Argentine Basin: the new search for oil in one of the least explored basins on planet Earth

Neil Hodgson[1*], Steve De Vito[1], Karyna Rodriguez[1] and Mike Saunders[1] present the characteristics of the Argentine Basin that is being opened up for exploration.

A remarkable property of the Argentine Basin, located in the Atlantic west of Argentina, is that within its 450,000 km^2 of extent – not one exploration well has been drilled. Compared to the world's other continental passive margins, this makes it the most unexplored high potential basin on Earth. Partly this is owing to a lack of modern seismic data in this basin, with exploration previously focused on rifts that lie on the continental shelf. Yet also it is unexplored because of the lack of industry access to the area in the last 10-15 years since deep water drilling technologies have become widely available.

However, this is all about to change. The Argentine government is opening the area to international exploration investment, at the same time as a new 35,000 km 2D seismic programme is being acquired by Spectrum in 2017 (Figure 1). This survey aims to reveal the fundamentals of multiple oil-prone hydrocarbon systems in the basin, which include Pre-Atlantic rift plays,

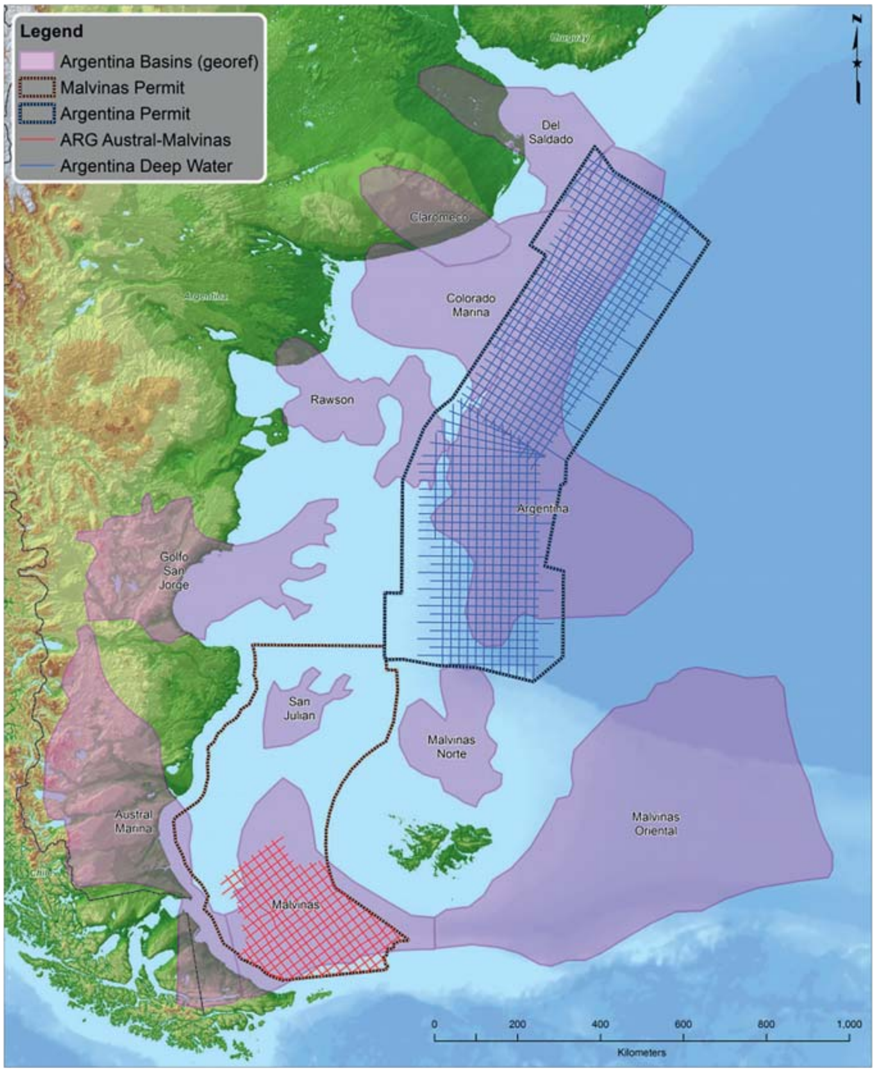

Figure 1 location map of the Argentine Basin, illustrating the seismic data being acquired by Spectrum in 2017. Argentina Deep Water Northern Phase 1 (ca 20,000 km 2D) acquisition complete by October 2017.

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[1] Spectrum
[*] Corresponding Author, E-mail: neil.hodgson@spectrumgeo.com

syn-rift and post rift plays in upper and lower slope settings, in addition to a base of slope/basin floor play that has the potential for ‘super-basin’ resource.

The Argentine Basin is a passive margin basin barely distinguishable from the Oriental del Plata Basin to the north in Uruguay. Exploration has been so limited off this shelf that the nearest truly deep water well to the Argentine Basin lies at the northern end of the Oriental del Plata Basin, where the Raya-1 well was drilled by Total in 2016. This was a ground-breaking exploration well as it was drilled in 3414 m of water, some 240 m deeper than the previous world record water depth. To drill this well required an innovative drilling operation, pushing the industry’s technological capabilities further in a manner that paves the way for the next generation of exploration in global deep water plays. However, despite the heroic effort, the Raya-1 well was only drilled to an Early Tertiary target, and no information was gleaned on the basin’s primary hydrocarbon systems in the Cretaceous. And it is in this Cretaceous section that the main potential of both the Oriental del Plata Basin and the Argentine Basin lies – in an oil prone base of slope and basin floor hydrocarbon system that is only now being explored with dramatic success elsewhere in the Atlantic.

Deep water exploration on the South Atlantic’s passive margins has made significant progress since Triton’s Ceiba discovery offshore Equatorial Guinea in 1999. Yet it was Kosmos’s Jubilee Field discovery in 2007 in Ghana that heralded a decade of drilling for analogue stratigraphically trapped slope channel plays on both the West African and South American margins. Even though Jubilee is now known not to be a simple slope channel stratigraphic trap and to be characterized by structural slope terracing to provide the depositional and trapping architecture, a number of giant discoveries have been made in this play including those in the Sergipe Basin of Brazil (Barra et al. discoveries >2bn Bbls), Guyana (Liza et al. discoveries >2bn Bbls) and Mauritania / Senegal (Tortue et al. discoveries >3bn BOE).

However, in 2017 a remarkable well was drilled by Kosmos offshore Senegal testing the Yakaar prospect, a Cretaceous basin floor fan play at the toe of a sand-rich constrained channel system. This is the first time in the South Atlantic that these Cretaceous Basin floor sediments have been tested, as the water depth they lie in is usually >3000 m. However, the Cape Verde mantle plume keeps the Mauritanian Ocean crust high, lifting the targets into drillable water depths. The basin floor fan deposits were turbiditic cascades of mixed sand and mud that were modified during transport by sea bottom contourite currents running across the slope (i.e. coast parallel). These contourites cleaned out the fine muds, leaving a dune sea of high net-to-gross sands behind. The Yakaar-1 discovery is reported to have potential resources of ca 2.5bn BOE demonstrating the true value of exploring this play, and yet it may itself be eclipsed by other exploration drilling on the Mauritanian/Senegal margin within the next few months.

In this play, with base of slope-basin floor Cretaceous clastic fans sitting at the mouth of sand rich slope channel systems, the most likely hydrocarbon phase is not gas (as in Mauritania / Senegal) but oil.

Regional geology and exploration

In an extraordinary paper by Franke et al. (2007), based on very limited and poor quality academic data from the 1980s across the Argentine Basin, the spatial distribution of crustal architecture has been mapped along the margin. In a west-east sense across the margin, the continental crust appears to thin from >30 km to zero in just 10-20 km, where it is replaced by thick Seaward Dipping reflectors (SDRs), prior to becoming classic MORB type Oceanic Crust 6-8 km thick farther out to sea. The SDRs here are volcanic, comprising flood basalts that have erupted initially over thinned continental crust, but then cooled and rotated into underlying magma chambers, creating space for the next flood basalts erupting from spreading centre, to flow on top, and so on repeating this process until a suite of SDRs are created. This spreading centre was, we suspect underlain by a hot up-warping mantle, hence the spreading centre was kept above sea level for some considerable time allowing a wide SDR belt to be deposited. Eventually, the spreading centre is not supported and subsides allowing a marine transgression which causes erupted basalt to be quenched on eruption, depositing MORB type basalts. The variation in mantle support along spreading centres due to dynamic topography may be the cause of ‘magmatic’ and ‘amagmatic’ margins (Hodgson and Rodriguez, 2017).

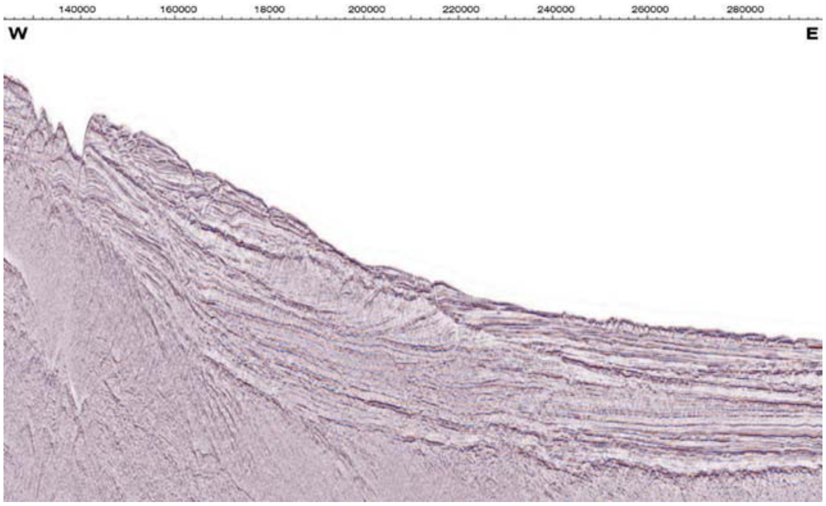

Figure 2 West-East Fast track PSTM example (TWT) from the 2017 Seismic Acquisition offshore Argentina. Line length 170 km. The thick sediment package, including Early Cretaceous basin floor fans, over Aptian Source rock and Tertiary contourite drifts all sitting over Continental crust to the left. SDR central and Oceanic Crust to the right are well imaged even on this early processing product.

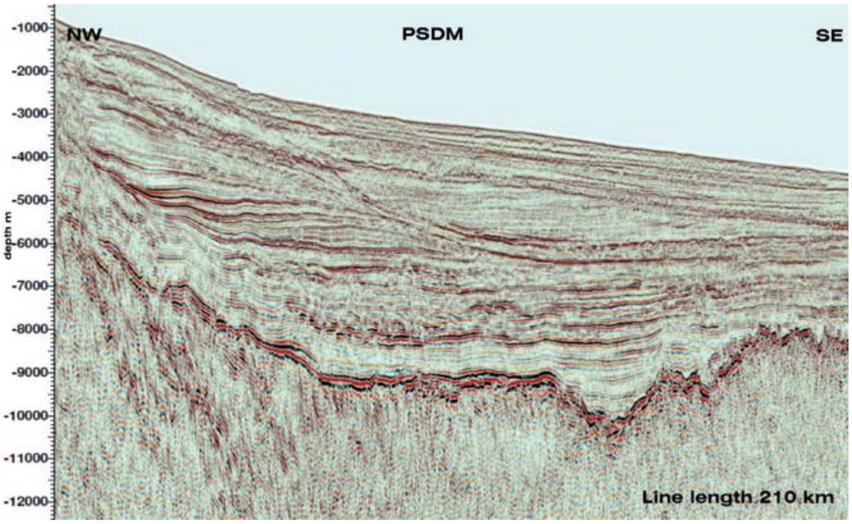

Figure 3 PSDM line from Oriental del Plata basin, Uruguay. This line shows basin floor fans dipping up in a seaward direction, contourite drifts and the character of the underlying Aptian source rock.

Franke et al. not only mapped crustal architecture, but also provide post-rift sediment thickness maps for the basin. While this data is too loosely constrained to accurately evaluate the basin for hydrocarbon leads/prospects, we have been able to use these maps to basin model hydrocarbon charge as we will see below.

2017 seismic data

An example of fast track PSTM data in TWT from the 2017 seismic acquisition is shown in Figure 2. The acquisition comprised a 12-km cable towed at 15 m, a 4260 cubic inch source towed at 8 m, 12.5 m shot point and 15 seconds record length. Processing of Figure 2 is very fast-track PSTM. However, the final product will be broadband PSTM and PSDM.

Reservoir

Although the shelf edge, slope and basin floor are unexplored in Argentina, the shelf itself to the east has received attention from explorers, seeking oil in rift grabens that cross the Argentine shelf. The major rifts include the Salado Basin in the north, and its neighbour the Colorado basin, and the San Jorge basin to the south (Figure 1). These basins are understood to have developed during the Mesozoic period as a series of major rifts that cross the Gondwanan continent representing a Permian-Triassic attempt to fragment the super continent. Such Gondwanan rifts preserved the Karoo sequences of intra-cratonic lacustrine source rocks, and clastic rich fluvial deposits that can be traced from India through Tanzania and Namibia/South Africa (the conjugate margins to Northern Argentina) and so into the Salado and Colorado basins. These basins were reactivated in the Jurassic period and infilled partly by Jurassic syn-rift sediments including lacustrine source rocks.

Yet the Atlantic rift finally separated in the Early Cretaceous period, with a north-south orientation orthogonal to the Jurassic and Karoo grain, such that during rifting and subsequent drifting, the Colorado and Salado basin synclines became conduits for sediments to cross the continental shelf and reach the shelf edge (Raggio et al., 2011; Loegering et al., 2013). Legacy seismic data and well penetrations in these rifts find shallow marine and delta top sediments in coarse clastic prograding clinoforms that cross the shelf right to the shelf margin, from where sediments will have poured down the slope in constrained sand channels to either pond on intra-slope terraces (Jubilee like), or accumulate at base of slope and spread out across the basin floor (Yakaar like).

While the basin floor was flat or sloping away from the coast in the Aptian, loading and cooling of the underlying crust or oceanic plate and the relative buoyancy of young oceanic crust ensures that the current dip of the Albian overlying the Aptian source is upwards out to sea. Basin floor fans are put into a trapping geometry facing away from the high risk slope channels creating giant prospects controlled by tilting tectonic plates.

In academia the field of study of contour parallel currents has been gaining momentum in recent years since the discovery of their potential for reservoir quality enhancement (e.g. in the >25bn BOE Rovuma basin). Turbidite and contourite depositional systems occupy a continuum from pure contour parallel systems, which rework pre-existing or pelagic sediments, through to ‘mixed systems’ where turbidity flows moving down slope interact with contourites running contour parallel to pure turbidity currents flowing down dip with no cross-current interference. While slope and deep-water sediments have been visualised mainly through turbidity current models, there is an increasing awareness that mixed systems are more common, and that these systems are more complex, and potentially more exciting than we had previously imagined.

Such mixed systems have been studied in part in the Argentine Basin and in more detail (on industrial 3D) in the Oriental del Plata Basin of Uruguay. While Lower and Upper Cretaceous contourite drifts (usually but not exclusively silt and mud rich) are visible in Oriental del Plata in Uruguay (Figure 3), the parent turbidite channels/fans comprising the sand rich turbidite mother deposits are visible as channels or sand sheets (dune fields) even on 2D data at the base of the sand conduit slope channels in offshore Uruguay.

Until the 2D data acquired by Spectrum in 2017 is processed, no data of sufficient quality is available to map plays in the Cretaceous of the Argentine basin. However, at the base of slope below the Salado and Colorado rift systems, where coarse clastic have demonstrably been poured into constrained channels, we expect to see similar mixed system behaviour, and the development of sand rich channels and fan/sand sheet deposits, sealed by migrating contourite drift materials. Demonstrating the presence of these, in the way that Spectrum has in the deep-water Cretaceous section of Uruguay, will be a key function for the 2017 seismic campaign.

Charge

Source presence and effectiveness (generation, migration and timing) in the Argentine Basin will be considered by some to represent a significant uncertainty. However, the evidence that there is no effective source is non-existent while the evidence that there is a working oil system is rather compelling. While it has often been said the there is no source rock south of the Walvis ridge, the Aptian sample from DSDP 361 deep-water South Africa and the three penetrations of thick >100 m Aptian source rock and indeed recovery of oil from Aptian sands in Namibia by HRT in their 2013-2014 drilling campaign has somewhat shown that to be a less than useful model.

By splicing seismic lines from Argentina and the Orange Basin in South Africa, we can match an Aptian seismic sequence from Namibia that is anomalously low amplitude and conformably bedded, sitting over SDRs, with an identical seismic sequence on the Argentine side (Figure 4). The implication we draw is that the Aptian is present on both conjugate margins because the Aptian basin was closed, restricted anoxic and therefore represents a source rock unit. Available equivalent seismic in Argentina, when spliced to Orange Basin sections from the South African Margin shows the same Aptian seismic sequence at the base of the sedimentary section over the SDRs, onlapping on to continental crust and oceanic crust respectively.

Having established the likely presence of Aptian source rock in the basin, we have used the distribution of continental crust, SDR and oceanic crust interpreted by Franke et al. (2007) to model variation in heat-flow or geothermal gradient across the basin. We assumed conservatively that continental crust might be associated with geothermal gradients of 30°C/km, SDR’s with 25°C/km, and oceanic crust with 20°C/km. These are unsubstantiated estimates, assuming that the fraction of potassium in the crust dominates heat flow. As passive margins are being drilled, however, we are finding many examples where more distal penetrations over oceanic crust have higher geothermal gradients than proximal penetrations (Kenya/Tanzania, Mauritania/Senegal, North Gabon/ Equatorial Guinea), suggesting that these estimates may not be correct. The reason for these variations is not fully understood. Mauritania/Senegal may be owing to Cape Verde Plume activity, North Gabon may be owing to complex transform faulting. In the Punta del Este/Argentine basin, however, the oceanic crust is significantly deeper than one would expect for the Crust of Early Cretaceous age even compensated for sediment loading and crustal thickness (i.e. a –ve residual (Hoggard et al., 2016)). This suggests at least that there is no mantle +ve thermal imprint on this basin.

Applying these thermal gradients to sediment package thicknesses estimated by Franke et al, and assuming that the Aptian source rock starts to generate oil at ca 90°C, we model that the Aptian along this whole margin in the basin and ca 1/3 up the slope will be mature for oil generation, yet the thickness of sediment never allows the Aptian to be mature for gas generation (Figure 5). Perhaps the final evidence available for de-risking the presence of a working hydrocarbon (oil) system is the detection of a number of sea-surface oil slicks along the margin on optical satellite data.

Additional plays

Although the major play in this basin comprises basin floor fans, dipping up in an out to sea direction, charged by underlying oil mature Aptian sources, several other play systems are considered highly prospective.

Terraces on the slope are observed in most legacy data, and here mixed system plays can leave very high N/G sands beneath contourite drifts on terraces that may be charged either vertically from underlying Aptian or from out of the basin from Aptian down dip. It may be on such terraces that proper Jubilee analogues may be found.

Recent discoveries of giant oil fields in constrained channel systems in Sergipe Brazil and Guyana, suggest that in certain circumstances up-dip bypass in slope channels can be achieved. Our working hypothesis is that that such bypass may be controlled by the steepness of the upper slope, but sediment supply mechanisms may play just as great a part in this. Only when we see and work the new broadband data from the Argentine Basin will we be able to suggest analogues to Sergipe discoveries.

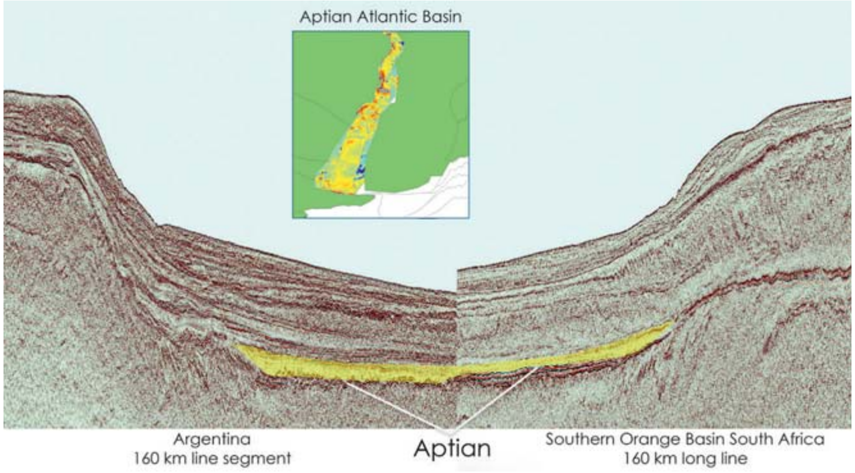

Figure 4 Splice of seismic data from South Africa and Argentina to demonstrate the correlation of Aptian source rock across the Aptian basin.

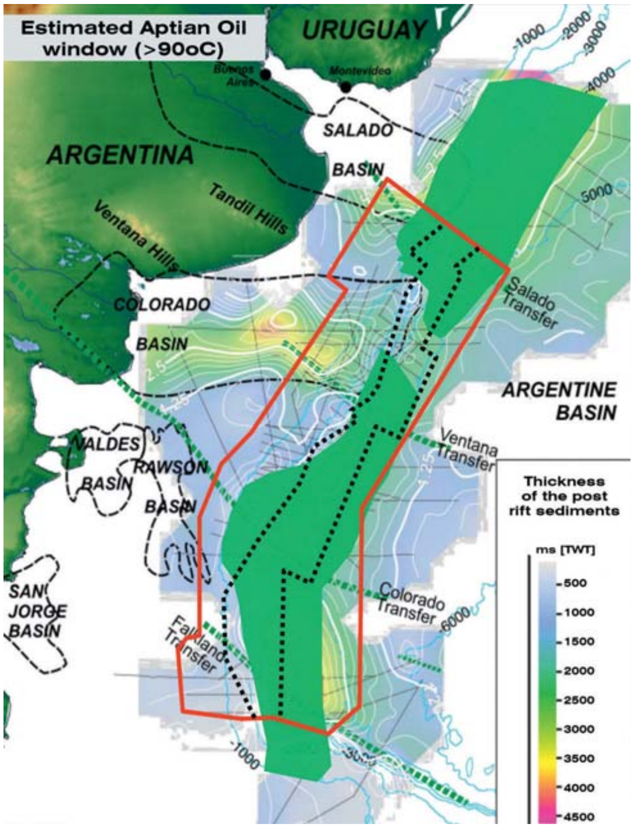

Figure 5 Initial Basin Modelling of Aptian source rock using data from Franke et al. (2007).

Not imaged by current datasets, we also envisage fractured quartzite plays equivalent to the Cape Fold Belt Table Mountain Group discovery in the GA-A well in the Pletmos sub-basin in South Africa (Rodriguez et al., 2017) and plays associated with slope syn-Atlantic-rift rotated fault blocks, and potentially Jurassic or even Karoo rift plays. Indeed wells drilled along the southeastern margin of the Colorado Basin have encountered upto 1200 meters of synrift section, including two early Cretaceous lacustrine shales that were mature for oil generation in the upper synrift, and from one well a sample of 39° oil was recovered, typed to a Jurassic lacustrine source in the lower synrift, whilst other pennetrations have encountered Permian marine source rocks also mature for oil.

Summary

An analysis of the play elements in the Argentine Basin suggest that a working hydrocarbon system with Aptian source, buried to be oil generative, charging overlying basin floor mixed system fans, or slope channels should be present all along the Argentine basin. Sand entry systems at the mouth of the Salado, Colorado and San Jorge Pre-Atlantic rift basins would be focused sand entry points. However, such sands might be reworked, or there may be too much sand in such locations such that plays systems are more likely to work in less sand rich areas.

In such an untouched basin, establishing the veracity of the hydrocarbon play elements is paramount early in the evaluation period – a task the 2017 2D seismic data is well suited to. Establishing the presence of the candidate source rocks, mapping these out and understanding the nature of the underlying crustal architecture to estimate heat flow, combined with a sequence stratigraphic analysis of the overburden, can be simply achieved with these new data. This can be combined with a reservoir oriented reading of the data (which will be broadband so ideal for sedimentological understanding) in terms of mixed system clastic deposition to establish the presence of the remaining play elements trap and reservoir.

The detailed imaging on the preliminary fast-track data seen so far tells us that the final broadband PSTM and PSDM data will be more than fit for purpose for these tasks, and are likely to bring new insights and surprises that we can't imagine as yet. One thing is surely set to change – it will not be long before the first wells are drilled into the Argentine Basin and, with a fair wind, the first giant oil fields are discovered.

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