

# Access and exploration opportunities – A view of the potential in frontier and mature basins

Brian Horn<sup>1</sup> demonstrates an overview of hydrocarbon prospectivity in six regions – East Africa, Equatorial South America, Southern Brazil, Uruguay, Argentina, and the Gulf of Mexico.

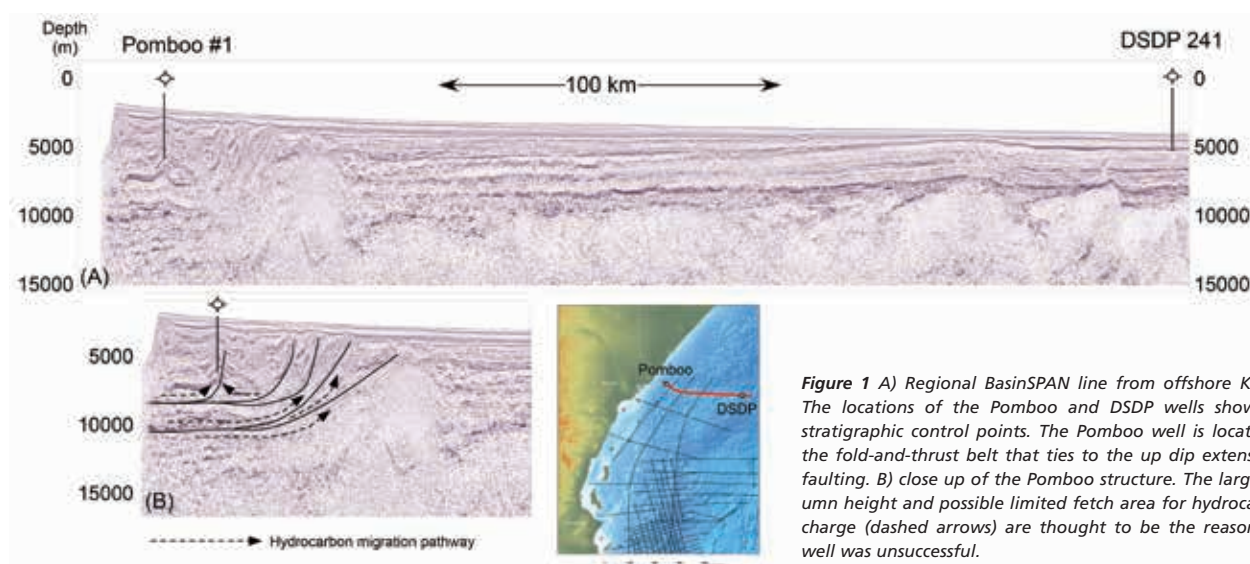
The continued search for commercial accumulations of hydrocarbons has often led geoscientists to believe that the remaining future potential for exploration in frontier and mature basins is diminishing with time. However, a brief overview of frontier, emerging, and mature basins around the world would suggest that several opportunities still remain. In 1952, Wallace Pratt summarized this pessimistic view of individuals and companies in the E&P industry noting, 'We have persistently underestimated the amount of oil and gas that have been stored up in the Earth's crust.' A brief overview of six regions (East Africa, Equatorial South America, Southern Brazil, Uruguay, Argentina, and the Gulf of Mexico) where the exploration activity ranges from frontier to mature suggests there is compelling evidence for optimism and future success. The purpose of this overview is to highlight a sample of potential key opportunities in each area

and demonstrate the importance of gaining a regional perspective in evaluating exploration/access opportunities. In many basins, as exploration matures and wells are drilled deeper stratigraphically as well as in greater water depths new petroleum systems are often identified. An exploration strategy that follows a 'bottoms-up' approach provides the framework and context to calibrate, compare and rank opportunities basin by basin on a global basis.

## East Africa

Over the past seven years exploration along the East African margin has experienced a renaissance with discovered reserves to date in excess of 200 Tcf. This area has undergone a significant paradigm shift since 2007 when the Pomboo well drilled in offshore Kenya had disappointing results. A more detailed analysis of the prospect indicated the structure that was tested lacked sufficient hydrocarbon

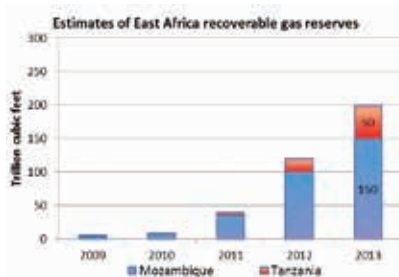
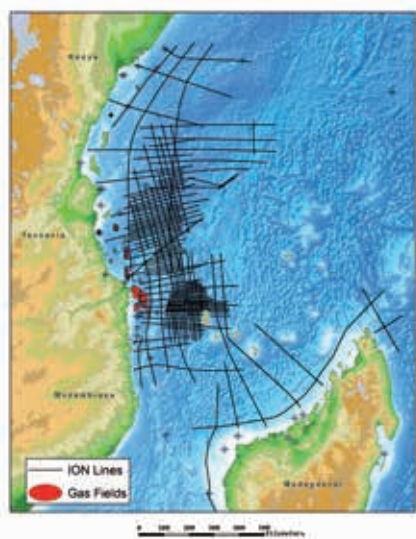
charge access possibly due to a limited fetch area (Figure 1). While other exploration targets seemed promising, no wells had been drilled in offshore Mozambique and the only significant gas discovery had been in Tanzania (Songo Songo Field). Industry perception was that the margin lacked significant exploration potential. Why this well had such an impact on the margin is unclear, however, what was apparent was the lack of an integrated technical understanding of the tectonic development and petroleum systems of the margin and its ultimate potential. In the next five years more than 30,000 km of regional 2D data were acquired (East AfricaSPAN), helping to provide a data set to put exploration plays into a regional context from the opening of the Rovuma Basin to how the rifting of Madagascar away from East Africa led to the development of the world-class petroleum system along this margin (Figure 2).



**Figure 1** A) Regional BasinSPAN line from offshore Kenya. The locations of the Pomboo and DSDP wells show the stratigraphic control points. The Pomboo well is located in the fold-and-thrust belt that ties to the up dip extensional faulting. B) close up of the Pomboo structure. The large column height and possible limited fetch area for hydrocarbon charge (dashed arrows) are thought to be the reason this well was unsuccessful.

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**Figure 2** A) Location map of East African Margin showing the distribution of BasinSPAN seismic coverage. The data cover four countries and are an integral part to understanding the tectonic evolution of the margin. B) Graph showing the estimated gas reserves discovered in the past decade along the Tanzania and Mozambique margin. Ledesma, D. [2013] East Africa Gas - Potential for Export. Oxford Institute for Energy Studies.

With the giant (gas) field discoveries in Mozambique and Tanzania from 2008 to 2014, the most recent interest has turned to the deep water on this margin. A primary question that remains is whether there is an outer oil play related to the giant gas discoveries. With the recent licence round interest in offshore Tanzania and the potential of extending the Tanzania and Mozambique discoveries east into the Comoros, one aspect of the future exploration will be the search for an oil-prone or liquids-rich petroleum system. The regional correlation and calibration to the giant gas discoveries to the west (Tanzania and Mozambique) provide the stratigraphic context and correlation of these reservoir-prone depositional systems into the Comoros. Seismic stratal geom-

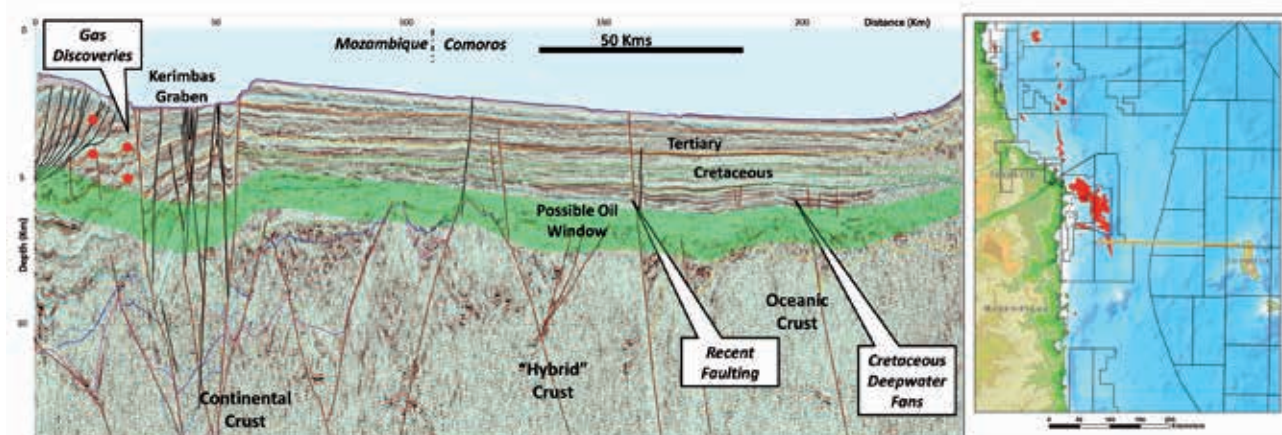
etries are interpreted as deep-water submarine fan complexes that possibly overlie Cretaceous source rock intervals. Preliminary modelling suggests that the Cretaceous source intervals are in the oil window (Figure 3). The challenge will be the uncertainty of source presence and the distribution in the outboard part of the margin. Understanding the tectonic evolution of the basin and structural reconstruction will provide the context to predict the magmatic/volcanic systems, when they were active and how to estimate heat flow based on these interpretations.

### Equatorial South America – Offshore Suriname and French Guiana

The discovery at the Zaedyus well in French Guiana opened up what is

considered to be a correlative play type to the conjugate West African margin discoveries in the Tano Basin (Jubilee Field) in Ghana. Since this initial well, results in the subsequent wells have not led to further discoveries along the equatorial margin (Figure 4). While the offshore French Guiana margin has similarities to Ghana, a more detailed analysis of the Demerara rise highlights the complex tectonic history of this part of the margin. A northwest-southeast seismic transect across the rise demonstrates the distinct differences between the western side of the rise in Suriname to the eastern part in French Guiana (Figure 5). Evaluation of the tectonic history along this part of the margin shows the extension of the Central Atlantic opening south to South America in Jurassic time (Pindell and Kennan, 2009). Jurassic age ocean crust is present on the northwest part of the Demerara rise (Figure 6) and Cretaceous Canje Fm (Cenomanian-Turonian) strata are considered to be the source kitchen that fed the onshore Tambaredjo-Calcutta Fields (Schenk, 2000; Staatsolie, 2014). The northeast and eastern margin is younger and related to the Cretaceous opening of the South Atlantic. The implication for the two-phase evolution of this area provides the potential for multiple different petroleum systems and plays (Reuber et al., 2014).

Seismic data along the Suriname margin show the potential for multiple play types; carbonate reservoirs in large



**Figure 3** Regional seismic line showing the correlation of the offshore discoveries in Mozambique to the potential exploration targets in deep-water Kerimbas Graben and offshore Comoros. The estimated of thermal maturity suggests Cretaceous strata may be in the oil window.



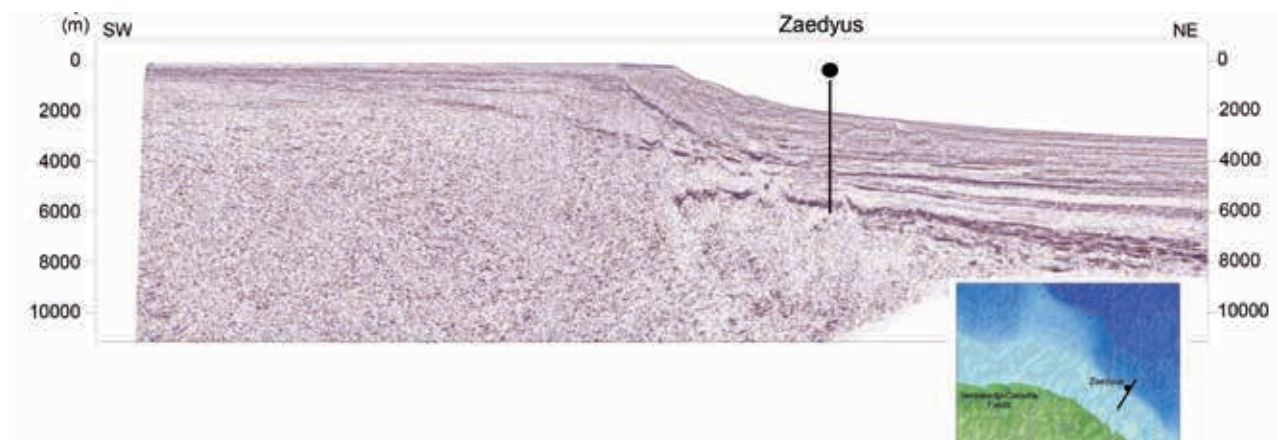


Figure 4 Seismic line offshore French Guiana. The location of the Zydaeus well is projected into the line and demonstrates the deep-water play along the margin.

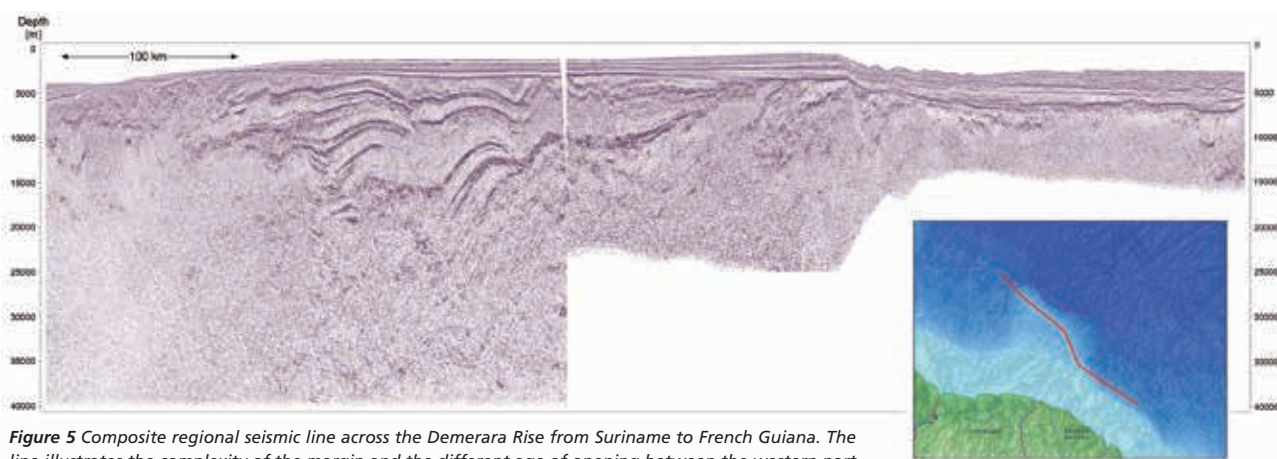


Figure 5 Composite regional seismic line across the Demerara Rise from Suriname to French Guiana. The line illustrates the complexity of the margin and the different age of opening between the western part of the margin and the eastern part of the margin.

structural closures, compressional fold belts related to the collapse of the margin, possibly submarine fan systems and Tertiary deep-water depositional systems ponded in topographic lows along the margin that may be potentially charged from Cretaceous deep-water source intervals (Figure 7). One critical aspect of this margin is the understanding of the crustal types across the area and the thick intervals of strata that appear to be interbedded volcanoclastic strata or volcanic (SDR?) deposits that underlie large sections of the margin. Understanding this deep section and crustal type is critical to determining heat flow and timing of maturation for developing sound exploration play concepts along this margin.

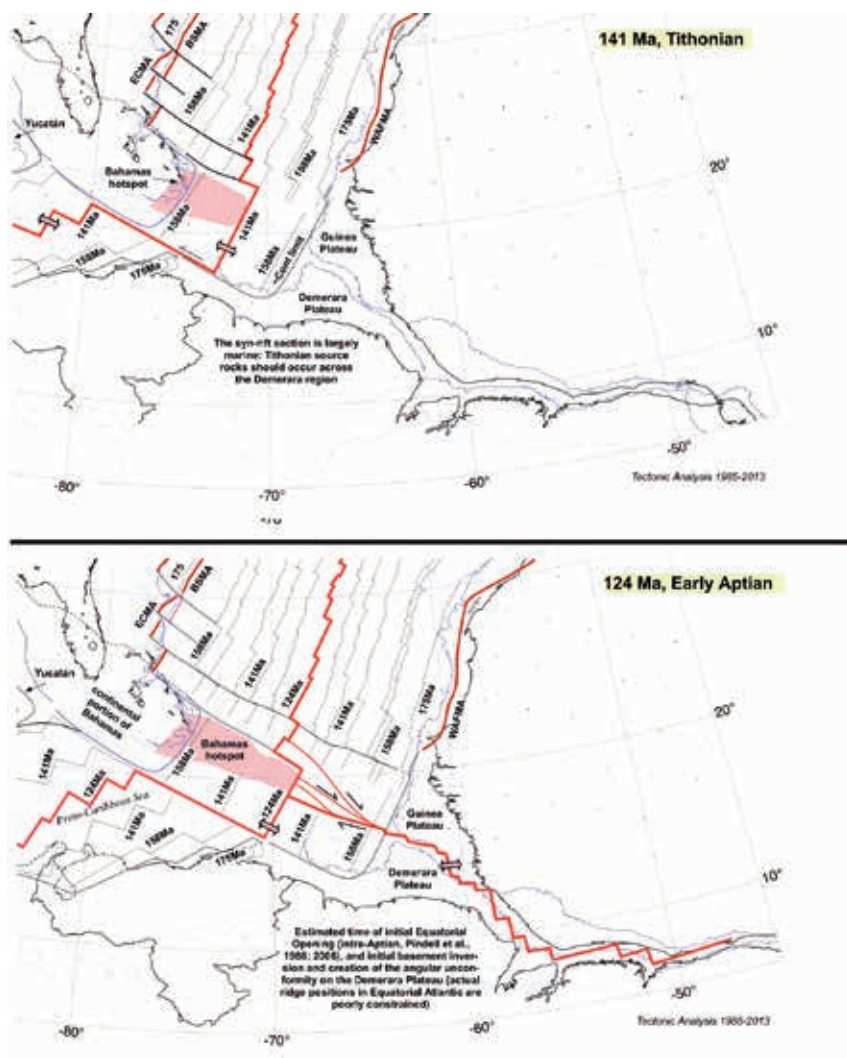
### Offshore Southern Brazil

With the past success and large discoveries in the Santos and Campos basins, the

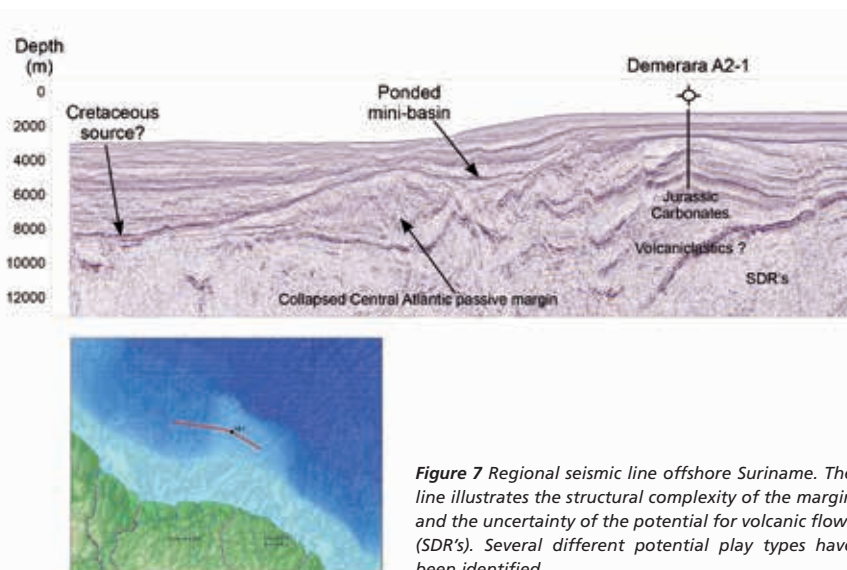
exploration potential in other parts of the South Atlantic, such as the Pelotas Basin, has not received as much attention. A primary difference in the Pelotas Basin is the greater degree of magmatic influence along this part of the margin in both the syn- and post-rift strata as well as the absence of salt. As a result, a different (younger) petroleum system related to the drift stage would greatly enhance the potential to charge the post-rift strata. In the northern Pelotas basin seismic data identify potential reservoir strata reservoirs draped over a large basement high (Figure 8). Several prograding successions interpreted to be marginal marine to deep-water submarine fan systems are situated along the flanks and crest of the regional high. The high basement block along this segment of the margin is composed of normal faulted, possible syn-rift interbedded clastics and volcanics or

faulted SDR packages. In the adjacent structurally low areas high-amplitude continuous strata are observed to onlap the high. Continuous, high-amplitude seismic reflections are interpreted as potential hydrocarbon source prone intervals that appear to be in the oil window given the present-day depth of burial (Figure 9). Large-scale geometries such as these are observed along the margin and are excellent configurations for regional hydrocarbon focus. Seismic amplitudes observed in strata in the structural high areas are also possible indicators of an active petroleum system.

In the southern part of the Pelotas basin stratigraphic geometries are observed potentially similar to many of the geometries in West Africa and the Equatorial Atlantic discoveries (Figure 10). The Rio Grande cone is a well-known area of deposition that



**Figure 6** Plate reconstruction models for late Jurassic (Tithonian) and Early Cretaceous (Aptian) time. The initial phase of rifting along the north-northwest part of the Demerara Rise is the extension of the Central Atlantic opening in Jurassic time. The eastern part of the margin opened during Cretaceous time (Modified from Pindell and Kenan, 2007).



**Figure 7** Regional seismic line offshore Suriname. The line illustrates the structural complexity of the margin and the uncertainty of the potential for volcanic flows (SDR's). Several different potential play types have been identified.

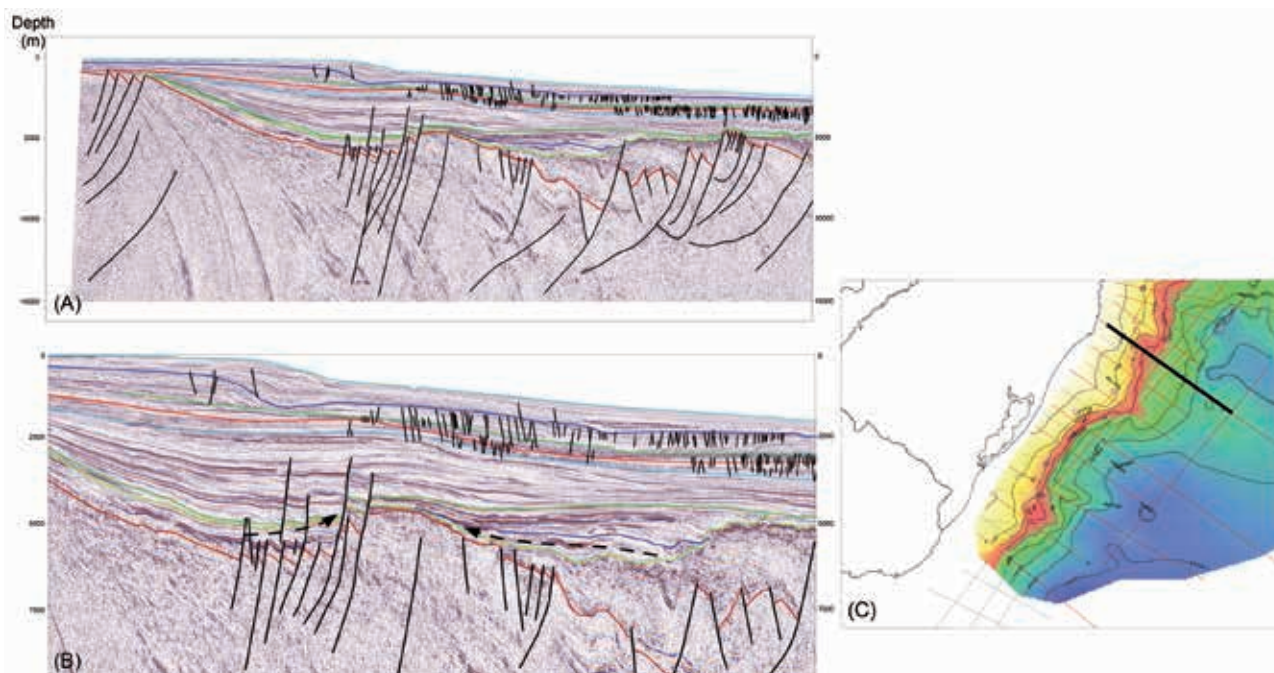
has intrigued explorers in this area for many years. The large volume of sediment deposited along this part of the margin has created depositional complexity and potential for stratigraphic trapping geometries. High-amplitude (Berramian-Albian?) reflectors present in the outboard part of the margin thin and onlap the continental hinge in a landward direction. Although Cenomanian-Turonian strata are considered to be the most prospective source interval on this part of the margin, older source intervals are present in adjacent areas (Morales, 2011). There are several onlapping geometries in Cretaceous strata observed along the margin. Seismic data indicate multiple deep-water fan systems are present that contain channelized and lobate geometries and are interpreted as evidence of several reservoir settings. In younger Tertiary strata, a prograding shelf margin has created an extensional fault system that has detached along an Oligocene (?) shale surface. This has created structural traps where potential reservoirs have structural closure in the hanging wall. In this example (Figure 11) the amplitude appears to be a possible DHI.

These examples from the Pelotas basin suggest that there may be significant unexplored potential along much of the margin. A key question will be the presence of potential source intervals and the ability to find stratigraphic traps capable of holding commercial volumes of hydrocarbons. The pre-salt discoveries in the basins to the north will continue to be the focus of much exploration activity, however. The development of new plays and ideas in other areas, while more complex, could potentially yield significant discoveries.

## Offshore Uruguay

The recent interest in this area was highlighted by many E&P companies in the 2012 round where several blocks were licensed in deep water (Figure 12). This part of the South American margin has limited exploration confined to shallow water areas. Currently there are no major discoveries in the Punta

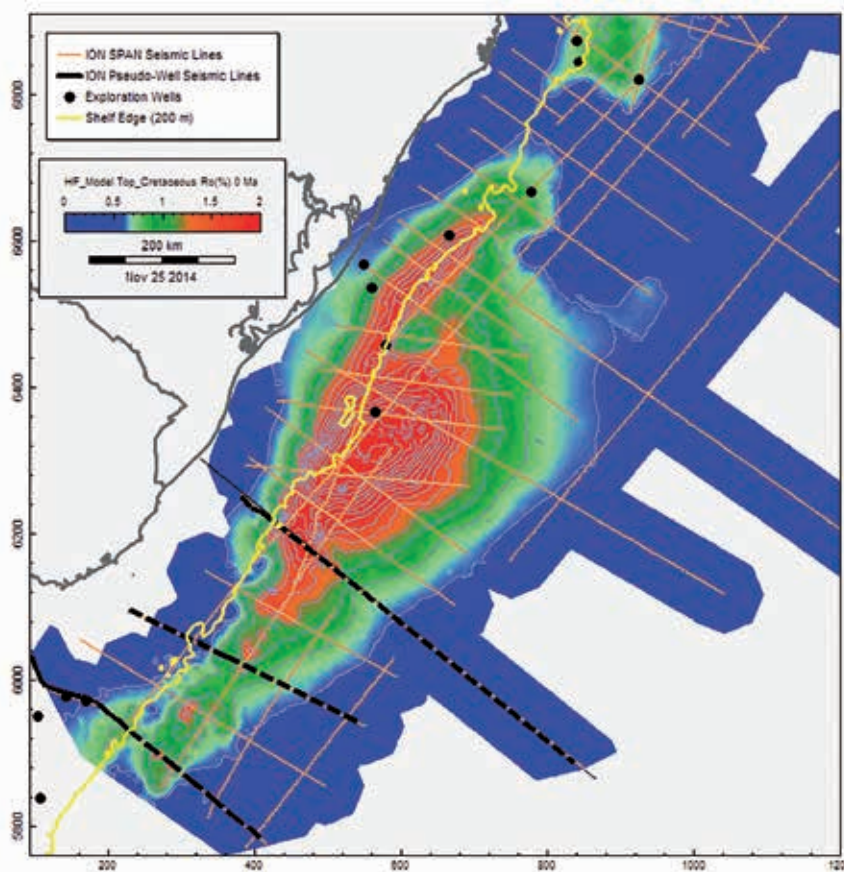




**Figure 8** Regional seismic line in the Northern Pelotas Basin. A) Seismic line illustrating the volcanic or magma-rich margin (SDR's) in the Pelotas Basin. The regional high located in the centre of the line separates two potential hydrocarbon kitchens. B) Close up of the regional high. Note the stratigraphic onlap on the flanks of the high and the offlapping clinoforms that prograde into the basin. C) Basemap showing the top Miocene structure map and the line location.

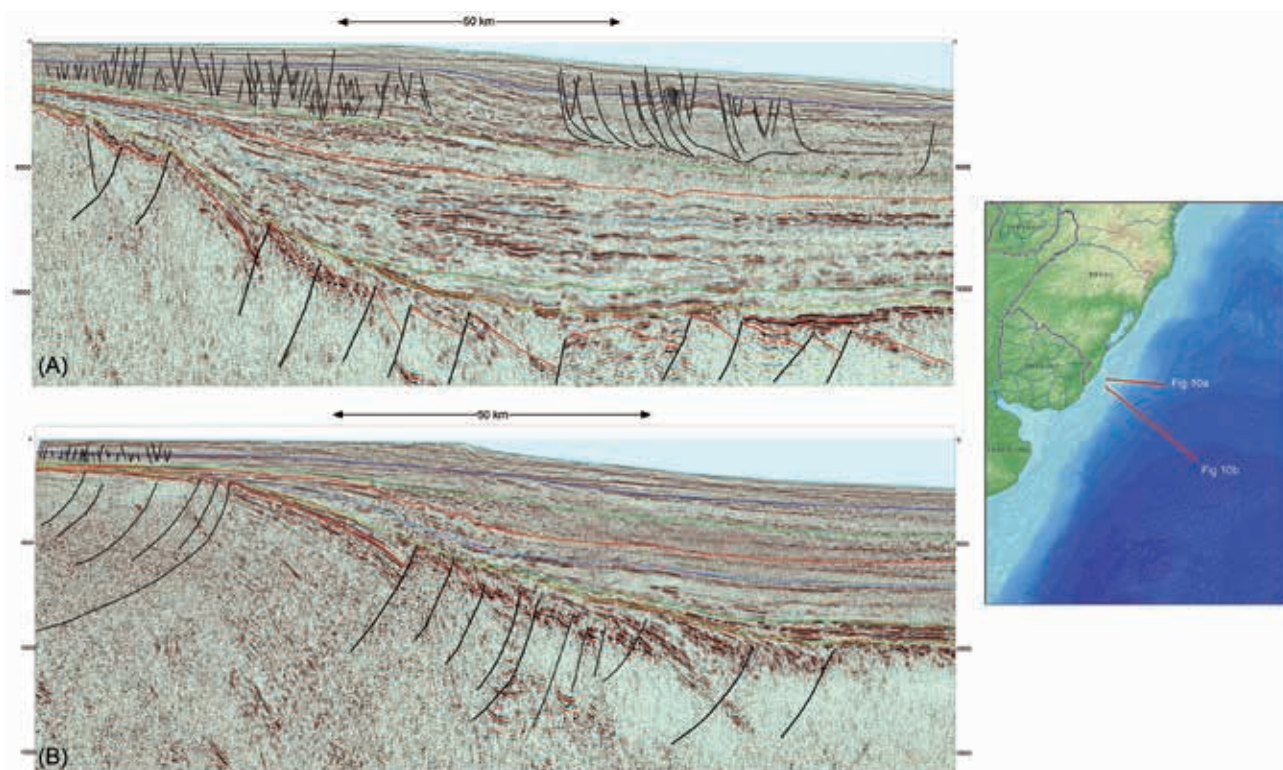
del Esta basin. Seismic data reveal the margin is structurally benign but has stratigraphic complexity from the slope to the deep water. Several different deep-water fan systems are observed to be located in what is typically considered seaward of the continental-ocean transition (COT). Typically, these areas were considered unprospective with source rocks thought to be immature, deposited on cold ocean crust. However, the volume of sediment deposited on the margin appears to be sufficient for burial deep enough to mature potential source rocks of Cretaceous age.

If there is an active petroleum system along this part of the margin, there is a high degree of potential in large-scale stratigraphic traps similar to those discoveries in West Africa and the equatorial margin. No wells have been drilled on the 2012 licence blocks, but the first well is scheduled to be drilled in the next two years. Analysis of the margin also shows the blocks in ultra-deep water (>3500 m) may have potential as well. Seismic data indicate that Cretaceous source intervals are present outboard of the shelf-slope areas and interest in exploring in these

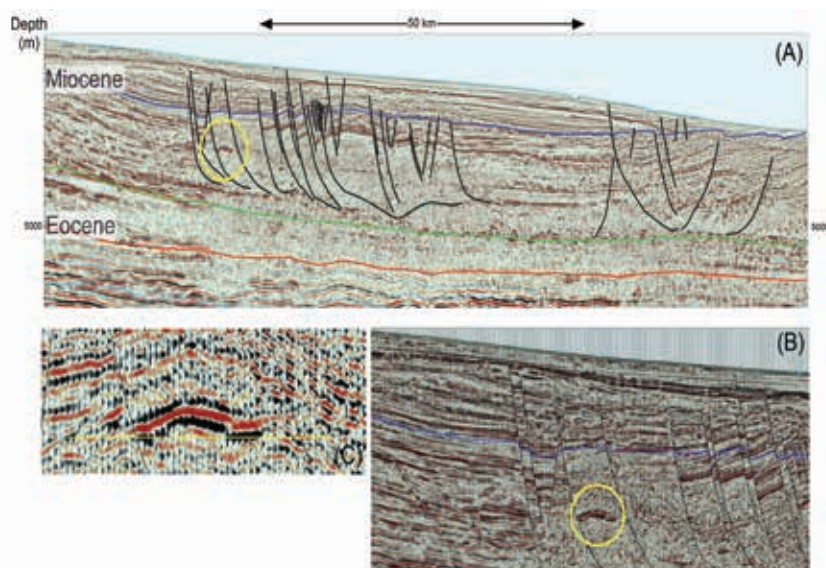


**Figure 9** Cretaceous thermal maturity map for the Pelotas Basin. The central part of the basin is presently in the gas window while the margins remain in the oil window or immature. Given the lack of structural complexity in this area understanding migration pathways will be critical.





**Figure 10** Regional seismic lines from the southern Pelotas Basin. A) Seismic line illustrating the thick stratigraphic section and the potential for multiple stratigraphic traps against the basin margin. The data indicate a high degree of stratigraphic complexity and multiple higher amplitude intervals. B) Seismic line showing the Tertiary deposition of the Rio Grande cone and the extensional faulting present in the shallower section.



**Figure 11** A) Seismic line showing the extensional faulting in the Tertiary section of the southern Pelotas Basin. Note the high amplitude reflector present in the hanging wall block on the left side of the figure (yellow circle). The strata close structurally into the fault plane indicating a trapping configuration. B) Close up of the structural closure with amplitude and trace display. C) Apparent flat spot (DHI) on the data is a potential hydrocarbon-water contact.

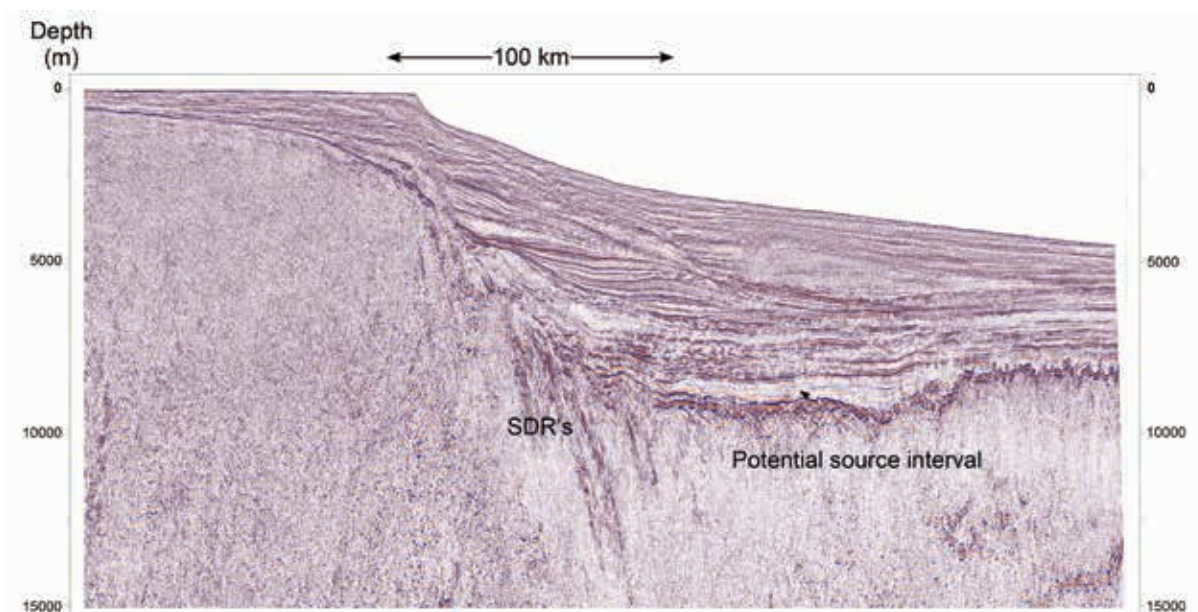
areas may be the impetus for the interest in an upcoming licence round in 2015-16.

### Offshore Argentina

The recent interest in unconventional or resource plays in Vaca Muerta Fm onshore Neuquén Basin have in

many ways overshadowed the significant potential in Argentine offshore areas. While the exploration activity has been limited, analysis of the older Jurassic rift basins present on the shelf and in the deep-water offshore Argentina suggest significant potential remains underestimated with the

limited drilling activity in the shallow water part of the basins. The tectonic history of the South Atlantic margin is well documented as being a volcanic or magma-rich rifted margin. The presence of seaward dipping reflectors (SDR's) and imaging of the mocho across this area demonstrate



**Figure 12** Regional seismic line offshore Uruguay. The line illustrates the large-scale stratigraphic heterogeneity along the margin and the multiple deep water fan systems present outboard of the shelf margin. Steeply dipping reflectors at the shelf margin are interpreted as SDR's thus placing most of the strata on oceanic crust. Parallel high amplitude reflectors are ponded outboard of the SDR packages and are potential source rock intervals that could provide a petroleum system on this margin.

the opening of the South Atlantic (Figure 13). The presence of older Jurassic rift basins (Colorado and Salado) with a rifting history predating the South Atlantic opening can be observed on these data. The dramatic thickness (>13 km) of strata in these basins contain Cretaceous, Jurassic and possibly Permian age strata are deposited in the deepest parts of the Colorado Basin and are known to contain source rocks. The question in these basins is one of thermal gradient and burial history that will determine whether these

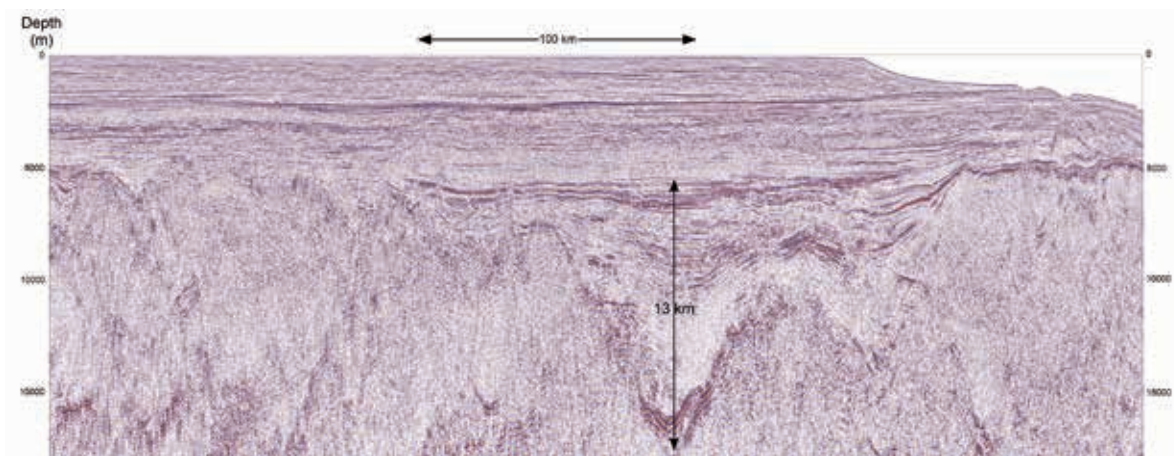
basins are oil or gas prone. The later opening of the South Atlantic margin developing the present-day ocean basin are thought to contain Cretaceous age source prone strata similar to the margins to the north.

Regional seismic data reveal an outer high that separates the Jurassic and Cretaceous rift basins. This regional high parallels the present-day shelf margin and in the right structural configuration creates a large area for hydrocarbon focus area for migration into this broad and regional structural closure from

both basins (Figure 14). While the data density is not sufficient to map individual structural closures or complex stratigraphic terminations, it does suggest that there are areas similar to this along the entire margin and that the conjugate margin in South Africa may contain undiscovered petroleum plays.

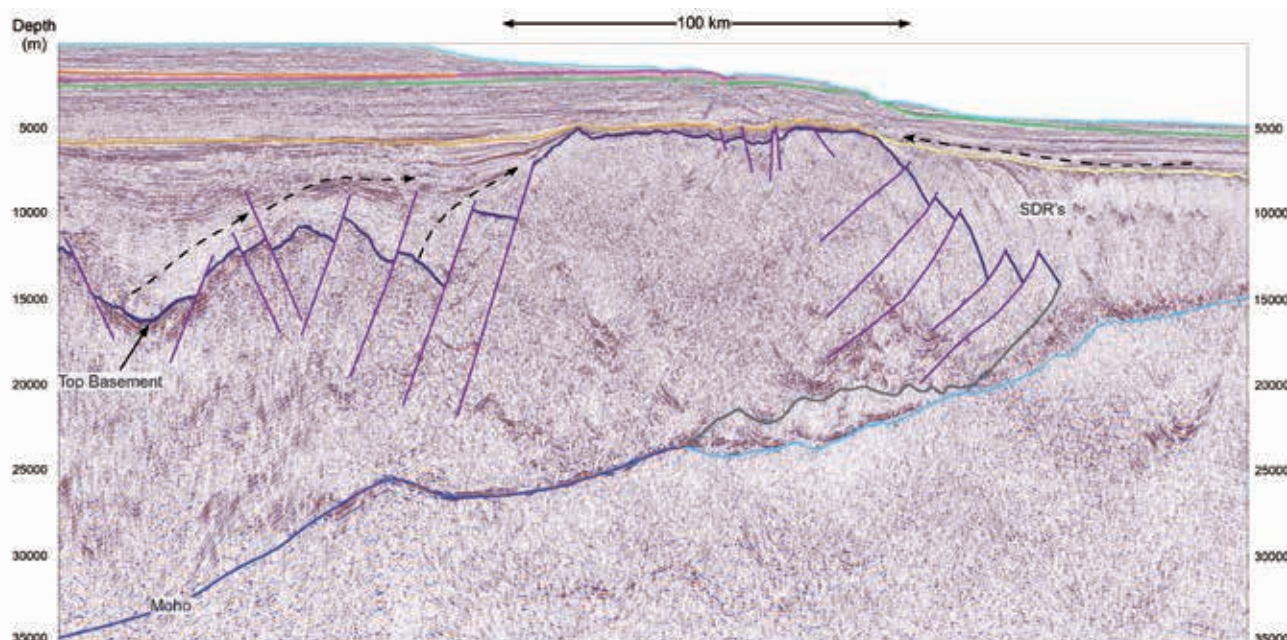
### Gulf of Mexico Basin

The US Gulf of Mexico offshore area is perhaps the most explored margin in the world. This prolific oil-prone region has undergone multiple phases



**Figure 13** Regional seismic line offshore Argentina. The Jurassic Colorado basin has as much as 13 km of basin fill and is situated inboard of the present-day shelf margin and forms a classic 'steer's head geometry'. Seaward of the basin margin is a present-day outer high that separates the older Jurassic basin from the younger southern Atlantic basin.





**Figure 14** Offshore Argentina line showing the outer high that separates the Jurassic and Cretaceous basins along the margin. The regional high is a potential hydrocarbon focus area for hydrocarbon migration out of both basins (dashed arrows).

of exploration and yet operators continue to discover new reserves and play types. With the discovery of the Lower Tertiary Wilcox play there have been roughly 12 BBO discovered in the past ten years in this play alone (Meyer et al., 2005). What is remarkable is the fact that this has been done primarily in US waters and represents only half of the basin. In Mexican water Pemex has had success extending the Perdido trend to the south with recent discoveries which expand the play fairway. With the changes in commercial terms in Mexico and the pending licence round in 2015, foreign operators will be able to explore in the offshore Mexican waters as well as partner with Pemex to participate in drilling leads in the Pemex portfolio.

A critical aspect of mapping and understanding existing and new exploration trends will be the correlation between the US waters, where the majority of well control and calibration are located, to the deep water in Mexico. Since the early 1970s there has been no acquisition of multi-client seismic data in this region and all data acquired are proprietary to Pemex. However, the reprocessing of the University of Texas 2D data acquired previously has been made available for licensing. These data reveal the presence

of the Wilcox trend in Mexico as well as several large structural closures in the Mesozoic age strata. There are multiple play types along the Mexican margin that would be extensions of the prolific onshore and shallow-water fields such as Chacontepoc or Cantrell. The extension of the structural trend of the Perdido fold belt where discoveries in the Wilcox section (Great White and Tobago) have been on production since 2010, demonstrate the commercial viability of the play and the prospectivity of its extension to the south where Pemex has made discoveries in correlative strata (Figure 15). In the deep water along the western margin of the basin regional data reveals three interesting features; 1) the large thickening of the entire stratigraphic section from the central part of the basin to the west, 2) a large structural closure (20-30 km) in the Cretaceous section and 3) the presence of a thick Mesozoic section below autochthonous salt in what would be considered syn-rift strata. These observations suggest that there are multiple untested play types that remain in the Gulf of Mexico Basin (Mexico and US) and demonstrate that even in a mature basin, new data and ideas can reveal significant untested remaining potential (Figure 16).

## Conclusions

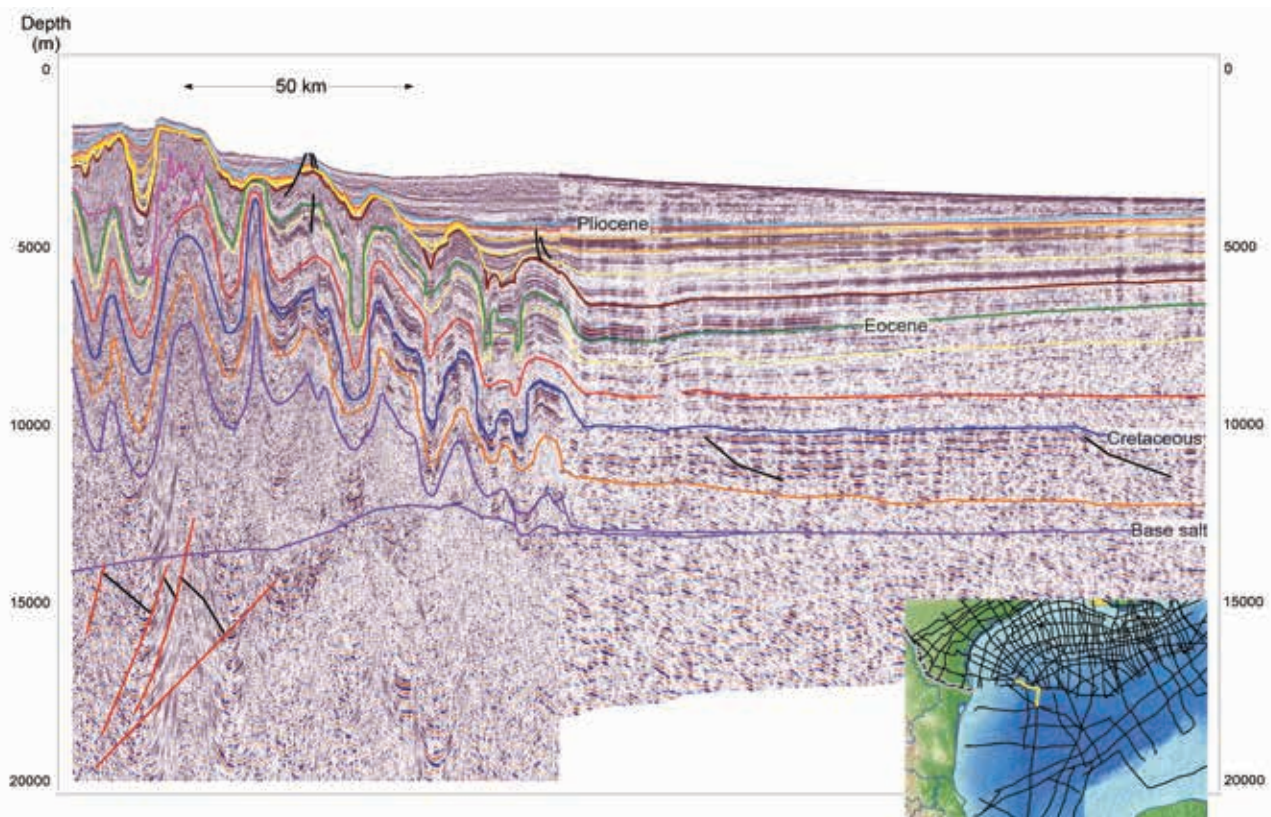
'... Rarely do we find oil in an old basin with an old idea,' Parke Dickey 1958.

These words are truer today than they were 56 years ago. New ideas and technology, the use of proper analogues in frontier areas, and new ways of thinking in mature basins are key components to finding hydrocarbons in areas that have either been overlooked or unexplored. What is apparent is that even with today's extensive data analysis techniques, data coverage, technical capabilities and tools available to geoscientists, there remain large areas of the earth's crust that have yet to be explored and, many of these areas may be in basins that have some of the greatest drilling activity. The renaissance that the industry has observed in the onshore basins with the development of resource plays may be the precursor to new ideas in frontier exploration, field development and appraisal techniques in mature basins or paradigm shifts in basins once thought not to be prospective.

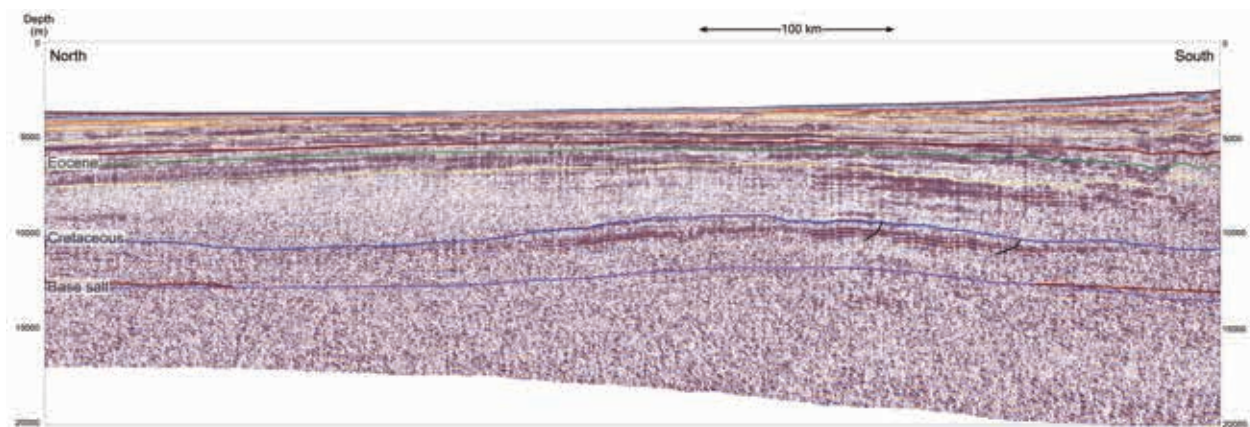
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**Figure 15** Arbitrary seismic transect from the Perdido Foldbelt into Mexican water. The line illustrates the continuation of the producing trend in the Tertiary Wilcox Fm from US into Mexico.



**Figure 16** Regional N-S seismic line across the Mexican sector of the Gulf of Mexico. The large-scale regional closure in Cretaceous strata could possibly be a giant regional trap. The thick Tertiary (Wilcox) section demonstrates the continuation of the productive trend into Mexico from the southern part of US water.

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