Shallow water 3D in South Gabon: a new generation of hydrocarbon prospects

Paolo Esestime[1*], David Eastwell[1], Karyna Rodriguez[1] and Neil Hodgson[1] challenge established exploration techniques in South Gabon by revealing new targets and prospects in modern 3D seismic data.

Introduction

Global exploration has seen a dramatic upturn in 2018, with close to 4 billion barrels of oil equivalent discovered in the first half of the year alone, and many exciting wildcat wells still to come. Although the oil price slide of 2014 changed the industry, with the focus now on commerciality and risk reduction, it is of interest that most of the new discoveries this year have been made in commercially challenging deep water. The reason for this is that our industry has been exploring shallow-water oil-prone basins since the invention of marine seismic methods in the 1950s, and they appear now to be 'mature' and depleted in material low-risk opportunities. Indeed the future of shallow-water exploration has been portrayed as binary: either mopping up around what we know or exploring new frontiers. However, in South Gabon we challenge the established idea that after 50 years of exploration the basin is mature, by revealing a new generation of prospectivity with modern 3D acquisition and processing (Figures 1 and 2). The play primarily chased so far has been the Gamba Sandstone play, the seismic imaging of which has always been a significant challenge, owing to the complex velocities in the post-salt geology, the heterogeneity and the halokinesis of the Ezanga Salt. Yet with the exception of the Muruba-2 discovery, few wells have deliberately targeted the syn-rift section below the Gamba, leaving the pre-salt section completely unexplored (Figure 1).

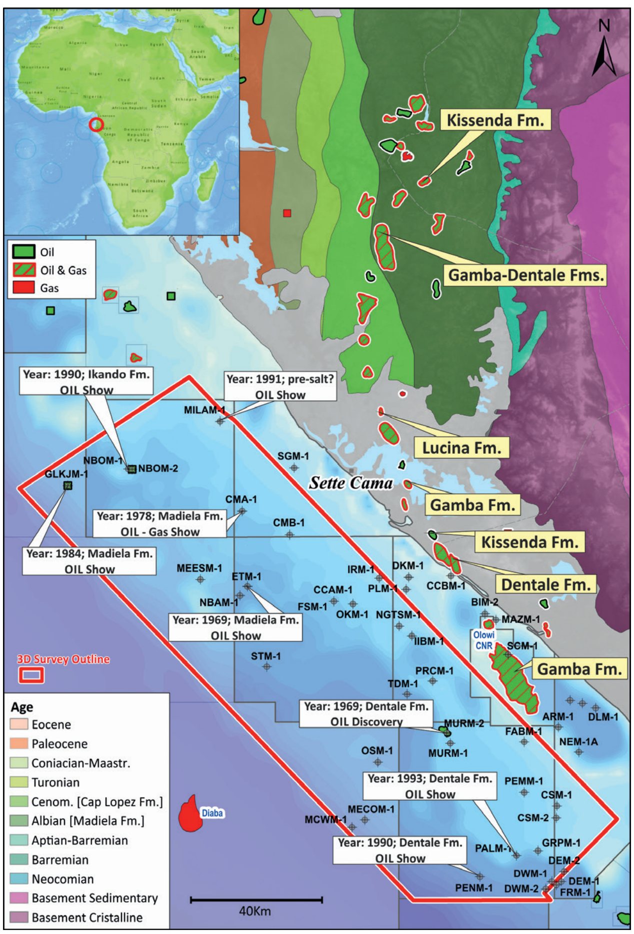

Figure 1 Map showing Spectrum`s 3D seismic survey in the shallow water of South Gabon. The figure summarizes the hydrocarbon exploration targets in both onshore and offshore (IHS data). Fields, discoveries and wells have been labelled according to their reservoir levels and exploration targets. The geological map of South Gabon (Thomas et al., 2001) has been integrated to correlate the structural trends from the outcrops and the distribution of the hydrocarbon fields/discoveries, both oriented N-S and NW-SE.

Diligent planning and acquisition (Esestime et al., 2017, 2018) of 3D data in South Gabon covering an area eight times the size of Greater London (11,500 Km^2), has enabled an imaging veil to be lifted. The intra-syn-rift is now visible and is revealing large-scale hydrocarbon prospects, capable of attracting interest from global exploration players (Figure 3).

Exploration geology background

In South Gabon, 50 years of exploration has resulted in a long history of success in the onshore area, where many discoveries have been successfully developed. This exploration proved the hydrocarbon potential of Lower Cretaceous syn-rift units. Several reservoir levels are present in sands from the Neocomian to the Aptian, laterally and vertically juxtaposed with a number of source rocks which also act as seals (Teisserenc and Villemin, 1990; Mounguengui and Guiraud, 2009).

The historical Gamba play consists of Mid-Aptian early sag post-rift marine transgressive sandstone, deposited after the erosion of the lacustrine syn-rift clastic deposits of the Dentale Formation. The Gamba Sandstone displays high porosity and permeability, and is almost totally sealed beneath a thin, high-TOC

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shale (Vembo Fm.), overlain by Late-Aptian evaporite (Ezanga Fm.). Charge is provided by the underlying Barremian syn-rift lacustrine source rock (TOC>6% in the Melania Fm.) at the base of the late syn-rift. As the Early Aptian Dentale sequence between the Melania source and the Gamba is often dip-divergent, a ready migration pathway exists in the Gamba Sandstone.

In the shallow water offshore, hydrocarbon exploration has attempted to extend the onshore discoveries with limited success. Until recently, exploration was blind below base salt, owing to the complexity of geology and limitations of available seismic imaging technologies.

The Gamba play has remained the main objective of exploration in South Gabon where a number of discoveries and fields were generated, such as Etame (1998), Olowi (2001), Ruche (2011) and Tortue (2013). The hunt for large discoveries, combined with advances in deep-water drilling has resulted in the latest discoveries in the sub-salt play: gas/condensate in the Diaman-1B well (Total, 2013), Leopard (Shell, 2015) and Oil in the Boudji-1 well (Petronas, 2018).

However, with one exception, intra-syn-rift play in South Gabon has remained unexplored. This has been highlighted at a more regional scale by numerous recent discoveries to the south west of Gabon in Congo. The discoveries in the pre-salt/intra syn-rift play of the Neocomian Djeno Formation (Nkala and Nene Marine) are equivalent to lower syn-rift in Gabon (Kissenda Fm).

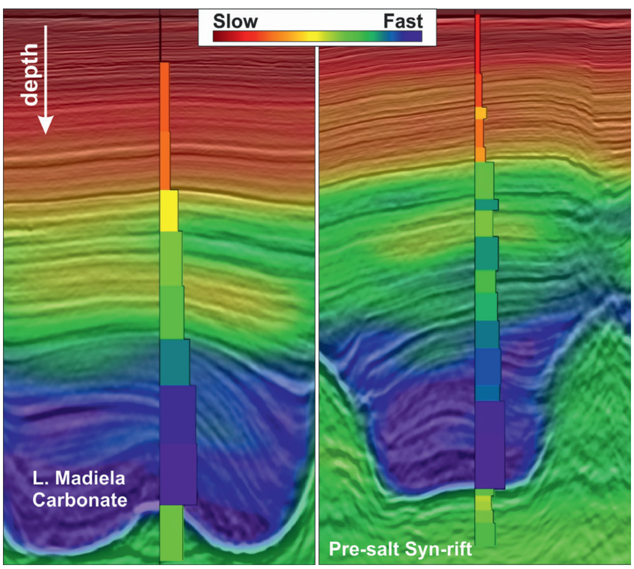

Figure 2 The panels correlate the final interval velocity field (6th Tomographic Update) and the raw well velocity profiles. Final Kirchhoff PSDM in the background.

Subsalt imaging challenges

The subsalt imaging challenges in South Gabon are mainly related to the difficult attenuation of multiples and the high seismic velocities present in the Madiela carbonate and in the salt bodies. Those units often have irregular geometries, which generate scattering and diffractions, hard to suppress with migration algorithms. These problems are worsened by the low acoustic impedance contrast in the subsalt and the high vertical and lateral variability, characteristic of a continental lacustrine environment controlled by the active tectonics of the syn-rift (Esestime et al., 2017, 2018).

Accurate velocity modelling has proven to be effective in mitigating imaging issues related to pre-stack depth migration (PSDM). The deep understanding of the geology and related seismic velocities was possible using the well data made available by the Gabonese Authorities (DGH) for this purpose. The velocity field accounted for the main seismic/lithological intervals and their response from the gathers, removing unwelcome RMO (Residual Move Out). Such a high level of detail was reached through six iterations of reflection tomography, which accompanied even more depth migration tests (Kirchhoff PSDM). In order to improve the pre-salt imaging, the velocity modelling focused mostly on the post-salt units, where the good reflectivity of the Madiela carbonate, breaking those into velocity intervals, highly consistent with the several carbonate sequences (Figure 2). The velocity floods were avoided in the post-salt, preventing potential artefacts related to the interpretation. As best practice, the use of horizons has been limited

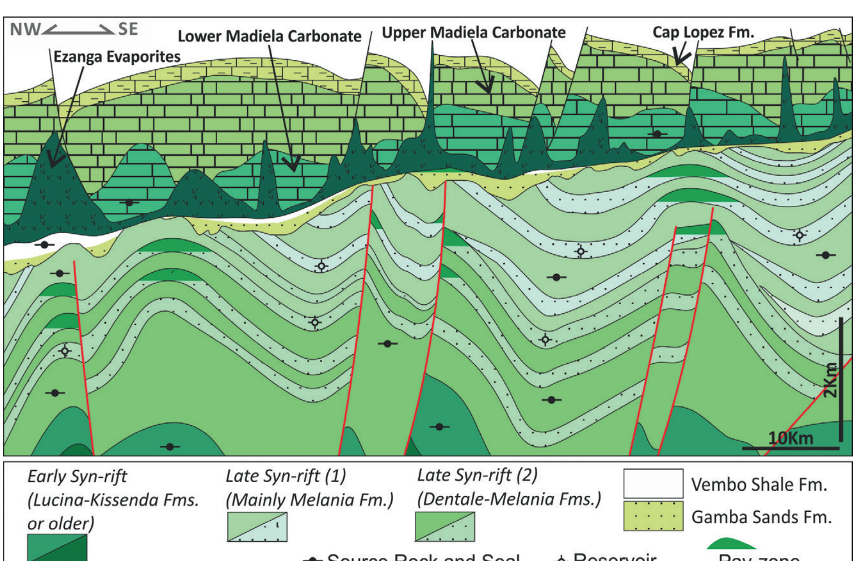

Figure 3 Geological sketch and petroleum systems of the pre- and post- salt section in South Gabon. Several types of structural traps and hydrocarbon pay zones are illustrated in the pre-salt section.

to a regional guide, to improve regional consistency in the velocity field, by creating a final seamless product through the 11,500 km^2, and an excellent level of detail at all well locations. Well tie and anisotropic corrections were performed during the tomographic iterations. The final test of the velocity model showed values of depth mistie at no more than 1-2% at the Madiela carbonate and the base salt (Figure 2).

Kirchhoff PSDM and Reverse Time Migration (RTM) algorithms have been tested with the final velocity field. The two algorithms provided complementary depth images. The Kirchhoff PSDM boosted the level of detail in the salt and post-salt intervals, already enhanced during the broadband processing, while the RTM, band limited at 30Hz, was set to target the pre-salt image, resulting in an unprecedented good S/N ratio with continuous and consistent horizons, increasing confidence in the generation of syn-rift prospects.

De-risking syn-rift targets and prospects

In 1981, an extraordinary well was drilled by Total in this area: the well Muruba Marine -2 (MURM -2). Although only oil shows were present in the Gamba (at which level we see now that there is no closure), this well flowed oil at a good rate from an intra-syn-rift reservoir (Figures 4B and 5). Yet, even 3D data acquired 20 years after this discovery shed little light on the size of the

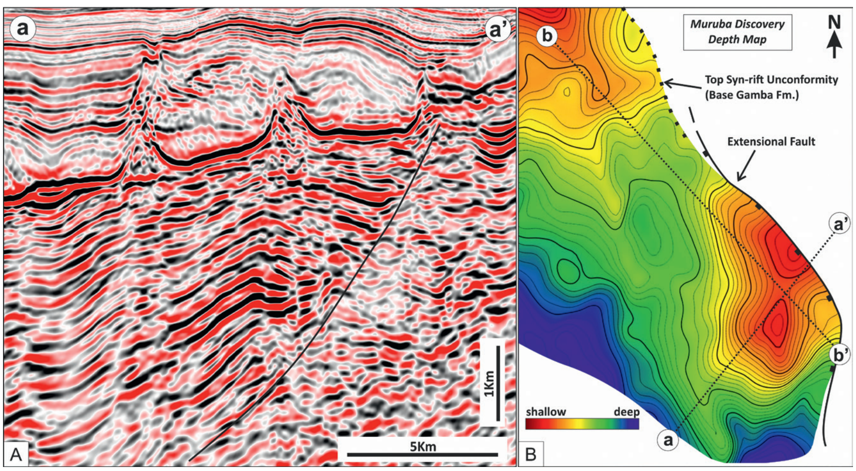

Figure 4 A) Arbitrary line depth section a-a', extracted from the 3D RTM Volume showing the structure tested by the wells Muruba -1 and Muruba -2. B) Depth map generated at the discovery targets in the well Muruba -2 (Dentale Fm.).

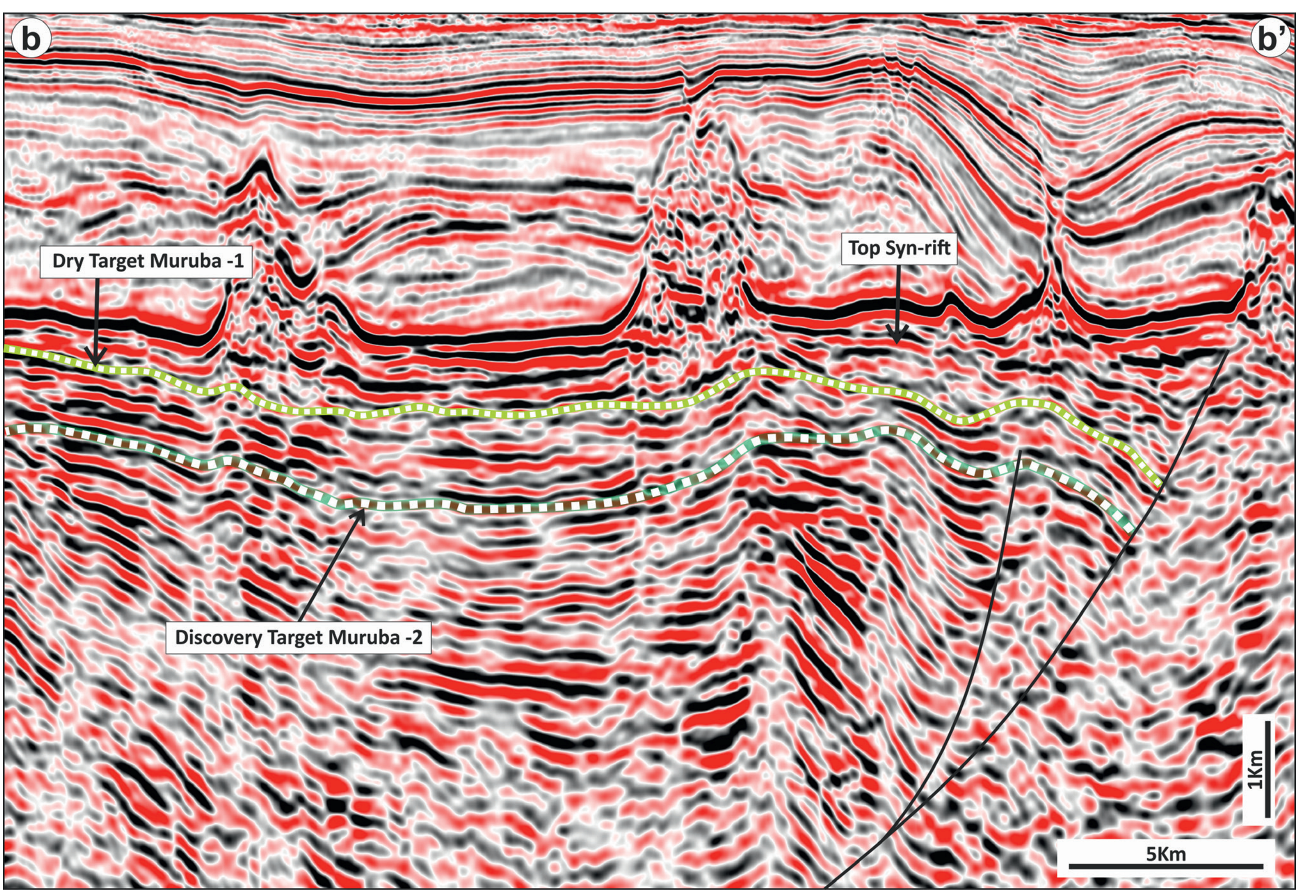

Figure 5 Seismic profile extracted from the 3D RTM volume showing the Muruba Structure/Prospect in its strike direction. The section is named b-b' and located in Figure 4B.

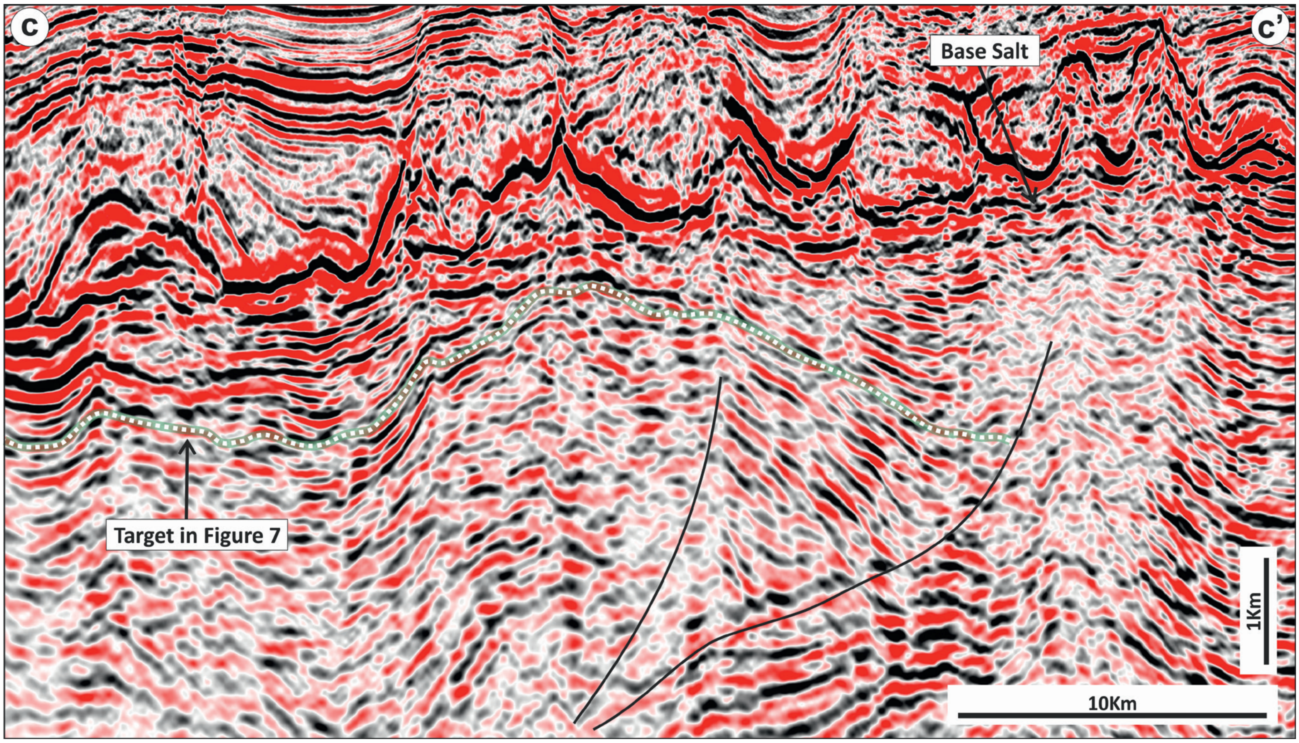

Figure 6 Seismic profile extracted from the 3D RTM volume across one of the large structural closures mapped in the pre-salt units (Dentale/Melania Fm.). The section is named c-c′ and located in Figure 7.

accumulation, the structure that was drilled, or organization and architecture of the intra-syn-rift play. A previous well, drilled on the same structure/prospect (MURM -1), targeted the Gamba and upper Dentale syn-rift, but only found oil shows. (Figure 5).

At the time of these wells only 2D seismic data was available, but now the new 3D seismic data opens to a post-drilling analysis and a re-evaluation of the Muruba structure as a learning case for the syn-rift targets. The structural closure is formed by a hanging wall anticline developed by a major extensional fault. The closure is provided by the flanks of the anticline and the fault plane, which act as seal for both the north-eastern flank and the structural culmination (Figures 4A and 4B).

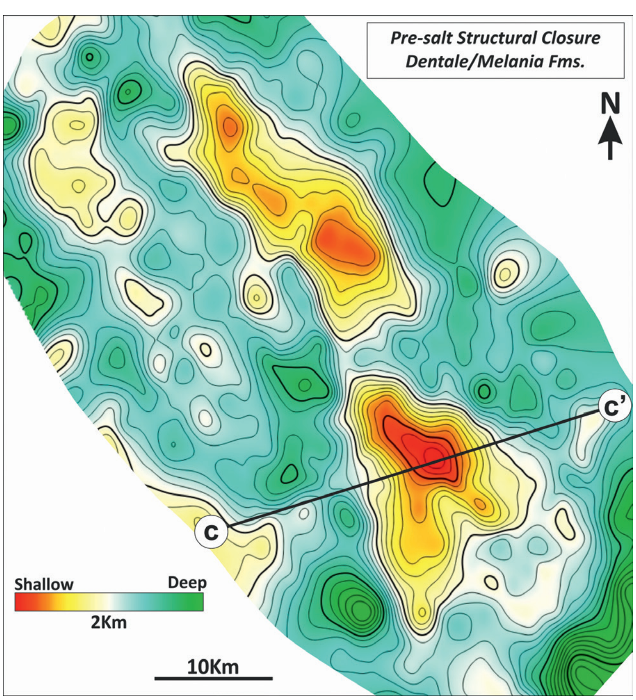

Figure 7 Structural closures mapped at target interpreted in the section c-c` of Figure 6.

The fault in the Muruba Structure is clearly syn-depositional; the growth is continuous at the Melania and Dentale intervals making it difficult to correlate the stratigraphy from the hanging wall to the footwall. Both the syn-rift and the fault plane are truncated at the base-salt, which form an abrupt transition from the syn- to the post- rift sequences. The syn-rift is formed of interbedded shales and sands, laterally continuous with both seal and reservoir properties, and porosity up to 19%, which identify several potential hydrocarbon pays or targets.

Seismic mapping at the targets of the wells suggest that both Muruba -1 and Muruba -2 are correctly located on the closure, and both intercept good pay zones (Figures 4A and 5). However, the fault growth has created different relationships between the closures and the truncation at the Gamba level. The shallower target in Muruba -1 is truncated too close to the structural culmination. Muruba -2 reached a pay zone approximately 400 m deeper, truncated farther to the north, widely outside the structural closure, which remained safely sealed (Figures 4A and 4B).

Analysis of the new 3D data illustrates that several wells have targeted the Dentale reflectors truncated by the top syn-rift unconformity and the Gamba Sands. Although several discoveries have pay-zones vertically stacked from the syn-rift to the Gamba Sands, they are within the closure of the base salt or Vembo seal. Muruba does not have this relationship, and all other wells drilled in the area TD below testing are a true closure at Muruba pay equivalent level.

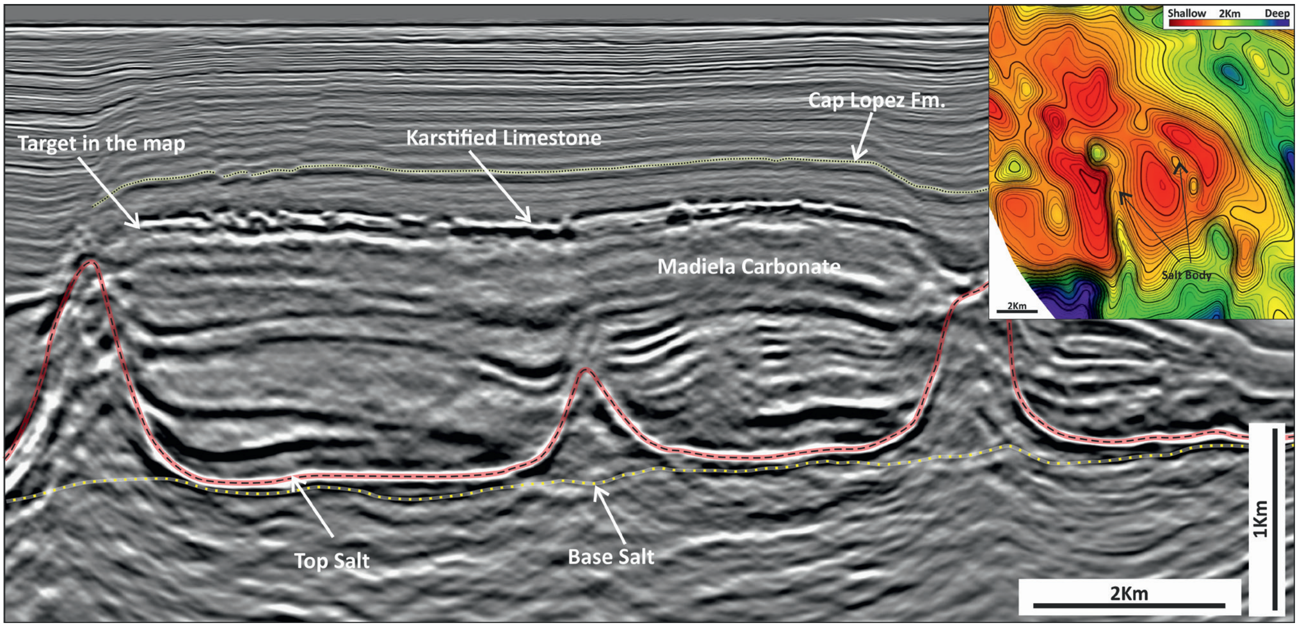

Figure 8 Seismic section extracted from the Final 3D Kirchhoff PSDM Volume, showing several carbonate sequences within the Lower and Upper Madiela Carbonate.

The level of structural detail of the new 3D data has improved dramatically on any previous data. The scale of the 3D data is semi-regional, such that fault planes can be tracked in low and high angle portions and the presence of regional mobile shales seems no longer necessary or plausible (Esestime et al., 2018).

Similarly to Muruba, a number of structures are now imaged with an antiformal shape, with steeper flanks along a portion of a controlling low-angle fault plane. However, the geometry does not match the classic model of a listric extensional fault, as a preferential level of detachment is not present. Fault planes combine both low-angle and high-angle sections, suggesting the presence of oblique kinematic energy during the tectonic extension. The fault ramp steps controlled dips and stratigraphic discordance in the syn-rift, creating a variety of prospects types, including tilted fault blocks and rollover anticlines (Figure 3).

Several targets can be identified within the fault growth, eventually confined to a single fault segment. A majority of those can be taken in the shallow subsalt section, although not in contact with the unconformity at the top of the syn-rift, in order to derisk seal presence at its culmination. As an example, the structure in Figure 6 has a clear culmination which cannot be identified at the base salt or Vembo Fm. This preliminary seismic interpretation generated two closures of approximately 200-300 km^2 (Figure 7). This target was picked only on adjacent hanging wall basins, and the resulting structures show trends oriented N-S and NW-SE, similar to other tectonic lineaments observed from the onshore geology and indicated by the trends of the hydrocarbon discoveries and fields.

Post-salt prospectivity

Numerous levels of structural closures can be mapped within several Madiela Fm. carbonate sequences. Tens of structural closures have been identified; at the Top Madiela only, these may extend up to 50-100 km^2 (Figure 8).

More prospects can be generated within the carbonate sequences. These are formed during several phases of salt withdrawal, which were mainly active during the Albian age and gradually less from the Cenomanian and the Turonian. The growth of the carbonate platform was controlled from both the passive margin subsidence and the local subsidence from loading on to the Ezanga Salt layer (Peel, 2014). The local accommodation space was created through subsidence and rotation of the carbonate rafts, until they ground, creating thin welds and subsequent gravity-driven extension, leading to a turtle structure formation. Eventually, regional subsidence moved inboard the pelagic facies, with gradually back-stepping of the carbonate margins, gradually replaced by Late Cretaceous and Tertiary clastic, which created an additional play system particularly in the north.

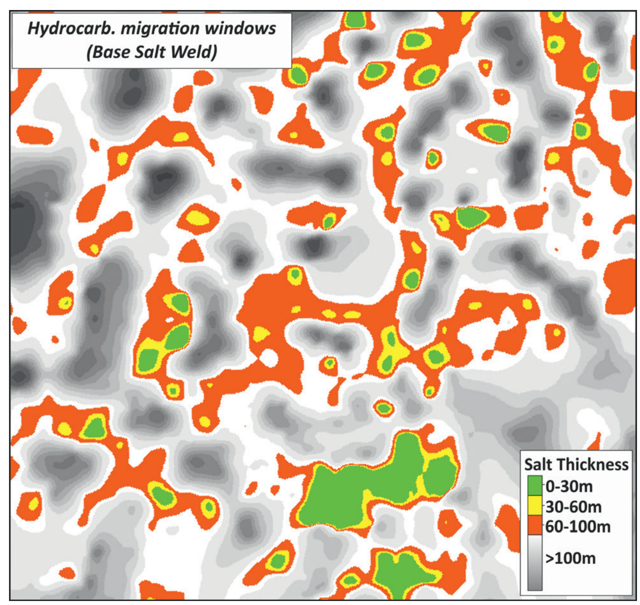

Figure 9 Salt thickness map showing potential windows for hydrocarbon migration from the pre-salt section into the post-salt traps.

The presence of multiple reservoir and seal units in the Madiela carbonate may form self-contained hydrocarbon systems. There have been many post-salt oil shows within the Gabon South 3D area (Figure 1), and although potential high-TOC shale units have been identified in the post-salt sequences they are often not regionally extensive or mature for hydrocarbon generation. The primary regional source rocks are identified in the pre-salt sequence in the Melania and Kissenda Fms.

Migration path through the syn-rift into the post-salt units may represent an element of risk for the Madiela prospectivity. The hydrocarbons have to cross two main barriers, the Vembo Shale and the Ezanga Evaporites. Both these have highly variable thickness and lithofacies, which may affect their sealing capacity. In particular, we note well penetrations where salt has withdrawn to less than 12 m, and also that the Vembo Fm. may include layers of carbonate and dolomites that may have affected seal capacity (Figure 9).

Salt windows in proximity to the closures, identified within Madiela Carbonate, may help to derisk the charge of those prospects. Salt thickness below 30 m is difficult to resolve in seismic data, and appear as welds between the pre- and post- rift. Guardado et al. (2000) and Rowan (2004) discussed the possibility for these salt welds to be migration windows to transfer the hydrocarbons from the pre- to the post- salt units. The salt isopach shows numerous potential migration windows, widely distributed, those having salt 10 to 60-m thick account for approximately 15-20% of the survey area, and 20-30% where the salt thickness exceeds 100 m (Figure 9).

Conclusion

The new 3D data is revealing a new level of prospectivity in the shallow water of Gabon, which is expected to be mostly oil-bearing. Syn-rift prospects are material, well imaged and target a play that has been proven in Congo, and with the Muruba wells, by historical drilling, but just could not be pursued with older data.

Previous exploration is being re-evaluated to generate a completely new set of hydrocarbon prospects in the syn- and the post-rift by recognizing that it was not the absence of prospectivity, but the absence of good imaging that was implying that the area was “mature” for exploration. Indeed, this is a successful strategy when exploring apparently mature basins, such as the North Sea or the Gulf of Mexico.

By applying leading-edge planning, acquisition and processing of 3D seismic data we have an evolved technology to image new plays and unlock new creaming curves. As Marcel Proust puts it: ‘*The real voyage of discovery consists of not in seeking new landscapes but in having new eyes*.’

Acknowledgments

We would like to thank the Direction Générale Des Hydrocarbures (DGH) for its collaboration. A special thanks also goes to the Geophysical Team in DownUnder GeoSolution and Beth Cox (Monarch Geophysical Services) for their dedication and excellent technical support.

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