Lithospheric Flexure and Related Stratigraphic Cycles in the Putumayo Basin, Colombia*

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Abstract

In continental forelands basins the response of the underlying elastic lithosphere via flexure to tectonic and sedimentary loads ultimately controls base level related sedimentary cycles in upstream fluvial deposits, in addition to the regional geometry of the basin. Seismic and well data from the Putumayo Basin in Colombia suggest a testable model showing how the nature, amount, distribution and timing of loading produce a variable, but identifiable set of seismo-stratigraphic architecture related to each flexural event. Four chronostratigraphic units from the basin, reduced to decompacted-thickness profiles, are forward-modeled to reproduce the successive deflections throughout the evolution of the basin. Tectonic related deflections are then calculated as the residual flexure of the first-order compensation due to sediments. Results suggest that most subsidence in the basin is caused by sediment loading (~75% of the total) and subsidence rate varies between 60 to 140 m/m.y. Additionally, the elastic thickness of the crust in the area (~ 25 to 35 km) did not change during basin history. Seismic-reflector geometry can be indicative of the dominant subsidence regime. Hinterland-onlap shifts, for example, probably reflect changes in the subsidence rate near to the thrust belt due to tectonic loading, while continuous foreland-onlap probably reflects subsidence due mostly to sediment loading. However, forebulges, which are developed individually for each loading event, and their characteristic flanking pinch-outs, are not recognizable in the Putumayo seismic data.

Reference

Turcotte, D.L. and G. Schubert, 1982, The Stefan problem, *in* D.L. Turcotte and G. Schubert, (eds.) Geodynamics; applications of continuum physics to geological problems, p. 168-171.

Lithospheric Flexure and Related Stratigraphic Cycles In the Putumayo Basin, Colombia

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SUMMARY

- Regional stratigraphy and accommodation in some continental retroarc foreland basins are controlled by flexure according to the nature loads: tectonic (~24 % of subsidence) and sedimentary (76 % subsidence)

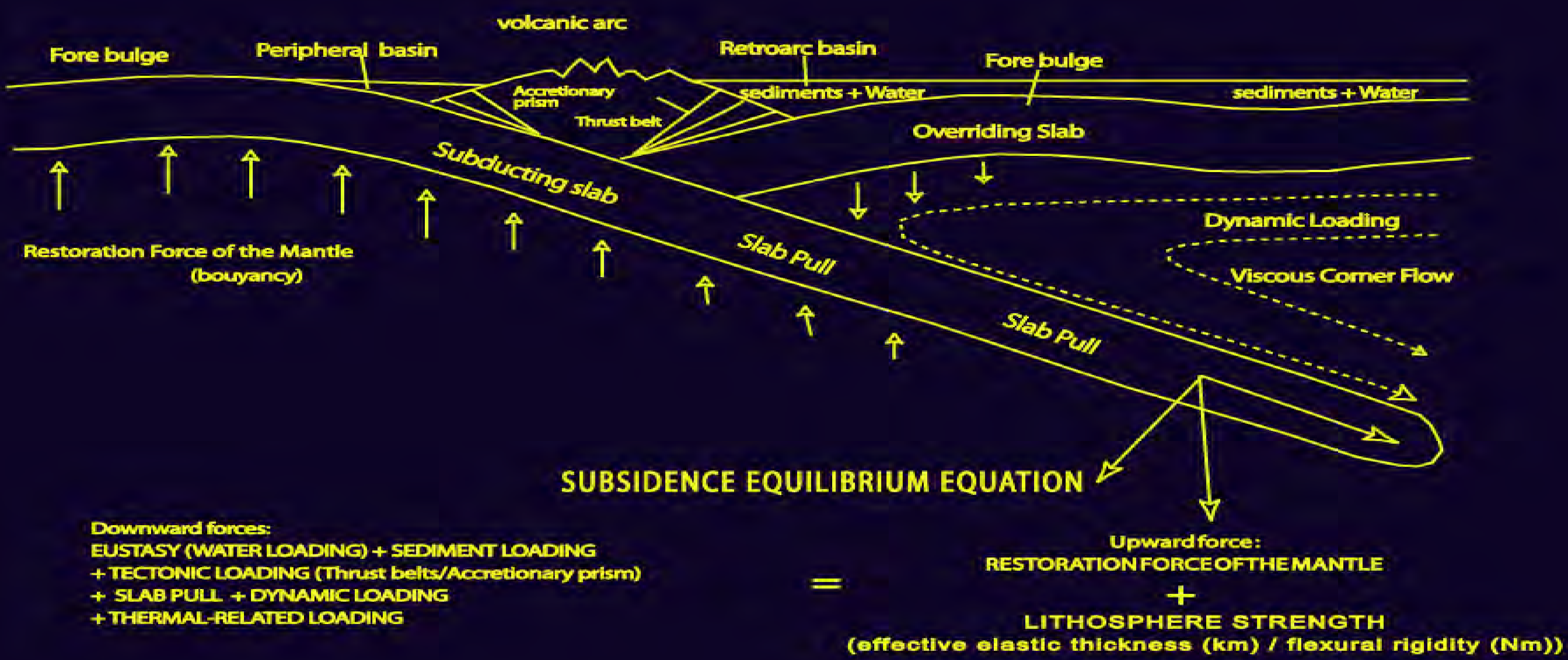
- According to our model some seismic facies can be linked to their mechanical origin in forelands: regional onlap shifts (from the foreland to the hinterland) indicate basin deepening due to tectonic loads, while continuous onlapping means compensation due to sediments.

- Forebulges location and geometry change according to nature of the loads. One forebulge exists for each loading event.

- In foreland basins continental sequences may develop during adjustment of fluvial systems to graded profiles according to isostatic compensation of the plate.

- The effective elastic thickness of the lithosphere does not change at scale of 10^7 years.

FORELAND BASIN CONCEPT

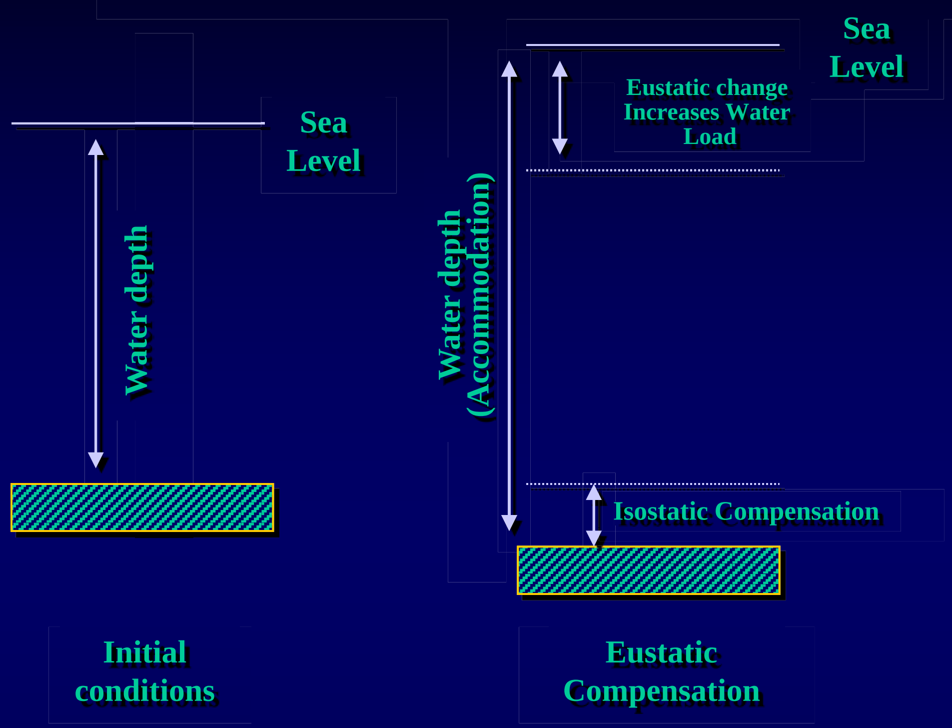


$$D\frac{d^4y}{d^4x} + (\rho_{mantle} - \rho_{fill}) \cdot y \cdot g - q(x) = 0$$

Turcotte and Schubert, 1982

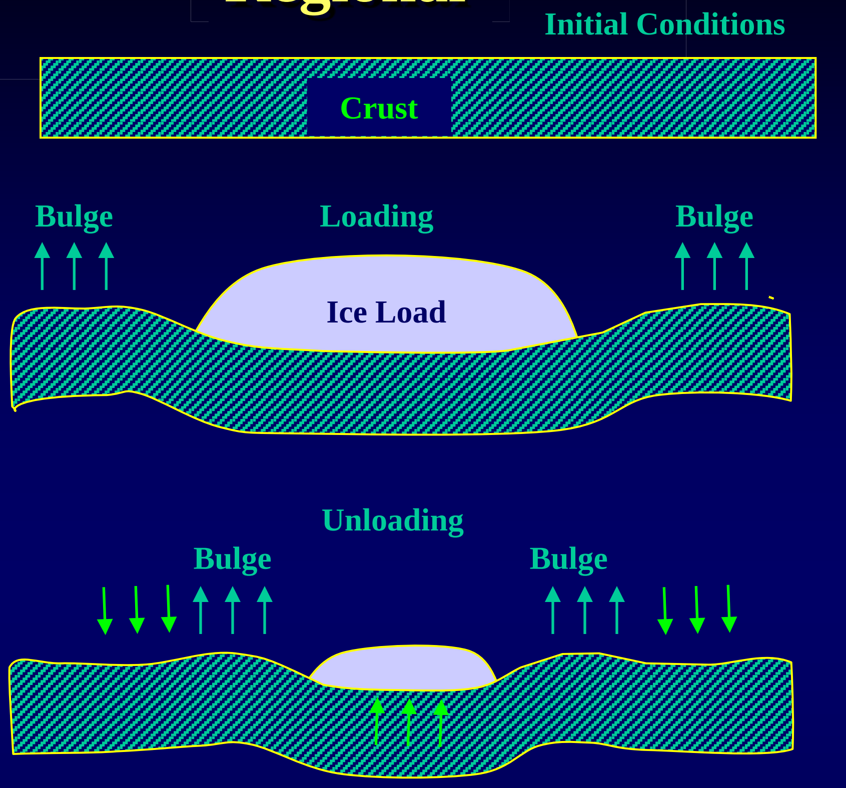
ISOSTASY

Local



Eustatic changes are good examples of local isostasy

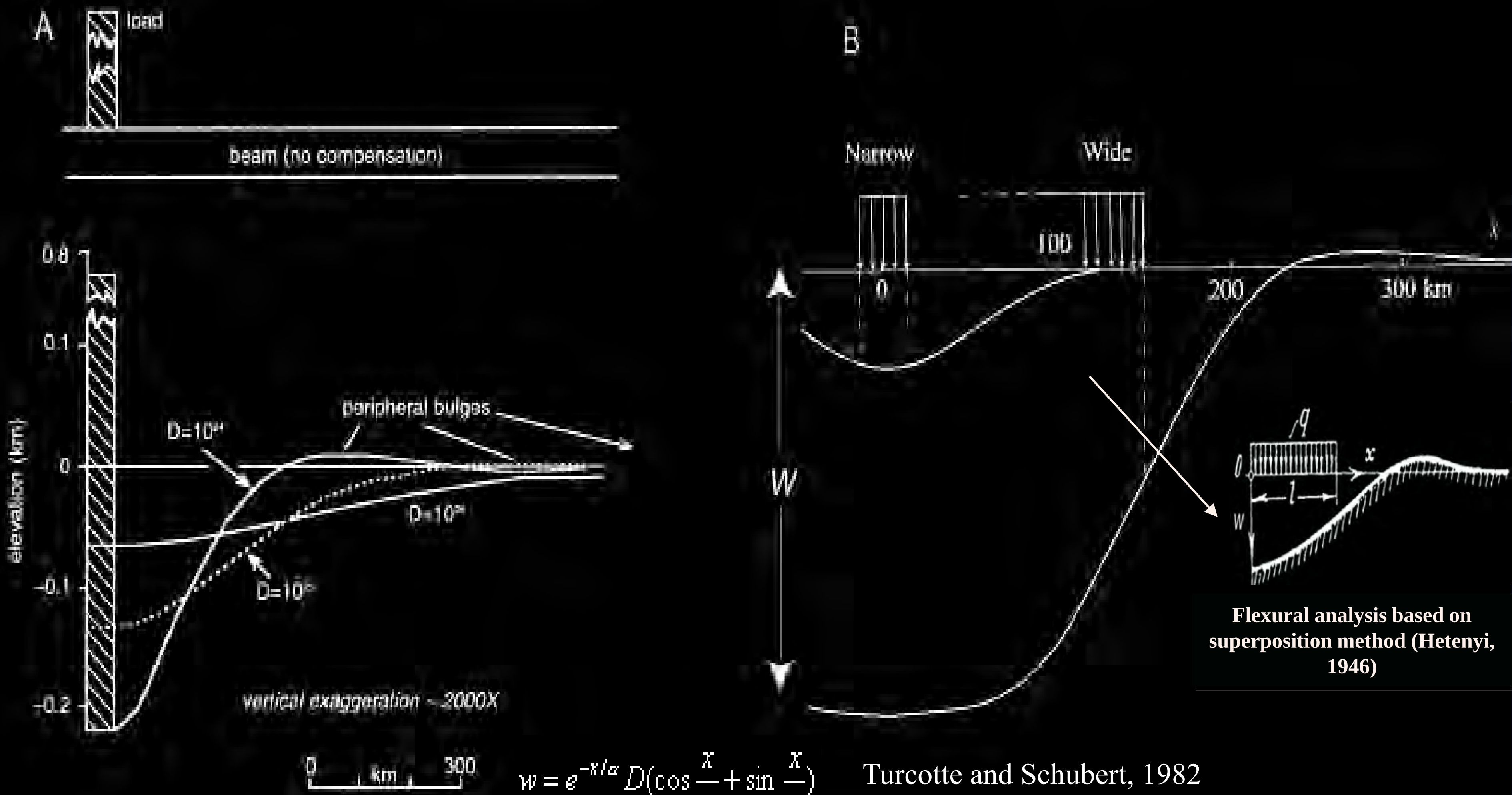
Regional



Glacial rebound is one example of flexure.

Bottom line: Foreland basins are regionally compensated (Flexure)

Mechanical Model For Foreland Basins



Flexural analysis based on superposition method (Hetenyi, 1946)

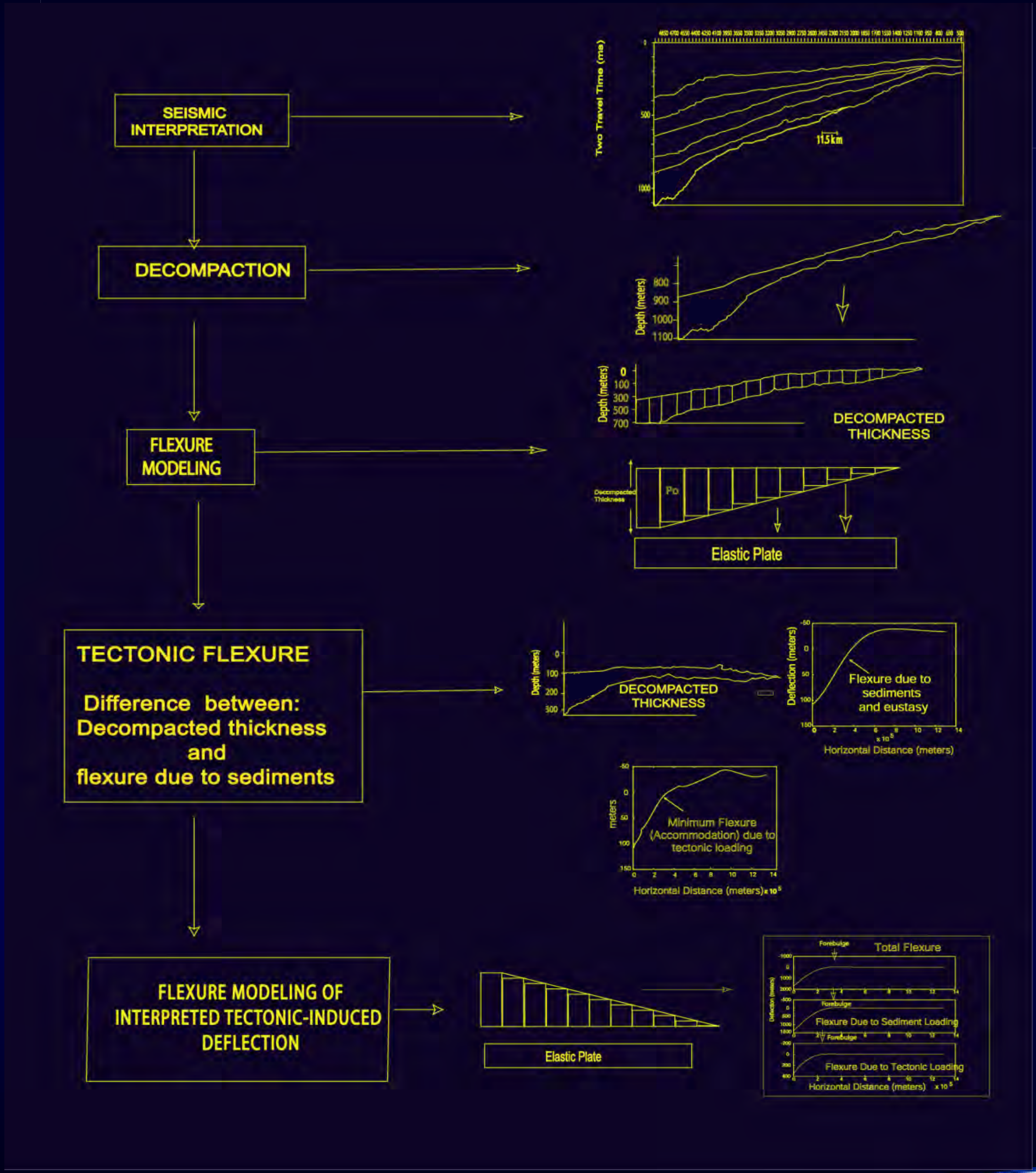
$$w = e^{-x/\alpha} D(\cos \frac{x}{\alpha} + \sin \frac{x}{\alpha})$$

Turcotte and Schubert, 1982

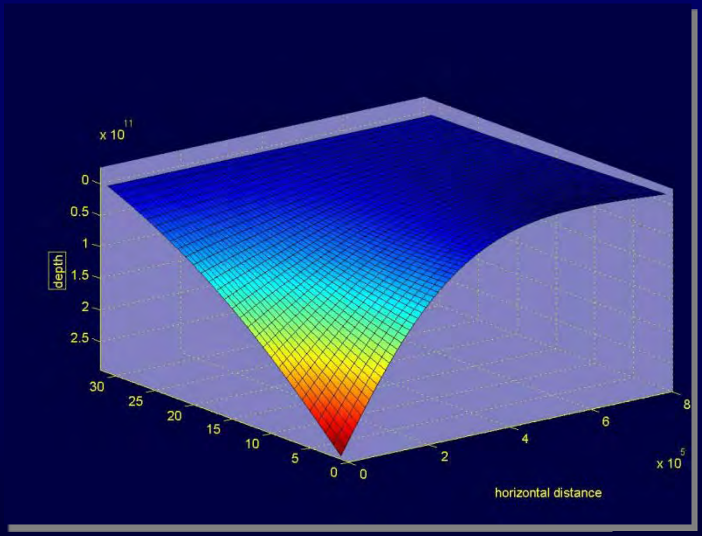
PROBLEMS

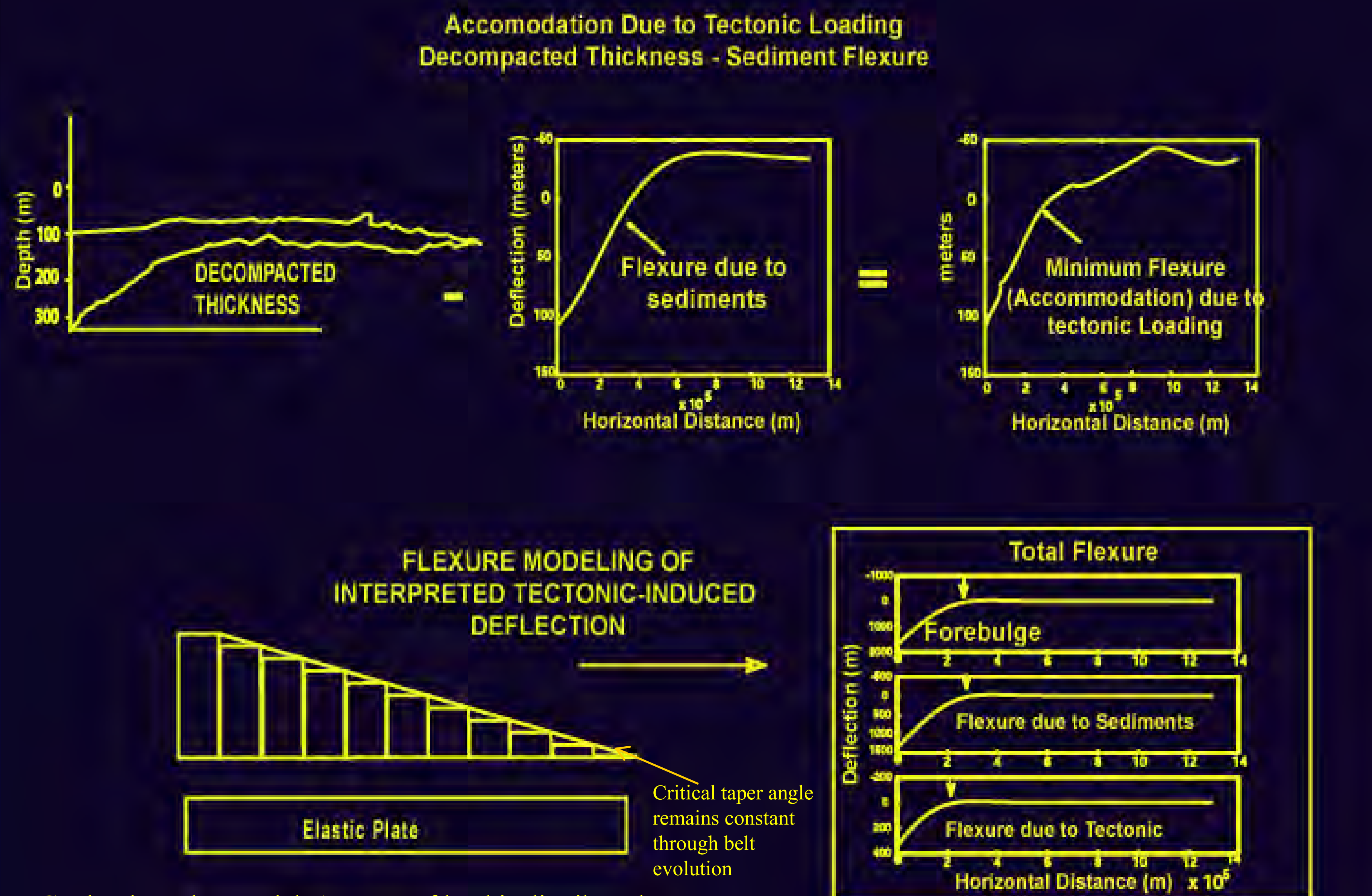
- What is the impact of flexure on the stratigraphic record and accommodation?
- Can seismic data reveal the origin of subsidence: sedimentary Vs. tectonic loads?
- What is the amount of subsidence caused solely by tectonic loading ? Can it be quantified?
- Does the effective elastic thickness of the plate change during basin evolution? If so, why?

FLEXURAL MODELING



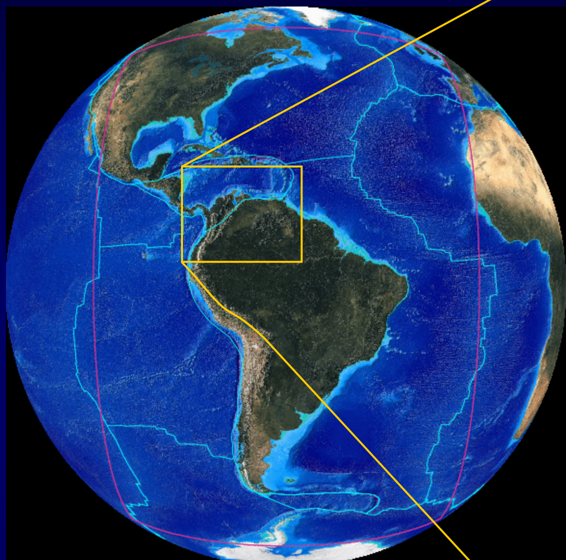
- Seismic interpretation
- Decompaction
- Forward modeling seismostratigraphic data via flexural-analysis (MatLab® routine)





Coulomb wedge model. Amount of load is distributed along the wedge. A minimum wedge-length is obtained for the residual flexure

PUTUMAYO RETROARC FORELAND BASIN (COLOMBIAN ANDES)



- **Passive margin between Precambrian and Permian Time**
- **Continental Foreland basin since latest Cretaceous time**
- **During Tertiary at least four tectonic-pulses have been interpreted and related to regional unconformities**

PUTUMAYO RETROARC FORELAND BASIN (COLOMBIAN ANDES)

Ospino-Caiman

Time gap
> 7 m. y. ⇨

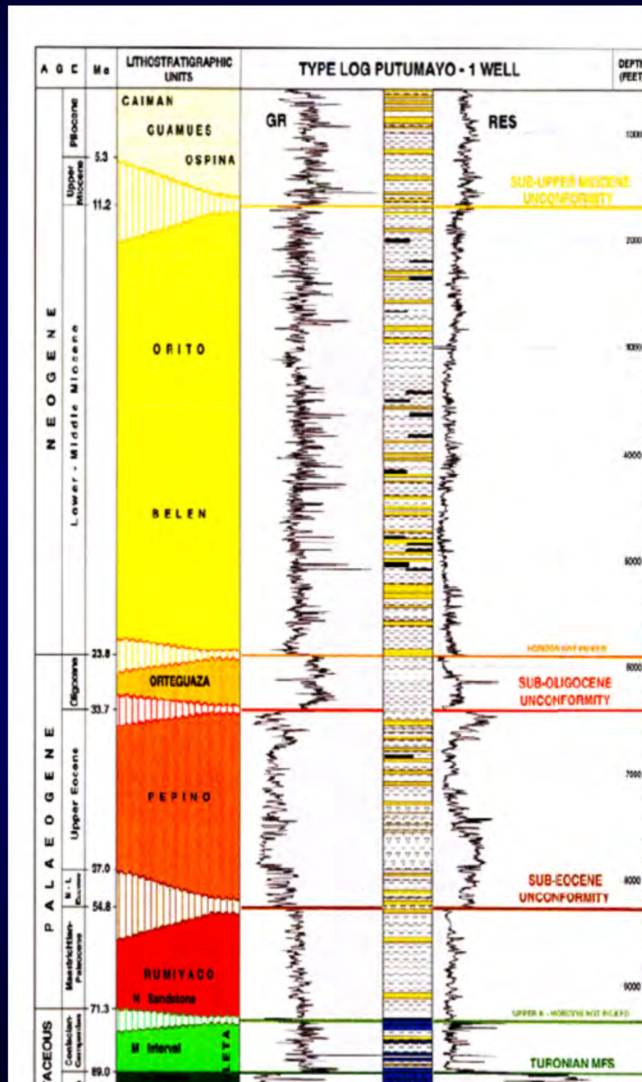
Orteguaza-Belen-Orito

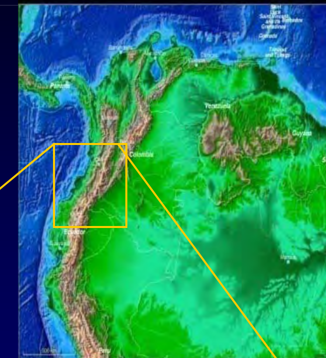
Time gap
> 6 m. y. ⇨

Pepino

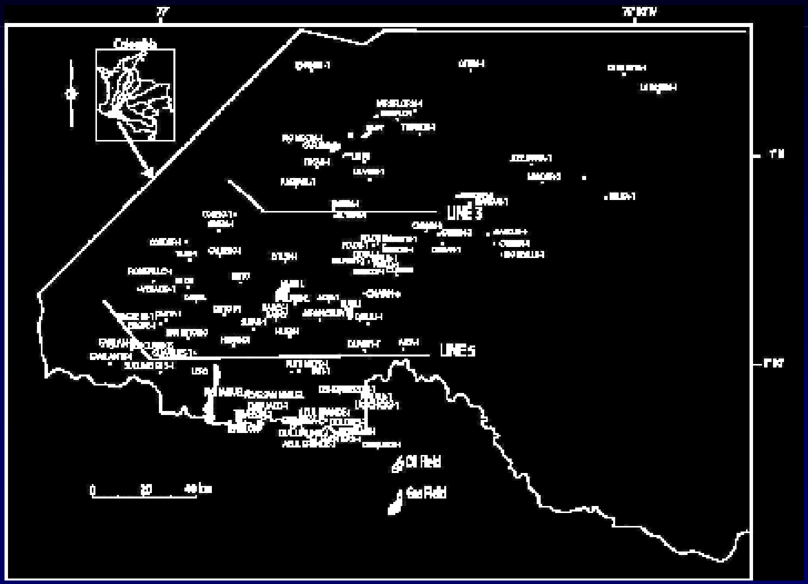
Time gap
> 13 m. y. ⇨

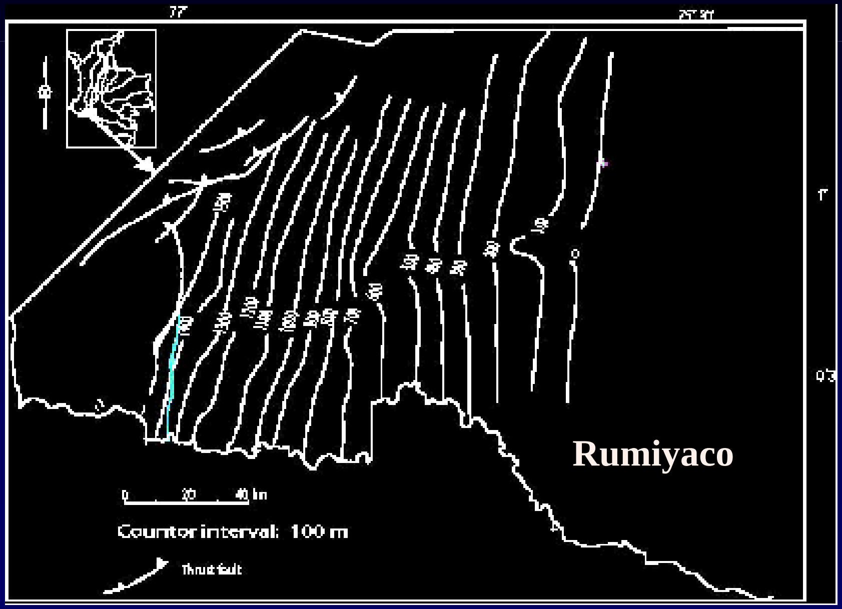
Rumiyaco

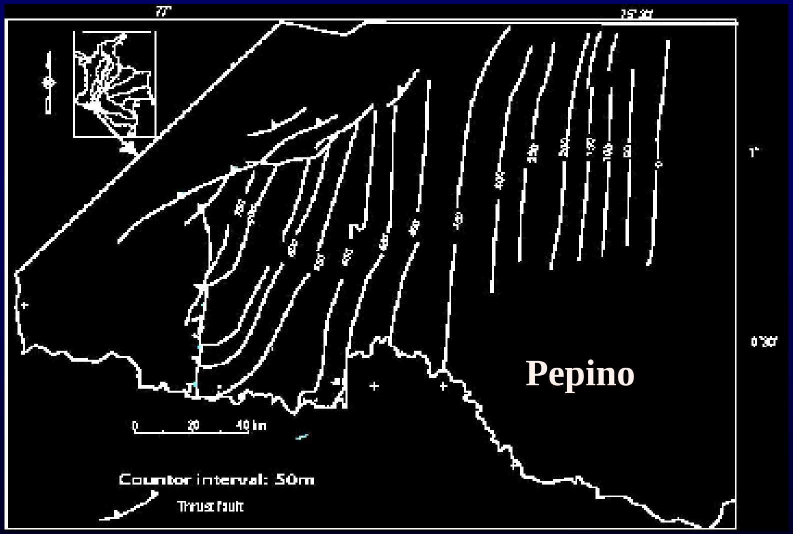


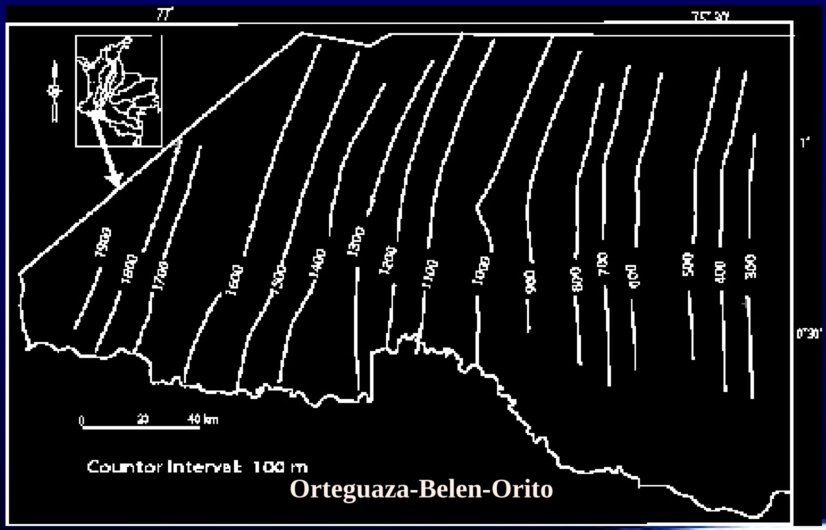


PUTUMAYO WELLS , SEISMIC DATA AND ISOCHORE MAPS (ECOPETROL, 2003)

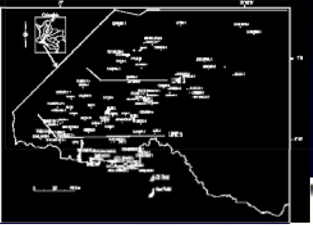


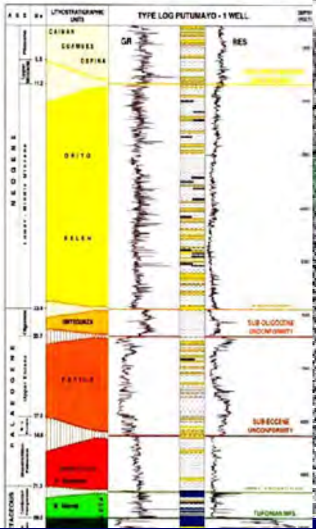


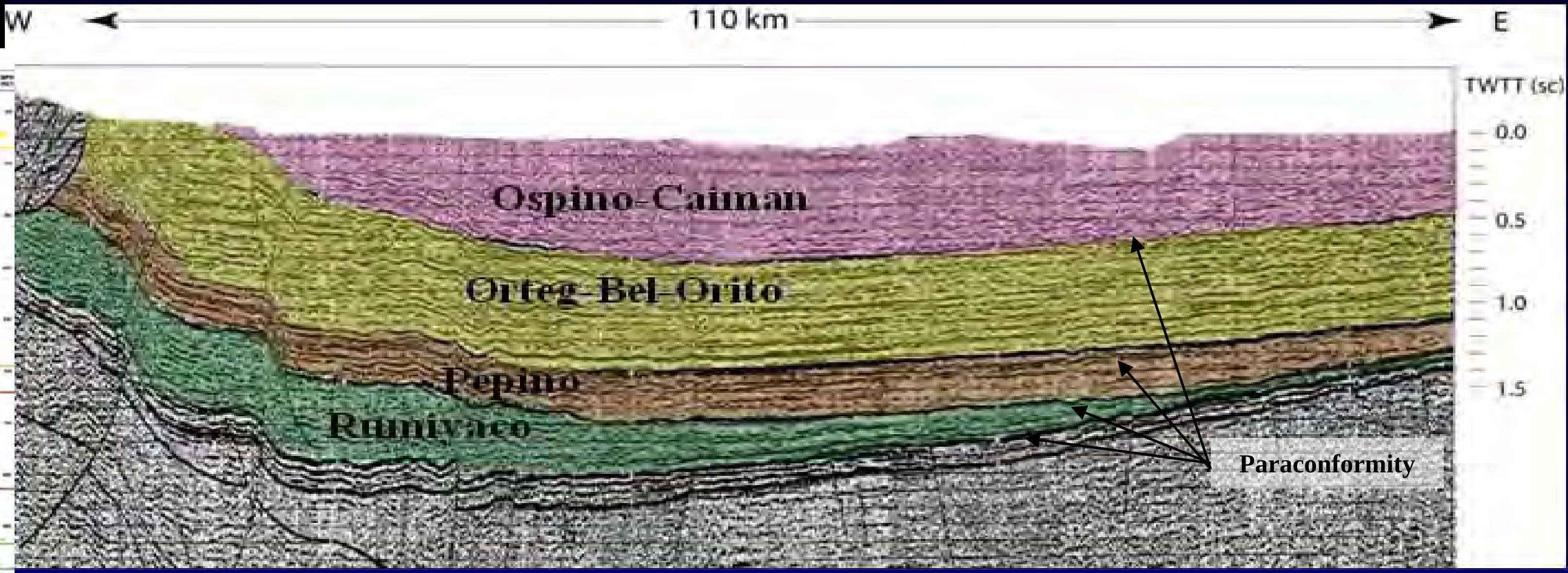


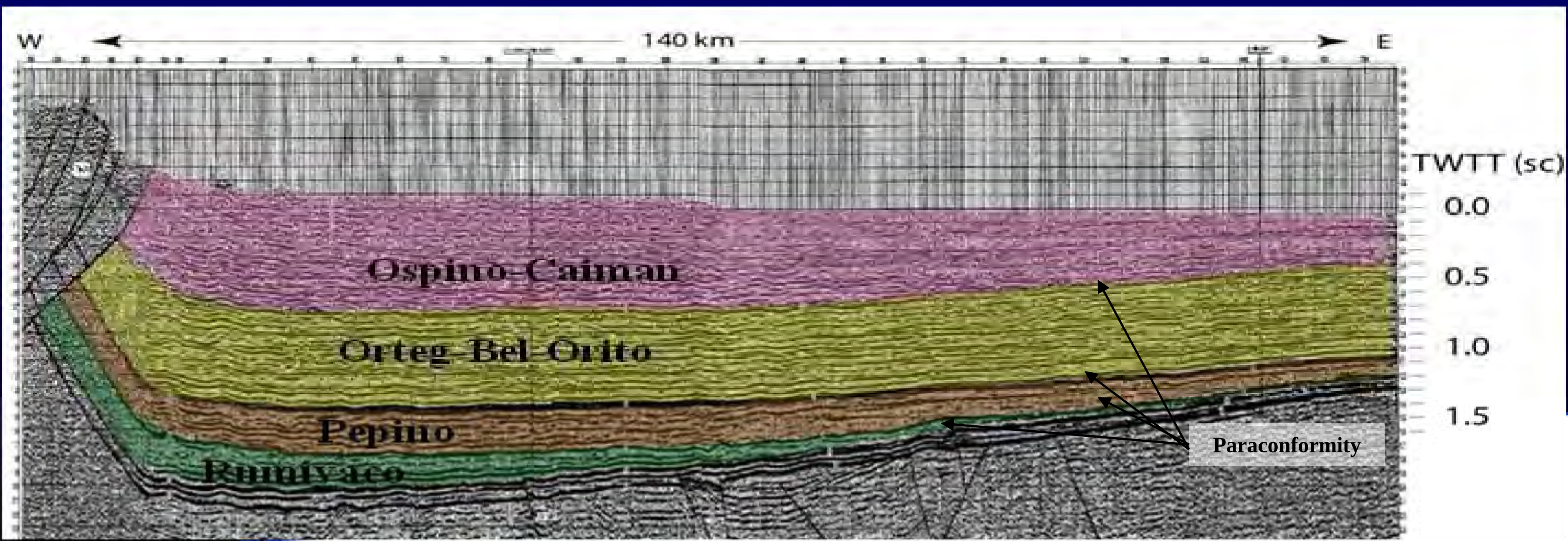


PUTUMAYO 2D SEISMIC DATA (ECOPETROL, 2003)

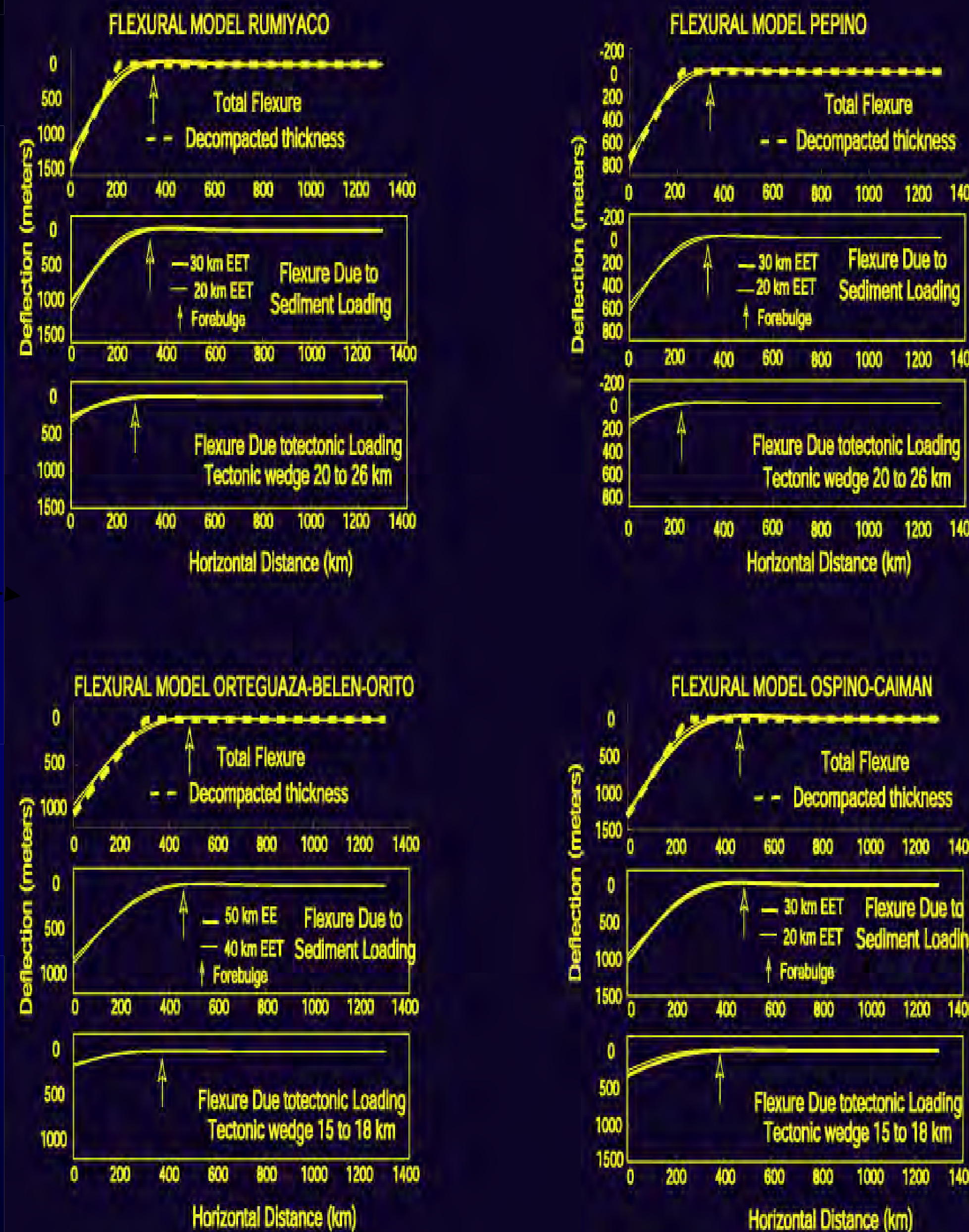




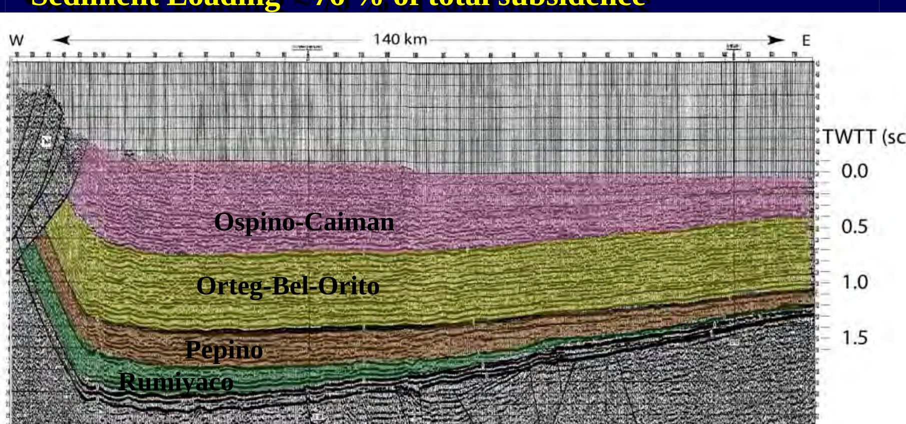




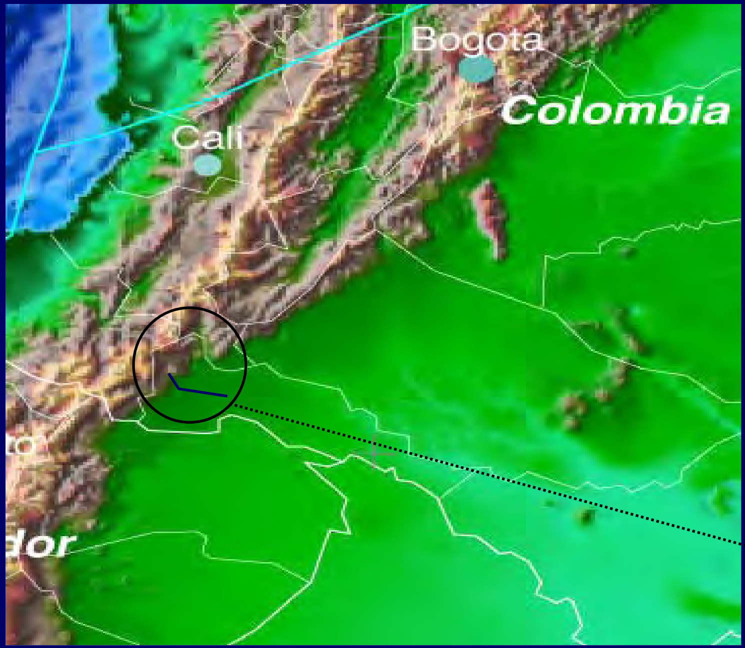
FLEXURAL RESULTS DATA LINE 5



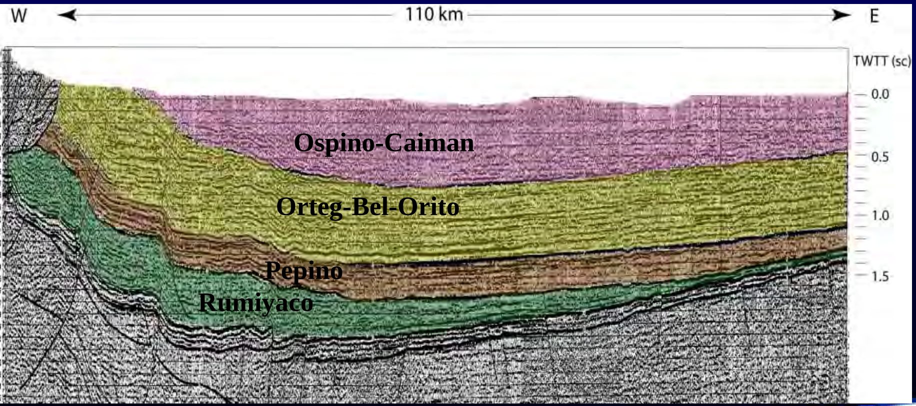
- •Effective elastic thickness is between 30 ± 10 km. It does not change during basin evolution
- •One forebulge for each loading event
- •Sediment Loading ~ 76 % of total subsidence

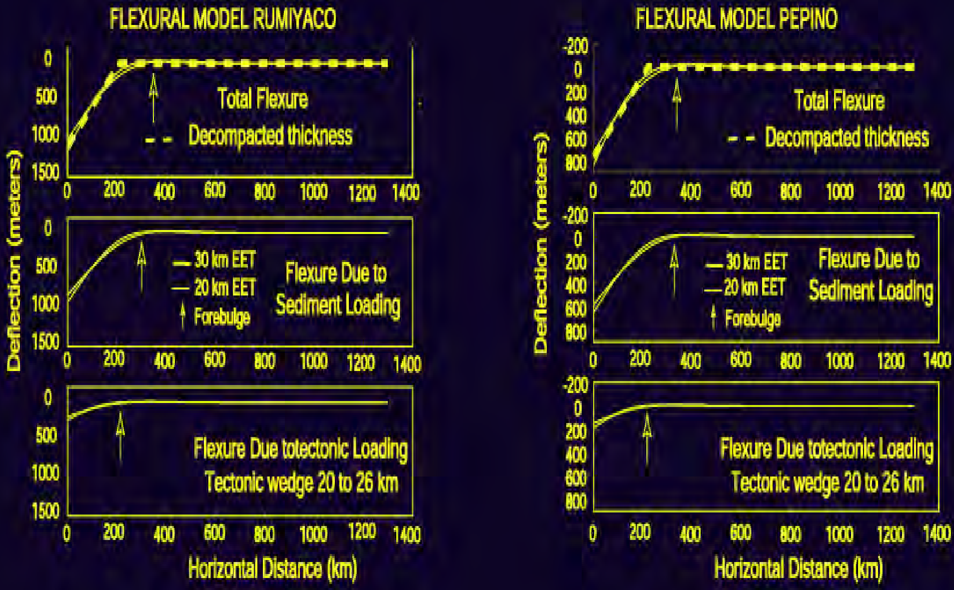


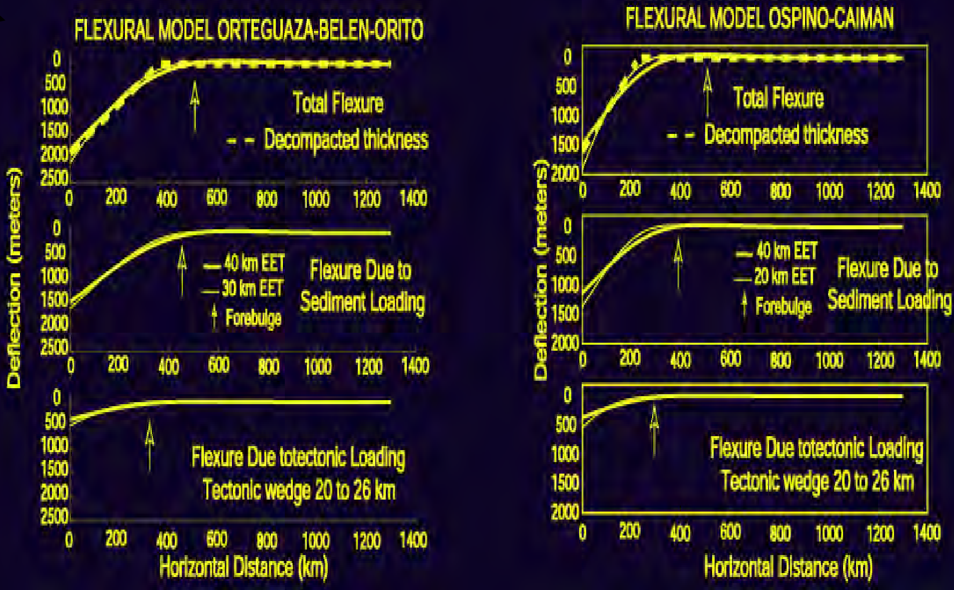
FLEXURAL RESULTS DATA LINE 3



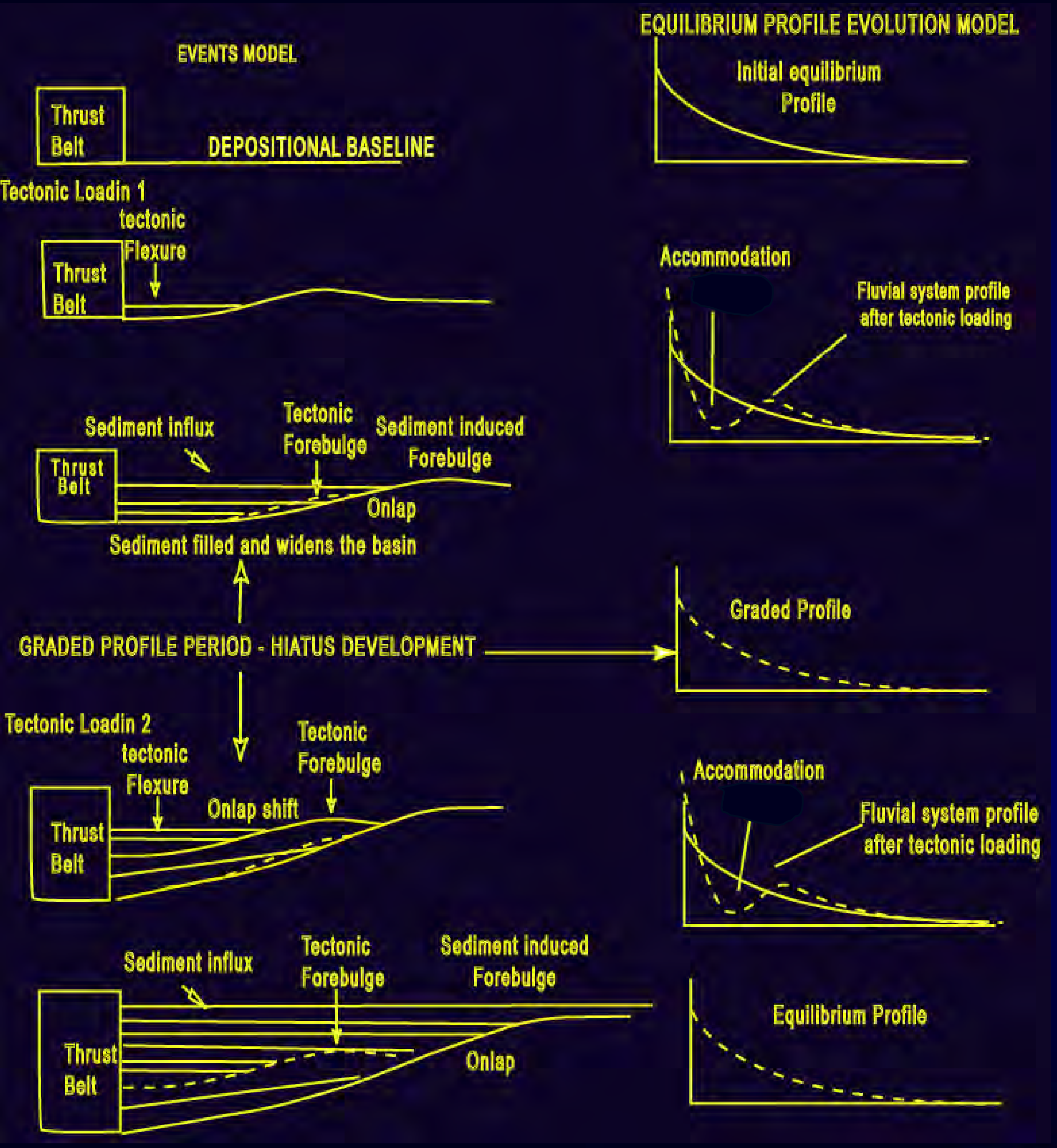
- •Effective tectonic load does not exceeded ~30 km in width or 2.5 km in height
- •Maximum subsidence rate ~ 155 m/my (Late Eocene)







STRATIGRAPHIC SEQUENCE MODEL FOR CONTINENTAL FOREDEEPS



Equilibrium profile: slope that rivers systems tend to adjust to (base level). The slope is the required to transport all the sediment load supplied to the basin. Non erosion or deposition (graded stage)

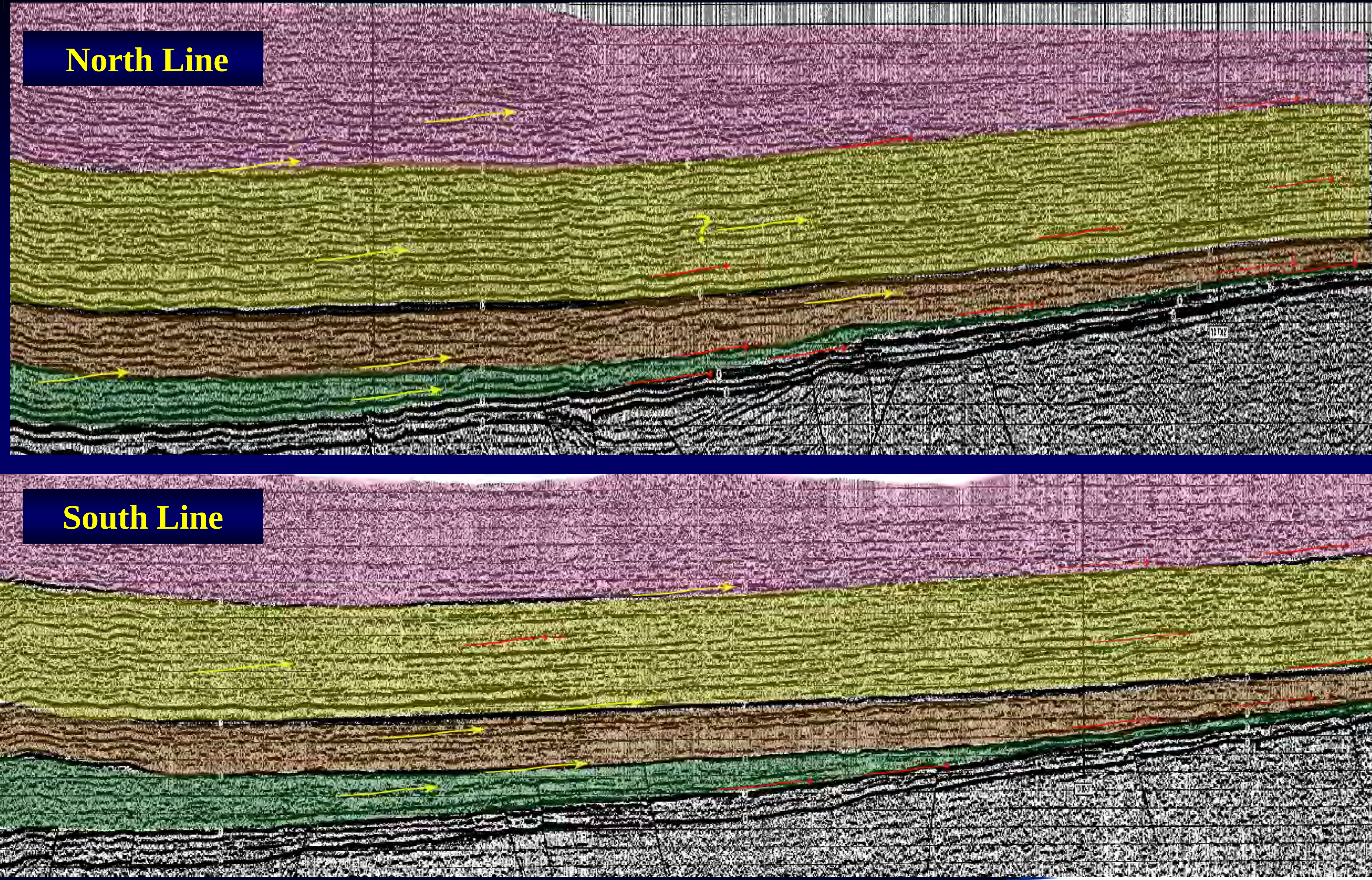
Hiatus: Interruption of the stratigraphic record. Time of non-deposition

Bottom Line:

Fluvial depositional sequences may develop during periods of adjustment of the river system to the graded stage.

Does hiatuses represent periods of graded profiles?

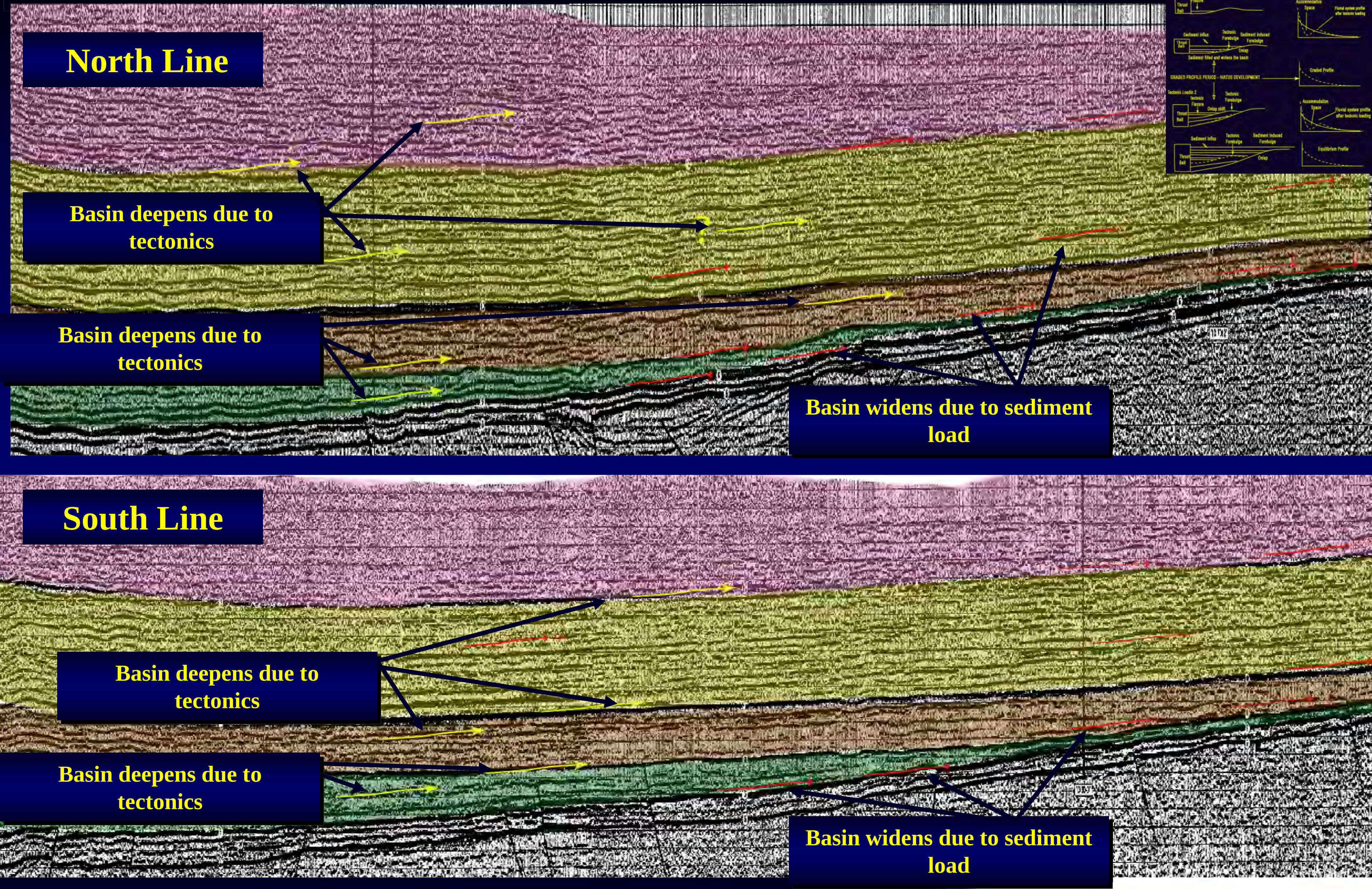
MODEL FOR CONTINENTAL FOREDEEPS



Onlap shift

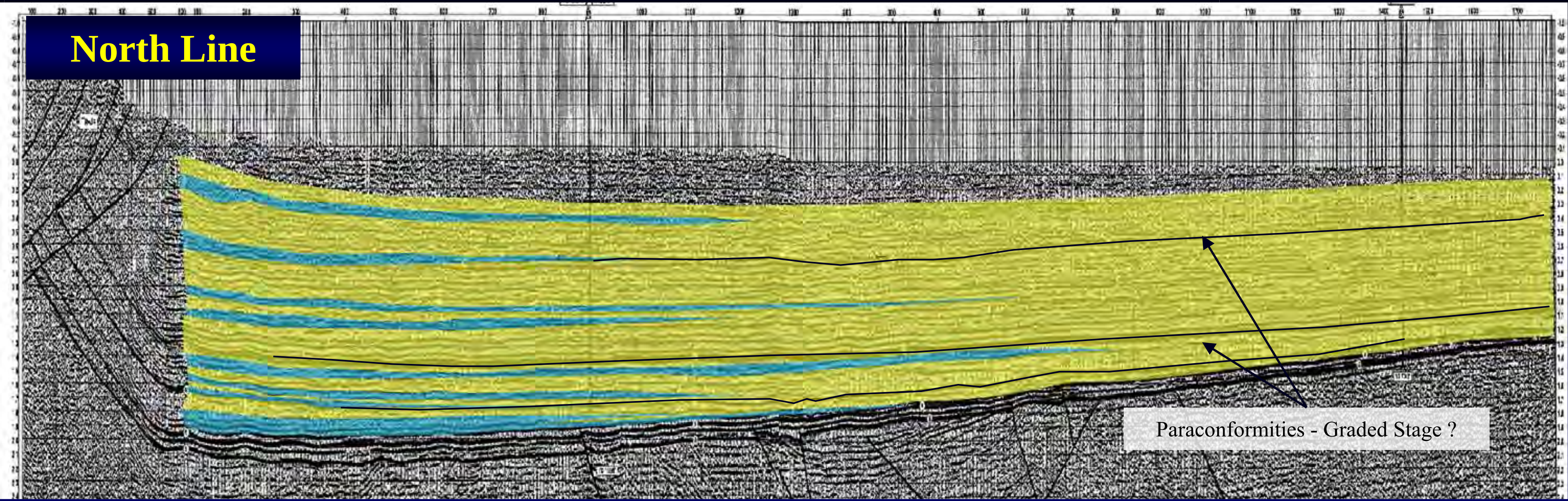
Onlap

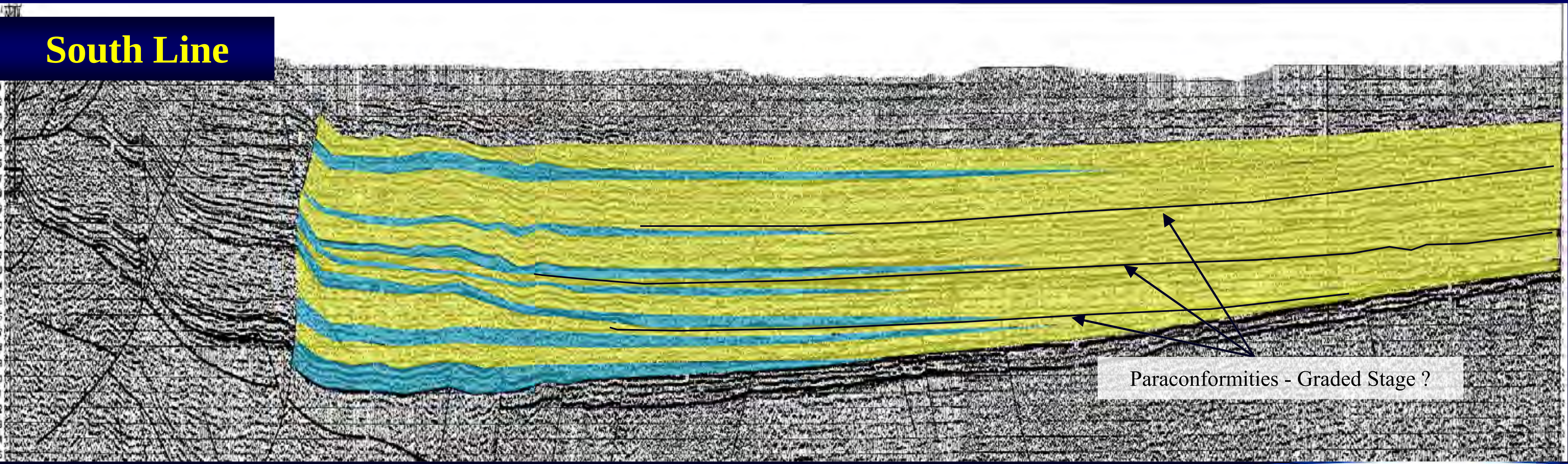
MODEL FOR CONTINENTAL FOREDEEPS



Onlap shift **Onlap**

MODEL FOR CONTINENTAL FOREDEEPS





Sediments Flexure

Tectonic Flexure

CONCLUSIONS

- **Accommodation in the Putumayo basin is controlled by sedimentary loads (76% average) and tectonic loading (24 % Average).**

- **Some seismic facies can be linked to their mechanical origin in forelands: onlap shifts indicates basin deepening due to tectonics, while continuous onlapping means compensation due to sediments.**

- **Continental depositional cycles inforelands tend to respond to the equilibrium-profile of the fluvial systems. Equilibrium profile is controlled by the flexure of the plate. Unconformities/hiatuses in Putumayo may represent tectonic quiescence: periods where fluvial system were near or at graded stage (equilibrium)**

- **Forebulges location and geometry change according to nature of loads. One forebulge exists for each loading event (relevant for heavy oil play concepts).**

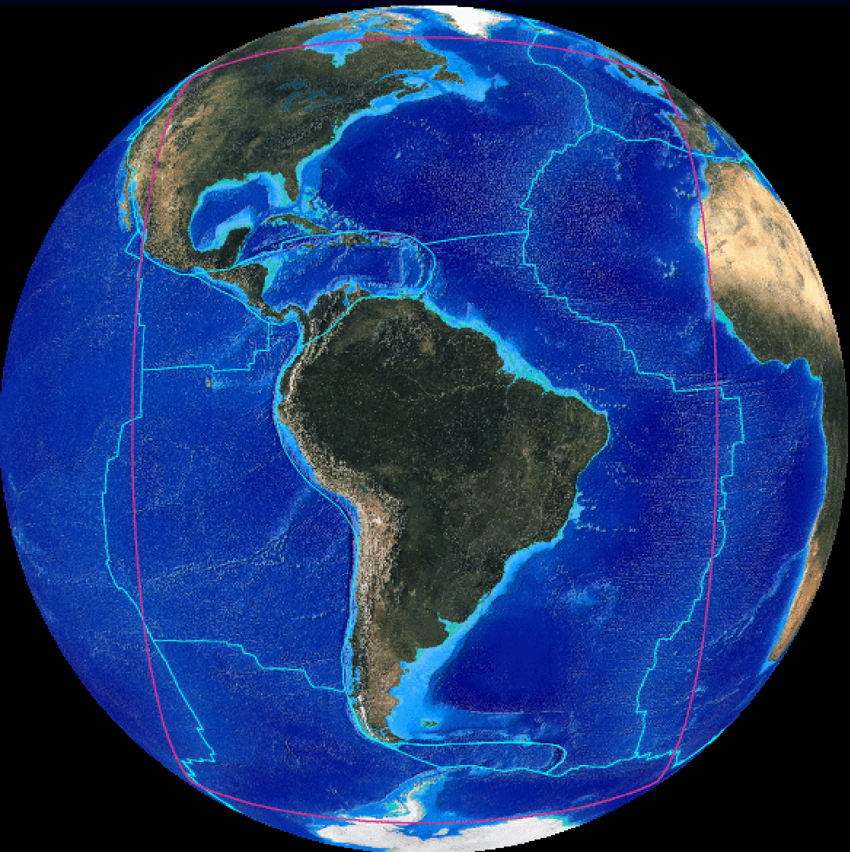
CONCLUSIONS

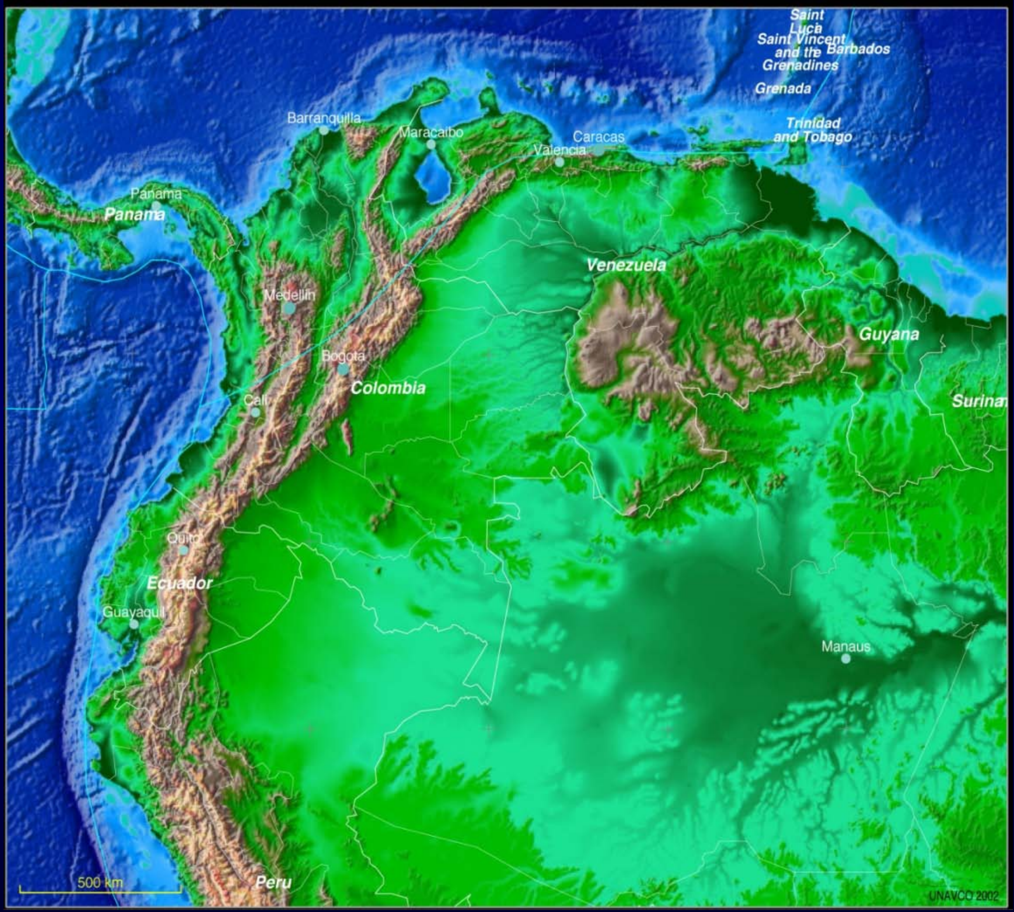
- At least 7 tectonic events are identified (in stead of the conventional 4) using seismic facies (regional onlap shifts). In Putumayo it is difficult to correlate the basin-wide unconformities to tectonism

- The effective tectonic load   (thrust belt) do not exceeds ~30 km in length during one loading cycle. This geometry and the wavelength of the first order flexural deflection (not exceeding ~400 km), preclude the need to invoke dynamic topography as a downward force acting in the Putumayo basin.

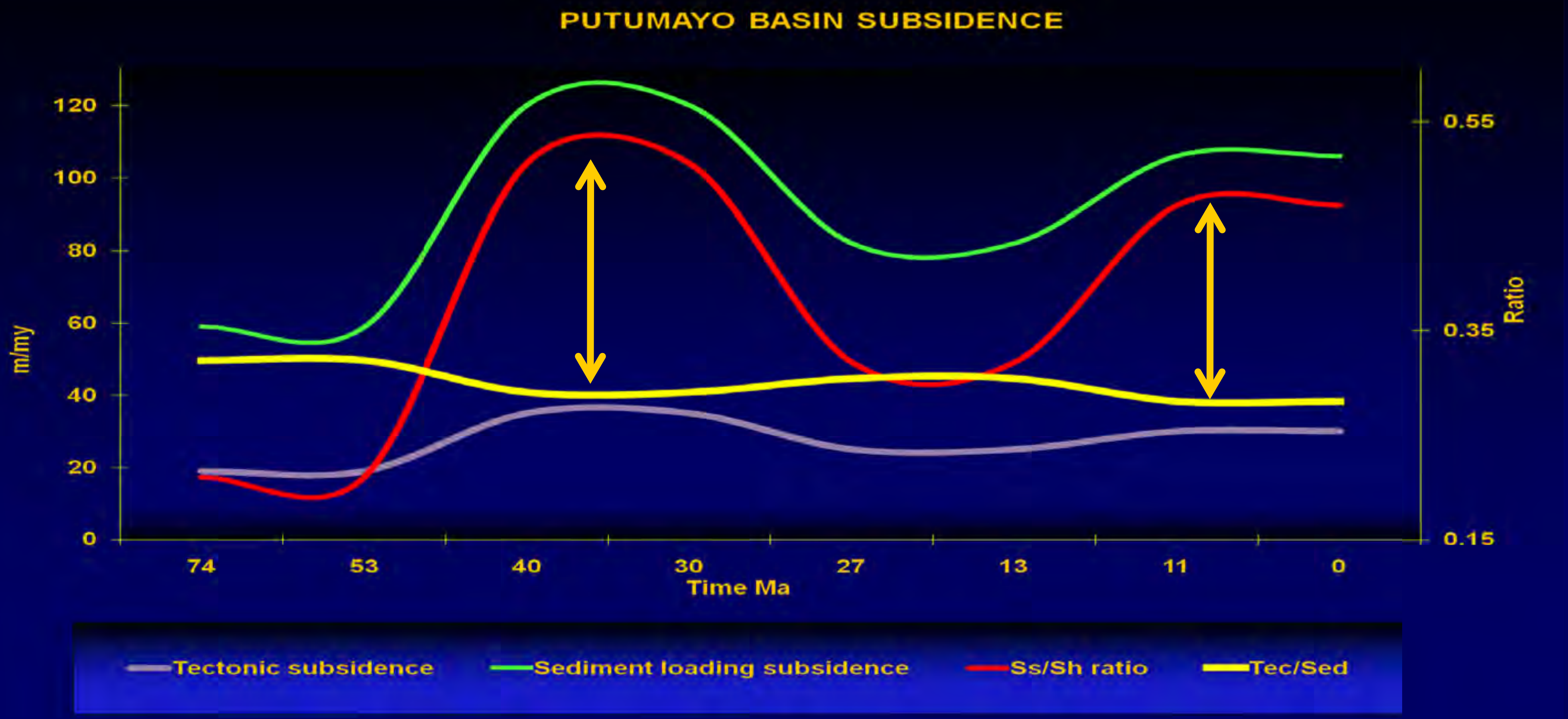
- Effective elastic thickness in the Putumayo basin is ~ 30 km, it did not change during basin evolution

QUESTIONS





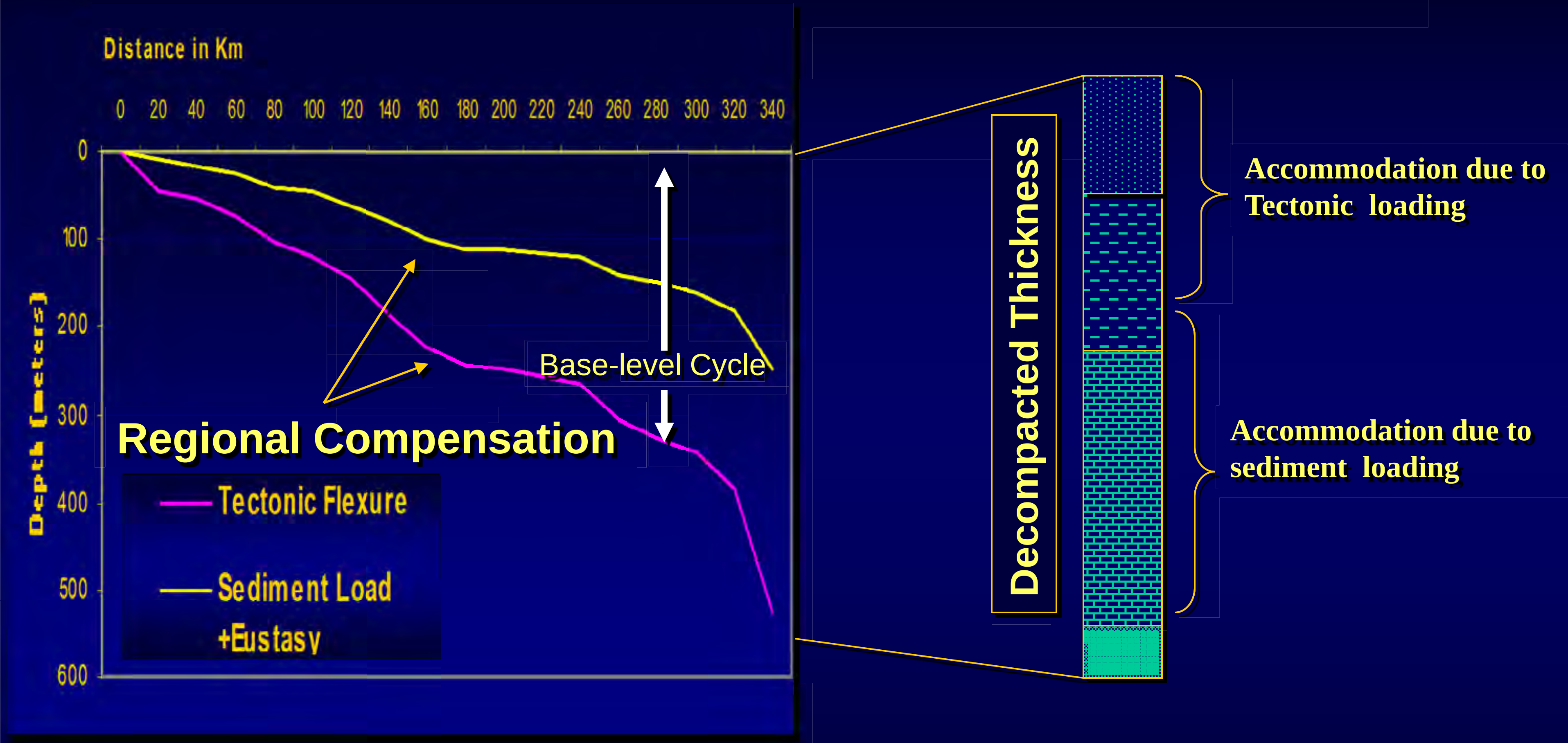
Saint Vincent and the Grenadines
Barbados
Grenada
Trinidad and Tobago
Barranquilla
Maracaibo
Caracas
Valencia
Panama
Panama
Venezuela
Medellin
Bogota
Colombia
Guyana
Cali
Quito
Ecuador
Guayaquil
Manaus
Peru
500 km
UNAVCO 2002



- Ss:Sh ratio is higher when ratio of Tectonic to Sediment loading is lower

- Tectonic activity does not correlates with coarse-grained sediments.

ACCOMMODATION



Δ Accommodation = Δbase level + Δ subsidence + Δcompaction