

Polarity of Asymmetric Half-Grabens in the South Atlantic and Its Influence on Trap Integrity: Examples from Offshore Brazil and Uruguay*

Oscar Lopez-Gamundi¹ and Ethel Morales²

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Abstract

The initial phase of the diachronous opening of the South Atlantic is characterized by Jurassic to Cretaceous synrift deposits confined to half-grabens followed by more areally extensive, early postrift (sag) sedimentation. Recent exploratory efforts in the South Atlantic have been focused on offshore Brazil, particularly in the pre-salt, postrift transitional (sag) section of the Greater Campos Basin (Santos, Campos and Espirito Santo basins). The underlying asymmetric half-graben configuration, with a clearly defined border fault margin and a ramp margin, is absent south of the Santos basin in the Pelotas basin but can be identified again further south in the Punta del Este basin in offshore Uruguay. Differential compaction due to the contrasting nature of rift fills and adjacent basement highs is the main control of the four-way traps in the pre-salt discoveries of the Santos and Campos basins. These 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. In this latter case, differential compaction at the half-graben border fault margin has been a critical factor to accentuate and/or create counter-regional dips necessary to form structural (four-way) closures at the sag level. Seismic evidence of differential compaction is provided by the presence of hangingwall compaction synclines 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. 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.

References Cited

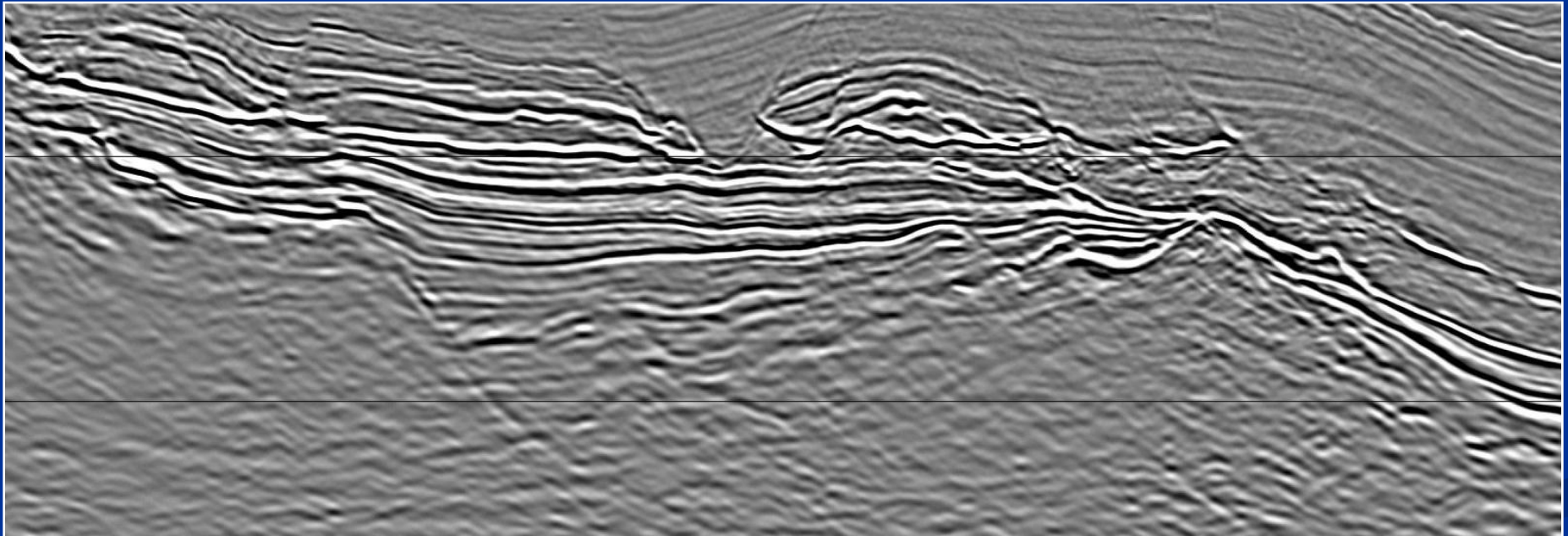
De Araujo, M.N.C., P.C.S. da Silva, G.C. de Matos, and R.D. Lima, 2009, Concepts, diagnostic features and seismic examples of folds associated with extension faults, rift section of the Campos and Santos basins: *Geoscience Boletim da PETROBRAS*, v. 17/1, p. 17-30.

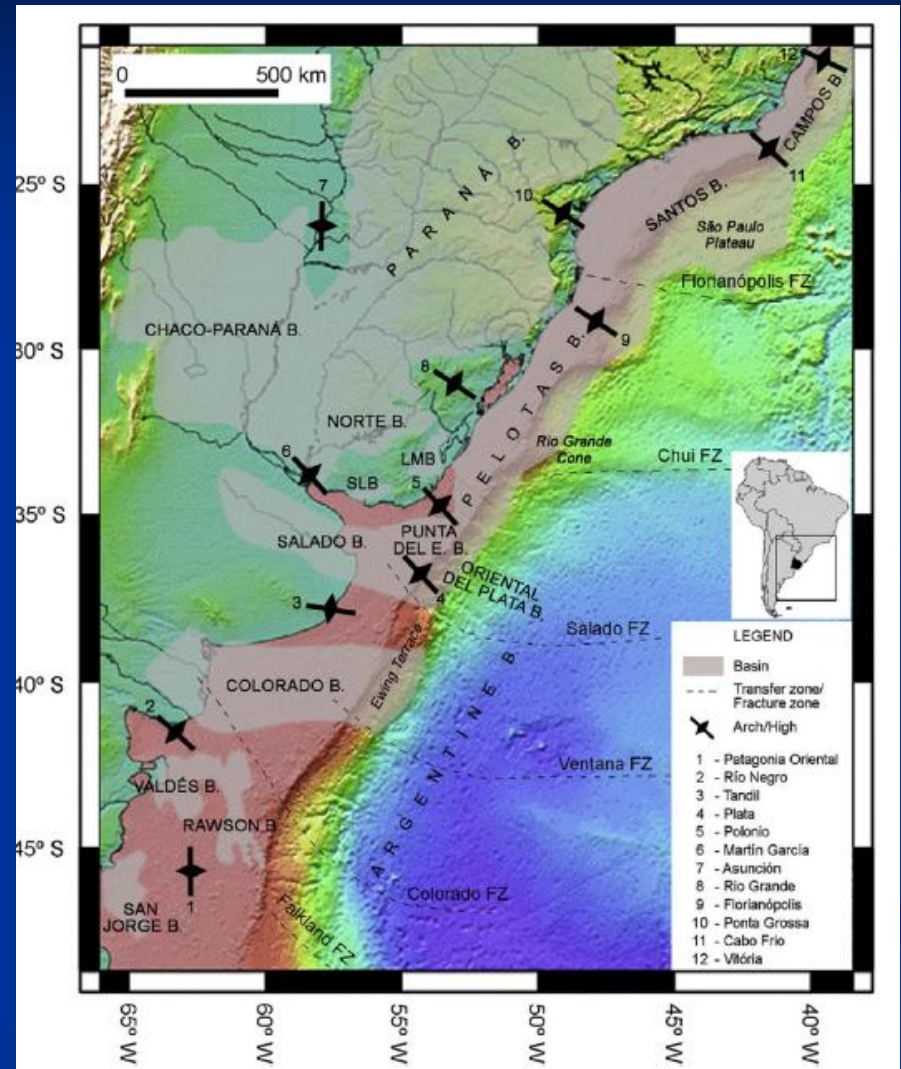
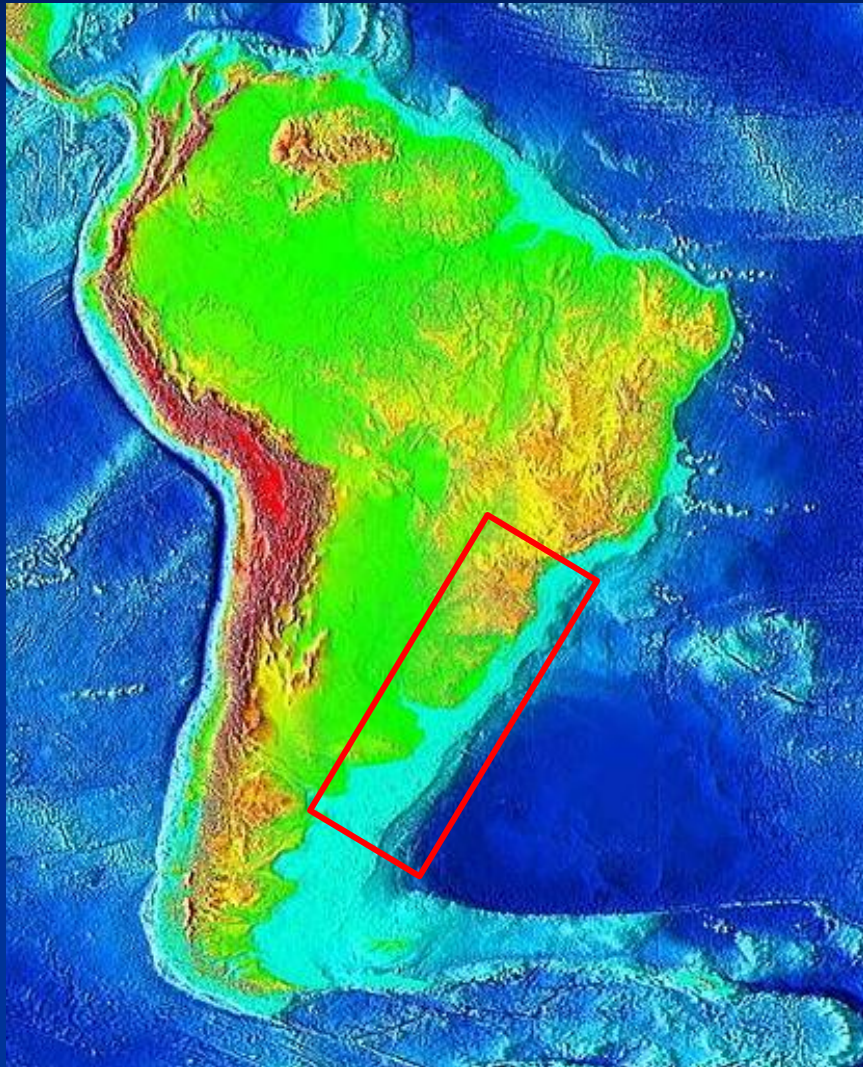
- Barr, D., 1991, Subsidence and sedimentation in semistarved half graben: A model based on North Sea data, *in* A.M. Roberts, G. Yielding, and B. Freeman, eds., *The geometry of normal faults: Geological Society of London Special Publication*, v. 56, p. 17-28.
- Davison, I., and J.R. Underhill, 2012, Tectonics and sedimentation in extensional rifts: Implications for petroleum system, *in* D. Gao, ed., *Tectonics and sedimentation: Implications for petroleum systems: AAPG Memoir 100*, p. 15-42.
- Lopez-Gamundi, O., 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: AAPG Memoir 100*, p. 143-158.
- Roberts, A.M., and G. Yielding, 1991, Deformation around basin-margin faults in the North Sea/Mid-Norway Rift, *in* A.M. Roberts, G. Yielding, and B. Freeman, eds., *The geometry of normal faults: Geological Society of London Special Publication*, v. 56, p. 61-78.
- 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 of London Special Publication*, v. 25, p. 29-43.
- Slater, J.G., and P.A.F. Christie, 1980, Continental stretching; explanation of post-Mid-Cretaceous subsidence of central North Sea basin: *AAPG Bulletin*, v. 64/5, p. 781-782.
- Skuce, A.G., 1996, Forward modelling of compaction above normal faults; an example from the Sirte Basin, Libya, *in* P.G. Buchanan, and D.A. Nieuwland, eds., *Modern developments in structural interpretation, validation and modeling: Geological Society of London Special Publication*, v. 99, p. 135-146.
- Versfelt, J.W., 1988, Relationships between Precambrian basement structure and the Cenozoic rift architecture of the Malawi (Nyasa) rift zone, East Africa: MS Thesis, Duke University, Durham, N.C., 68 p.
- Xiao, H., and J. Suppe, 1992, Origin of rollover: *AAPG Bulletin*, v. 76/4, p. 509-529.

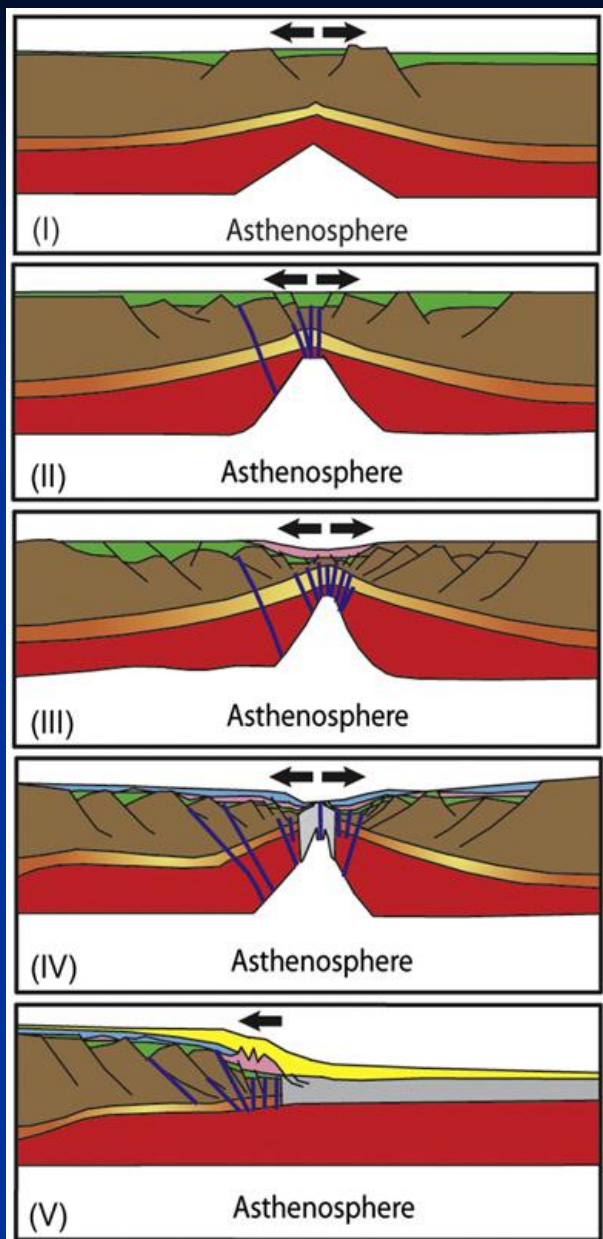
Polarity of Asymmetric Half-Grabens in the South Atlantic and Its Influence on Trap Integrity: Examples from Offshore Brazil and Uruguay

Oscar Lopez-Gamundi¹ and Ethel Morales²

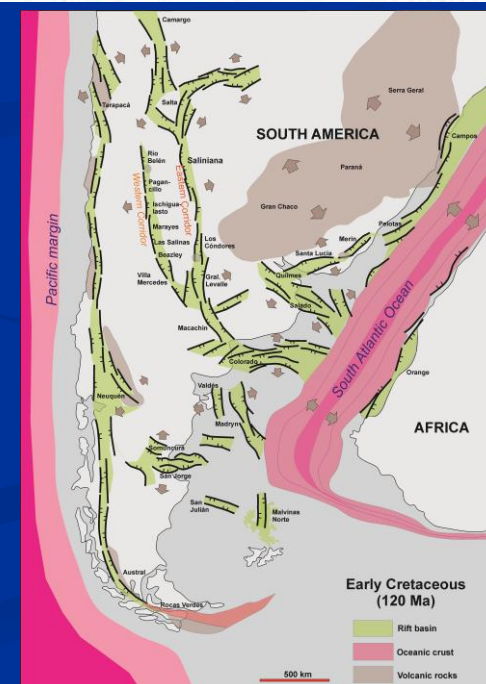
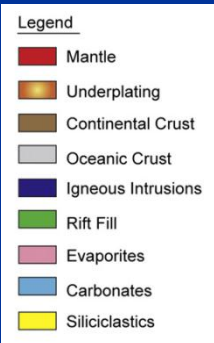
- 1. P1C Consultants, Houston, Texas, United States.**
- 2. ANCAP, Montevideo, Uruguay.**

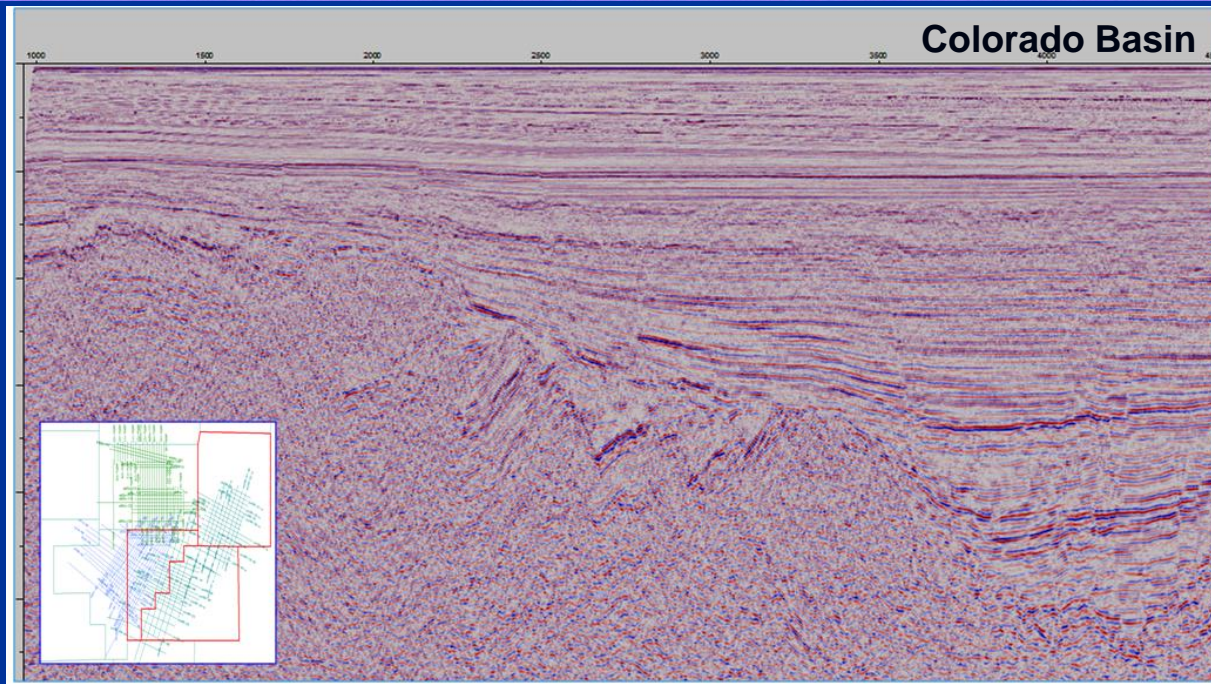
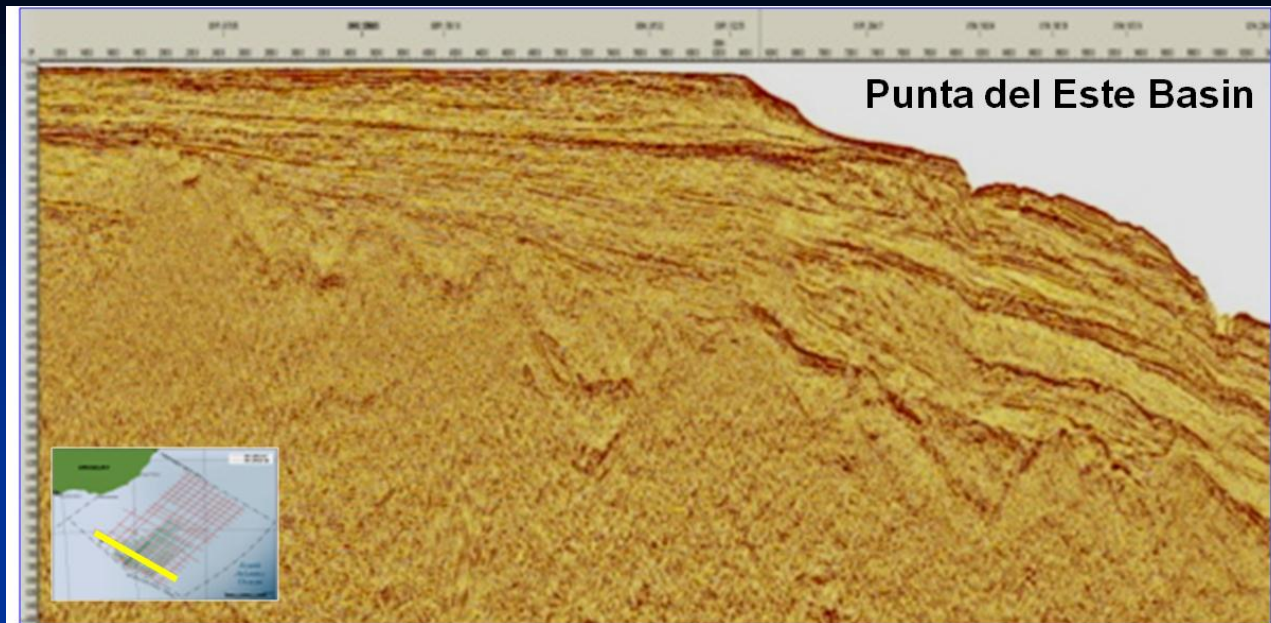




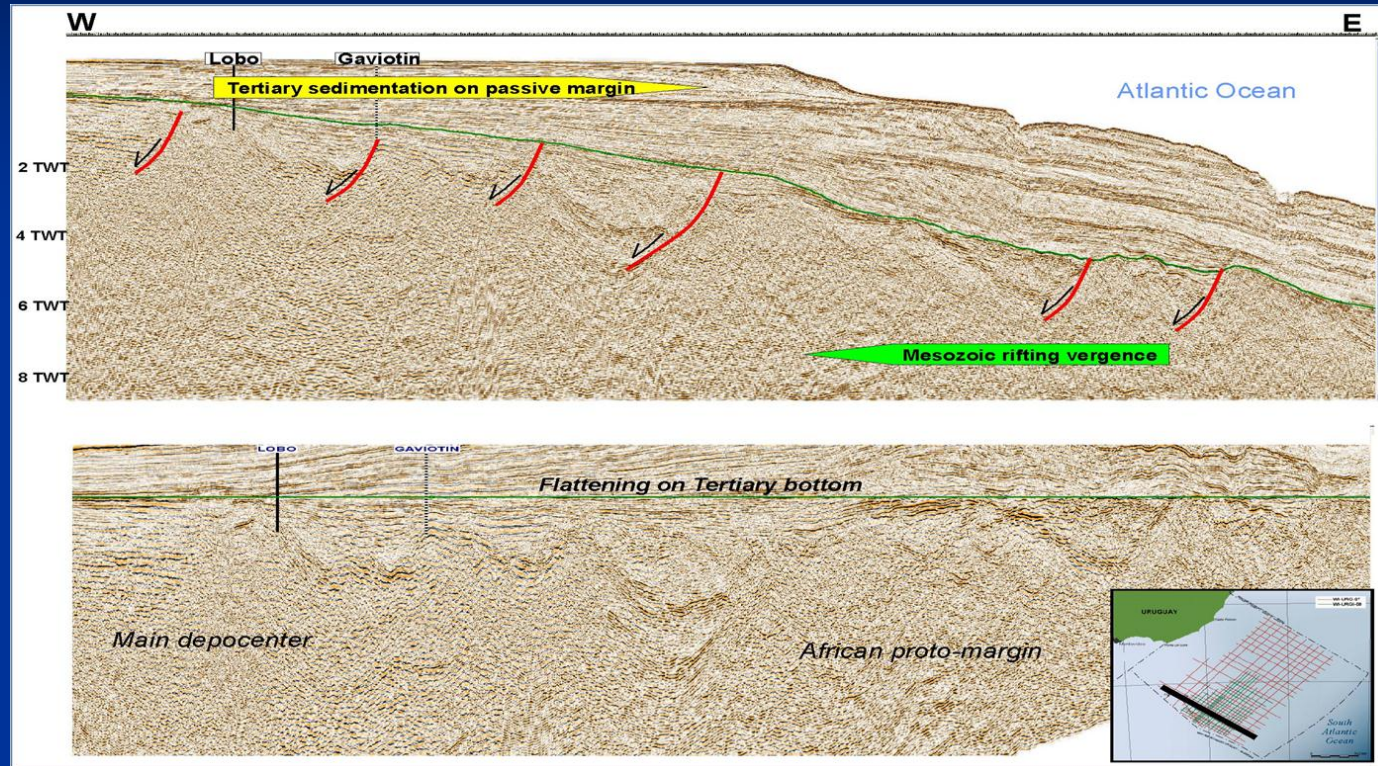


The tectonic setting of the rifting during the opening of the South Atlantic is centered around the presence of half graben. This underlying tilted half-graben configuration, with a clearly defined border fault margin adjacent to the deepest part of the rift basin and a ramp margin, is widespread in 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 Salado, and North Falkland (Malvinas Norte) basins in offshore Argentina.



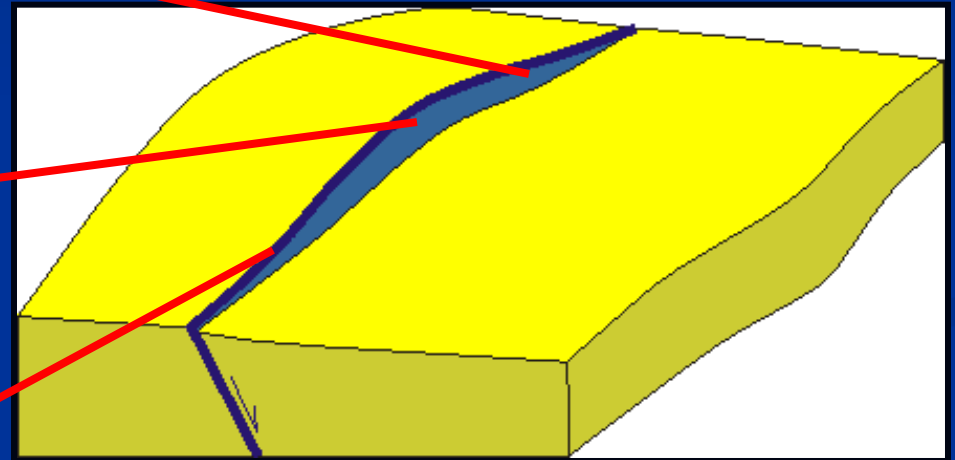
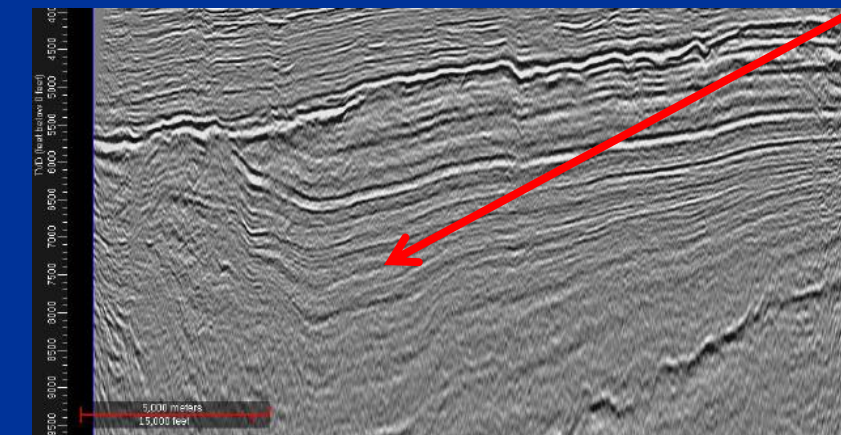
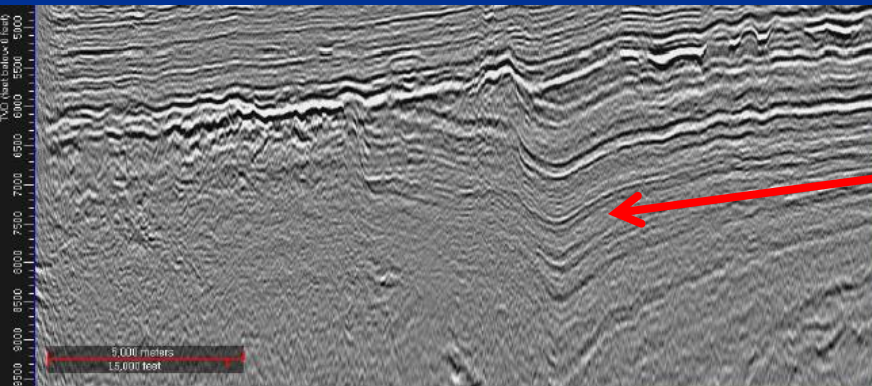
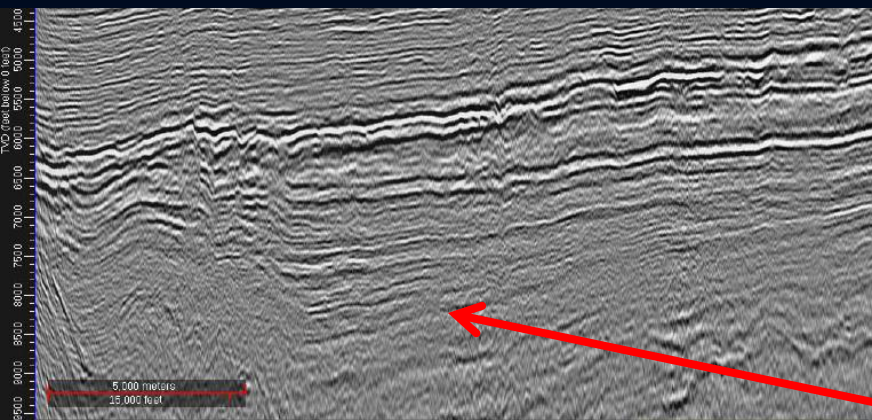


Half Grabens in Punta del Este Basin



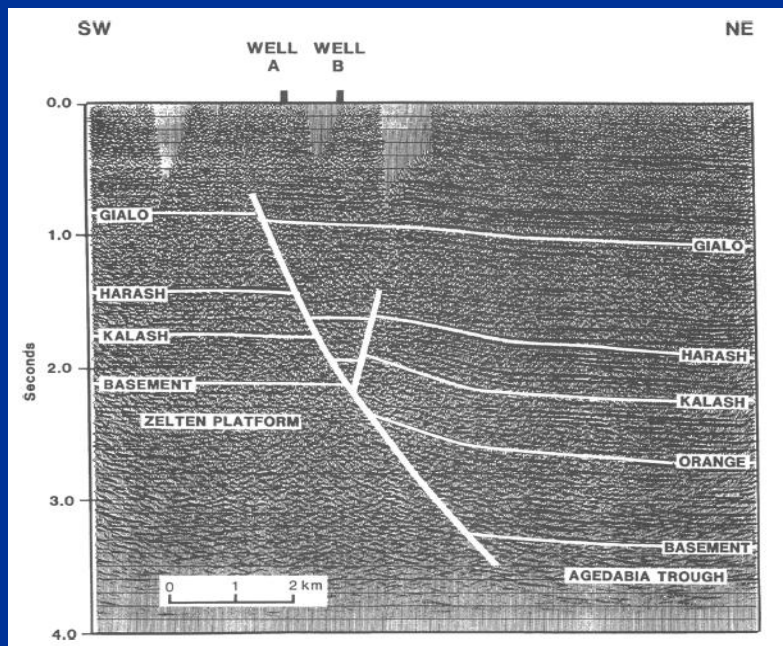
Dominant landward (westward) vergence, opposite to the present deepening of the continental margin.

Seismic Expression of Compaction Synclines

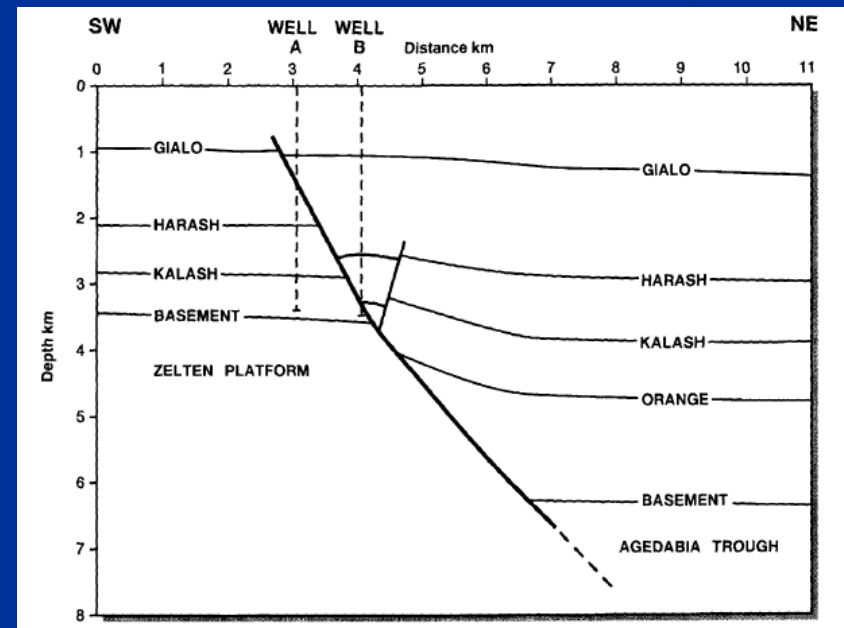


Compaction above Normal Faults

- Two distinctive features related to compaction above normal faults:
 - a) A vertical synclinal axial plane above the hangingwall cutoff of the basement.
 - b) inclined but less distinct anticlinal axial plane above the footwall cutoff of the basement.



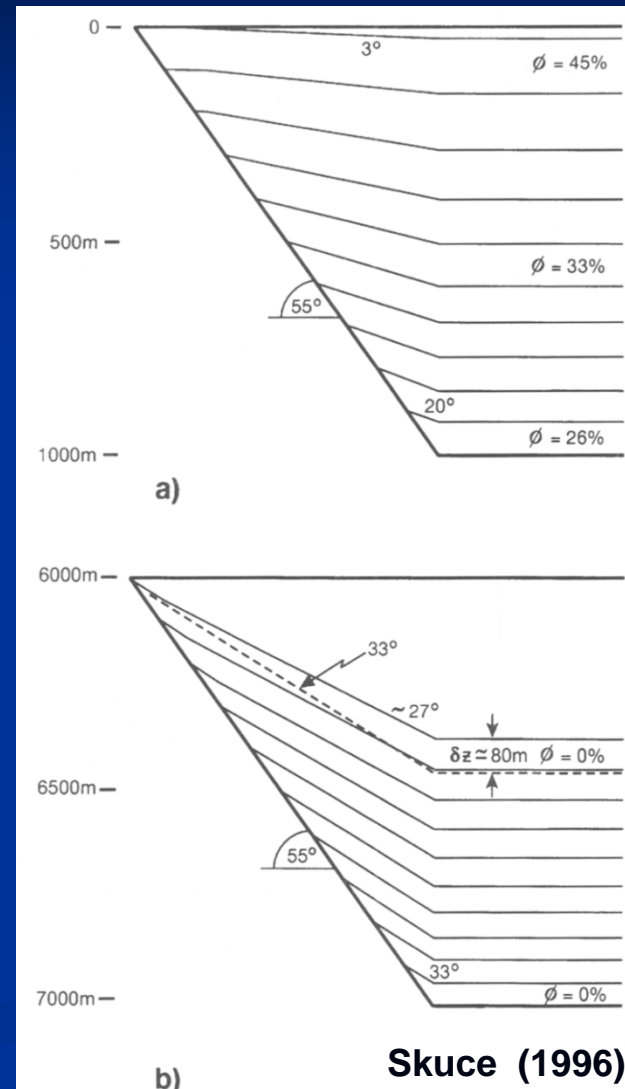
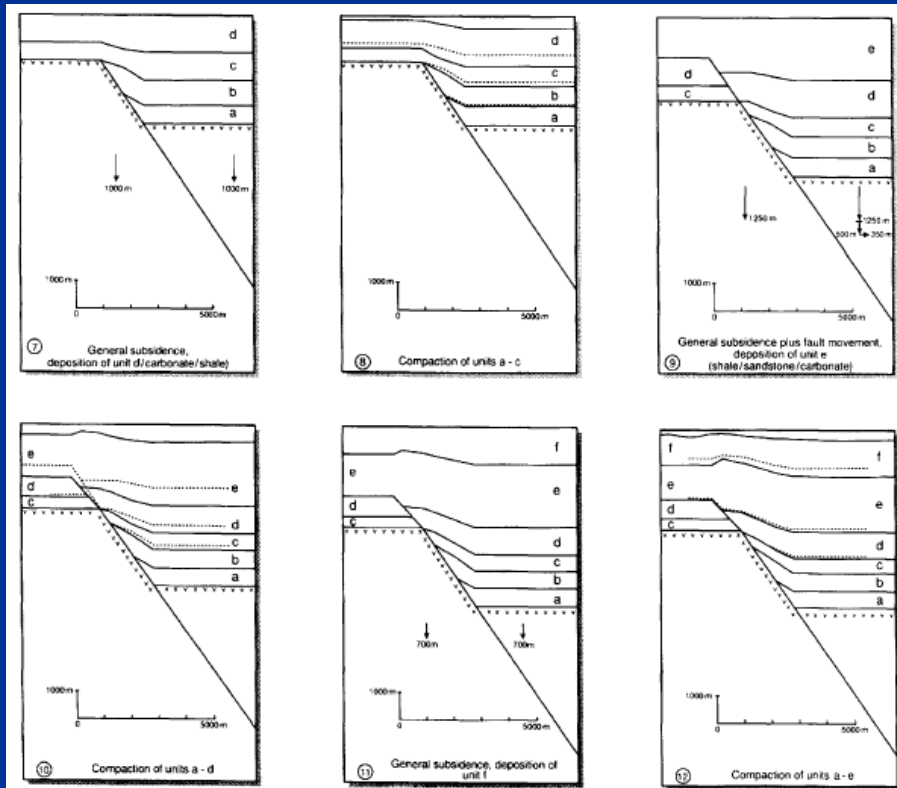
Sirte Basin, onshore Libya



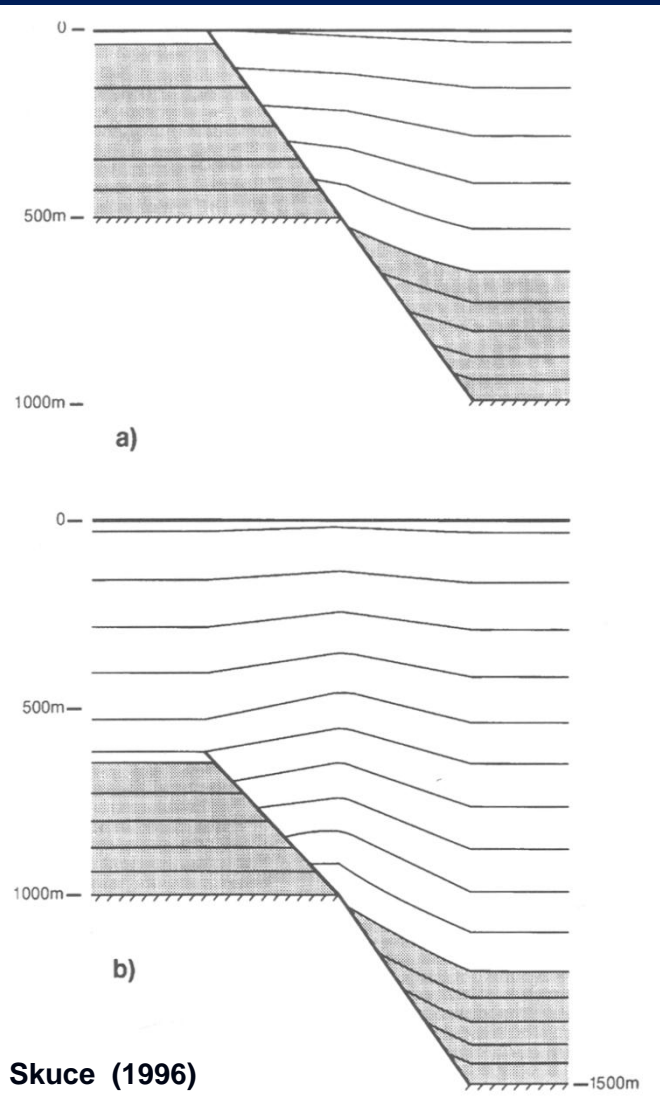
Skuce (1996)

Compaction Synclines

Compaction synclines generally will be most obvious over large planar faults that involve basement.



Formation of a compaction anticline

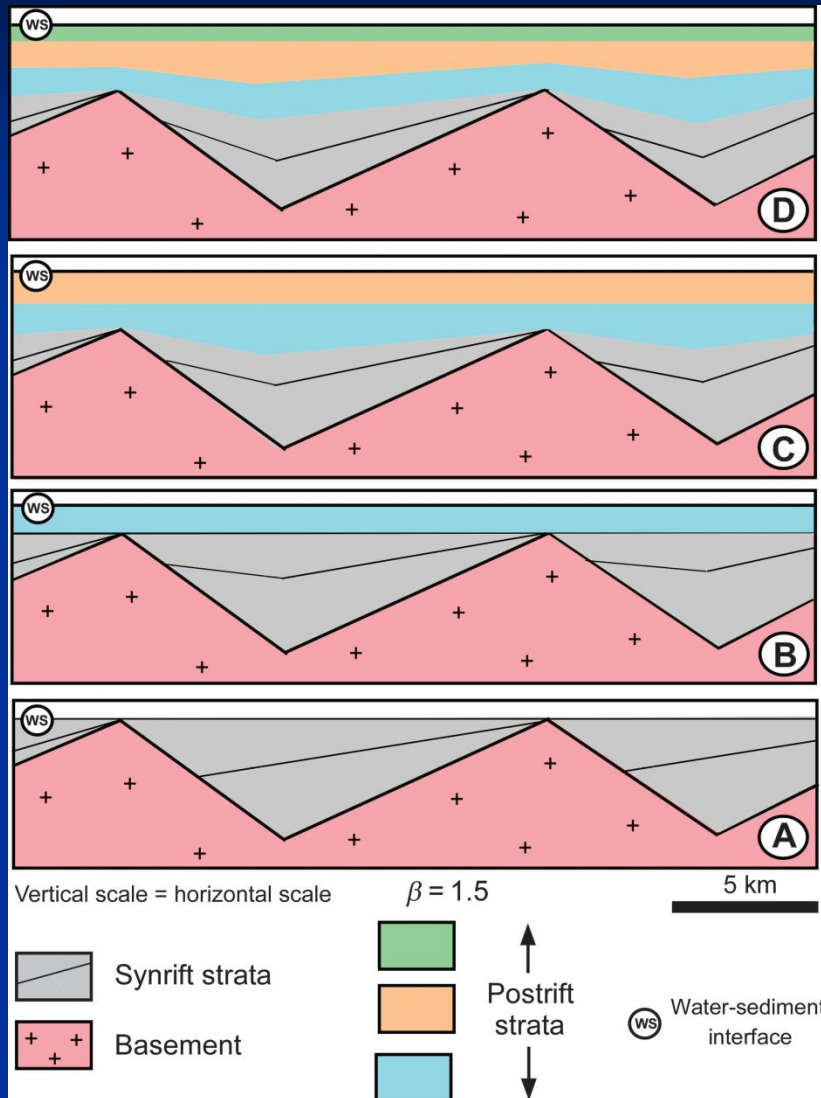


- (a) Before faulting, the basement subsides in five stages of 100 m, depositing five layers of shale (shaded) which compact at each stage. Subsequent faulting in five stages of 100 m allows the deposition of five layers of sandstone (unshaded) which compact themselves and the underlying shales in the hanging wall at each stage. The compaction functions used for shales and sandstones derived from the North Sea by Sclater & Christie (1980).

- (b) Faulting ceases and the entire model subsides in five 100 m stages with deposition of the five top layers of sandstone. Compaction of the sediments in the footwall results in rotation of the fault plane and the formation of the left flank of the anticline; compaction of the hanging wall steepens the right flank of the anticline. The amplitude of the anticline has a maximum of about 70 m at 500 m depth.

Compaction can produce anticlinal structures in normal fault hanging walls that could easily be confused with inversion structures.

Development of hangingwall compaction synclines

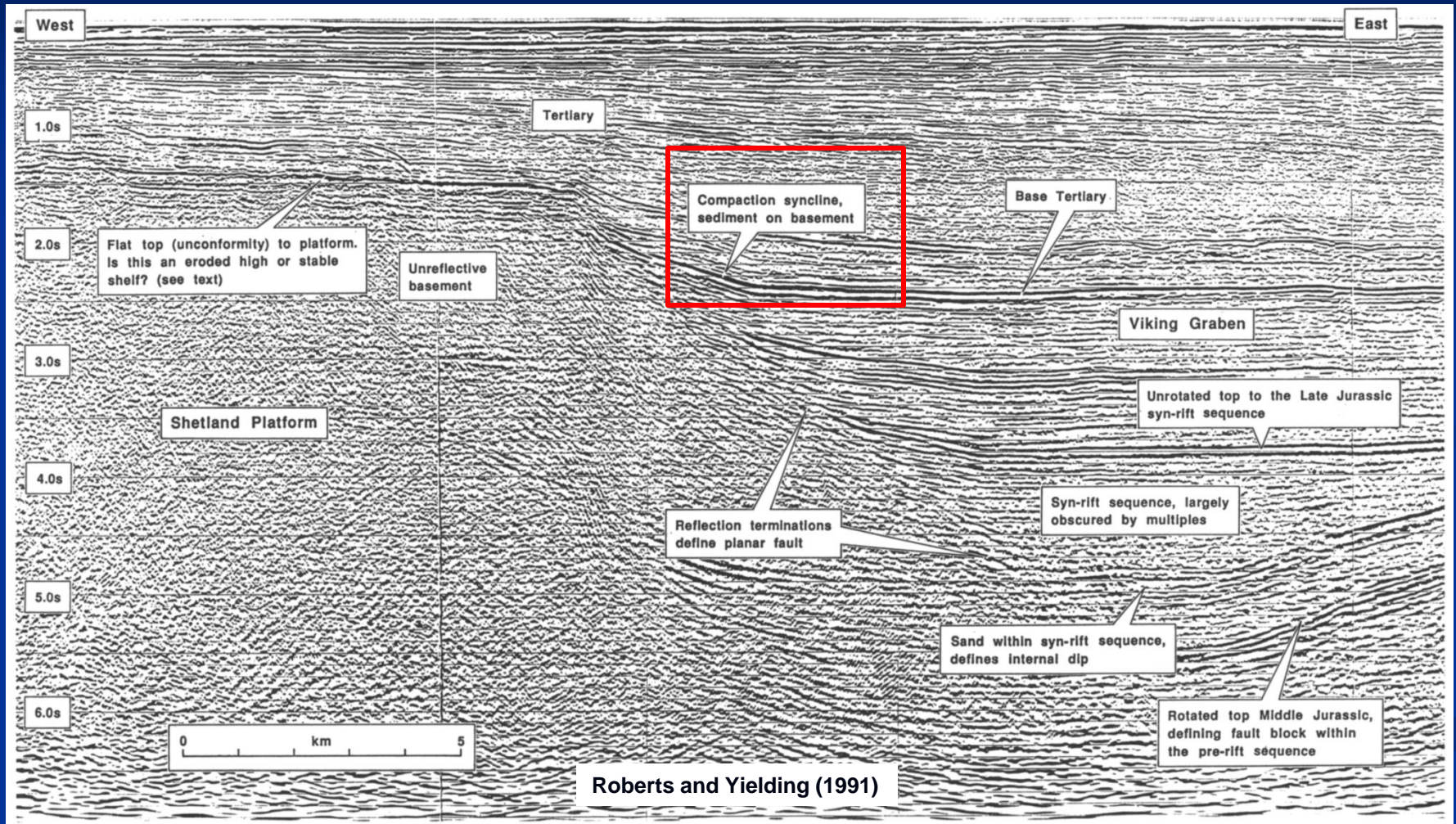


Evolution of sedimentary fill from initial synrift phase (asymmetric half graben) to postrift (sag) phase and development of hangingwall compaction synclines. Basement is defined as any non compactable or precompact sedimentary, metamorphic, or igneous rocks such as the prerift. Note that the steepness of the dips is greater on deeper horizons, the location of the synclinal fold axis immediately above the hanging-wall cutoff of the basement and approximately vertical to the synclinal axial plane. A stretching factor of $B = 1.5$ is used.

Modified from Barr (1991)

AAPG ICE, Cartagena, 9-11 September, 2013

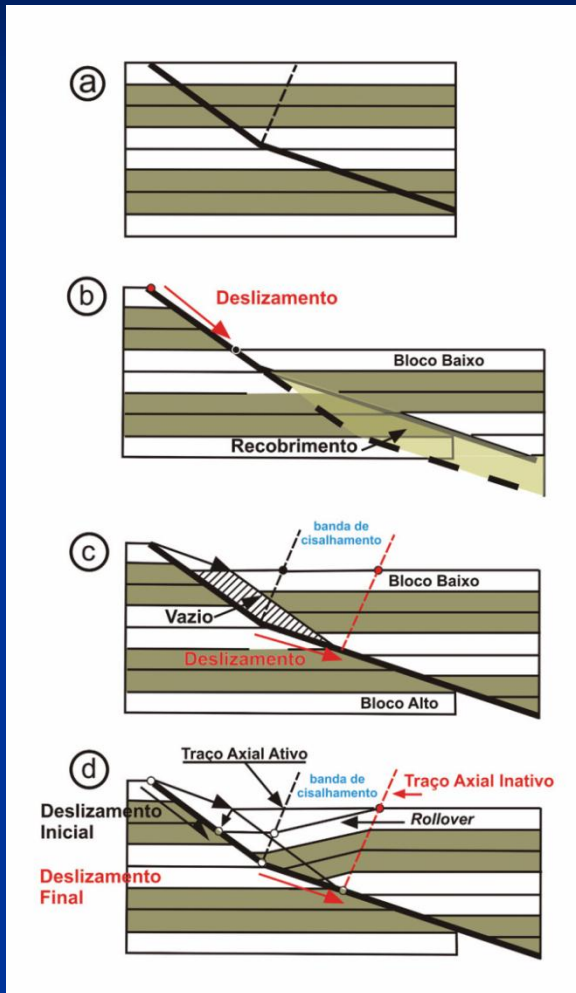
Compaction Synclines



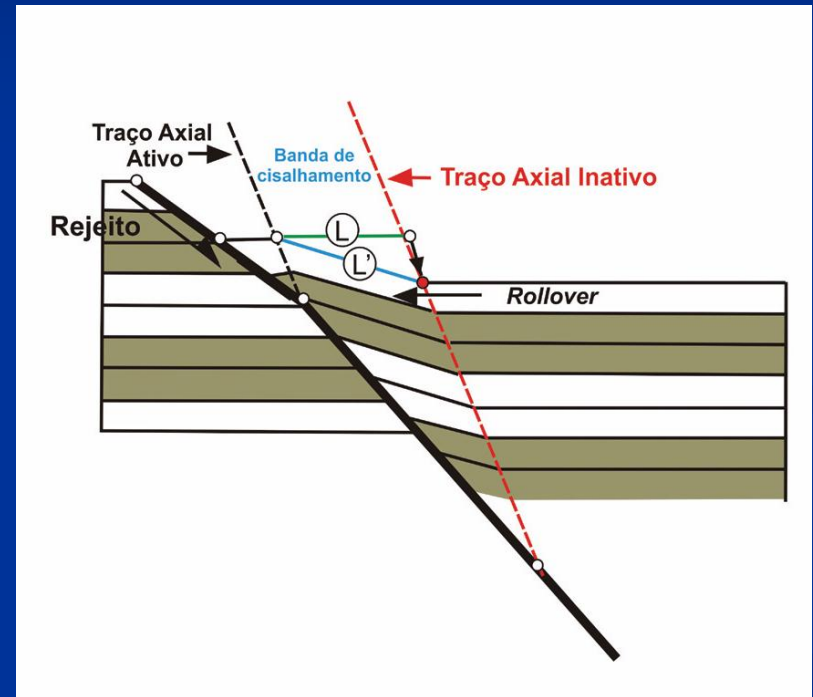
Alternative models

- *Drag* 'Normal-drag' and 'reverse-drag' are commonly used terms to describe, respectively, synclinal and anticlinal structures with geometries such as those discussed herein. Typically, such drag zones are tens of meters wide and have synthetic dips in the footwall and hanging wall. Effects on such a scale would not usually be observable seismically.
- *Folding over convex fault bends (fault bend folding, cf. Xiao & Suppe, 1992):* requires a convex (listric) fault plane not present in the cases discussed herein.
- *Extensional forced folding*
- *Inversion, compression,* not documented in the area under study

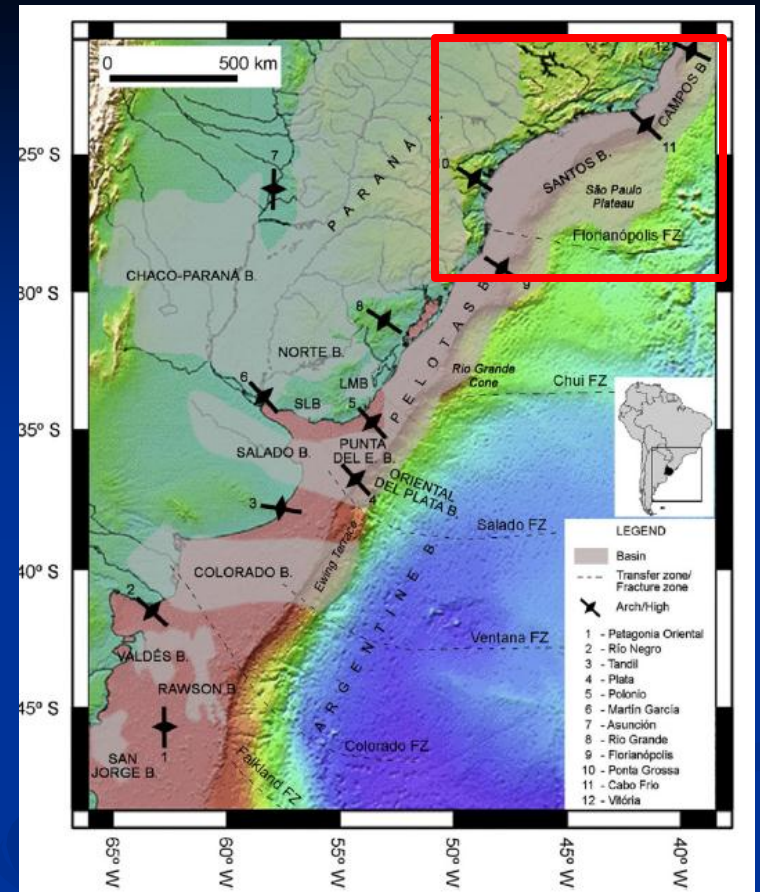
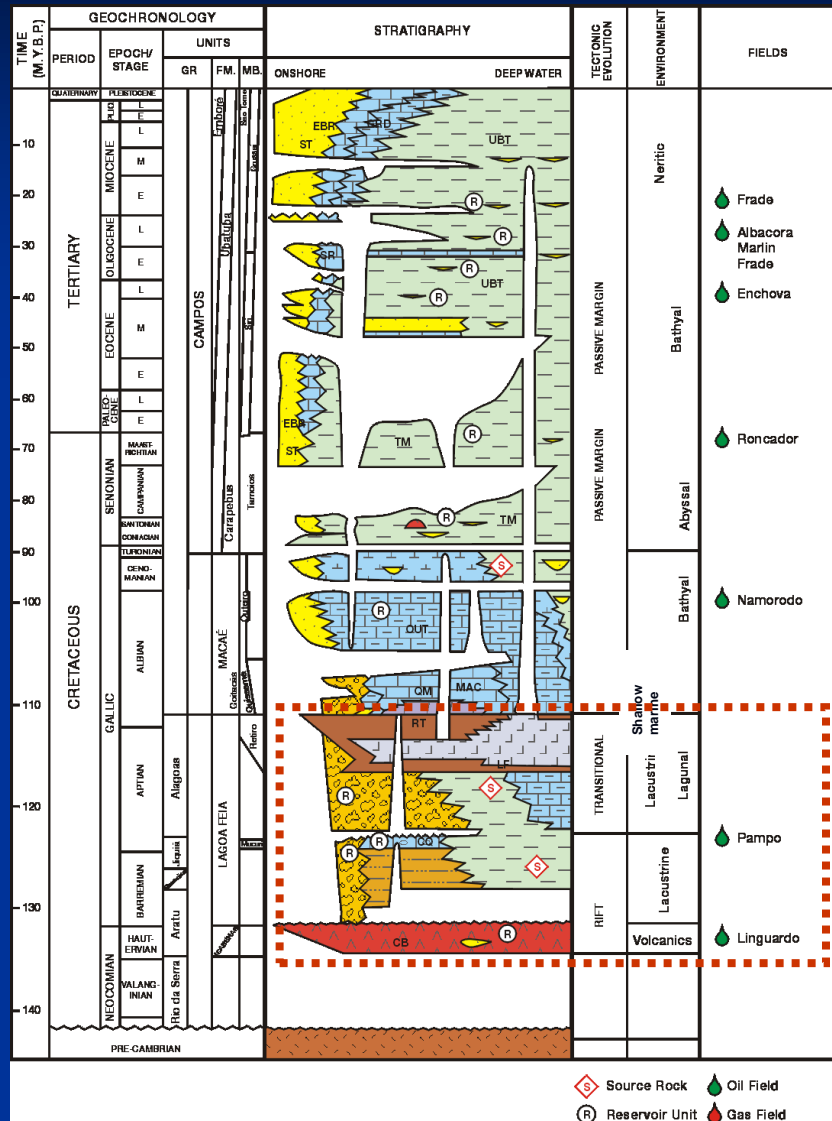
Folding over convex fault bends as mechanism for compaction synclines



Two-dimensional model of rollover development for a single sharp concave up fault plane

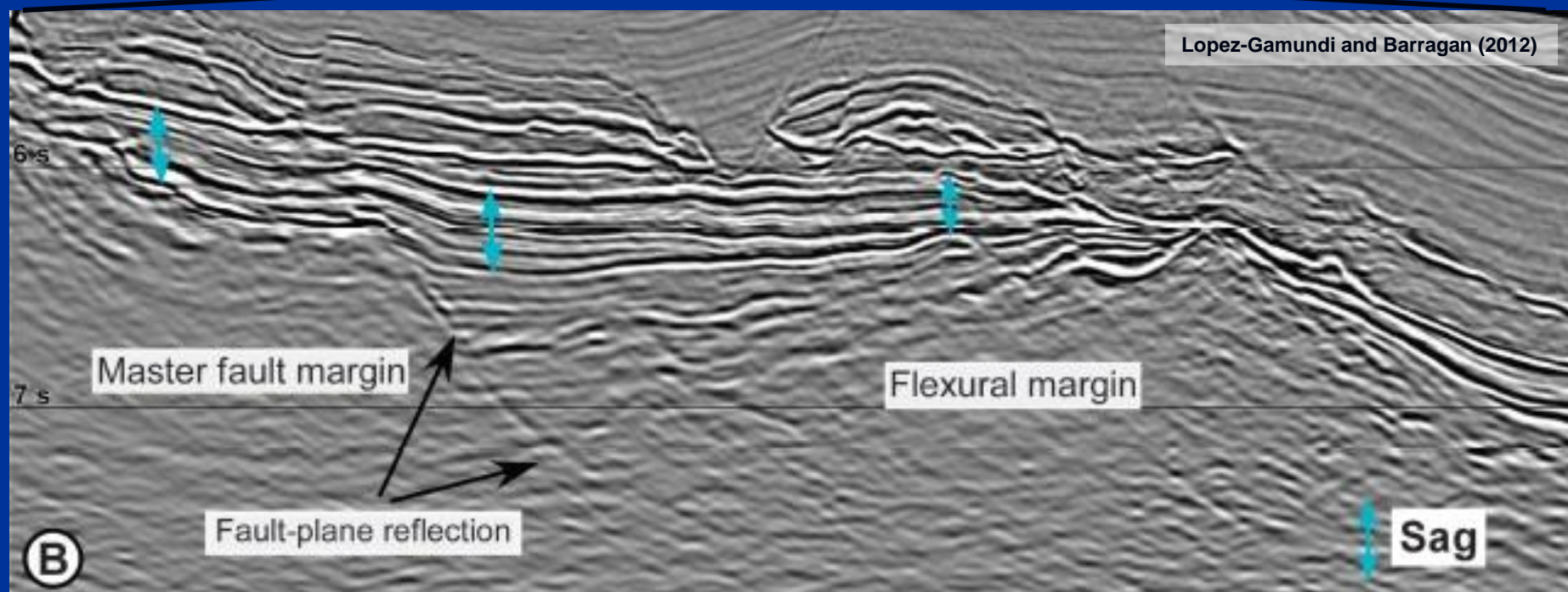
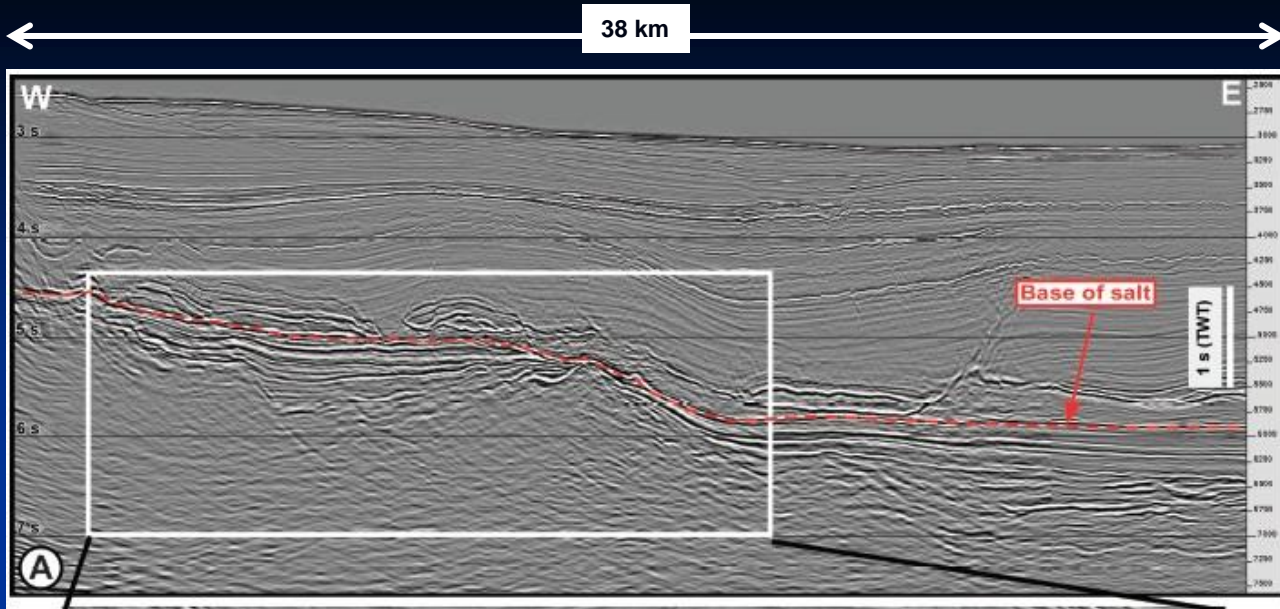


Model of a rollover associated with a convex upward fault-bend.

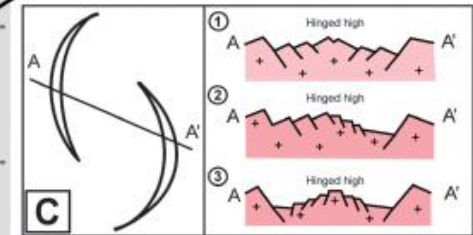
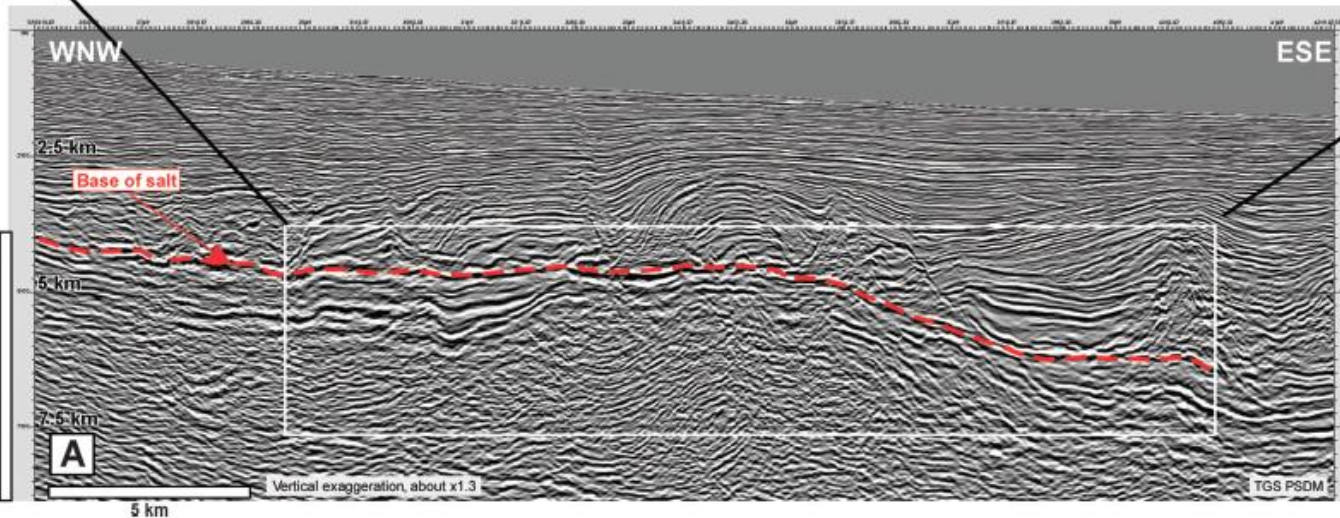
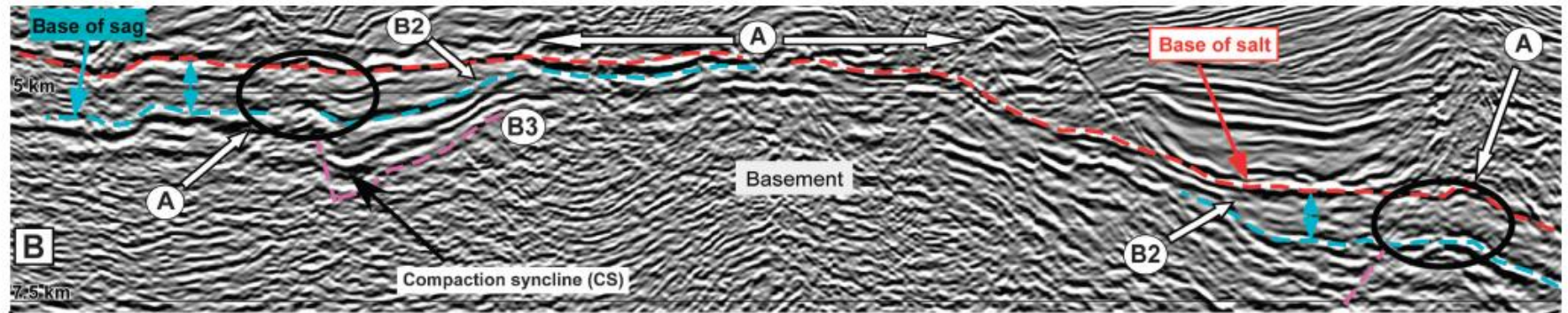


➔ Pre-salt Stratigraphy

Central Campos Basin



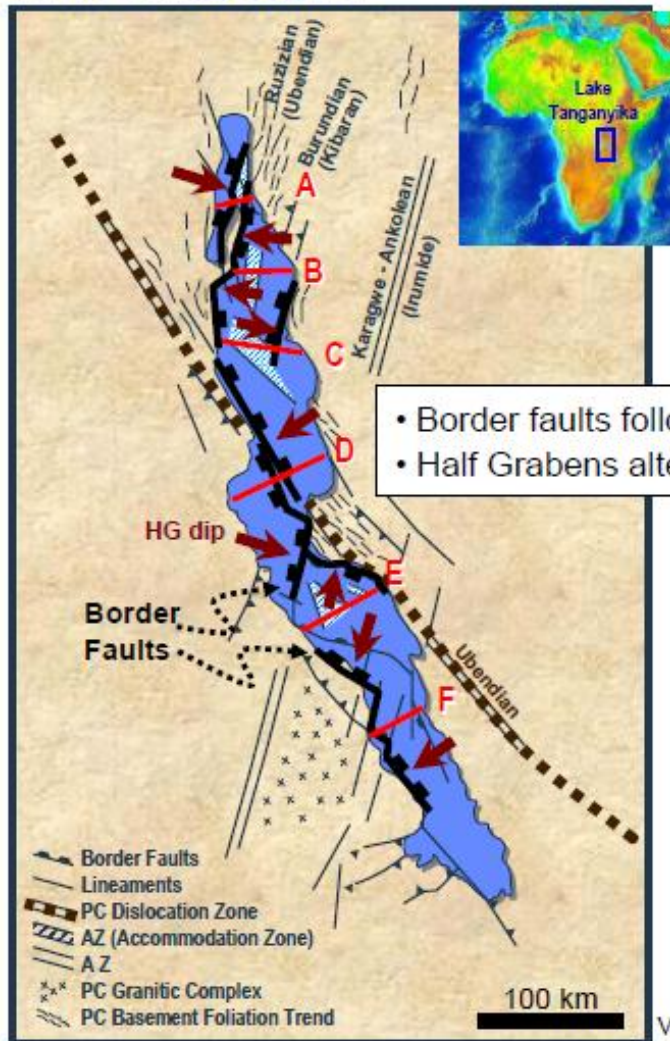
Trap types in the synrift and sag sections Northern Campos Basin



Lopez-Gamundi and Barragan (2012)

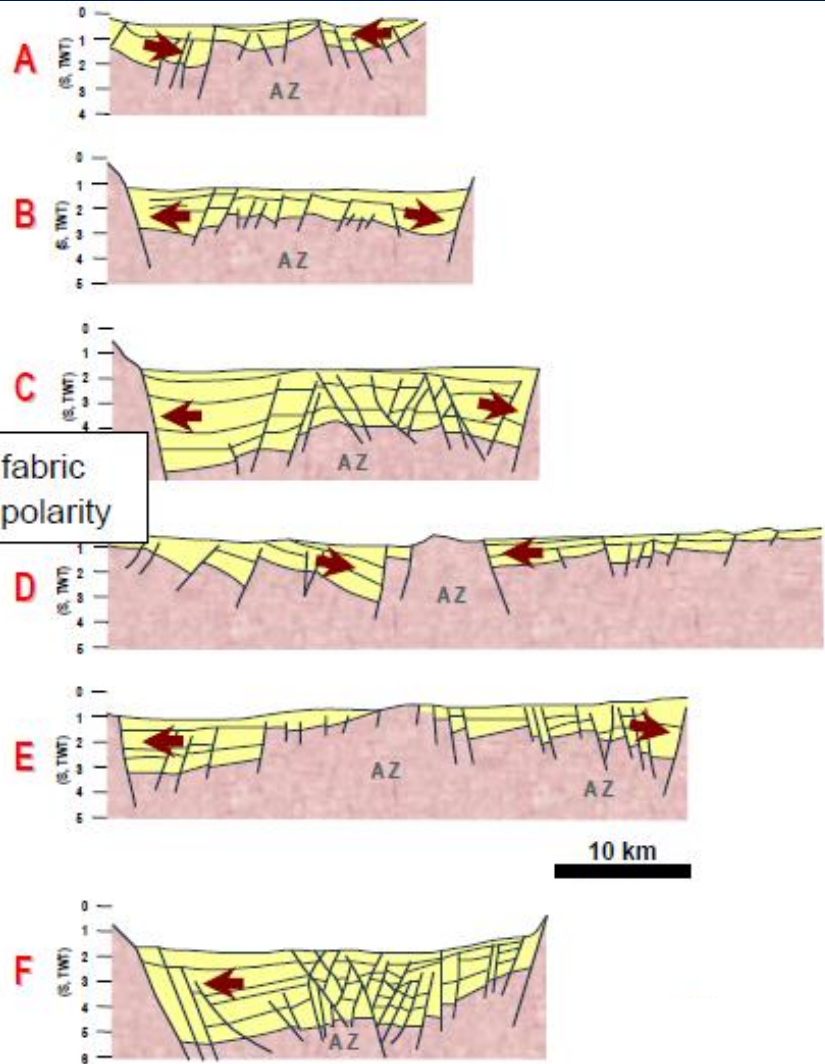
(A) Regional configuration of presalt high with opposing half grabens on both flanks. (B) Differential compaction on the flanks of large basement high created counterregional dip necessary to form structural (four-way) closures at the sag level (trap type A). The smaller subsidiary A traps on the flanks of the large four-way closure are controlled by differential compaction evidenced by compaction synclines at the rift level. Updip onlap and three-way dips define combined structural-stratigraphic traps (trap type B). (C) Linking mode with overlapping half grabens. Note the similarity between cross section A and the seismic section in panel B (based on Rosendahl et al., 1986).

Lake Tanganyika

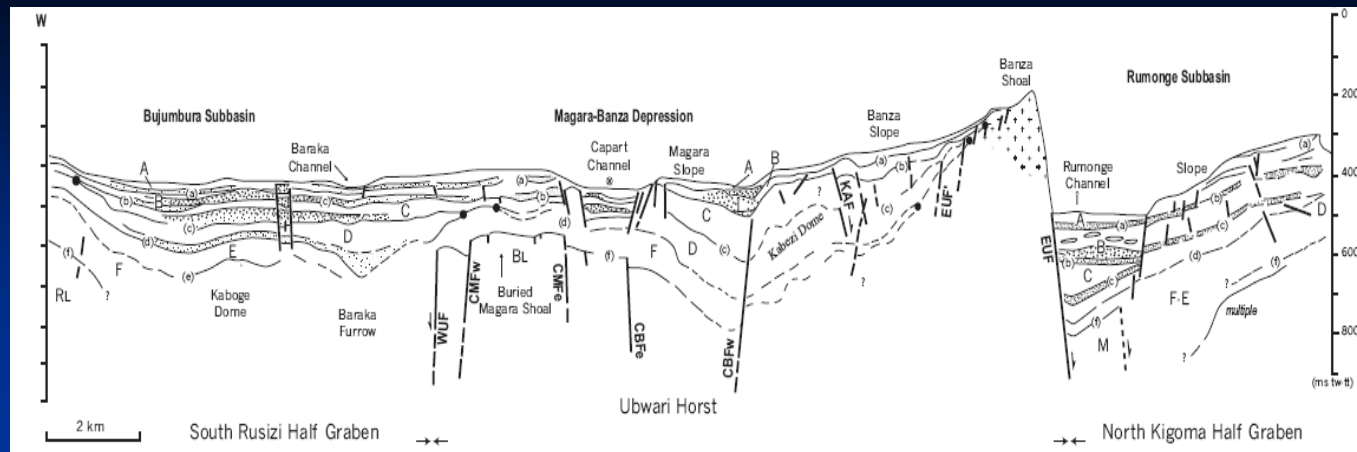


- Border faults follow pre-rift fabric
- Half Grabens alternate dip polarity

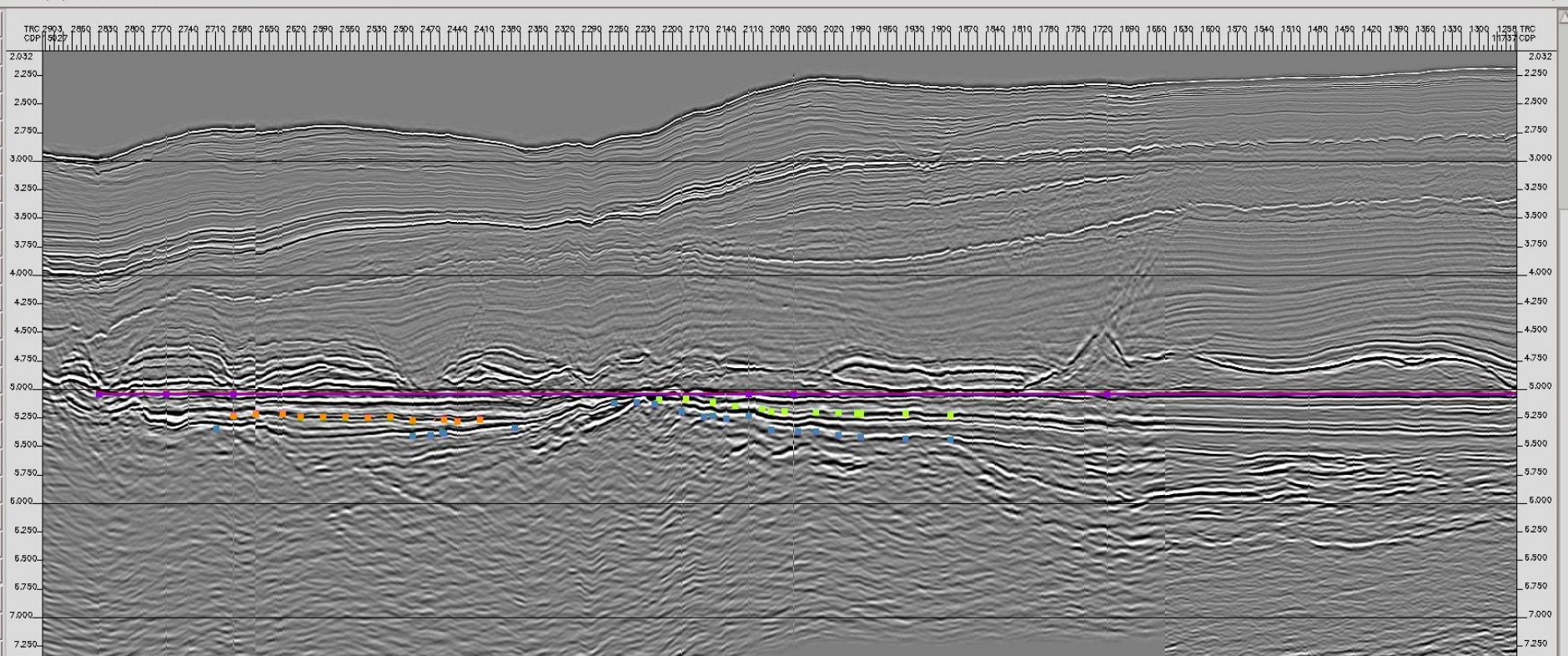
Versfelt (1988)



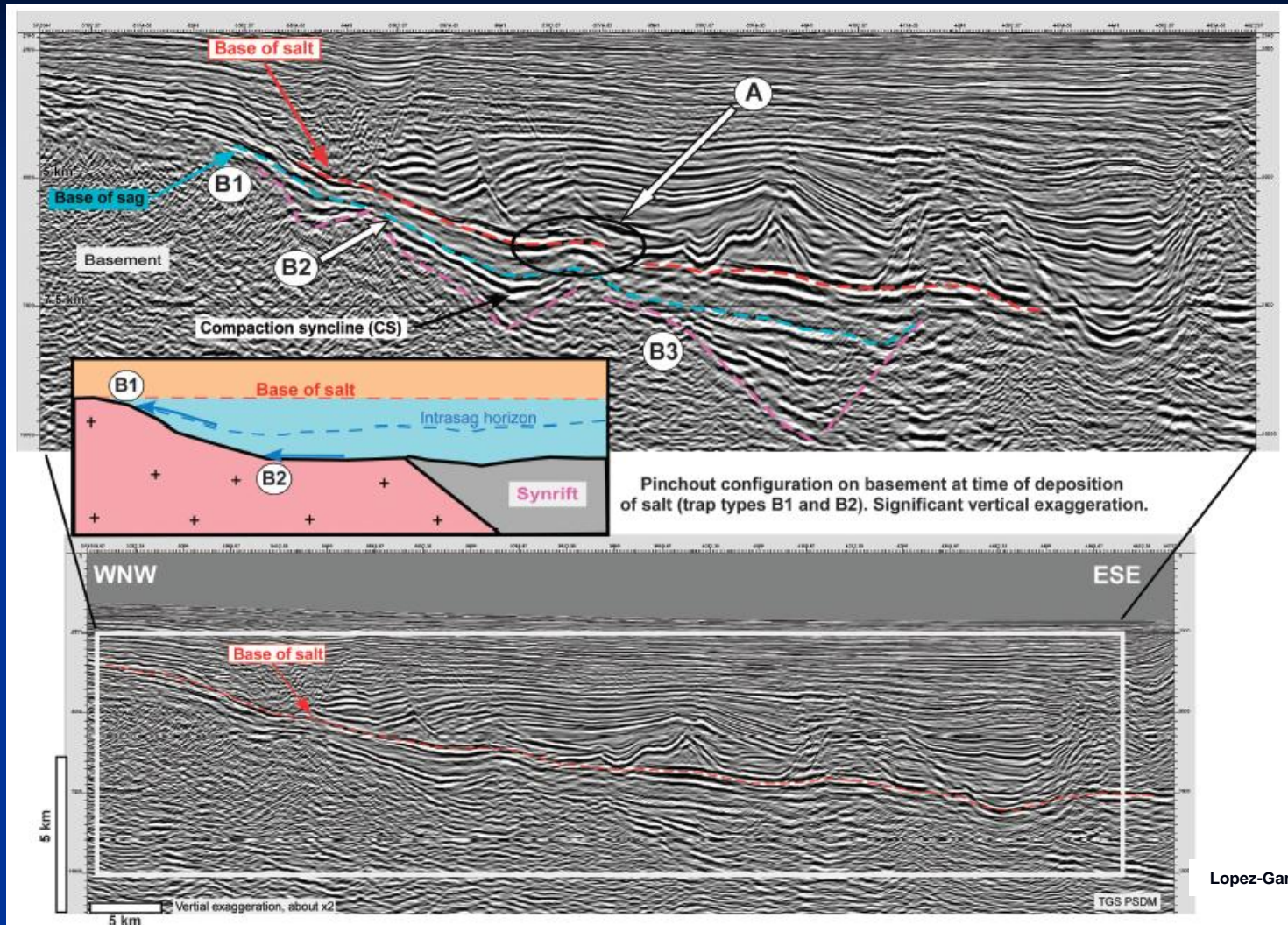
East African Rift System



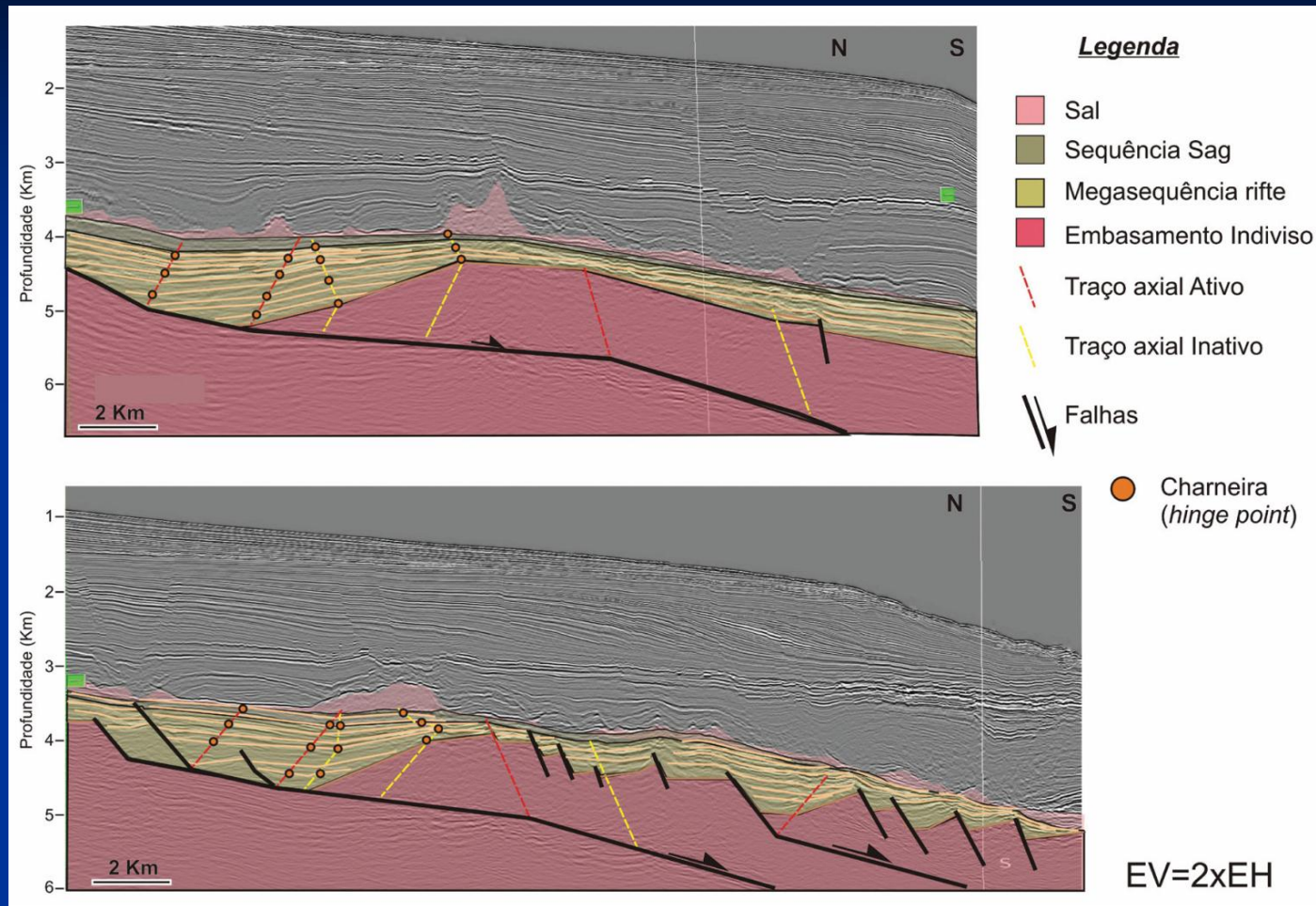
Campos Basin



Trap types in the synrift and sag sections Central Espirito Santo Basin

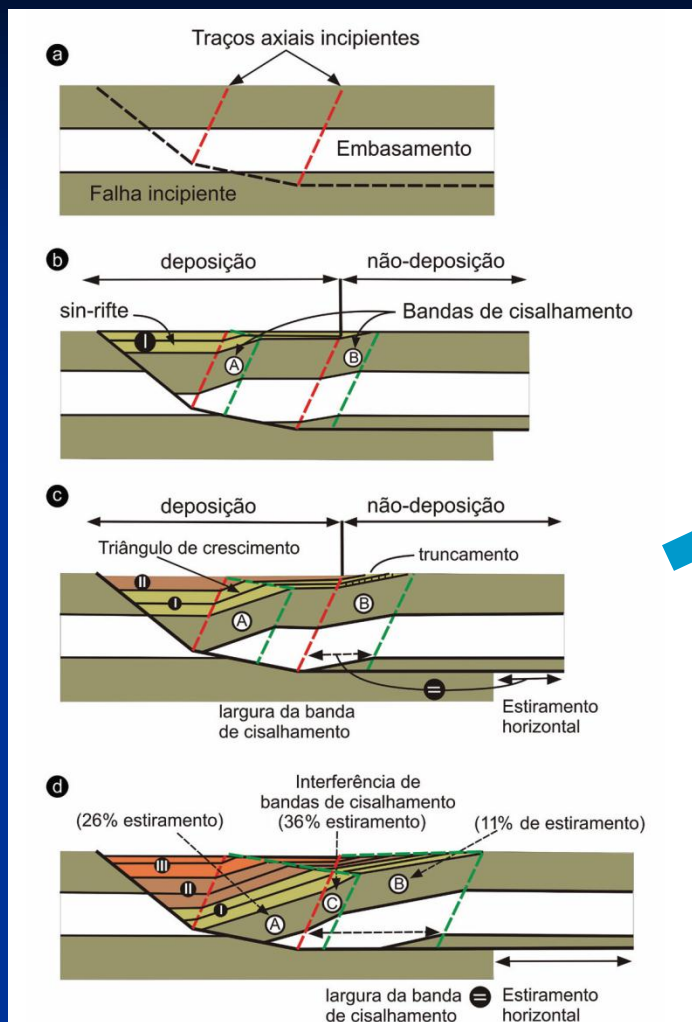


Hanging wall compaction syncline created counterregional dip necessary to form structural (four-way) closures at the sag level (trap type A). Combined traps (B trap family) : trap type B2 defined by an updip pinchout component at the base of the sag or at any horizon within the sag interval in the case of trap type B1. Examples of these geometries are common inboard (B1) and are also on preexisting half graben ramp margins basinward (B2). A potential for onlap/pinchout traps is also present at the rift-fill level on the ramp flank of the half graben (trap type B3).

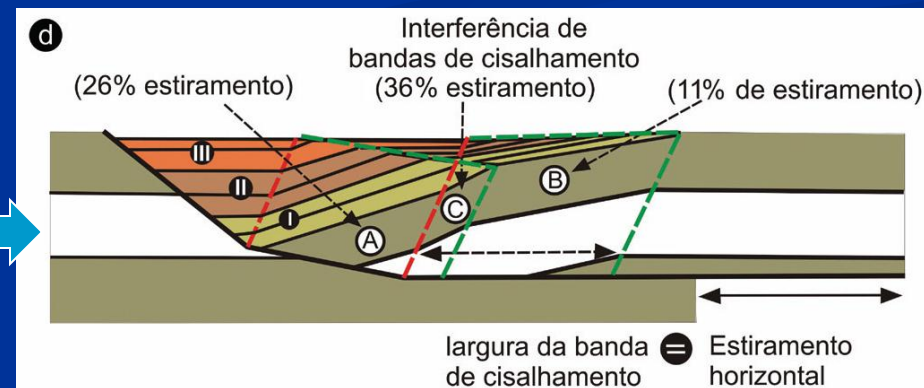
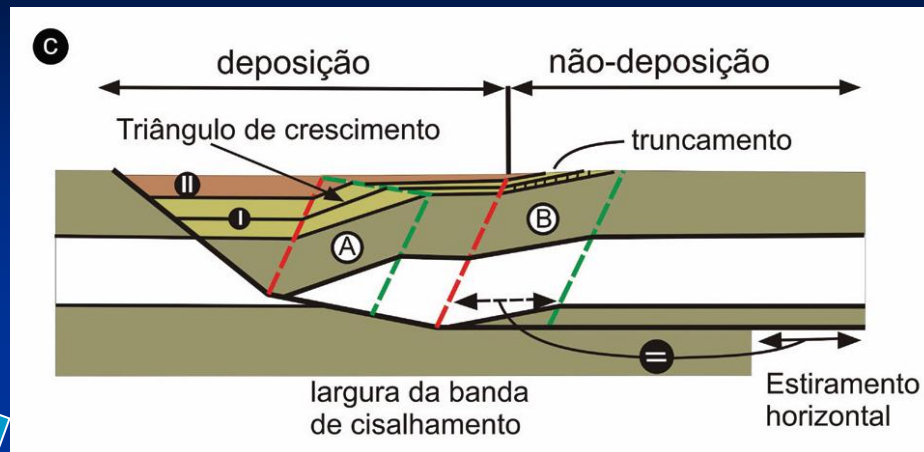


Araujo et al. (2009)

Depth converted seismic section in the Campos Basin central segment interpreted according to the extensional fault-bend folding model. Note the dip changes and active (red) and inactive (yellow) axial surfaces.



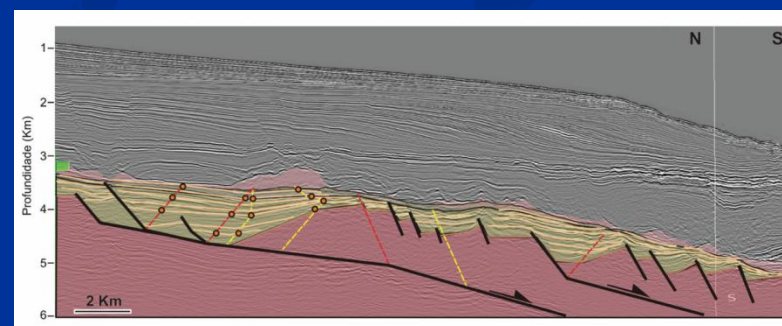
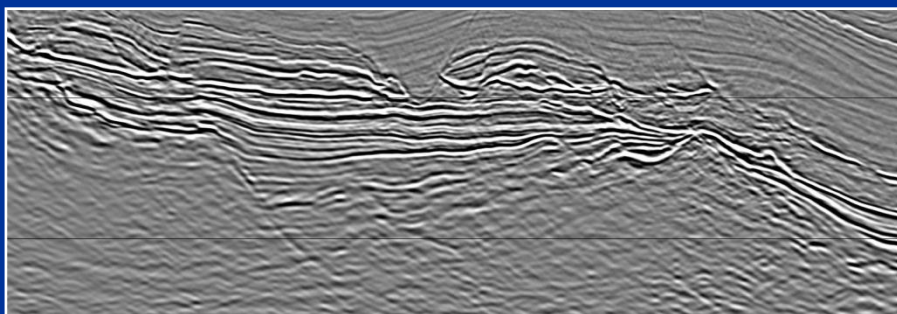
Sequential model of half-graben development above a normal fault that flattens to horizontal through two bends.



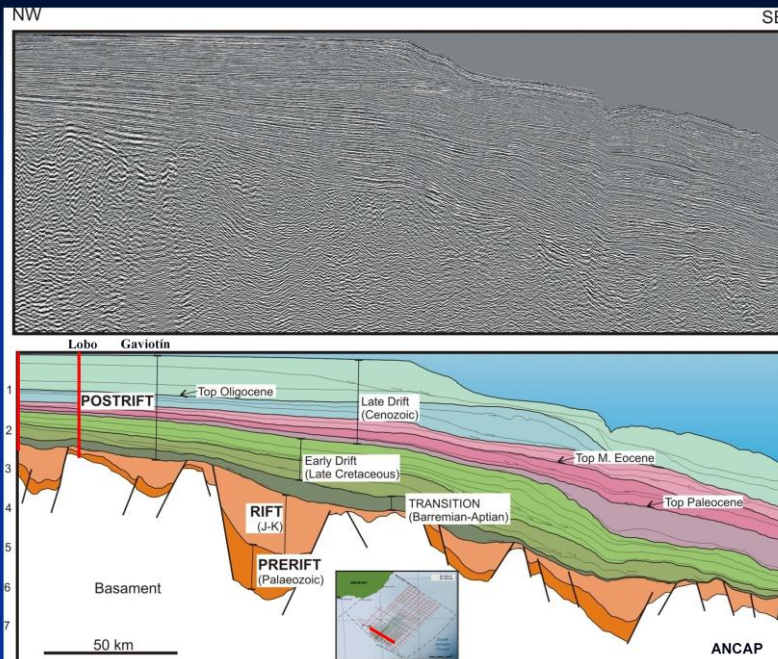
Araujo et al. (2009)

Listric or Planar Master Faults?

- The recognition of low-angle normal faulting and the apparent listricity displayed by seismic time sections, led to structural interpretations that were consistent with the listric model.
- However, there seems to be an inconsistency with neotectonic observations. Coseismic activity on neotectonic faults demonstrated that most normal faults in continental rifts are almost planar (straight in cross section) within the upper crust dipping at angles between 30 and 60 degrees down to mid crust levels. The curvature and progressively shallow dip on the fault on seismic sections was removed when velocity models were applied and they were depth converted (Davidson and Underhill, 2012).



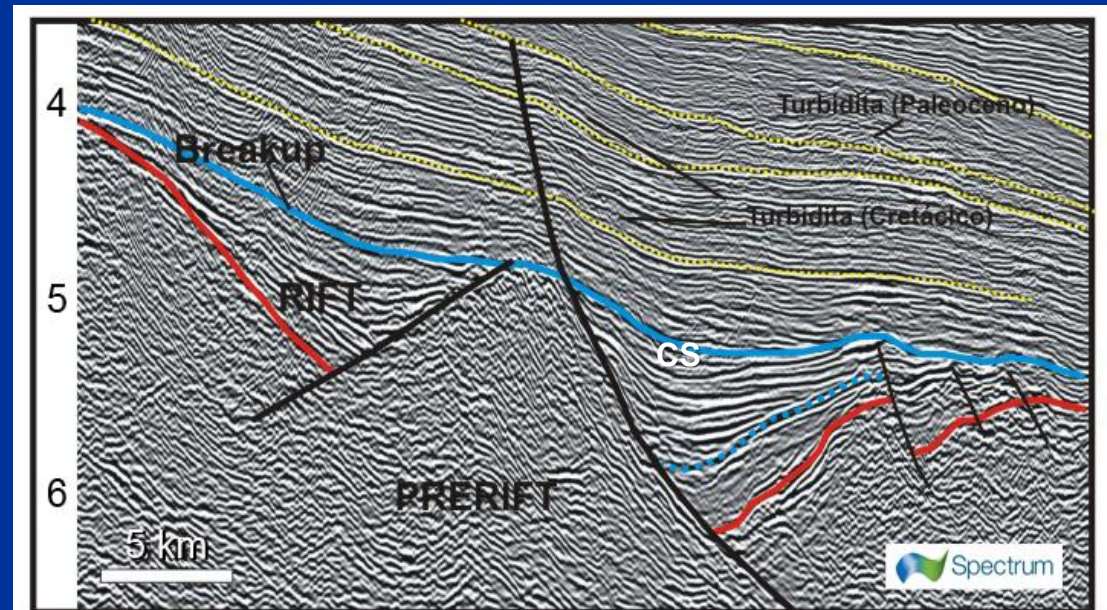
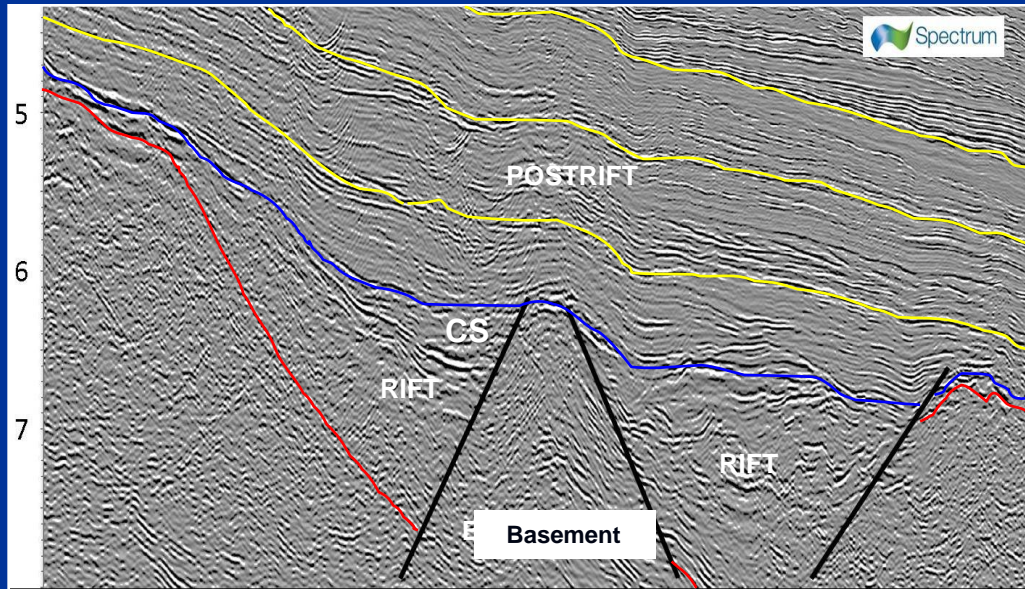
Punta del Este Basin



Presenter's notes: This is a dip seismic section along the Punta del Este Basin. The Punta del Este Basin is a failed rift, in which you can recognize grabens and half-grabens controlled by normal faults. The prerift mega-sequence is represented by Palaeozoic sedimentary rocks drilled by the Gaviotín well, correlated with the geological units that outcrop in the Norte basin.

The synrift mega-sequence includes alluvial-fluvial and lacustrine deposits interbedded with volcanic and volcanoclastic deposits. It is remarkable that the prerift sequence is preserved spatially coincident with the development of synrift sequence, being partially eroded on highs. The transitional sequence includes fluvial-deltaic deposits and distally marine deposits. It develops during a period of thermal subsidence after the end of the synrift phase. The base of the transitional sequence corresponds to an onlap surface, being the graben shoulders surpassed for the first time. Based on regional correlation; the age of this transitional sequence is probably Barremian-Aptian. The drift mega-sequence can be divided in a Cretaceous early drift and a Cenozoic late drift. The Cretaceous early drift is coloured in green in the picture and it is composed by regressive deposits in a context of rising sea level. In the Cenozoic, the sedimentation is controlled by the interplay of eustatic oscillations of sea level, regional subsidence and sediment supply.

Trap types in the synrift and sag sections Punta del Este Basin



Conclusions

- The South Atlantic 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.
- In this latter case differential compaction at the half-graben border fault margin has been a critical factor to accentuate and/or create counter-regional dips necessary to form structural (four-way) closures at the overlying sag level.
- Seismic evidence of differential compaction is provided by the presence of hangingwall compaction synclines 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.
- 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.

Acknowledgments

- TGS-NOPEC
- PGS
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- Hess