# 1D Petroleum Systems Modelling: An Application of McKenzie's Lithospheric Stretching Technique*

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## Abstract

Exhumation and paleobathymetry corrections are paramount to the authenticity of the total petroleum systems models of partially exhumed basins as applicable constraints, risk and the tendency to overestimate undiscovered resource potentials pose significant challenges. McKenzie lithospheric stretching technique is regarded as a valid framework for the evaluation of exhumation in intracratonic rift basins of which Williston Basin is a suitable example. This assessment applies a workflow that allows the continuous deterministic adjustment of paleobathymetry and the corresponding response of exhumation data within reported erosional episodes as observed water loaded basement subsidence and McKenzie's theoretical subsidence profiles converge at non-erosional intervals. It further demonstrates how a general assumption of 100m paleo-water depth for most Williston basin Phanerozoic units with the exception of Bakken and Lower Lodgepole; a notion that suggests a negligible bathymetry effect could be applied to basin modelling, could introduce large uncertainty. Resulting estimations and models are more detailed and enhanced for accuracy

## Introduction

This project is part of a large, integrated assessment of the Phanerozoic fluids and petroleum systems of southern Saskatchewan conducted at the Universities of Alberta and Regina. The overall goal of this project is to examine, analyze and characterize the fundamental processes involved in the generation, migration and entrapment of hydrocarbons within Phanerozoic strata, specifically regarding how and where hydrocarbons in the Saskatchewan subsurface were generated and where and when they migrate over geologic time to help determine where they are most likely to have been trapped at the present time.

This particular study seeks to integrate various data sets, both existing and new, into a series of 1D, 2D and ultimately 3D Basin models that seek to describe the maturation, generation and migration of petroleum into, and within, Saskatchewan.

Basin modelling is the forward simulation of the evolution of geological events within a basin through geologic. The creation of a burial history curve for a given well is typically the initial step in the work flow and one of the most fundamental steps, since the accuracy of the burial history curve can markedly influence the timing and onset of oil generation. However, one of the most challenging aspects facing modellers engaged in building burial history curves is the determination erosional thickness and paleobathymetry. Uplift and the removal of overburden is referred to as exhumation (erosional thickness) while paleobathymetry refers to the depth of water depth within the depositional basin.

The determination, quantification and application of paleobathymetry and erosional thickness in the assessment of petroleum generation in a basin that has undergone period uplift helps minimise the overestimation or underestimation of hydrocarbon potential. It also facilitates the development of an approach that constrains resources and the risk forecast.

This paper presents preliminary work and an exhumation and paleobathymetry solution as applied to basin modelling within the northern portion of the Williston basin.

## Theory and Method

Intracontinental sags, rifts, failed rifts, and passive continental margins fall within evolutionary suite of basins unified by the process of lithospheric stretching (Allen and Allen, 2005).

Falvey (1974) initially proposed the quantitative relationship between crustal and subcrustal lithospheric extension and the subsidence histories of various continental basins and rifted margins. Developing the concept, McKenzie (1987) proposed a uniform lithospheric stretching model, as a means of proving a solution when seeking to predict synrift subsidence followed by an exponentially declining post-rift thermal subsidence. McKenzie's uniform lithospheric stretching model facilitates the calculation of theoretical subsidence curves (for a given stretch factor β) which can then be compared with the observed tectonic subsidence profile derived from decompacted and backstripped water loaded sediment columns. Deviations of the observed from the predicted subsidence curves can be used, in most cases, to estimate the magnitude and timing of exhumation (Corcoran et al., 2005). Estimated exhumation data can be applied to burial history profiles, other forward simulation processes and general estimations of erosional thickness.

McKenzie (1978) defined uniform lithospheric stretching model as:

$$y_s = \frac{y_L\left\{(\rho_m^* - \rho_c^*)\frac{y_c}{y_L}\left(1 - \alpha_v \frac{T_m}{2}\frac{y_c}{y_L}\right) - \frac{\alpha_v T_m \rho_m^*}{2}\right\}(1 - 1/\boldsymbol{\beta})}{\rho_m^*(1 - \alpha_v T_m) - \rho_s}$$

Where:

β = Stretch factor
$y_L$ = Initial thickness of the lithosphere
$y_c$ = Initial thickness of the crust

$\rho_m$* = Density of the mantle at 0°C
$\rho_c$* = Density of the crust at 0°C
$\rho_s$ = Average bulk density of sediment or water filling the rift
$\alpha_v$ = Thermal expansion coefficient of both crust and mantle
$T_m$ = Temperature of asthenosphere
$y_s$ = Subsidence or uplift

To determine the magnitude of exhumation and estimate paleobathymetry using the McKenzie lithospheric stretching technique, theoretical subsidence curves are modelled for each selected well and fitted to their respective backstripped and decompacted subsidence curve (observed subsidence) by adjusting the stretch factors (β) for the crust and the mantle. Paleobathymetry is further estimated by adjusting the initial zero input to other numerical values, the observed water loaded basement subsidence and McKenzie's theoretical subsidence profiles converge at non-erosional intervals. The resulting vertical departure from the theoretical curve is a measure of denudation as deterministic bathymetric values.

For example, vertical differences *m*, *n*, *o*, and *p* in Figure 1 represent the estimated Mid-Ordovician, Sub-Devonian, Sub-Triassic and Sub-Cretaceous erosional events respectively. The resulting paleobathymetry and exhumation data are then applied to the 1D forward simulation processes of selected wells within the Basin model.

## Results and Discussion

Multiple paleobathymetry and exhumation solutions for three of wells shown in Figure 2 provide a number of significant results. Firstly, the derived McKenzie stretching solution concurs with the widely held belief that the water depth for the Bakken was approximately 250m in the Saskatchewan portion of Williston basin. Secondly, the results show that paleobathymetry values vary systematically across the basin, yielding Bakken paleobathymetry values of 150m, 270m and 385m from the basin margin to depocenter (Figure 1).

Thirdly, attempts to generate burial history curves with and without applying the McKenzie stretching solution yield very different results, as shown in Figure 3.

This demonstration was conducted following three scenarios: (1) assumed negligible (zero) bathymetry, (2) modelled Bakken bathymetry and (3) modelled bathymetry for all non-erosion intervals. The resulting burial history profiles are shown in Figure 3 and visually present a striking contrast between un-corrected (Figure 3a) and the corrected model Figure 3b) in which the full McKenzie stretching solution has been applied. The corrected model generates a burial history curve that is not only more geologically realistic but generates data that actually better conforms to the evolution theory of the Williston basin. While the Williston basin Phanerozoic strata have undergone substantial erosions during the Sub-Cretaceous, sub-Triassic, sub-Devonian and Mid Ordovician, they were generally previously modelled as having been deposited close to sea level. In some cases, with the exception of Bakken and Lower Lodgepole in which formations are supposedly deposited in water depths less than 100m, bathymetry effects could be considered as negligible in Williston basin burial history models. The application of the McKenzie stretching solution has other general applications outside Basin modelling, providing a means of deriving estimations of erosional thickness.

## Conclusion

Published 1D model are not typically decompacted or corrected for paleobathymetry and exhumation. These corrections are crucial and they have a profound impact on the outcome of any forward simulation model when seeking to determine the generative potential of a formation or basin through Basin Modelling. This study has provided a solution and workflow that allows the quantification and application of paleobathymetry and erosional thickness, thereby providing more accurate boundary conditions and improved forward simulation of basin evolution and petroleum systems assessment.

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## References Cited

Allen, A. P., and R.J. Allen, 2005, Basin Analysis Principles and Applications, Second Edition: Blackwell Science Limited, a Blackwell Publishing Company, p. 63-112.

Corcoran, D. V., and A.G. Dore, 2005, A review of techniques for the estimation of magnitude and timing of exhumation in offshore basins: Earth-Science Reviews, v. 72, p. 129–168.

Falvey, D.A., 1974, The development of continental margins in plate tectonic theory: The APEA , v. 14, p. 95-107.

McKenzie, D., 1978, Some remarks on the development of sedimentary basins: Earth and Planetary Science Letters, v. 40, p. 25–32.

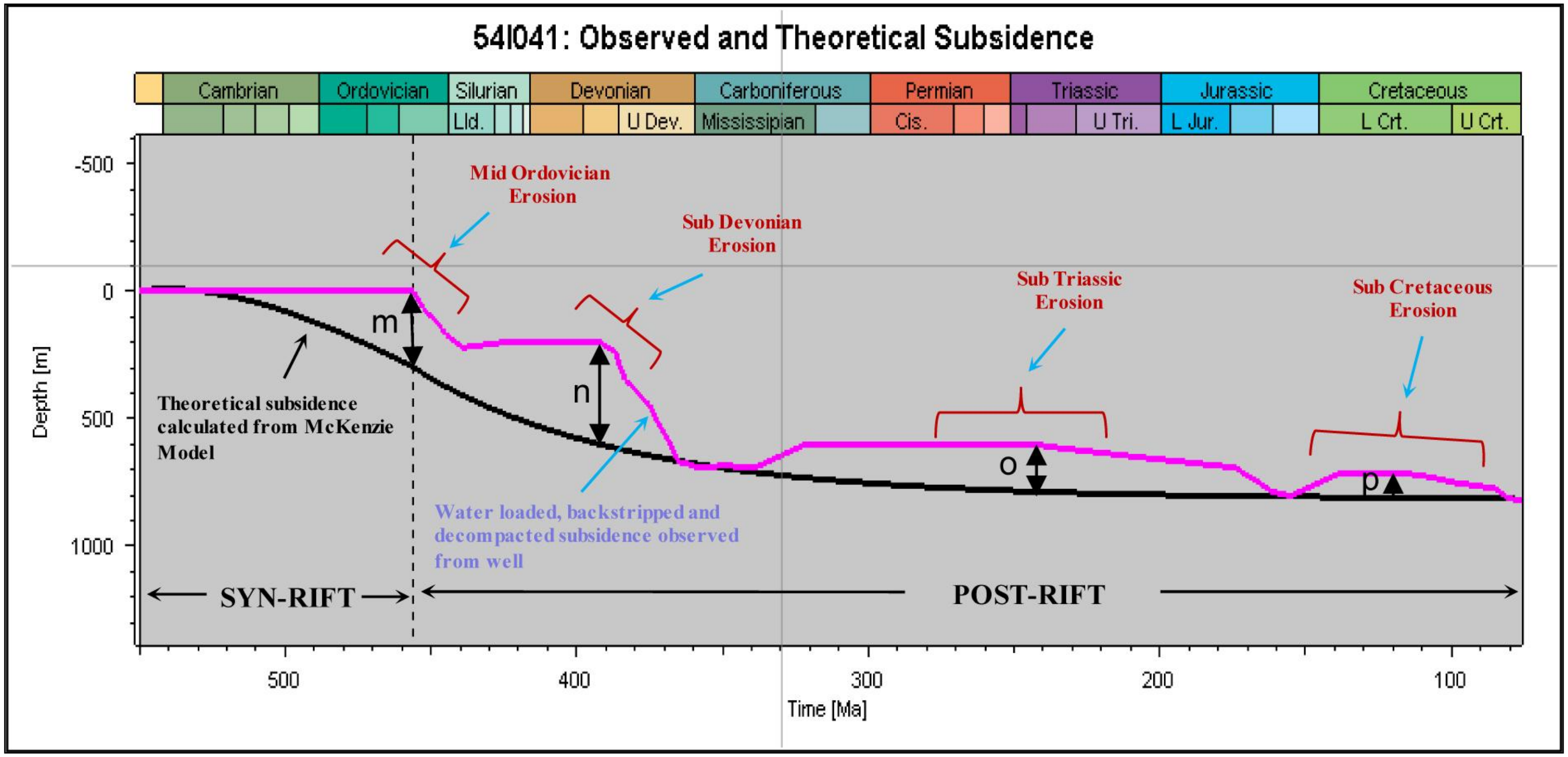


Figure 1. Observed basement subsidence curve (blue) compared to the McKenzie stretching solution curve (black), the vertical departures between curves represent uplift and erosional events.

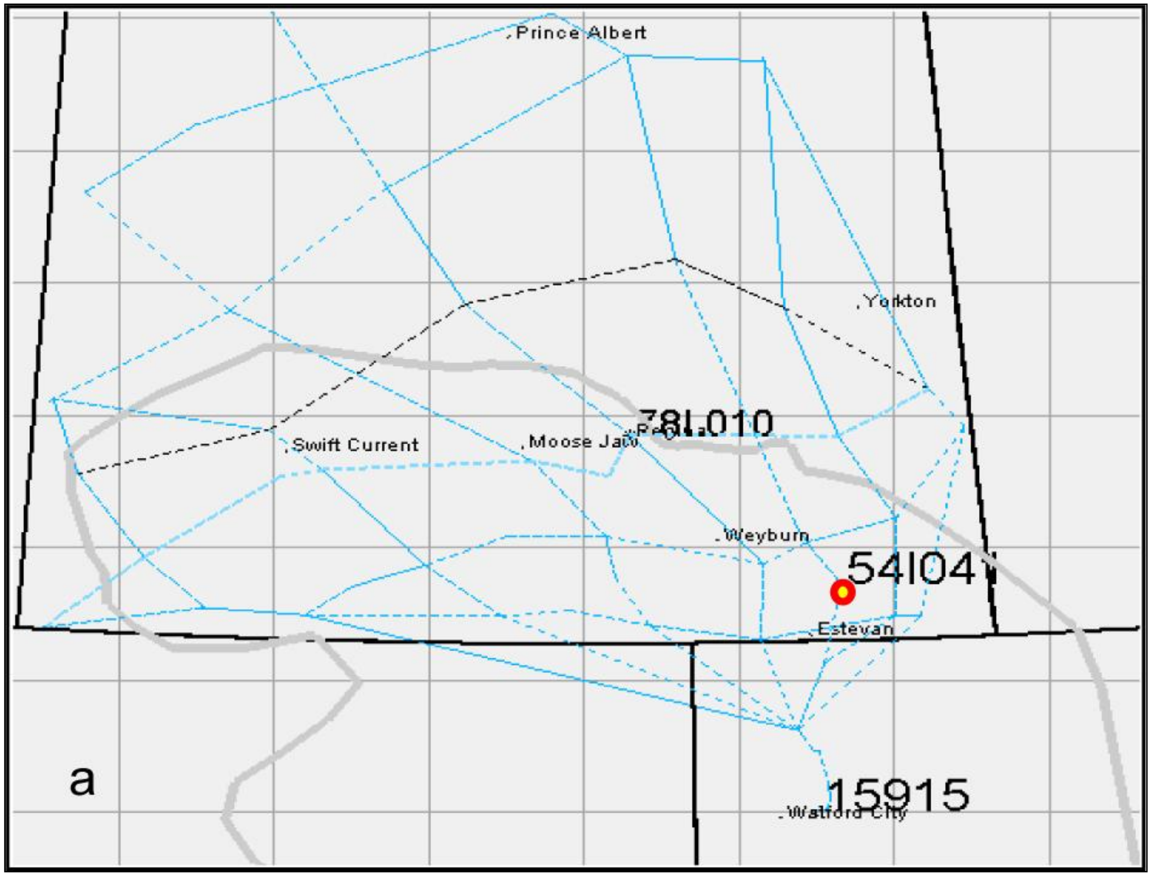


Figure 2. Location of the three selected wells: 78L010, 54I041 (red) and 15915 presented on the outline of the Williston basin boundary.

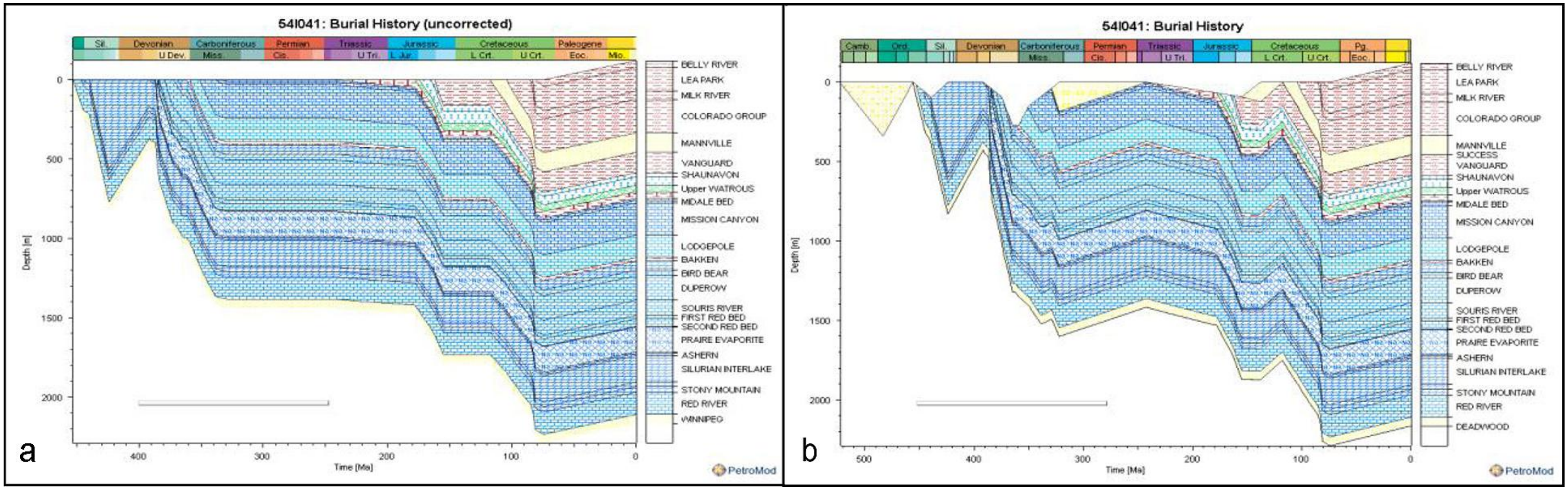


Figure 3. a) Burial history profile from well 54I041 with assumed zero paleobathymetry and no erosion or correction. b) Burial history model from well 54I041 with McKenzie's model derived exhumation and paleobathymetry corrections.