PS 3-D Numerical Modelling of Hydrocarbon Generation from the Barremian-Aptian Source Rock Unit of the Northern Orange Basin, South Africa*

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Search and Discovery Article #11199 (2019)**
Posted March 18, 2019

*Adapted from poster presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018
 DOI:10.1306/11199Samakinde2019

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Abstract

A 3D Numerical modelling of hydrocarbon-generation from the Barremian/Aptian source rock intervals encountered in the northern part of the Orange Basin was done using the Basin boundary conditions of Heat Flow (HF), Sediment Water Interface Temperature (SWIT), and Paleo-Water Depth (PWD). The model results shows source rock reached a sufficiently mature stage around 108 Ma (Late Albian/Cenomanian), with VR values ranging from 0.64 to 0.72 in the northeastern to southwestern section of the study area respectively. The model reveals transformation of organic matter began from the center of the study area (graben-filled depocenter) and increases towards the fringes. Hydrocarbon-generation reached its peak during the late Cretaceous, which coincides to the period of uplift of the entire Africa margin. At present day (0.0 Ma), 100% transformation of organic matter into hydrocarbon has occurred at the central section of the study area, while transformation into hydrocarbon has not occurred in the extreme northeastern section. Consequently, good potential for future source rock transformation into hydrocarbon in the northern part of the area may be expected. Additionally, the 3D model precision was tested using 1D calibration data from wells AO-1, AE-1, and AF-1 spaced along the North-South trend in the study area. The calibrated temperature data from the three wells agrees well with the modelled temperature, while there are slight variations in modelled Vitrinite data and the calibrated Vitrinite data in the three wells, especially during the Cenomanian-Turonian and late Maastrichtian. These variations suggest the influence of additional regional or localized heat flow during these periods. However, 1D temperature and maturity calibration data for well AO-1 (northern part) also indicates that the source rock is not yet thermally matured, which agrees well with the 3D model which indicates source unit in the northern part has not reached a maturity stage. The bulk generation and expulsion statistics shows that, at present day, 43070.94 Mtons of gas and 3839.53 Mtons of oil had been generated by both primary and secondary cracking processes, representing 91.81% and 8.19% of organic matter transformed into gas and oil respectively. The source rock has an expulsion efficiency of 0.77 on a scale of 1, which suggests good efficiency.

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3D NUMERICAL MODELLING OF HYDROCARBON GENERATION FROM THE BARREMIAN-APTIAN SOURCE ROCK UNIT OF THE NORTHERN ORANGE BASIN, SOUTH AFRICA.

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Introduction

Hydrocarbon-generation (Primary migration) and -expulsion (secondary migration) are part of the workflow of Basin and Petroleum system modeling (BPSM). However in this study, A 3D Numerical modelling of hydrocarbon-generation from the Barremian/Aptian source rock intervals encountered in the northern part of the Orange Basin was done using the Basin boundary conditions of Heat flow (HF), Sediment Water Interface Temperature (SWIT), and Paleo-Water Depth (PWD). The aim here is to investigate the thermal maturity of the source rock units, timing of hydrocarbon-generation and the volume of hydrocarbon already generated from the source rock units. Organic and thermal maturity data from three exploration wells(AO-1, AF-1 and AE-1) drilled within the most northern exploration block in the South Africa section of the Orange Basin are used for the model calibration.

Study Location And Geology

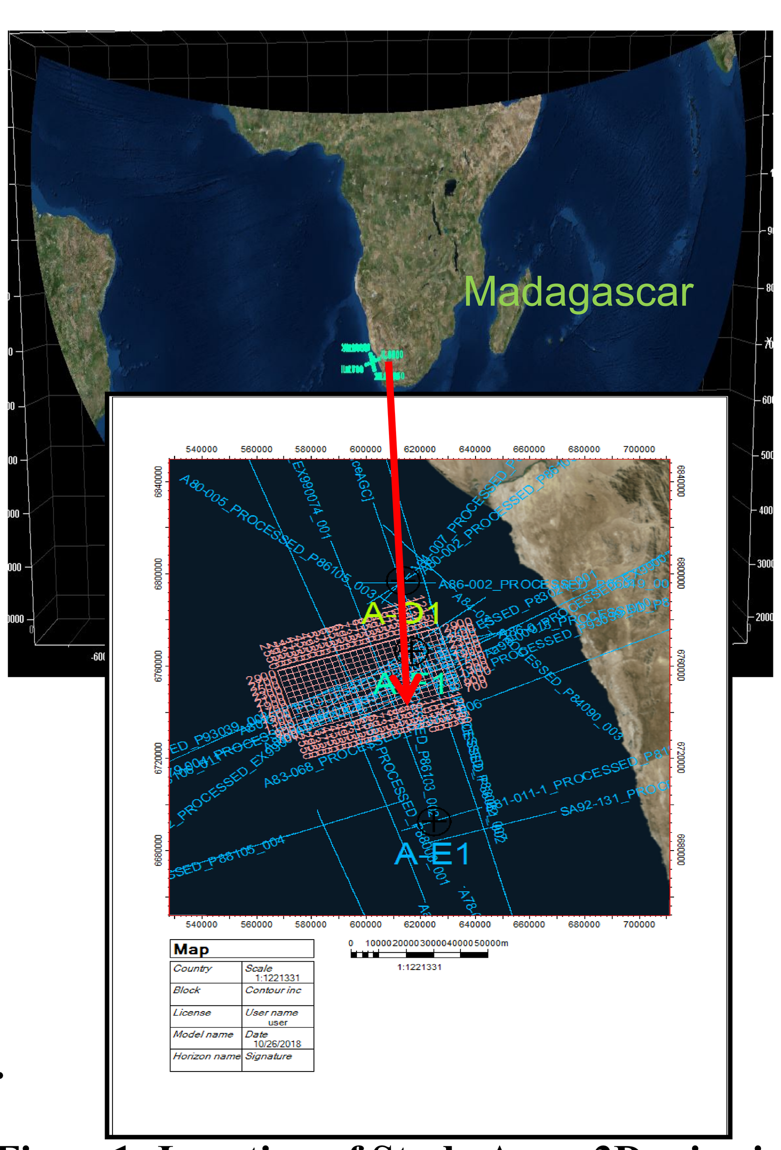


Figure1: Location of Study Area, 3D seismic volume in green grid and the three wells used for this study, offshore West Coast, South Africa

The Orange Basin is situated along the passive South Atlantic continental margin that straddles the borders of Namibia and South Africa (Hirsch et al., 2009). The architecture of the basin is defined by the Walvis Ridge in the north and Agulhas- Columbine arch in the south. Margin evolution was initiated by extensional forces that started in the early Mesozoic and culminated in rifting and drifting apart of the South American and African continents, in the late Jurassic and early Cretaceous.

The pre-rift basement rocks are overlain by a succession of Pre-Barremian, syn-rift basic lavas within the central rift sequence and coarse continental clastic, fluvial and lacustrine sediments, along with volcanic deposits within the marginal rift. These are in turn overlain by a Barremian to Post-rift succession of alternating fluvial and marine rocks that are deposited as a result of transgression and regression of sea level.

Methods

Boundary Conditions

Sediment Water Interface Temperature (SWIT):

The latitude of a sedimentary basin influences temperature variations during source rock deposition and more importantly influences the rate of geochemical reaction within a source rock unit. By estimating the present day SWIT, the past SWIT can be estimated using the Wygrala (1989) model for latitude 33S Orange Basin.

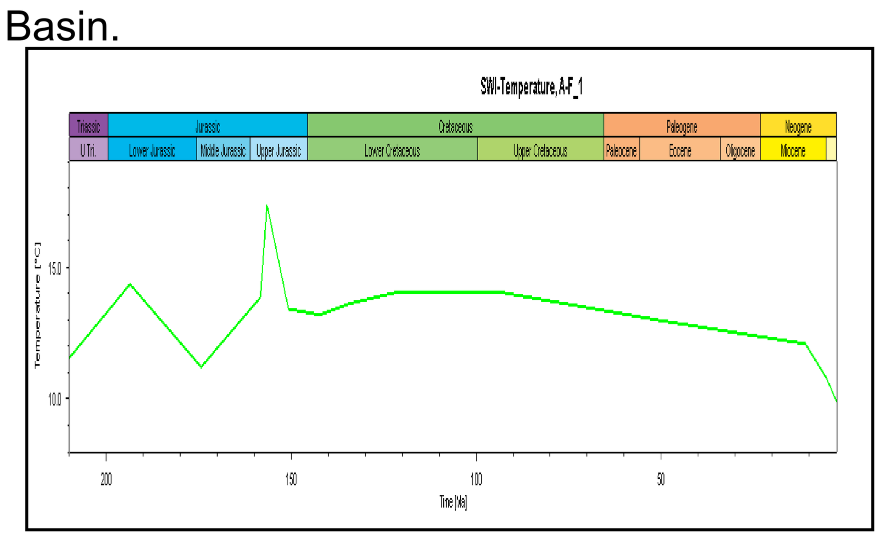


Figure2: Sediment Water Interface Temperature plot used for this study (Wygrala,1989).

Paleo-Water Depth (PWD):

The PWD was estimated by using the present day water depth to estimate paleo-water depth from the SWIT trend.

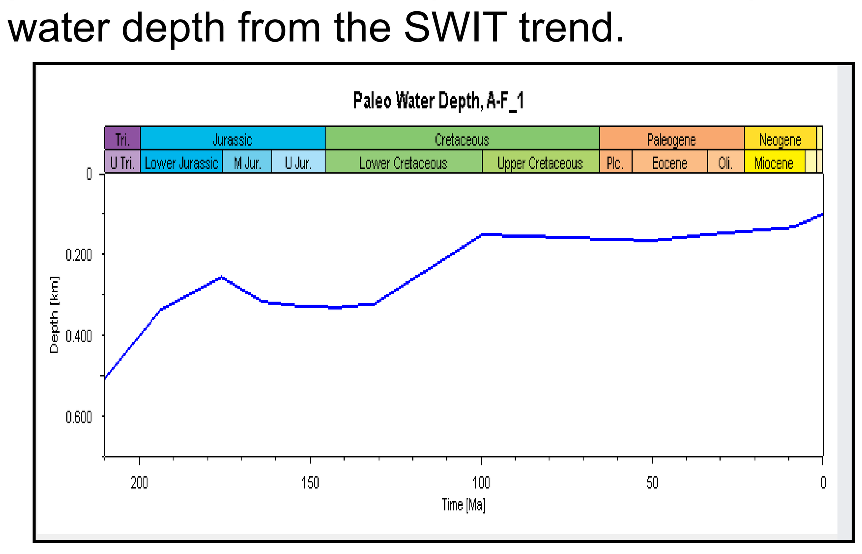


Figure 3: Paleo-water plot of the Orange Basin estimated from Wygrala (1989) model.

Heat Flow(HF)

Higher heatflow was taken into account during the break up and separation of the Africa and South America plates in the early Cretaceous, during the uplift of the late Cretaceous and the Miocene. The Mckenzie Heatflow model(1978) was adjusted for these events .

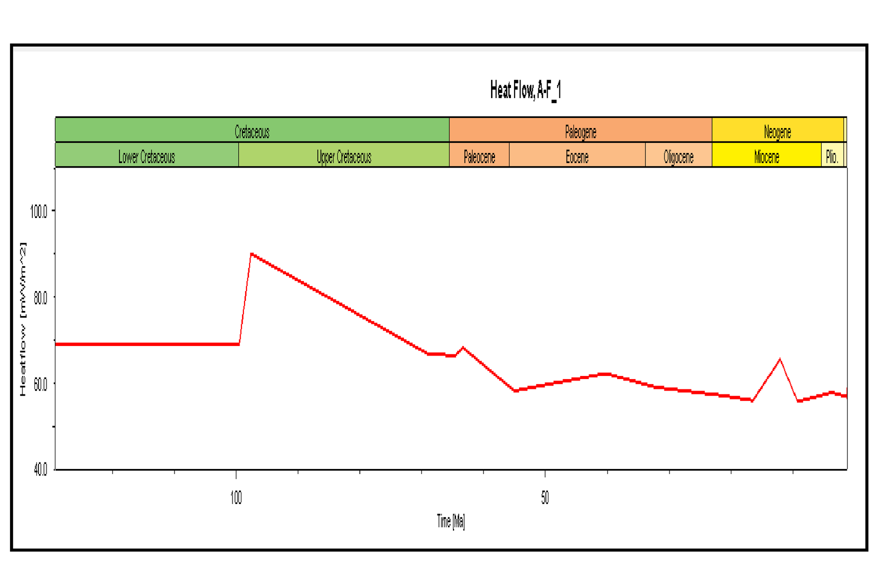


Figure 4: Heatflow model used for the study. Modified from Mackenzie Heatflow model for extensional basins.

Methods

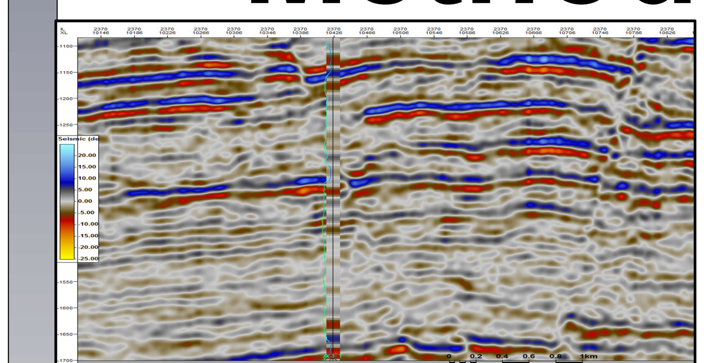


Figure 5

Seismic-Well ties for AF-1(Central part) prior to mapping of surfaces .

Table1 Model Input

Name	Color	Lithology Value	TOC Mode	TOC Value [%]	TOC Map	Kinetics	HI Mode	HI Value [mgHC/gTOC]	HI Map	Petroleum System Elements
sea floor_Facies_1		Sh25Ss70Si5								none
maastrichtian_Facies_1		Sh25Ss70Si5								none
Turonian_Facies_1		Sh70Ss25Si5	Value	3.00		Pepper&Corvi(1995)_TII(B)	Value	285.00		Source Rock
Ceno_Facies_1		Si70Ss25Sh5								none
seal_Facies_1		Sh70Ss25Si5								Seal Rock
Albian_Facies_1		Sh50Ss50								Reservoir Rock
Barremian_Facies_1		Sh70Ss25Si5	Value	0.60		Pepper&Corvi(1995)_TIIIH(DE)	Value	290.00		Source Rock

The Sekiguchi model (1977) was used for thermal conductivity, radiogenic heat calculated based on lithology using the Waples model (2004), and Athy's law (1930) was used for porosity prediction. In addition, the model described by Schneider et al., (1996) for prediction of chemical compaction of rocks was used, while multipoint model for permeability, bilinear equation to determine sealing properties and bulk modulus for rocks elasticity were used.

Results

Depth maps

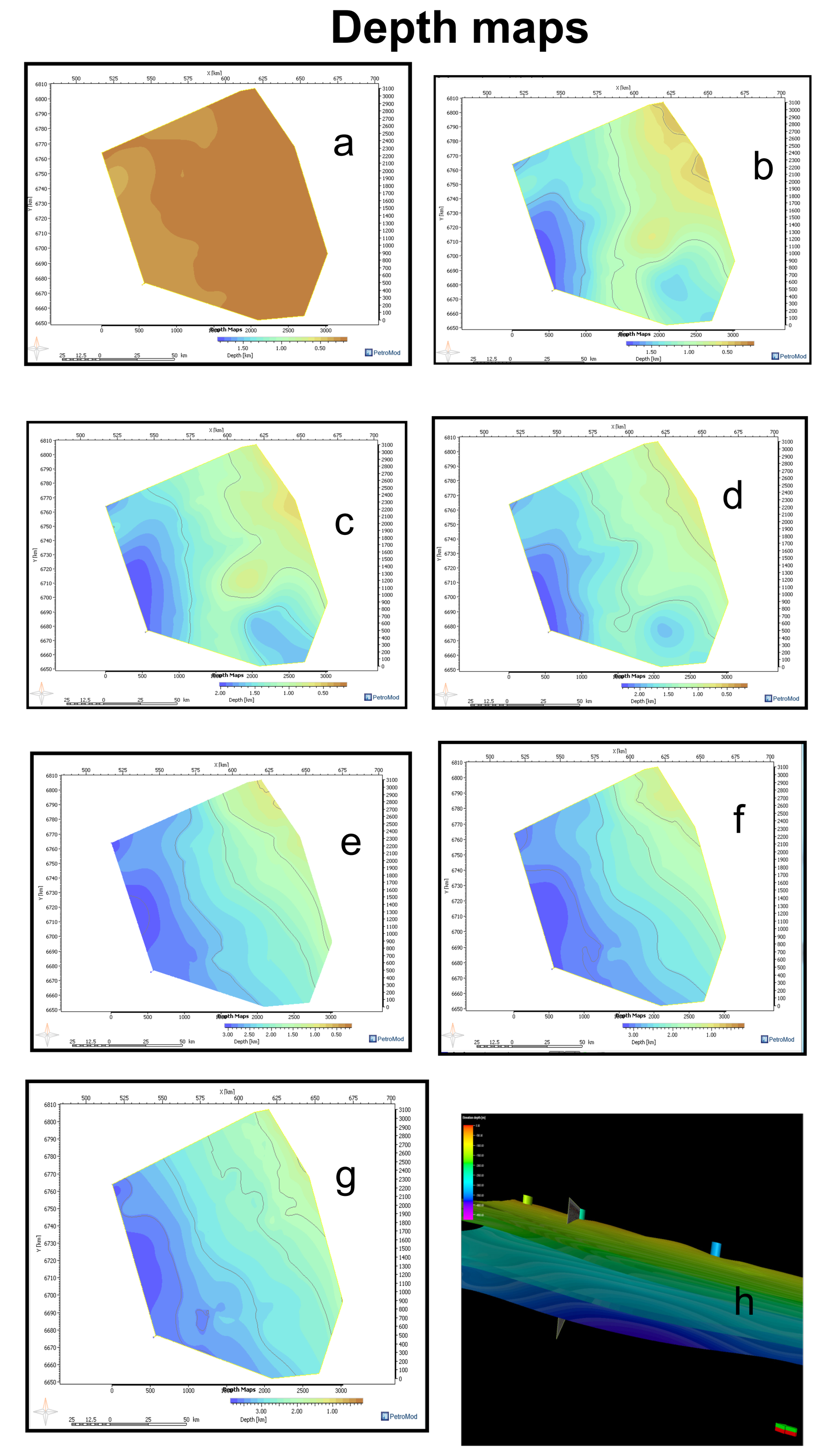
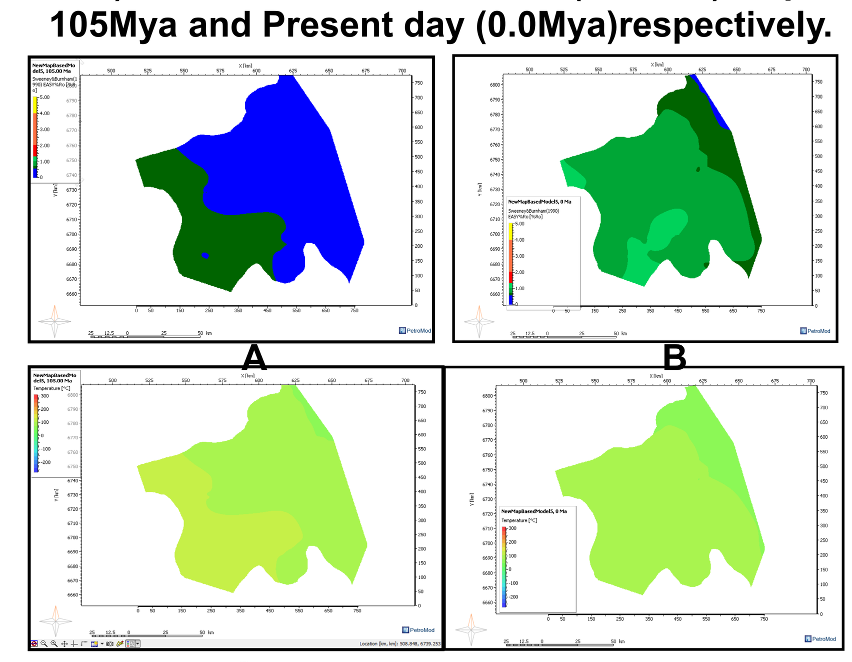


Figure 6: Sea Floor (a), Maastrichtian(b), Turonian(c), Cenomanian(d), late Albian (e), Albian (f) Barremian/Aptian source rock(g) and surfaces mapped with the three wells used for the study.

Vitrinite Reflectance (A and B), Temperature Index (C and D) and Transformation Ratio(E and F) Maps at 105Mya and Present day (0.0Mya)respectively.



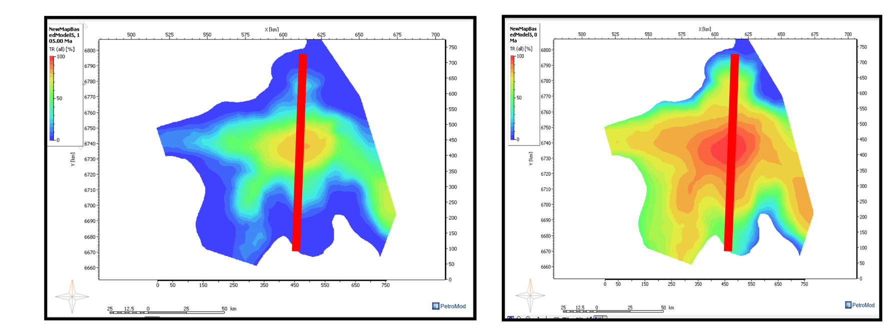
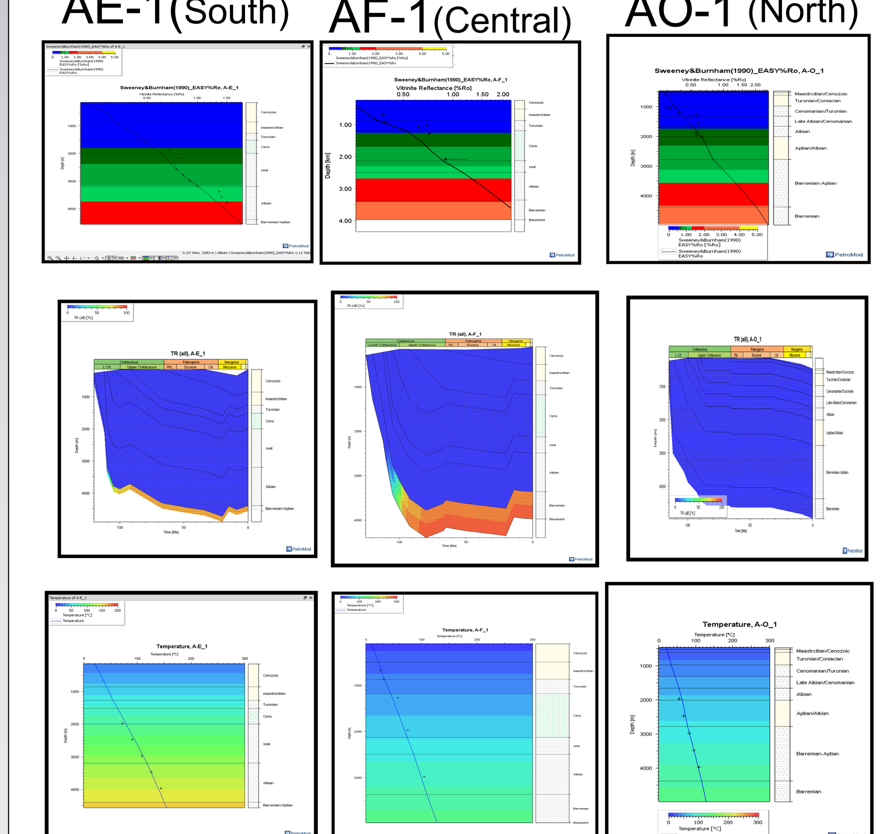


Figure 7(A-F)

Calibration of data (VR, TR and Temperature) with model from South-North.



Volume Generated and Timing of accumulation and expulsion.

The volume of hydrocarbon generated by primary cracking and secondary cracking (A). Peak accumulation in the source unit occurred during the Cenomanian while the late Cretaceous uplift might have influenced peak expulsion(B).

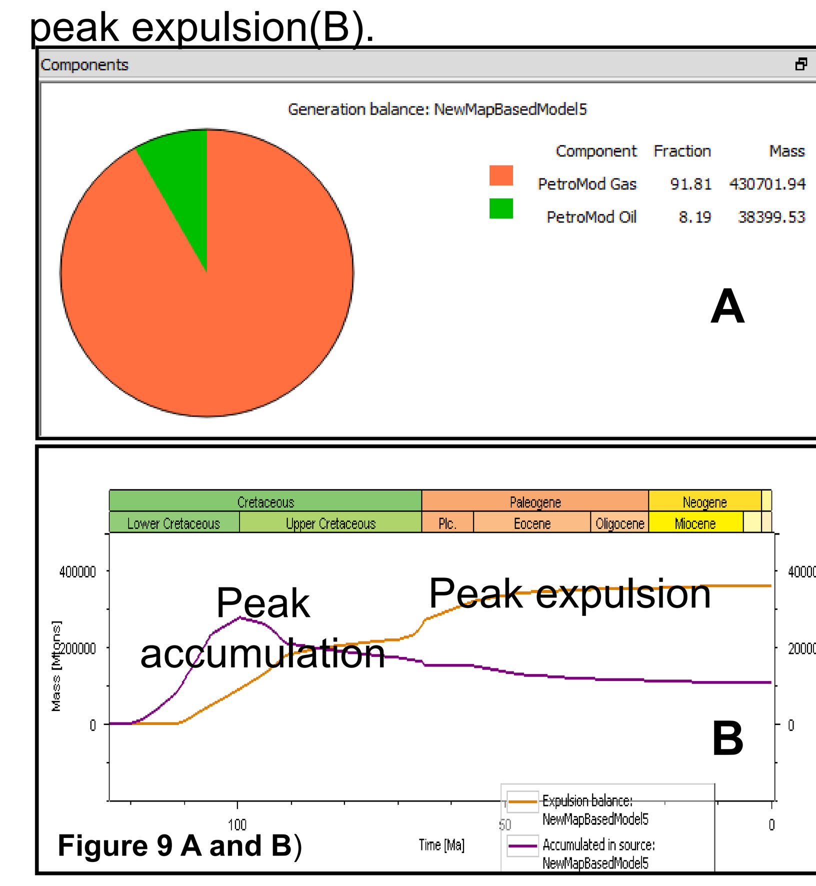


Figure 9 A and B)

Conclusions

The 3D model reveals that the source rock unit has reached a sufficient maturity stage, particularly in the central part as at present day. Hydrocarbon generation started as early as 105Mya, apparently because of high thermal conductivity as the Barremian/Aptian unit was deposited as graben-filled. 92% of hydrocarbon generated is gas while 8% is oil. The expulsion efficiency of the source rock unit is 0.77. The model suggest that the north-eastern section of the source unit is immatured. The VR values in well AO-1(northeastern section) calibrates well with the 3D model and indicates immatured source unit and a future potential for hydrocarbon transformation.

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