The Punta del Este Half Grabens, Offshore Uruguay: The Next Exploration Frontier in the South Atlantic*

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Abstract

The South Atlantic opening is characterized by an initial extensional phase dominated by asymmetric half grabens which can be identified, from south to north, in the North Falkland / Malvinas Basin, Punta del Este (PdE) Basin and Santos Basin. Flanked by the world class pre-salt fields of Santos Basin (Tupi, Jupiter, Carioca, Iracema, Iara among others) to the north and the recent discoveries in the North Falkland / Malvinas Basin (Sea Lion, Zebedee, Isobel Deep) to the south, the PdE half grabens in offshore Uruguay emerge as the new frontier exploration along the South American margin of the South Atlantic.

Recently acquired seismic allowed to refine the asymmetric configuration of these NW-SE - oriented rifts in the PdE Basin, a common feature with the pre-salt half grabens in offshore Brazil and the North Falkland / Malvinas Basin. It also helped to identify synrift and laterally extensive postrift (sag) sections. This configuration has the potential for stratigraphic and/or combined onlap / pinchout traps at the synrift and sag levels on the flexural margin, similar to several presalt traps, and also stratigraphic traps with synrift, turbidite reservoirs like in the Sea Lion discovery. Landward dipping master border faults present in the PdE half grabens, opposite to the present deepening of the continental margin, enhance trap integrity of structural (four-way) closures. This is due to the critical role played by differential compaction at the half-graben border fault margin to accentuate and/or create counter-regional dips necessary to form structural traps at the overlying sag level.

The North Falkland / Malvinas Basin could be a good analog for source rock presence in the PdE half grabens. It contains a late Jurassic (Tithonian) to early Cretaceous lacustrine source rock in the synrift section and an early Cretaceous (Valanginian to Barremian or Aptian) organic-rich interval in the early postrift (sag) section. The Sea Lion discovery contains waxy oil in Lower Cretaceous, base-of-slope to basin-floor fan sandstone reservoirs. Overlying early post-rift immature source rocks acted as a seal. Additional potential could come from Permian sandstone reservoirs, where light oil (39° API) was found in the Cruz del Sur x-1 well in the Colorado Basin, south of the PdE Basin.

Introduction

The tectonic setting of the opening of the South Atlantic is centered around the presence of asymmetric half grabens, which represent the initial stretching phase of the extensional breakup of the South American and African continents (Lavier and Manatschal, 2006; Mohriak and Leroy, 2008). This tilted half-graben configuration, with a clearly defined steep border fault margin adjacent to the deepest part of the rift basin and a ramp or flexural margin, is widespread in the Espirito Santo, Campos, and Santos basins of offshore Brazil, absent south of the Santos Basin in the Pelotas Basin but present again in the Punta del Este Basin in offshore Uruguay, and further south in the North Falkland (Malvinas Norte) basins (Figure 1). Flanked by the world class pre-salt fields of Santos Basin (Tupi, Jupiter, Carioca, Iracema, Iara among others) to the north and the recent discoveries in the North Falkland / Malvinas Basin (Sea Lion, Zebedee, Isobel Deep) to the south, the PdE half grabens in offshore Uruguay emerge as the new frontier exploration along the South American margin of the South Atlantic. In this contribution we review key elements of the half graben architecture as identified in 2D seismic lines in the PdE basin and propose the half grabens of the Santos and Campos basins and the North Falkland/North Malvinas Basin in southern South America as possible synrift and early postrift (sag) play analogs.

Syn-rift plays are associated with lacustrine/fluvial facies and trap geometries related to half-graben development and associated differential compaction (López-Gamundi and Morales, 2014), while early post-rift (sag) plays also include shallow water to restricted hypersaline lacustrine carbonate facies (i.e. microbial limestones in Santos and Campos basins, Buckley et al., 2015; Muniz and Bosence, 2015; Petersohn and Abelha, 2013) in combination with traps indirectly influenced by the underlying half graben configuration.

Seismic Expression

Recently acquired 2D seismic allowed to refine the asymmetric configuration of these NE-SW - oriented rifts in the PdE Basin, a common feature with the pre-salt half grabens in offshore Brazil (Figure 2) and the North Falkland / Malvinas basin. It also helped to identify synrift and laterally extensive postrift (sag) sections. The lines selected are oriented WNW-ESE, parallel to subparallel to the inferred extension that generated the half grabens.

The asymmetric half graben configuration has the potential for stratigraphic and/or combined onlap / pinchout traps at the synrift and sag levels on the flexural margin, similar to several presalt traps, and also stratigraphic traps with synrift, turbidite reservoirs like in the Sea Lion discovery the North Falkland / Malvinas basin. Landward dipping master border faults present in the PdE half grabens, opposite to the present deepening of the continental margin, enhance trap integrity of structural (four-way) closures (Figure 3).

Like in the Santos and Campos basins the PdE rifts show variable (landward or basinward) polarity but in some cases there is a dominant landward (westward) vergence, opposite to the present deepening of the continental margin (Figure 2). In this latter case, differential compaction at the half-graben border fault margin has been a key factor to accentuate and/or create counter-regional dips necessary to form structural (four-way) closures at the sag level. Trap integrity of the four-way closures is then enhanced in asymmetric half grabens with landward dipping master border faults. Conversely, half grabens with basinward vergence, defined by basinward dipping master border faults and landward dipping ramp margins, create gently dipping, counter regional dips and therefore contribute to the formation of riskier four-way traps (López-Gamundi and Morales, 2014). Where half grabens with opposite vergence (landward and basinward dipping master border faults) are contiguous interbasinal highs are identified (Figure 3) showing a configuration common in rifts of the East African Rift System (EARS, Rosendahl et al., 1986).

The synrift fill is seismically characterized by concordant base and top, a gradual fanning of the horizons, strongly divergent internal configuration on the fault margin, and thinning (convergent internal configuration) on the flexural margin (Figure 3 and Figure 4). This divergent internal configuration has been interpreted as the product of differential, tectonically-triggered subsidence caused by normal faulting.

Seismic evidence of differential compaction is provided by the presence of hanging wall compaction synclines (CS) over basement footwall cutoff points. The synclines are characterized by approximately vertical fold axes immediately above the hanging wall cutoff of the basement. In poorly imaged areas, the termination of the divergent seismic configuration of the synrift strata can be used to place the master fault of the half graben (Figure 5).

The synrift section can be recognized by a thick package of reflectors that diverge towards the border faults. In some of the half grabens the synrift fill can be subdivided into two kinematic sequences: a) an early phase that is areally confined and with strongly divergent pattern, and b) a later phase that laps on the underlying sequence and basement on the flexural border (Figure 5). The early phase was triggered by the highest rate of fault-related, tectonic subsidence which created accommodation space close the master border fault and consequently potential conditions for lacustrine basinal sedimentation. These conditions are met when the rate of space accommodation creation (in this case mainly caused by tectonic subsidence along the half graben master fault) greatly exceeds the rate of sediment supply. These two kinematic sequences are separated by a sequence boundary characterized by angular truncation below and onlap stratal terminations on top (Figure 3 and Figure 6).

Analogs and Exploration Plays

The North Falkland / Malvinas Basin could be a good analog for source rock presence in the PdE half grabens. It contains a late Jurassic (Tithonian) to early Cretaceous lacustrine source rock in the syn-rift section and another organic rich interval in the early postrift (sag) section, of early Cretaceous (Valanginian to Barremian or Aptian) age. The Sea Lion Field contains waxy oil in the 24.5–29.3°API range (Farrimond et al., 2015) in Lower Cretaceous base-of-slope to basin-floor fan reservoir sands. These fans are dominated by mass flow and high-density turbidite sandstones associated with lacustrine shales (Griffiths, 2015). The turbidite reservoirs, identified by amplitude anomalies, comprise a series of canyon-fed fans deposited into a deep, anoxic lake on the eastern fault-bounded margin of the basin (Lohr and Underhill, 2015). The oil is likely to be sourced from Lower Cretaceous lying beneath the reservoir sands. Overlying early postrift immature source rocks acted as a seal.

The PdE half grabens are strikingly similar in architecture and dimensions to those identified in the Santos and Campos basins (Figure 7). Virtually all of the hydrocarbons discovered in the Santos and Campos basins originated from Lower Cretaceous synrift lacustrine facies of the Lagoa Feia Formation and equivalent units (Mello and Maxwell, 1990). Additional source rock potential has been identified in thick shales associated with the maximum flooding surfaces of the transitional interval and lower sag Jiquia sequence in the Santos and Campos basins

(Guthrie et al., 2011). Similar rift dimensions and configurations identified in the PdE Basin suggest the possibility of synrift lacustrine organic-rich facies.

Permian sediments with oil and gas inclusions were recently identified in the prerift basement of the PdE Basin in the Gaviotin-1 well. In the prerift, a Lower Permian source rock has been also proven in the Brazilian part of the Pelotas Basin. This source rock was deposited in a restricted marine environment represented by marine oil shales with TOC values up to 13.5% (Ferro et al., 2015). The shales can be correlated with the Permian units of the onshore Palaeozoic Paraná Basin (Mangrullo Formation in Uruguay, Iratí Formation in Brazil). Additional potential could come from prerift Permian sandstone reservoirs, where light oil (39° API) was found in the Cruz del Sur x-1 well in the Colorado Basin, south of the PdE Basin.

Conclusions

New seismic in the PdE Basin in offshore Uruguay allows to draw significant analogies with the offshore basins in Brazil (Santos and Campos basins) and North Falkland/ North Malvinas Basin. The PdE Basin exhibits similar half-graben geometries followed by a laterally extensive sag fill.

The South Atlantic rifts show variable (landward or basinward) polarity. Both types are present in the PdE Basin, although there seems to be a dominant landward (westward) vergence, opposite to the present deepening of the continental margin. Landward dipping master border faults present in the PdE half grabens along with differential compaction enhance trap integrity of structural (four-way) closures.

Two kinematic sequences can be identified in some of the PdE half grabens: a) an early phase that is areally confined, and b) later phase that laps on the underlying sequence and basement on the flexural border. The early phase was triggered by the highest rate of fault-related, tectonic subsidence which created accommodation space close the master fault and setting consequently conditions for lacustrine basinal facies.

The Sea Lion in other recent discoveries in North Falkland / Malvinas Rift Basin are good analogs for the Cretaceous half graben play in the PdE Basin. Waxy lacustrine oils in in North Falkland / Malvinas Basin discoveries were derived from Lower Cretaceous lacustrine source rocks lying beneath the reservoir sands in stratigraphic/structural traps on the hanging wall located along the fault margin of the asymmetric half graben.

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References Cited

Buckley, J.P., D. Bosence, and C. Elders, 2015, Tectonic Setting and Stratigraphic Architecture of an Early Cretaceous Lacustrine Carbonate Platform, Sugar Loaf High, Santos Basin, Brazil, *in* D. Bosence, K. Gibbons, D. Le Heron, W. Morgan, T. Pritchard, and B. Vining (eds.), Microbial Carbonates in Space and Time: Implications for Global Exploration and Production: Geological Society, London, Special Publications, v. 418, p. 175-191.

Farrimond, P., A. Green, and L. Williams, 2015, Petroleum Geochemistry of the Sea Lion Field, North Falkland Basin: Petroleum Geoscience, v. 21, p. 125-135.

Ferro, S., P. Gristo, B. Conti, C. Romeu, and H. de Santa Ana, 2015, Uruguay. Small Country, Big Opportunities: GeoExpro, v. 12/5, p. 42-45.

Griffiths, A., 2015, The Reservoir Characterization of the Sea Lion Field: Petroleum Geoscience, v. 21, p. 199-209.

Guthrie, J., J. Hohman, S. Crews, C. Nino, and O. López-Gamundi, 2011, Stratigraphic Architecture, Distribution, and Quality of Pre-salt Lacustrine Source Rocks of the Greater Campos Basin, Offshore Brazil: AAPG Annual Convention and Exhibition, April 10-13, 2011, Houston, Texas, Abstract.

Lavier, L., and G. Manatschal, 2006, A Mechanism to Thin the Continental Lithosphere at Magma-Poor Margins: Nature, v. 440, p. 324-328.

Lohr, T., and J. Underhill, 2015, Role of Rift Transection and Punctuated Subsidence in the Development of the North Falkland Basin: Petroleum Geoscience, v. 21, p. 85-110.

López-Gamundi, O.R., and E. Morales, 2014, Polarity of Asymmetric Half-Grabens in the South Atlantic and Its Influence on Trap Integrity: Examples from Offshore Brazil and Uruguay: AAPG International Conference and Exhibition, Cartagena, Colombia, September 8-11, 2013, Search and Discovery Article #30317 (2014). Website accessed August 2017.

López-Gamundi, O.R., and R. Barragan, 2012, Structural Framework of Lower Cretaceous Half Grabens in the Presalt Section of the Southeastern Continental Margin of Brazil, *in* D. Gao (ed.), Tectonics and Sedimentation: Implications for Petroleum Systems: American Association of Petroleum Geologists Memoir 100, p. 143-158.

López-Gamundi, O.R., E. Rossello, and H. de Santa Ana, 2009, The Early Cretaceous Rift and Sag Phases in the Offshore Basins of Brazil and Uruguay: How Much in Common? AAPG, International Conference and Exhibition, Rio de Janeiro, Brazil, Abstract, CD #652587.

Mello, M.R., and J.R. Maxwell, 1990, Organic Geochemical and Biomarker Characterization of Source Rocks and Oils Derived from Lacustrine Environments in the Brazilian Continental Margin, *in* B.J. Katz (ed.), Lacustrine Basin Exploration - Case Studies and Modern Analogs: American Association of Petroleum Geologists Memoir 50, p. 77-95.

Mohriak, W.U., and S. Leroy, 2013, Architecture of Rifted Continental Margins and Break-Up Evolution: Insights from the South Atlantic, North Atlantic and Red Sea - Gulf of Aden Conjugate Margins, *in* W.U. Mohriak, A. Danforth, P.J. Post, D.E. Brown, G.C. Tari, M. Nemcok, and S.T. Sinha (eds.), Conjugate Divergent Margins: Geological Society, London, Special Publications, v. 369, p. 497-535.

Muniz, M.C., and D. Bosence, 2015 Pre-salt Microbialites from the Campos Basin (Offshore Brazil): Image Log Facies, Facies Model and Cyclicity, *in* D. Bosence, K. Gibbons, D. Le Heron, W. Morgan, T. Pritchard, and B. Vining (eds.), Microbial Carbonates in Space and Time: Implications for Global Exploration and Production: Geological Society, London, Special Publications, v. 418, p. 221-242.

Petersohn, E., and M. Abelha, 2013, Brasil Pre-salt, Geological Assessment: National Agency of Petroleum Natural Gas and Biofuels, http://www.brasil-rounds.gov.br/arquivos/Seminarios_P1/Apresentacoes/partilha1_tecnico_ambiental_ingles.pdf. Website accessed August 2017.

Rosendahl, B.R., D.J. Reynolds, P.M. Lorber, C.F. Burgess, J. McGill, D. Scott, J.J. Lambiase, and S.J. Derksen, 1986, Structural Expressions of Rifting; Lessons from Lake Tanganyika, Africa, *in* L.E. Frostick, R.W. Renaut, I. Reid, and J.J. Tiercelin (eds.), Sedimentation in the African Rifts: Geological Society, London, Special Publication, v. 25, p. 29-43.

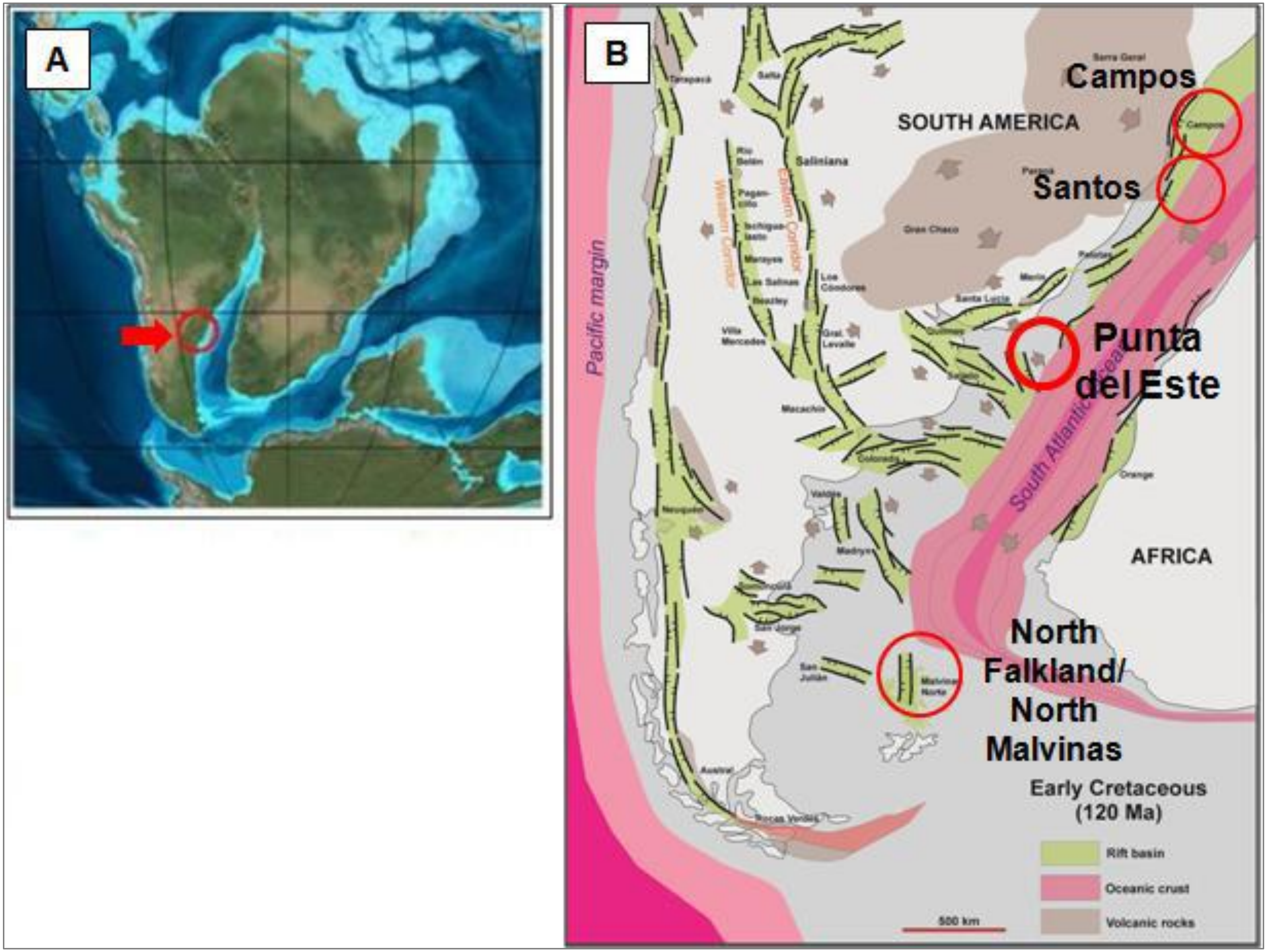

Figure 1. A: Early Cretaceous paleogeography during the initial opening of the South Atlantic. Red arrow indicates location of PdE Basin. B: Structural framework of the southern South American margin. Basins with tilted half-graben configuration discussed herein are highlighted in red.

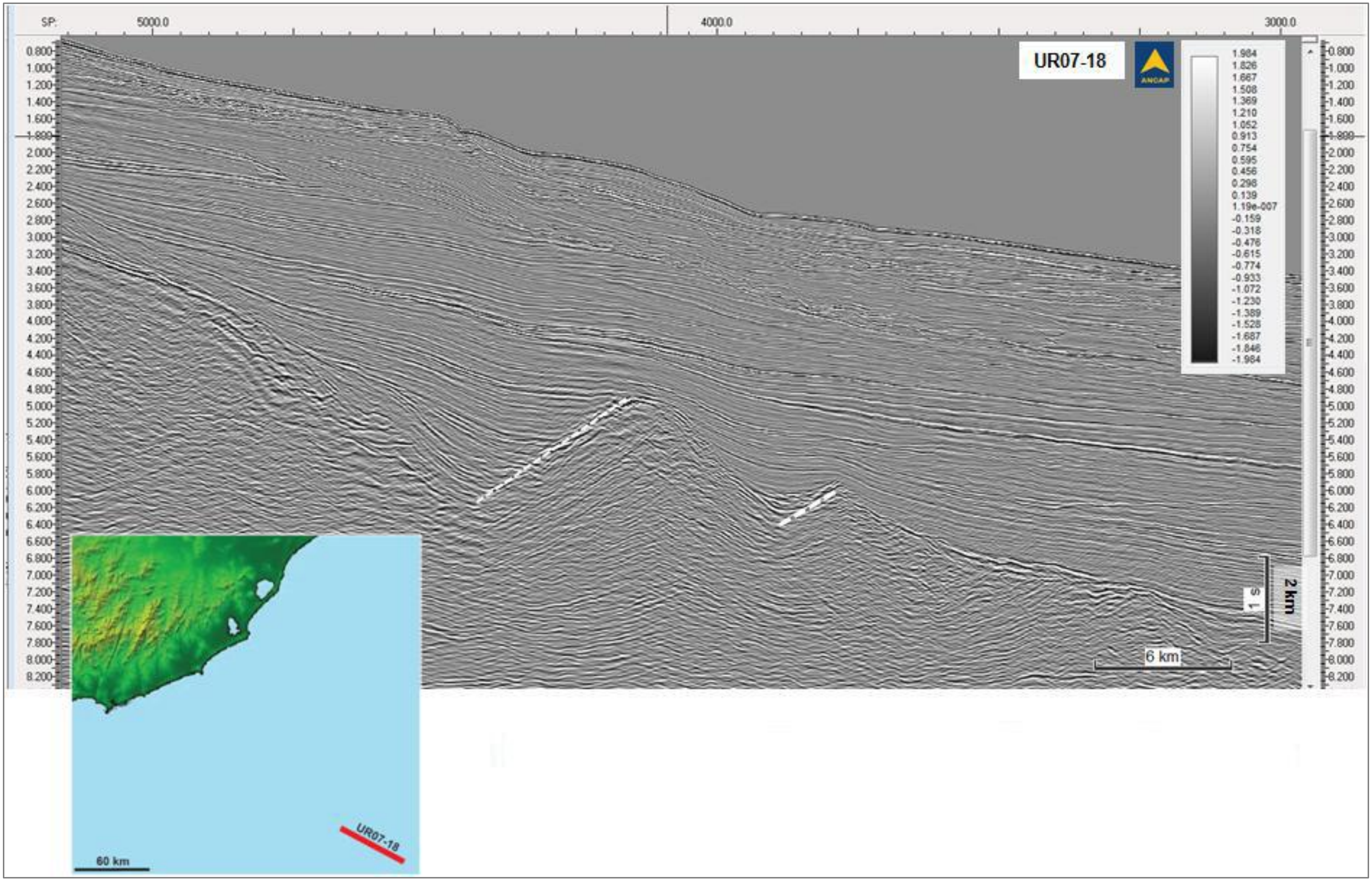

Figure 2. Rift Stage: dominant landward (westward) vergence (landward dipping master border faults).

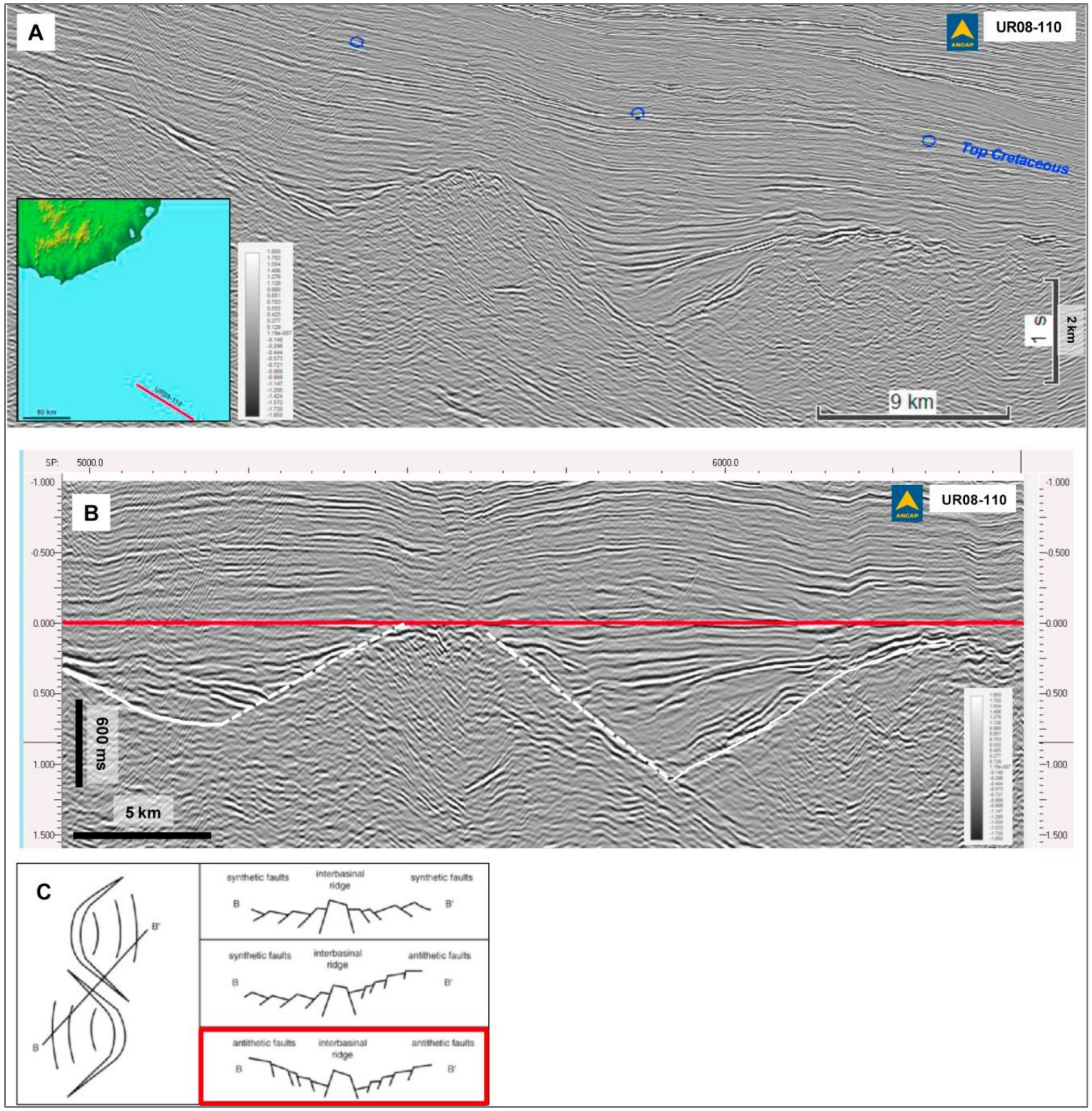

Figure 3. A: Contiguous rifts with opposite (landward and basinward) polarities (A and B). Note interbasinal ridge or high located between the half grabens with configuration similar to EARS example (C). B: Seismic section flattened on the top rift horizon (red) shows the wedge-shape geometries: i) divergent internal configuration on the fault border (white dashed line) and ii) convergent internal configuration and onlap terminations on the flexural margin (solid white line).

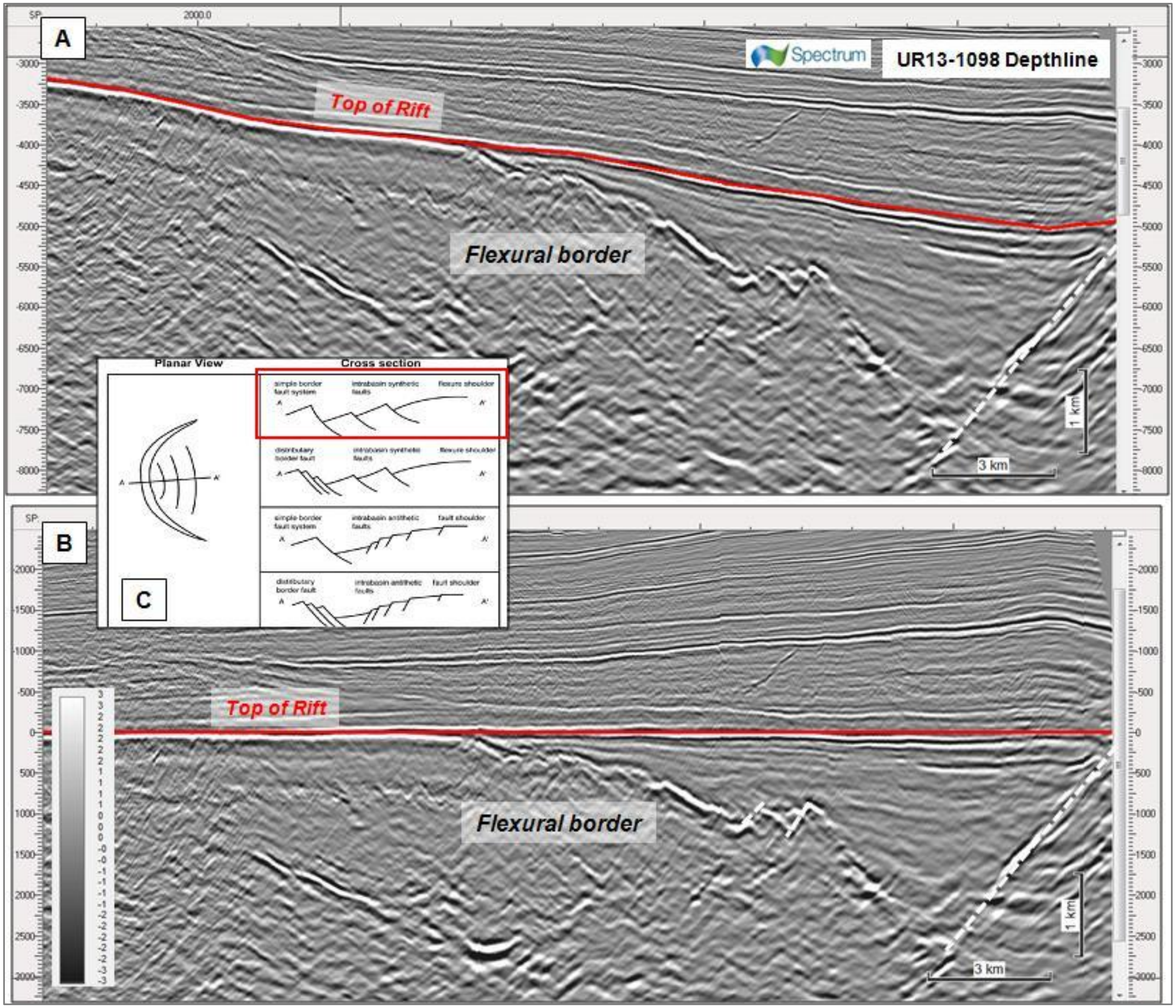

Figure 4. A. Depth seismic line (UR13-1098) illustrating asymmetric half-graben configuration with basindward (eastward) vergence in PdE Basin, red horizon: top of rift. B. Asymmetric half-graben configuration flattened to the top of rift horizon. Flexural border with intrabasin synthetic faults and simple border fault system (see cross section in C, after Rosenthal et al., 1986). Seismic courtesy of Spectrum.

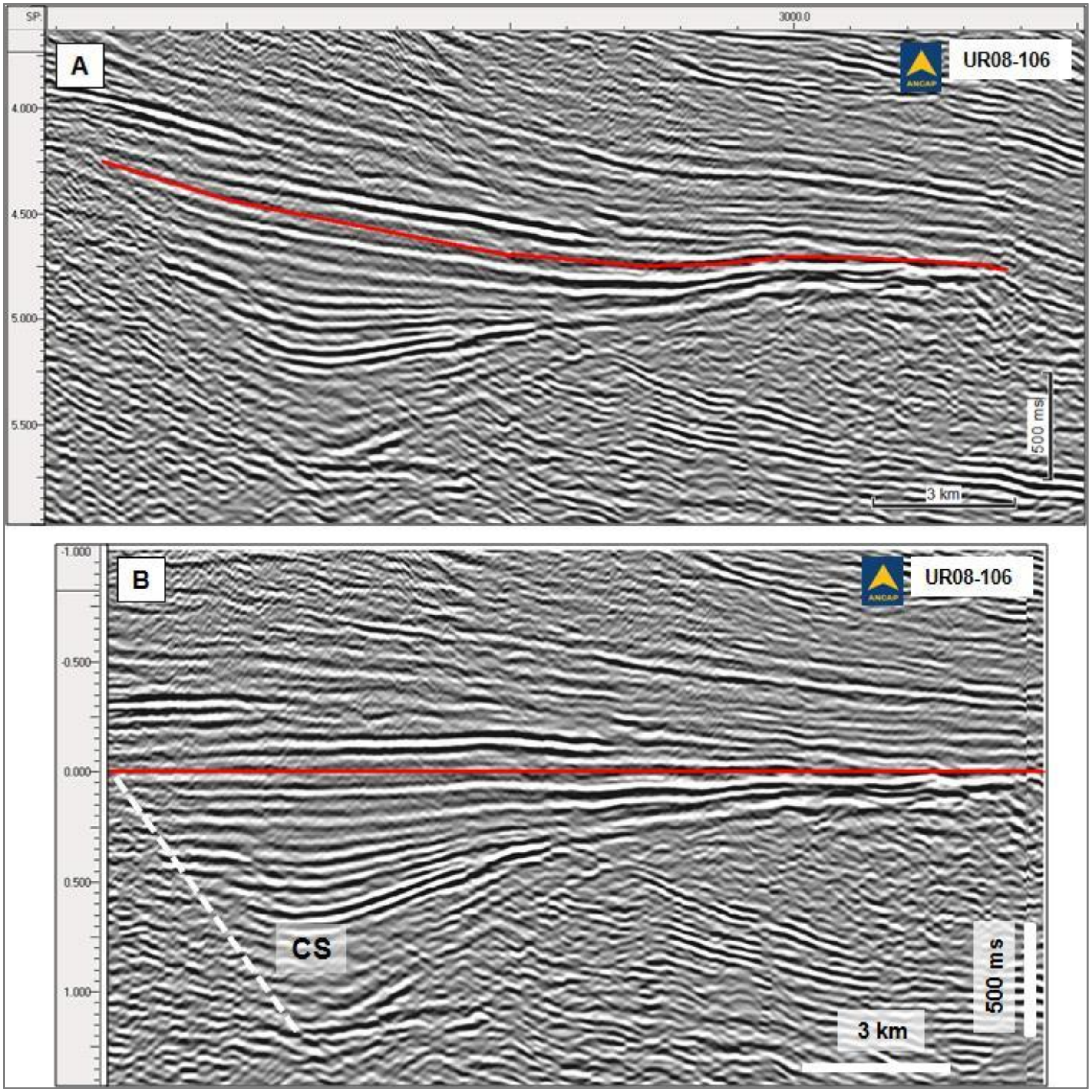

Figure 5. Time seismic line showing expression of asymmetric half graben with landward (westward) vergence, Punta del Este basin. A: Asymmetric half graben with simple flexural and fault margins; note divergent internal configuration toward the border fault margin (left) and convergent internal configuration which laps on flexural margin (right). B: Half graben flattened to top of rift horizon; compaction syncline (CS) helps define location of master border fault. Seismic courtesy of ANCAP (UR08-106).

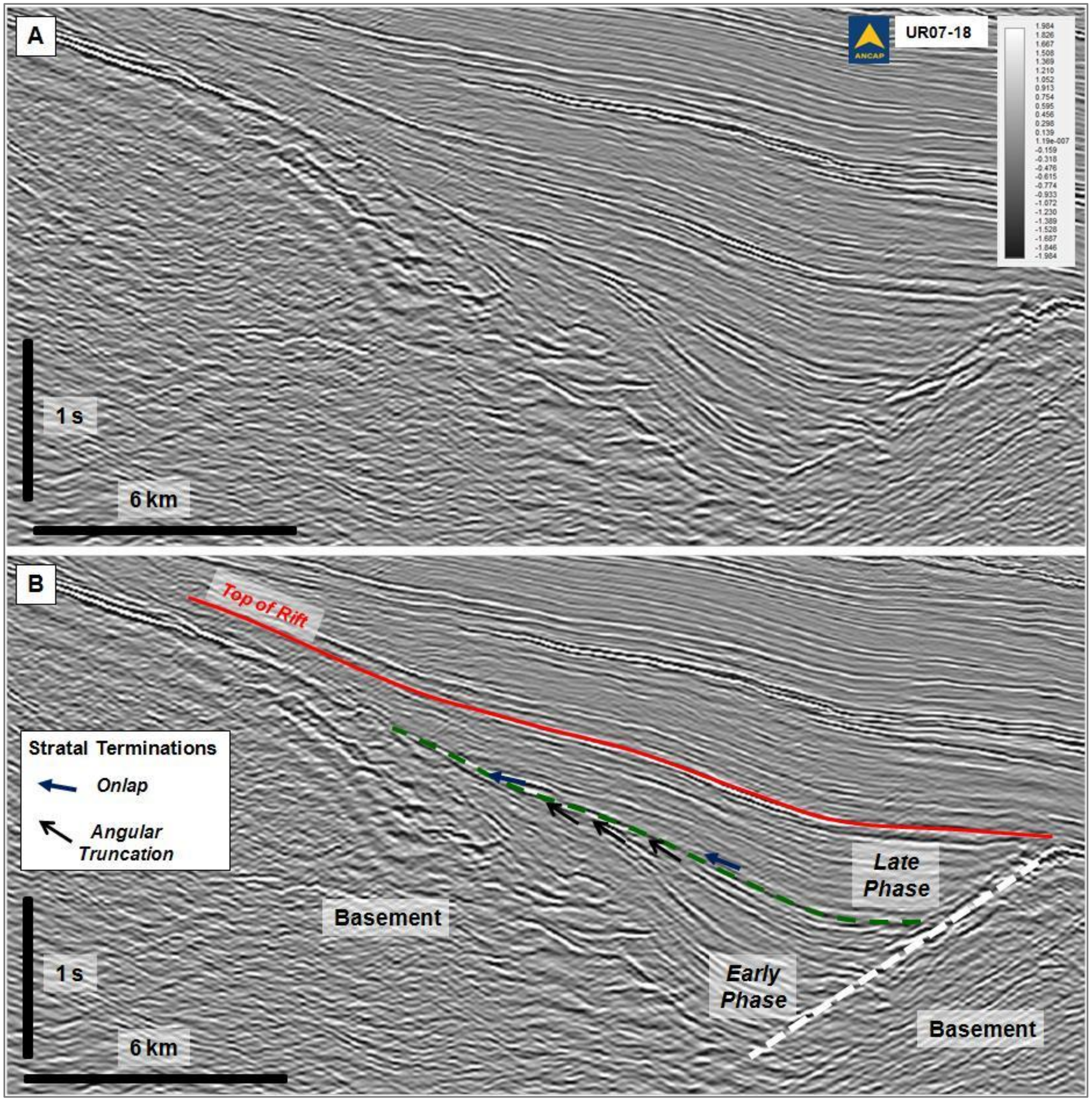

Figure 6. Seismic expression of PdE asymmetric half grabens with landward (westward) vergence. A: uninterpreted line, B: interpreted line of rift fill of asymmetric half graben with simple fault and flexural margins. Rift fill is subdivided into an early and a late phase separated by an unconformity (dashed green line) defined by angular truncation below (black arrows) and onlap (blue arrows) above.

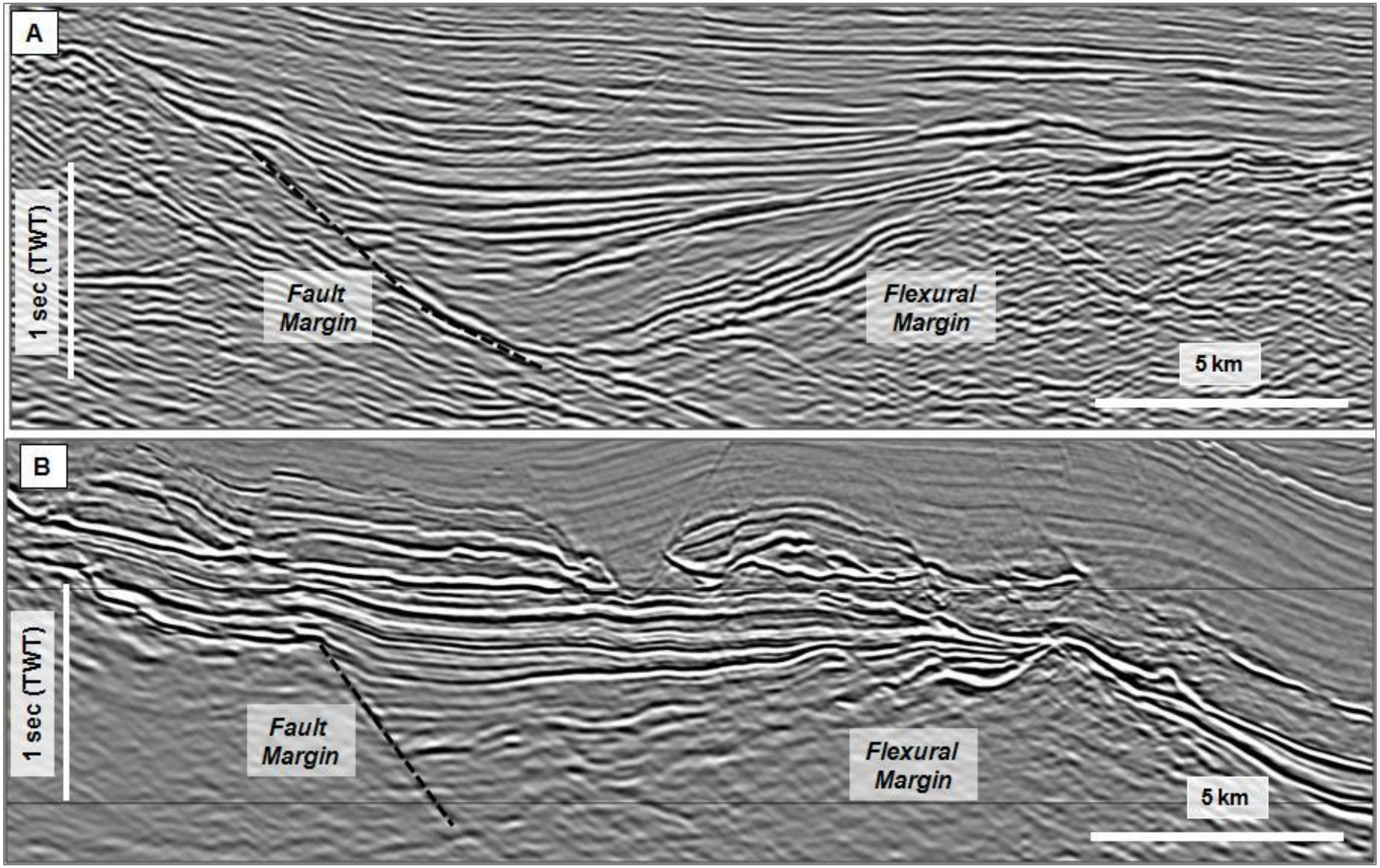

Figure 7. Seismic expression of asymmetric half grabens with landward (westward) vergence. A: Asymmetric half graben with simple flexural and fault margins, Punta del Este Basin. Seismic courtesy of ANCAP (UR08-110). B: Asymmetric half graben with simple flexural and minor intrabasin synthetic faults on flexural margin, Campos Basin. Seismic courtesy of Petroleum Geo-Services (PGS). Both lines with the same horizontal and vertical scales.