A New Look at Inverting Subsidence to Heat Flow in Rift-Related Basins – Deconvolution of Processes and Phases*

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Abstract

We present a new methodology to derive the heat flow history in rift-related basins from the subsidence history with significantly better results that are consistent with geological observations and deliver more precise prediction for petroleum systems. Extension related basins generally experienced a syn-rift phase during lithospheric stretching and a post-rift phase with mantle cooling, both generating tectonic subsidence. In petroleum systems modeling (PSM), the heat flow through geological time is required to reconstruct the thermal history of the basin. The standard multi 1D workflow to estimate the heat flow evolution in rift basins or passive margins is to invert the basin's subsidence by fitting the observed tectonic subsidence by thickness changes within the lithospheric layers. The resulting stretching factors are used to calculate the heat flow at the base of the sediments throughout the basin evolution. The new inversion method presented in this paper eliminates most limitations of the multi 1D approach. Brittle deformation of the upper crust tends to generate syn-rift highs (horsts) and lows (graben/half-graben). Post-rift subsidence however may just be as high over a high as it is over the low next to it. The post-rift subsidence is controlled by cooling processes within the upper mantle, while the syn-rift subsidence is controlled by processes within the mantle and the crust. Taking these processes into consideration, we apply a two-step process: 1) fit the upper mantle stretching to the post-rift subsidence and 2) use the results together with the syn-rift subsidence for the fitting of the crustal stretching. This way we deconvoluted the stretching in both lithospheric layers and gained geologically reasonable inversion results for the respective b-factors. In the Browse Basin case study, we compare the new methodology with the traditional one and illustrate significant enhancements to lithospheric modeling results. As the thickness of the upper mantle through geological time defines the distance of its base (1330°C isotherm) to the base of the sediments, our enhanced predictions for mantle stretching and

cooling deliver a better correlation between the observed subsidence and the final thermal history for PSM. We illustrate how the new inversion method delivers more confidence in the thermal history and how the timing and location of hydrocarbon generation, migration and trapping can be predicted with higher accuracy.

Selected Reference

White, N., and D. McKenzie, 1988, Formation of “steer's head” geometry of sedimentary basins by differential stretching of the crust and mantle: Geology, v. 16, p. 250-253.

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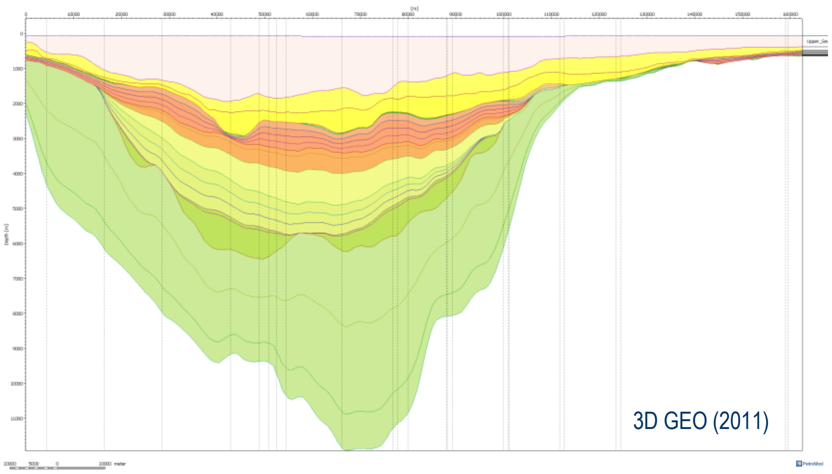
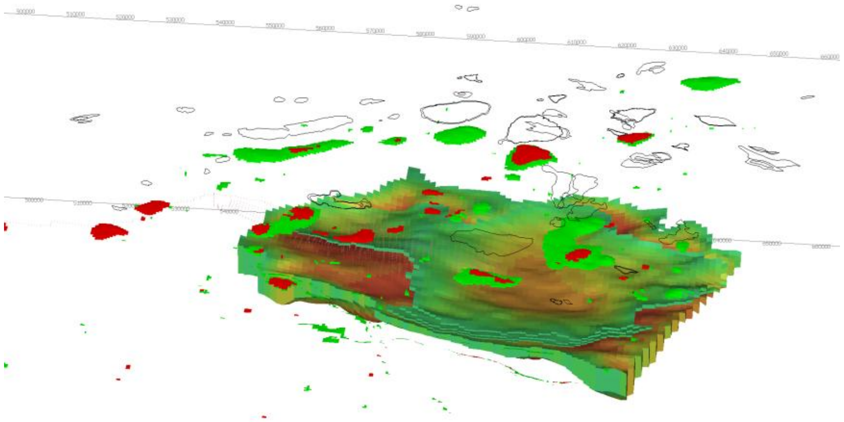
Outline

1. Problem and Motivation
2. Solution Workflow
3. Application (Gippsland Basin, Australia)





Problem and Motivation

How do we get to a consistent temperature history of a rift basin?

Reconstruct the tectonic subsidence of the basin and invert the subsidence according to isostatic principles:

Stretching

Lithospheric layer thicknesses

Base sediment heat flow

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Problem and Motivation

What are the <u>geological processes</u> and what are the <u>tools</u> we apply?

<u>Processes</u>

- Stretching of the crust
- Stretching of the upper mantle
- Thickening of the upper mantle (cooling)

<u>Tools</u>

Inversion using **local isostasy**

- *Transient solutions*
- *Convection*
- *Radiogenic heat*
- *Multiphase*
- *Etc.*

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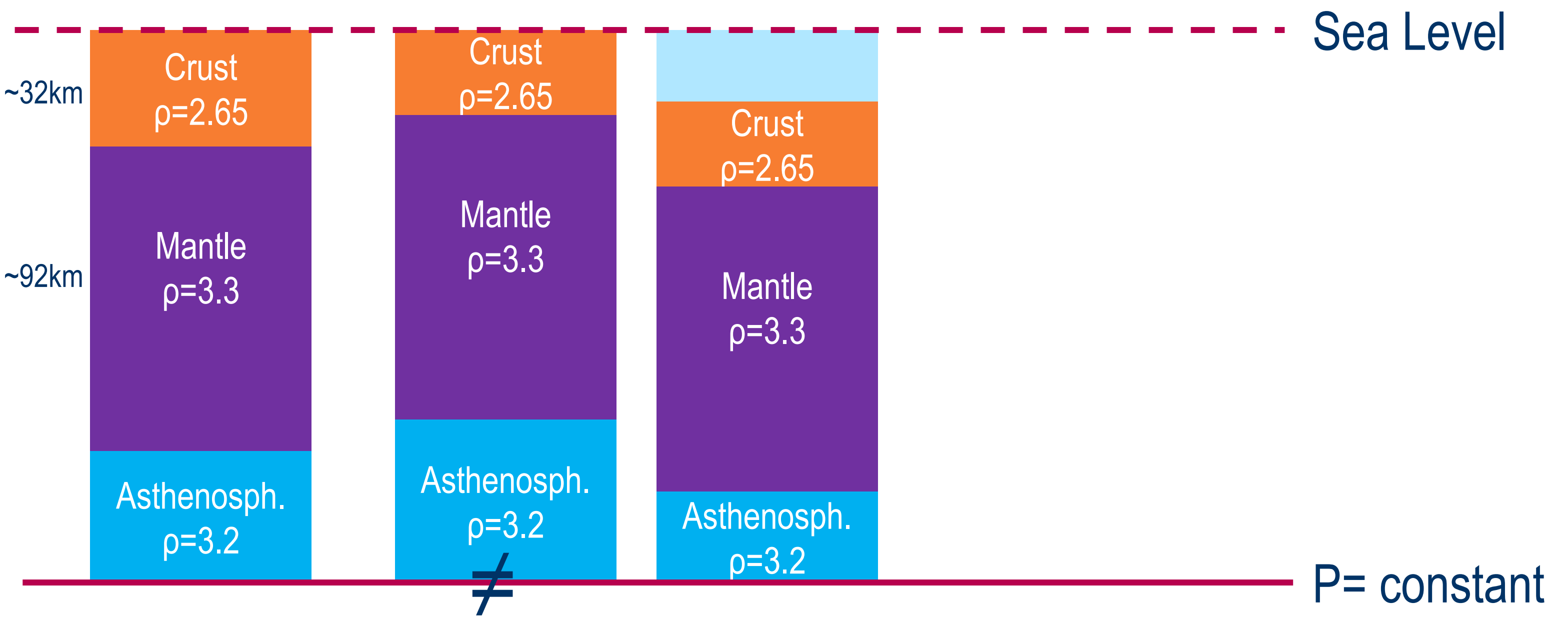
Isostasy



$$\rho_w g h_w + \sum_{i=0}^{n} \rho_{si} g h_{si} + \rho_{cu} g h_{cu} + \rho_{cl} g h_{cl} + \rho_m g h_m + \rho_a g h_a = constant$$

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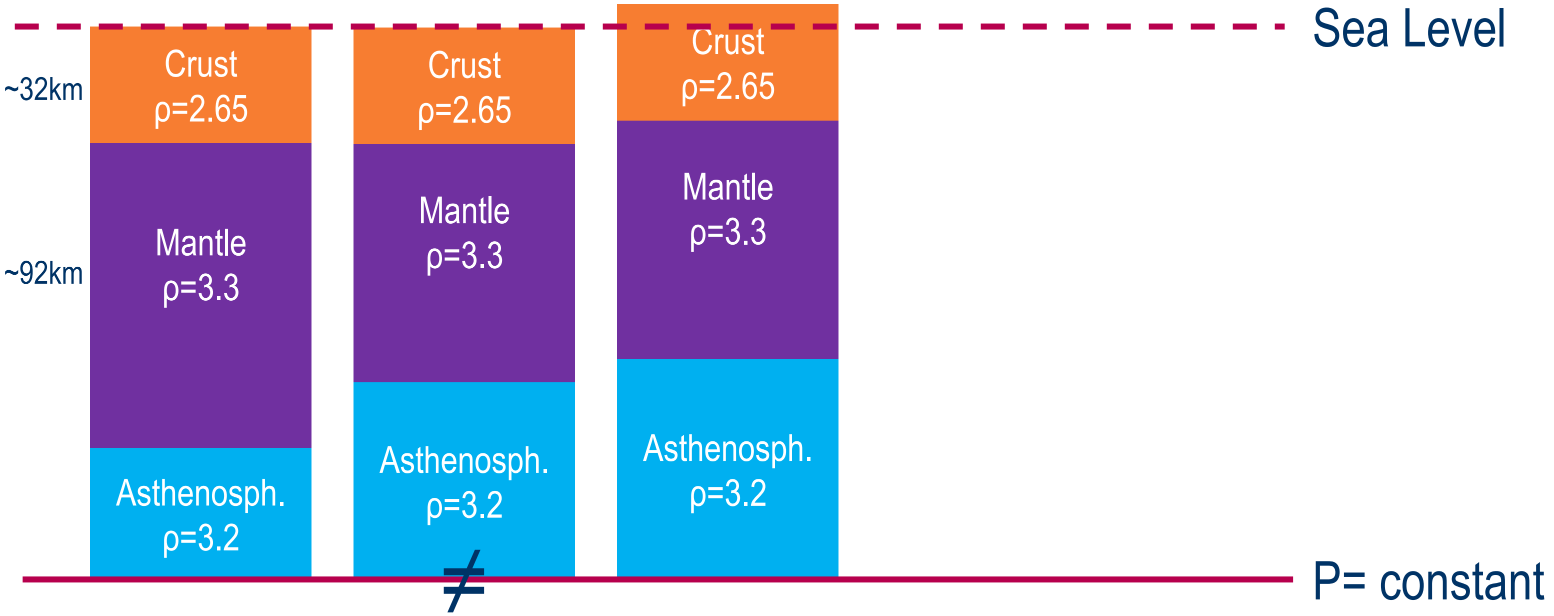
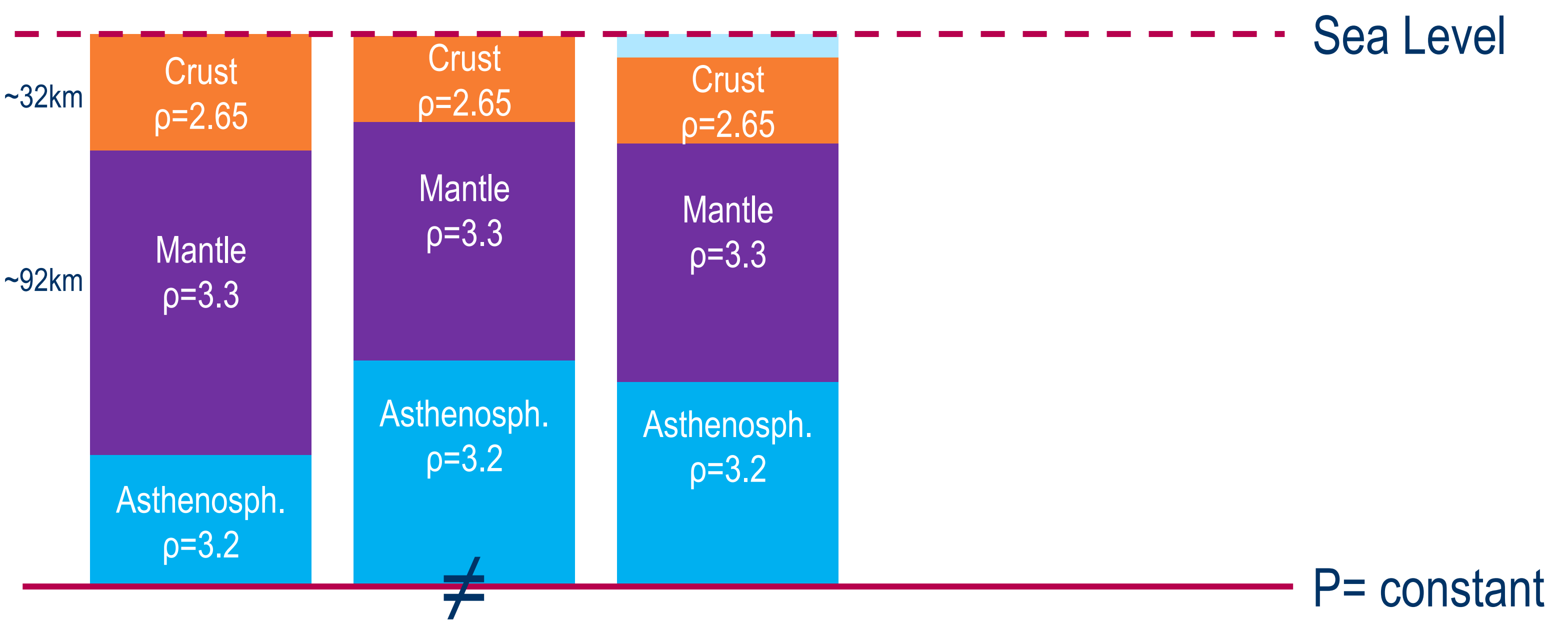
Isostasy



$$\rho_w g h_w + \sum_{i=0}^{n} \rho_{si} g h_{si} + \rho_{cu} g h_{cu} + \rho_{cl} g h_{cl} + \rho_m g h_m + \rho_a g h_a = constant$$

Isostasy



$$\rho_w g h_w + \sum_{i=0}^{n} \rho_{si} g h_{si} + \rho_{cu} g h_{cu} + \rho_{cl} g h_{cl} + \rho_m g h_m + \rho_a g h_a = constant$$

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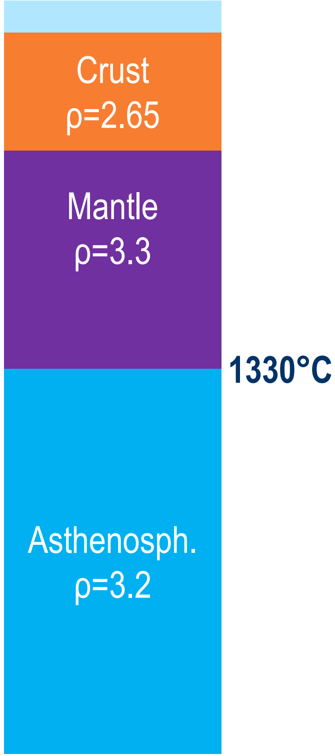
Problem and Motivation



<u>We “know”:</u>

- Extension leads to the thinning of the lithosphere during the syn-rift phase
- The base Lithosphere is “known” to be ~1330°C
- A post-rift phase is characterized by cooling and thickening of the lithospheric mantle

<u>We observe:</u>

Syn- and Post-rift total subsidence through geological time

<u>We interpret:</u>

The distance between the base lithosphere (1330°C) and the sediment variation during the basin evolution

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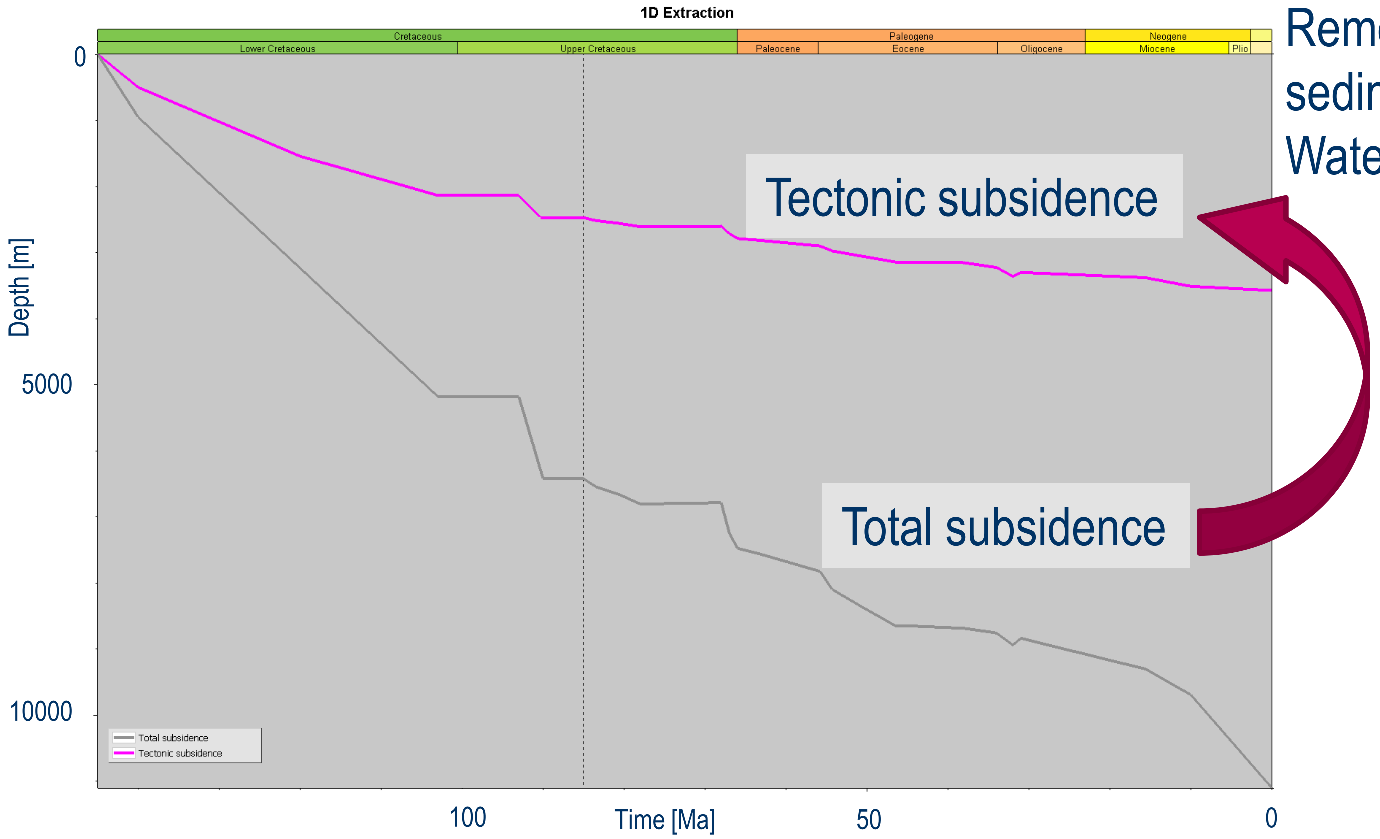
Problem and Motivation



Remove the isostatic effect of sediment loading:
Water-filled subsidence

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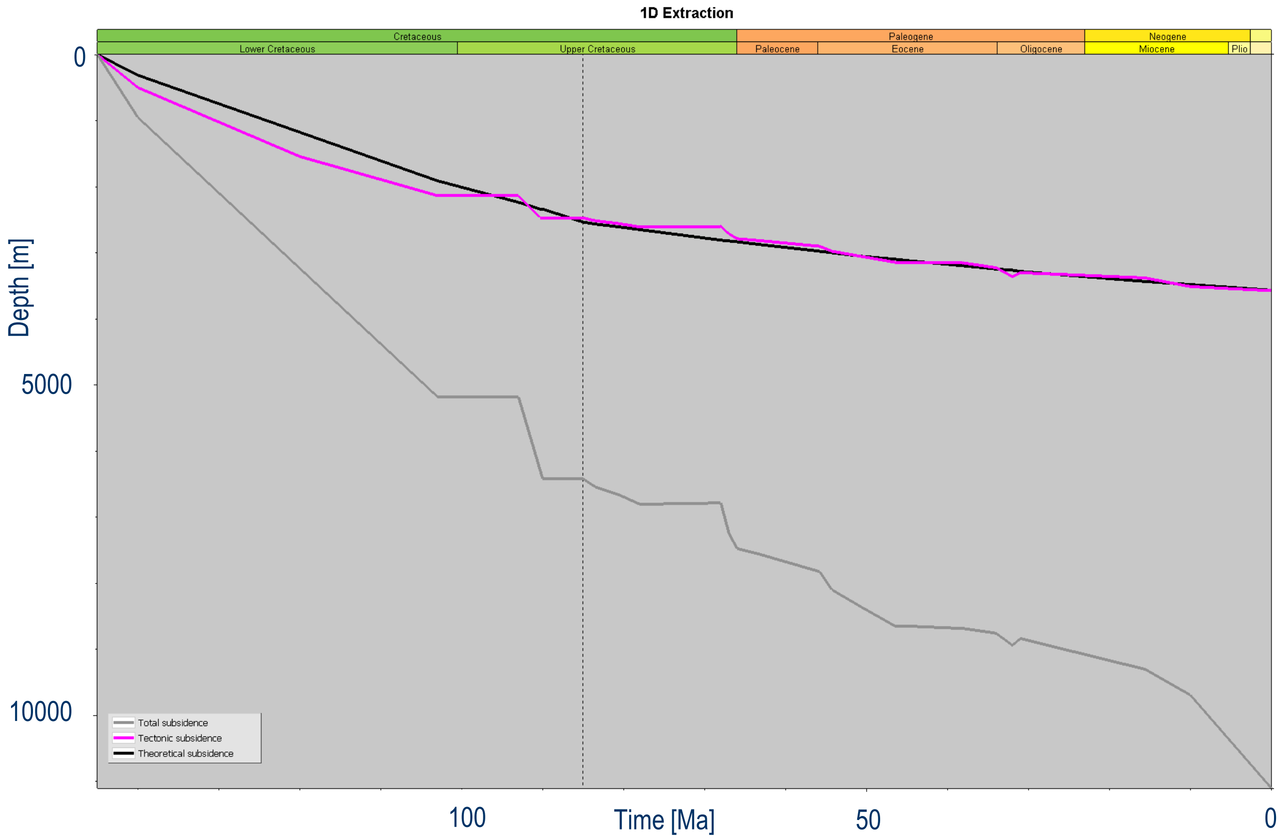
Problem and Motivation



Apply a single fitting curve that varies the mantle and crustal thicknesses, to achieve a best fit to the tectonic subsidence during syn- and post-rift

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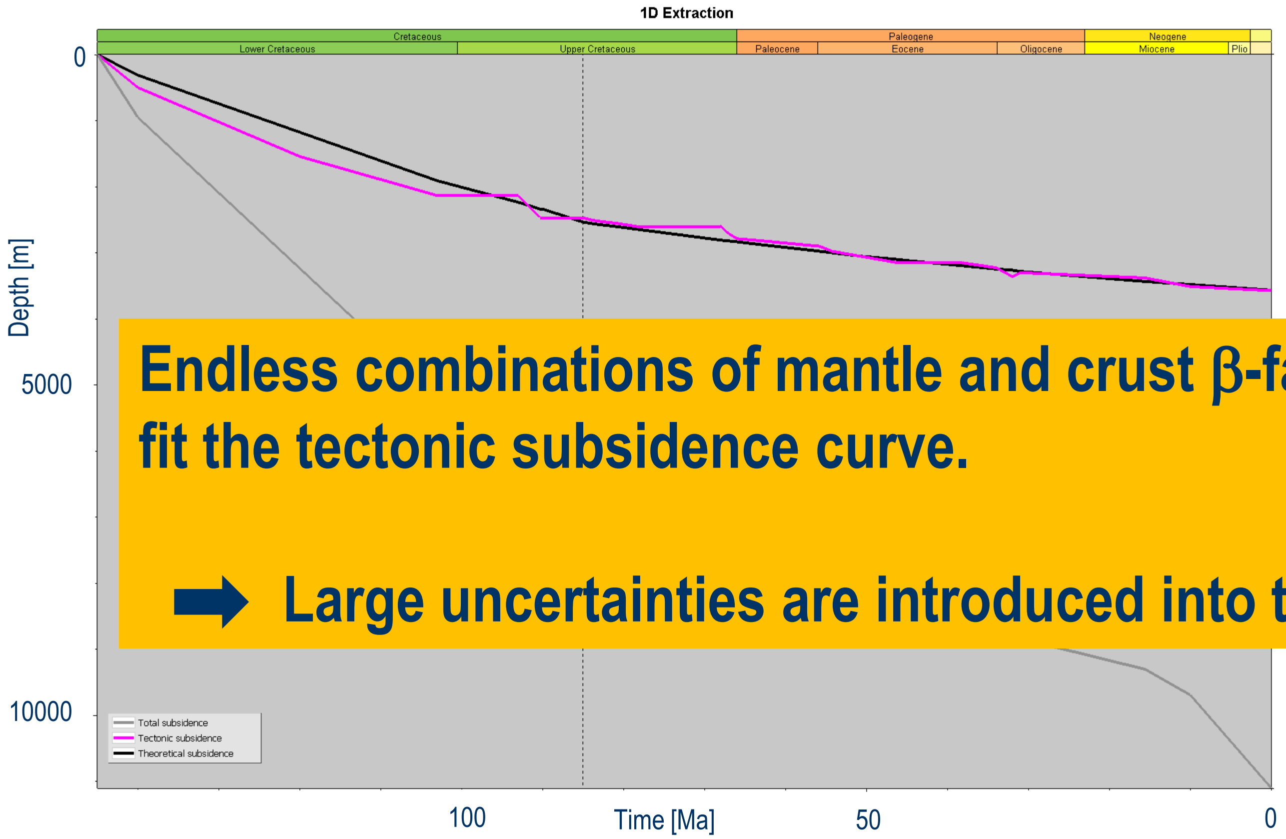
Problem and Motivation

1-step solution



Endless combinations of mantle and crust β-factors are possible to fit the tectonic subsidence curve.

➡ Large uncertainties are introduced into the thermal model

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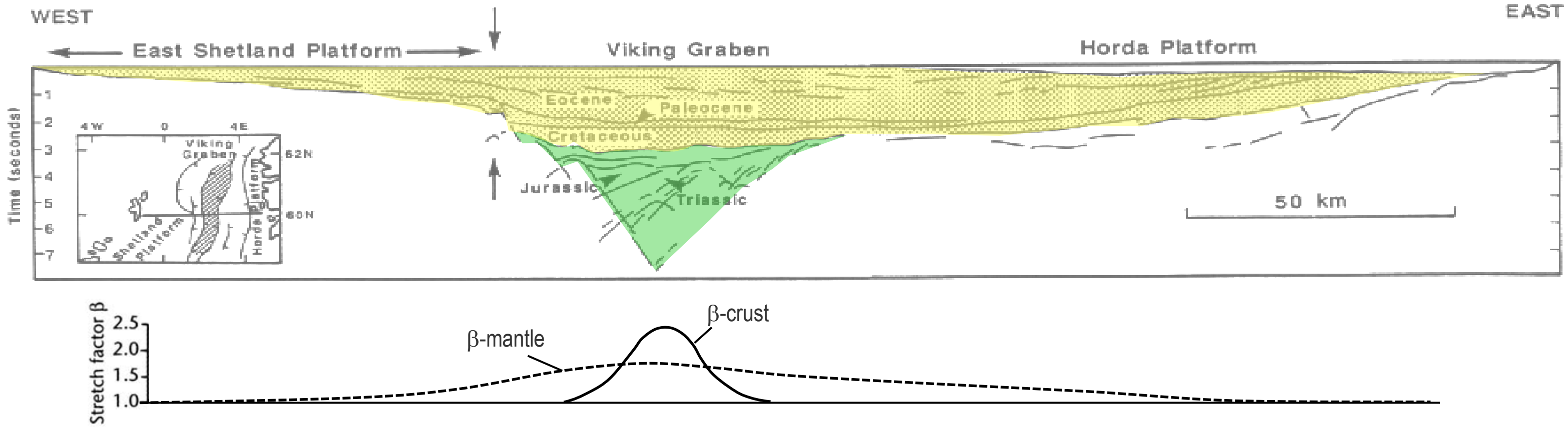
Solution workflow

Use a **two step** method for McKenzie Inversion

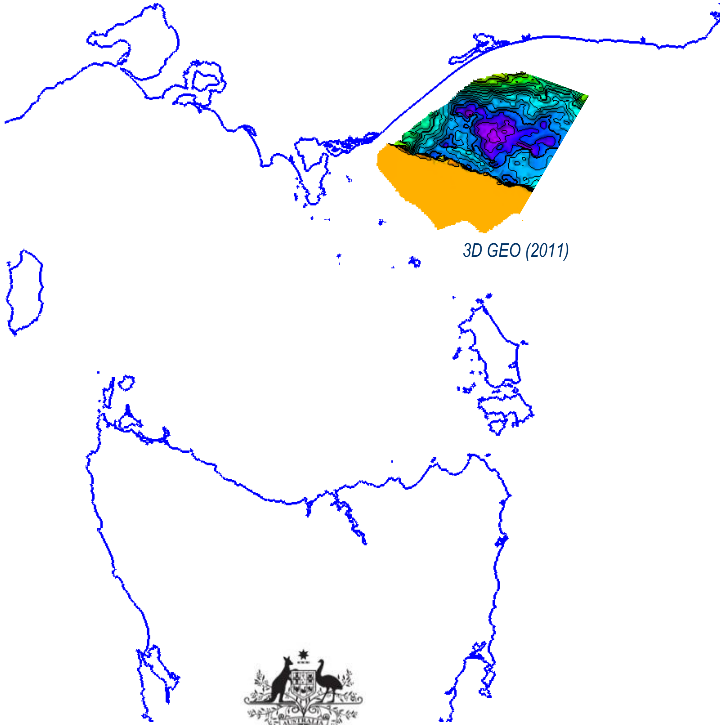
1. Use post-rift tectonic subsidence to invert for mantle thickness maps
2. Use post-rift stretching map and syn-rift subsidence to derive crustal thickness map with calculated mantle stretching from step 1



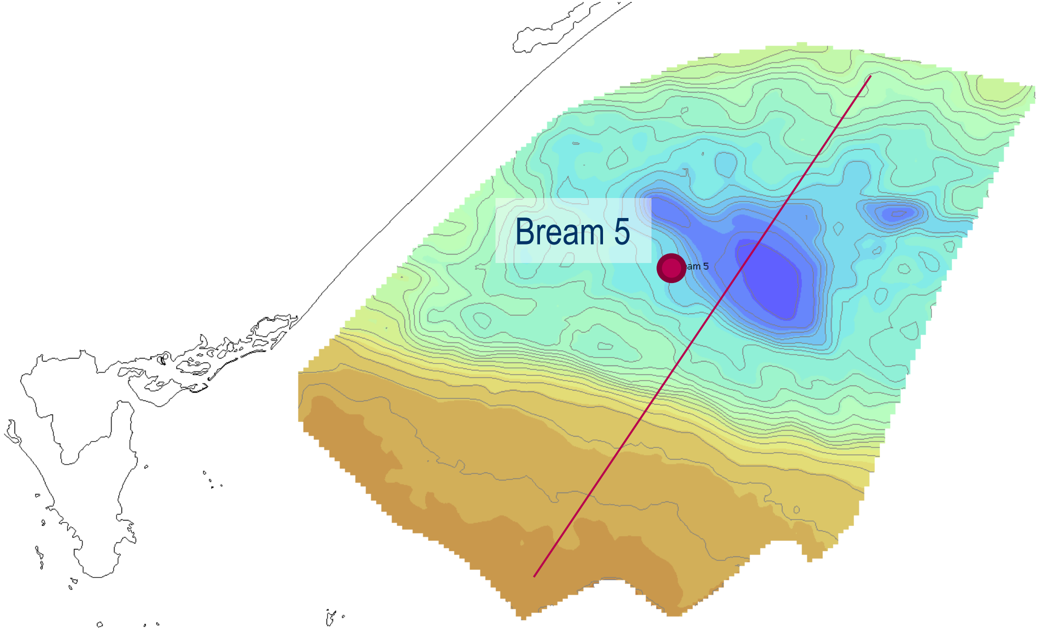
Adopted from White & McKenzie, 1988

Application

Gippsland Basin, Australia



3D GEO (2011)



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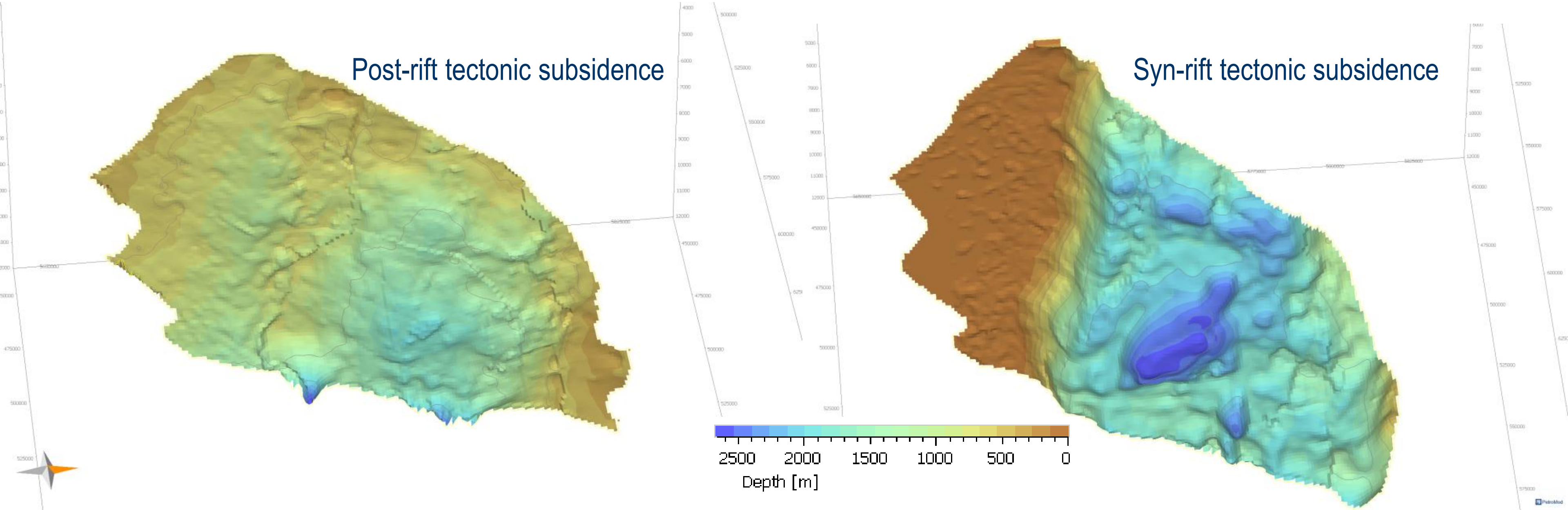
Solution workflow

Step 1:
Inversion of post-rift tectonic subsidence to β-mantle (the post-rift cooling is a function of its syn-rift thinning)

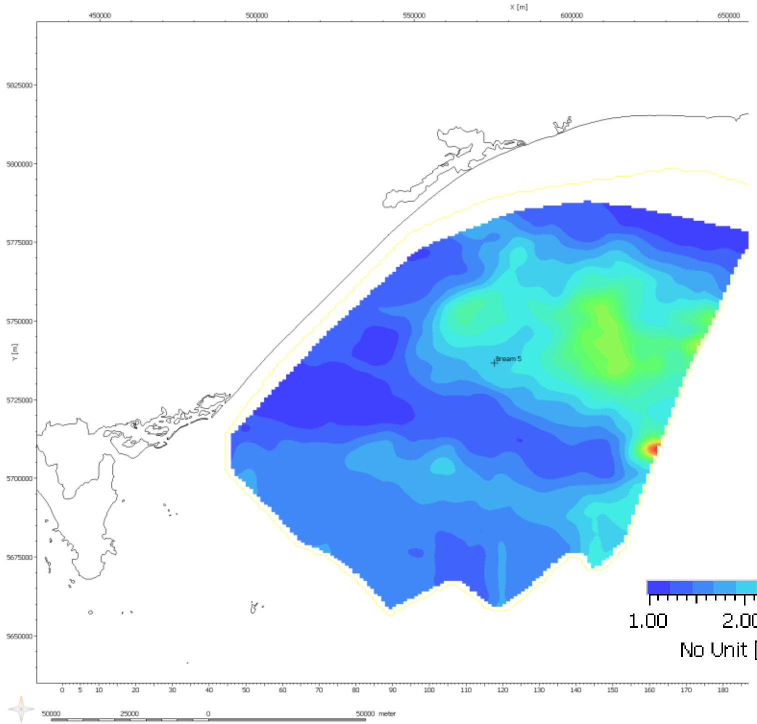
Step 2:
Inversion of syn-rift tectonic subsidence together with the result of Step 1 to β-crust

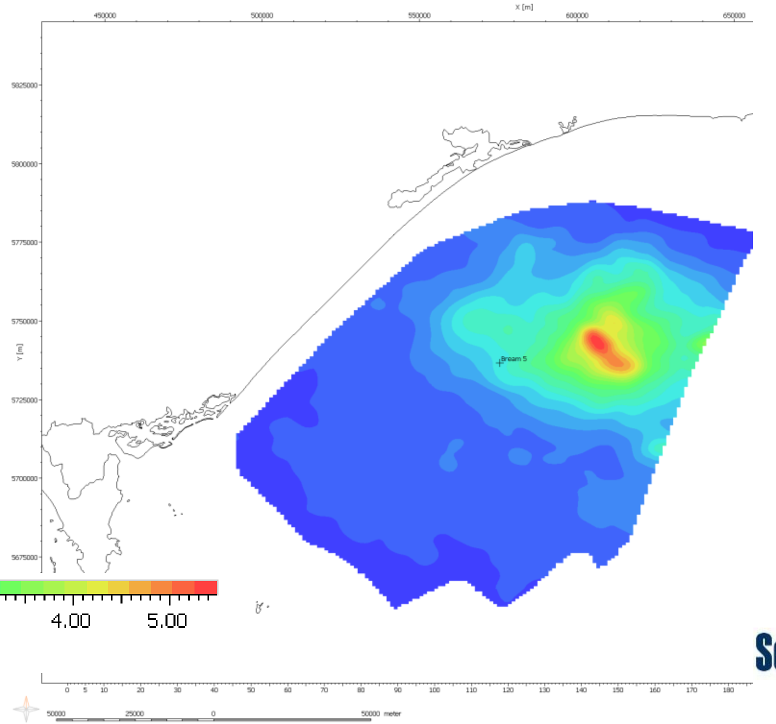


Application

Stretching (β) maps - Mantle

1-Step solution << 2-Step solution





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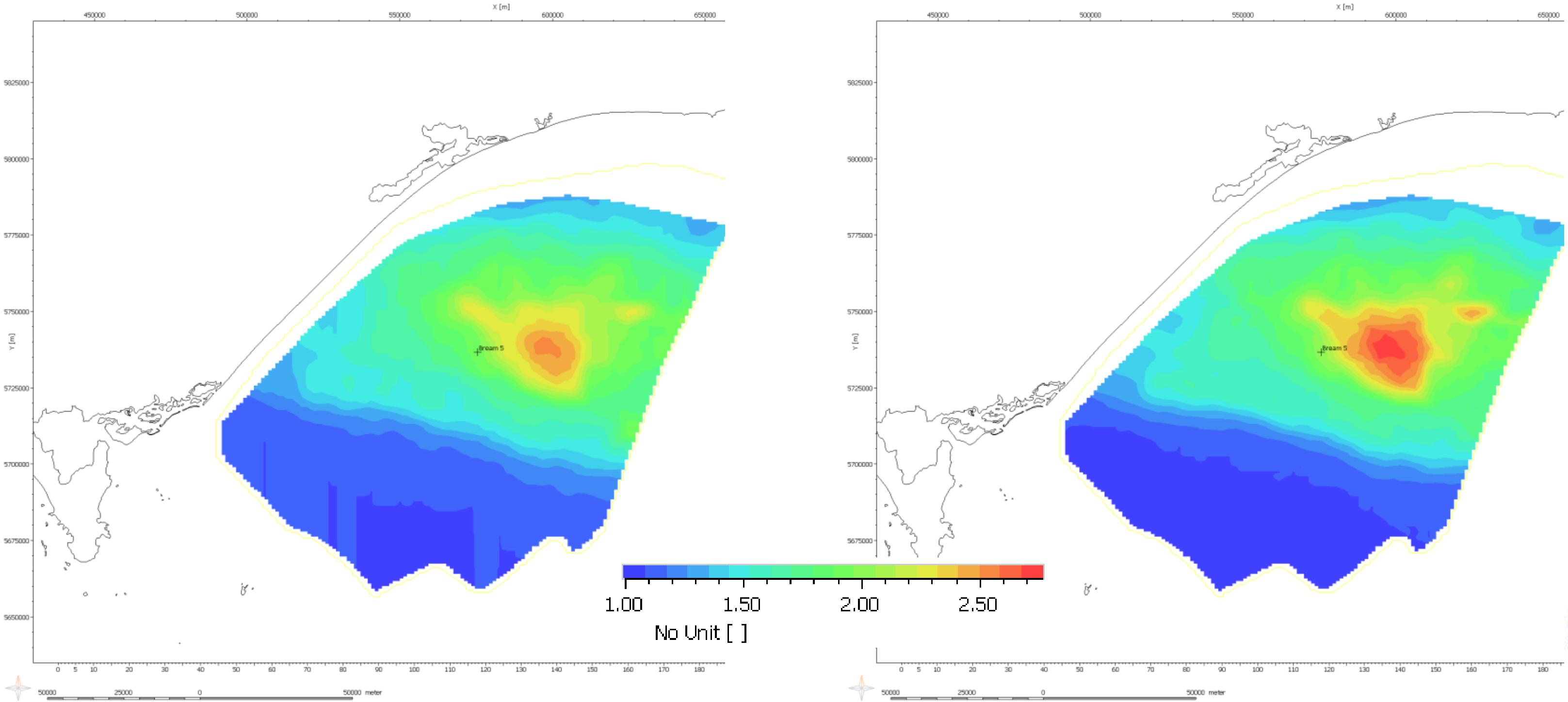
Application

Stretching (β) maps - Crust

1-Step solution << 2-Step solution



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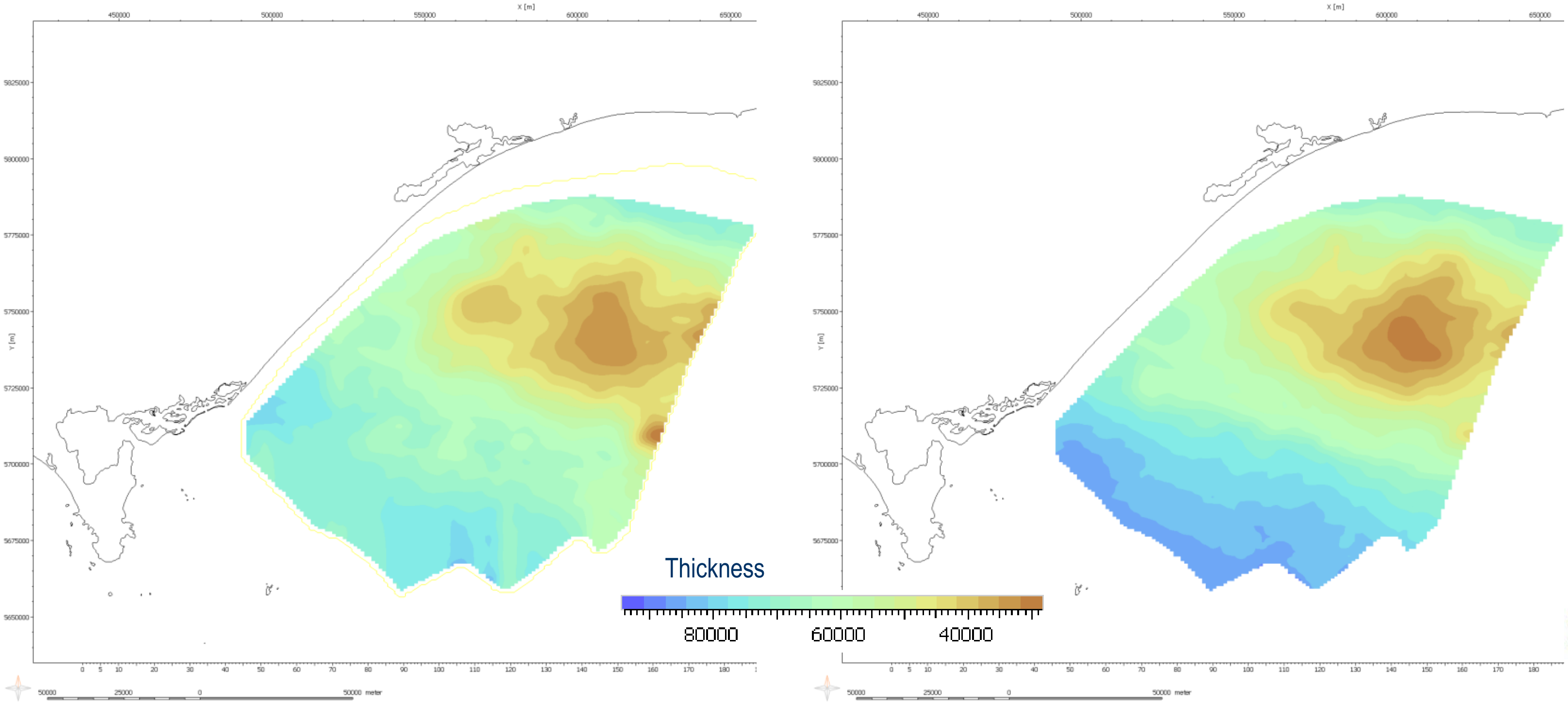
Application

Mantle thickness maps @ end of syn-rift

1-Step solution << 2-Step solution



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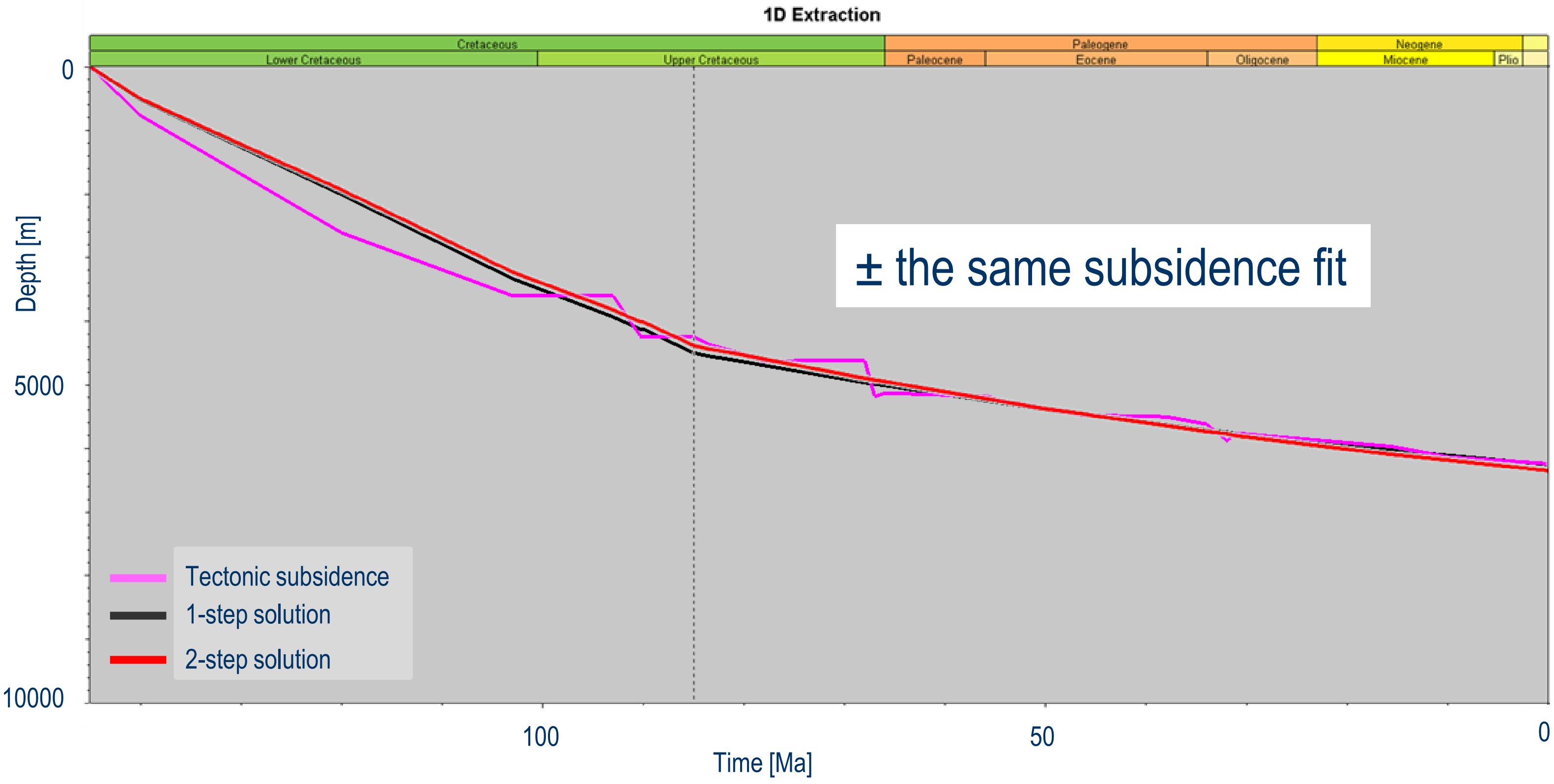
Application
Calibration



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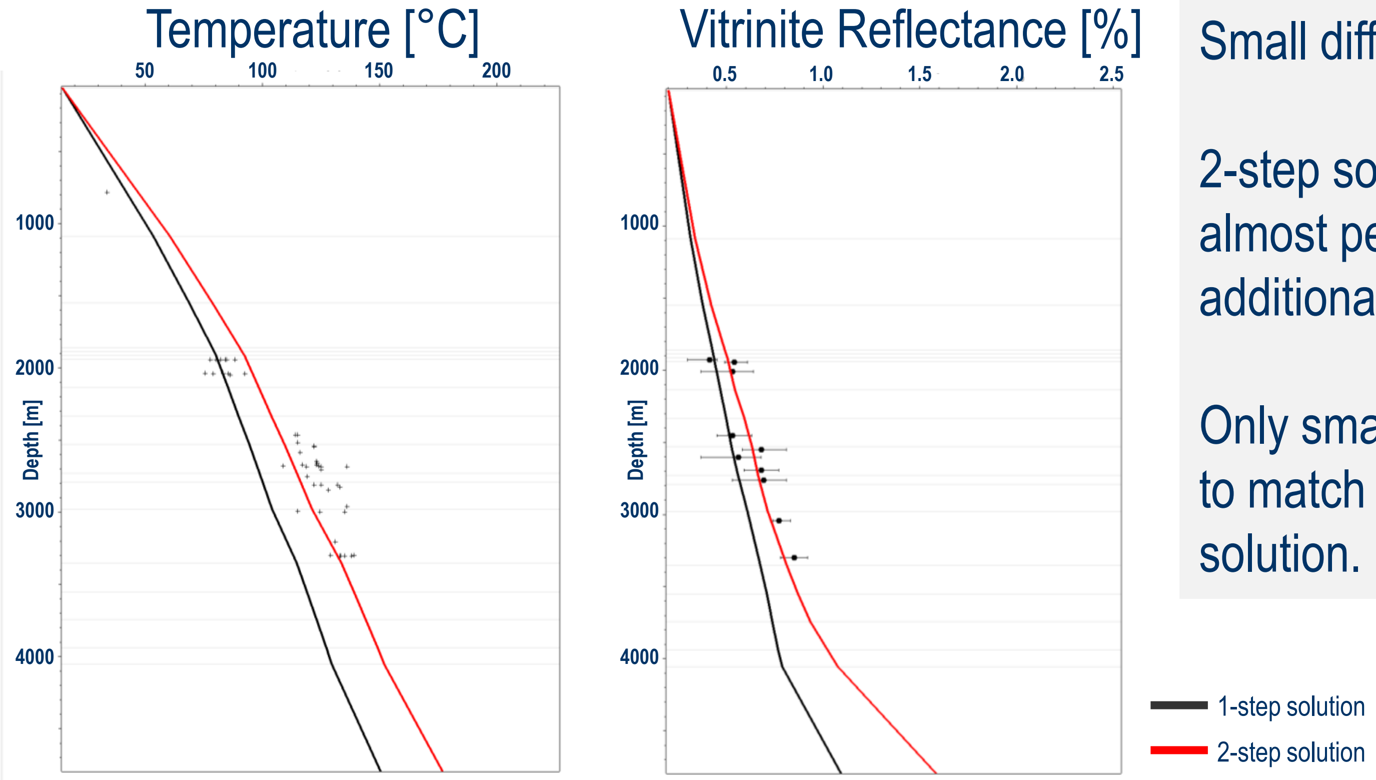
Thermal Calibration



GA (Geoscience Australia) (2017)

Small difference:

2-step solution is (accidentally) almost perfect without any additional heat flow adjustments.

Only small heat flow shift required to match calibration data for 1-step solution.

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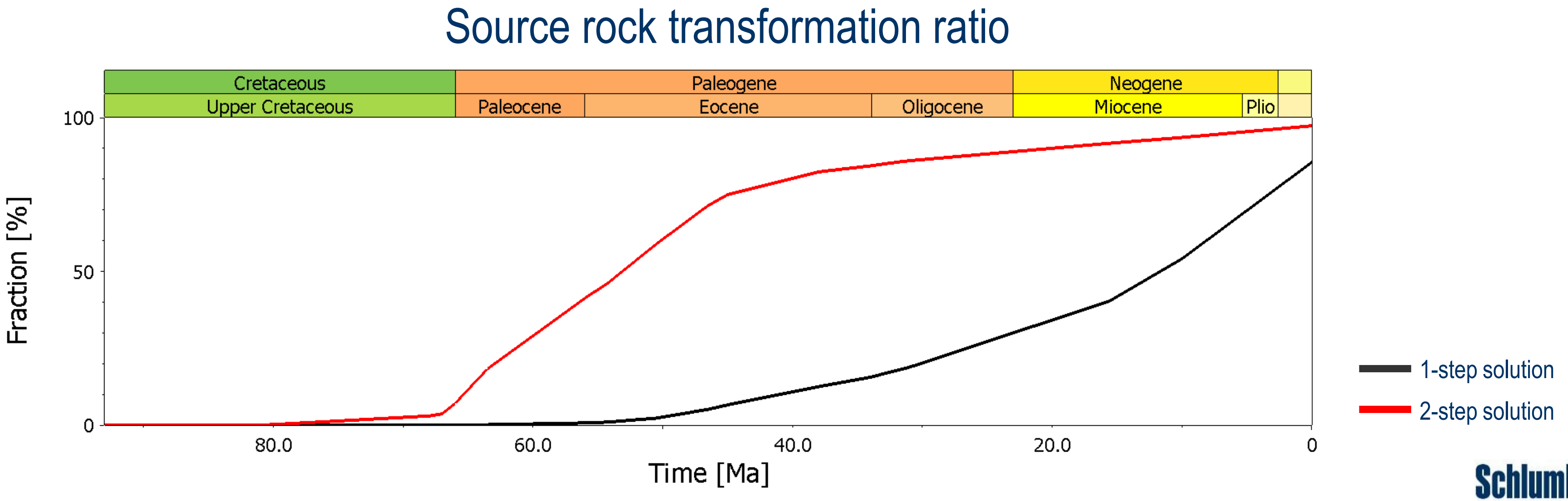
Application

Timing of hydrocarbon generation



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Application

Summary

Isostatic inversion of subsidence to lithospheric layer thicknesses and basal heat flow needs geological control to reduce the ambiguity during the application of a fitting routine!

Solution:
Ensure that the subsidence drivers (stretching and cooling) are treated separately

The **2-step inversion solution** delivers the required **geological control** and ensures **consistent** heat flow scenarios with **less uncertainty** are defined.

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