Pitfalls of "Structural Styles" Analysis in Frontier Basins*

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Abstract

"Structural styles" – assemblages of structures thought to be diagnostic of specific stress regimes such as extension or compression – are commonly used as interpretation guidelines in petroleum exploration. However, "styles" represent simplistic end members of the very broad spectrum of possible geological structures, and structural trap analysis should consider the entire spectrum of possible structures. Additional complexities are introduced by structural overprinting during multiple tectonic events. The interpreter should consider all structural geometries that are possible as the result not only of tectonic and gravitational stress, but stratigraphic anisotropy, basement anisotropy, prior deformation, and numerous other factors.

Shelf-margin structures of the Barreirinhas Basin in northern Brazil provide examples of both atypical structures that do not readily fit into a traditional structural "style", and the complexities introduced by overprinting of multiple deformation events. Initially interpreted as strike-slip features because of their complexity and position near the landward extension of an oceanic fracture zone, the structures represent the overprint of two differing types of gravity-driven thrusting, which Krueger and Gilbert (2009) termed Type III and Type IV deep-water fold belts. Both generations of structures developed along a passive shelf margin over-steepened by massive influx of fine clastics, likely during sea level falls. The initial Santonian (Type III) down-slope sliding occurred along a bedding-parallel detachment that linked a shelfal extension zone (characterized by closely-spaced listric faults) with a downdip zone of stacked imbricate thrust sheets. The entire deformational event was geologically "instantaneous", occurring during an interval in the latest Santonian. A second, Tertiary-age Type IV, cycle of deformation occurred above a non-bed parallel detachment that cut across stratigraphy both in the dip and strike directions to produce a three-dimensionally complex fault system linking listric normal faults updip with imbricate thrusts downdip. This second fault system cut down through the older Santonian system, carrying the older

deformed hanging-wall and the footwall within the hanging wall of the Tertiary system. Though not as aerially extensive, the latter type of structure was longer lived, with fault motion occurring through much of the Tertiary.

Type IV structuration is not unique to the Brazilian Equatorial Margin, occurring along other passive margins, and may provide useful information on the potential collapse of other lithologically homogeneous rock masses such as the Canary and Hawaiian Islands submarine volcaniclastic piles. Similarly, strike-slip or "wrench" structures are erroneously identified in intracratonic basins, based on (1) apparently anomalous variations in stratigraphic thicknesses across faults, and (2) what appear to be mixed compressional and extensional deformation across a single fault. In reality demonstrable strike-slip deformation is uncommon. Many "wrench" features prove to be either "Sunda folds" (inverted half-grabens), the margins of partially inverted grabens, or steepening-downward normal faults formed as the result of a strong contrast in mechanical strength between the basement and the sedimentary cover. In actual practice strike-slip deformation can be reliably identified only from map-view analysis, using either specific diagnostic fault map-pattern features or - less commonly - stratigraphic or other piercing points.

References

Figueiredo, J.J.P., D.M. Hodgson, S.S. Flint, and J.P. Kavanagh, 2010, Depositional Environments and Sequence Stratigraphy of an Exhumed Permian Mudstone-Dominated Submarine Slope Succession, Karoo Basin, South Africa: JSR, v. 80/1, p. 97-118.

Krueger, A.C., and E. Gilbert, 2009, Deep-Water Fold-Thrust Belts: Not All the Beasts Are Equal: Search and Discovery Article #30085. Web accessed 17 August 2011. http://www.searchanddiscovery.com/documents/2009/30085krueger/images/krueger.pdf

PITFALLS OF “STRUCTURAL STYLES”ANALYSIS IN FRONTIER BASINS

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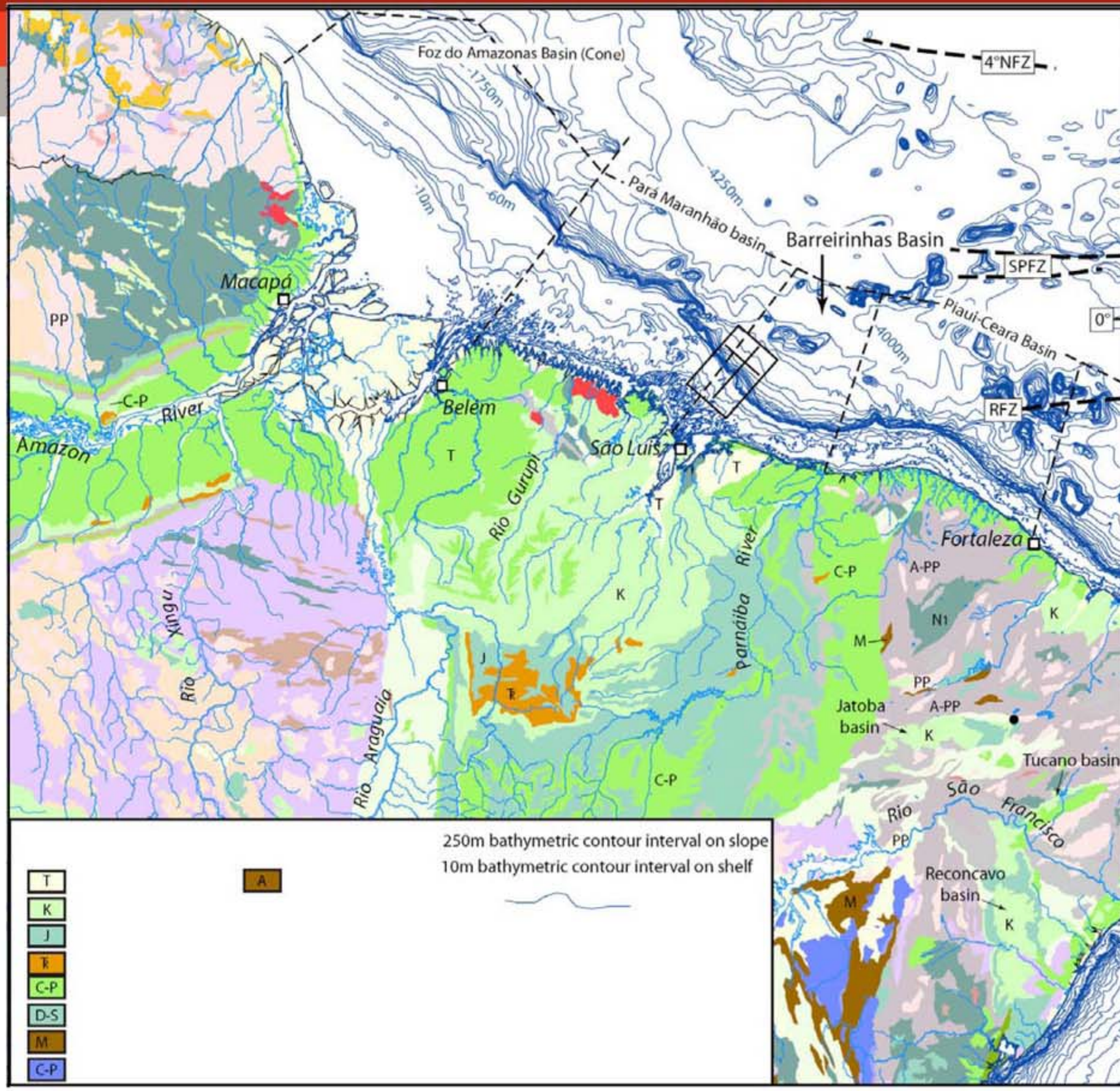
Examples from the Barreirinhas basin



Notes by Presenter: In this presentation I will focus on offshore examples of the Barreirinhas basin.

Common Challenges in choosing analogues:

- Similar geometries may have different genesis.
- Multiple structural styles in the same area.
- Structural styles can overprint each other.

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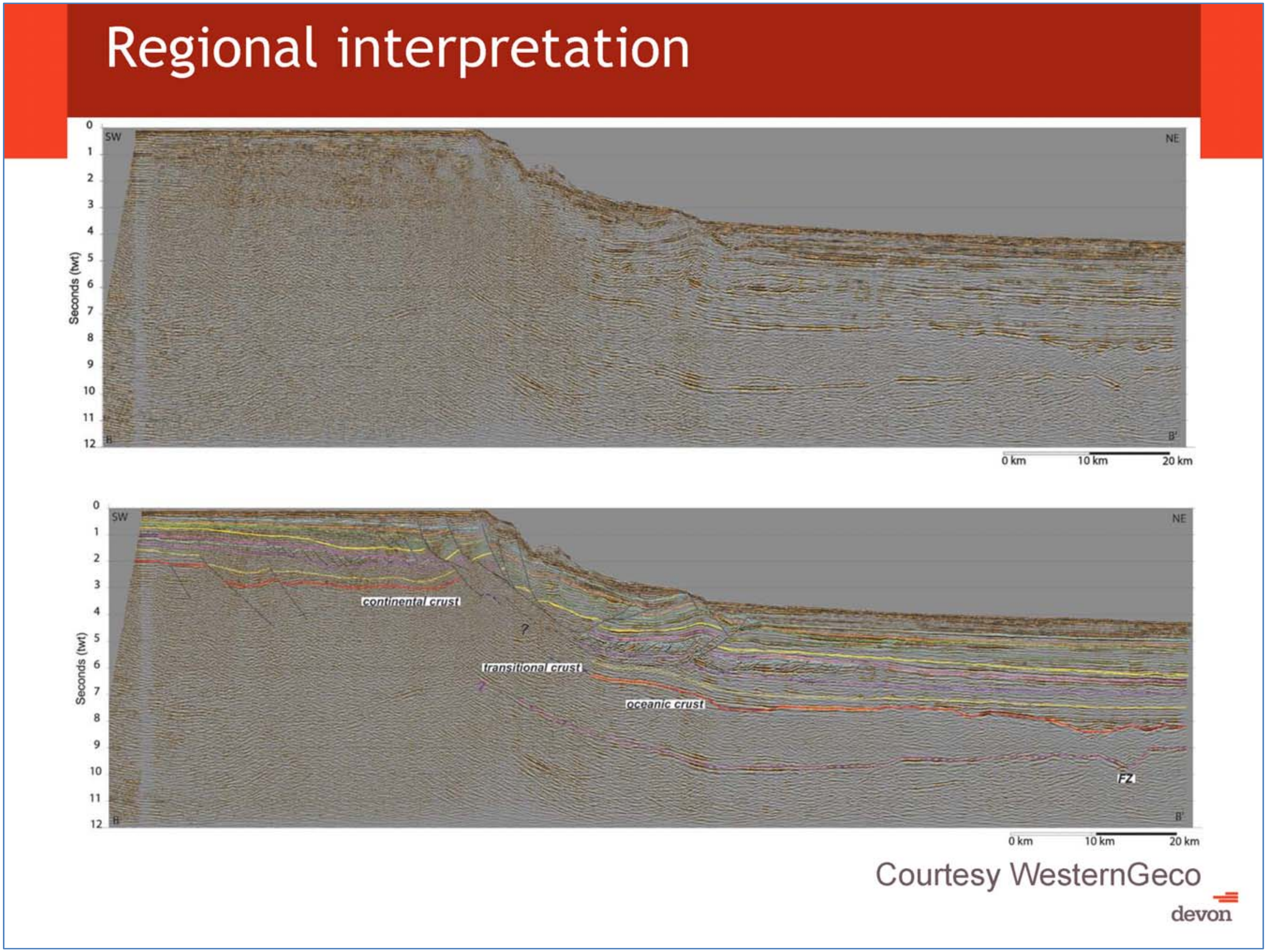
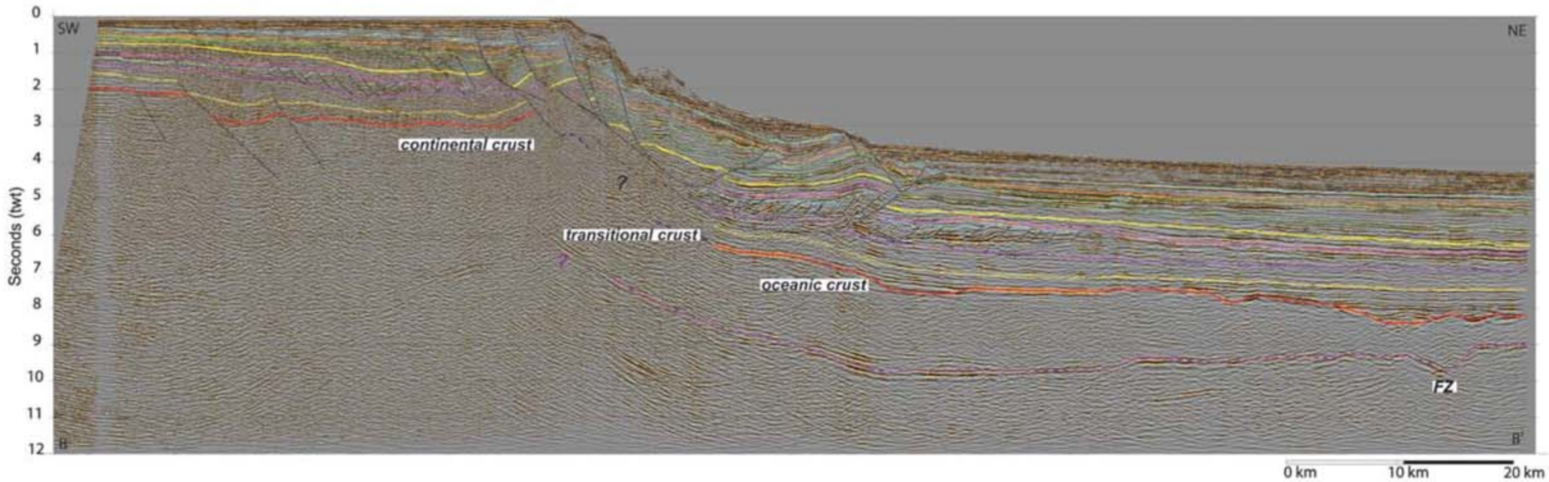


Notes by Presenter: In the Barreirinhas basin a mix of compression and extension, and its location next to a major oceanic fracture zone may lead people to believe these could be flower structures.

The Barreirinhas Deep Water Fold and Thrust belt (DW-FTB)

Mechanism: Gravity driven
Characteristics: linked extension and compression



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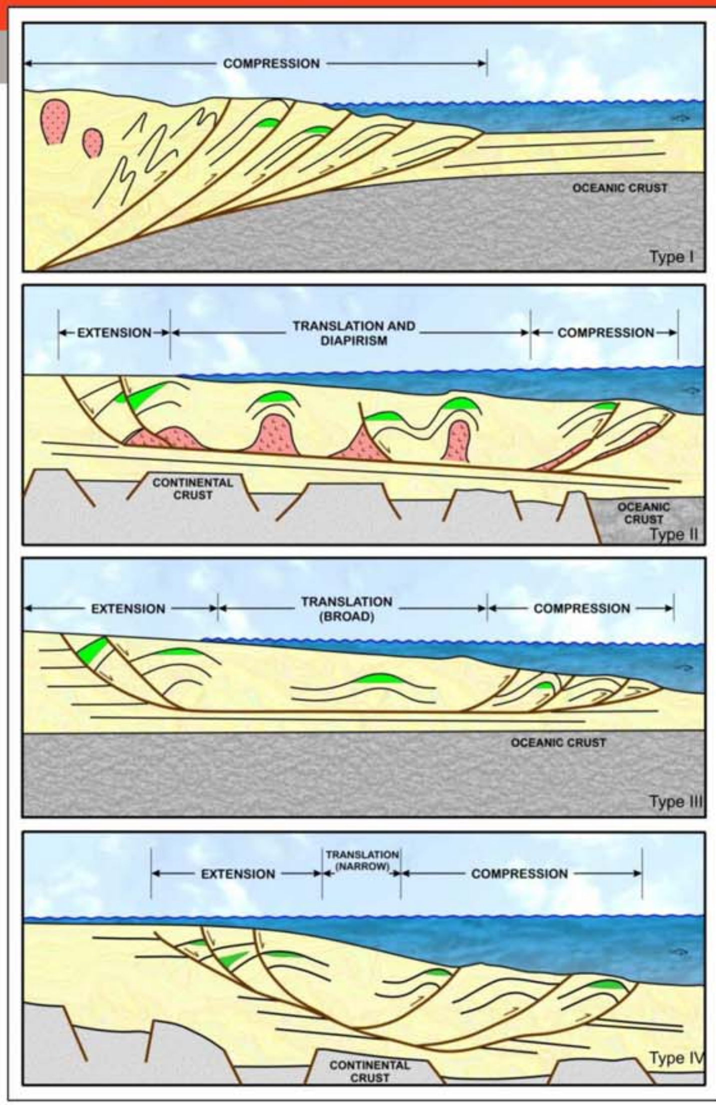
Notes by Presenter: A more likely model would be of a gravity driven deep water foldbelt.

Deep-water foldbelts classification

(Krueger and Gilbert, 2008)



Active subduction zones:
Ex: Nankai, Japan

Regional Salt decollement DW-FTB:
Ex: Campos, Santos, Angola

Regional Shale decollement DW-FTB:
Ex: Nigeria, Namibia, South Texas, Barreirinhas

Shale local non-discrete decollement DW-FTB:
Ex: Rio Muni, Barreirinhas

Krueger and Gilbert, 2008

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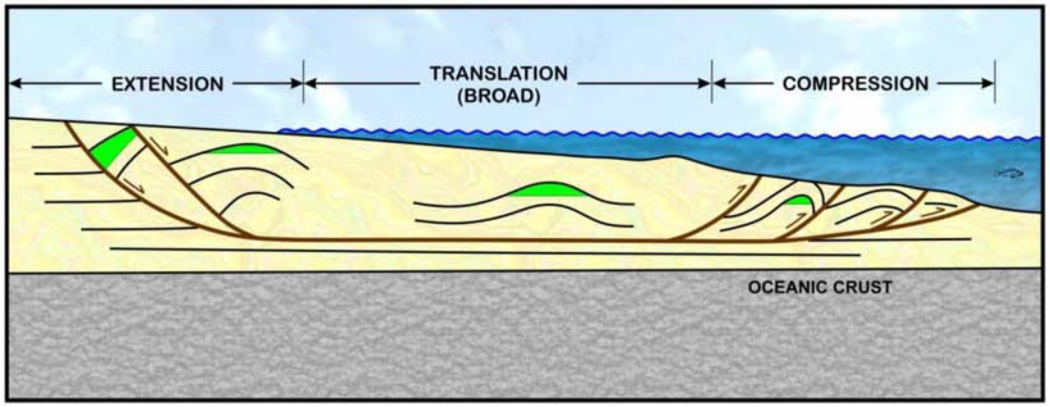
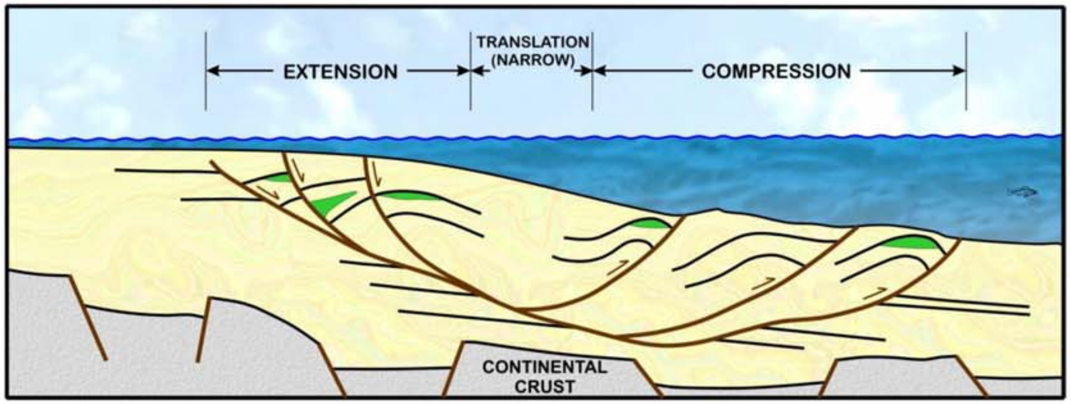
Notes by Presenter: Deep-water foldbelts can be classified into 4 different types

Barreirinhas Basin at least two gravity driven events of deformation

Cretaceous Regional Shale decollement DW-FTB



Tertiary non-discrete Shale decollement DW-FTB



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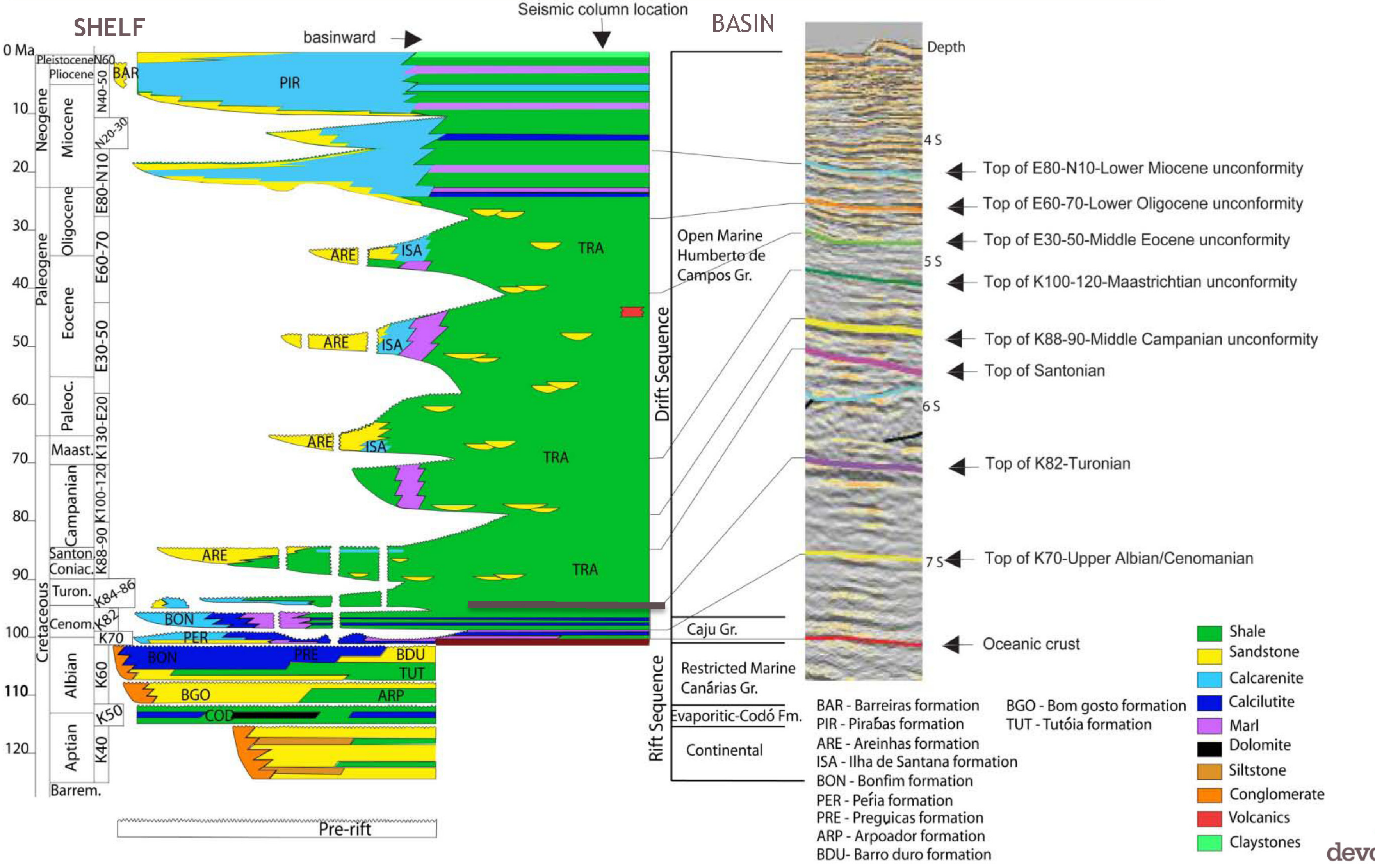
Notes by Presenter: In the Barreirinhas basin at least two events of deformation occur one during the Cretaceous and one during the Tertiary. Crosscutting

Barreirinhas Basin Stratigraphy



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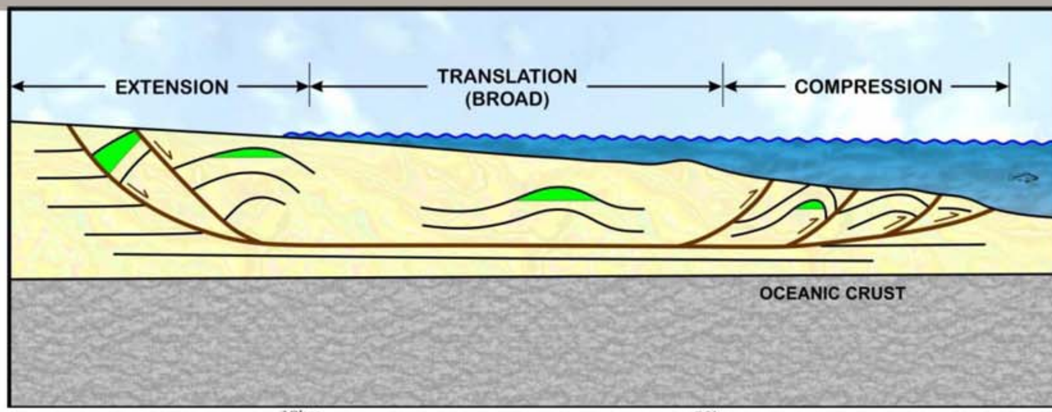
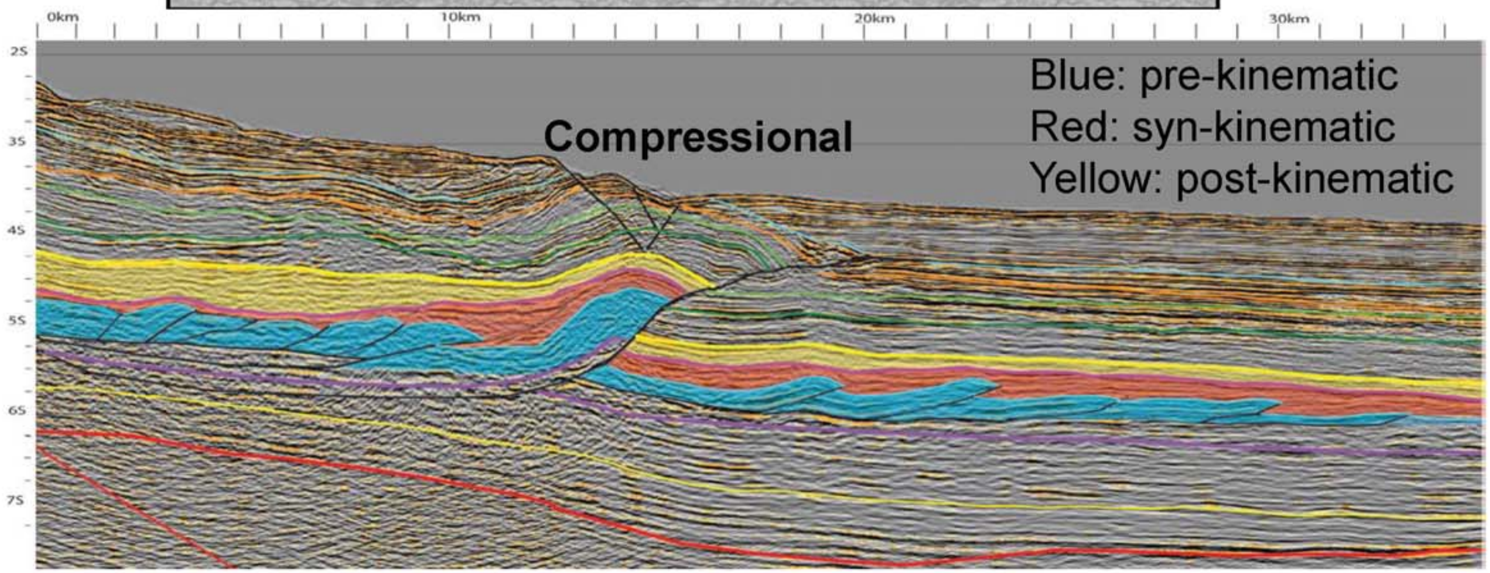
Barreirinhas Basin 1st gravity sliding deformational event

Cretaceous Regional Shale decollement DW-FTB





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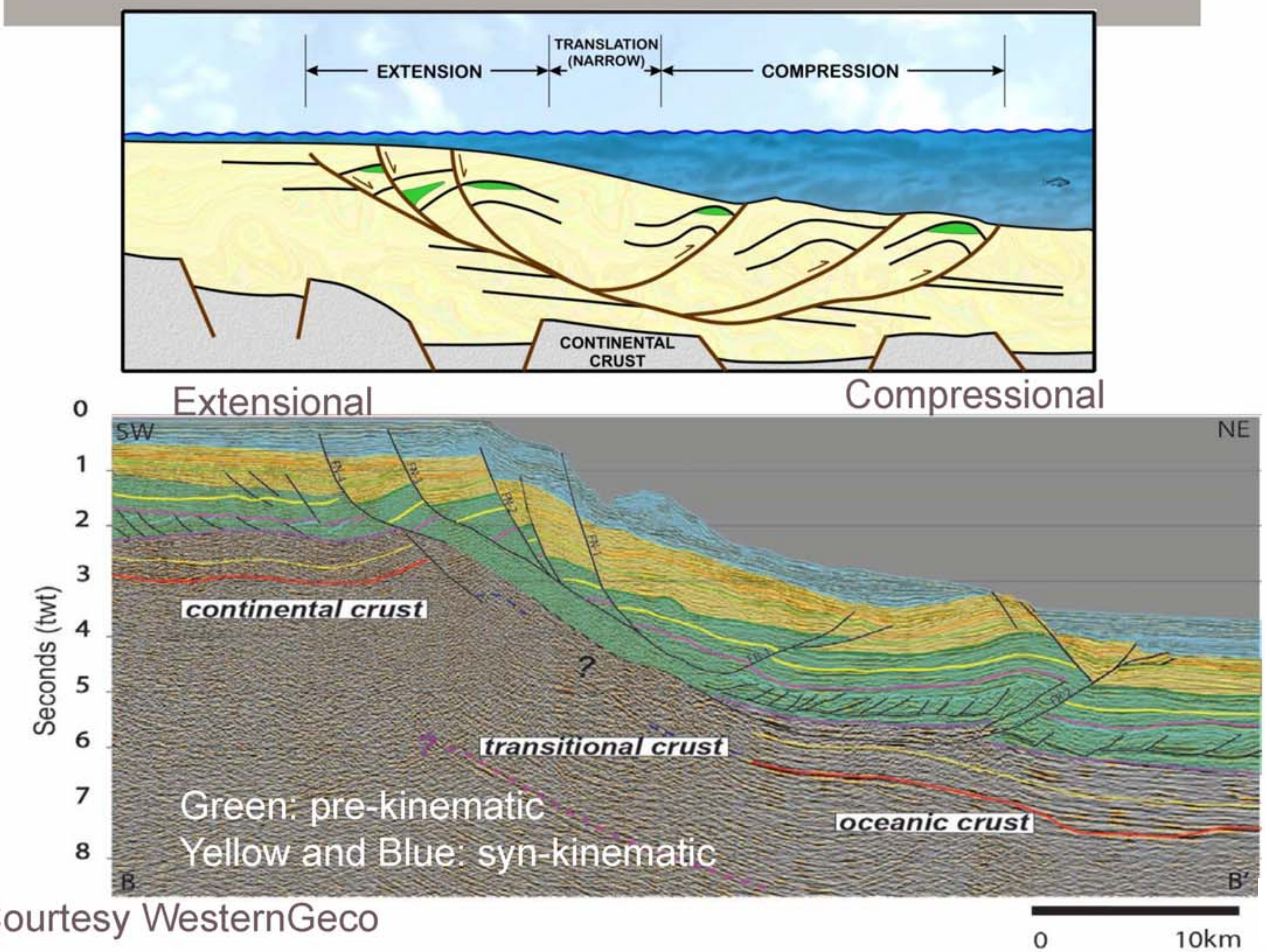
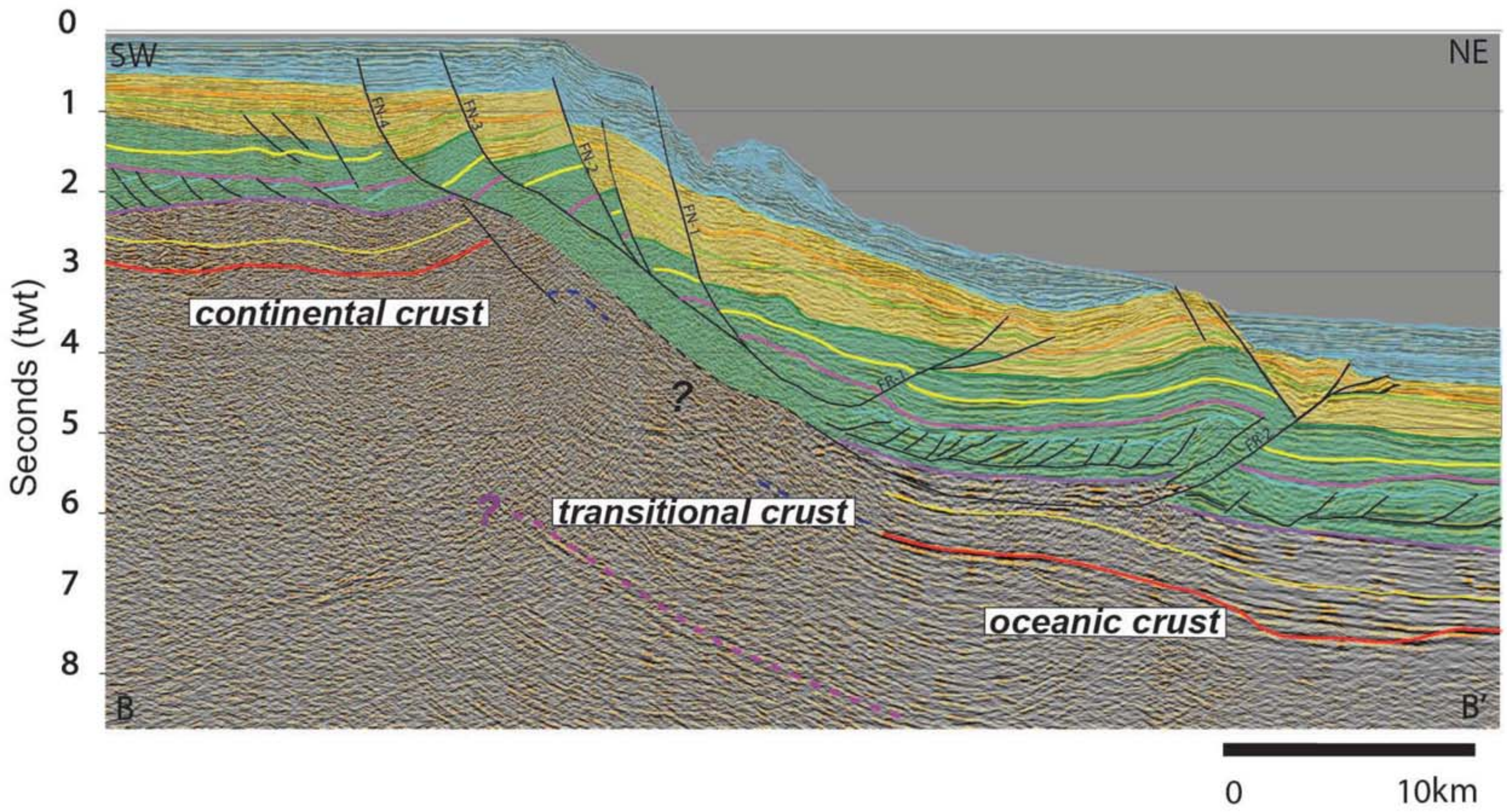
Notes by Presenter: This is a detail on the compressional domain of the Cretaceous system. In Blue is the pre-kinematic (pre-Phase 1) sequence Note crosscutting by Phase 2

Barreirinhas Basin 2nd gravity sliding deformational event
Tertiary non-discrete Shale decollement DW-FTB



Notes by Presenter: Phase 2 structures crosscut older Phase 1
Describe the minor basement faults reactivation as well.

Barreirinhas basin



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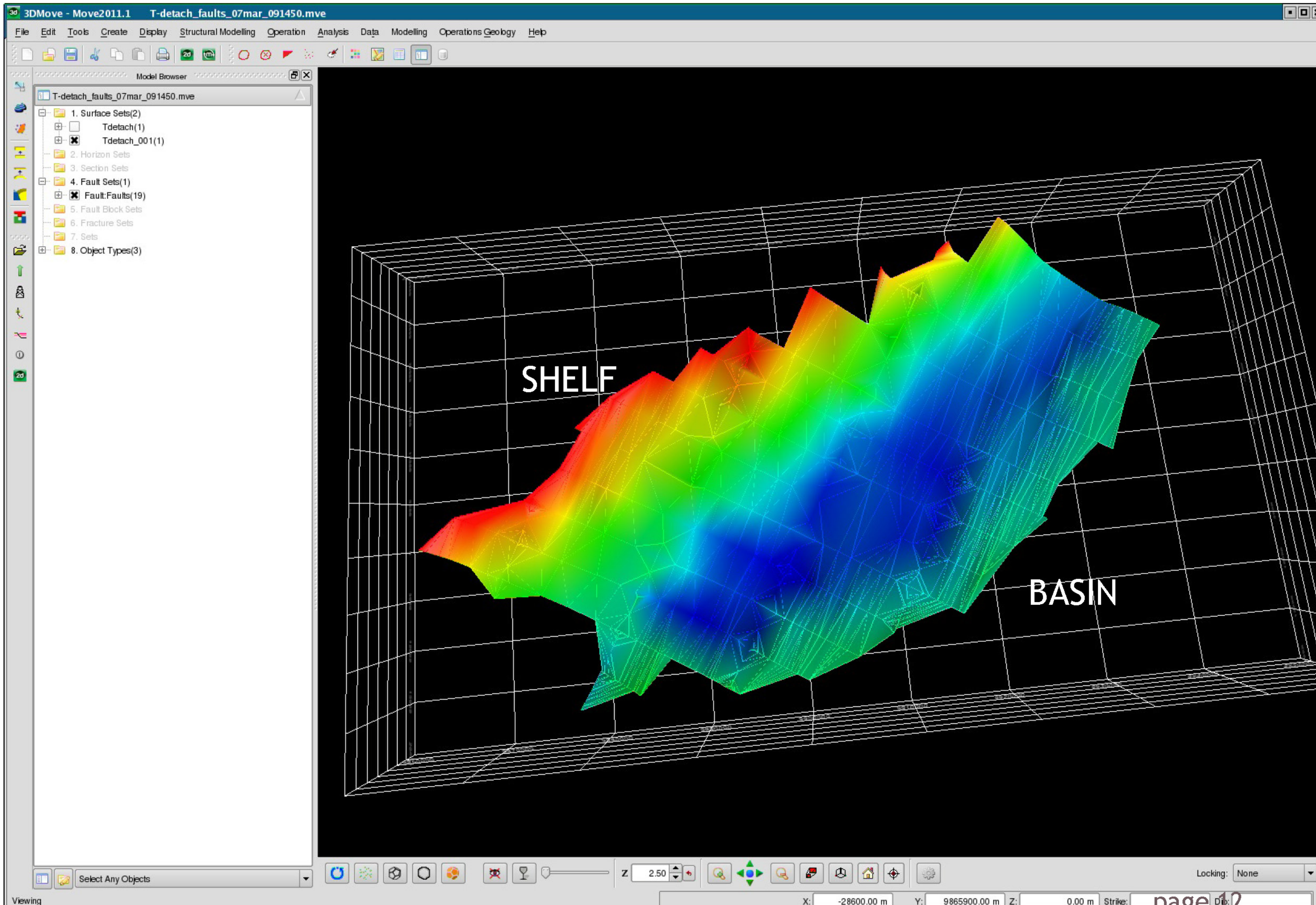
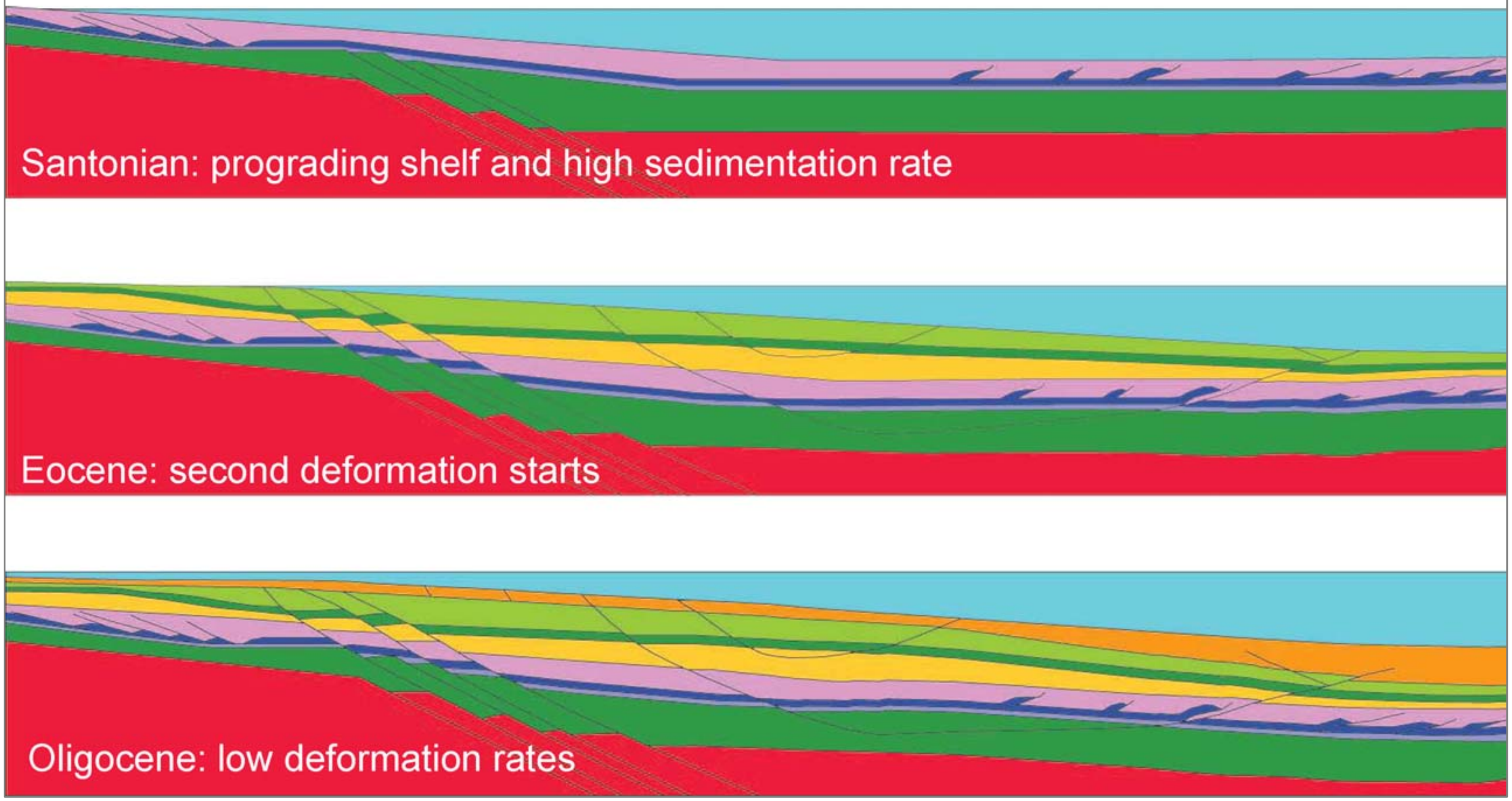
Notes by Presenter: Because of the complex overprint of multiple deformational events to fully access it is required to restore the line to adequately understand it.

Geometry of Tertiary Fault Surface

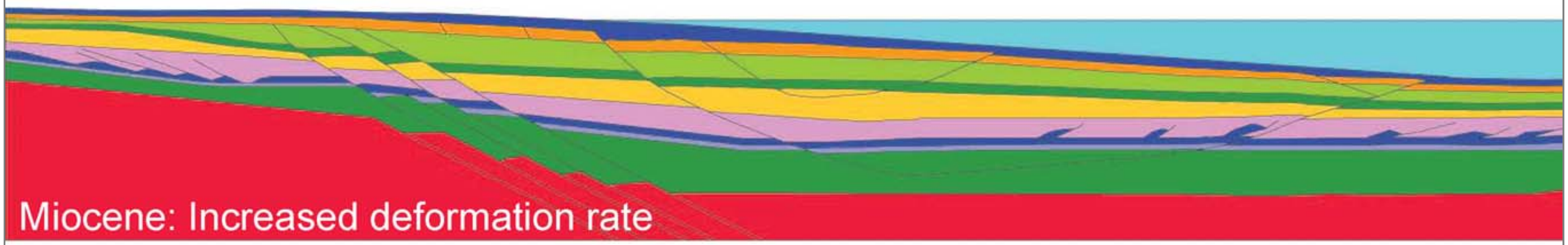


Palinspastic Restorations



Notes by Presenter: Here I present the results of our palinspastic reconstructions.
Reconstructions start post-Cretaceous deformation.
NOTE sections are 1:1
Note Maastrichtian activity of basement faults, cause not completely understood.

Palinspastic Restorations



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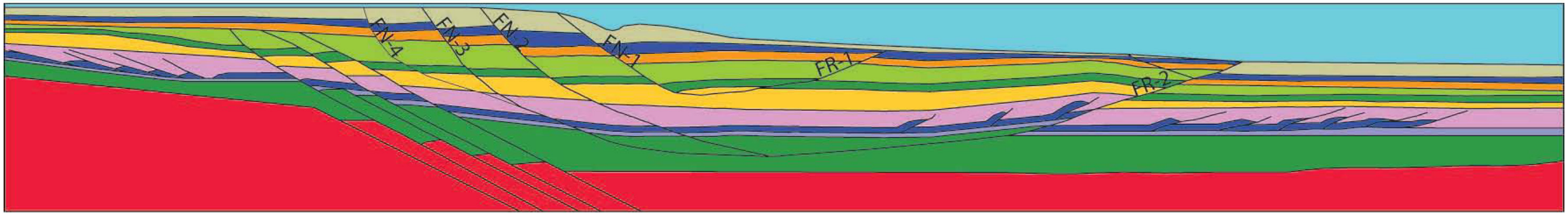
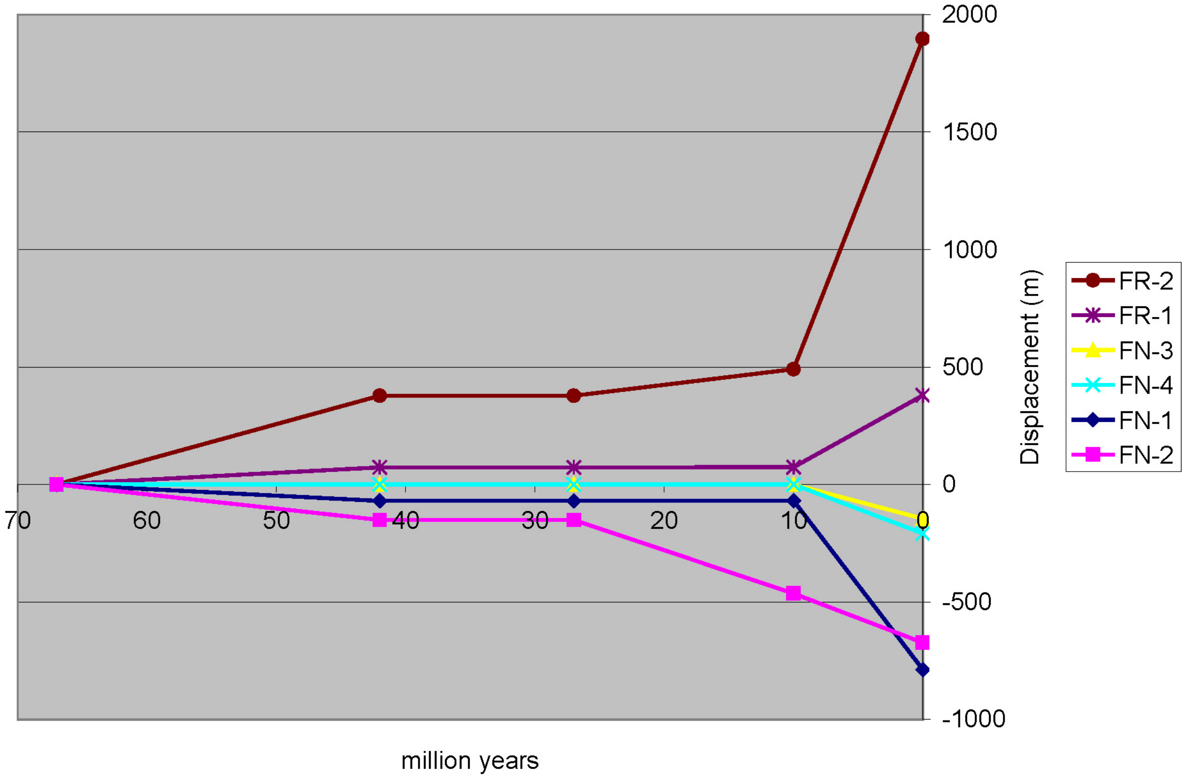
Notes by Presenter: Strain increases at Miocene
Cause? Amazon evulsion

Kinematic analysis: system linkage





- Strain analysis proves it is a linked system, normal and reverse faults mirror each other in both timing and strain (net compression = net extension).

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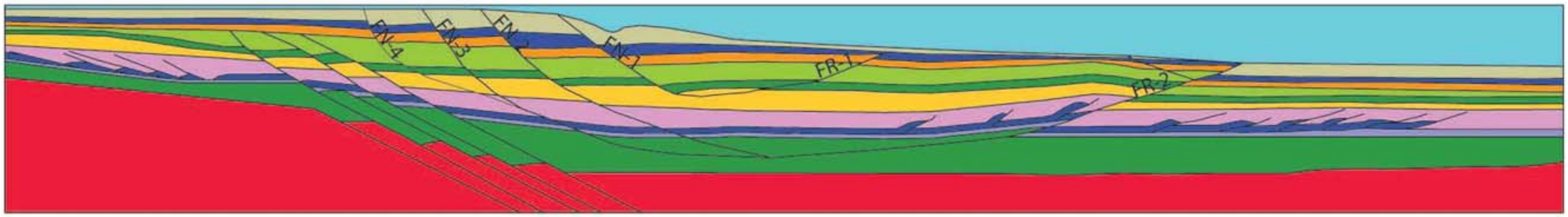
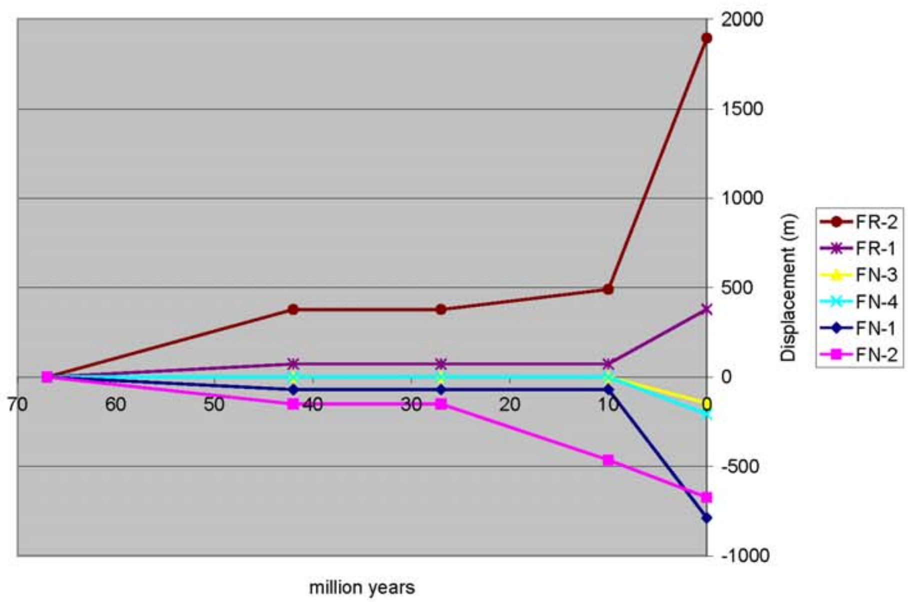
Kinematic analysis: strain rate





- Strain rate increase, shelf unstable at Eocene and Miocene.
- Strain rates increase at10 Ma.
- Landward propagation of normal faults, normal faults 3 and 4 initiate later, at 10 Ma.
- Landward propagation of reverse faults, reverse fault 1 is active later.
- Finite fault motion rates approx 0.22mm/year; minimal stick-slip motion?

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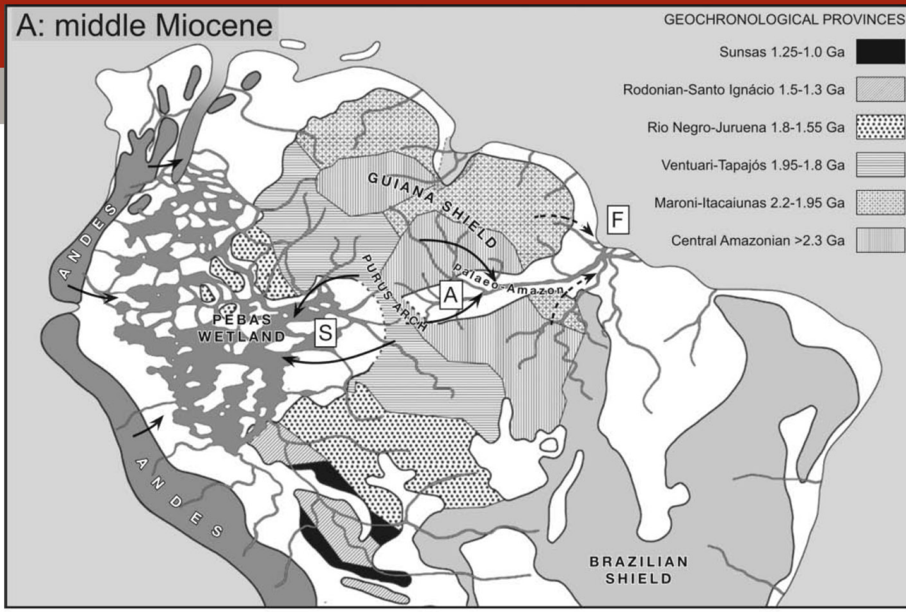
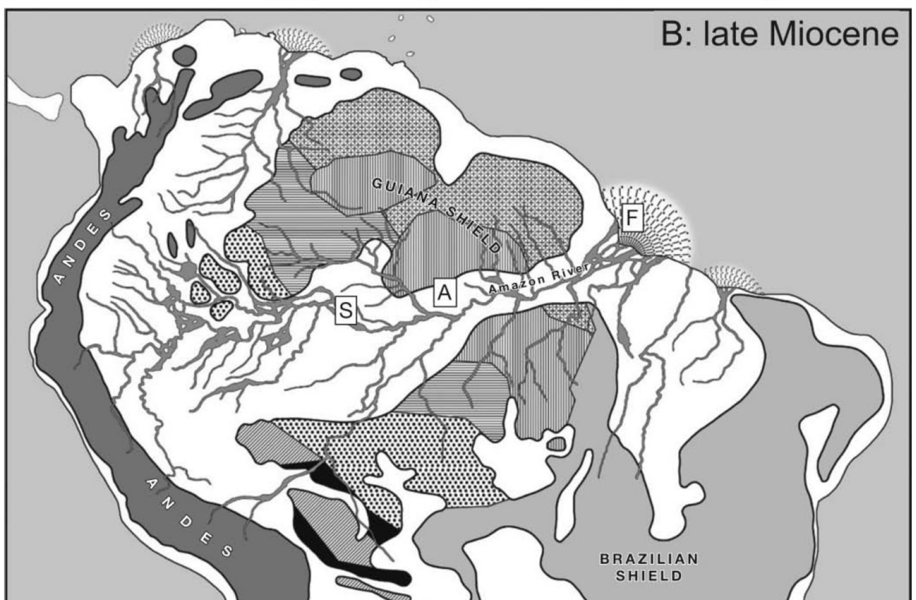
Notes by Presenter: Plotting displacement through time for each fault, allows us to understand deformation ratio, stress partitioning, and linkage of the system.

Paleogeography (Figueiredo et al., 2010)





- Higher deformation rates coincide with late Miocene drainage rearrangement.

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Conclusions

- Deformation rates prove the linkage of the tertiary system.
- Landward propagation of normal and reverse faults.
- Increased deformation rates at 10 Ma, likely related to changes in the paleogeography at late Miocene.
- A good Structural Style analogue requires more than similar geometries.
- Classifying Structural Styles can be problematic in areas of polyphase deformation as in the Barreirinhas basin.
- Slope instability is as much of a structural issue as a sedimentology issue.

Acknowledgments

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