An Optimized and Focused Lithospheric Deformation Model for Reconstructing the Mesozoic Evolution of the Gulf of Mexico Basin

Satyam Pratap Singh[1], Sabin Zahirovic[1], Maria Seton[1], and Nicky M Wright[1]

[1]Affiliation not available

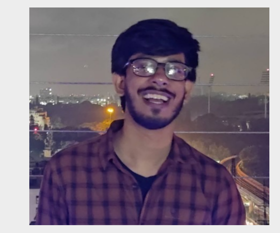
December 27, 2023

Abstract

The Gulf of Mexico (GoM) is a passive rift margin that is shrouded in thick sedimentary layers, making it challenging to trace its Mesozoic evolution. Traditionally, plate tectonic models have required an assumption of rigid plates, limiting our ability to understand the evolution of passive margins given the wealth of geological and geophysical evidence indicating significant crustal deformation during rifting processes. However, recent advances have been made in our ability to incorporate deformation into plate tectonic models.Here, we present a novel approach to reconstruct the evolution of the GoM by using an optimized and focused deformable plate model. Our new model uses a time-evolving focused deformation along the rift, where the strain rate evolves over time from being more uniform initially to increasing exponentially seaward to the point of continental rupture and ocean crust formation.By incorporating time-evolving deformation into our plate reconstruction, we can additionally derive crustal thickness and thermal and tectonic subsidence through time, which allows us to better explore the depositional history of the presalt deposition and crustal architecture evolution of the GoM basin. Our deformation model is optimized to minimize the root mean squared error (RMSE) between predicted present-day crustal thickness and the GEMMA crustal thickness model, resulting in an RMSE of 5.6 km compared to GEMMA, with <2 km absolute error in the northwest and northeast GoM. The resulting tectonic subsidence of ~1.5 km before the Yucatán block drifted in Late Triassic providing routes for the deposition of red beds through the paleo-drainage systems of the northern GoM as successor basin infilling. We find rapid subsidence occurred in the central GoM during the Early Jurassic shifting red bed deposition to a location that presently lies beneath the salt formation, potentially reconciling ~40 Myrs of missing sedimentary strata. Extension rate and stretching factor calculations reveal a transition from a magma-rich to a hyperextended margin, with possible mantle exhumation.Through our study, we highlight the significance of adopting optimized deformable plate reconstruction models, which enables quantitative interpretations of the tectonic history and geological evolution in rift basins globally.

An Optimized and Focused Lithospheric Deformation Model for Reconstructing the Mesozoic Evolution of the Gulf of Mexico Basin

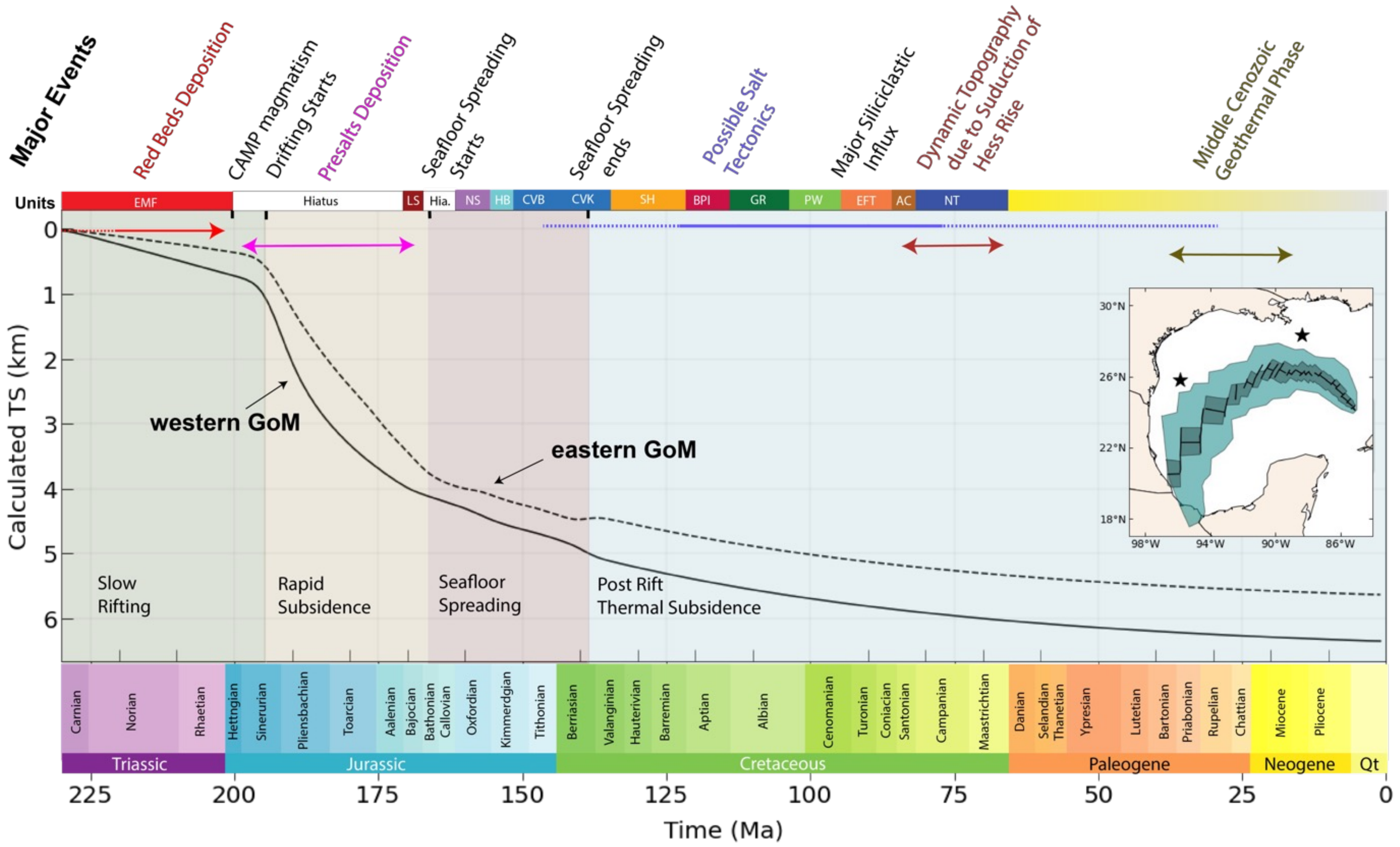
Satyam Pratap Singh, Sabin Zahirovic, Maria Seton, Nicky M. Wright
EarthByte Group, The University of Sydney, NSW, Australia
Correspondence: satyampratap.singh@sydney.edu.au

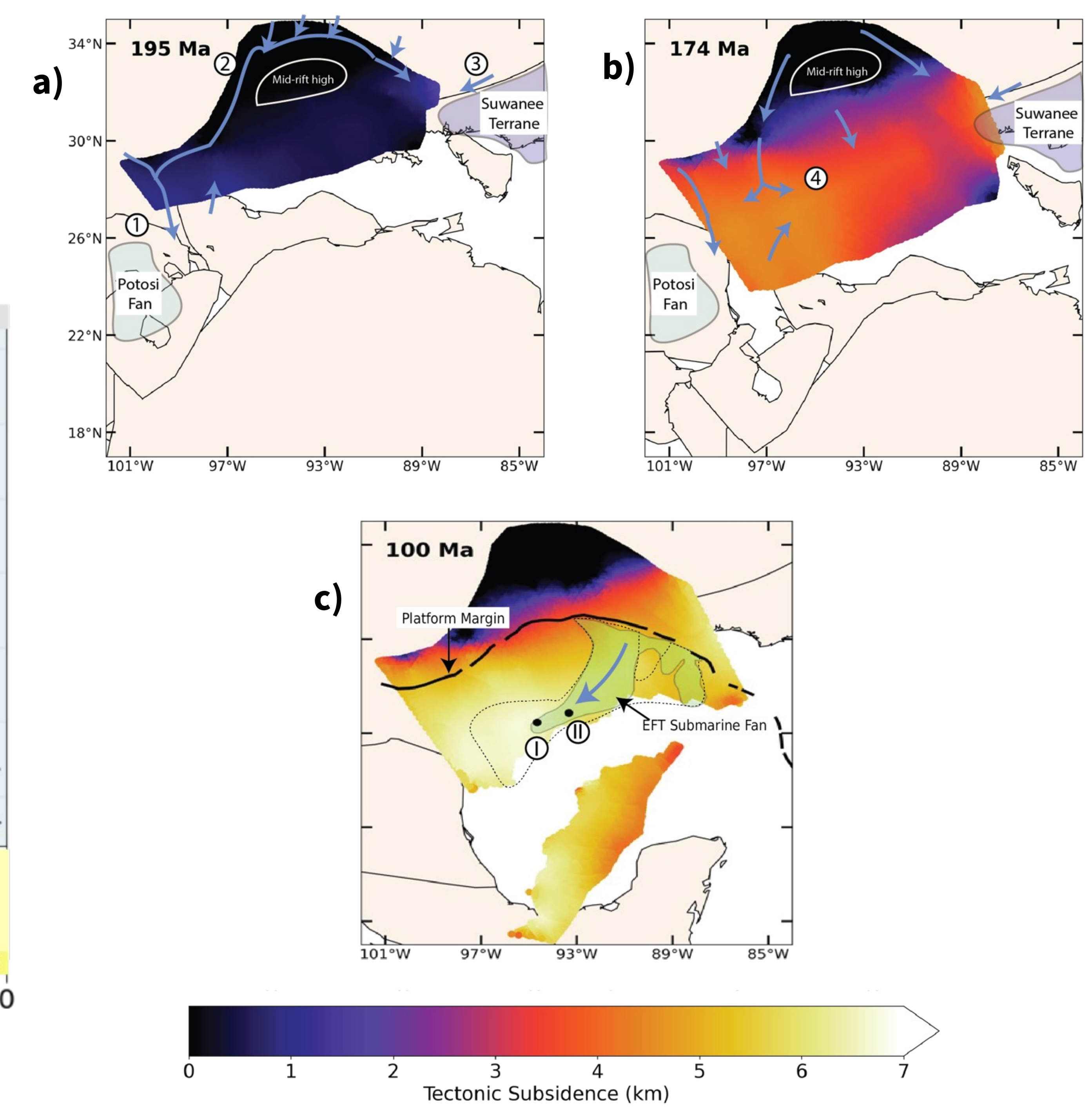


Highlights

- An optimised deformable plate model for Gulf of Mexico (GoM) is introduced that dynamically adjusts stretching factor during rift evolution.
- The ~40 Myrs gap in northern GoM's Mesozoic strata is due to rapid subsidence, shifting red bed deposition beneath Jurassic salt formations.
- The GoM basin transitioned from a magma-rich to a hyperextended margin with possible mantle exhumation.
- The westward deflection of the Cenomanian-Turonian sandy submarine fan is a result of increased differential tectonic subsidence from eastern to western GoM and may extend further west.

Graphical Abstract





Tectonic subsidence (TS) calculation from our model shows four stages can be used to describe the tectonic evolution of the GoM basin.

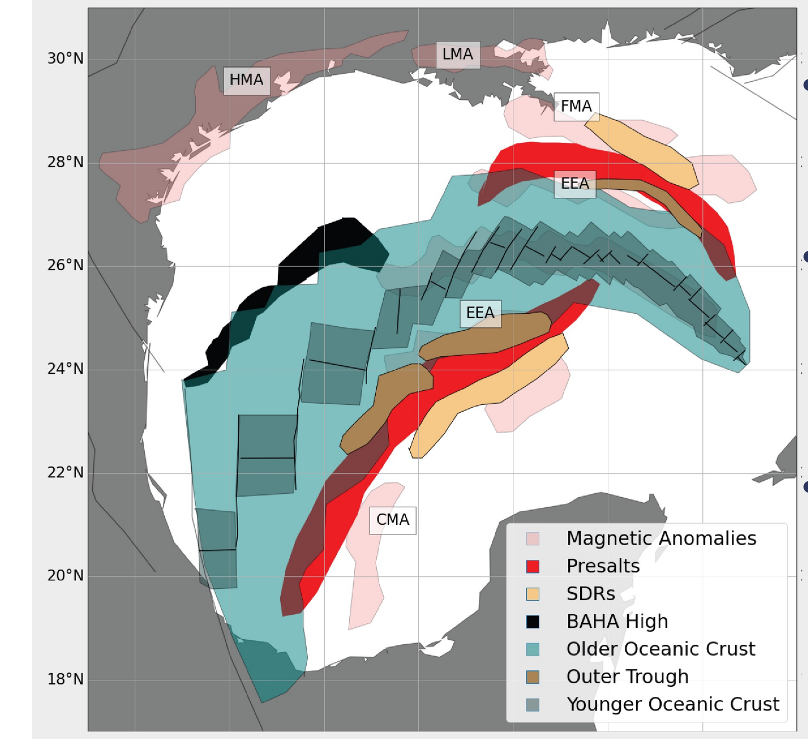
1. Slow rifting Phase: A small amount of tectonic subsidence creates accommodation for infilling the GoM basin with red beds. Sediment routing in **(a)** are based on detrital zircon geochronology analysis (Snedden & Galloway, 2019).

2. Rapid Subsidence Phase: A rapid subsidence followed which resulted in 3-4 km of subsidence. Sedimentation was a continuous process but due to this rapid subsidence, the red bed deposition shifted further south near the Yucatán margin beneath Jurassic salts **(b)**.

3. Seafloor Spreading Phase: The seafloor opening starts first, in the western GoM, followed by the eastern GoM. The evolution of crustal architecture was completed by the end of this phase.

4. Post-Rift Thermal Subsidence Phase: The last stage is marked by conductive cooling of the lithosphere resulting in gradual tectonic subsidence. The westward deflection of Cenomanian-Turonian Eagle Ford-Tuscaloosa (EFT) sandstones might be influenced by the differential tectonic subsidence in east to west direction **(c)**.

Major unresolved issue with GoM's Mesozoic history



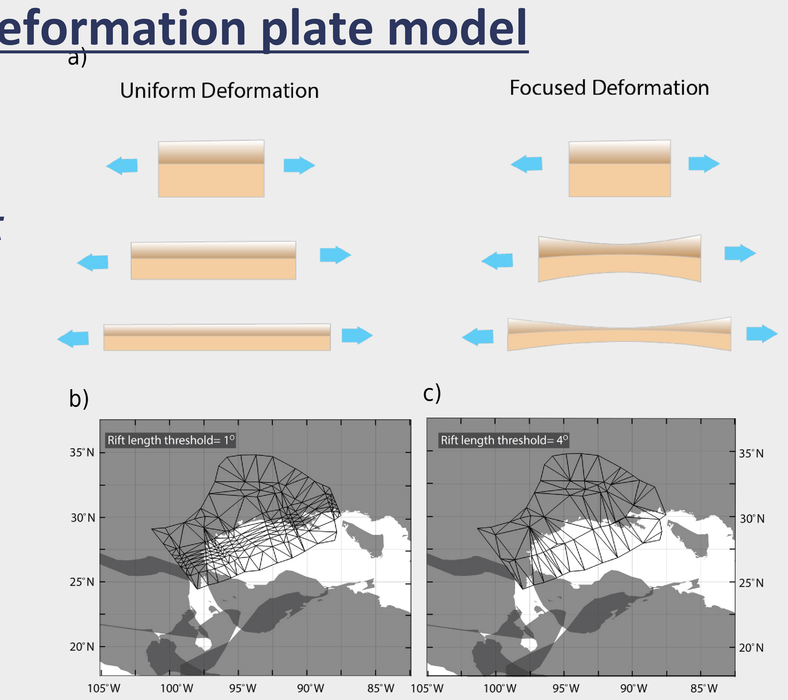
- *Ambiguous model for pre-salt sedimentary strata formation.*
- *Seaward dipping reflector and high magnetic anomalies suggests magma rich margin.*
- *Analogue rock properties of EEA matches peridotite which suggest mantle exhumation, hence a magma poor margin.*

Uniform vs focused deformation plate model

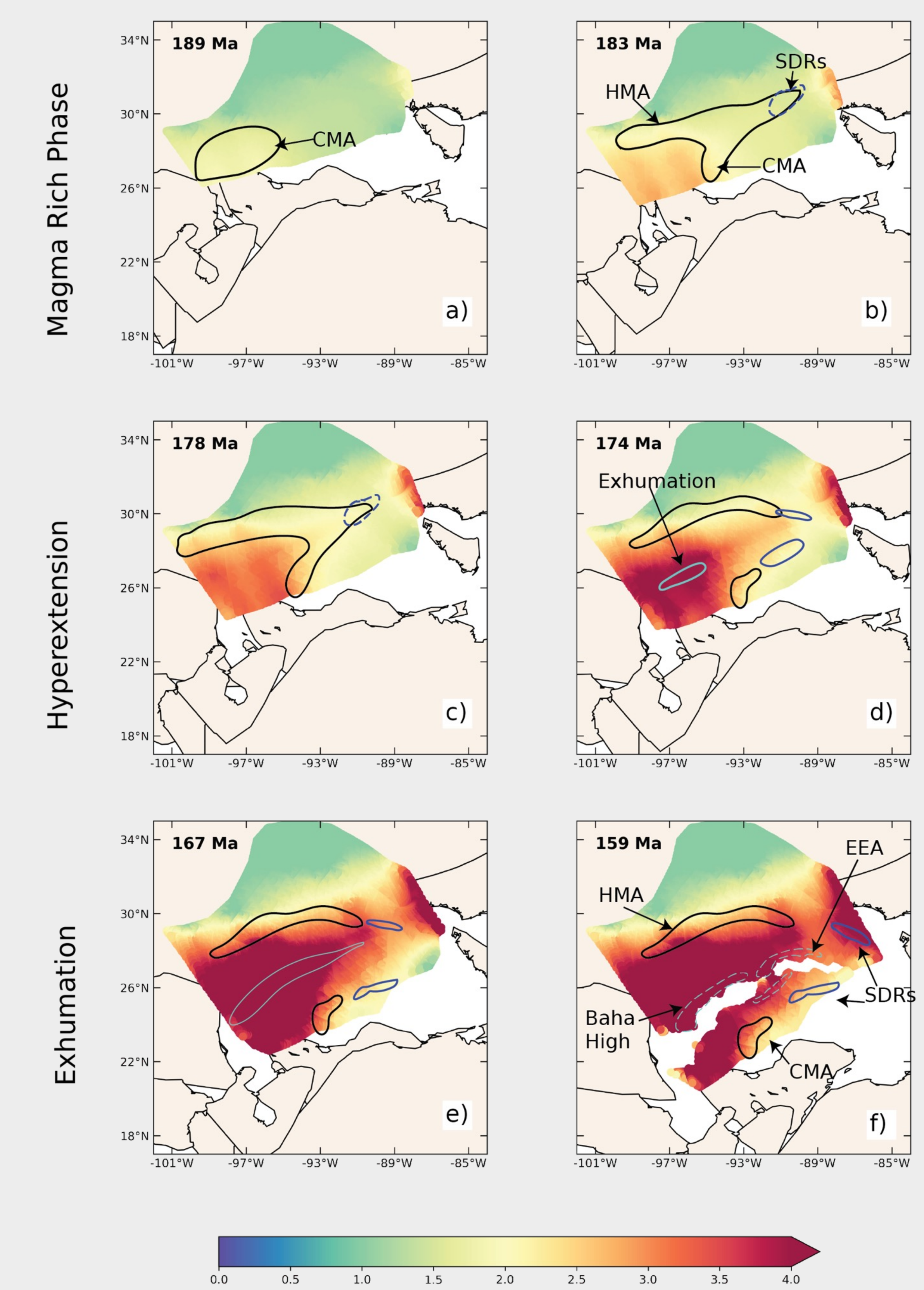
Our method allows for the control of the spatial variation of strain rate in a rift profile using different parameters.

Our model can be used to calculate:

- *Crustal thickness,*
- *Crustal stretching and thinning,*
- *Tectonic Subsidence in deep time.*



Summary of the evolution of the GoM crustal architecture.



➢ **The GoM basin started as a magma-rich margin but transitioned to a hyperextended margin with possible mantle exhumation before seafloor spreading.**