INTEGRATION IN EXPLORATION

Carl Watkins, Dan Carruthers, Pedro Duran, Simon Otto & Mark Cowgill, CGG, UK, explain how integrated exploration efforts are producing new workflows for new challenges.

As deepwater exploration continues to gradually emerge from a relative lull in activity, the challenges to success remain as complex as ever. In the new reality of more limited exploration budgets and increased scrutiny, innovative ways for explorationists to extract maximum value from all available data are required. Truly integrated approaches to exploration workflows represent one way of addressing this problem. Using a diverse range of geoscience data sets from the deepwater Atlantic margins, this article demonstrates frontier and data-rich integrated geoscience workflows designed to support and de-risk exploration.

The challenges to deepwater exploration on the Atlantic Margins stem from a wide variety of technical, economic and political risks. In terms of the subsurface, key risks include fundamental play element identification in data-poor frontier areas and detailed petroleum system qualification in more data-rich areas, including issues such as subsalt imaging, source rock de-risking and reservoir characterisation.

In exploration of frontier areas where data are sparse, consistent play evaluation methods are required to develop and rank opportunities. Combining global play fairway databases [CGG's Robertson Basins & Plays] with Earth Systems Modelling predictions [CGG's Robertson Predictions] and remote sensing techniques [CGG's NPA Satellite Mapping group] can support de-risking of exploration in these truly frontier areas.

In key parts of the Atlantic Margin, CGG has acquired large 3D seismic surveys that combine the latest depth imaging and processing techniques with an integrated geoscience approach to offer new insights into subsurface structure and stratigraphy. CGG's JumpStart™ packages adopt an integrated approach in these areas of new data availability, where geological analysis is performed in parallel with the seismic data processing to address the key subsurface problems on the fly as new data becomes available.

Geodynamic framework

Crustal types, basin architecture and particularly the presence and influence of salt are key uncertainties in many deepwater Atlantic settings. Sub-salt plays are key targets in locations as diverse as the Santos Basin of Brazil, the Gulf of Mexico (US and Mexico) and much of the West African margin. Key reservoirs and source rocks are associated with the syn-rift successions in all of these settings, and questions arise as to the seaward extent, geometry and thickness of these successions.

As an example, in Gabon CGG recently acquired a 3D seismic data set in the deepwater area in the south of the country, and compiled an integrated geoscience 'JumpStart' package to provide a geological context for the seismic data. Whilst the sedimentary section was imaged in great detail (Figure 1), there was also excellent imaging in the crustal section (Figure 2). Imaging of deep crustal structures and integration with potential field data allowed clear recognition of the Moho, and identification of regions of thin, hyper-extended upper crust where the Moho is shallow. Areas of candidate-exhumed mantle with high magnetic susceptibility could be mapped and were used to inform analysis of the rifting style and opening geometries. This information provides the framework required to investigate the seaward continuity and thickness of both the syn-rift and sag sequences that contain the key source rocks and reservoirs (Figure 2).

High-quality imaging and integrated geological work offer unique insights into the rift-drift evolution of the margin, and have significantly enhanced understanding of the effects of this history on the deposition of source and reservoir rocks, the age and thickness of salt, the temperature and maturation of the source rocks and potential timing of charge.

Source rock presence and quality

A robust geodynamic framework forms the backdrop for developing palaeogeographic reconstructions and considering the elements of the petroleum system in their original spatial context. Source rock represents a key risk in frontier areas and is often the first element of the petroleum system to be considered. However, source rocks are often underrepresented in available data sets and are commonly unpenetrated, even in more mature basins. Structural highs, a common drilling target in the early phases of basin exploration, are not typically important locations for evaluating source rock presence and effectiveness, and the corresponding lows may be beyond drilling range.

Source rock distribution is a matter of intense debate in key areas of the Atlantic margins, such as the Gulf of Mexico and North West Africa. To help answer these questions, modelling and interpolation approaches are combined to help constrain palaeogeographic and paleobathymetric reconstructions, making use of world-class plate models (CGG's Robertson Plate Kinematics). In the absence of direct evidence from drilling, source rock evaluation relies on a range of alternative means of evaluation, including seep identification (NPA's Global Offshore Seepage Database), surface geochemical sampling, geochemical analysis of available recovered fluids from the shallower parts of the section, analogue studies, basin modelling and predictive methods.

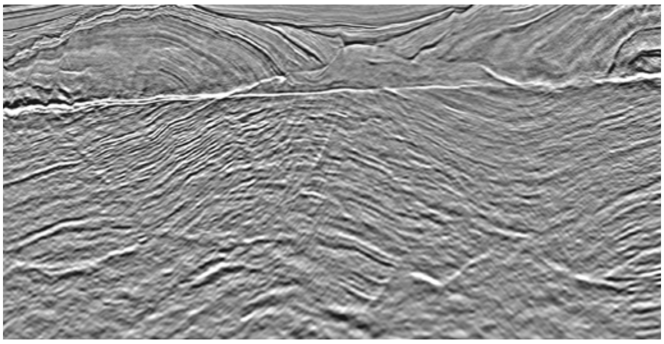

Figure 1. *Madiela Formation rafts, Ezanga Formation salt pillows and the Lower Cretaceous sedimentary section offshore Gabon. Note the angular unconformity between the pre- and post-salt packages.*

Mapping the distribution of organic productivity in ancient seas has allowed the development of novel methods for the prediction of the lateral variation in source rock quality.[1] Paleo-digital elevation models (Figure 3) are coupled with state-of-the-art paleo-Earth systems models (UK Meteorological Office HadCM3 paleoclimate model)[2] to model the supply of nutrients to the photic zone and generate a prediction of original source facies richness. Whilst these models are based on first principles and are therefore unconstrained by data, they can be tested with data and provide a logical audit trail to estimate original source facies presence and richness. The often-quoted aphorism that "All models are wrong… but some are useful" is particularly apt here.[3] Combining predictive source facies modelling with all available data, including surface geochemistry, satellite seep identification and oil geochemistry provides a powerful integrated toolbox.

Data-poor frontier settings

The Mauritania-Senegal-Guinea Bissau-Conakry (MSGBC) Basin in North West Africa has seen recent activity and success. Cretaceous slope plays remain a significant target, and chasing the potential extent of these plays northwards from the MSGBC Basin into more frontier areas is of considerable exploration interest. Despite disappointing results to date offshore Morocco, the size of the margin and the lack of data in deepwater settings suggest that the prospectivity has not

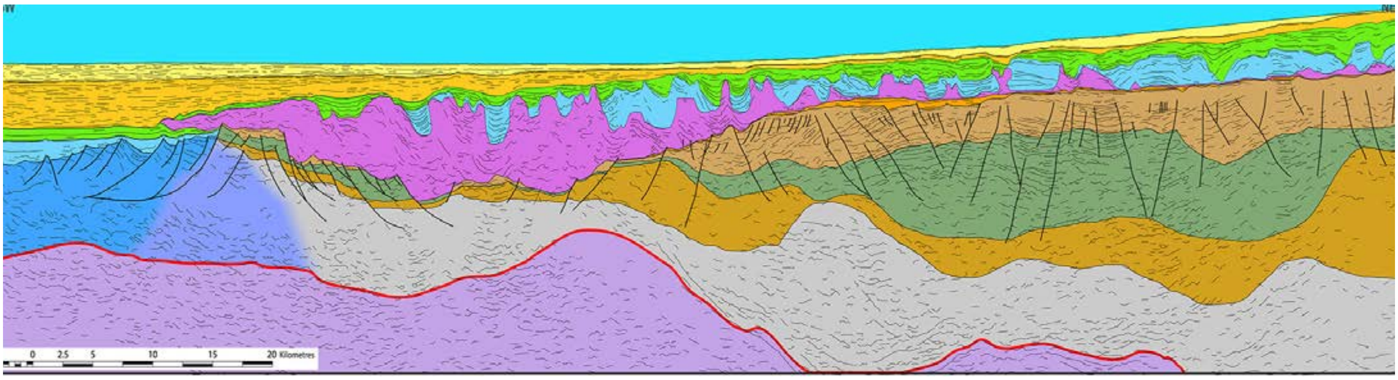

Figure 2. *Geoseismic section across the southern Gabon margin illustrating the transition from continental to oceanic crust. Note the shallow depth of the Moho and thick salt accumulation in the zone of hyper-extended crust.*

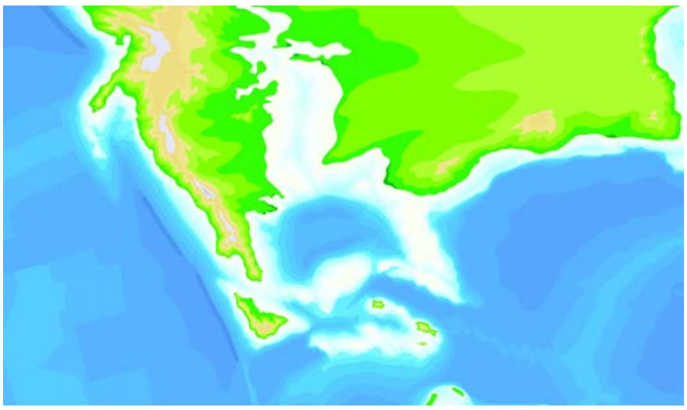

Figure 3. *Late Cretaceous palaeogeography highlighting the proto-Rocky Mountain topography, the Western Interior Seaway and deepwater Gulf of Mexico.*

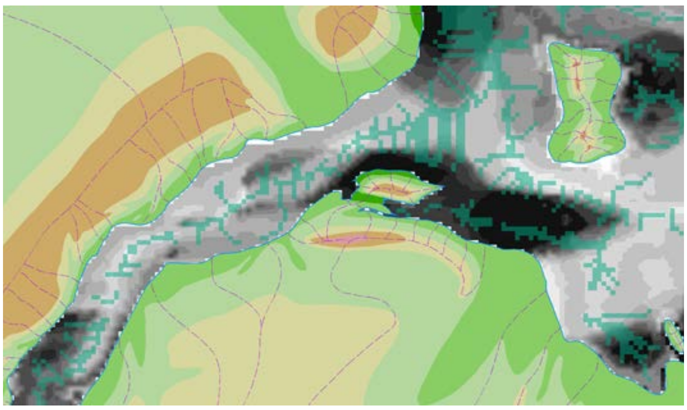

Figure 4. *Middle Jurassic source predictions in North West Africa in their original position in paleo-space.*

been fully tested. De-risking of this huge frontier therefore requires innovative integrated approaches.

There is virtually no well control in the offshore Doukkala Basin, with only some limited onshore wells and a few DSDP wells in ultra-deepwater. In the Aaiun-Tarfaya and Essaouira Basins to the south there is sufficient control data to attempt mapping of source rock distribution and kitchen areas. The same is true of the Pre-Rif/Rharb Basin to the north, but without such data in the Doukkala Basin, how can the significant source rock risk be mitigated?

Whilst candidate reservoirs along this margin are considered most likely to be Cretaceous in age, the Albian to Turonian source rocks that work elsewhere on the margin are likely to be immature in the deep offshore. The Toarcian (Early Jurassic) Amsittene Formation may form a potential source rock interval in this area. The Toarcian is a period of Earth history for which a global Earth Systems Model is available as part of CGG's Robertson New Ventures Suite, allowing prediction of the processes that lie behind source facies generation. The results indicate a strong likelihood of an upwelling-driven paleo-productivity system in the Toarcian along the North African margin and preservation of the resulting organic-rich sediments (Figure 4). The predicted source facies can be rotated into present-day space (Figure 5). Post-Toarcian burial and maturation of the source rock is assessed using 1D and 2D basin modelling that tracks the thermal history of the source rock as it is buried. Basin modelling relies on developing an understanding of stratigraphic architecture and basin fill derived from seismic stratigraphic studies, to facilitate the mapping of a 'predictive oil kitchen' (Figure 6) that lies beyond the present extent of drilling. Whilst the petroleum system can only be fully tested with the drill bit, use of satellite slick identification (Figure 7) shows an intriguing match with the predicted kitchen area. This integrated method and new tool for frontier exploration provides a logic-based prediction with an audit trail that can be tested, and allows the global assessment of source rock risk in frontier basins that is increasingly seen as a key feature of the explorationist's toolbox.

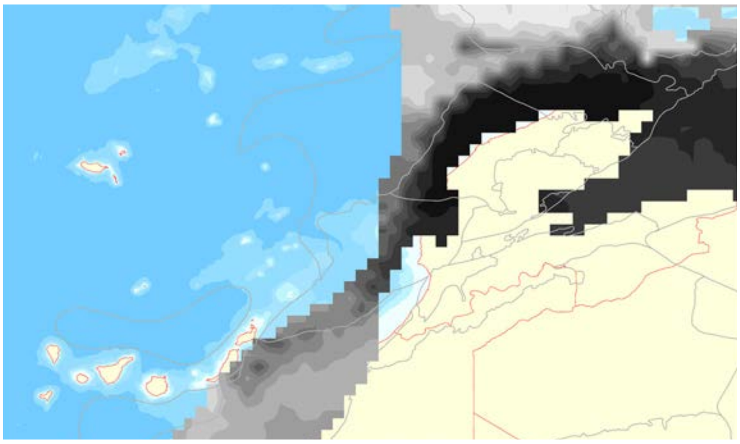

Figure 5. *Middle Jurassic source predictions in North West Africa rotated to present day space.*

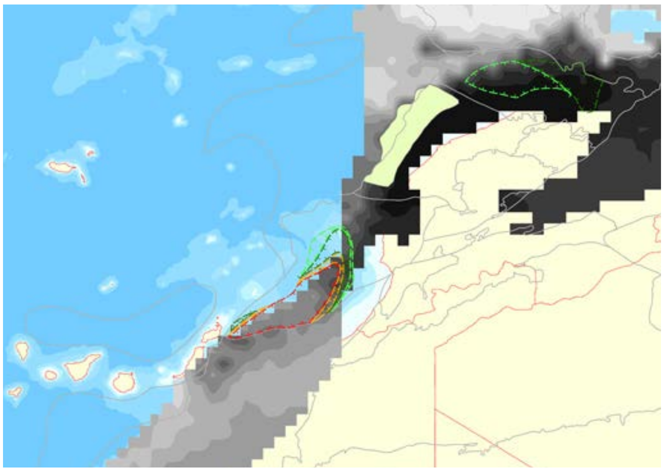

Figure 6. *Middle Jurassic source predictions in North West Africa. Present day space with associated source rock kitchens.*

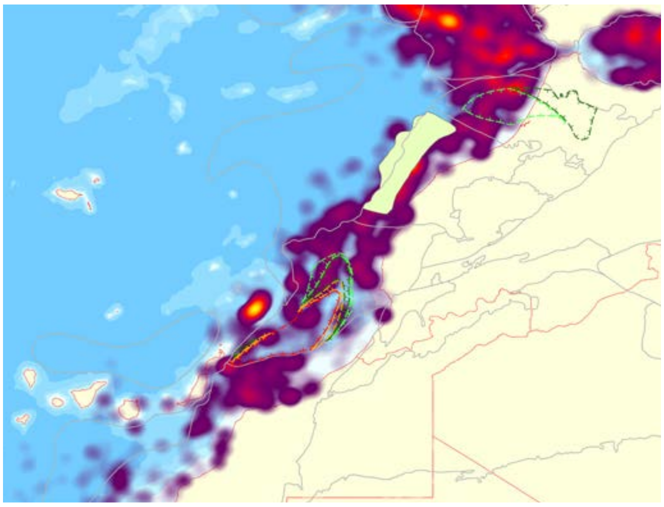

Figure 7. *Middle Jurassic source kitchens and possible seep heat map, North West Africa (image courtesy of CGG NPA Satellite Mapping).*

3D seismic as a core data set

In the Perdido Fold Belt, western Gulf of Mexico, CGG has created a JumpStart package over the footprint of its 38 000 km^2 Encontrado seismic reprocessing project. Deepwater plays here include the Eocene Upper Wilcox Formation equivalents, with proven oil accumulations in BHP's Trion wells and in wells further outboard. However, in the absence of any Mesozoic well penetrations, a key question regarding prospectivity relates to source rock age, depth, quality, distribution and maturity. All available geochemical data were extracted and structured to provide a consistent, unified and enhanced data set. Intersection of this data with a revised stratigraphic framework, constrained by the remarkable quality of the available seismic, enriched the raw, discipline-specific data. Generation of a multidisciplinary and richly attributed database that made use of data science techniques further enhanced the original data. As a result, the geochemical character of oils from both inboard and outboard wells could be interrogated and compared with regional knowledge of candidate source rock intervals elsewhere in the Gulf of Mexico. Based on geochemical 'finger printing' of fluids, a clear difference was recognised between the fluids in the inboard Trion sub-basin and those in the more distal Maximino area. Systematic variations in the original character of the organic matter, best explained by variations in oxygenation of bottom waters at the time of deposition, agree with observations made from palaeogeographic mapping and source facies prediction using the methods described above. Integration of the data with regional interpretation, basin modelling and a robust plate model provides new insights into factors controlling the spatial extent of the key oil families and has allowed a material de-risking of the presence and character of otherwise poorly-known source rocks.

Basin visualisation

By combining all the data sets and workflows described above, it is possible to create rich basin visualisations and generate integrated results as part of a consistent exploration toolkit. In the Mexican case study these components are used to generate a rich basin visualisation, consisting of regional stratigraphic horizons that provide the framework to undertake detailed evaluation of the elements of both proven and potential petroleum systems. Reservoir characterisation work undertaken

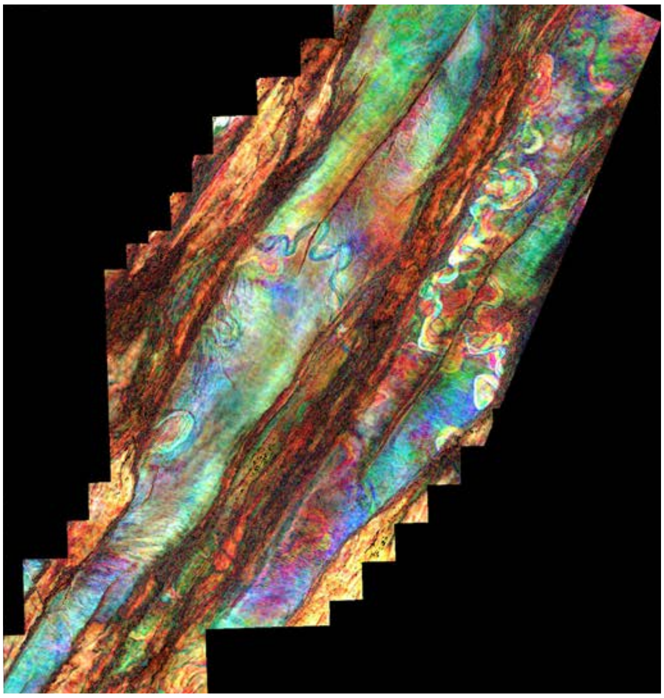

Figure 8. *Spectral Decomposition, Encontrado volume Perdido Foldbelt, Gulf of Mexico. Detailed mapping of high-sinuosity channel systems with contrasting input directions that vary with stratigraphic level.*

in this framework is informed by regional knowledge (hinterland analysis, provenance information and palaeogeographic reconstructions), stratigraphic data are tied directly to the available seismic and a consistency of interpretation is ensured. The generation of spectral decomposition volumes and stratal slicing is not unique but, on the scale developed here, the remarkable image quality and CGG's understanding of the regional framework offers new insights into the processes that lead to deepwater reservoir formation (Figure 8).

Conclusion

Data availability and reliability are prerequisites for developing effective strategies for geoscientists engaged in frontier exploration, particularly in emerging areas where limited drilling activity and data coverage constrain conventional exploration programmes. In these situations, it is important to maximise the value of all available data sources to support business decisions made by exploration managers and steer business development activity. One way to achieve this goal is the development of truly integrated geoscience programmes, where data and information from individual disciplines are combined to make each 'better than it would otherwise be' and realise value from a diverse suite of data and information. Integration works; it improves each individual discipline, maximises the value of each and, if it leads to the generation of a coherent and truly consistent data set, can be used for the next stage in the exploration workflow: prospecting.

References

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Note

All figures courtesy of CGG.