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Since the discovery of the giant Tupi-Lula pre-salt complex in the Santos Basin of Brazil, explorers have been integrating new seismic technology advances with the fundamentals of regional basin geology to extend the pre-salt play across the Atlantic margin into deep waters and below the salt off the west coast of Africa.

In 2005, Petrobras drilled a wildcat well on the Parati prospect in the deep waters of the Santos Basin, and encountered condensate gas below a thick layer of salt. The following year, Petrobras and its partners, BG Group and Galp Energia, announced that the Tupi wildcat, drilled to 16,060 ft in almost 7,000 ft of water, flowed at 4,900 B/D of sweet 30°API crude oil, 0.7 sulphur content, and 6.6 MMcfd gas on a ½-in choke. This confirmed that a new geologic play had been discovered below the salt. Over the next few years, exploration efforts continued in this new pre-salt play, resulting in additional discoveries in the Santos and to the north in the Campos and Espirito Santo basins.

Agencia Nacional do Petroleo (ANP) studies suggested that the charge and accumulation models for this new pre-salt cluster area of the Santos Basin contained reserves exceeding 30 billion bbl and possibly as large as 60 billion bbl of oil reserves. Though the thick layers of salt above the oil accumulations create challenges in seismic imaging and exploratory drilling, the salt has also served, through geologic time, as a superb seal that allows thick columns of oil to accumulate and be preserved.

Many exploration companies have already constructed regional geologic and plate tectonic models that recognize that these world-class pre-salt hydrocarbon accumulations off the east coast of Brazil may have counterparts on the conjugate margin of the Atlantic Basin in the deep waters offshore Congo, Gabon, Angola, and Namibia. A geologic model from Cobalt International shows a cross section of the Atlantic rift system that predicts similar geology between the two margins (Fig. 1).

**Reconstructing Geology**

Reconstructing the geology of the basin early in the rifting process shows that 120 million years ago, the Kwanza Basin area offshore Angola appears to have been adjacent to the Whale Park Basin area offshore Campos Basin. At that time, exploration blocks in the Kwanza Basin would have been only 50 to 100 miles away from the area offshore Brazil, where the Jubarte well tested at 14,500 BOPD and the Cachalote well tested at more than 20,000 BOPD. According to this reconstruction, these areas shared common source rocks and perhaps would also contain similar oil accumulations (Fig. 2).

**Integrating New Seismic Technology and Regional Basin Geology Now a Must**

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*[Fig. 1—The Atlantic Conjugate Rift Model. Image courtesy of Cobalt.]*

The question remained: Would the pre-salt areas offshore Angola contain the same thickness of pre-salt sediments and effective reservoir rocks, favorable traps and structures, and massive accumulations of hydrocarbons that were being discovered offshore Brazil? Some early wells drilled offshore Angola below the salt in the 1980s and 1990s contributed a few important pieces to the exploration puzzle.

The Diamond Shamrock Denden 1 well drilled in 1983 and the Mobil Baleia 1 well drilled in 1996 had oil present below the salt, but in low-porosity carbonate rocks; it was deemed insufficient as a reservoir. Also, the ConocoPhillips Falcao 1 well drilled in 1992 penetrated almost 2,000 ft of rich source rock, with up to 9.5% total organic carbon that flowed oil to the surface. These wells were determined to be noncommercial, but they did indicate that a petroleum system was active in the area.

**Determining Viability**

What remained was to determine whether there was a thick enough sediment section below the salt and whether it contained appropriate structures, traps, and reservoir rocks for hydrocarbons to accumulate in commercial quantities. With encouraging in-hand regional geology and petroleum system information that provided the lateral analog to the discoveries in Brazil, explorationists turned to the seismic data to see if the vertical view could confirm a potentially economic play below the salt offshore Angola.

Because of the salt properties, pre-salt seismic data had not produced clear images in the areas of interest. It was deemed insufficient as a reservoir. Also, the ConocoPhillips Falcao 1 well drilled in 1992 penetrated almost 2,000 ft of rich source rock, with up to 9.5% total organic carbon that flowed oil to the surface. These wells were determined to be noncommercial, but they did indicate that a petroleum system was active in the area.

The seismic industry was developing new acquisition techniques to improve the target illumination. Solutions design and modeling for such successful acquisition also took into account local geologic and salt geometries and rock physics parameters.

Similarly, processing technologies were also advancing, which further improved the signal-to-noise ratio and better focused images to create an improved view of the geology below the salt. As the signal-to-noise ratio in the pre-salt or sub-salt regimes is so low, it is imperative to comprehensively remove any contaminating multiple energy chains.

A generalized surface multiple attenuation to successfully predict and remove surface multiples resulting from reverberation within the water layer causing distortions in below-salt images is important. Further, ray path geometries are very complex. Accordingly, construction of comprehensive multiparametric...
earth models, as input to geologically constrained imaging using the two-way wave equation migration, produces improved results. Through the determination of the earth model parameters, anisotropy can be corrected in the seismic imaging to more accurately spatially position events, resulting in additional uplifts in data quality.

The combination of acquisition, processing, and earth model building techniques greatly improve the quality of the seismic image from seafloor to basement. Fig. 3 is a 3D variance cube sculpted close to the water-bottom horizon, which shows near-surface features such as pock marks formed above a channel now buried in the sediment, and positive seafloor topography over a steeply dipping salt ridge. These pock marks are of great interest to drilling engineers because they may indicate an unstable seafloor, where fluids are escaping the seabed.

Applying New Technologies

Exploration companies have identified presalt prospects that they are now testing with the drill bit. In January, Maersk Oil announced that its Azul 1 presalt wildcat in Block 23 of the Kwanza basin had resulted in the discovery of hydrocarbons. The well was drilled in more than 3,000 ft of water, reached a depth of 17,500 ft, and demonstrated a flow capacity greater than 3,000 BOPD from presalt reservoirs. The following month, Cobalt announced that it had identified more than 900 ft of light oil pay in a 1,200-ft column at its presalt Cameia discovery in Block 21 offshore Angola. This well flowed at over 5,000 BOPD and 14 MMcf/D with a flow capacity of 20,000 BOPD from a high-quality thick carbonate reservoir with excellent vuggy porosity. Cobalt is currently drilling an appraisal well on its discovery.

As more Kwanza basin wildcats are drilled to test the extent of this promising new presalt play in western African deep waters, the results will be combined with the latest seismic technology to further develop the new presalt play that began in 2005 across the Atlantic margin in Brazil (Fig. 4). The industry is also discovering that the use of analogs, such as Tupi-Lula’s, to explore across the rift is working with other new plays as well—but in the opposite direction. For example, the discovery of the giant Jubilee complex offshore Ghana and the use of the new deepwater turbidite discovery as an exploration analog have led to the identification of a similar play in deepwater French Guiana across the rift in South America. With each new major discovery, integration of regional geology and seismic data will be useful in reducing the uncertainty in exploring other similar plays across the great Atlantic rift and potentially in other rift systems as well. JPT

John Robert Dribus, SPE, is global geoscience advisor for Schlumberger, a position he has held since 2010. His extensive expertise in exploration, with a specialization in reservoir geology, subsalt exploration, and geologic risk analysis, has been acquired during a 38-year career that began at Mobil Oil as a uranium field geologist, offshore exploration and production petroleum geologist, and leader of an exploration team in the Gulf of Mexico. He also has more than 15 years’ experience exploring below salt and in deep water, and has worked on exploration projects in the Gulf of Mexico, Greenland, the Black Sea, the Red Sea, Brazil, Angola, Ghana, and Gabon. Since joining Schlumberger in 2000, he was the Gulf Coast Data and Consulting Services manager, and global director of geoscience training until 2009.