Th D 07

Evidence for a More Complex Crustal Setting Offshore Gabon: Support from a High-Resolution Regional Seismic Dataset Int

P. Martinez Duran* (CGG, Geoconsulting), M. Pearsons (CGG, Multi-Physics Imaging), W. Soyer (CGG, Multi-Physics Imaging), G. Duval (CGG, Multi-Client and New Ventures)

Summary

A high-resolution regional seismic, gravity and magnetics dataset was acquired offshore southern Gabon, which allowed an in-depth and integrated approach for analyzing the crustal setting in this area. Detailed analysis of the datasets available, and 3D modeling of the crust over this region, suggests that a more complex crustal setting than previously discussed in papers using either long offset 2D seismic, or detailed prospect scale 3D seismic datasets. Placing this information into the framework of the mega-regional publicly available gravity and magnetic datasets provides insights into the possible relationships between the changing upper and lower plate crustal settings experienced at different times in this area.

Introduction

The study area is located at the African margin of the central segment of the South Atlantic. Because of the absence of seaward-dipping reflectors (SDR) in the central segment, the scientific literature has defined the offshore of Gabon as a non-volcanic passive margin. The high-resolution regional seismic, gravity and magnetics dataset available for this study allowed an in-depth and integrated approach for analyzing the crustal setting in this area. Detailed analysis of the datasets available and 3D modeling of the crust suggests that the structures and tectonic evolution is more complex than previously described in this area. Identification of some of the important tectonic structures for understanding the timing and evolution of this basin are outlined below.

Geophysical data

The primary dataset used in this study is the result of a large-scale multi-client seismic survey where marine magnetic and gravity data were acquired concurrently. The high-resolution broadband seismic data benefitted from variable-depth streamer BroadSeis acquisition and long offsets over a 25,000 km2 area. The final output PreSDM (Pre-Stack Depth Migration) extends to a depth of 20 km in order to enable modeling of deep crustal features. Having concurrently acquired gravity and magnetic data provided detailed anomaly maps for use in the 3D potential fields modeling.

Having high-resolution seismic imaging to 20km forming a 3D dataset over a large regional area allowed regional trends in the deep crust to be illustrated, and these were tied with detailed analysis of the sedimentary layers in 3 dimensions. Previous work has used long offset 2D lines in a regional network, or detailed 3D seismic surveys of more prospect level dimensions. This dataset provides the benefits of a high resolution 3D seismic survey and allows for 3D regional imaging of the deep crust.

Well data was available for a number of wells within the survey area, and these data were used both in the seismic imaging, as well as in the conversion of seismic velocity volumes to calibrated density volumes for the gravity modelling.

Regional public domain datasets were also important in the study. Public domain EMAG2 magnetic data and satellite derived gravity datasets were evaluated to determine whether trends in the study area could be related to large-scale structures resulting from the Atlantic spreading. These data were used as a framework within which the detailed modelling with the high-resolution data could occur.

Structural Framework

The opening of the South Atlantic Ocean and the nature of this extension is the subject of numerous papers as modern seismic data is continuously showing deeper and more detailed images of the crust.

The broad variety shown in most recent literature has revealed the discrepancy amid different research teams in the study area covered by the 3D Gabon data. From a lower-plate extensional model to being on the boundary between an upper plate to lower plate margins (Lister et al. 1986) because of a sharp transfer zone from (Peron et al. 2015) or defined as indefinite/uncertain for classification as “magma-poor” or “magma-dominated” margin (Reston. 2009). The geometry of extensional faulting in the upper lithosphere and how continental ribbons fit within this structural framework is another debated topic. The high resolution CGG BroadSeis 3D seismic data aims to shed light on these questions on the tectonic context in the offshore of Gabon.

Methodology

Initially 2D models were constructed throughout the area to better understand the structures seen at in the crust with the seismic. In many areas the Moho was distinctly evident, in others there was evidence of geobodies within the crust. The 2D models were used to quickly test various geological scenarios, but it was evident that to properly model these structures, 3D modelling would be required.

The key surfaces used within the 3D model were: bathymetry, top of salt, base of salt, depth of 100% certain sediments, depth of meta-sediments, depth of basement, intra-crustal boundary, and Moho. These surfaces were chosen primarily for density contrasts, but in the case of the 100% certain sediment horizon, the layer was used to constrain any inversions for basement depth from rising into an area where the seismic clearly showed sediments. Densities for the deeper crustal layers were derived from literature and public domain datasets. For the sedimentary layers, a well and seismic velocity derived sediment density voxet was used.

Magnetic depth estimates were performed to obtain depths to magnetically susceptible material. During the inversions for basement and crustal features, these estimates were used to calibrate and verify the results. The 3D Euler results also provided important information on crustal changes through the 3D area.

Using the constraint from the seismic and magnetics, 3D gravity inversions were performed over the model area, and maps of the thickness of the crust and the depth of Moho were produced. On the western side of the study area, there was some difficulty in determining the extent of the continental-oceanic transition zone. Thinning of the crust was observed shoreward of a portion of the high density crust that was modelled in the gravity as thicker and still lighter than oceanic crust (Figure 1).

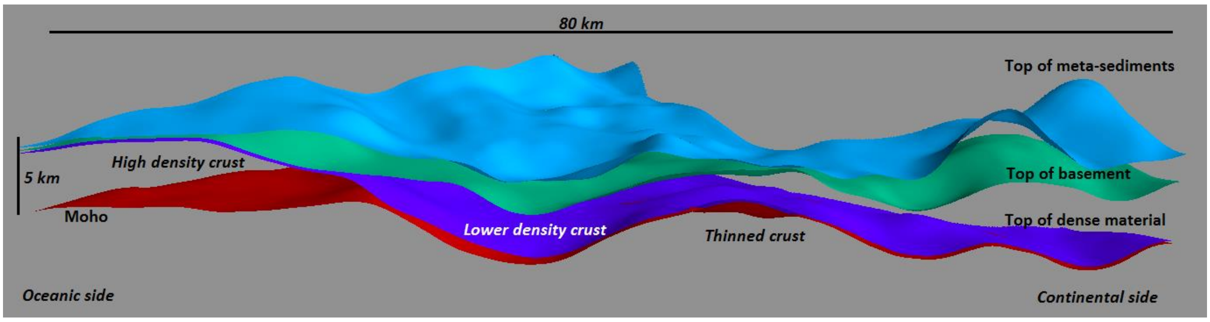

***Figure 1** Slice through the 3D crustal gravity model.*

Results

Both the seismic and the gravity data suggested a fragment of more continental style crust in the western edge of the study area. The magnetic data did not show strong signals on the western side where continental crust is modelled by the gravity, though there did appear to be strong responses directly to the east of this area, and in the eastern region of the study area in general.

The regional gravity and magnetic data sets were analyzed for evidence of fracture zones that might explain why the west and eastern areas of the study area had different magnetic characteristics, and produced different crustal structures from the 3D gravity modelling. By integrating structures seen in the mega-regional datasets with more detailed structures seen in the marine gravity and magnetic data sets, the hypothesis that a continental ribbon could exist on the western side of the study area was proposed. The seismic interpretation was able to observe structures both on a larger scale (extensional upper plate faulting) and smaller scale (sediment drainage patterns) which could support this.

Unlike in Peron et al. (2015), the structural geometry showed by the 3D seismic dip-lines outlines an upper-plate margin model with a clear regional décollement detaching from where Moho's ramp reaches its shallowest points underneath the hyper-extended salt basin (Figure 2). This detachment levels off underneath the hyper-extended continental crust where the thickest section of the allochthonous salt is recorded. Large extensional faults rooted from this main detachment create the thinning of the continental crust (Figure 2). In some areas, it is still possible to describe a symmetric faulting, recalling to the first stages of pure shear extension. Embrittlement of the lower-middle crust increases coupling between the upper and lower crust, coinciding with areas where exhumations seem more plausible. The development of this set of detachments can be related to areas of possible serpentinization of the mantle (Reston, 2009).

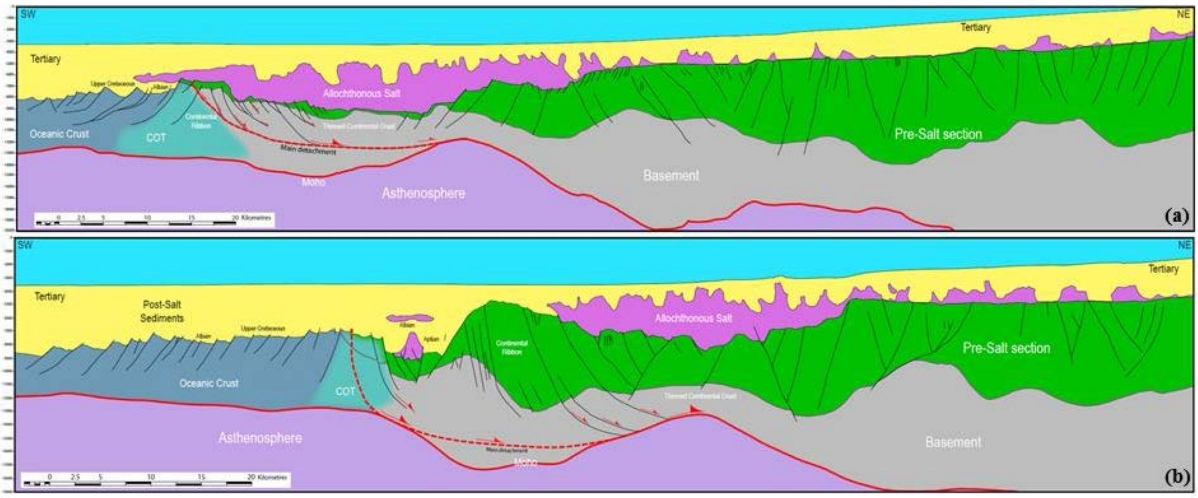

Figure 2 *Seismic lines showing the continental ribbon severely eroded (a) and with a prominent topographic relief (b). The large extensional faults rooted into the main detachment - red dash line above Moho- are thinning the continental crust and breaking down the ribbon.*

The continental ribbon described in the west of the survey acts as an important deflector of the movement of the salt tongue oceanward (Figure 2b). The large extensional faults thinning the continental crust break it down, giving rise to areas with much less topographic relief in the ribbon (Figure 2a). Unlike other areas along the salt basin, Moho deepens under this feature as seen in the grav/mag model, making the ribbon more buoyant than its nearby features. Where this continental ribbon preserved a prominent relief (Figure 2b) the seismic data shows a radiating drainage pattern rooted from an elongated NW-SE watershed. This drainage could be caused by the sub-aerial exposure of this continental ribbon by buoyancy during the Albian as being surrounded by the denser oceanic and hyper-extended or exhumed areas.

Another important feature observed in the seismic data is the presence of strong reflectors parallel or sub-parallel to Aptian-Albian sediments. These strong reflectors most probably correspond to intruded volcanic material. Magnetic depth estimates also provide support for this observation of magnetic material within the sedimentary column. Hence, in the Gabon margin it may be more appropriate to use the terminology of "magma-poor" as opposed to "magma-dominated" (Sawyer et al. 2007 and Reston, 2009) rather than "non-volcanic" or "volcanic" margins. These two above-mentioned considerations lead to a more suitable label for the study area as a hyper-extended magma-poor margin, where first order features indicative of an upper-plate margin can be observed.

Conclusions

Integrated high-resolution datasets covering a large area offshore southern Gabon provided the opportunity to study the correlation between sedimentary 3D features and deeper crustal trends. Interpreting the seismic data with a 3D gravity and magnetic model allowed various tectonic scenarios to be tested, and hypotheses for new structural frameworks to be proposed. One of the important observations was the possibility of a more complex crustal setting than previously discussed in papers using either long offset 2D seismic, or detailed prospect scale 3D seismic datasets. A main detachment underneath the hyper-extended basin is branched by large extensional faults and governs the extension and the existence of a continental ribbon in the western offshore area. This correlates with previously proposed mechanics of an upper plate crustal setting. Placing this information into the framework of the mega-regional publicly available gravity and magnetic datasets provides insights into the possible relationships between the changing upper and lower plate crustal settings experienced at different times in this area.

References

Clark, D.A. [2012]. New methods for interpretation of magnetic vector and gradient tensor data I: eigenvector analysis and the normalised source strength. Exploration Geophysics, 43 (4), 267-282.

Clerc, C., J-C Ringenbach, L. Jolivet and J-F Ballard [2017]. Rifted margins: Ductile deformation, boudinage, continentward-dipping normal faults and the role of the weak lower crust. *Gondwana Research*, (in press).

Granot, R. and Dyment, J., [2015]. The Cretaceous opening of the South Atlantic Ocean. *Earth and Planetary Science Letters*, **414**, 156-163

Lister, G.S., Etheridge, M.A. and Symonds, P.A. [1986]. Detachment faulting and the evolution of passive continental margins. *Geology*, **14** (3), 246-250.

Meyer, B., R.Saltus and A. Chulliat [2016]. EMAG2: Earth Magnetic Anomaly Grid (2-arc-minute resolution) Version 3. National Centers for Environmental Information. NOAA, Model, doi:10.7289/ V5H70CVX.

Parsons, M., P. Martinez Duran, W. Soyer and G. Duval (CGG), 2017, Understanding the tectonic history offshore Southern Gabon with high resolution seismic, gravity and magnetics, *First Break, Vol. 35, September 2017.*

Pérez-Díaz, L., and Eagles, G., [2017]. A new high-resolution seafloor age grid for the South Atlantic. *Geochemistry, Geophysics, Geosystems*. **18** (1), 457-470.

Péron-Pinvidic, G., Manatschal, G., Masini, E., Sutra, E., Flament, J.M., Haupert, I. and Unternehr, P. [2015]. Unravelling the along-strike variability of the Angola-Gabon rifted margin: a mapping approach. *Geological Society, London, Special Publications*, **438**, 49-76.

Reston, T.J. [2009]. The structure, evolution and symmetry of the magma-poor rifted margins of the North and Central Atlantic: A synthesis. *Tectonophysics*, **468**, 6-27.

Sandwell, D.T., R.D. Müller, W.H.F. Smith, E. Garcia, R. Francis, [2014]. New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. *Science*, **346** (6205), 65-67.

Sawyer, D.S., Coffin, M.F., Reston, T.J., Stock, J.M. and Hopper, J.R. [2007]. COBBOOM: The Continental Breakup and Birth of Oceans Mission. *Scientific Drilling*, **5**, 13-25.

Seton, M., Whittaker, J.M., Wessel, P., Müller, R.D., DeMets, C., Merkouriev, S., Cande, S., Gaina, C., Eagles, G., Granot, R., Stock, J., Wright, N., and Williams, S.E. [2014]. Community infrastructure and repository for marine magnetic identifications. Geochemistry, Geophysics, *Geosystems*, **15** (4), 1629–1641.