Geologic and Volumetric Evaluation of Prospects Offshore Uruguay*

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Abstract

Exploration activity offshore Uruguay has grown exponentially in recent years with the acquisition of approximately 12,000 km of 2D and 40,000 km^2 of 3D seismic, despite being a frontier area without proven petroleum systems. The seismic data acquired cover the three basins recognized offshore Uruguay, Punta del Este to the west, Pelotas to the east and Oriental del Plata Basin to the south, representing together an area of approximately 125,000 km^2. These basins are still underexplored, with only two exploratory wells drilled in 1976 in shallow waters of Punta del Este Basin. The sedimentary infill includes a prerift phase with Paleozoic to Mesozoic units, an Early Cretaceous synrift phase, and a Cretaceous to Cenozoic postrift phase. The seismic data allowed the identification of numerous stratigraphic and structural leads and prospects that revealed a promising geology which led to the decision of drilling a new well in 2016 in ultradeep waters of Pelotas Basin.

The objective of this study is to present the hydrocarbon potential offshore Uruguay through the volumetric resource estimation of different prospects. A seismic stratigraphic analysis applied to the available 2D and 3D seismic data, using the principles of Sequence Stratigraphy, was the methodology utilized for the definition and interpretation of prospects and the speculative petroleum systems associated with them. For the volumetric calculation, after the probabilistic distributions for each input variable was defined, we performed 10,000 iterations of simulation for each prospect in order to obtain the probabilistic distribution of prospective resources. In this work we present the results of four selected prospects. The criteria used to select these prospects was to show the diversity of plays, the different petroleum systems, the existence of siliciclastic and carbonate reservoirs and the different types of traps present in the basins. The first prospect analyzed is an anticline structure associated with the prerift megasequence, the second prospect is interpreted as a lacustrine fan system associated with the synrift phase, the third one is a carbonate construction deposited in a horst structure during the Early Cretaceous postrift phase, and finally the fourth selected prospect is a Paleocene turbidite deposited in the drift phase. The probabilistic aggregation of the undiscovered hydrocarbon initially in place of these four prospects gives a mean value result of approximately 14,000 MMBbls of oil and 33 TCF of gas.

Introduction

This work focuses on the hydrocarbon potential offshore Uruguay. The area of study is located in the South Atlantic Ocean between 50º00’ and 55º60’ west longitude and 33º75’ and 37º80’ south latitude. It extends from shore to the 200 nautical miles covering an area of approximately 125,000 km^2 and bathymetries that ranges between 20 and 4000 m. Three typical passive margin basins develop in this area, Punta del Este Basin located in the west near the border with Argentina and Pelotas Basin to the east near the border with Brazil and Oriental del Plata to the south in ultradeep waters (Figure 1).

These basins were generated during the process of fragmentation of the Gondwana supercontinent and later opening of the South Atlantic Ocean during Lower Cretaceous. Punta del Este Basin (Figure 2) has a funnel shape with a NW-SE trend, constituting a failed arm (aulacogen) of the rifting process. The main feature of this basin is the development of large half-graben structures that could comprise more than 4 km of sedimentary fill. The Pelotas Basin extends through offshore Uruguay and Brazil with a NE-SW orientation representing the flexural margin of a rifting process that later evolved into a passive margin. The Oriental del Plata Basin develops to the south in ultradeep waters, overlying both transitional and oceanic crust and limits with Punta del Este Basin through the landward limit of the seaward dipping reflectors (SDRs) (Soto et al., 2011). Two main phases are recognized in the evolution of these basins that will be discussed later, synrift and postrift. In 1976 the first two exploratory wells were drilled offshore Uruguay (Lobo x-1 and Gaviotin x-1) in shallow waters, between 40 and 50 meters, of the Punta del Este Basin. Both wells were declared dry and due to their proximal location did not reach levels with source rock. After these results the exploration activity was halted for decades. However, in recent years, as a result of the E&P contracts signed among ANCAP and IOCs after Uruguay Round 2009 and II, and multi-client agreements among ANCAP and service companies, the activity has grown exponentially with the acquisition of several 2D and 3D seismic surveys that approximately represent 12,000 km of 2D and 40,000 km^2 of 3D seismic, covering all the offshore basins.

Therefore, nowadays the offshore of Uruguay has an important amount of seismic data but very scarce direct information through wells. This seismic data allowed the identification of numerous stratigraphic and structural prospects that led to a new exploratory well to be drilled in 2016 located in ultradeep waters of Pelotas Basin (Figure 3). In this study four different prospects were selected and described to show the diversity of plays, different speculative petroleum systems and the variety of reservoirs present in the basins. In order to emphasize the hydrocarbon potential of these particular prospects, a volumetric resource estimation was made.

Stratigraphy of Punta del Este and Pelotas Basins

The seismic interpretation of Punta del Este and Pelotas basins allowed us to identify three megasequences that were previously defined, bounded by second order unconformities: prerift, synrift and postrift (Fontana, 1987; Ucha et al., 2004; Bueno et al., 2007).

Prerift

The prerift megasequence was identified by wells both in Punta del Este Basin and Pelotas Basin (drilled in the Brazilian segment). The last 139 meters of Gaviotin x-1 well in Punta del Este Basin encountered Permian sandstones and shales that were correlated with sedimentary sequences that outcrop onshore Uruguay (Veroslavsky et al. 2003) in the intracratonic Parana Basin (the Uruguayan sector is termed Norte Basin). This megasequence was deposited during the Paleozoic in a continental environment previous to the fragmentation of the Gondwana supercontinent and the genesis of Punta del Este and Pelotas Basin. Offshore Uruguay, the seismic interpretation shows that the Paleozoic sequence reaches, in some areas, several kilometers thick and develops in the proximal region of both basins, mainly related with the extension of the Polonio High. In onshore Uruguay the Paleozoic section is well known comprising Devonian and Permian sequences. The Devonian sequence constitute a complete transgression-regression cycle with continental sandstones and organic rich marine shales while the Permian sequence represents a more complex geological evolution with continental and marine deposits comprising diamictites, conglomerates, sandstones and marine shales with high TOC values (de Santa Ana, 2004). Both Devonian and Permian sequences include potentially high quality reservoir and source rocks.

Synrift

The synrift phase developed in a continental environment during the Early Cretaceous (Barremian) and is represented by volcano-sedimentary sequences associated with the rifting of continental crust and later installation of lacustrine systems. The synrift megasequence is constituted by the infill of graben and halfgraben structures that developed mostly in the proximal part of Punta del Este Basin and to a lesser extent in the Pelotas Basin. The synrift also develops in a more distal position of these basins associated with the seaward dipping reflectors (SDR). The synrift sequence is represented by volcanics and continental sediments. The two offshore wells located in Punta del Este basin drilled almost 1,000 m of the synrift section, encountering basalts, pyroclastic rocks, conglomerates and sandstones. It is important to notice that both wells were located in basement highs and did not drilled the depocenters of the halfgraben structures that could reach more than 4 kilometers of sedimentary infill. The seismic data allows us to recognize in these depocenters continuous and parallel reflectors that could be interpreted as lacustrine systems. This synrift lacustrine interval was drilled in the conjugate Orange Basin encountering shales with important TOC values (>10%) that represent high quality source rocks (Paton, 2008)

Postrift

The postrift or drift phase developed since Aptian times to present day and is represented by a succession of predominantly siliciclastic sequences associated with the establishment of marine conditions. The deposition of this megasequence is controlled by sea level changes. The seismic interpretation of this package allows us to interpret at least four maximum flooding surfaces (Aptian-Albian, Cenomanian Turonian, Paleocene and Miocene). It is possible to recognize in the Upper Cretaceous sequences and upwards the development of shelf and slope geometries and submarine fans with a high potential for reservoirs. According to seismic and regional data, the first marine transgression in the offshore basins of Uruguay took place during Aptian-Albian times presumably constituted by high TOC marine shales deposited during the first Oceanic Anoxic Event (OAE) of the Cretaceous, representing one of the most significant source rocks of the South Atlantic basins. Another important potential source rock for the postrift phase would be associated with marine shales of the Cenomanian-Turonian transgression, deposited during the second OAE of the Cretaceous. A third significant marine transgression took place in the Lower Paleocene that could represent not only a potential source rock but a thick and widespread regional seal.

Description of Plays and Prospects

Analyzing and interpreting the 2D and 3D seismic data, we selected four prospects. Each prospect was chosen to show the diversity of plays existing in the basins, and the various source and reservoir rocks, including siliciclastics and carbonates. The approximate location of the four selected prospects is shown in Figure 4.

Prospect A

The first prospect selected is associated with the prerift megasequence and constitute an anticline structure (Figure 5A) with four-way closure that develops in the proximal segment of the Pelotas Basin. This anticlinal structure is bounded by a reverse fault that represents the main hydrocarbon migration pathway. The source rock would be represented by Early Permian restricted marine shales and Early Devonian marine shales with high TOC values that are proven in the onshore Norte Basin of Uruguay. The reservoirs are associated with Upper Permian and Early Jurassic aeolian-fluvial sandstones, with the seal represented by Early Cretaceous basaltic floods. Dry gas is expected for this prospect due to the significant overburden of the potential source rocks (7000 m).

Prospect B

The second prospect develops in the synrift megasequence associated with the infill of a deep halfgraben structure located in the proximal segment of Punta del Este Basin. The prospect itself is represented by sandstones from a lacustrine fan system deposited at the top of the synrift phase (Figure 5B) and intercalated with lacustrine shales that represent both source and seal. The migration of hydrocarbons for this prospect is expected to be direct due to the intercalation between source and reservoirs rocks.

Prospect C

The third prospect is located in the proximal segment of Pelotas Basin and constitutes a carbonate construction deposited in a horst structure between halfgrabens (Figure 5C) in Aptian-Albian times during the Early Cretaceous postrift phase. The main source rock that could feed these carbonates are the lacustrine shales of the synrift phase, while the marine shales of the Paleocene transgression represent the regional seal. The migration is expected to take place through the main normal fault that generates the halfgraben structure.

Prospect D

The fourth selected prospect is an Early Paleocene turbidite deposited in the drift phase (Figure 5D). The seismic analysis allows us to identify a sigmoidal geometry that represents basin floor fan sands that are covered with Paleocene marine shales. For this case the source rocks are associated with Aptian-Albian or Cenomanian-Turonian marine shales. Several subvertical faults connecting potential source and reservoir rocks were identified in seismic.

Volumetric Calculations

Probabilistic procedures are most suitable during prospect appraisal, when the greatest degree of geologic uncertainty is faced. Therefore, due to the uncertainty inherent at this stage to all input variables, volumetric calculations were conducted stochastically by 10,000 iterations of Latin Hypercube type sampling and Mersenne Twister generator, with probability distributions as input for each variable.

Hydrocarbon Initially In Place volumes (HIIP) were calculated according to the formula:

$$HIIP = A \times GPT \times GCF \times NTG \times \Phi \times Sh / FVF$$

Where:

A: Area
GPT: Gross Pay Thickness
GCF: Geometry Correction Factor
NTG: Net-to-gross
Φ: Porosity
Sh: Hydrocarbon Saturation
FVF: Formation Volume Factor

The area of each prospect was defined by the interpretation of the available 2D and 3D seismic data, taking into account a maximum and a minimum value. Reality checks were performed for the high ends and for the mean area of each prospect, comparing them with Gulf of Mexico, West Africa and Campos Basin prospects data.

Gross Pay Thickness, Geometry Correction Factor and Net-to-gross parameters were also inferred from seismic but including well data. The resulting recovery yield was submitted to reality checks according to the quality of the expected reservoir.

Porosity distributions were constructed for each prospect taking into account the burial effect using various porosity vs depth datasets, and hydrocarbon saturation distribution was considered for all the prospects between 60% and 85% (P90-P10).

The corresponding Formation Volume Factor (Bo or Bg) was selected with regards to the most probable fluid scenario and taking into account prospect's depth. Prospect 1 is considered dry gas bearing while prospects 2, 3 and 4 are considered oil bearing. Additionally, for oil bearing prospects, the associated gas was calculated according to typical black-oil's Gas:Oil Ratio range following a uniform distribution.

The results of the hydrocarbon volumes in-place calculations for each prospect are presented in Table 1 as well as its probabilistic aggregation. Additionally, estimated recovery factors (RF) were considered with a distribution between 15% and 30% (P90-P10) for prospects 2, 3 and 4, while a range of 30% and 60% was used for prospect 1. The Estimated Ultimate Recovery (EUR) was calculated according to:

EUR = HIIP x RF

The results of estimated ultimate recovery calculations for each prospect are presented in Table 2 as well as its probabilistic aggregation.

Conclusions

The seismic data indicates an important potential for accumulation of hydrocarbons with diversity of stratigraphic and structural plays, various types of source rocks and reservoirs that include siliciclastics and carbonates. Several prospects have been analyzed with 3D data and are considered drillable prospects by the authors. The probabilistic aggregation of the four prospects analyzed gives a Mean value result of Oil Initially in Place of approximately 13,300 MMBbls and 30 TCF of Gas Initially in Place, which corresponds to mean Prospective Resources of approximately 3 billion barrels of oil and 9 TCF of gas. Considering that these four selected prospects are only an example of several other additional prospects identified in the offshore de Uruguay, the results suggest a huge potential for this frontier area.

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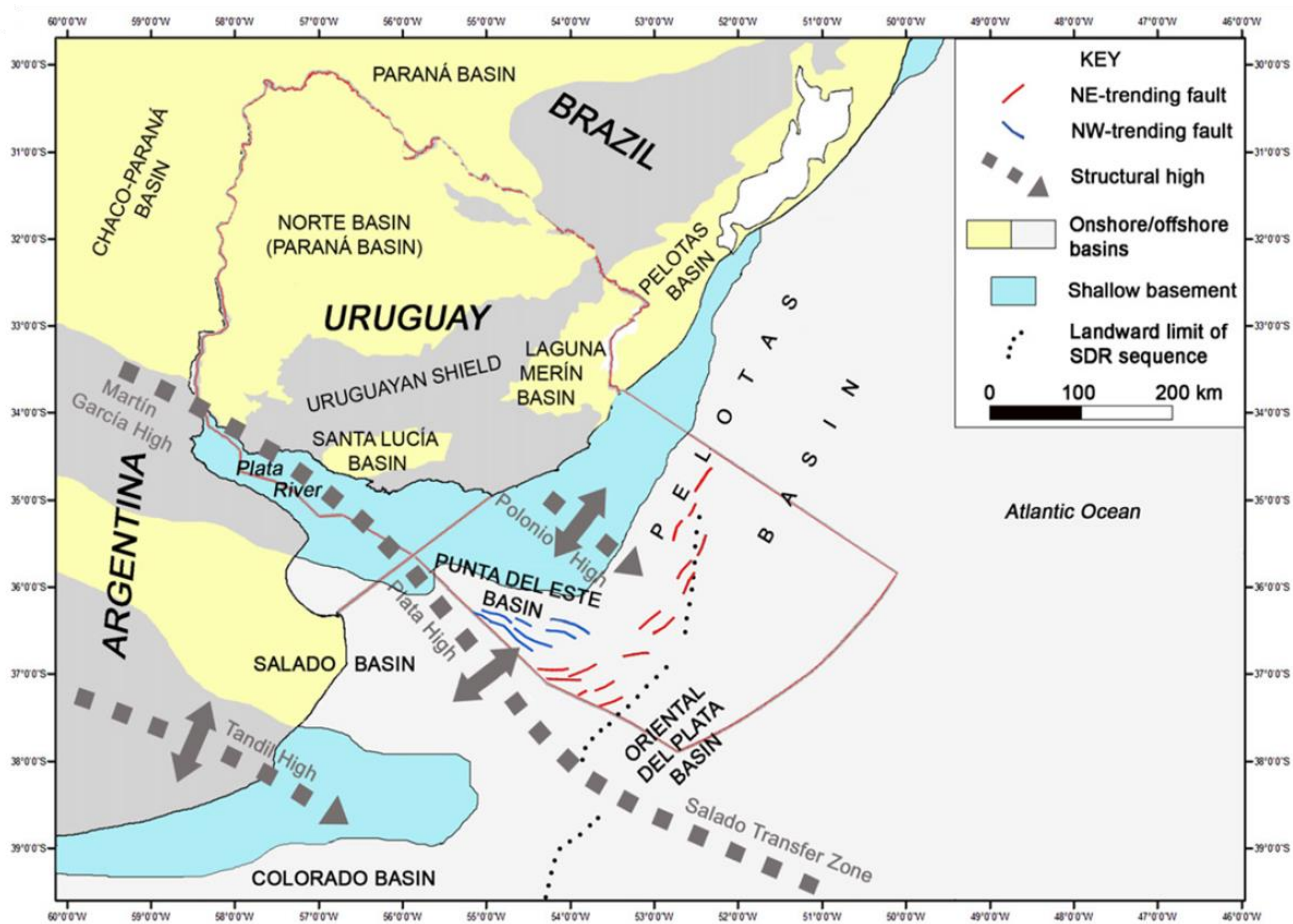

Figure 1. Distribution of Punta del Este, Pelotas and Oriental del Plata basins in offshore Uruguay with location of main structures; Soto et al. (2011).

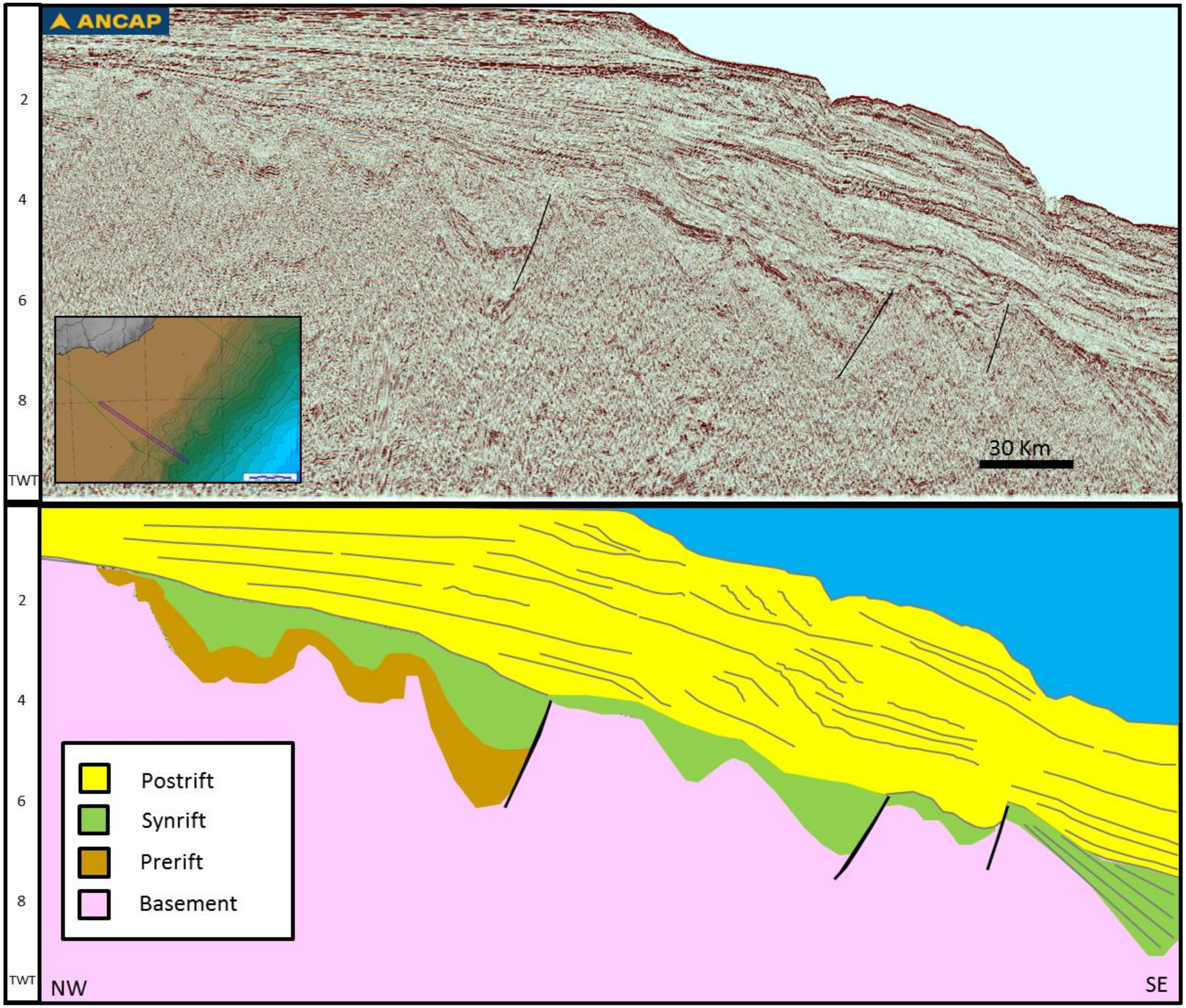

Figure 2. Dip seismic line of Punta del Este Basin (above) and sketch with interpretation of megasequences (below). Seismic section property of ANCAP.

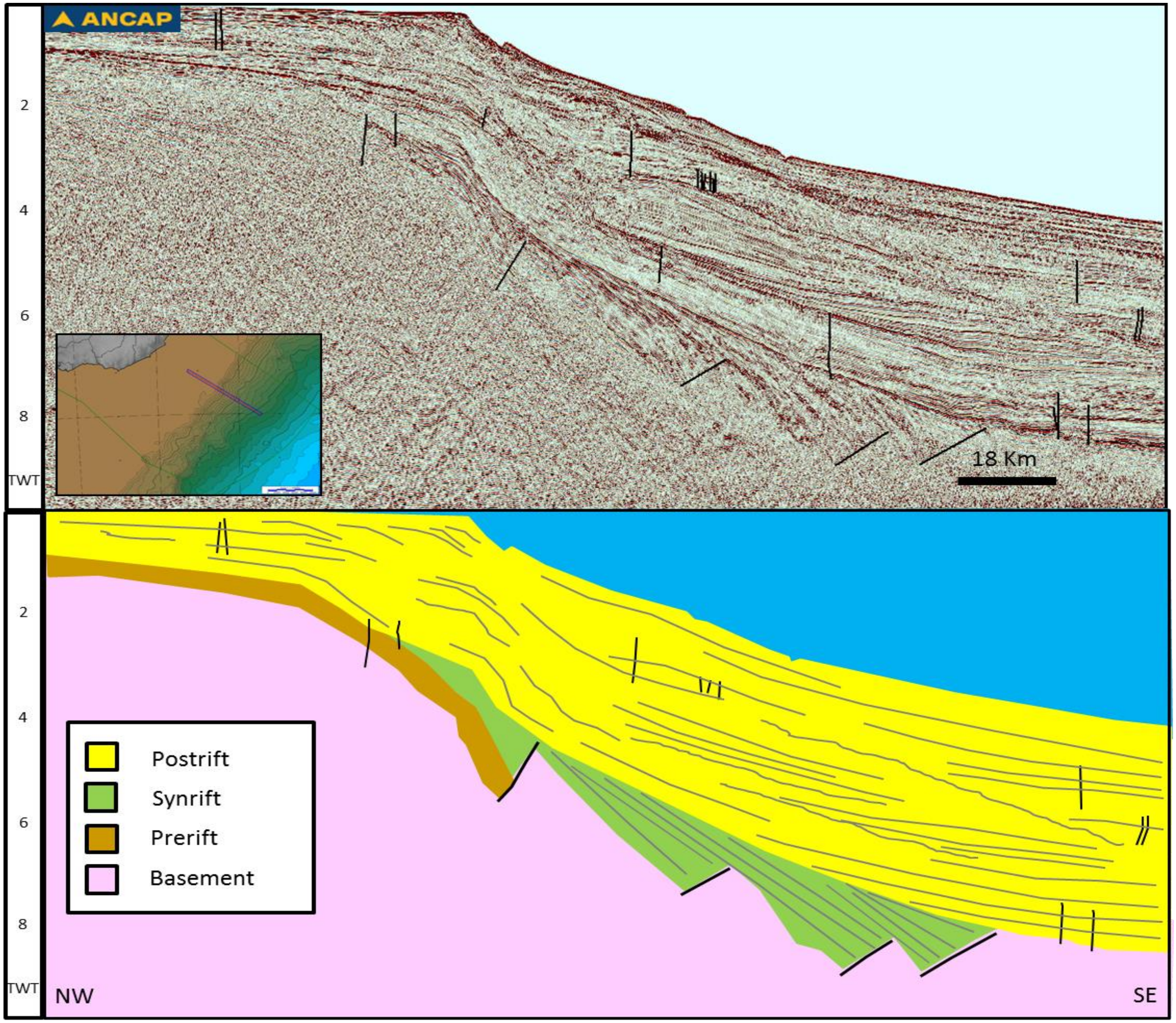

Figure 3. Dip seismic line of Pelotas Basin (above) and sketch with interpretation of megasequences (below). Seismic section property of ANCAP.

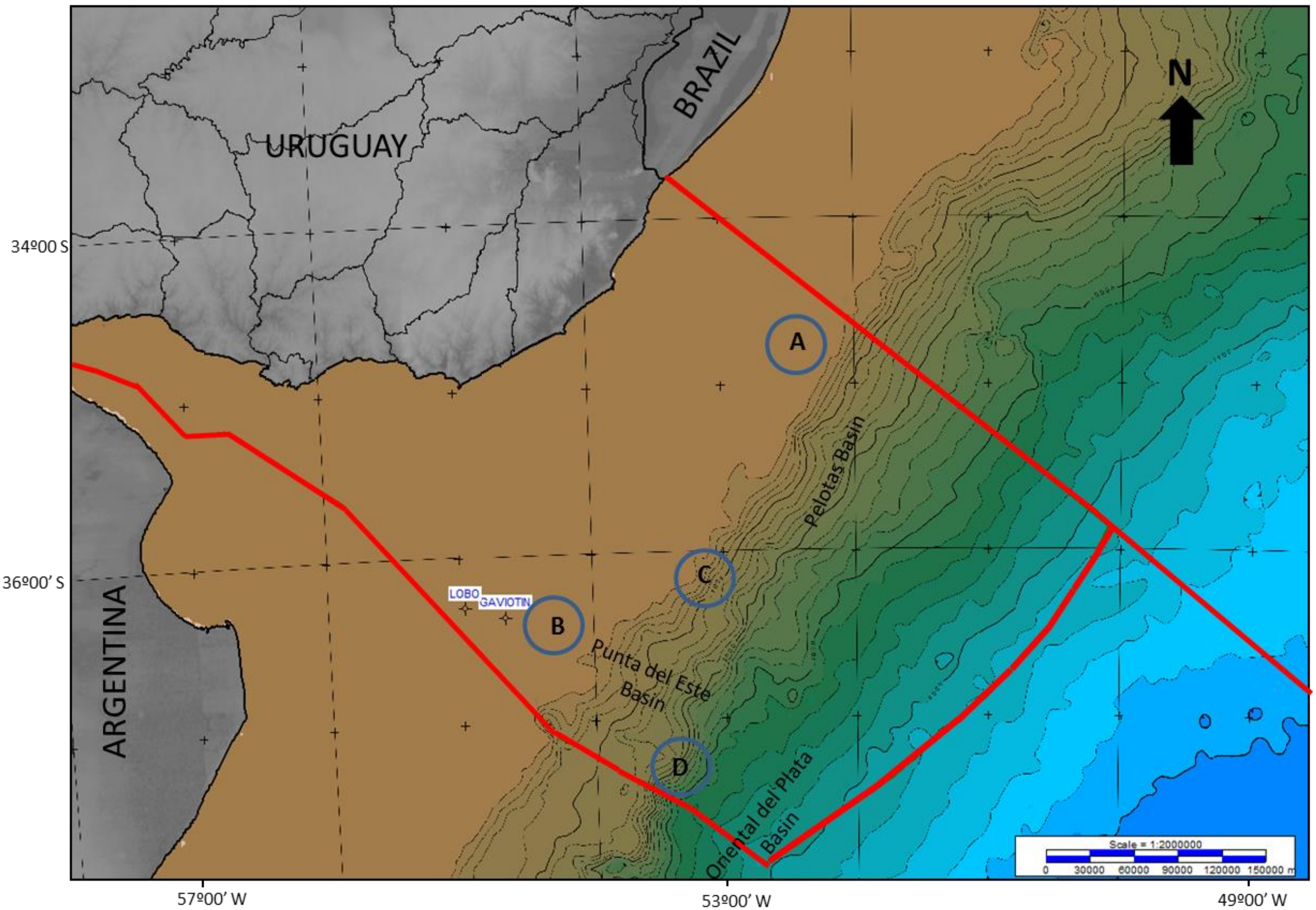

Figure 4. Approximate location of selected prospects.

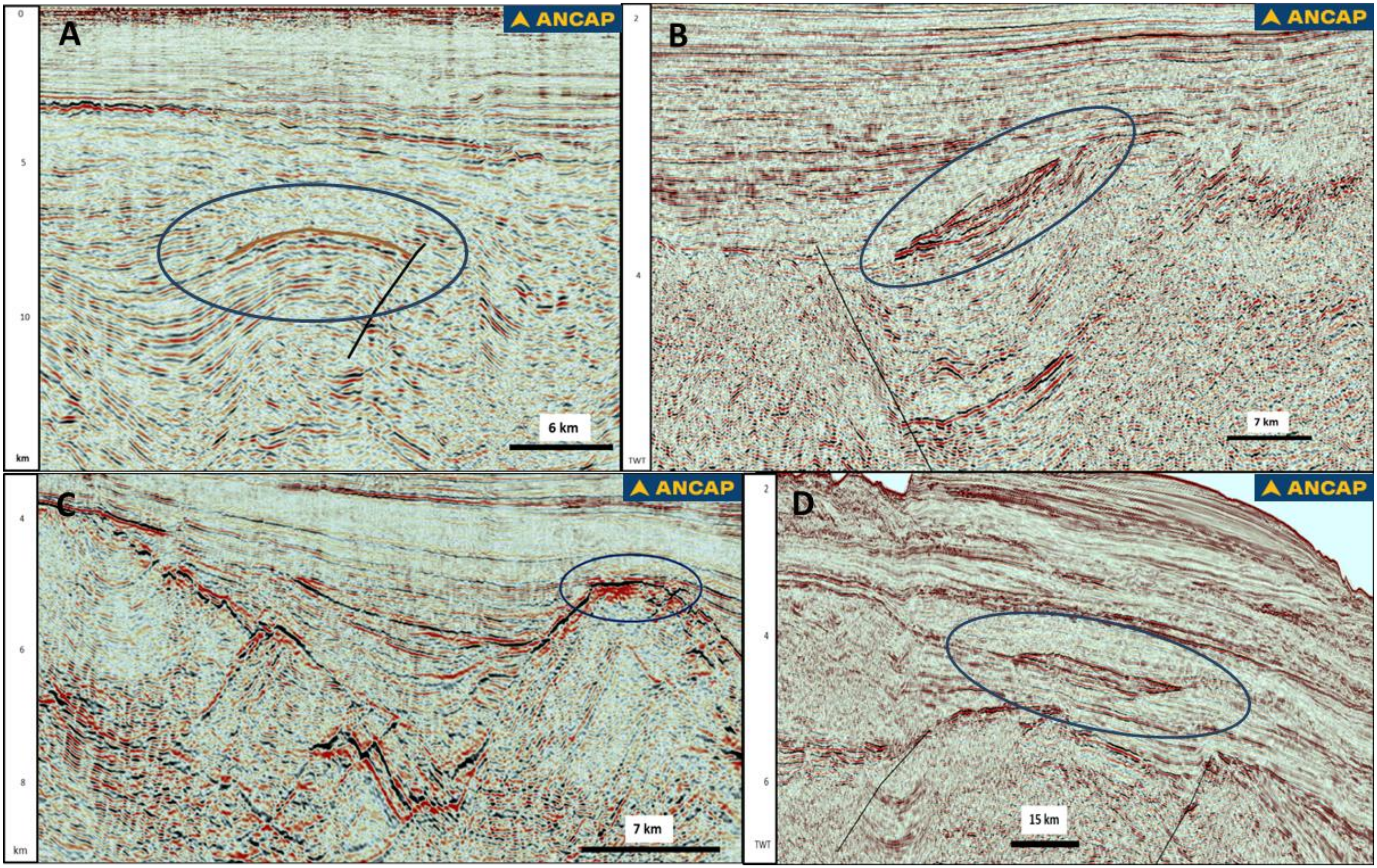

Figure 5. Seismic sections showing the selected prospect (circled in blue). (A) Prospect A: Anticline structure in Paleozoic prerift section bounded by reverse fault. (B) Prospect B: Lacustrine fan on top of synrift megasequence in halfgraben structure. (C) Prospect C: Potential carbonate construction deposited in horst structure. (D) Prospect D: Lower Paleocence Submarine fan. Seismic sections property of ANCAP.

	Oil (MMBbls)			Gas (TCF)		
Prospect	**P90**	**P10**	**Mean**	**P90**	**P10**	**Mean**
A				1.0	26.6	11.0
B	1,377	19,324	8,553	2.5	28.5	13.1
C	470	2,832	1,480	0.3	4.3	1.9
D	477	7,543	3,244	0.4	10.3	4.2
	4,527	**25,362**	**13,276**	**11.2**	**55.4**	**30.3**

Table 1. Undiscovered hydrocarbon in-place volumes for each studied prospect and its probabilistic aggregation.

	Oil (MMBbls)			Gas (TCF)		
Prospect	**P90**	**P10**	**Mean**	**P90**	**P10**	**Mean**
1				0.9	10.8	5.0
2	285	4,239	1,901	0.2	5.9	2.5
3	96	641	328	0.1	1.0	0.4
4	98	1,717	723	0.1	2.3	0.9
	959	**5,633**	**2,952**	**3.0**	**16.4**	**8.8**

Table 2. Estimated Ultimate recovery for each studied prospect and its probabilistic aggregation.