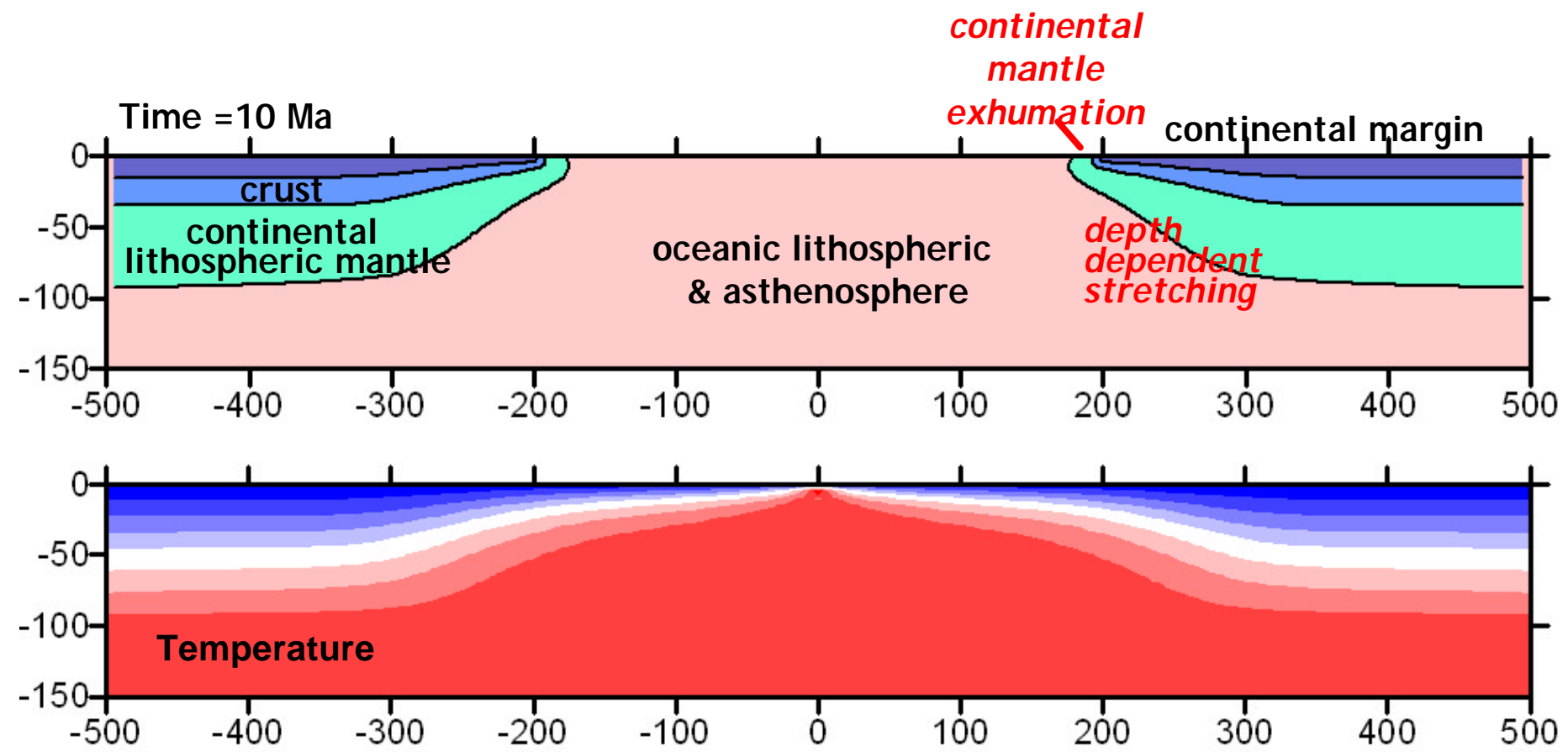
$$V_x = 1 \text{ cm/yr}, V_z/V_x = 1$$



Modelling Volcanic Margin Formation



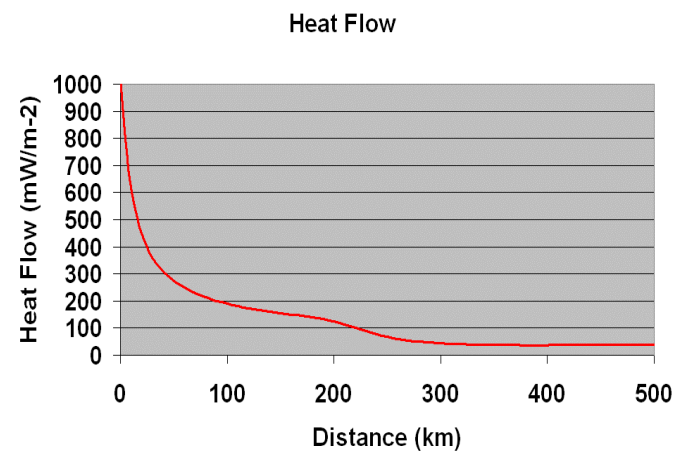
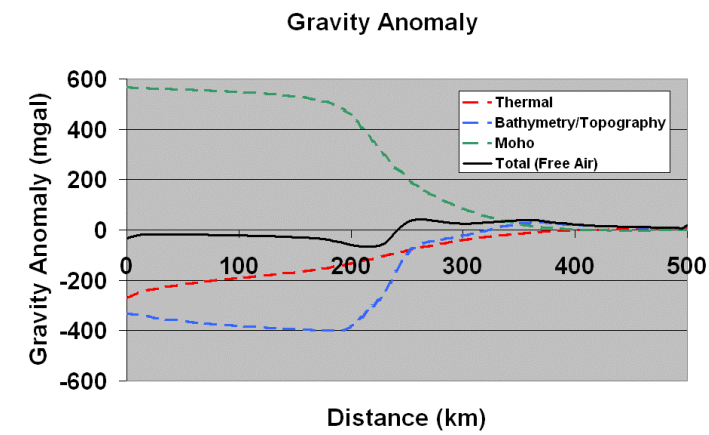
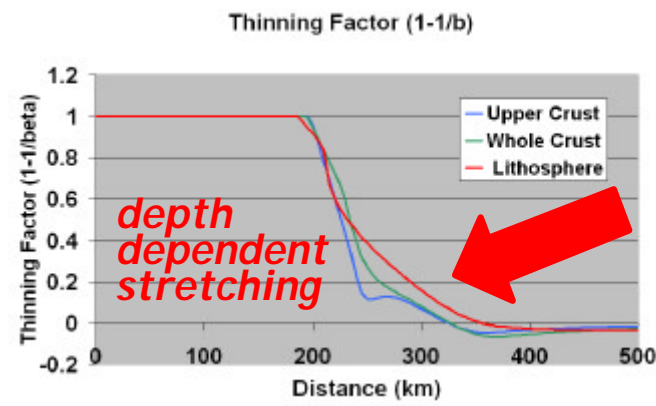
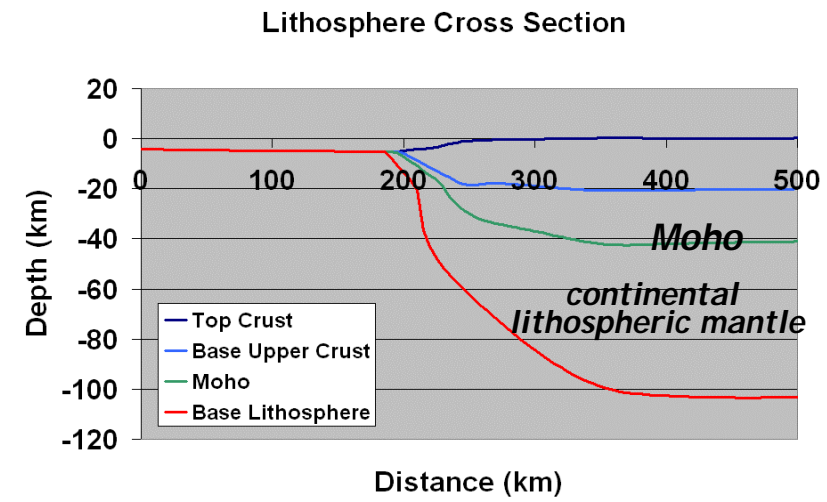
Modelling Non-volcanic Margin Formation



Modelling Margin Formation

New model predicts

- Depth dependent stretching
- Mantle exhumation
- Bathymetry and subsidence history
- Heat flow history
- Gravity Anomalies



SfMargin - Modelling Margin Formation

The image shows a screenshot of the SfMargin XL software interface. The main window is titled "SfMarginXL" and contains a "Calculate" sub-window. The interface is organized into several sections with various input fields and checkboxes:

- Spatial Resolution:** High (1 km) , Medium (5 km) , Low (10 km)
- Gravity Anomaly:** Off , On . Regional gravity (mgal) input: 0.
- Main sea-floor spreading:** Total RunTime (Ma) input: 10; Vx (cm/yr) input: 1; Vz (cm/yr) input: 1.5.
- Time Step Resolution:** Time Step (1,000 yrs) , Time Step (10,000 yrs)
- Sediment Loading:** Off , On
- Model Width:** 500 km , 1000 km , 2500 km , 5000 km
- Oceanic crust:** Thickness (km) input: 0.
- Initial transient V₂>>V_x event:** Transient duration (Ma) input: 2; Vx (cm/yr) input: 1; Vz (cm/yr) input: 5; Cut-off depth(km) input: 0; Static Cut-off ; Dynamic Cut-off .
- Observed data:** Coordinate shift (km) input: 0.
- Finite Deformation:** Off , On
- Pre-breakup extension:** Lithosphere extension (km) input: 0; Pure shear width (km) input: 300.

Buttons at the bottom of the Calculate window include "Clear Results", "Compute", "Post Process", "Plot", and "Exit". The version information "V5.3 - 24/08/2004" and "Copyright NJ Kuszniir" is displayed in the center.

The "Plot" sub-window is also visible, titled "Plot SfMarginXL". It features a small sailboat icon and several buttons for visualization and analysis:

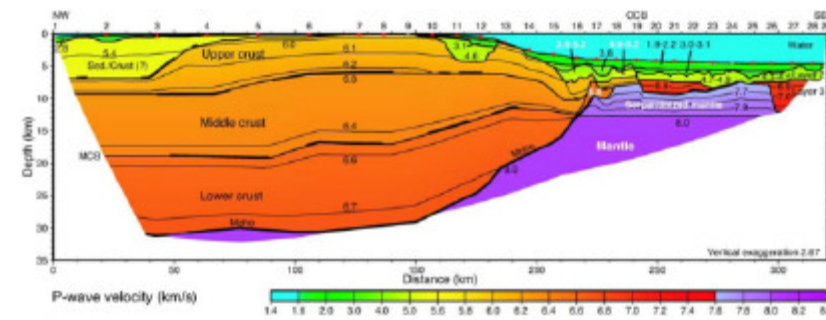
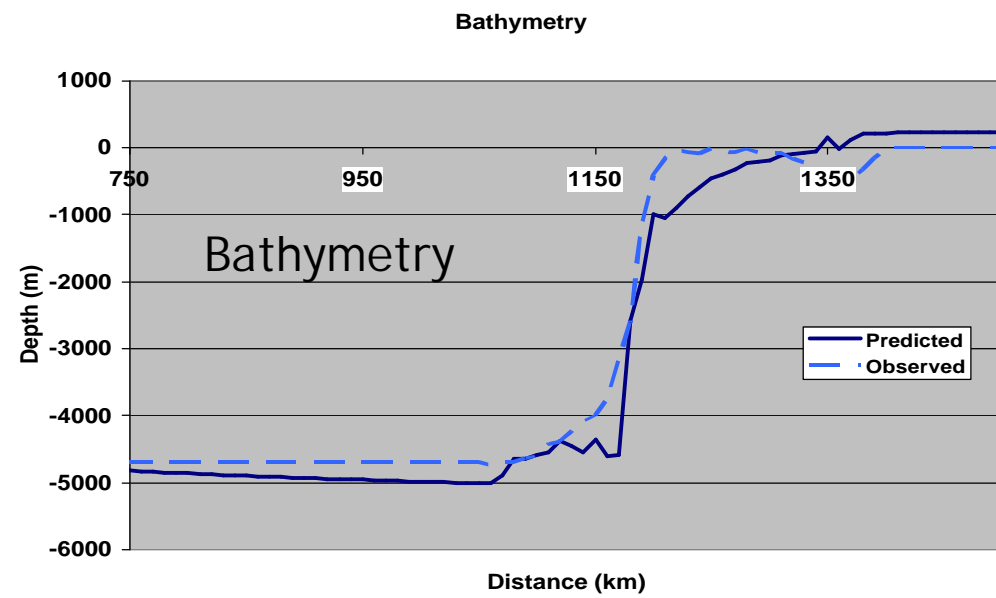
- Model Predictions:** Lithosphere Xsection, Subsidence, Thinning Factors, Gravity Components, Heat Flow.
- Calibration:** Bathymetry/Topography, Gravity Anomaly.
- Model Input:** SFS Velocity History.

An "Exit" button is located at the bottom of the Plot window.

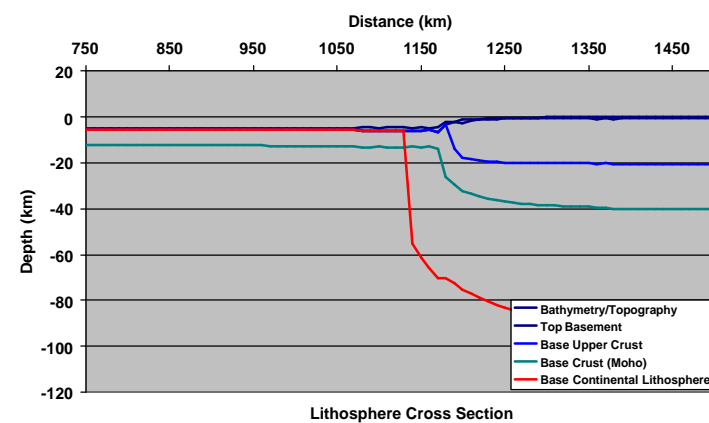
SfMargin Applications

NSF/Intermargins/ESF Margin Modelling Workshop Pontresina July 2004

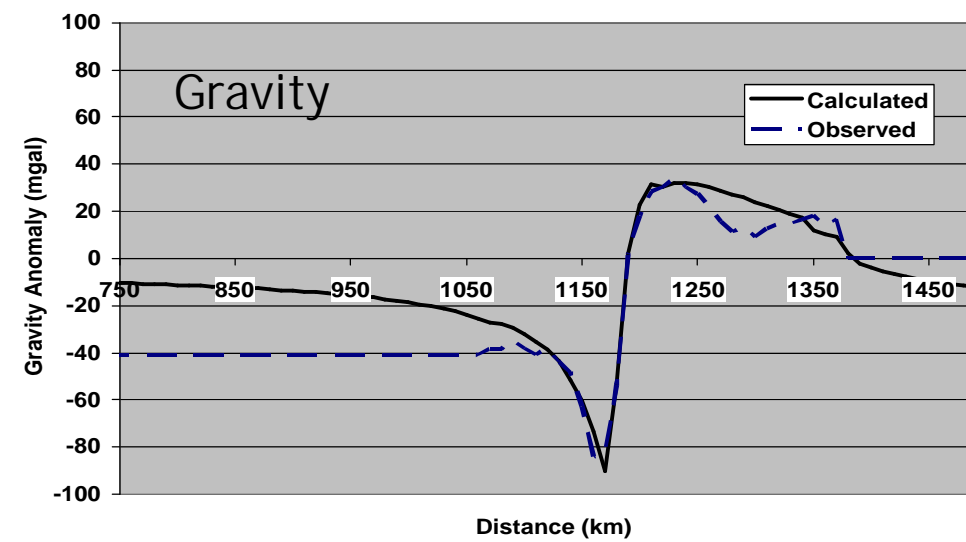
Newfoundland Margin Screech 1



$V_z/V_x = 1.5, b = 1$
(with sediments)



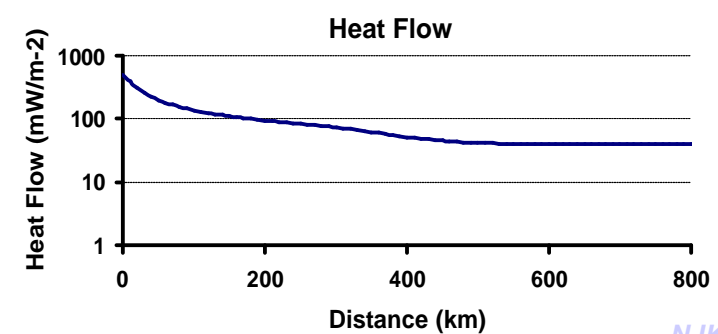
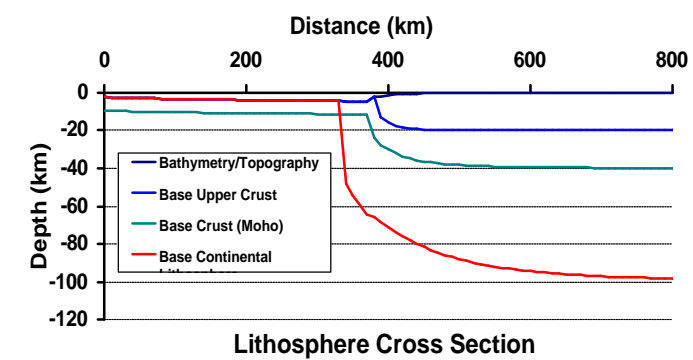
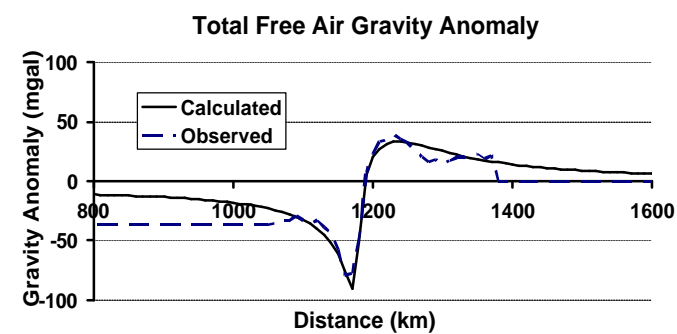
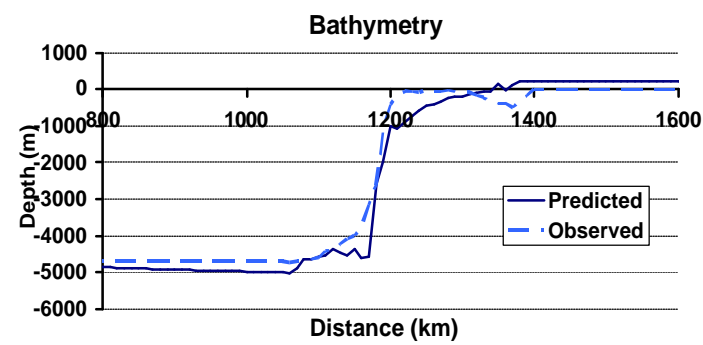
Total Gravity Anomaly (FAG-Ocean/Bouguer-Land)



SfMargin - Modelling Margin Formation

Workflow for Industry Applications

- Invert observed bathymetry & gravity data to give margin deformation kinematics
- Use model to predict -
 - margin crustal structure
 - lithosphere temperature
 - heat flow
 - subsidence history



Inverse Methods

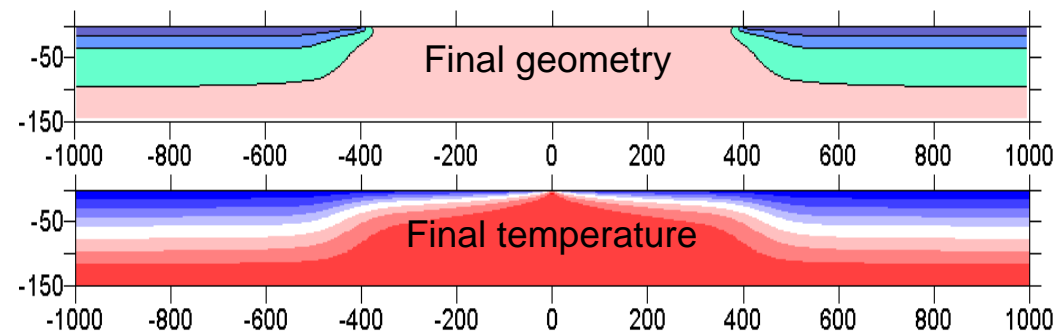
Synthetic Data

Forward model input parameters

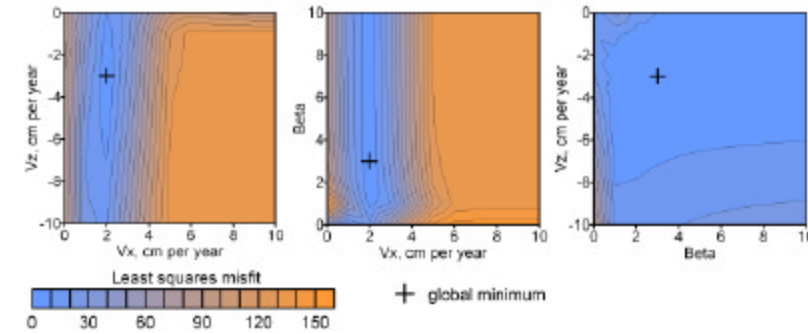
- $V_x = 2 \text{ cm yr}^{-1}$
- $V_z = 3 \text{ cm/yr}$
- $\beta = 3$

Grid search inversion using predicted thinning factor, bathymetry and gravity

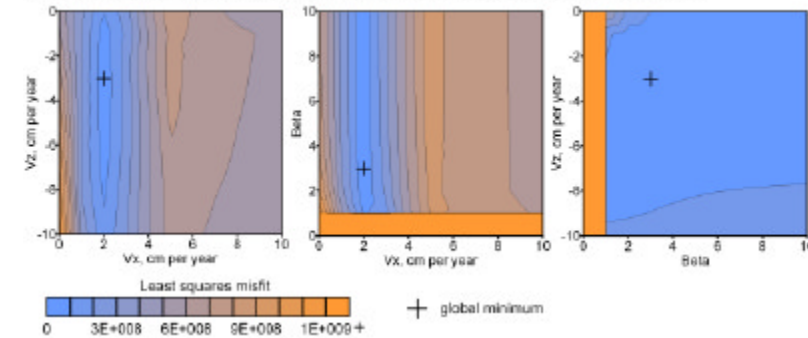
Successful recovery of input parameters with zero least squares misfit (L2 Norm)



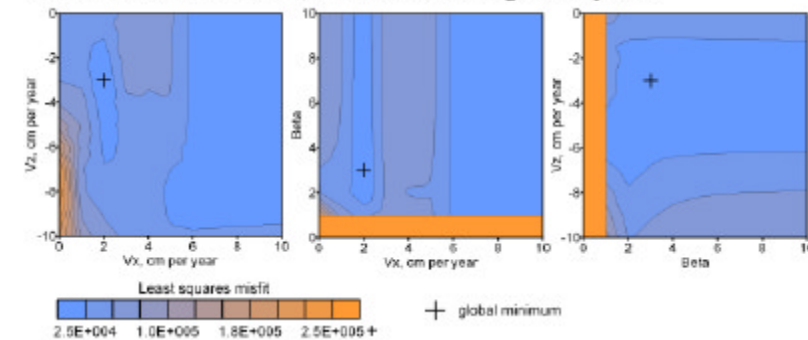
Misfit as a function of V_x , V_z and β using Thinning Factor data



Misfit as a function of V_x , V_z and β using Bathymetry data



Misfit as a function of V_x , V_z and β using Gravity data

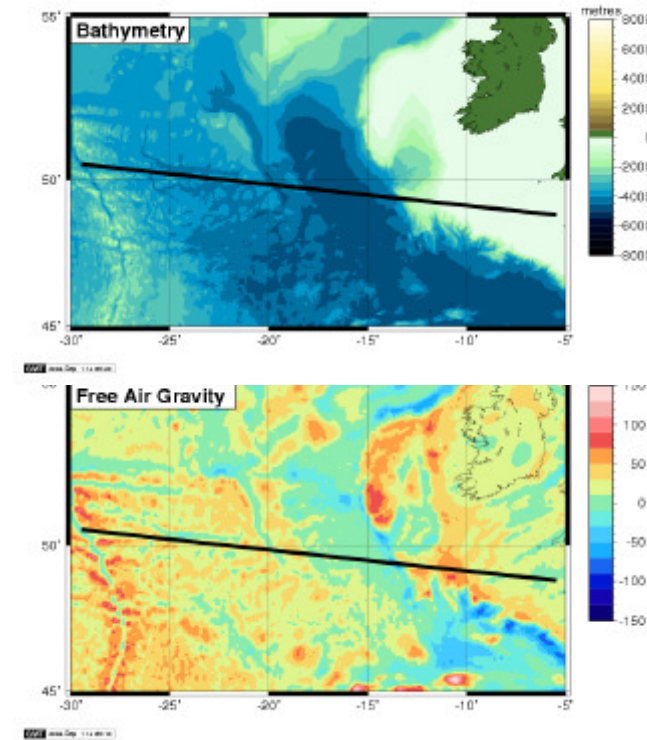
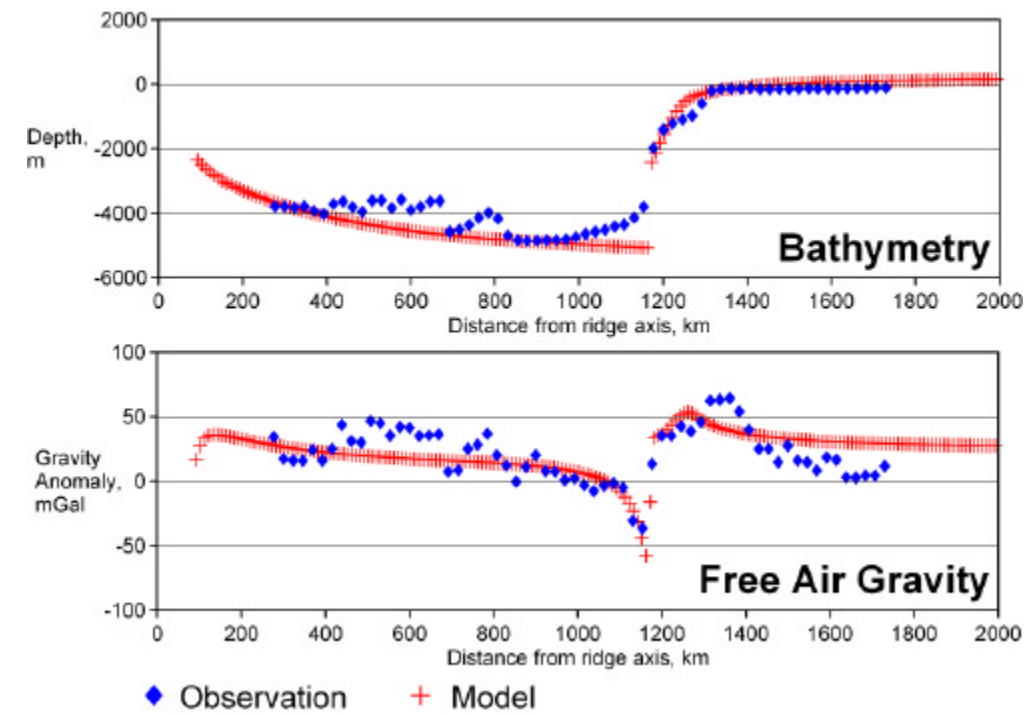


Inverse Methods

Goban Spur

Grid search inversion – minimum misfit

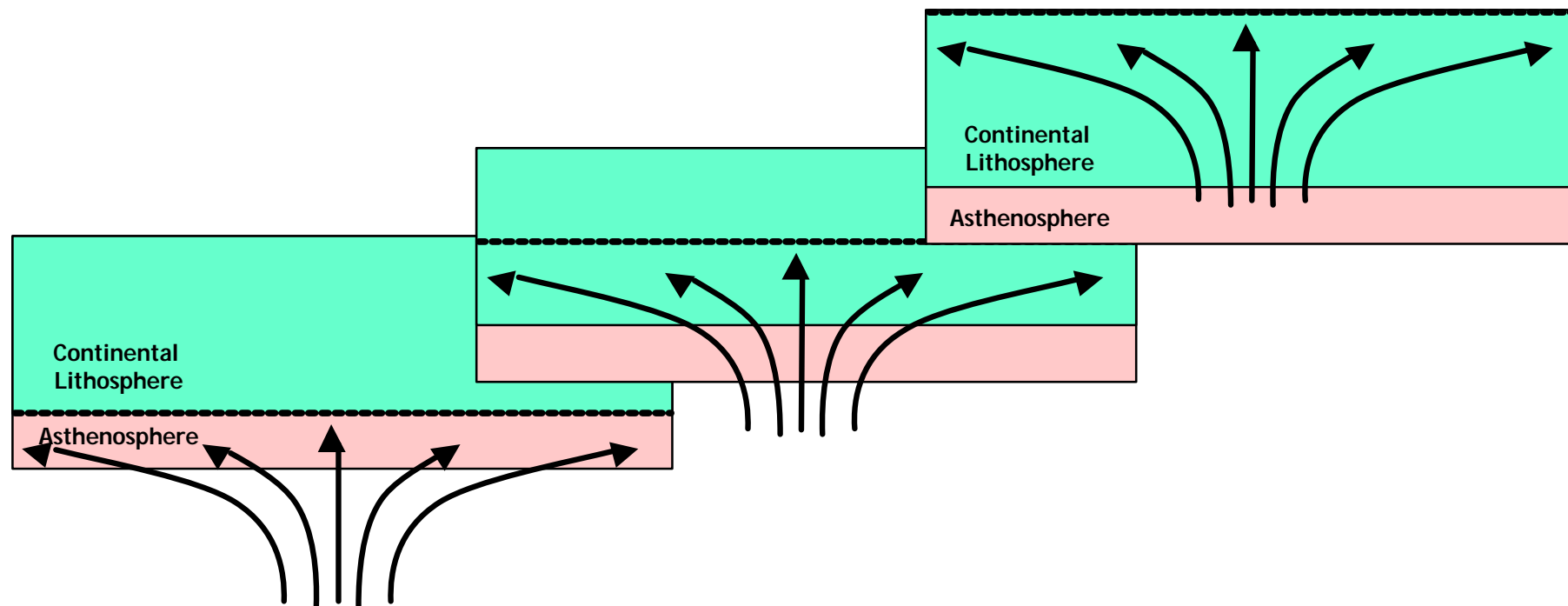
- $V_z/V_x = 1.25$
- $\beta = 1.5$



Comparison of best fit model prediction with observations

Breakup Initiation & Pre-Breakup Basin Formation

- Application to basins formed during sea-floor spreading initiation or failed breakup
- Model upward propagation of upwelling divergent flow field within continental lithosphere & asthenosphere



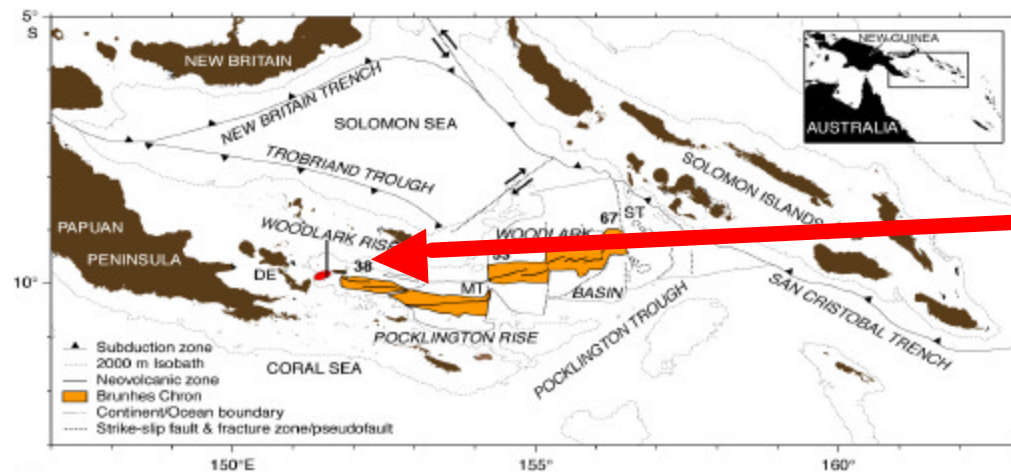
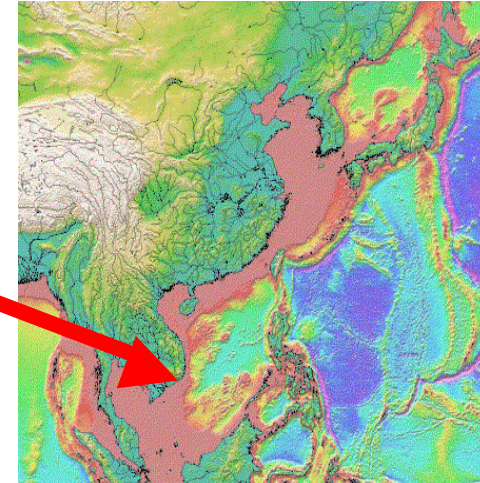
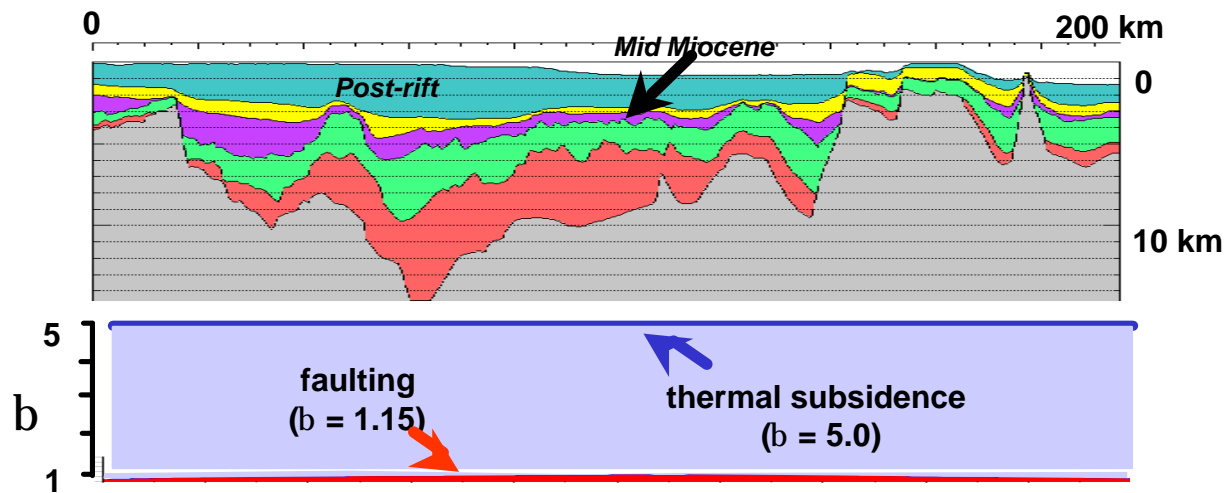
Examples

- Woodlark Basin, Nam Con Son Basin, Faroes-Shetland Basin

Nam Con Son Basin

Located at propagating SW tip of mid-Miocene sea-floor spreading in South China Sea

- Large post-rift subsidence
- Little continental upper crustal extension

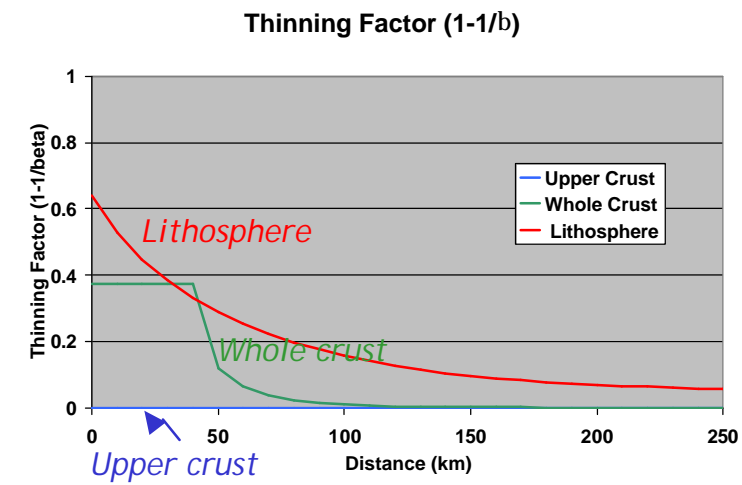
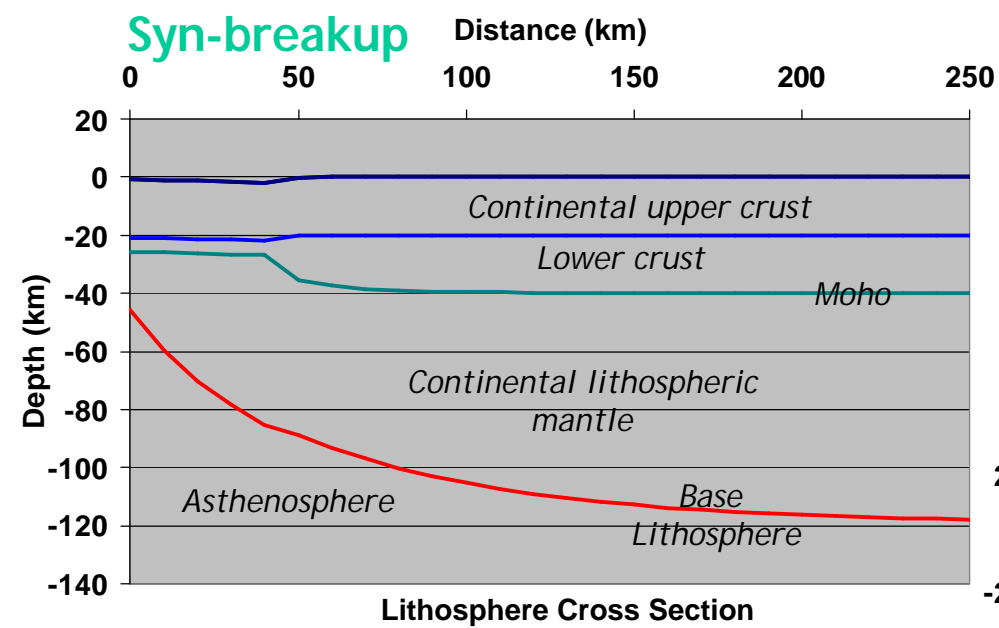


Woodlark Basin

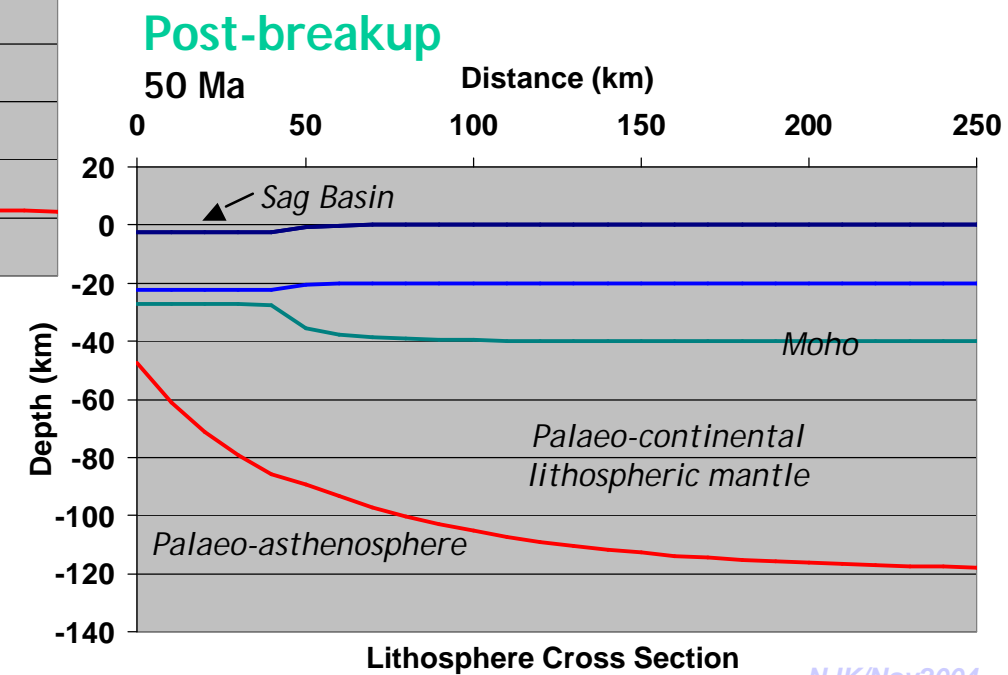
- Young ocean basin - initiated ~ 8 Ma
- 3000 m subsidence in continent ahead of propagating tip
- Little continental upper-crustal extension

SfMargin Applied to Pre-breakup Basin Formation

- No stretching of the upper crust
- Large thinning of lithospheric mantle and lower crust



- Broad syn-breakup sag basin
- Large post-breakup subsidence



iSIMM Posters -Geodynamic Modelling

David Healy - Breakup Kinematics from Inversion of Bathymetry & Gravity Data

Vijay Tymms - Effects of Temperature Dependent Rheology on Continental Breakup & Margin Formation

Neil Hurst - Thinning, Subsidence and Plume Uplift on the Faroes Margin from Flexural Backstripping & Gravity Inversion



Hatton Bank /July 2002