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# Depocenters with Potential Preservation of Pre-Carboniferous Rocks in Norte Basin (Uruguay)*

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## Abstract

An area in the West part of the Norte Basin was selected with the objective of characterizing the preservation of potential pre-Carboniferous sequences in depocenters. As a main result, a NW trending corridor named Salto-Tambores was defined. This corridor, which develops between the Daymán and Arapey faults, can be divided in two segments with different morphology, structural setting and volcano-sedimentary fill. The Eastern segment topography is represented by hills with strong slopes with elevation of 270 m above sea level. Sub-surface data for this segment indicates that basement depth reaches 800 m and that the Devonian sequence is preserved (confirmed by several wells), covered by Late Permian units that crop out or are covered by Eo-Cretaceous basaltic flows. The Western segment is represented by a plane topography with gentles slopes (< 4°) and elevations of 140 m above sea level. From the central to the West segment of the corridor, the basement deepens from 1000 to 3000 m as a result of NE trending lystric and normal faults that rotated the basement blocks to Southwest direction. In this area the Itapebí fault was defined, which controls the deepest depocenter showed in seismic sections (>3700 m). Near and parallel to the Uruguay River, surface and subsurface analysis allowed to identify N-S trending fault. There, the magnetotelluric (MT) section shows that the basin reaches more than 3500 m in thickness. The deepest depocenters identified in this work have not been drilled yet, therefore the sedimentary fill for these areas is unknown. Well data indicates the pinch out of the Carboniferous units towards the Southwest. Also Devonian thickness of more than 300 m is improbable for this section. Regarding these, the preservation of Paleozoic units older than the currently known for the Norte Basin is highly probable.

## Introduction

The oldest sediments recognized in Norte Basin are Devonian in age and outcrop in the Southern border (Figure 1). De Santa Ana, (1989);

Ucha and de Santa Ana, (1990) suggested that the strong NW trending compartmentalization of Norte Basin could preserve older sedimentary relicts.

Recent magnetotelluric studies (Oleaga et al., 2005; Rosa et al., 2015) and 2D seismic reprocessing shows in some regions the basement at 3500m depth and deeper. The presence of deep depocenters could have important implications to the petroleum exploration model in addition to hydrogeology and geothermal potential of the basin.

Regarding this potential, the objectives of this work were to identify and characterize the deepest depocenters of Norte Basin, identify and characterize the most important faults that control them, and the potential infill.

## Location

The study area is located in the Northwestern region of Norte Basin (Figure 2), defined by the following geographic coordinates UTM (21S) – Datum WGS-84: **1)** X: 400.000m, Y: 6.600.000m; **2)** X: 561.000m, Y: 6.600.000m; **3)** X: 561.000m, Y: 6.460.000m; **4)** X: 400.000m e Y: 6.460.000m.

## Methodology and Database

Basin analysis was the methodology used in this work, which integrates different data and information from surface and subsurface (Allen and Allen, 2005), for the interpretation of the genesis and evolution of the sedimentary infill and evaluating its economic potential.

Regarding surface data, LANDSAT satellite images were used to make a morphological and structural interpretation of the area (topography, lineaments, and geomorphology). In relation with subsurface data, 95 km of magnetotelluric sections, gravity data, 325 km of 2D seismic, 6 stratigraphic wells and 4 exploratory wells located in the study area were available for interpretation. All this information is property of ANCAP (the National Oil Company of Uruguay).

## Geological Setting

The Parana Basin constitutes an extensive area of Gondwanic accumulation which hosted Paleozoic and Mesozoic sedimentation, with significant magmatic events related to its evolution. The syneclise that generated the basin was established during Neo-Ordovician times over stabilized continental crust (Milani, 1997). The current geographic distribution of the Parana Basin exceeds over 1,400,000 $km^2$ covering part of Argentina, Brazil, Paraguay, and Uruguay, with thickness that reach 7000 m (Zalán et al., 1990). The volcanic-sedimentary infill of the basin extends from Ordovician to Cretaceous and is product of the overlap of several basins. It is defined as intracratonic basin although several aspects of its evolution are controversial, in particular its genesis. Milani, 1997 suggested a foreland genesis for the basin. In general terms, the evolution of the Parana Basin is controlled by two main tectonic events. On one hand, the active margin of Western Gondwana which led to compressive processes during the Paleozoic and, on the other hand, the fragmentation of Gondwana and subsequent opening of the South Atlantic Ocean during the Mesozoic.

Regarding the structural framework, the main directions of the Paraná Basin are NW-SE; NE-SW and E-W (Zalán et al., 1990), (Figure 3). In addition to these, many authors indicated the existence of clastic depocenters with a NNE directions and Cambro- Ordovician-Silurian fills.

Some examples are the Central Rift in Brazil discovered in 1990, Las Breñas, discovered by the homonymous well in 1940 and Corrientes Graben recently indicated by Mira et al., 2015 with magnetotellurian and gravimetric data. (Figure 4)

In Uruguay, the southern portion of Parana Basin is named Norte Basin with a surface of approximately 90,000 $km^2$ and a maximum drilled thickness of 2377 m. In Norte Basin there have not been identified sediments of Ordovician and Silurian age. The oldest Paleozoic units recognized are Devonian, corresponding to Cerrezuelo, Cordobés, and La Paloma formations, which constitutes the Durazno Group (Bossi, 1966). They outcrop in the south central portion of the basin and represent a complete transgressive-regressive cycle.

The Permocarboniferous sequence (de Santa Ana, 2006) extends across all the Norte Basin although outcrop in the Eastern region. It is represented from base to top by Late Carboniferous to Late Permian sedimentary rocks (Figure 5).

## Results

### Surface Analysis

The topography analysis suggests that the study area has two different segments. Eastern segment is characterized by hills with strong slopes and elevation above sea level up to 270 m. The Western segment has a flat topography with less than 4° slopes and elevations less than 140 m. The drainage analysis show that 1$^{st}$ order rivers (Daymán and Arapey) are controlled by the main faults (NW), while the 2$^{nd}$ order drainage is controlled by NW and NE trend faults with different behavior in Eastern and Western segment. In the first one, the drainage is continuous from Daymán to Arapey fault and has one direction (NW mainly), but in the case of Western segment the drainage is discontinuous and it has a radial direction (N-S, NW and SW).

An interpretation of lineaments was made using LANDSAT satellite images of the area. This analysis was completed with field trips in which many of the lineaments were defined as faults. From the study emerged that the Arapey and Daymán faults constitute a NW trending structural corridor that was named Salto – Tambores Corridor (STC). Also, a central fault was identified that controls the Valentin Creek with NNW direction and is the limit between the two segments identified. In the extreme Western segment, a N-S trend fault was identified too (Figure 6).

### Subsurface Analysis

Through the seismostratigraphic analysis three regional unconformities were recognized. The first one represents the unconformity between basement and the sedimentary infill of the basin, while the other two unconformities (base and top of the Permocarboniferous sequence) delimit three mega-sequences: Pre-Carboniferous, Permocarboniferous and Juro-Cretaceous (Figure 7).

The structural analysis showed a set of sub-vertical and listric faults that dislocate the basement and segment the three mega-sequences identified. Also, was useful to known the dip of the faults identified in the surface analysis. In the seismic line can be recognized depocenters of more than 3,700 meters controlled by NW trending faults.

The MT data was useful to know the depth of the basin and distinguish how the different mega-sequences respond to this method. It is particularly good to interpret faults and separate igneous from sedimentary rocks. The MT shows for this section a depth of basement of more than 3500 m with a WNW – ESE control for the depocenters. The basalts in this area have a thickness of around 1000 meters with relatively high resistivity (> 100 Ohm.m). The sedimentary Permocarboniferous mega-sequence has relatively low resistivity (< 35 Ohm.m) and is cross-cut by high resistivity sills. Finally, before reaching the high resistivity deep basement (> 200 Ohm.m) a different unit was recognized with resistivity between 35 and 129 Ohm.m, related to potential Pre-Carboniferous rocks.

With the subsurface information (seismic, MT, and wells) was created a geological cross-section of the western extreme of study area, which shows the depocenter (Figure 8).

## Conclusions

In this work is described, for Norte Basin, the NW trend Salto-Tambores Corridor (STC), with a 177 km of extension and 60 km width limited by two main faults (Daymán and Arapey). The STC controls a set of NE trending normal and listric faults, responsible for the deepening of the basin to the West. The structural configuration of the STC has a good correlation between the surface and subsurface data. The important deepening of the SCT in the Western segment, as a result of a set of NE and NS faults could preserve Pre-Carboniferous sedimentary rocks.

The Eastern segment has a width of 45 km between faults. Its topography is represented by hills with strong slopes, with elevation above sea level up to 270 m. Sub-surface data for this segment indicates that basement depth reaches 800 m and that the Devonian sequence is preserved (confirmed by several wells), covered by Late Permian units that crop out or are covered by Mesozoic basaltic flows. The Western Segment has a width of 75 km between Daymán and Arapey faults and is represented by a plane topography. The Itapebí Fault with NW strike and dipping North, located between Daymán and Arapey faults is recognized as very important control of basin preservation. From Itapebí Fault towards North, was identified a 3700 m depth depocenter. In this Western segment and parallel to Uruguay River, N-S trend faults were identified in the surface and subsurface analysis. These structural setting is very important because allows to presume a pre-carboniferous rocks preservation.

## Acknowledgements

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Figure 1. Onshore basins of Uruguay and surface geology, modified from Veroslavsky et al. (2006).

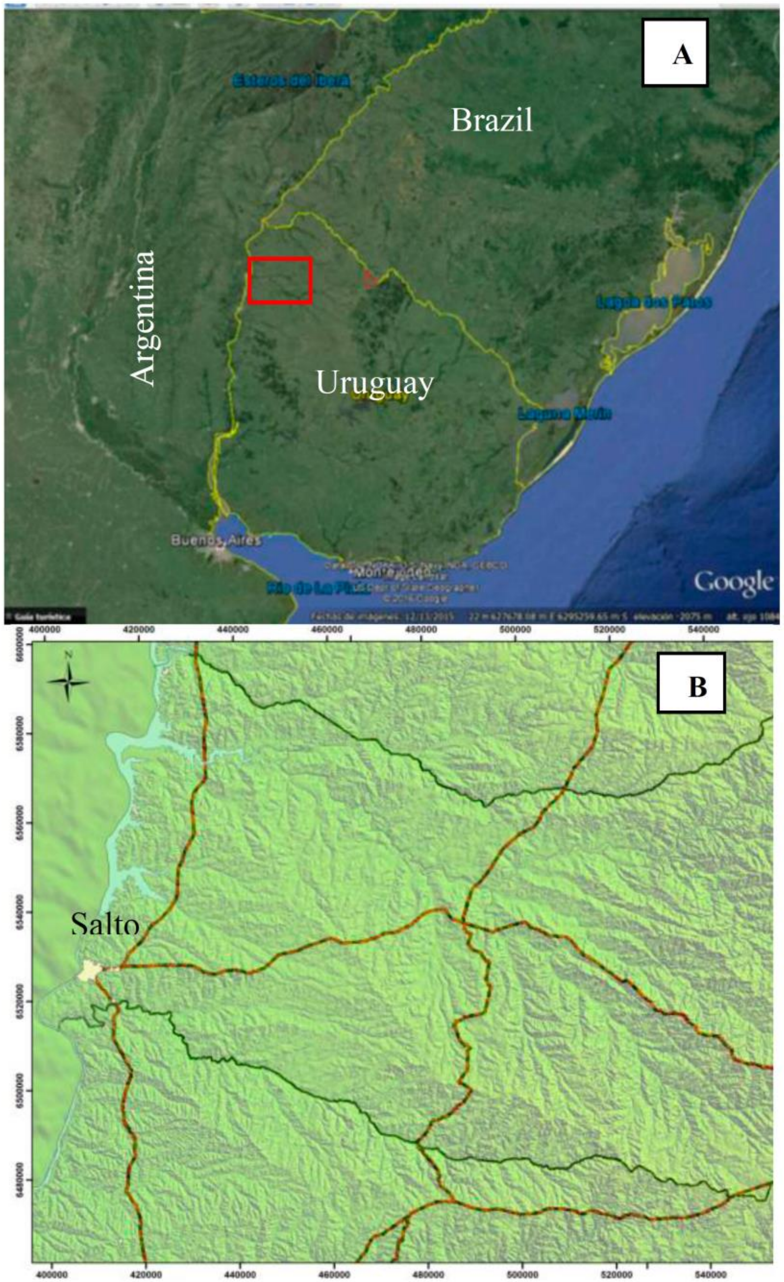


Figure 2. (A): Regional location of the study area. (B): Study area, scale map 1:700.000.


Figure 3. Structural setting of the Paraná Basin. Modified from Zalán et al., 1990. Include the main structural lineament indicated by Preciozzi et al., 1979 for Uruguay.

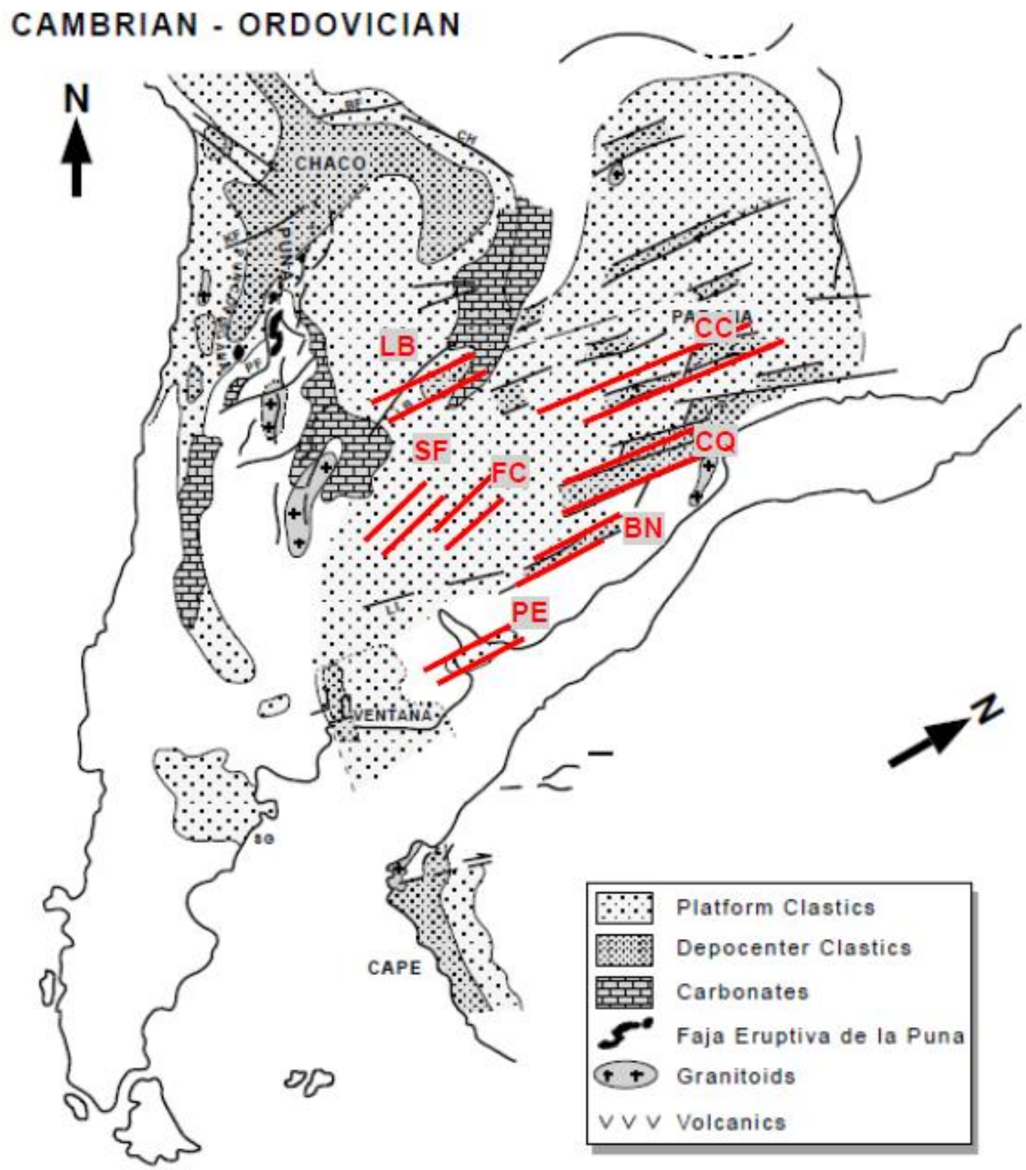


Figure 4. Cambrian, Ordovician and Silurian clastic depocenters with N-NE preferential direction. BN (Barriga Negra, Uy), CC (Central rift, Br), CQ (Camaqua, Br), FC (Corrientes graben, Ar), SF (Santa Fé graben, Ar), PE (rift Punta del Este, Uy). Modified from Tankard et al. (1995).

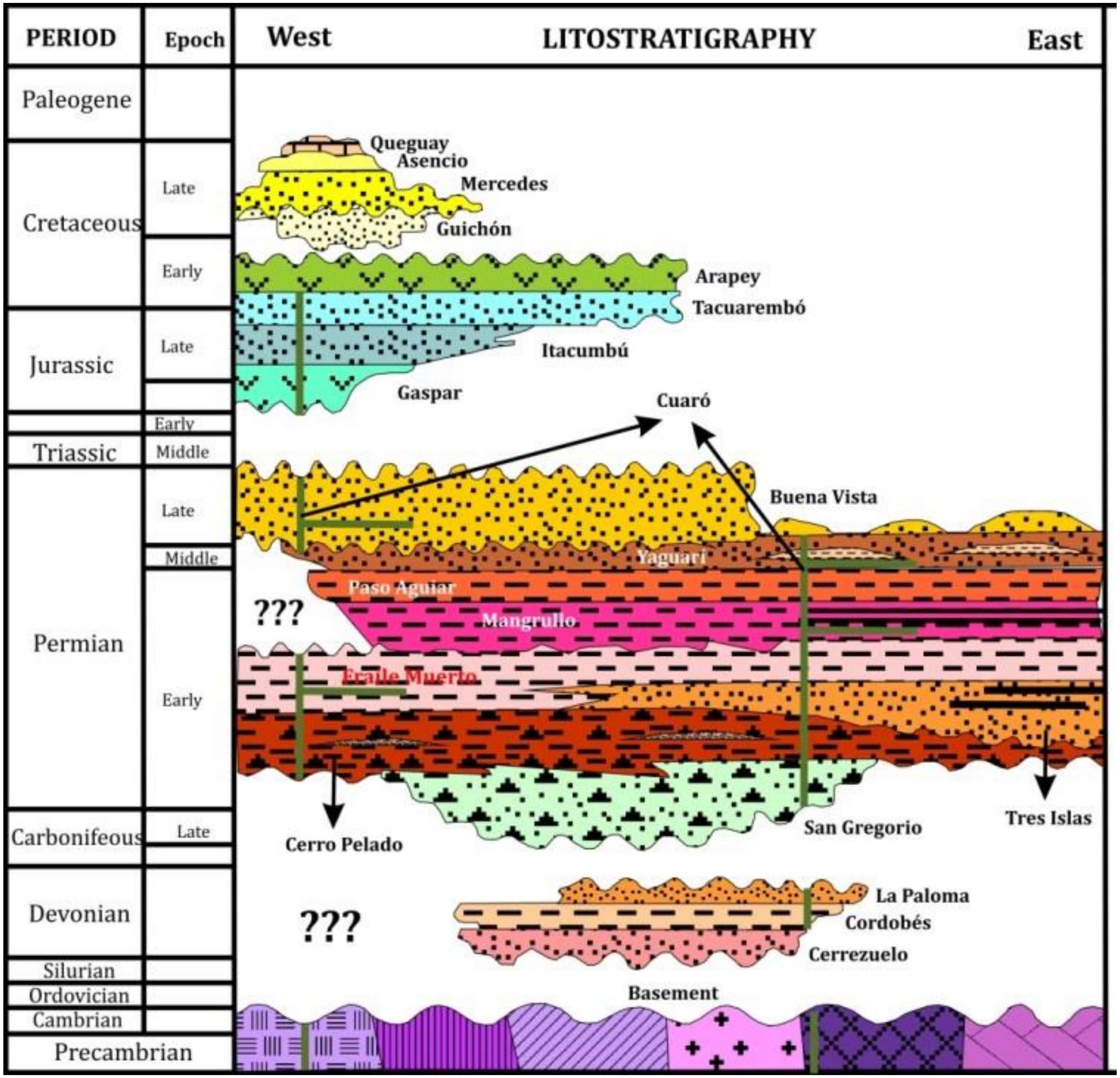


Figure 5. Stratigraphic chart of Norte Basin. Modified from de Santa Ana, (2004).

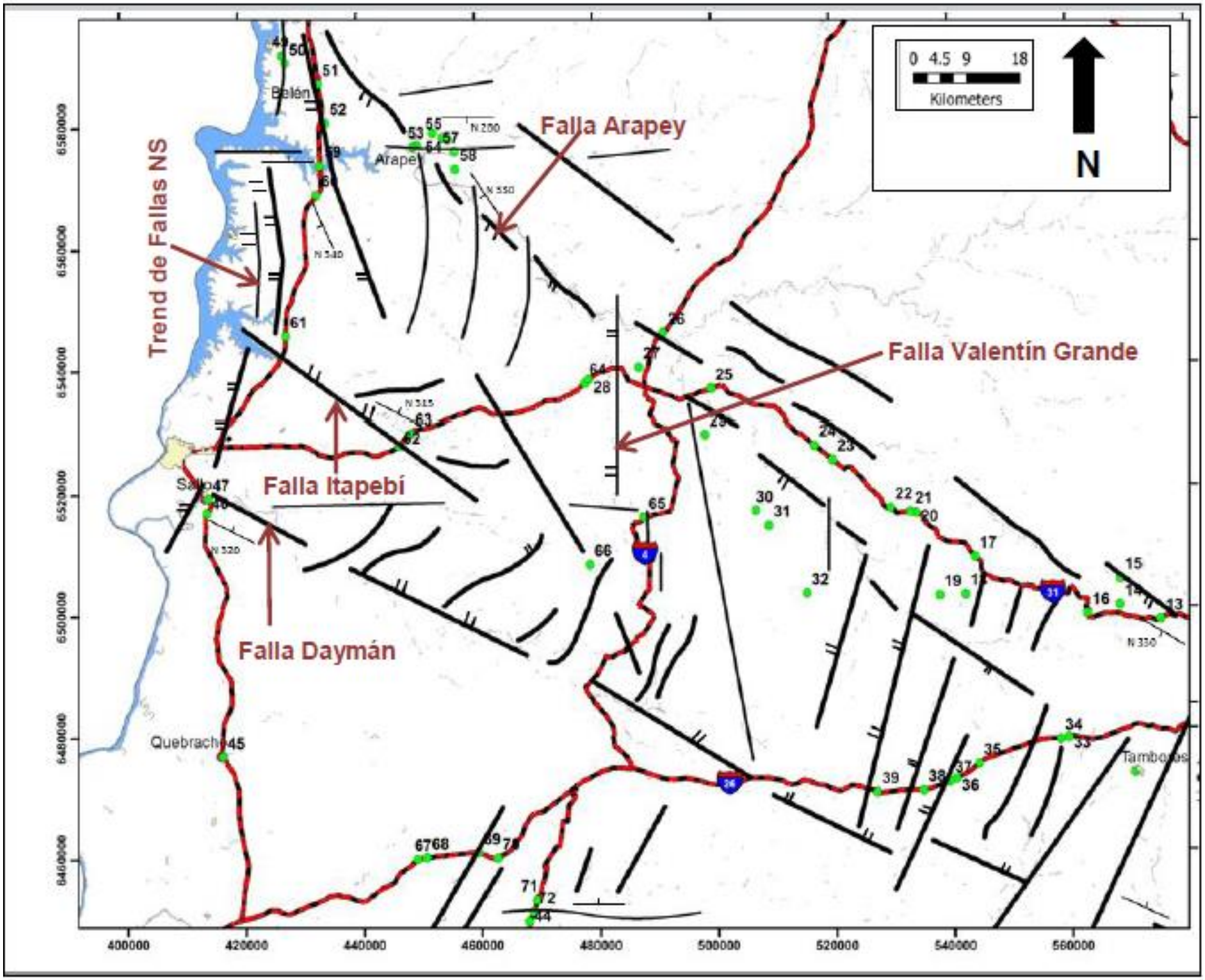


Figure 6. Map with the location of the Salto – Tambores structural corridor (STC) defined by Daymán and Arapey faults.

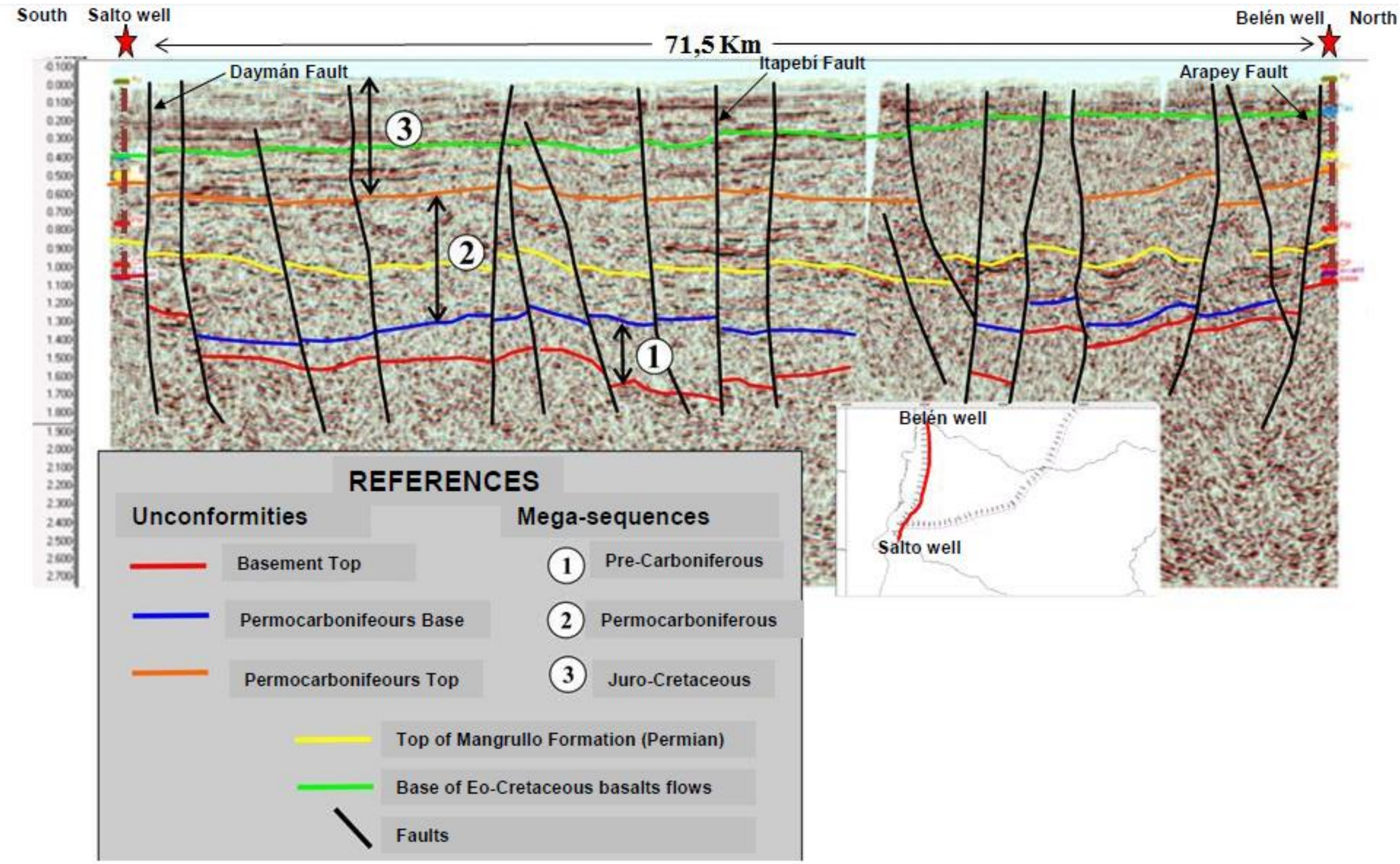


Figure 7. Seismic interpretation (arbitrary line composed by reprocessing 2D seismic UR84-YPF-60; UR84-YPF-61 and UR84-YPF-62).

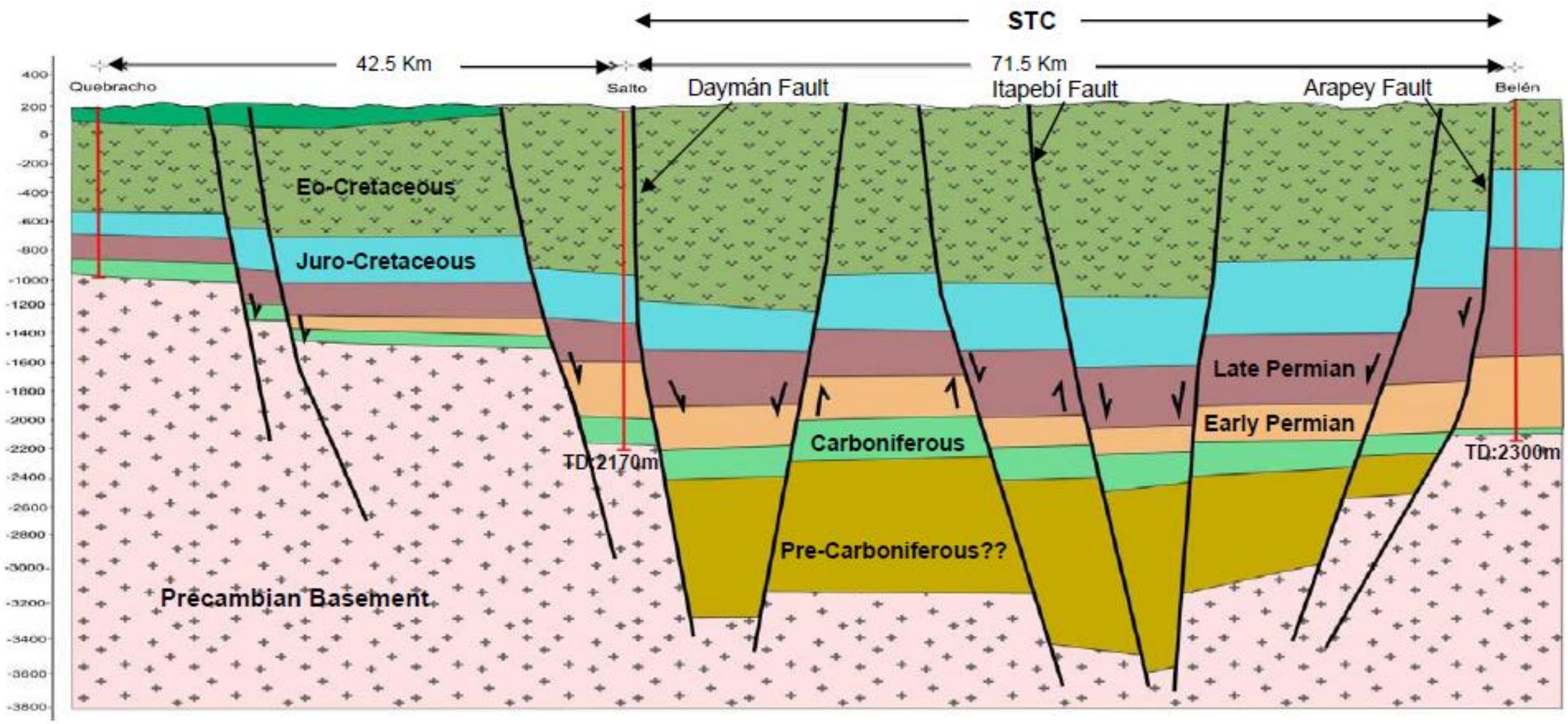


Figure 8. N-S geological cross section in the western segment. Is integrated seismic, MT, and geological well data.