Breaking up is hard to do - using regional geophysics and multi-scale earth models for integrated basin analysis and pre-salt reservoir prediction in the south Atlantic

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Abstract

Regional potential fields data and digital elevation models provide critical input into multi-scale earth models and inter-disciplinary basin analysis to determine fundamental controls on pre-salt petroleum systems. Using both commercial and proprietary geophysical studies, we have constructed models from the global to the reservoir scale that predict the influence of plate tectonics, paleogeography, climate, and basement structure on pre-salt reservoirs in the south Atlantic.

Introduction

Stratigraphic modeling can be used to supplement seismic imaging for pre-salt reservoir prediction in the south Atlantic. The Cretaceous south Atlantic rift systems have significant stratigraphic heterogeneity resulting from variations in the fundamental controls on basin fill: tectonics, climate, and water-level.

Regional geophysical data and digital elevation models provide critical input into multi-scale earth models and inter-disciplinary basin analysis to determine fundamental controls on pre-salt depositional systems. Using both commercial and proprietary geophysical studies, we have constructed models from the global to the reservoir scale to better understand the influence of plate tectonics, climate, basement structure, and paleogeography on pre-salt reservoir distribution in the south Atlantic.

The nature of the break-up between the African and South American continents had a profound influence on pre-salt petroleum systems in the southern Atlantic Ocean. Complete continental break-up did not occur until latest Aptian (approx. 112 ma). Until that time, restricted conditions existed throughout the south Atlantic margins, with climate variations having more influence on depositional environments than eustasy.

Geophysical modeling and plate tectonic reconstructions constrain interpretations of both global and local paleogeography. Paleogeographic models, in turn, provide input to global climate and drainage models. Both regional and local controls on reservoir distribution can be understood using this integrated approach to basin analysis.

Geophysical analysis and plate tectonic setting

We mapped the Continent – Ocean Boundary (COB) throughout the conjugate margins of the south Atlantic using various enhancements of gravity data. Magnetic data was interpreted using Werner deconvolution to map general rift fabric, volcanics, basement morphology and depth. These data and interpretations were integrated with seismic interpretations to interpret the regional geological framework, and to construct basement, crustal and plate tectonic models to help us understand the nature of extension, volcanism and changes in plate motions. Continental extension was variable in time, space, and depth. A regionally extensive, long-lived high in the Sao Paulo Plateau prevented complete crustal break-up until the Early Albian. Prior to approximately 112 ma, the continents were still locked along the Santos / Namibe margin, as well as parts of the Equatorial Atlantic margins.

We used two different commercially available plate tectonic and paleogeographic models for quantitative input into multi-disciplinary basin analysis in the south Atlantic. Additionally, we have studied three public domain plate models. While there are significant regional differences in these plate models, some general conclusions about the timing and nature of continental break-up are consistent, regardless of the model used.

Paleogeographic Modeling

GETECH's South Atlantic Geodynamics and Petroleum Geology study as well as other licensed geophysical data were used to understand regional paleogeographic controls on deposition. From latest Barremian to Aptian, prior to ultimate break-up, a mega-regional depositional fairway existed between the Romanche fracture zone to the north and the Walvis Ridge to the south. Rift tectonics set the stage for both source and reservoir distribution along the conjugate margins. The early rift stage was dominated by volcanics and continental siliciclastics overlain by lacustrine carbonates and shales. Seismic and magnetic data were interpreted to map and restore local basins that were separated by dominant rift-related topography and volcanic centers, creating a "fill and spill" drainage pattern along an axial system.

In late Aptian, changes in plate motions, depth-dependent stretching, and sub-aerial volcanism associated with an emergent spreading center, led, in some cases, to very wide "hyper-extended" margins with extensive, partially restricted, hyper-saline, sag basins, formed near base level, where both the source and reservoir rocks for the prolific pre-salt plays were deposited.

Once full ocean circulation was established in the Albian, open marine conditions existed along the entire conjugate margins, with eustasy controlling depositional environments.

Plate tectonics, rift geometry and fault timing have setup basin configurations and played an important role in the evolution of pre-salt depositional systems. However, the mega-scale stratigraphic heterogeneity along these systems can be best explained by climatic variations.

Climate Modeling

Our geophysical mapping of the COB identified a number of continental land-locks that existed throughout the Aptian, creating partially restricted conditions between the South American and African continents. During this time, latitudinal paleoclimatic zonation and climate cyclicity played a more critical role in controlling local lake-levels than global sea-level changes.

To determine both regional and local controls on source and reservoir distribution, paleogeographic models and digital elevation models provide input to global paleoclimate and mega-regional drainage models. Fast ocean atmosphere climate models (FOAM) were run in conjunction with Cretaceous paleogeographic reconstructions from the PaleoMap project to constrain the climatic regime in the South Atlantic at key time intervals. Several model runs were made at precession-scale end-member conditions to capture potential variability in the climate system. For the purpose of regional basin analysis, our study focused on evaluating surface temperature, precipitation, river runoff, runoff to ocean, and Koppen climate classes. Runoff was calculated from the FOAM simulation (precipitation minus evaporation, soil moisture and infiltration) in conjunction with drainage basins calculated directly from paleotopography.

Results

Model output revealed the likely presence of a large tropical axial drainage system that fed the northern end of the rift system and a series of smaller transverse inputs. This dominant axial source has allowed for potential fill and spill along the rift system with periodic output depending on water balance and basin configuration.

Figure 1 shows an example of compiled climate data for one paleoclimate end member, "Hot Southern Hemisphere Summer". The Aptian axial drainage basin occupied a large area in the tropics while the transverse drainage basins had smaller areas located in temperate, semi-arid, and arid climate. As a result, the volume of the axial river drainage is significantly larger than the volume of the transverse (local) drainage.

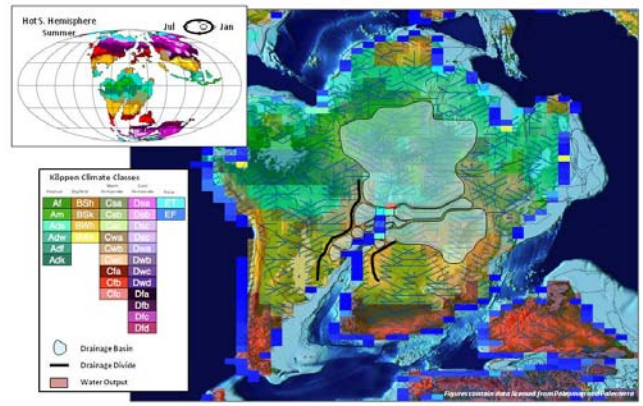

FIG.1 – Example of continent-scale compiled analysis, Koppen climate classification, drainage, and run-off, "Hot S. Hemisphere Summer"

Precipitation was much greater in the tropics at the northern end of the rift system. The southern basins had limited input from local transverse rivers, and therefore had net evaporation during periods of the Aptian. Evaporite volume also increased to the south, while siliclastic input decreased from north to south.

Persistent semi-arid/arid conditions and the resulting water balance explains the presence of extensive carbonate intervals in the Campos and Santos Basins.

Geophysical mapping demonstrates that these carbonate platforms were underpinned by syn-rift basement highs, as shown in Figure 2.

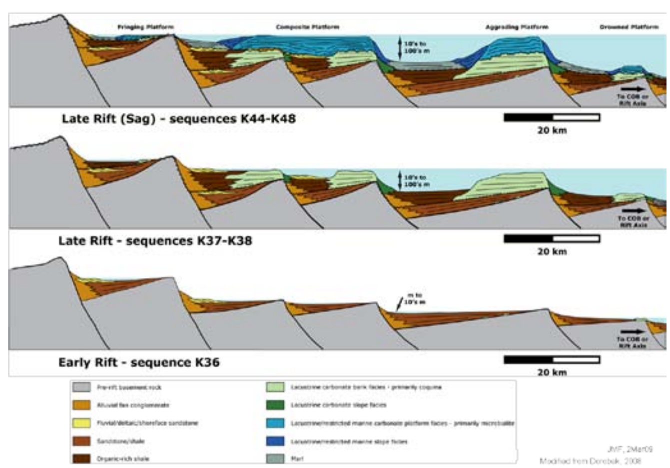

FIG.2 – Pre-salt Depositional Model

There were significant seasonal and orbital cycle variations in climate and run-off. Total run-off varied by twelve percent from the maximum climate extreme ("Hot Equinox") to the minimum ("Hot Northern Hemisphere Summer"). The variability between "Hot Equinox" and "Hot Southern Hemisphere Summer" was 10%. Most of the run-off variability comes from the axial system alone.

However, there is a significant sixty percent difference in transverse run-off between climate extremes.

The carbonate platforms in the south were frequently sub-aerially exposed due to significant seasonal and orbital cycle variations in climate and run-off.

Application to offshore southern Brazil

Offshore Brazil, in both the Campos and Santos basins, pre-salt depositional systems were dominated by carbonate platform trends underpinned by basement highs; however, significant differences in depositional environments resulted from differences in the underlying basement morphology and rift tectonics of each basin, and these differences can be seen in our geophysical interpretations. The Campos carbonate platform was formed on a basement high connected to the rifted craton. As a result, the Campos Basin Pre-Salt has a complex mixing zone of siliciclastic and carbonate sediment. The carbonate platform in the Santos basin formed over an outer basement high resulting from extreme crustal asymmetry in the Santos rift system. The Santos platform was therefore isolated from significant siliclastic input.

Conclusions

Integrated basin analysis has proven to be an important technique for play prediction. Potential fields and seismic data provide fundamental constraints to plate tectonic, paleogeographic, climate, and stratigraphic models. Our workflow integrates mega-regional to pore-scale geophysics and geological observations with quantitative modeling to better understand the evolution of the prolific South Atlantic pre-salt petroleum systems.

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