



ONSHORE URUGUAY: Geology and Prospectivity



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1. General information about Uruguay

Uruguay is located in South America between Brazil and Argentina with coasts on the Atlantic Ocean, (Fig. 1). It is the second smallest nation in South America, with a land surface area of 176,215 km² and a total area of 318,413 km², considering rivers and territorial waters. The population is slightly higher than 3.285 million inhabitants, of which 40% live in Montevideo, the capital city. There are no remarkable topographic features; most of the country's landscape consists of rolling plains and low hills with fertile coastal lowland. The country has 660 Km of coastline with beautiful beaches. Its weather and topographic features make Uruguay especially suitable for agriculture, forest and livestock production, which represent the main sources of gross domestic product (GDP) within the country. Uruguay has long standing traditions of democracy and legal and social stability, and a solid financial and legal framework, which makes it attractive to foreign investors looking for business ventures in the region.



Fig. 1 – Left: Location of Uruguay in South America (in yellow). Satelital image from NASA (2016).
 Right: Pictures of Uruguay.

2. Regional Geology

Six sedimentary basins are recognized in Uruguay. Three of them are located offshore: Punta del Este, Pelotas and Oriental del Plata basins (Ucha *et al.*, 2004; De Santa Ana *et al.*, 2009). The other three basins are located onshore: Norte, Santa Lucía and Laguna Merín basins (Fig. 2).

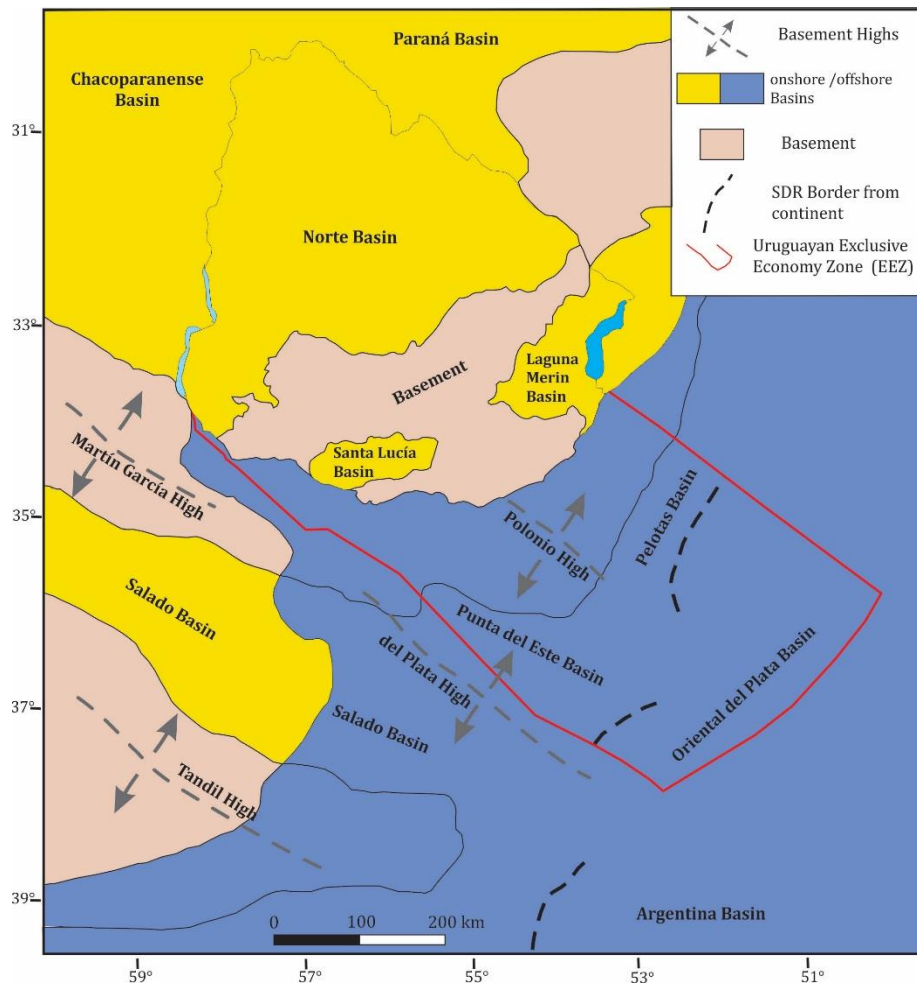


Fig. 2 – Uruguayan offshore and onshore basins and main structures.

Norte Basin is the most southern part of Paraná Basin (> 1,200,000 Km²) which extends, apart from Uruguay, over Argentina, Brazil and Paraguay territories. In Uruguay, this basin extends over an area of more than 90,000 Km², and has a maximum drilled thickness of 2,377 m. Its infill is represented by volcanic and sedimentary sequences drilled by exploratory wells, ranging in age from Devonian to Late Cretaceous. This report will focus in the Norte Basin geology and its exploratory potential for hydrocarbons. However, a brief description of Santa Lucía and Laguna Merín basin is made below.

The genesis of the southern onshore basins (Santa Lucía and Laguna Merín) is related to the breakup of Gondwana, which took place in the Middle Jurassic – Early Cretaceous. Both basins constitute the Santa Lucía – Aiguá – Merín structural corridor (SALAM) with a WSW – ENE direction.

Laguna Merín Basin extends over an area of 15,000 Km² in the southeast of Uruguay, but also develops in Brazilian territory, where it is known as the onshore portion of Pelotas Basin. In Uruguay, the basin infill is mainly volcanic and its total thickness is unknown. Estimates made through geophysical data (gravity, magnetotelluric and seismic) indicates a depth of 3,000 m and potential sedimentary facies with a probably Paleozoic age are interpreted below the Mesozoic volcanic sequence. An interesting geophysical characteristic that is important to highlight is the large positive Bouguer anomaly that covers almost the entire basin (+106 mGal). See Fig. 3.

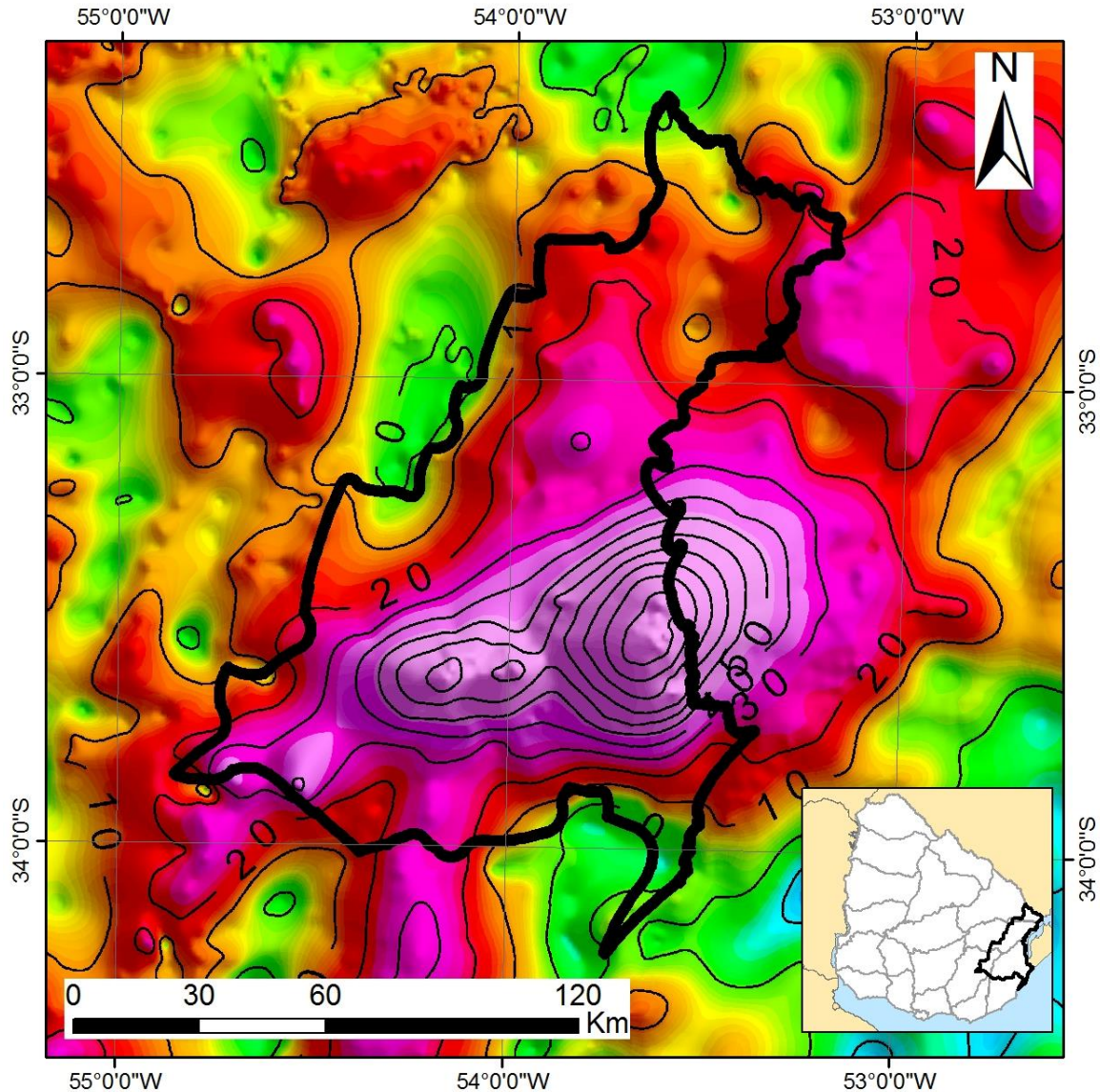


Fig. 3 – Laguna Merín Bouguer anomaly.

On the other hand, Santa Lucía is defined as a pull-apart basin (Veroslavsky, 1999) which extends over 8,000 Km² with ENE – WSW direction in southwest Uruguay. The volcano sedimentary infill ranges from Jurassic to Quaternary sequences and its maximum drilled thickness reaches 2,450 m (Sauce 1 well). The internal Santa Rosa High (ENE direction) divides the basin in two sub-basins, North and South. Indeed, through seismic and gravity data, in the South sub-basin two depocenters are recognized, named Sauce and Piedra Sola (Fig. 4).

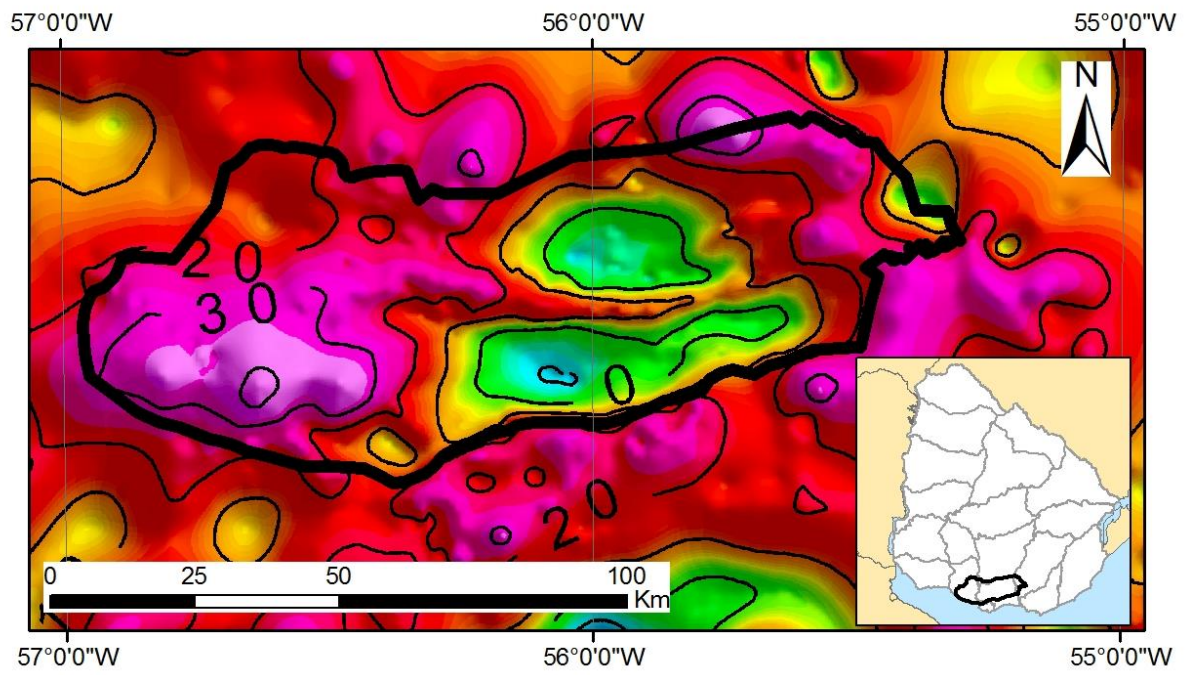


Fig. 4 – Santa Lucía Basin Bouguer Anomaly map. Notice the 2 Sub-Basins and the 2 depocenters in the South Sub-Basin, Sauce (1) and Piedra Sola (2).

3. Tectonic setting

It is stated by several authors that sedimentary basins are established on pre-existing basement discontinuities. In Uruguay these discontinuities are of Proterozoic age and related to the genesis of the Río de la Plata Craton, which includes the agglomeration of different crustal blocks. Norte Basin has three main structural trends (NW- SE, NNE-SSW and E-W). These discontinuities were reactivated several times during the Paleozoic, Mesozoic and Cenozoic, conditioning the type of infill, the sedimentation arrangement and the preservation of geological units (Fig. 5). Santa Lucía Basin has an E – W main trend, which is the same direction of the green stone belts on which it is developed. The eastern border of this basin is controlled by the Sarandí del Yí Shear Zone (Oyantçabal et al., 1993 apud Veroslavsky, 1999) and the western border is covered by the Río de la Plata waters, showing a NW trend like the Martín García High (Fig. 6).

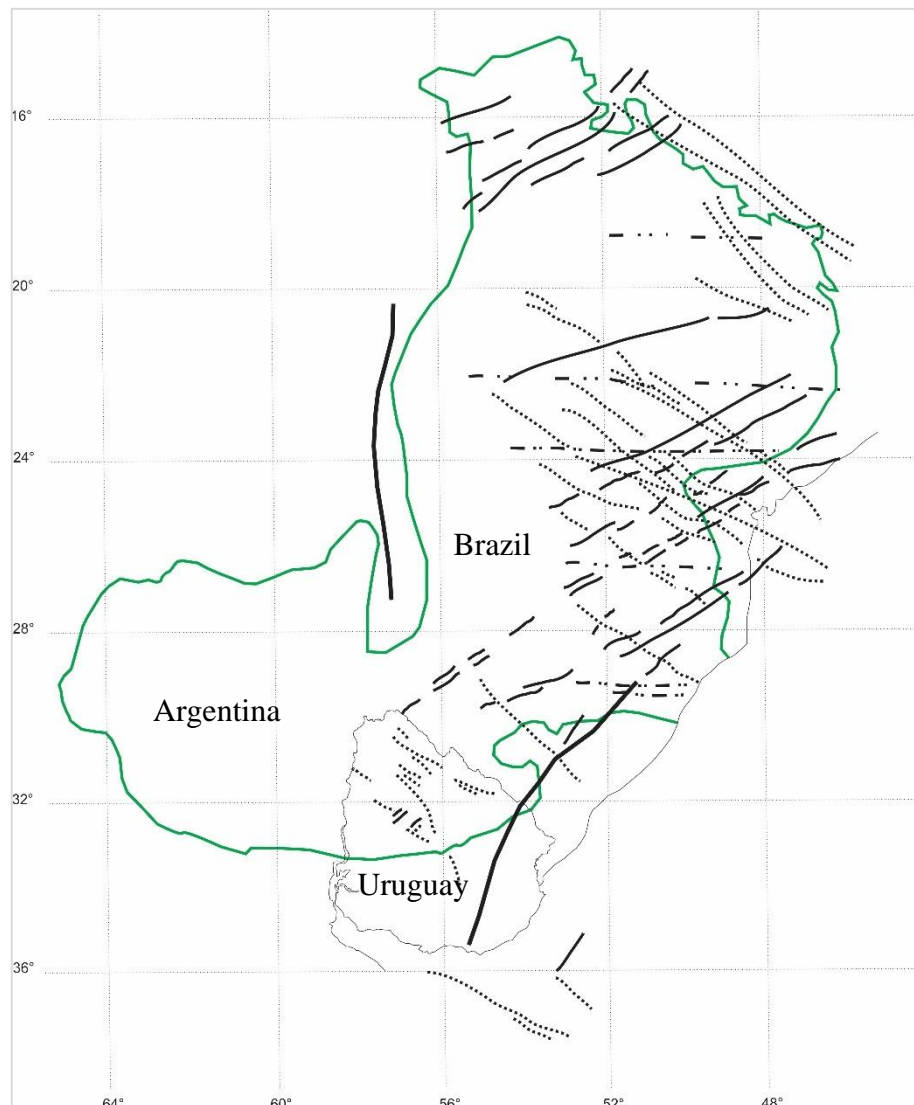


Fig. 5 – Main structural framework of Paraná and Norte basins (modified from Zalán, 1990 in Marmisolle, 2015).

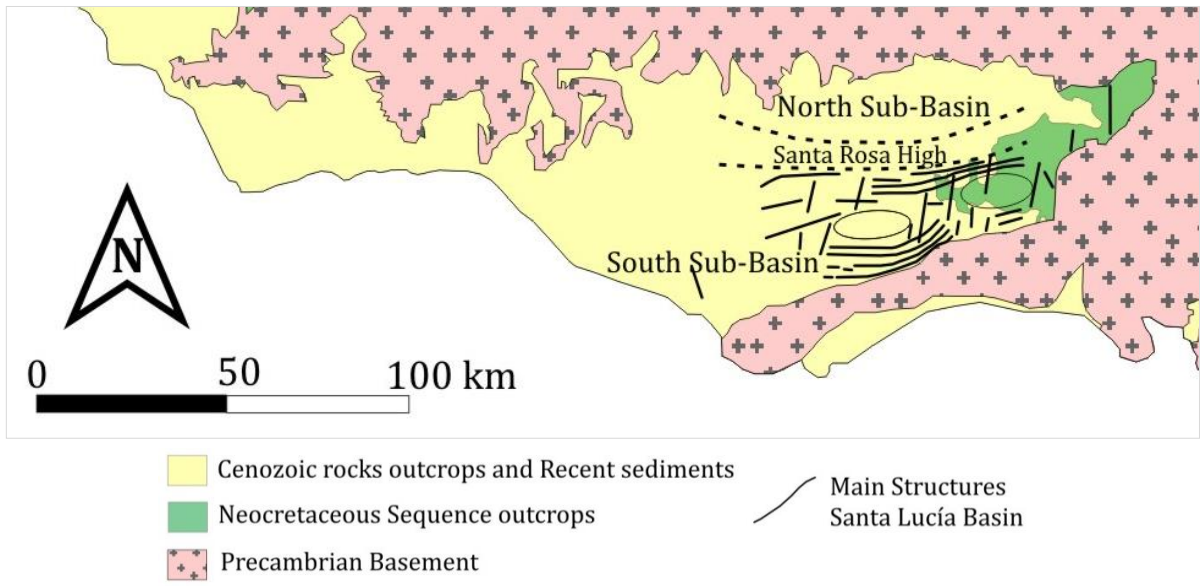


Fig. 6 – Main structural framework of Santa Lucía Basin (modified from Veroslavsky, 1999).

4. Onshore basins

Norte Basin

Norte Basin is the most southern region of the Paraná Basin, which was defined as an intracratonic basin. These types of basins develop over continental crust, far away from active margins, and generally have an oval shape. The evolution process in this type of basins is dominated by continental extension, thermal subsidence in extensive areas and late isostatic readjustments (Klein, 1995).

The Norte Basin basement is constituted by lithological units of different crustal domains which conditioned the development of the stratigraphic sequences. These were controlled by the dynamics of Gondwana, which incorporated blocks in successive events of subduction and collision (Cordani et al., 1984; Milani and Ramos, 1988; Ramos, 1993; López Gamundi et al., 1994; Milani, 1997). Each tectonic event produced an important unconformity in the stratigraphic record and, as a consequence, the Paraná and Norte basins show three main structural directions: NW-SE; NE-SW and E-W (Zalán et al., 1990, De Santa Ana et al., 1989; Ucha & De Santa Ana, 1994; De Santa Ana & Veroslavsky, 2004; Marmisolle, 2015). See Fig. 5.

From base to top, the stratigraphy in Norte Basin is divided in four megasequences, 1) Devonian, 2) Late Carboniferous – Permian, 3) Juro-cretaceous and 4) Late Cretaceous (Fig. 7). Up to now, no Early Paleozoic (Cambrian, Ordovician and Silurian) units were recognized in Norte Basin, although they developed in other sectors of Paraná Basin (Las Breñas in Argentina or Calha Central and Camaquã in Brazil). See Fig. 8. In recent years, after new studies in the Norte Basin, a structural NW corridor was identified (Marmisolle, 2015; Marmisolle et al., 2017), which could preserve pre-Devonian units.

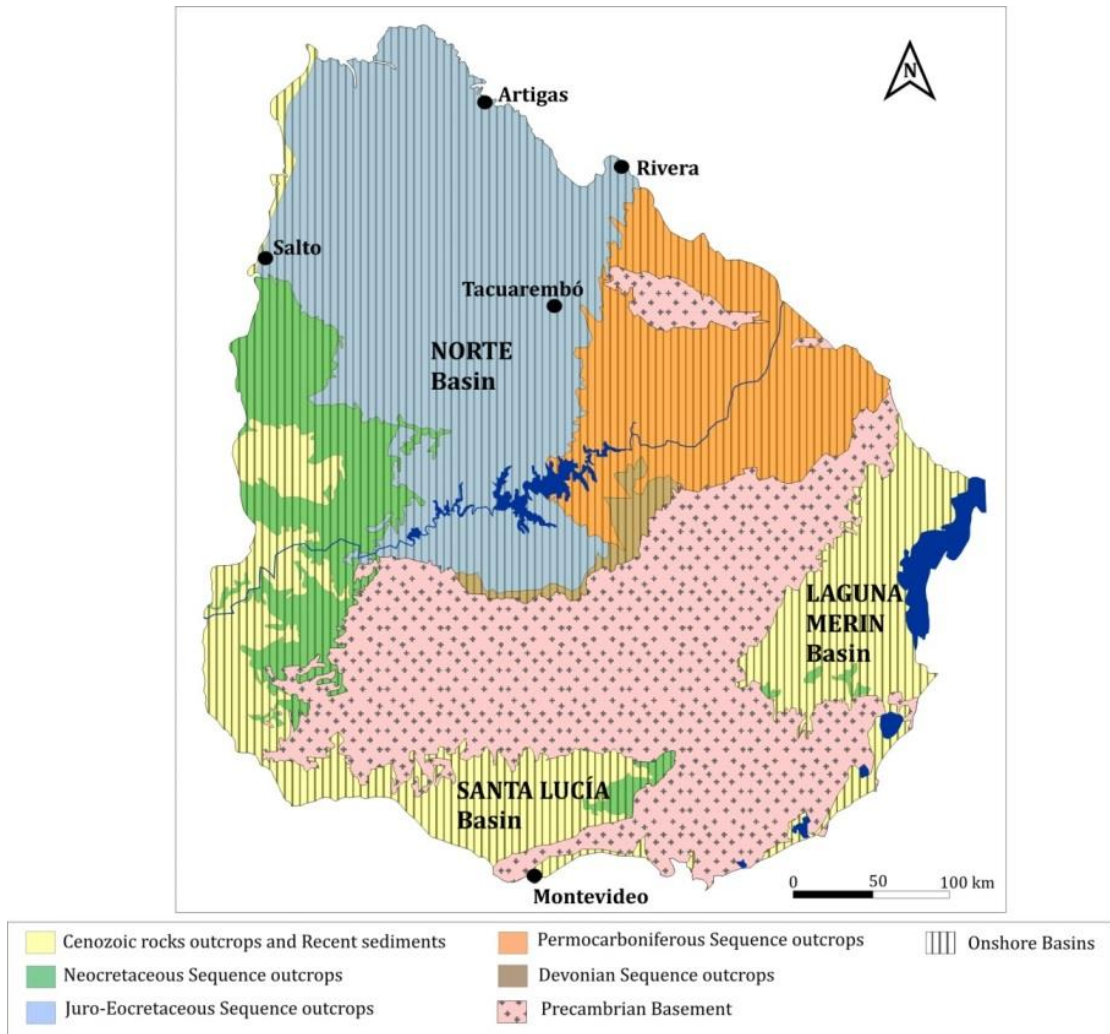


Fig. 7 – Onshore basins and stratigraphic sequences outcrops location.

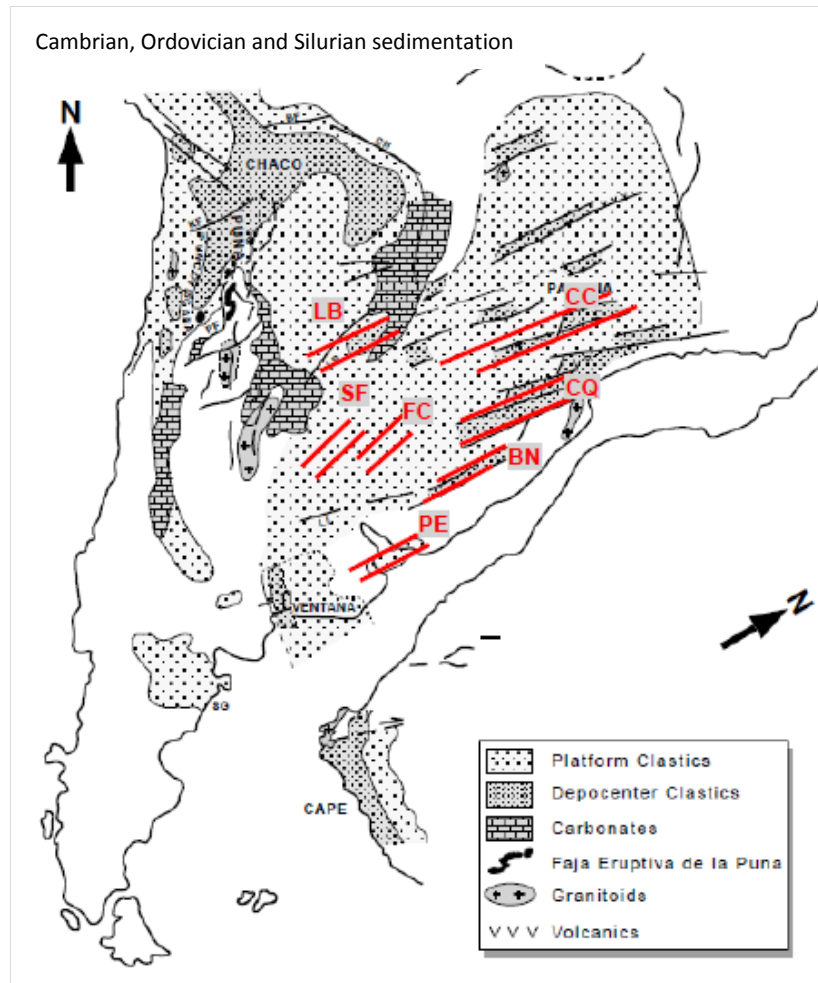


Fig. 8 – Distribution of the Early Paleozoic units into Paraná Basin. Argentina: (LB) Las Breñas Basin, (SF) Santa Fé Depocenter; (SC) Corrientes Depocenter; Brazil: (CC) Calha Central Rift; (CQ) Camaquã Basin. Modified from França et al., 1995.

The Devonian megasequence outcrops in the southern-central border of Norte Basin (Fig. 7). This megasequence is composed of three units, from base to top, Cerrezuelo, Cordobés and La Paloma formations, which constitute the Durazno Group, completing a Transgression – Regression cycle (Fig. 9).

In sub-surface, the new geophysical and geological analysis, including new 2D seismic acquisition and vintage seismic re-processing, have allowed the extension of the limits of the Devonian sequence beyond the limits that were recognized up to the moment.

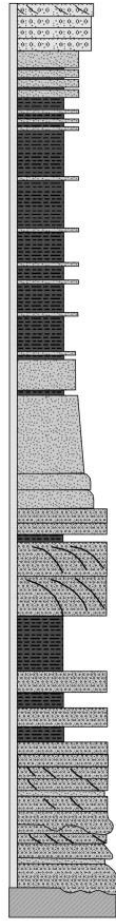
Lithostratigraphic		Lithology	Environments
DURAZNO GROUP	LA PALOMA FORMATION		Litoral plains with marine action
	CORDOBÉS FORMATION		Turbidites deposits Shaly shelf Turbidites deposits
	CERREZUELO FORMATION		Sandy shelf Tempesty deposits Sandy shelf Braided delta (terminal section) Braided delta (terminal section) Lobe and interlobe Braided delta (terminal section) Braided
	Basement		Disconformity Precambrian basament

Fig. 9 – Lithostratigraphic column of Devonian Sequence (Durazno Group).
 Modified from Veroslavsky et al., 2006.

The Carboniferous – Permian megasequence (Fig. 10) includes an extensive number of units. In the base, San Gregorio Formation of Late Carboniferous – Early Permian age constitutes fluvial, lacustrine and diamictites glacial deposits. The best exposures of this sequence are located in the southern border of the basin, over the Devonian megasequence. The next Paleozoic unit is Tres Islas Formation (Early Permian) that includes mainly medium to fine deltaic sandstones and outcrops in the eastern region of the basin. Then, Melo Group (Early Permian) is integrated by three formations (Fraile Muerto, Mangrullo and Paso Aguiar). Fraile Muerto includes gray marine shales; Mangrullo includes black shales, limestone and oil-shales deposits; and Paso Aguiar is integrated by marine shales with fine sandstones lenses. Overlying Melo Group, close to the top of the Paleozoic, develops Yaguarí Formation that is interpreted as a sandy marine shelf with shallow marine deposits. The last unit of this megasequence is represented by Buena Vista Formation, which includes fluvial deposits on the base and aeolian sandstones on the top, evidencing the continentalization of the environment and closure of the Pangea super-continent.

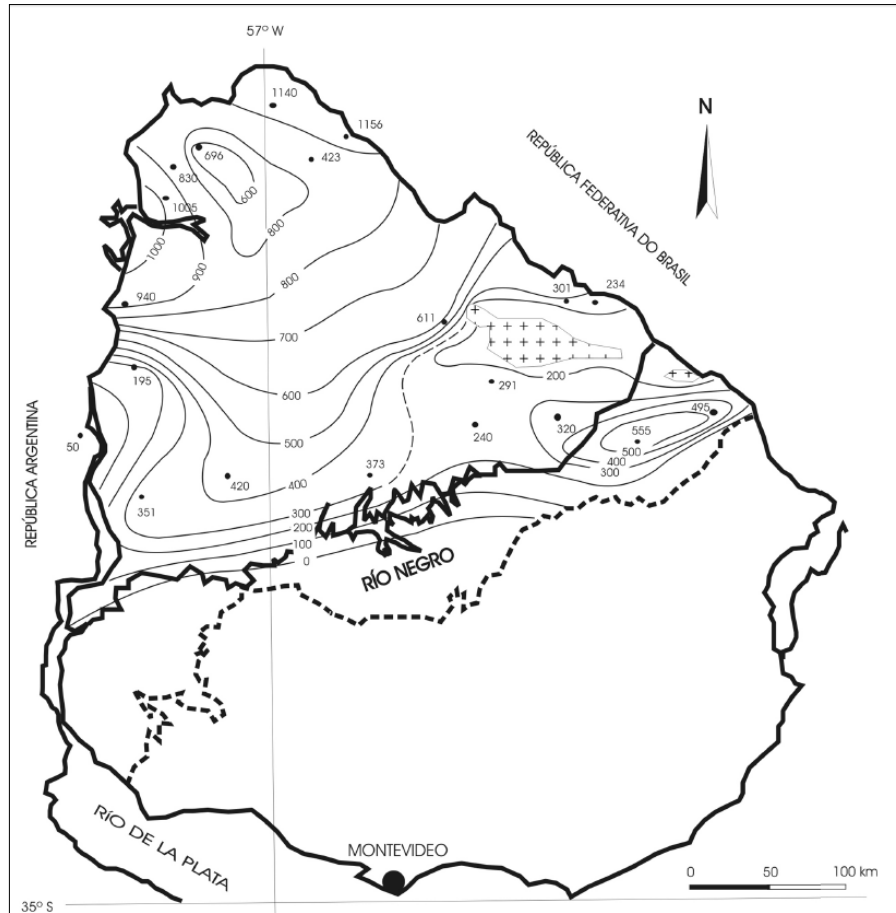


Fig. 10 – Isopach Map of Carboniferous-Permian Sequence, Norte Basin. (De Santa Ana, 2004)

The Juro-cretaceous megasequence is represented by volcano sedimentary deposits (Fig. 11). From base to top, the units are Tacuarembó and Arapey formations. Tacuarembó Formation is represented by fine to medium sandstones and shales from fluvial to lacustrine deposits on the base, and medium sandstone from aeolian deposits at the top. Arapey Formation is constituted by a large volume of basalts associated with the fragmentation of Gondwana, which are part of the Parana – Etendeka LIP (Large Igneous Providence).

Late Cretaceous is the last megasequence recognized in Norte Basin. These post basalts units, from base to top, are Guichón and Mercedes formations (Fig. 12). Guichón is represented mainly by fine to medium fluvial sandstones, but conglomerates (channel infill) and shales are also recognized. Mercedes Formation is characterized by sandstones and conglomerates, in which is very common to find calcareous, ferriferous and siliceous processes affecting these lithologies. Several shale levels are also found.

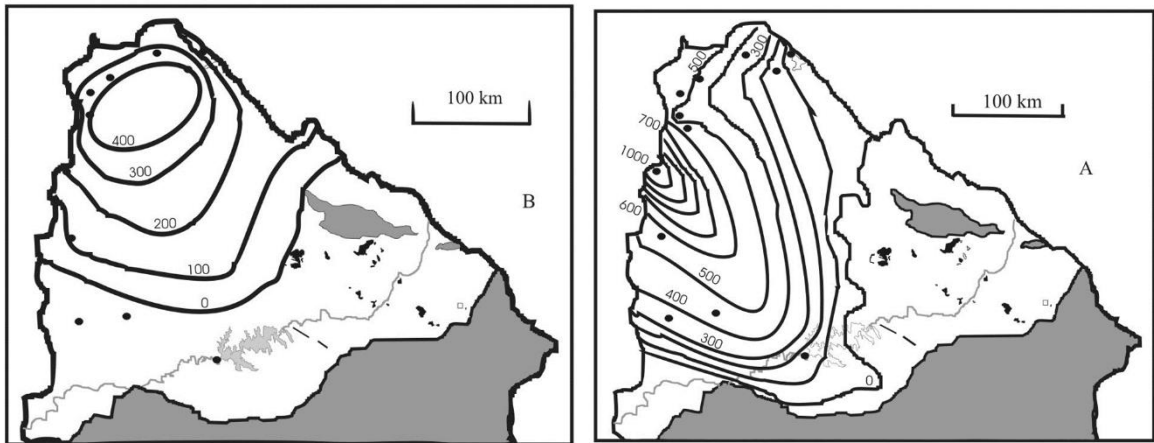


Fig. 11 – Isopach Map of: (A) Juro-cretaceous sandstones; (B) Cretaceous basalts.
(De Santa Ana & Veroslavsky, 2004)

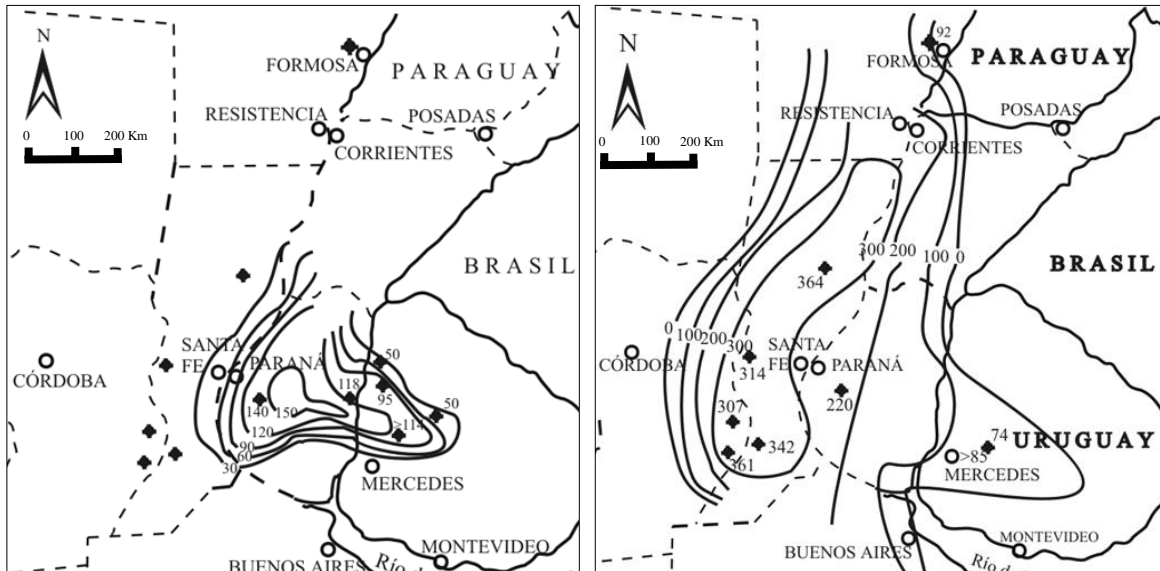


Fig. 12 – Isopach Maps of Late Cretaceous sequence, (A) Guichón Formation and (B) Mercedes Formation (Goso & Perea, 2004).

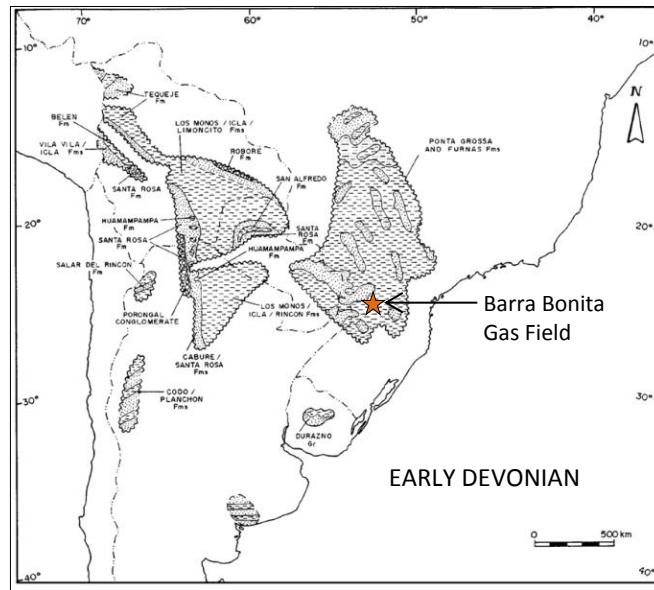


Fig. 14 – Distribution of Devonian sequence in Paraná Basin and Barra Bonita Field location. Modified from França *et al.*, 1995.

The second active petroleum system is associated with Permian bituminous shales of Iratí Formation (Brazil) that are well developed in the southern half of the Paraná Basin (Fig. 15) and exhibit TOC content, reaching values as high as 20% of lipidic-rich, oil-prone organic matter. Abundant oil shows related to this unit appear in the Lower Permian sandstones of the Rio Bonito Formation, and were probably generated by a mechanism of heating, influenced by Mesozoic intrusive dykes and sills. In the northeastern region of Paraná Basin (Brazil), Triassic fluvial-aeolian deposits are impregnated with heavy oil (tar sands) which is geochemically correlated with Iratí oil shales.

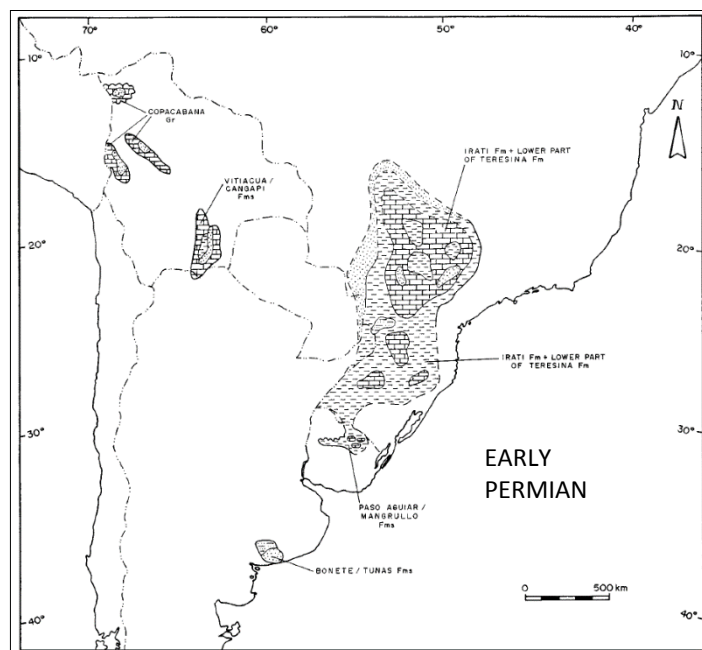


Fig. 15 – Distribution of Iratí (Brazil) and Mangrullo (Uruguay) formations in Paraná Basin. Modified from França *et al.*, 1995.

In Uruguay, the petroleum system is still speculative, but the same source and reservoir rocks of the Paraná Basin petroleum system are recognized. The Devonian Ponta Grossa Formation is correlated with Cordobés Formation and the Permian black shales of Iratí Formation are correlated with the Mangrullo Formation (Fig. 16).

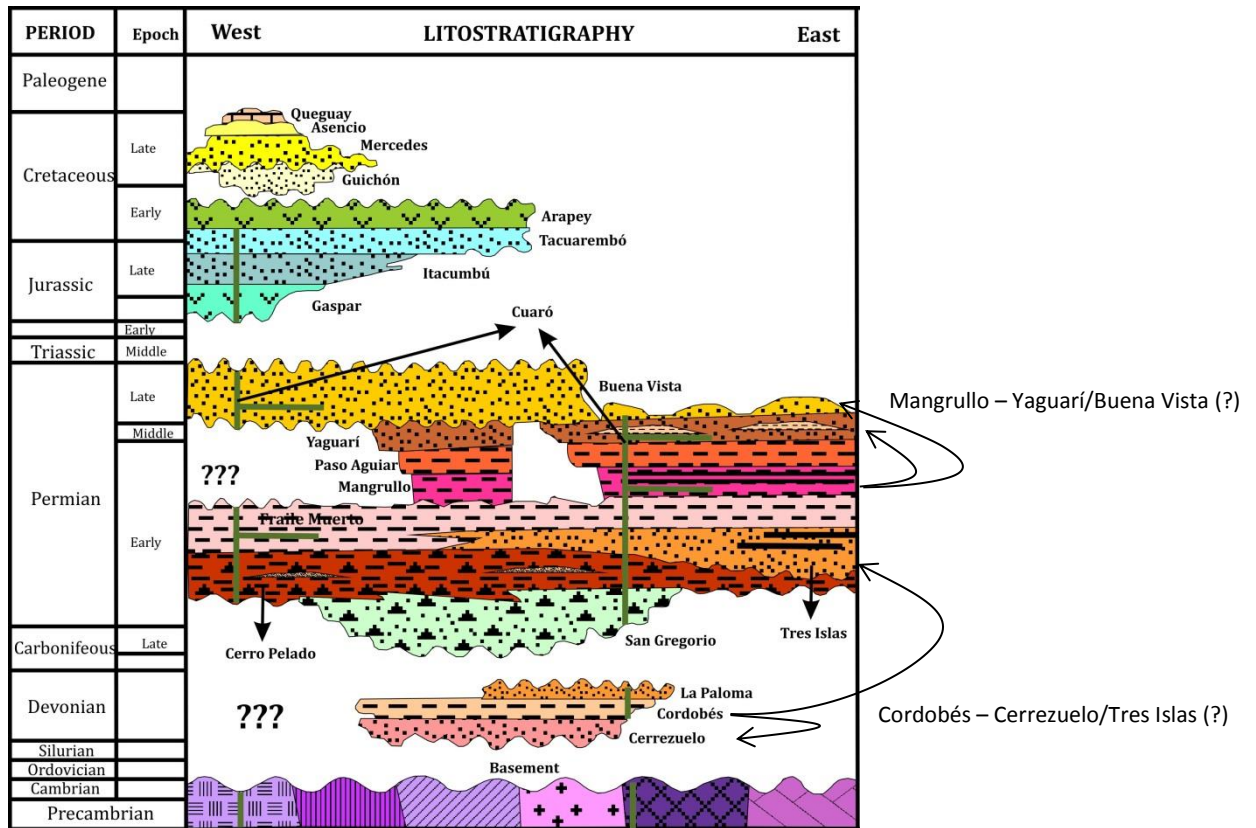


Fig. 16 – Speculative Petroleum System proposed for Norte Basin

Source rocks

As mentioned previously, in Norte Basin two potential source rocks are recognized, Cordobés (Devonian) and Mangrullo (Permian) formations.

The marine black shales of Cordobés have a percentage of total organic content ranging between 1.7 and 3.6% TOC, a kerogen type I and II, and its Hydrogen Index is up to 400 mg HC/g TOC. This unit has been recognized in several wells in the south of the basin and mapped in seismic lines. Its extension in sub-surface is currently being studied, as new seismic data are acquired and new interpretation is performed (Figs. 17 y 18).

Mangrullo Formation (Permian) has very high values of organic content, ranging from 6 to 12% TOC with a kerogen type I, and Hydrogen Index up to 600 mg HC/g TOC. The development of this unit in sub-surface was historically limited to its outcrops area in the eastern side of Norte Basin. Nevertheless, in an exploratory well drilled in 2013, the black shales of Mangrullo were identified in a central position of the basin, opening new exploratory possibilities (Figs. 19 y 20).

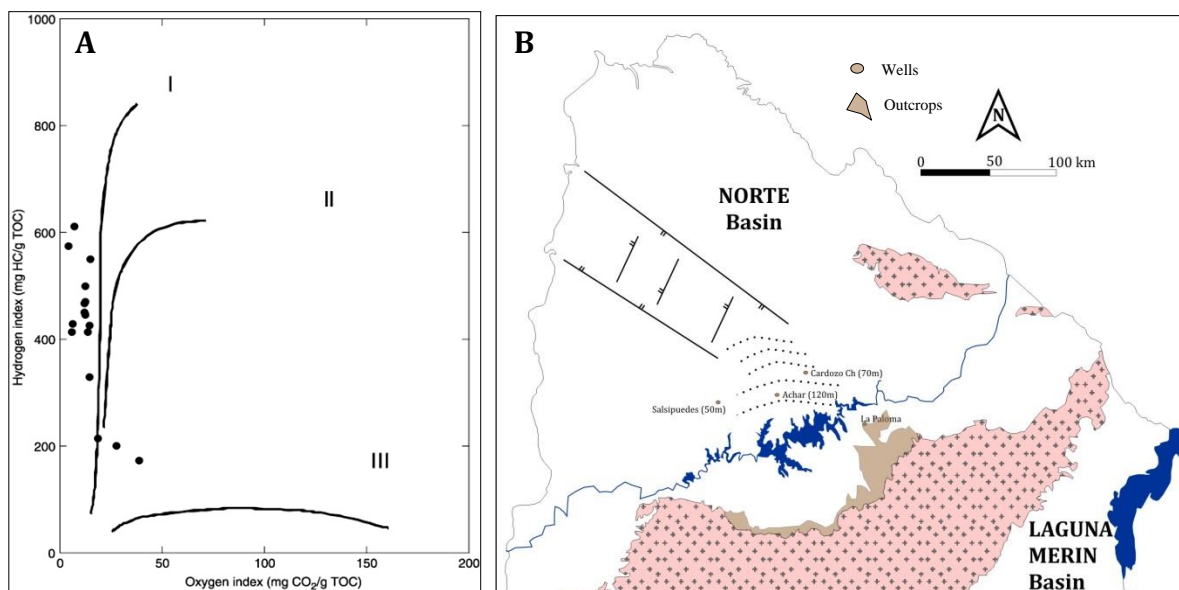


Fig. 17 – Van Krevelen Diagram of Cordobés Formation (A) and Devonian distribution in Norte Basin (B).



Fig. 18 – Black shales of Cordobés Formation (Devonian)

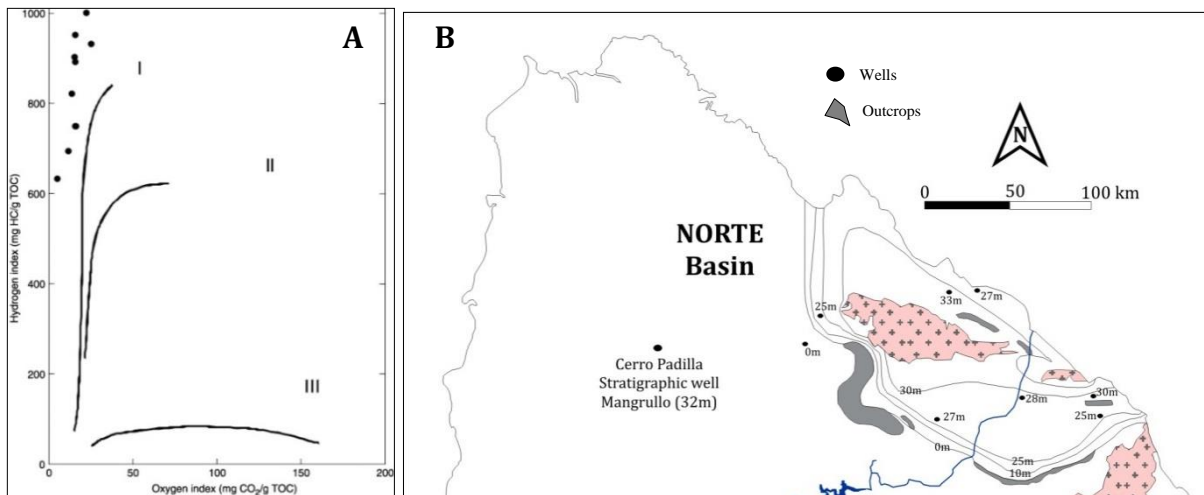


Fig. 19 – Van Krevelen Diagram of Mangrullo Formation (A) and Mangrullo distribution in Norte Basin (B).

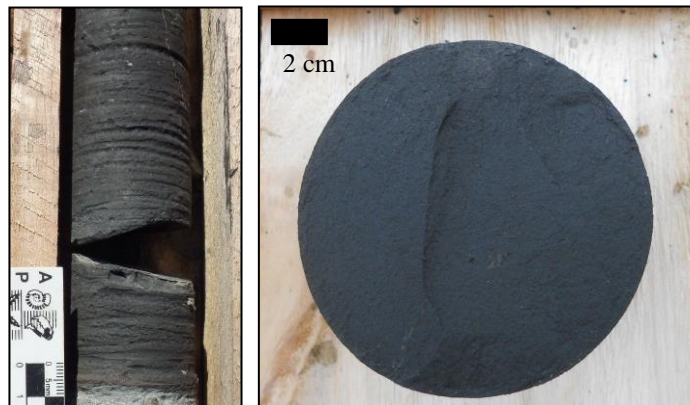


Fig. 20 – Black shales of Mangrullo Formation

Maturation

Several analyses showed that the Devonian shales are mature (average ~ 0.64 %Ro), entering the oil window at shallow depths or at a stratigraphic position close to the surface (Achar E1 Well). See Fig. 17. The geological model suggests that the Devonian shales are more mature when they are preserved in the structural deep depocenters.

Mangrullo Formation maturity analyses show that the unit is immature near to the surface, where it was historically identified. The new stratigraphic position, at 730 meters where Mangrullo was found (Cerro Padilla E1 Well), showed an average maturity of 0.7 %Ro.

Reservoir rocks

Several proven high-quality reservoir rocks have been found in the sedimentary record infill of Norte Basin, with porosity values ranging between 18 and 25% and permeability values up to 600 mD. The most important ones are related to the fluvial system of the Devonian sequence (Cerezuelo Formation), deltaic sandstones of Tres Islas Formation (Early Permian) and the aeolian sandstones of Buena Vista Formation (Late Permian). See Fig. 20.

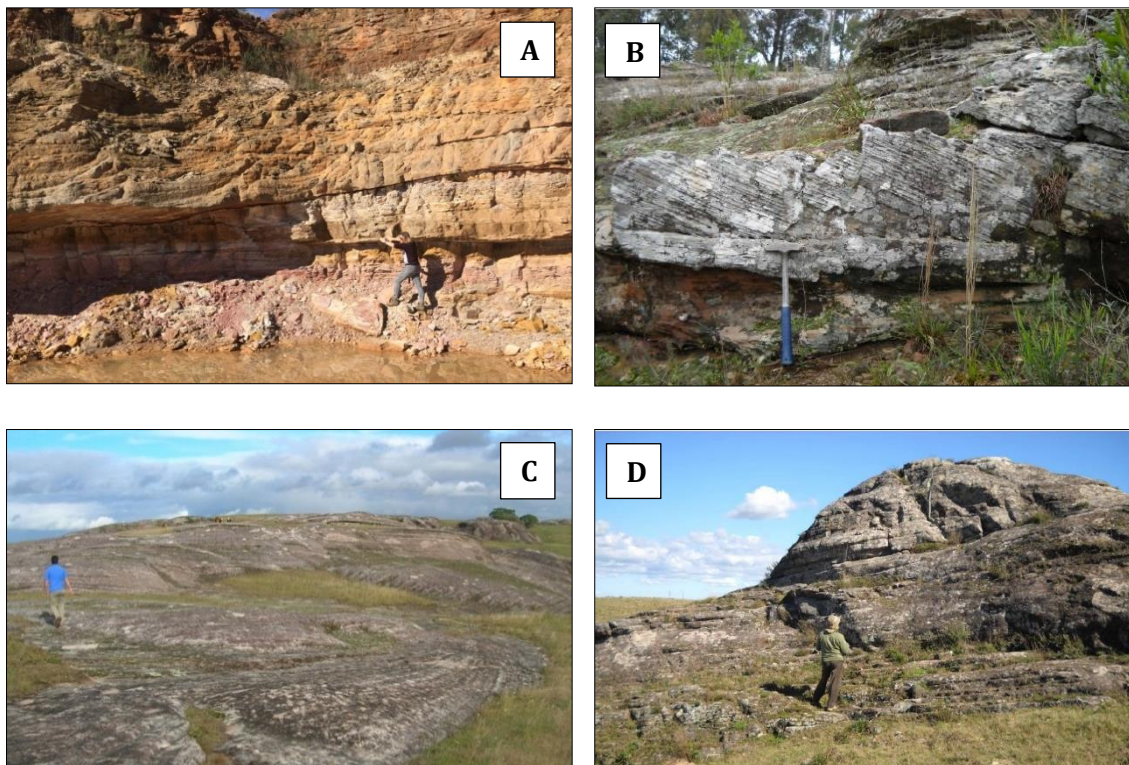


Fig. 20 – Sandstones outcrops of **A)** Cerezuelo; **B)** Tres Islas; **C)** and **D)** Buena Vista.

Seal rocks

Several stratigraphic levels are identified as local and regional potential seal rocks. An example of this are the Permian shales or the Cretaceous basalts, dykes and sills. Many times, the Cretaceous deformation associated with intrusions create anticlines structures generating plays similar to the Barra Bonita Field in Brazil.

Migration pathways

The tectonic activity was very dynamic during the evolution of Norte Basin. Throughout Permian times, the NW-SE and NNE-SSW faults were reactivated. These reactivations conditioned the sedimentation and the preservation of many units in the sub-surface. During the Mesozoic, a new tectonic activity took place, generating new E-W directions and reactivating the old ones. The faults are of great importance because they are connecting potential source and reservoir rocks (Fig. 21). In addition, the faulting generated structural traps like anticlines or roll over napes.

Other mechanisms of hydrocarbon migration include diffuse vertical migration through low permeability layers, and horizontal migration through carrier beds in contact with source rocks.

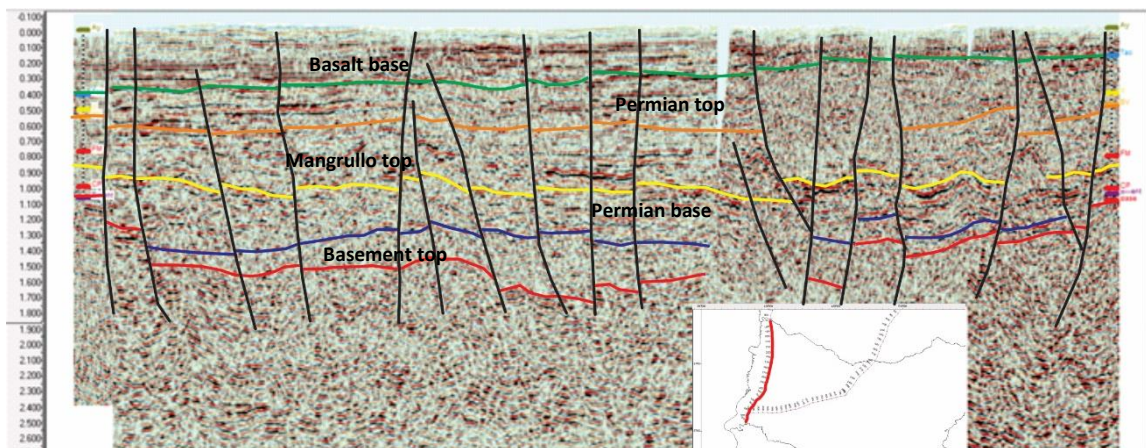


Fig. 21 – Reprocessed vintage seismic line (UR84_06) located in Norte Basin with N-S direction, showing how faults cut the sequences. Modified from Marmisolle, 2015.

Exploratory situations

Taking into consideration the distribution of the main source rocks of the basins, the presence of migration pathways, the development of significant reservoir rocks and the presence of a regional seal, the Devonian and the Permian Sequences are the most prospective. Different structural and combined leads and prospects are recognized in Norte Basin (Fig. 22).

The possibility of Devonian preservation in deep depocenters of the Paleozoic, which in some areas reach a thickness of more than 3,000 meters, increase the chances of generation and expulsion. A similar situation occurs with Mangrullo, which was drilled in a different position of the basin.

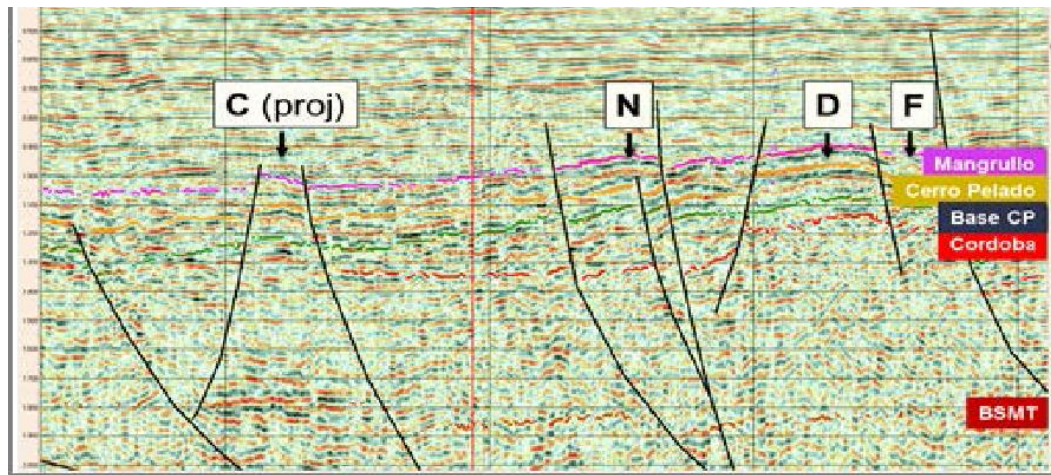


Fig. 22 – Example of Norte Basin prospects. Taken from Petrel web page (published in Energy Oil and Gas Conference, Sydney 2015)

6. Hydrocarbon evidences

There are few direct and indirect evidences of the occurrence of hydrocarbons, which confirm hydrocarbon generation and the presence of an active petroleum system in the basin. Some of these evidences include oil leaching from Devonian sandstone registered in Achar exploratory well drilled in 2011 by Schuepbach Energy Uruguay (Fig. 23), and gas detection (kick) registered in Belén and Yacaré exploratory wells, which were drilled in 1986-87 by ANCAP (Fig. 24).



Fig. 23 – Oil stains in Cerrezuelo sandstones (Devonian) from core of Achar E-1 stratigraphic well. Taken from Petrel web page (published in Energy Oil and Gas Conference, Sydney 2015)

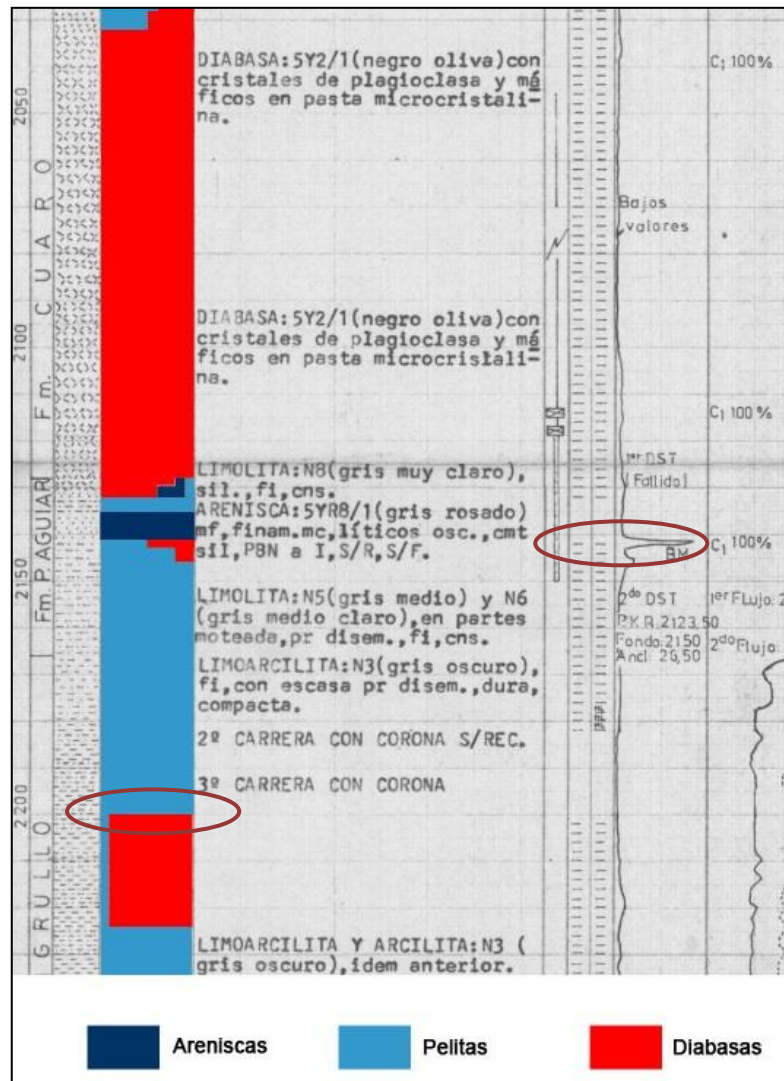


Fig. 24 – Partial mud logging of Belén exploratory well with evidences of gas detection in the interval between 2,191 – 2,200 meters.

7. Remarks

Uruguayan onshore basins are still underexplored, with 12 exploratory wells drilled in Norte Basin and other 12 located in Santa Lucía Basin. The interesting geology and the analogies, particularly between Norte Basin and proven petroleum systems and plays of Paraná Basin, increase its exploratory potential. A number of structural and combined exploratory situations have been identified and direct and indirect hydrocarbon evidences do exist, such as oil stains and gas detection.

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USEFUL WEBSITES:

ENTITY	WEBSITE	SITE INFO
ANCAP	http://www.ancap.com.uy/	National Oil Company of Uruguay (Institutional website)
E&P - ANCAP	http://exploracionyproduccion.ancap.com.uy/	G&G, exploration opportunities, database, data licensing, legal framework.
Uruguay XXI	http://www.uruguayxxi.gub.uy/invest/	Investment and Export Promotion Institute

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