Thermal history modelling in an extensional basin

Tunwal M.[1,2]*, Mulchrone K.F.[2], Meere P.A.[1]

[1]School of BEES, University College Cork, Cork.
[2]Department of Applied Mathematics, University College Cork, Cork.
*Contact email: m.tunwal@umail.ucc.ie (Mohit Tunwal)

Introduction

In sedimentary basins, maturation of hydrocarbon source rocks depends on the temperature history after deposition. Sedimentation rate, geothermal gradient and duration of sedimentation are therefore key parameters controlling the thermal evolution. The McKenzie model is widely accepted model for extensional basin formation which can be used for estimating post-rift subsidence and rate of sedimentation. In this work two numerical models in 1D have been implemented based on McKenzie's model and allows the estimation of the thermal evolution of post-rift sediments.

McKenzie's Model

Step 1: Instantaneous stretching

Isostasy equation $$\int_0^c \rho_c dz + \int_c^a \rho_m dz = \int_0^{c/\beta} \rho_c dz + \int_{c/\beta}^{a/\beta} \rho_m dz + \left(a - \frac{a}{\beta} - s_I\right)\rho_m(T_a) + s_I \rho_s$$

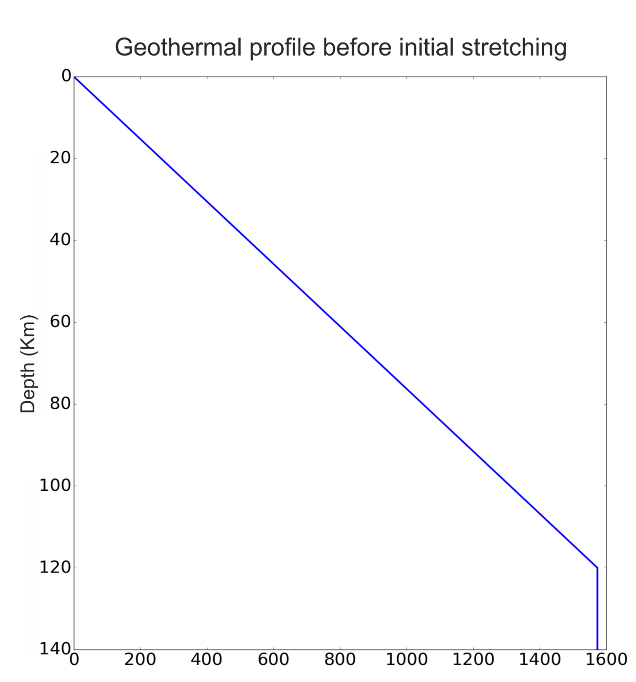

Fig. 1 (a). Geothermal profile at a relaxed state. Crust of 36 Km and lithosphere of 120 Km is taken. Temperature increases linearly to 1300˚ C till 120 Km. Constant temperature is assumed below lithosphere.

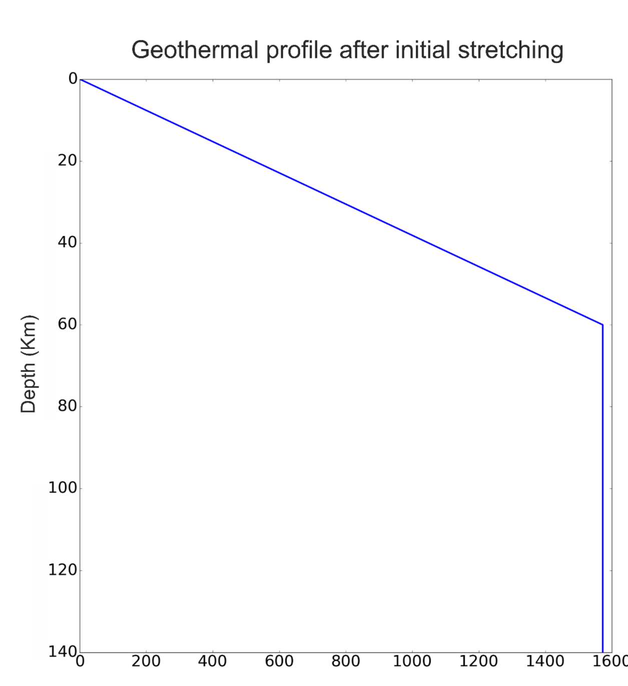

Fig. 1 (b). Instantaneous stretching occurs in the order of a million year. After stretching, the lithosphere gets thinned and as a result the geothermal gradient steepens. Since the density of rocks is dependent on the temperature there will be an initial subsidence for the system to remain in isostatic equilibrium. In the McKenzie model, the geothermal profile is assumed to be not affected by the sediment cover added on the top.

Step 2: Subsidence due to thermal cooling

Temperature equation $$\frac{\partial T}{\partial t} - \kappa \frac{\partial^2 T}{\partial t^2} = 0$$

Isostasy equation $$\int_0^a \rho_m(T(z,t))dz + \rho_s s_T(t) = \int_0^a \rho_m(T_I(z))dz + \rho_m(T_a)s_T(t)$$

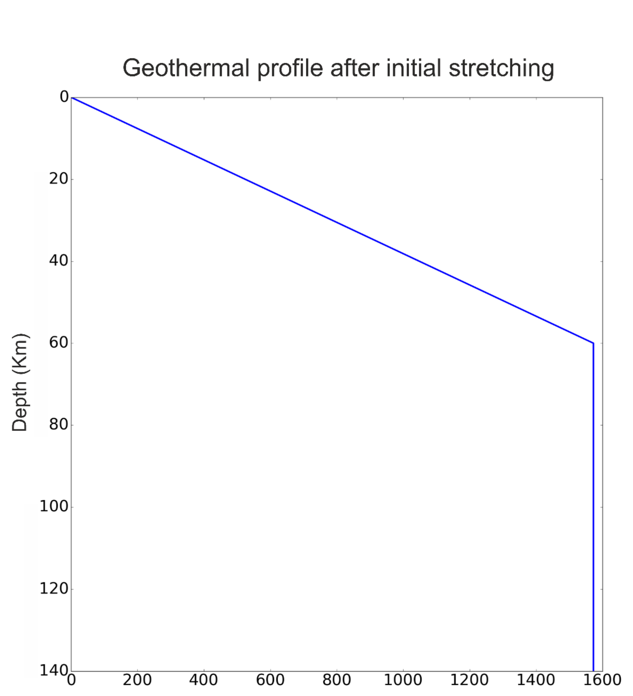

Fig. 1 (c). After the instantaneous stretching, the rocks starts cooling. Therefore, this profile is taken as starting point for the calculation of thermal diffusivity equation. Sediment cover at the top due to instantaneous stretching is ignored.

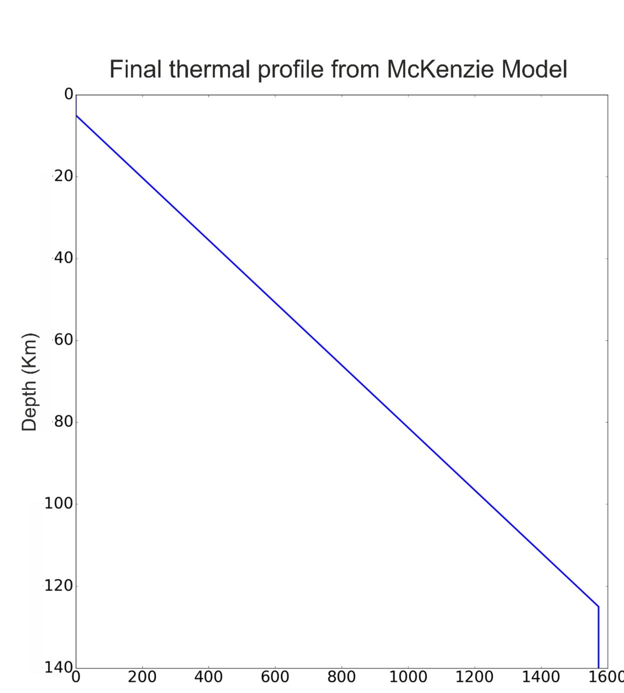

Fig. 1 (d). For solving the heat equation analytically, the final geothermal gradient is assumed to be the same as the initial geothermal gradient before the stretching. The isostatic equilibrium is maintained for the profile just after instantaneous stretching (at the start of thermal cooling) and at any time t during thermal cooling with sediment cover at the top. Thus, thermal subsidence is calculated.

Proposed Numerical Models

The finite difference method is used to solve the heat equation in the system. At each time step, subsidence due to thermal relaxation is calculated and added to the system and in this way the generalised moving boundary thermal diffusion problem is solved. Two different Models are proposed:

Model 1

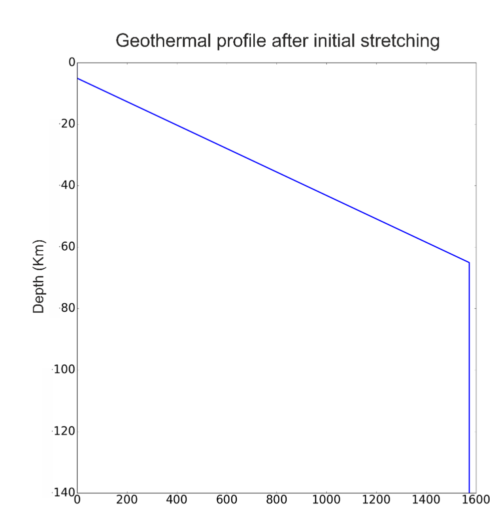

Fig. 2 (a). Geothermal profile at the beginning of thermal cooling consists of sediment cover at the top. This is due to the instantaneous stretching in the basin. For crust of 36 Km, lithosphere of 120 Km, the initial subsidence is of 5.05 Km.

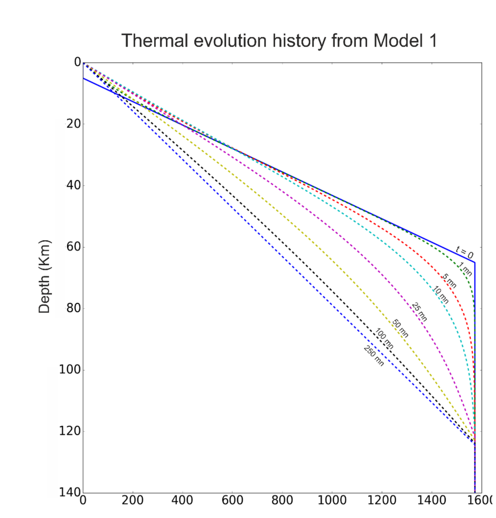

Fig. 2 (b). Cooling path of the system according to Model 1 is shown with time at t=0, 5 mn, 10mn, 25mn, 50mn, 100mn and 250mn years respectively.

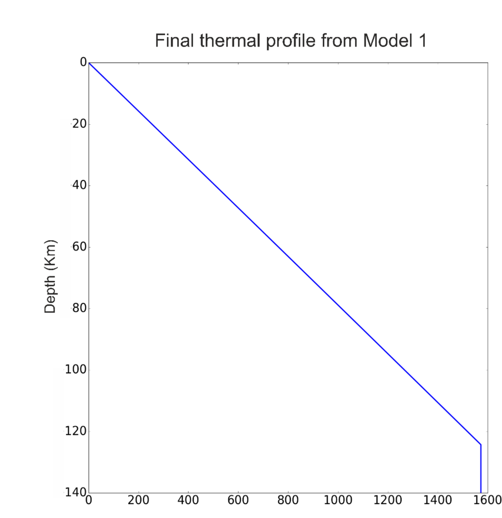

Fig. 2 (c). In this Model, the additional sediments added on the top accounts for the change in the final boundary between lithosphere and asthenosphere.

Model 2

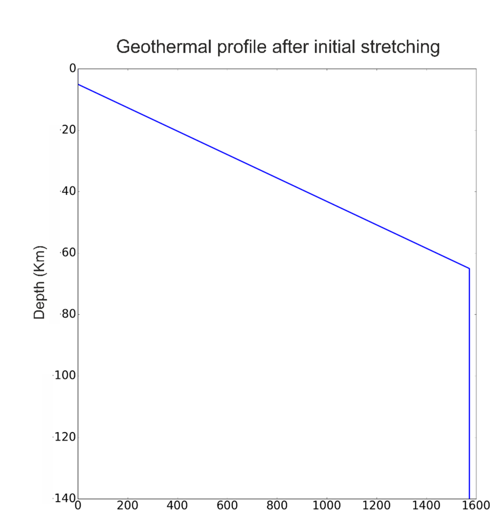

Fig. 2 (d). Geothermal profile at the beginning of thermal cooling consists of sediment cover at the top. This is due to the instantaneous stretching in the basin. For crust of 36 Km, lithosphere of 120 Km, the initial subsidence is of 5.05 Km.

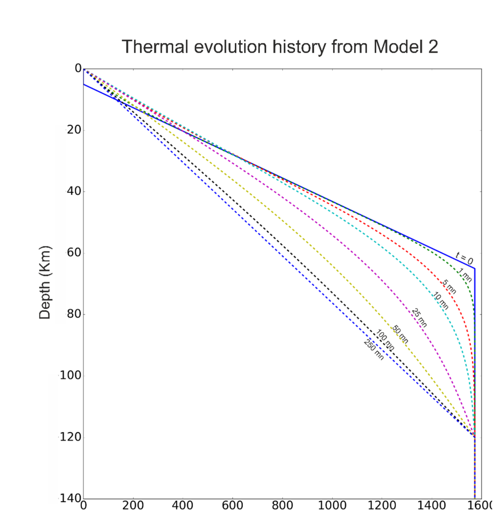

Fig. 2 (e). Cooling path of the system according to Model 2 is shown with time at t=0, 5 mn, 10mn, 25mn, 50mn, 100mn and 250mn years respectively.

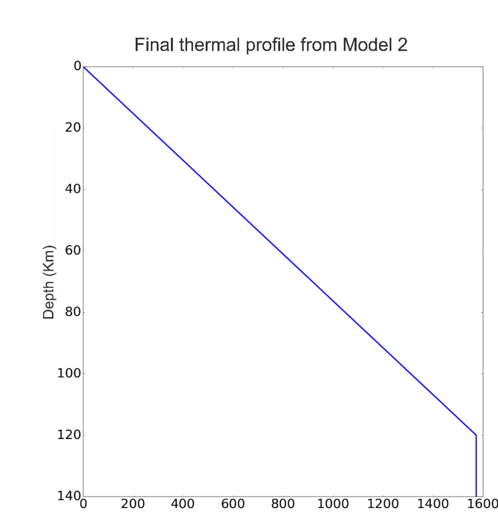

Fig. 2 (c). The final geothermal gradient according to this model matches the very initial gradient before instantaneous stretching. Temperature at the 120 Km level and below is assumed to be constant for this model.

Results and Conclusion

McKenzie model shows the highest, Model 1 shows intermediate and Model 2 shows lowest value for the thermal subsidence.

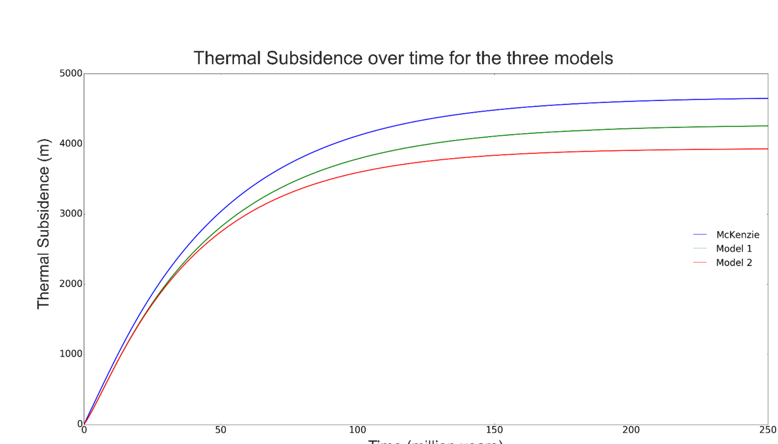

Fig. 3 (a). Thermal subsidence over a period of 250 million years is compared for the three models. McKenzie model presents the highest value, Model 1 the intermediate and Model 2 the lowest value throughout the time of calculation.

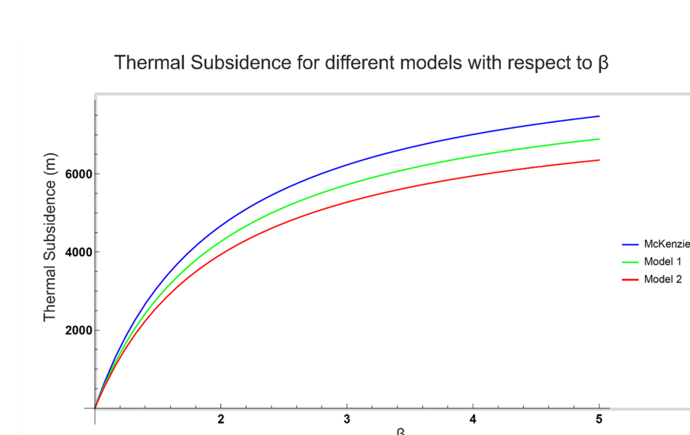

Fig. 3(b). Maximum possible thermal subsidence level that can be achieved for the three models are compared with respect to the stretching factor. With a significant lower β value, the McKenzie model will estimate a similar amount of thermal subsidence compared to the numerical models.

When the contribution of sediment cover is taken into account for the thermal solution, the estimated thermal subsidence is found to be significantly lower than the McKenzie's model. Considering radiogenic heat sources in the sediments and the difference in thermal diffusivity of the sediments, crust and mantle will further improve the numerical model.

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