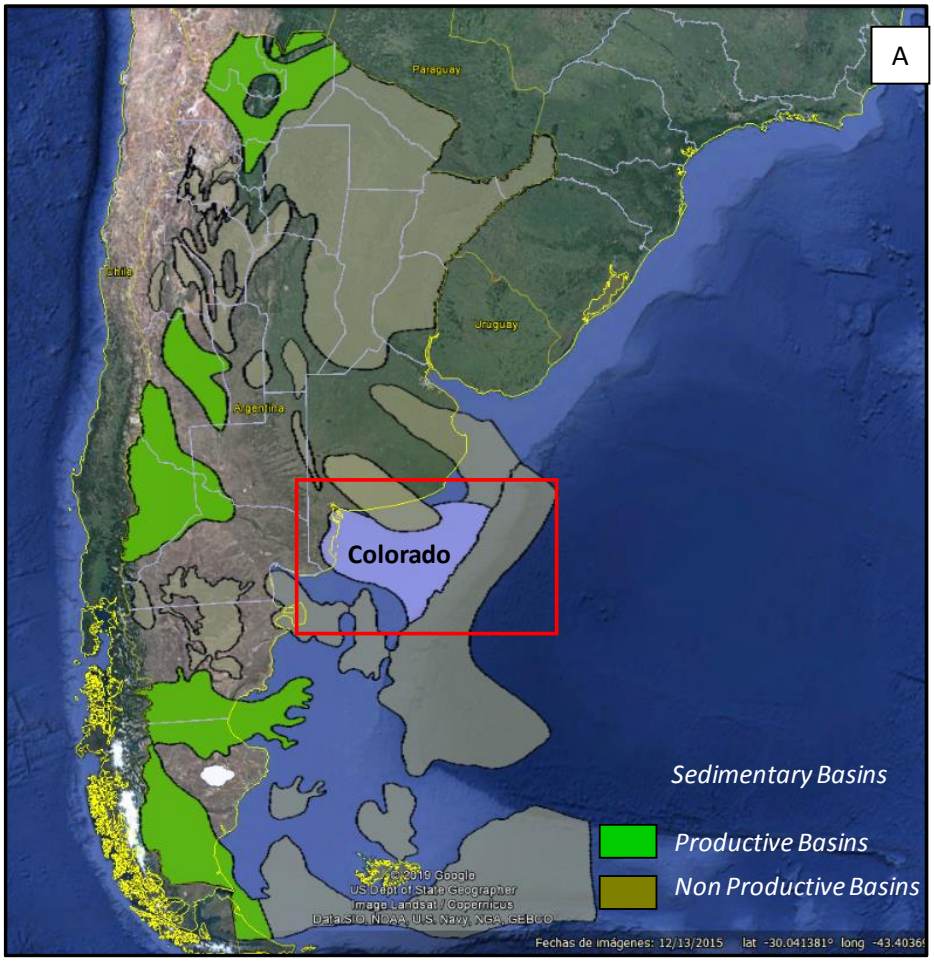
Colorado Basin, Offshore Argentina

Exploration Review

Located in southeastern part of Argentina, it has more than 125.000 km2 extension, with an onshore and offshore (115.000 Km2) portions (Fig. 1 a & b). Three major depositional centers were identified within the Colorado Basin, of which the deepest is supposed to hold up to 50000 ft. of sediment (Bushnell *et al.* 1999).



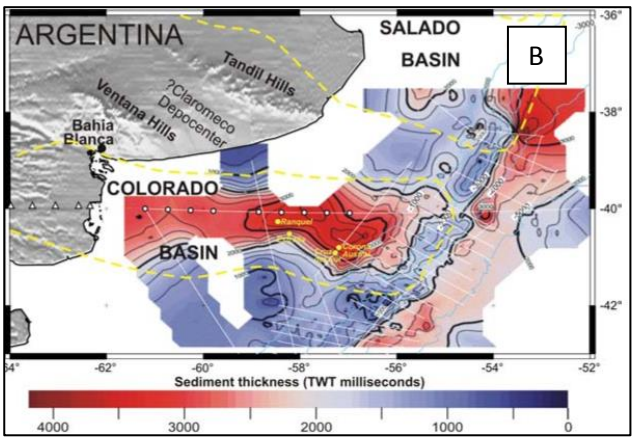


Fig. 1 a-Argentina´s sedimentary Basins. Colorado basin main location in red and b- sedimentary thickness in milliseconds (Mod. from Dieter *et. al*, 2006)

Exploration History

The basin has more than 70 years of exploration history, where 27 wells were drilled, 9 in onshore and 18 in the offshore section (Table 1 and Fig.2).

Several 2D seismic lines were acquired in different campaigns, and more than 2000 Km2 of 3D seismic (Fig. 2).

Year	Company	Well ID	TD m	Location
1946	YPF	Pedro Luro-1	3278	Onshore
1948	YPF	Ombucta	1836	Onshore
1960	Shell	Elvira-1	953	Onshore
1960	Shell	La Blanqueada-1	944	Onshore
1960	Shell	Lagunas Dulces-1	442	Onshore
1960	Shell	Oyola-1	861	Onshore
1960	Shell	O'Connor-1	654	Onshore
1961	Shell	C.O-1	3394	Onshore
1961	Shell	Los Gauchos-1	N/D	Onshore
1970	Hunt	Ballena	4402	Offshore
1970	Hunt	Delfin	2515	Offshore
1970	Hunt	Pinguino	2268	Offshore
A to I (9 wells)	Phillips/AGIP		from 858 to 3997.	Offshore
1977	YPF	Puelche	4063	Offshore
1977	YPF	Ranquel	4466	Offshore
1994	Union Texas	Cruz del Sur	4288	Offshore
1995	Union Texas	Corona Austral	3724	Offshore
1995	Union Texas	Estrella	3546	Offshore
1996	Shell	Pejerrey	3003	Offshore

Table I. Detailed Well list drilled in offshore and onshore sections of the Colorado basin (Enarsa, 2008).

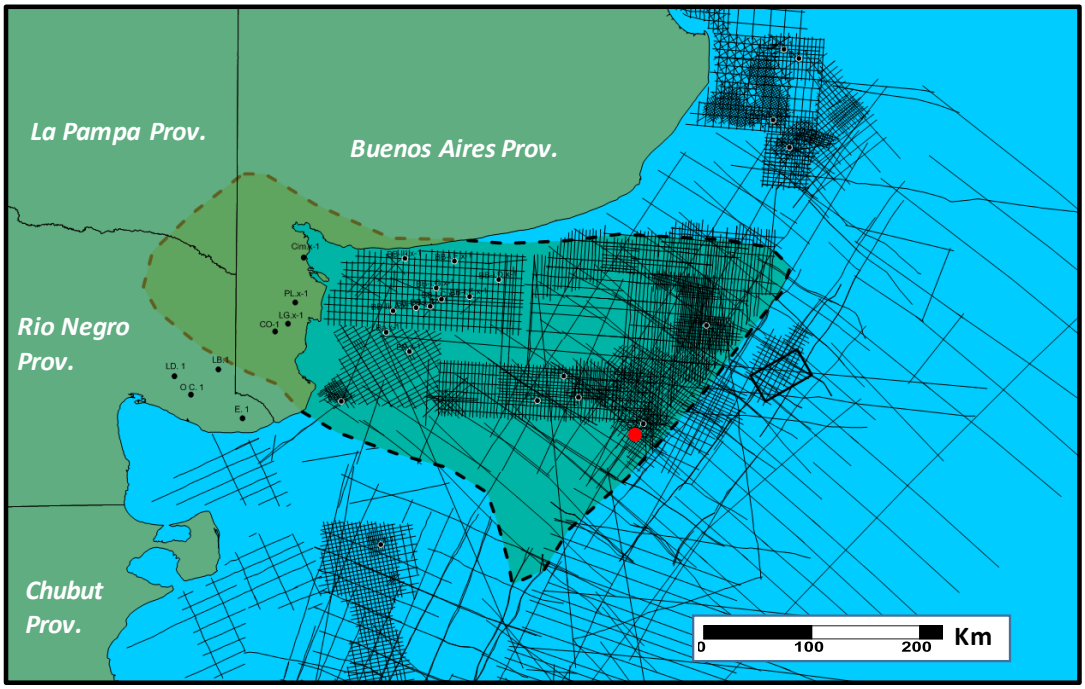


Fig. 2. Wells, 3D and 2D seismic information of the Colorado Basin. In red *Cruz del Sur* well location.

All wells were dry, but oil samples have been recovered from the Cruz del Sur x-1 well, proved an active petroleum system in the Upper Jurassic and Lower Cretaceous rift sequence (Fig. 2)

Regional Geology

The Colorado Basin exhibits a complex history that makes it difficult to examine an onset of rifting that resulted in the final formation of the basin (Tankard *et al*. 1995). Following the Palaeozoic dominantly compressional setting, rifting began in the Early Jurassic along the southern margin of Africa and progressed southwestwards in Patagonia (Urien et al. 1981).Within this first phase of extension the San Jorge Basin was formed in a backarc environment and the basin became restricted in the mid-Jurassic (Urien et al.1981; Dalziel et al. 1987). Probably the Colorado Basin region was affected by this extension phase as well.

In Late Jurassic–Cretaceous, immediately before and during the break-up of the South Atlantic, extension propagated inboard and was widely distributed (Uliana et al. 1989). A linked system of NW–SE orientated basins, associated with a northwest-trending dextral shear system (Tankard et al. 1995) developed along the shelf, including the Colorado Basin (Kelley & Light 1993; Urien et al. 1995). Whether this stage was a renewed period of rifting or a continuation of Triassic/Jurassic extension is still a matter of debate (Light et al. 1993). The final opening of the South Atlantic took place in Early Cretaceous time (e.g. Rabinowitz & La Brecque 1979; Unternehr et al. 1988; Nürnberg, D. & Müller, R.D., 1991; Lawver et al. 1998) with inferred opening ages for Argentina/South Africa ranging from 127.7 to 135.5 Ma. Most plate tectonic reconstructions describe the opening as a combination of complex rift and strike-slip faults and a stepwise, northward-propagating rift for the South Atlantic.

Stratigraphy

The pre-rift substrate at the basin limits is formed by intrusive and metamorphic rocks from Precambrian and lower Paleozoic times (Fig. 3).

In the rest of the basin, the basement for the Jurassic-Cretaceous sediments is formed by Permian continental black shales (Fig. 3 and 4). Beneath these, were deposited Permo-Carboniferous diamictite.

The black shales were drilled by *Puelche* well (YPF S.A.), with a partial thickness of 1500 m.

After a well-defined angular unconformity, a Mesozoic pre-Maastrichtian sequence was deposited, that can reach more than 6000 m thickness in axial zones (Sin-Rift and Sag stages, Fig. 5)

The basal section called Fotín formation is composed by alluvial conglomerates, mostly restricted to NW-SE half grabens, with 2000 m thickness according with the seismic information.

The upper part of the sequence, called Colorado formation, was divided in two sections, the lower is composed by continental deposits (in drilled positions) and the upper with better reservoir conditions, is composed by coastal deposits.

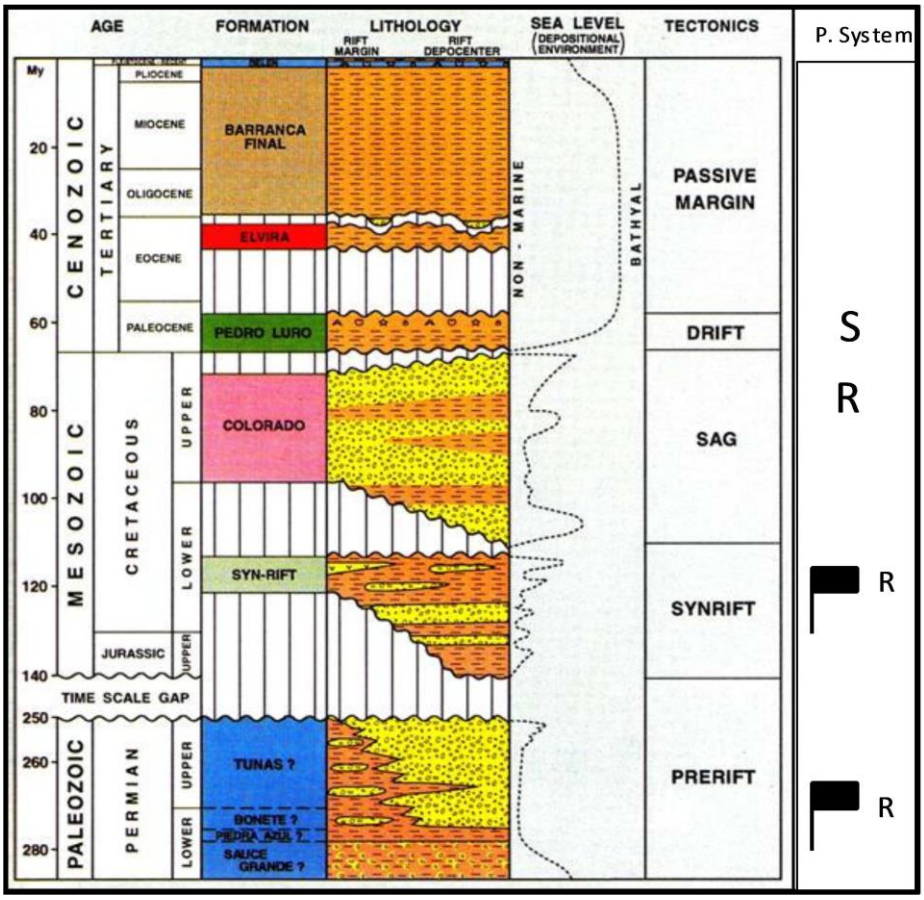


Fig. 3. Chrono stratigraphic chart of the Colorado Basin (Mod. from ENARSA, 2008). Includes petroleum system, facies and tectonic phases (S: seal, R: reservoir, Flag: source)

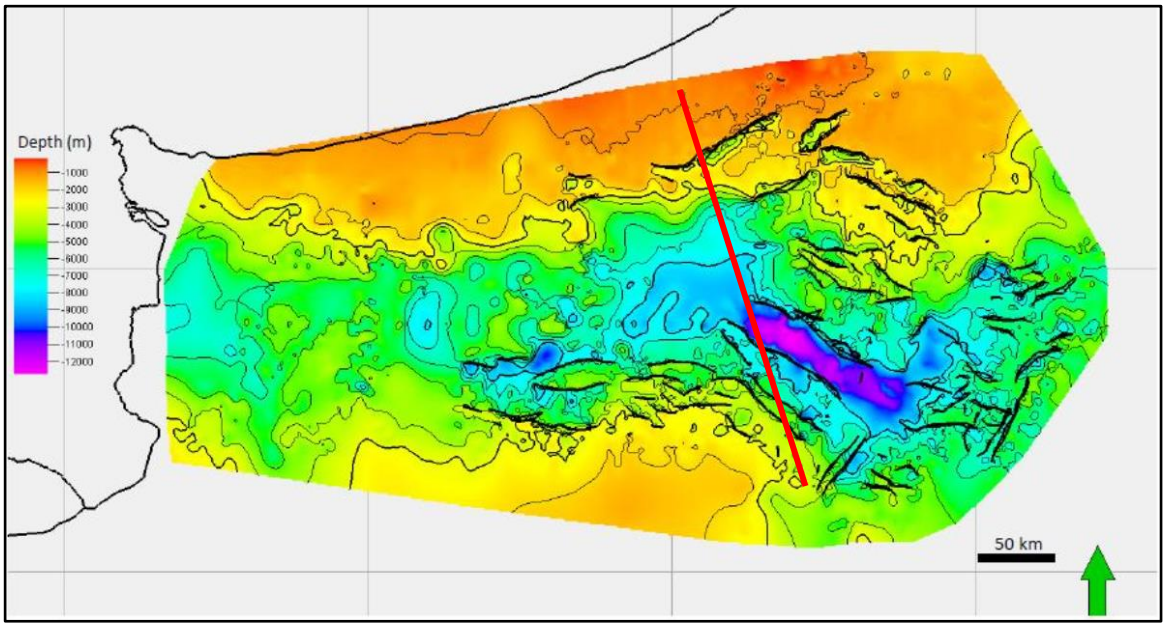


Fig. 4. Depth Structural map of the Pre rift (Permian Basement), (Loegering, M. J. et al, 2013). Red line indicate the position of figure 5.

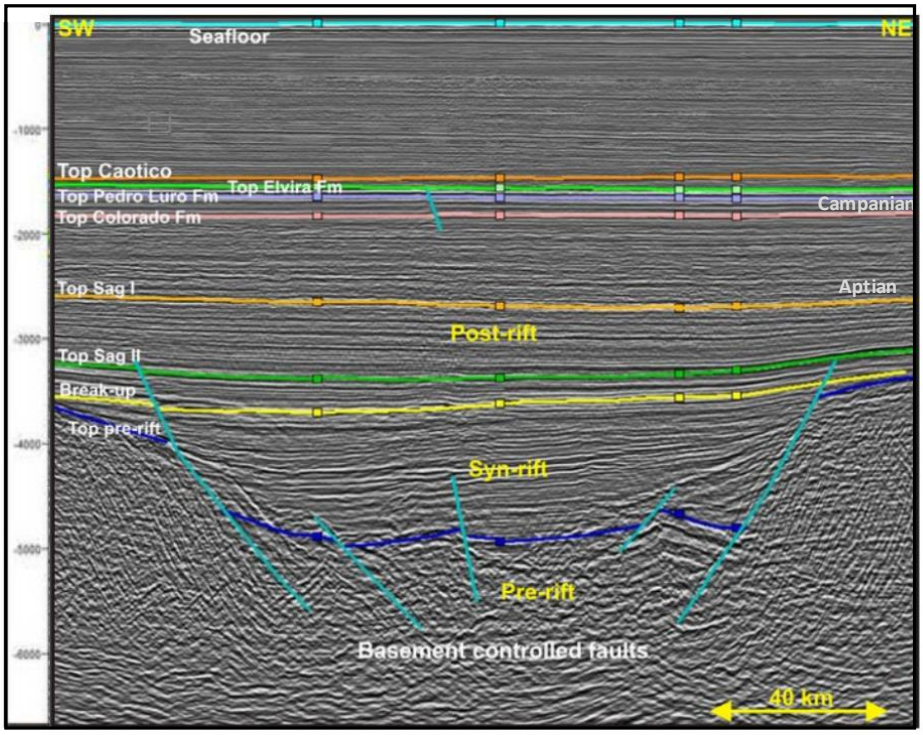


Fig. 5. Schematic NW-SE section based in 2D interpretation showing the main stratigraphic units, (Loegering, M. J. et al, 2013). Depth in ms. Location in Fig. 4

The Albian Cenomanian deposits are expected marine facies, from deltaic to turbiditic in the slope part of the basin.

The upper part of the sedimentary column (Maastrichtian-Cenozoic) is composed by marine sediments (shallow platform), up to 2500 m thickness.

Petroleum system

Source rocks

The Cruz del Sur-1 well recovered a small amount of good quality (39° API) moveable oil from an Early Cretaceous syn-rift sandstone reservoir (Fig 2). The oil is believed to be sourced from Permian shale, and Paleozoic strata are imaged on the seismic data as a parallel bedded pre-rift sequence in the offshore Colorado and Salado Basins.

The geochemical analysis performed in Puelches well indicates marginal conditions for dry gas generation in this section of the basin for the Permian lacustrine shales.

The upper Permian section In the Estrella well, indicates oil potential generator with TOC values around 3.4%

A Neocomian source rock with some hydrocarbon potential was also encountered in the Cruz del Sur-1 well, but was immature at the well location. A 25 m-thick source interval was reported to have an average TOC value of 2.4%. These source rocks are more deeply buried in the center of the Colorado Rift, and could source hydrocarbons which migrated into rotated fault terrace plays, which are present along the basin margins. The Colorado Basin is separated from the Atlantic margin by an outer high. This high could

also access a syn-rift source rock kitchen (Fig. 6)

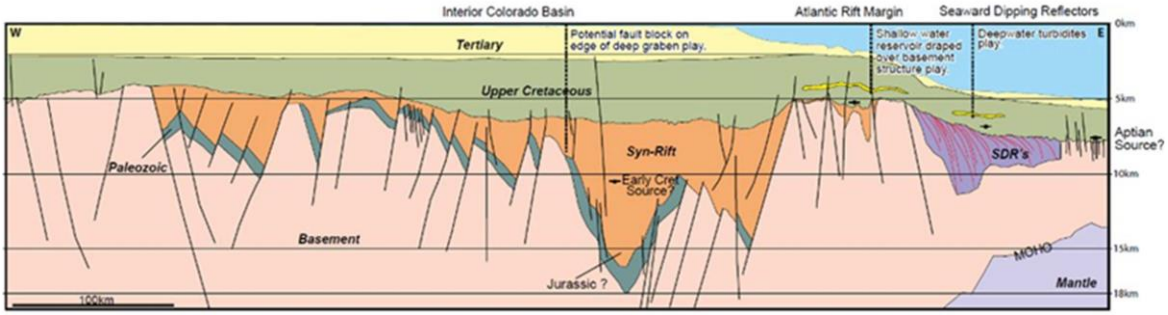


Fig. 6. Schematic E-W section based in 2D interpretation showing the Early Cretaceous source rock position (Horn *et al*., 2015).

The "oil seeps" detecting by radar images and the presence of thermogenic gas in samples of the bottom sea, are a strong indicator of an active petroleum/s system/s.

Reservoirs

The older rocks with reservoir conditions detected by several wells are the Permian conglomerate sandstones, with low porosities due to the high compaction.

In some places with strong deformation, could constitute natural fractured gas reservoirs.

The Syn rift section presents sandstones deposits with porosities from 10 to 15%, but with high argillaceous matrix.

The best reservoir conditions were registered in the Colorado formation, with porosities from 22 to 30%. In the western part of the basin, these sandstones were deposited in deltaic and fluvial environments (Enarsa, 2008).

Seals.

The intercalated shales at the top of the Syn rift section are potential local seals.

The regional seal for the Colorado formation (main reservoir), is the Pedro Luro formation (bathyal shales, clayey to marly sediments)

Traps

There are two main styles.

In the continental platform, the basement highs and 3-way closure against fault of the Syn rift section are considered potential traps (Fig. 6).

Rotated fault blocks with northwest oriented lineaments is the main structural feature in this section.

In the slope zone, big structures (hundreds of km2) could generate variated type and size of traps (Fig. 7).

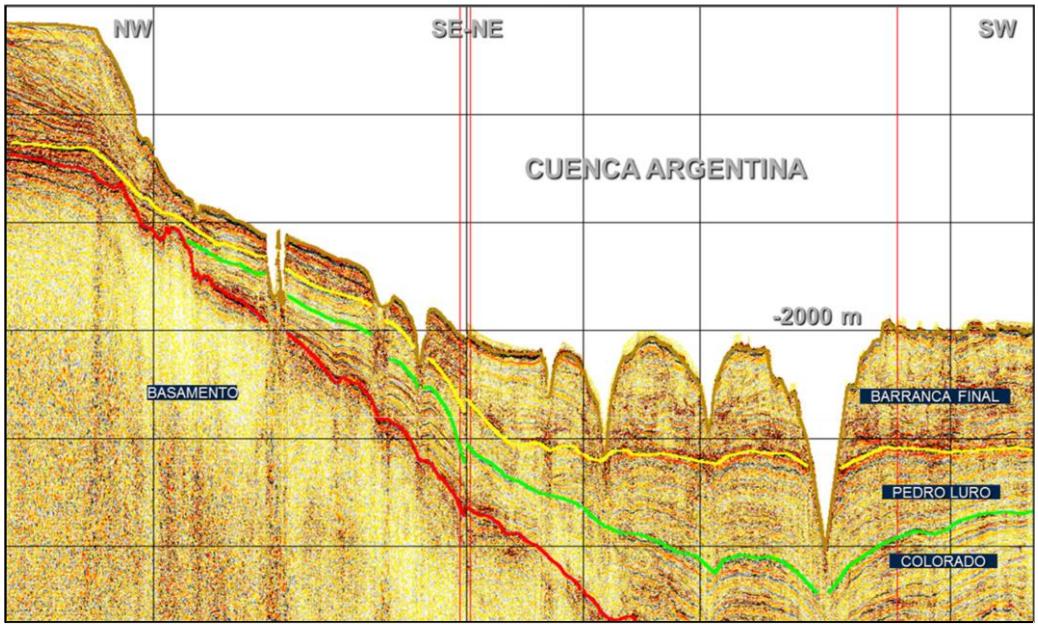


Fig. 7. NW-SE 2D interpreted line, showing the structural configuration (Enarsa, 2008).

Exploration potential

Three main plays were identified:

Rift margin Play

The Colorado Basin is separated from the Atlantic margin by an outer high (Fig. 6 and 8). This high could also access a syn-rift source rock kitchen. Subtle closures have been imaged above the syn-rift faults at Early Cretaceous level over this high and later small reactivations caused faulting extending up to the Cretaceous level to allow migration into potential shallow water reservoirs. Bright, structurally conformable amplitude anomalies have been identified by YPF over at least one of these large Cretaceous level closures in their previously-operated Colorado blocks. The prospects lie in shallow water, and have good access to Neocomian source rocks sitting in the oil window (Argentina Energética, 2009).

The continental Slope Play

The seismic interpretation allowed the identification of big structural 4-way closure and 3-way closure against fault potential traps, conformed by basement blocks, with closures of hundreds of km2 (Fig. 9).

The reservoirs (Cretaceous) are platform and turbidity clastics.

The potential source rocks (Cretaceous and Jurassic), were originated in lacustrine and marine environments and the petroleum system would have adequate timing.

The potential resource for each structure is 2000-3000 MBOE

(Argentina Energética, 2009).

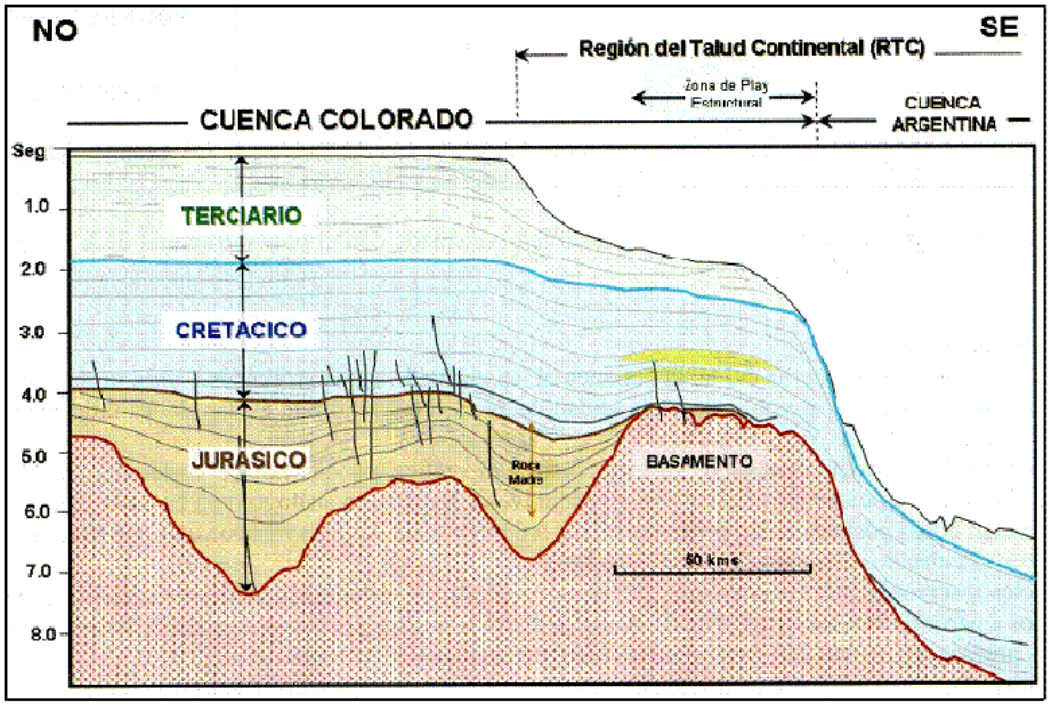


Fig. 8. Schematic cross-section showing the rift margin play (Enarsa, 2008). In yellow potential hydrocarbons traps.

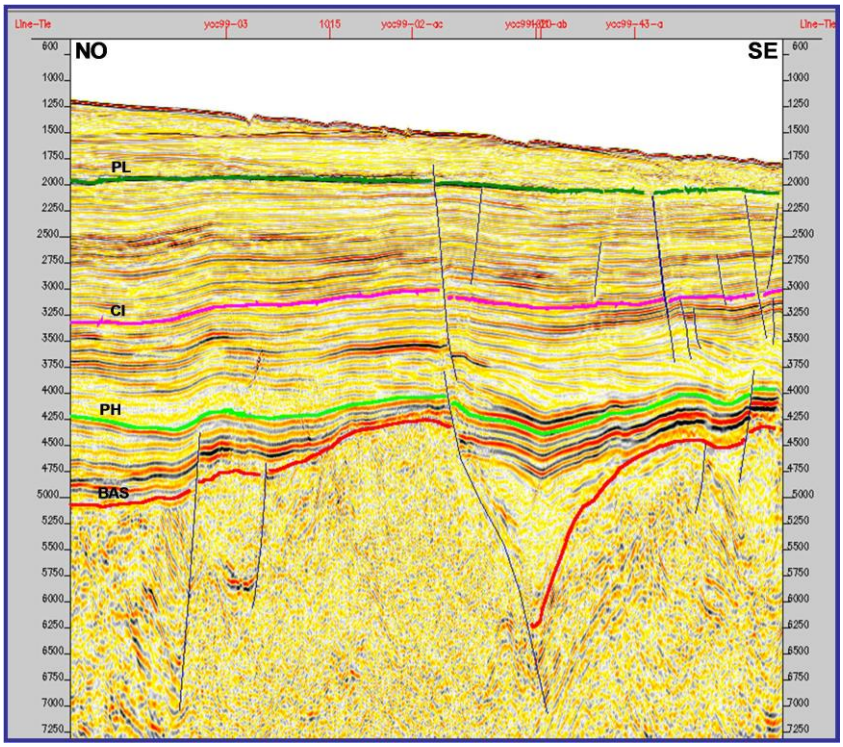


Fig. 9. Seismic line showing a potential trap in the Continental Slop (Argentina Energética, 2009). Ref. Bas: Basement, PH: Syn Rift, CL: Colorado Fm. and PL: Pedro Luro Fm.

Thrust belt play

At this morphoestructural place, is expected big structural traps, with closures of hundreds of km^2 (Fig 10).

The reservoirs are marine clastics from the Tertiary, deposited in deep basin environments (turbidities).

The potential source rocks (Cretaceous and Jurassic), are originated in marine environment and all the petroleum system would have adequate timing.

The expected fluid is gas, according to *DHI* (gas chimneys?).

The estimated resources are 800 to 1500 MBOE for each structure (Argentina Energética, 2009).

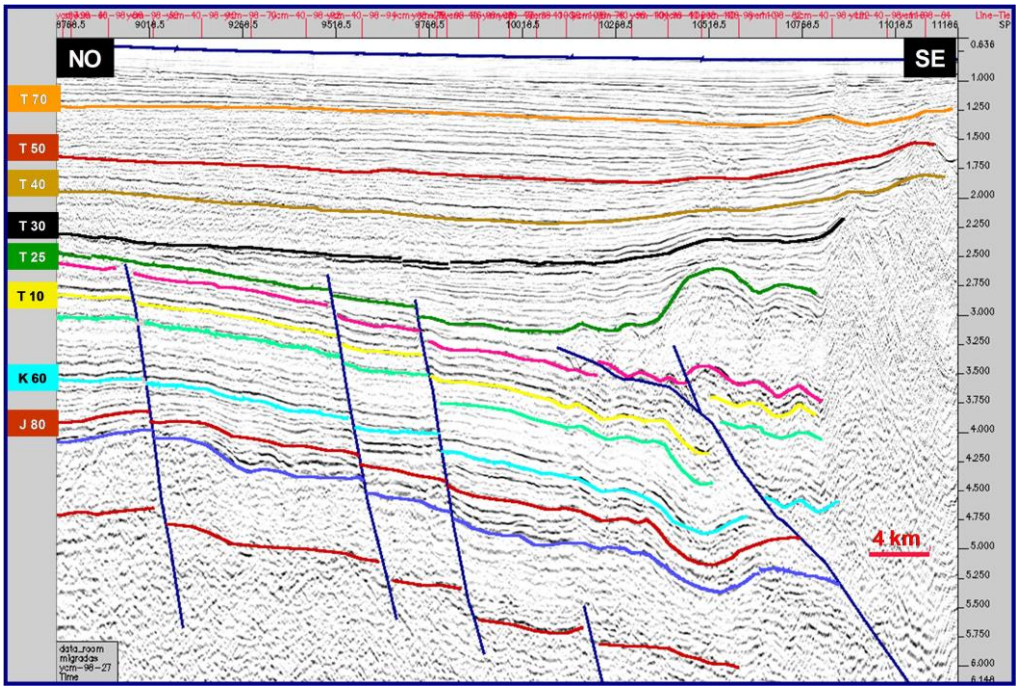


Fig. 10: 2D interpreted seismic line showing the thrust belt play and the different sequences (Enarsa, 2008).

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