Resolving the Structural Complexities in the Deepwater Niger-Delta Fold and Thrust Belt: A Case Study from the Western Lobe, Nigerian Offshore Depobelt*

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Abstract

The deep-water Western Niger-Delta region in a little more than a decade has been a beehive of exploration, development and production activities and represents a major oil and gas province. The region holds several giant oil accumulations and large gas fields with a lot of unexplored opportunities trapped in a variety of structural styles spanning through the continental shelf to the continental slope within the Nigerian Offshore depobelt. The diverse and complex structural styles entrenched within the region presented challenges to Geoscientist and Explorationist alike and required the application of specialized interpretation techniques in defining the prevailing structural styles.

Detailed structural interpretation, section reconstruction, seismic stratigraphy and facies analyses, afforded by high quality seismic data, integrated with field analogues from within the deepwater Niger-Delta and other published examples around the world were key to defining the prevailing structural styles within the region. Mapping the internal reflectivity and architecture of the identified structures including the toe thrust anticlines, listric and transcurrent faults, shale diapirs and mud volcano gave good insight into the prevalent structural element in the subsurface.

Initial structural models showed that the delta has been influenced by tertiary gravitational tectonics and has identified several fracture zones. We expand upon these theories and identified the presence of an additional fracture zone up-dip within the extreme deepwater Western Niger-Delta, named the Benin fracture zone for the purpose of this study. The large amount of lateral movement along this fracture zone transposes two distinct structural regimes to the east and west of the wrench fault, resulting in diverse structural styles in the deepwater Nigerian Offshore.

We considered evidence from deepwater discoveries, Offshore Nigeria and resolved that in terms of trap and retention capacity, structures south of the wrench fault are highly favourable, while acreages located to the north of the major transcurrent fault does not conform to the conventional Nigerian deepwater play. We also attempt to review the overall structural styles within the region to ensure that successes made in the past can be repeated and also make significant advances to ensure future exploration success.

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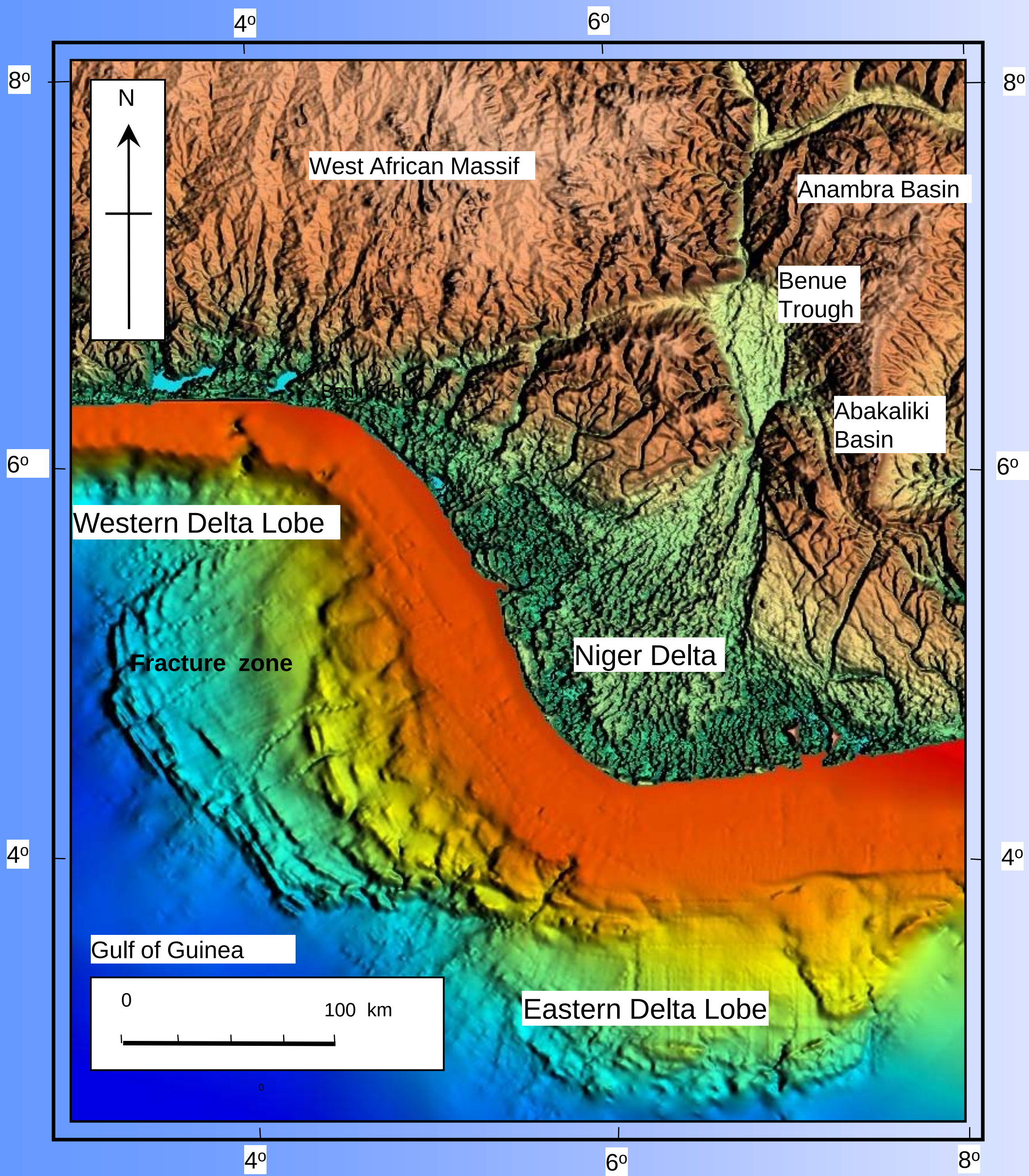
Methodology

- Review the structural styles within the deepwater Western Niger Delta.
- Use available Geologic and Geophysical dataset from the study area and published literatures to determine the prevailing structural regime within the deepwater Western Niger Delta.
- Assess the implication of the structural styles on the trapping mechanism and prospectivity of the study area.

Study Location Map, Deepwater Niger Delta



Entrenched within the Gulf of Guinea

Divided into lobes by the Charcot fracture zone

Characterized by numerous fracture zones

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Stratigraphy

- The offshore Niger Delta comprises Cretaceous through to recent marine clastic deposits overlying a continent-ocean transition.
- The main stratigraphic units are the “Akata” and “Agbada” Formations
  - The Akata shale is considered to be the main detachment horizon for the compressional toe structures
- Turbidite sand reservoirs deposited as
  - Slope channel complexes
  - Lowstand fans in ponded basin
- Seismic Interpretation
  - A number of key regional seismic horizons have been interpreted across the western delta lobe.
  - Youngest mapped, the Pliocene H1
  - Oldest Mapped, the Cretaceous? H7
  - Horizons dated using available well biostratigraphy and regional correlation.

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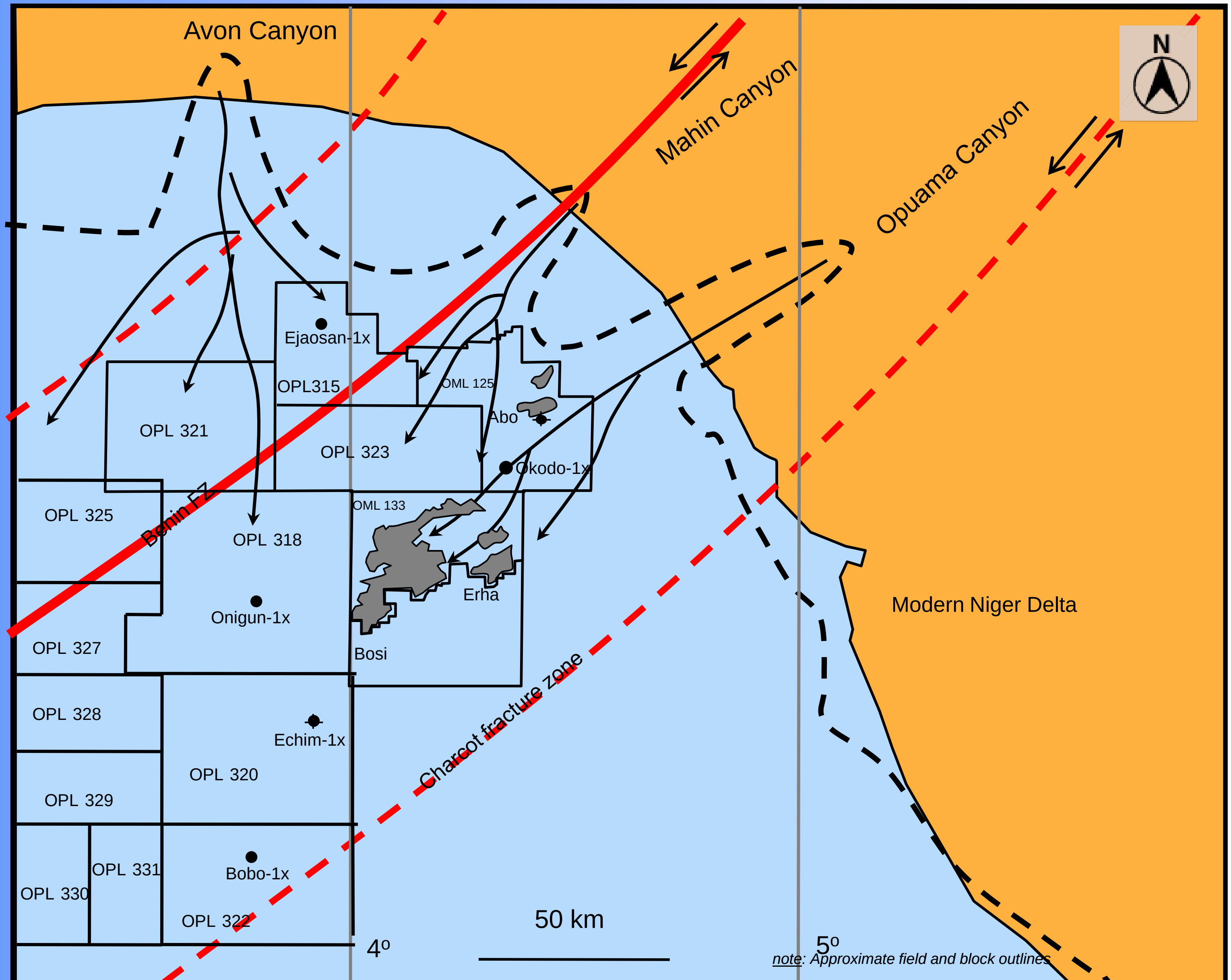

Canyon System Incising the Continental Shelf, Western Niger Delta

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Structural Styles of the Deepwater Niger Delta

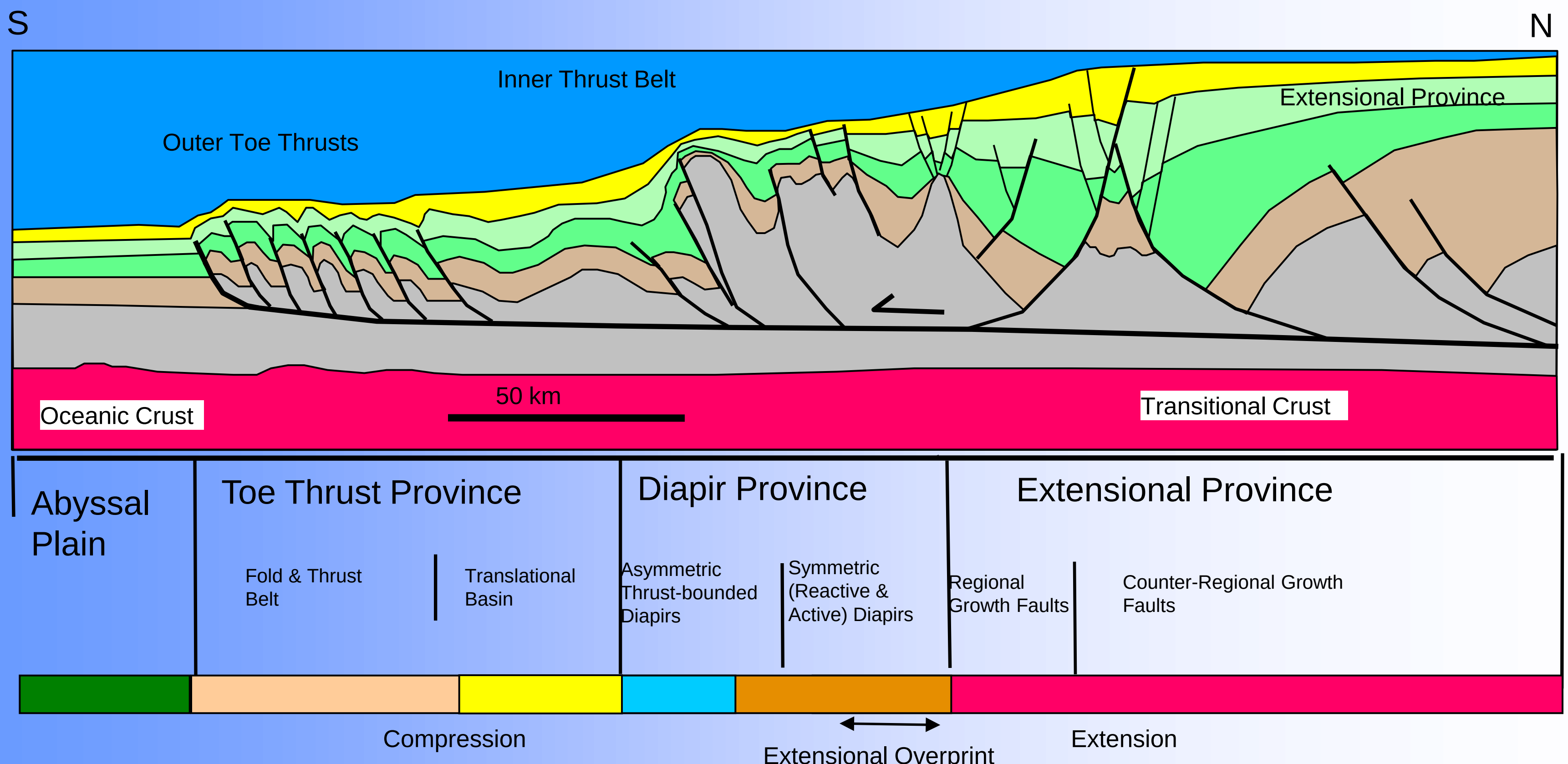

Fig. adopted from Corredor et al., 2005

- Extensional and compressional belts have been pushed down-slope on a deep-seated over-pressured shale detachment zone
- Structures are organised into a series of belts (Structural provinces), each characterised by a specific structural style.

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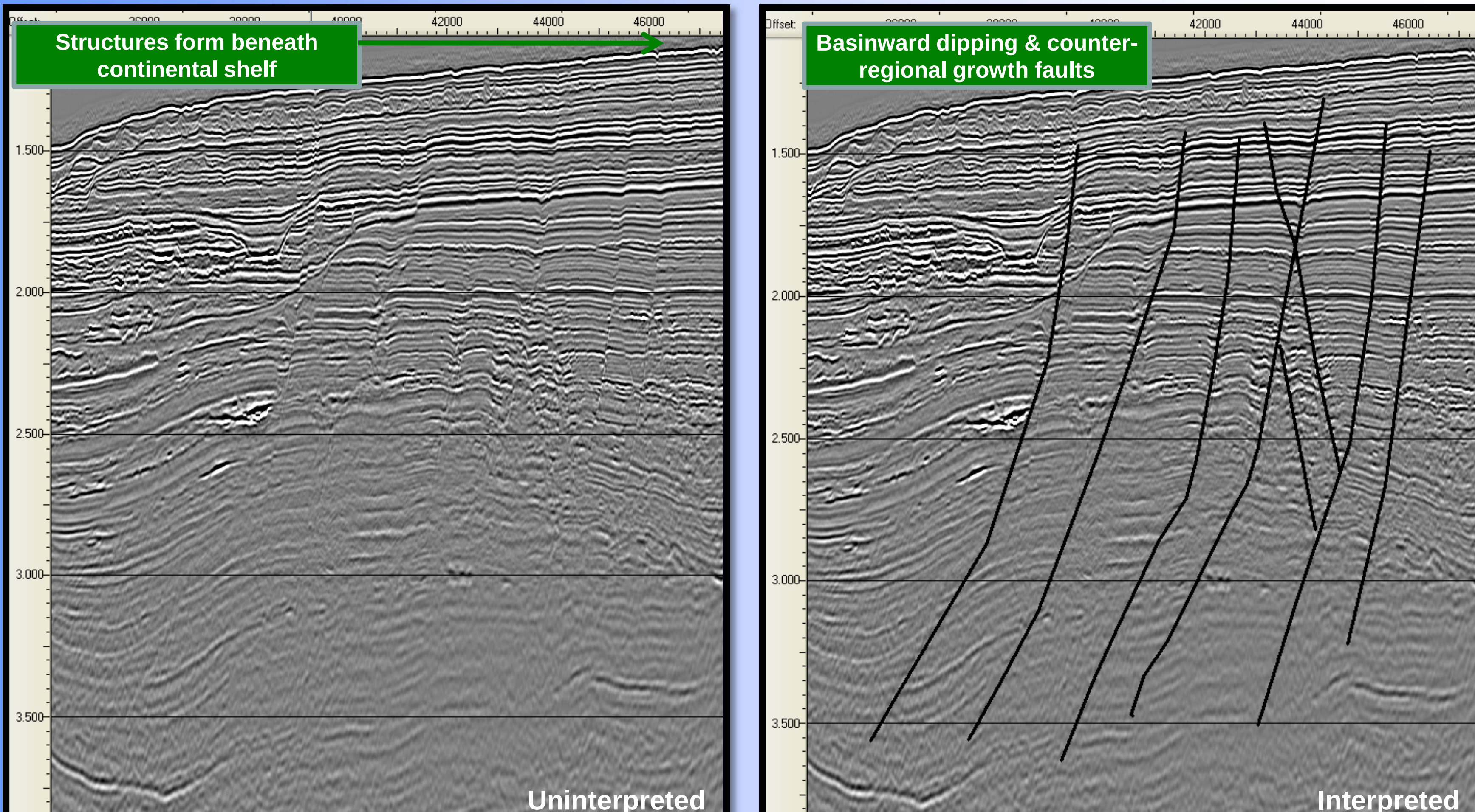
Extensional Province

- Located beneath the continental shelf.
- Characterized by
  - Down to basin normal faults
  - Counter-regional growth normal faults
  - Associated rollovers observed
  - Localized depocenters
  - Linked to the other zones through a major detachment surface

Extensional Structural Style



Uninterpreted and interpreted 3-D PSTM seismic line across Extensional Province, Deepwater Western Niger Delta

Shale Diapir Province

- Located beneath the upper continental slope
- Characterized by passive, active & reactive mud diapirs

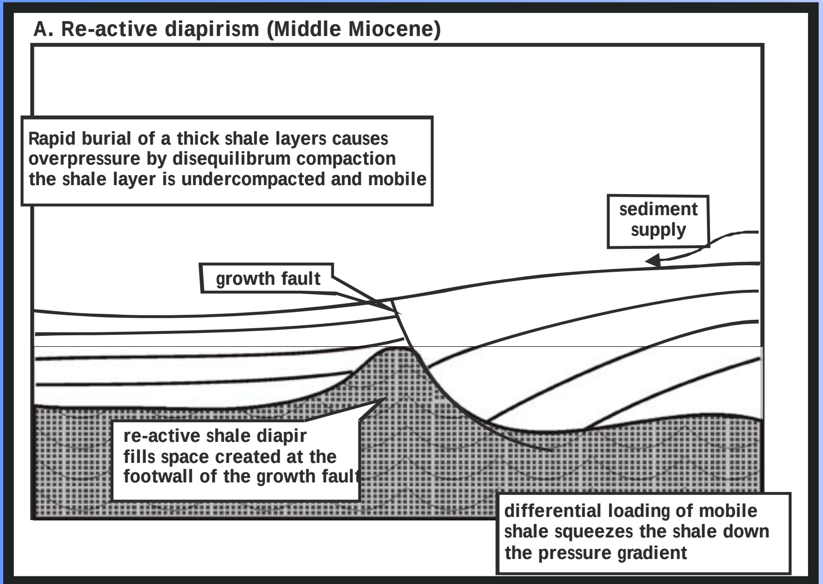
  -Shale ridges

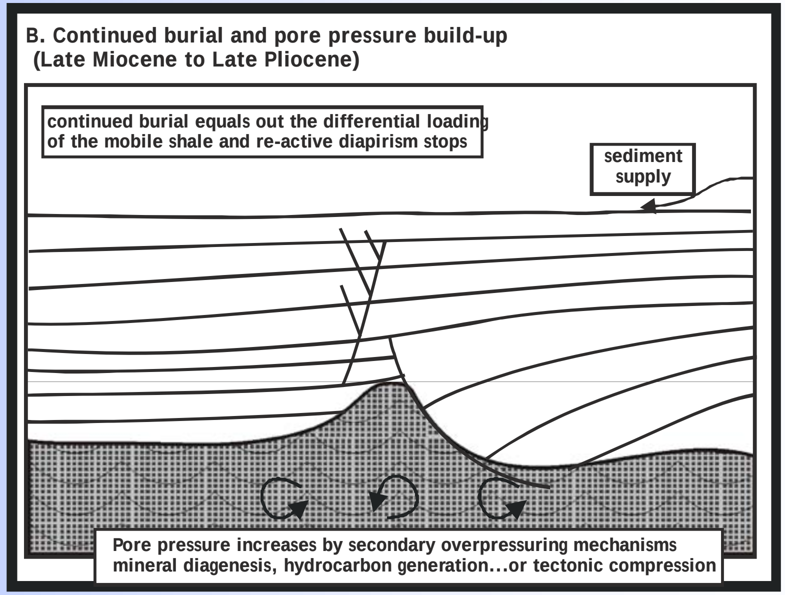
  -Shale overhangs

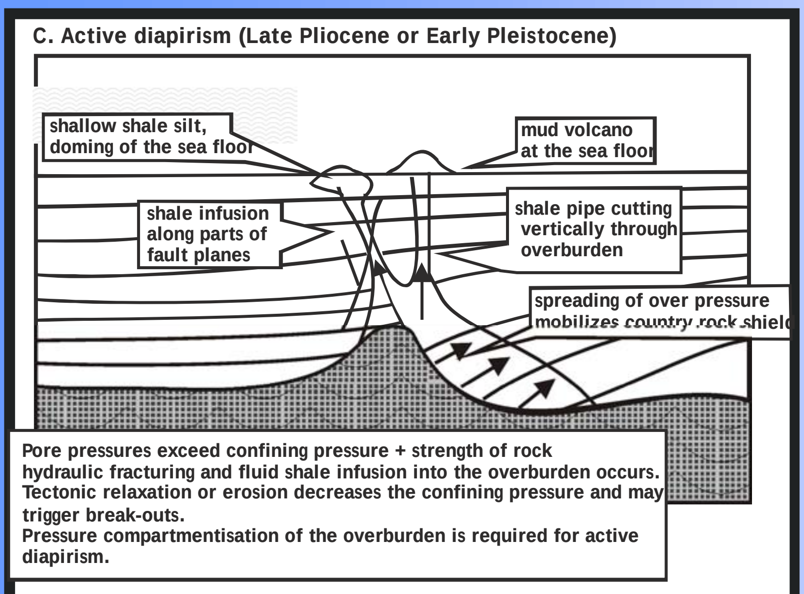
  -Vertical mud diapirs that form mud volcano at the seafloor (Graue, 2000).

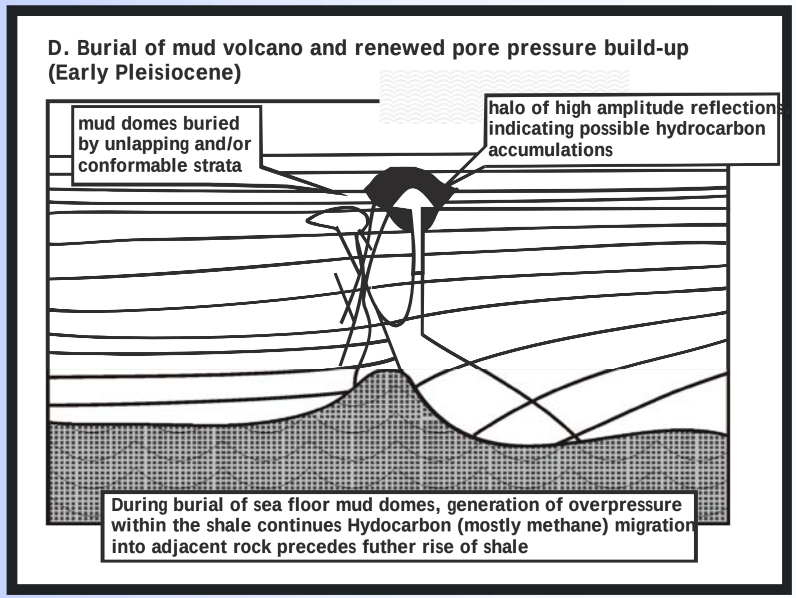
  - Interdiapir depocenters

Shale Diapir Formation



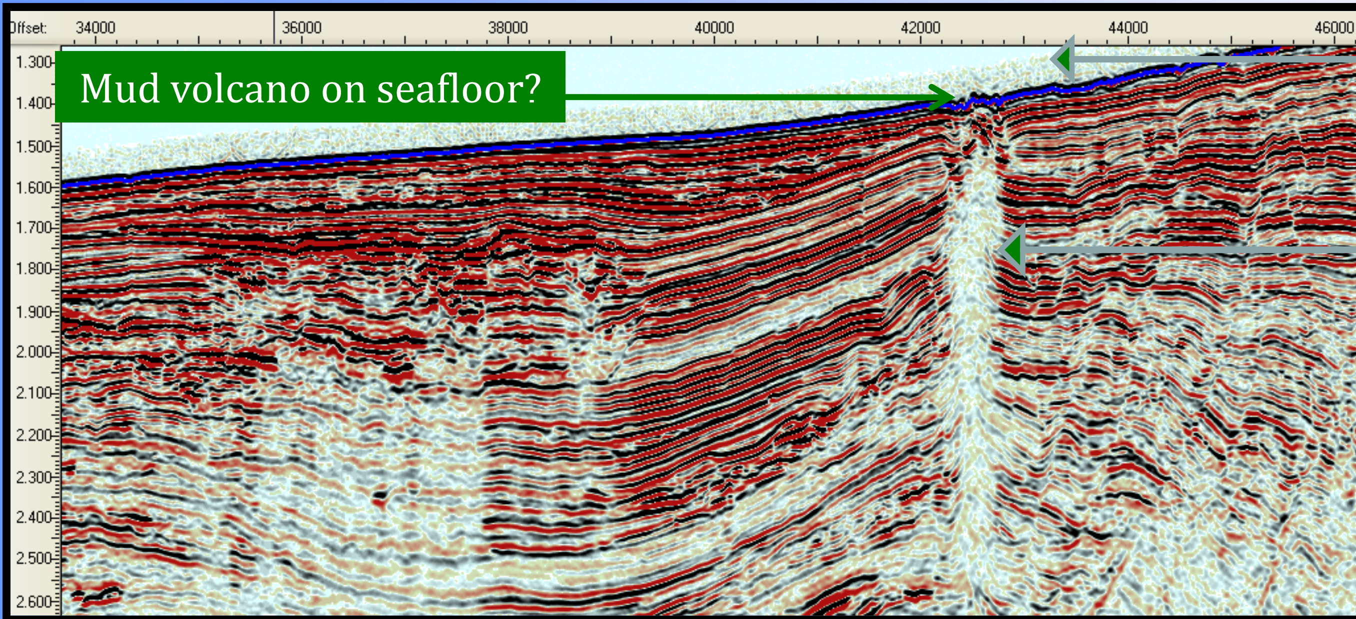






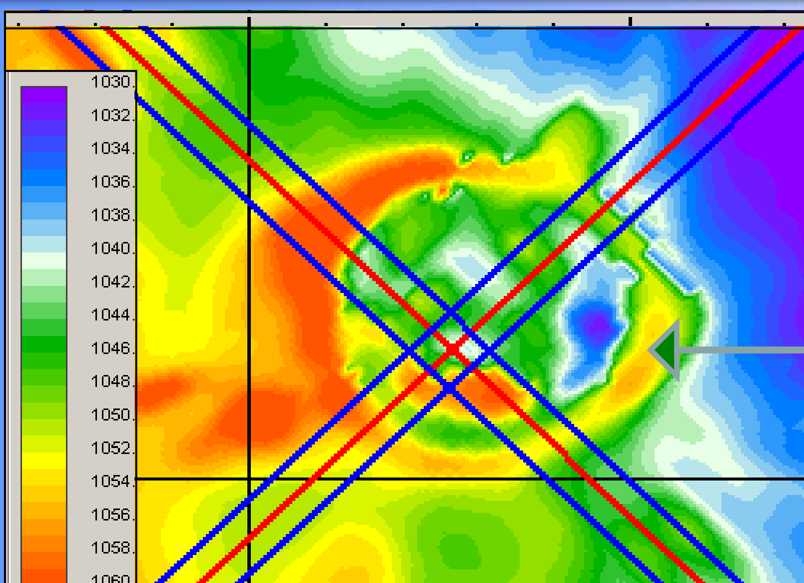
Structural evolution of shale diapirs from reactive rise to mud volcanism: Modified after Van Rensbergen et al.

Shale Diapir Structural Style (Active Diapirism)



Upper Continental Slope.

Vertical shale Diapir?



Mud volcano on seafloor?

3D Seismic line and map view from Deepwater Western Niger Delta

Inner Fold and Thrust Belt

- Located within the lower continental slope

- Characterized by

  - Basinward verging thrust faults with prominent fault plane reflections

  - Tertiary to Holocene deep marine sediments

  - Folds that develop very rounded forms and faults that show only minor bending after ramping up from the detachment

  - Buried thrusts with cessation of movement

  - A weak expression of the underlying fold at the seabed (no recent activity).

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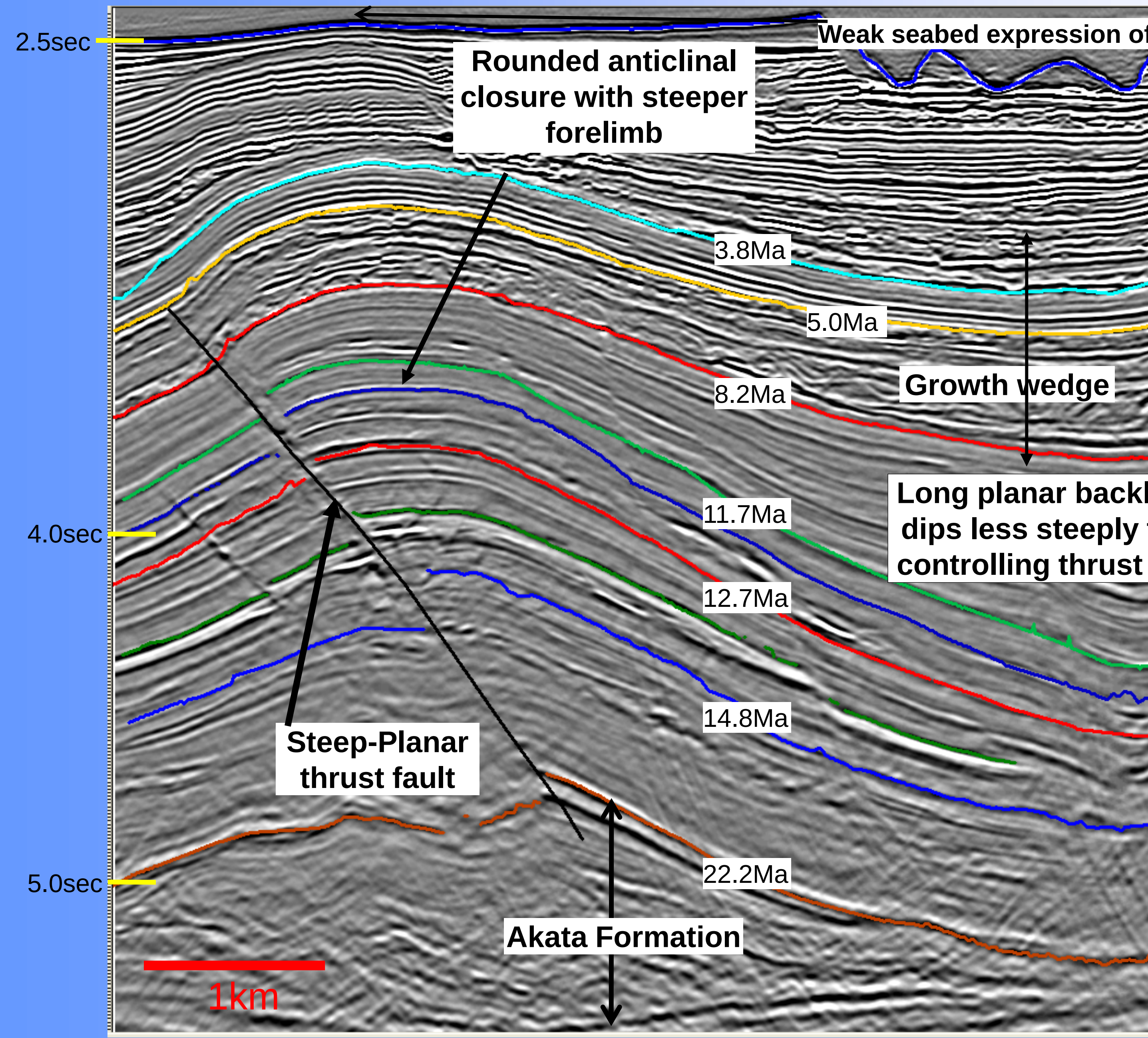
Inner Fold and Thrust Belt Structural Style

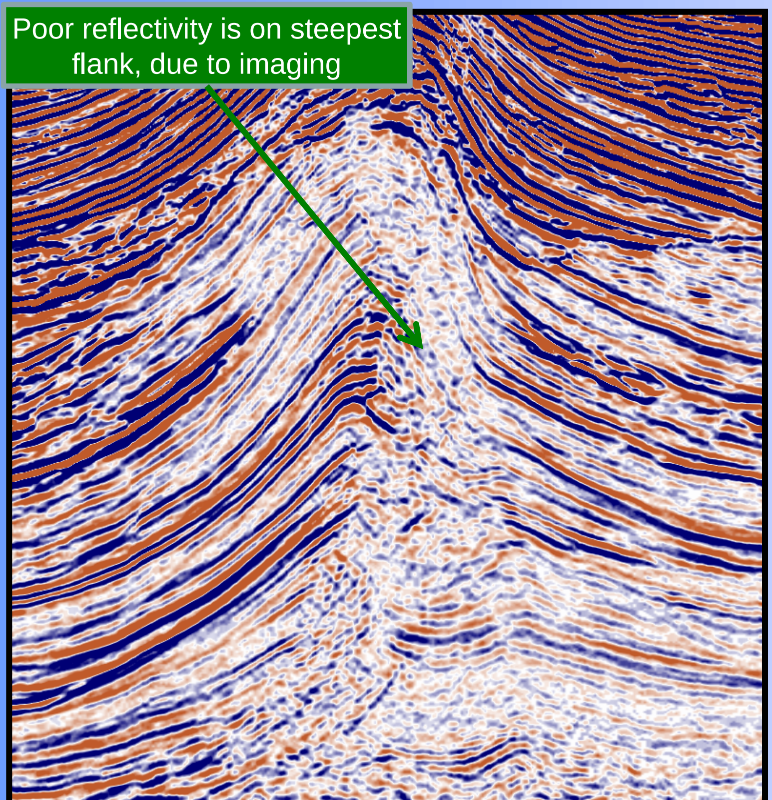


3-D Seismic line from deep-water Western Niger Delta

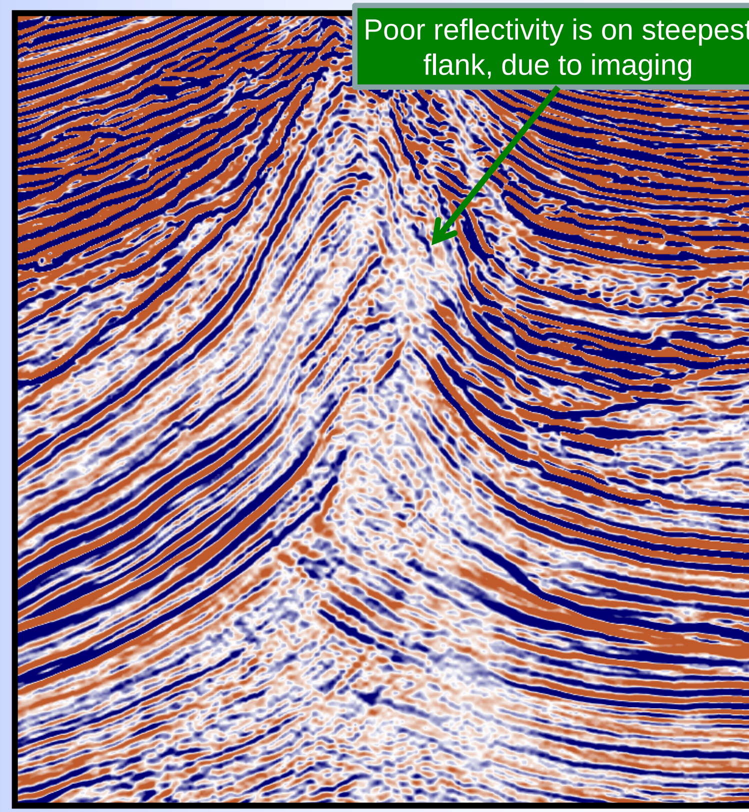
Outer Fold and Thrust Belt

- Located beneath the lower continental slope
- Characterized by
  - Basiward verging and imbricated thrust faults.
  - Long planar backlimbs that dip less than the fault ramp.
  - Short forelimbs compared to backlimbs
  - Detachment folds
  - Sole to detachment surface within the Akata formation
  - Syntectonic strata onlaping the fold limbs where growth sedimentation rates are low relative to uplift rates
  - Fold crests which may become emergent while the structure is active.
  - Multiple sediment wedges suggesting intermittent fault activity.

Internal Reflectivity of Some Outer Thrust Folds



“B” - Structure



“G” - Structure

- Note the fair internal geometry and continuity of reflectors. Reflectors dim at steepest points of the features only
- Reflectivity dimming across the structures is interpreted as poor seismic imaging due to the angle of bedding, and not to shale diapirism

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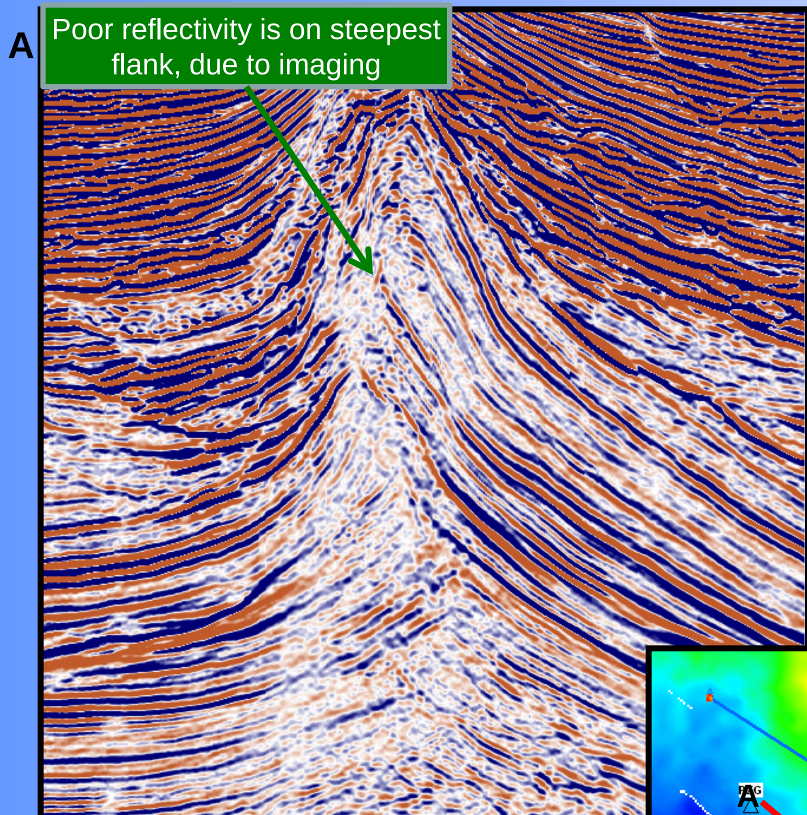
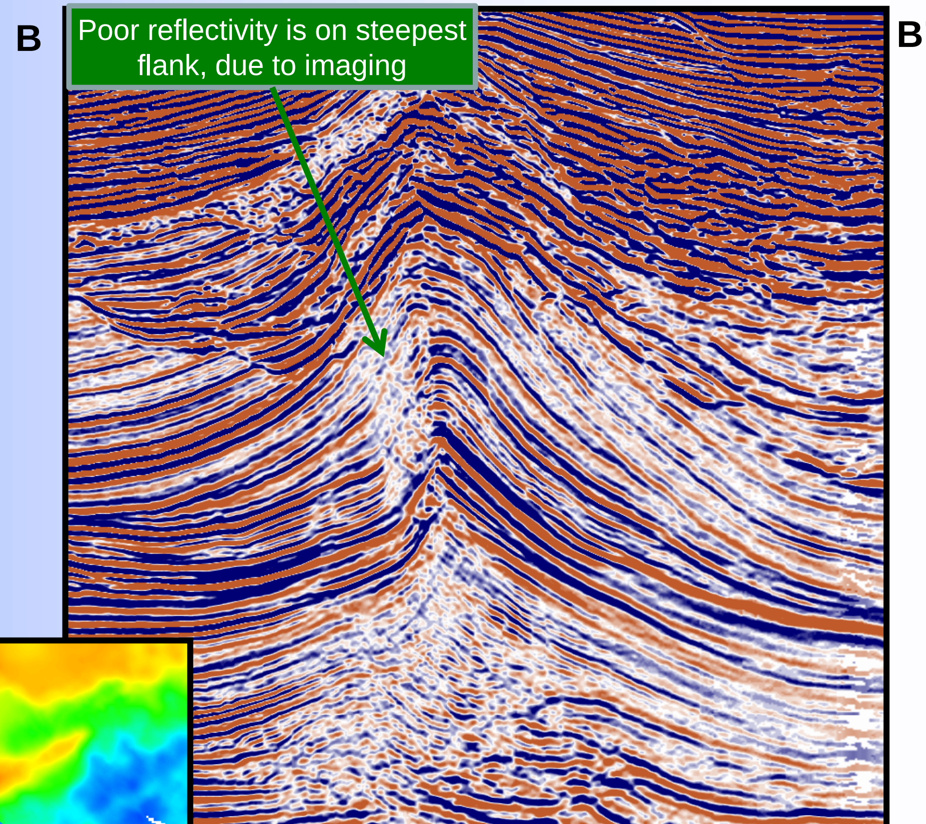
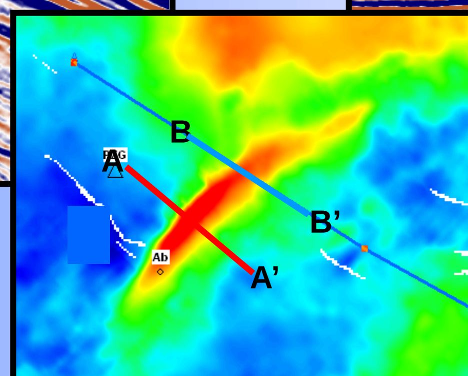
Outer Fold and Thrust Belt (G Structure)



Crest



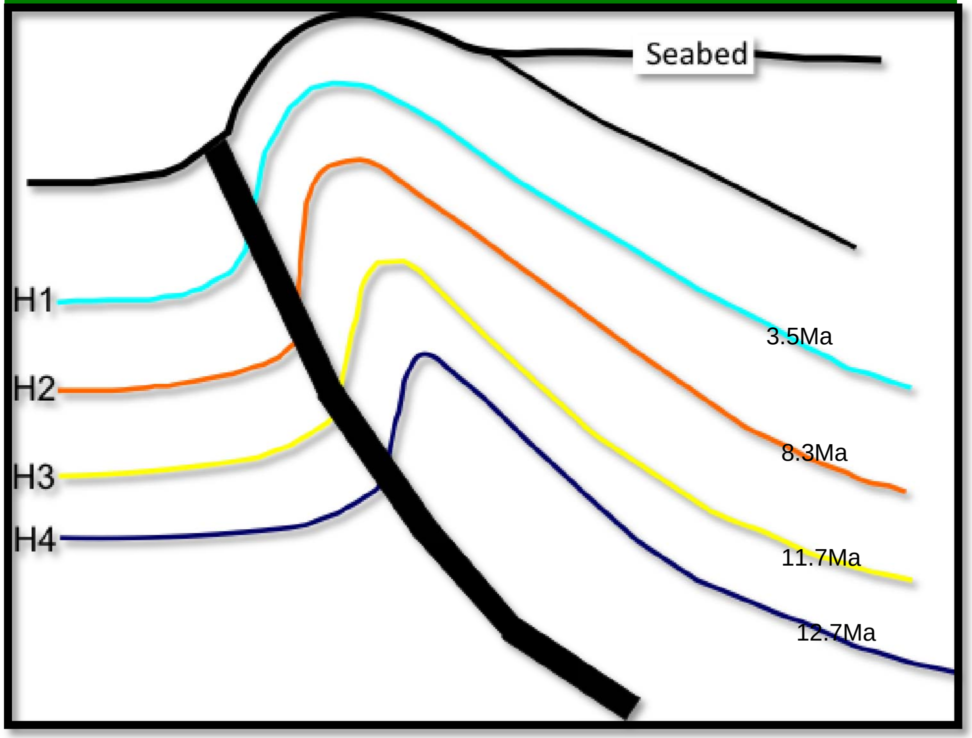
Flank



Note that there is fair continuity of reflector on the flank, with the exception of the steepest part of the feature (not associated with the core), where seismic imaging is poor

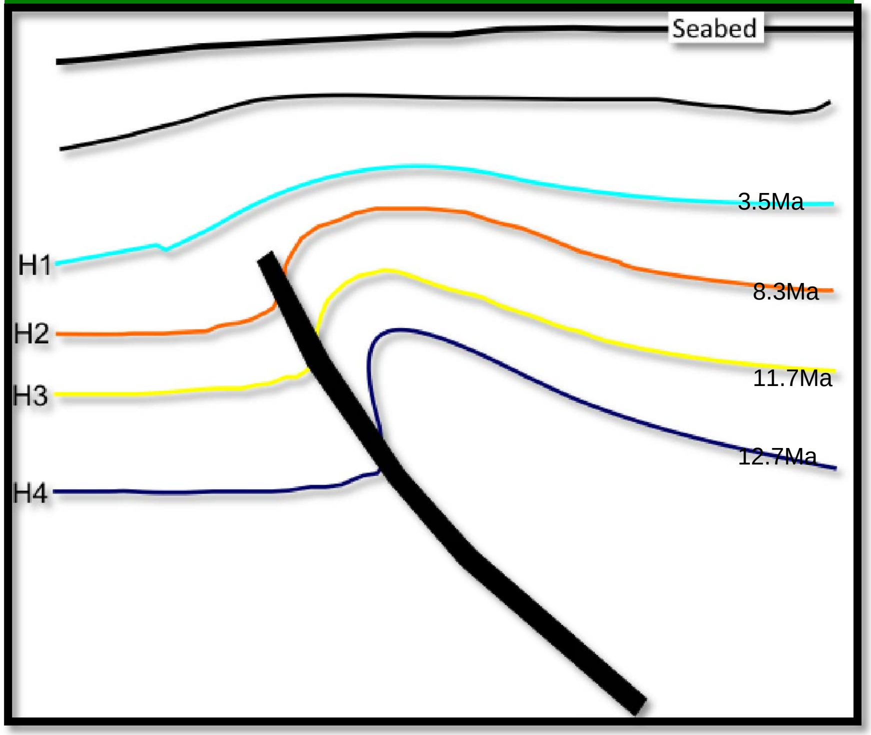
Structural timing of thrust faults based on the age of last movement

Emergent Thrust Fault (Active?) (G-Structure)



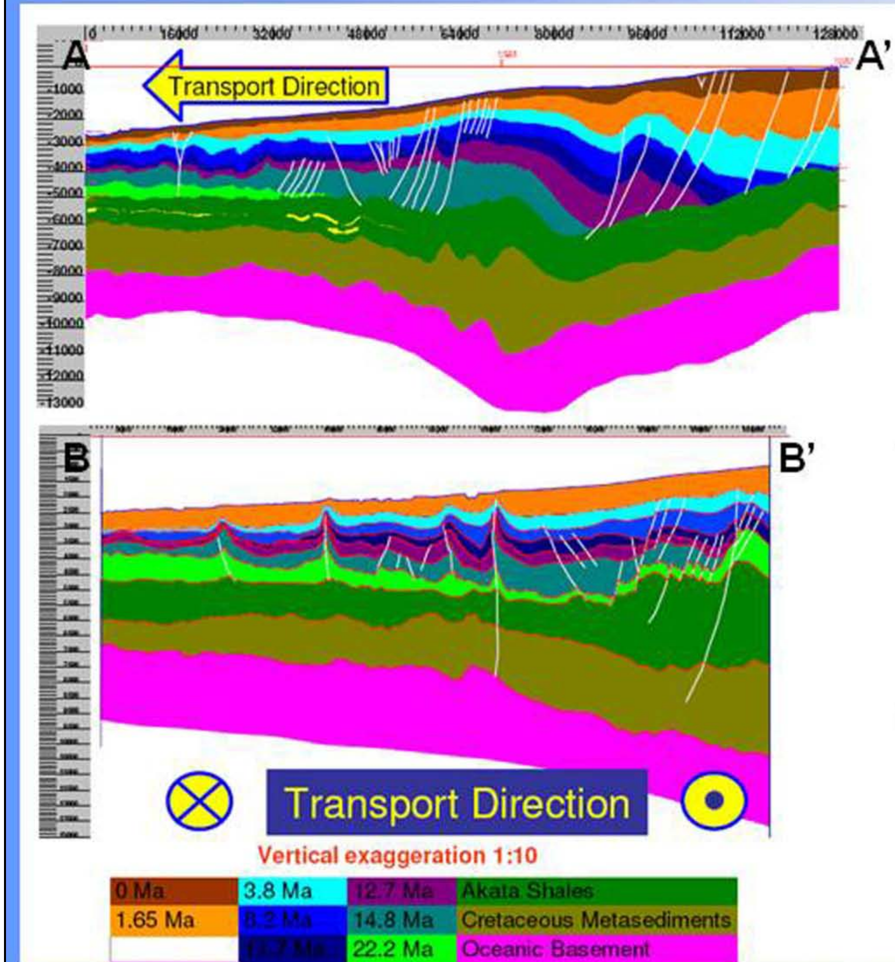
- Large seabed scrap observed.
- Fault emergent on seafloor

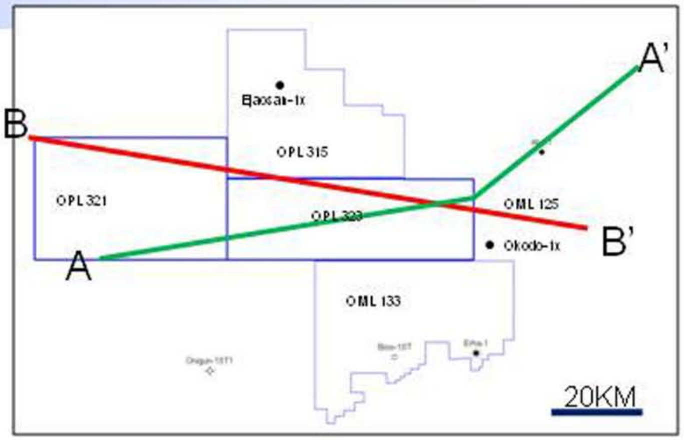
Buried Thrust Fault (Non Active ?) (B-Structure)



- No seabed expression of fault observable.
- Buried thrust fault

Balanced and Restored Depth Sections



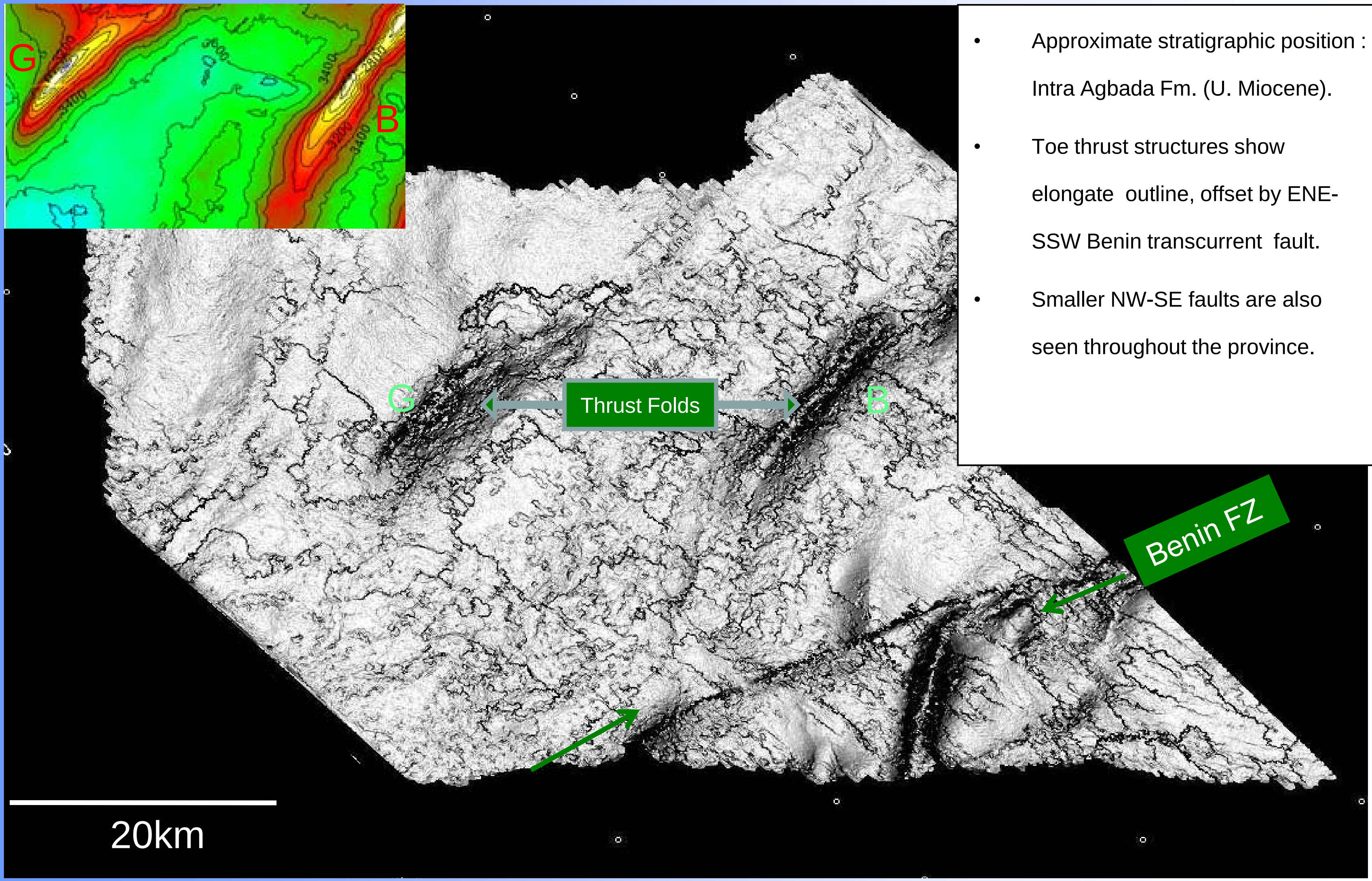


- **In Section A-A' the delta continues to build, with sediment accommodation being developed due to deformation of the overpressured Akata Shale.**
- **High angle transpressional faults continue to deform the B-B' section. Differential compaction and strike slip motion accentuate the Anticline.**

Notes by Presenter: The regional driving forces in the area will appear to be:

- The building out and gravity tectonics of the delta
- Transpressional stresses of the fracture zone refracted through the Akata shales.

Structural Style in the Outer Fold and Thrust Belt



- Approximate stratigraphic position : Intra Agbada Fm. (U. Miocene).
- Toe thrust structures show elongate outline, offset by ENE-SSW Benin transcurrent fault.
- Smaller NW-SE faults are also seen throughout the province.

Maps showing the Benin Fracture Zone to the South and some thrust fold structures of the deepwater Western Niger Delta to the North

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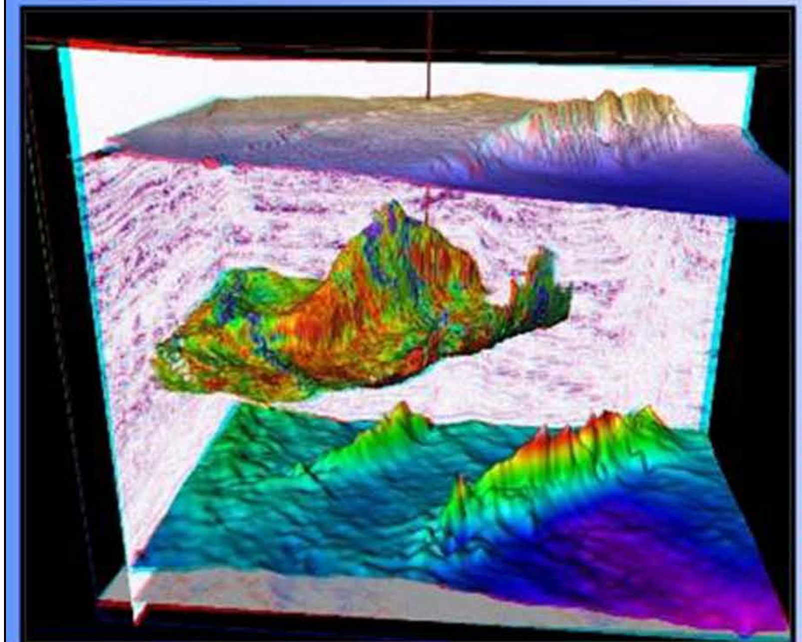
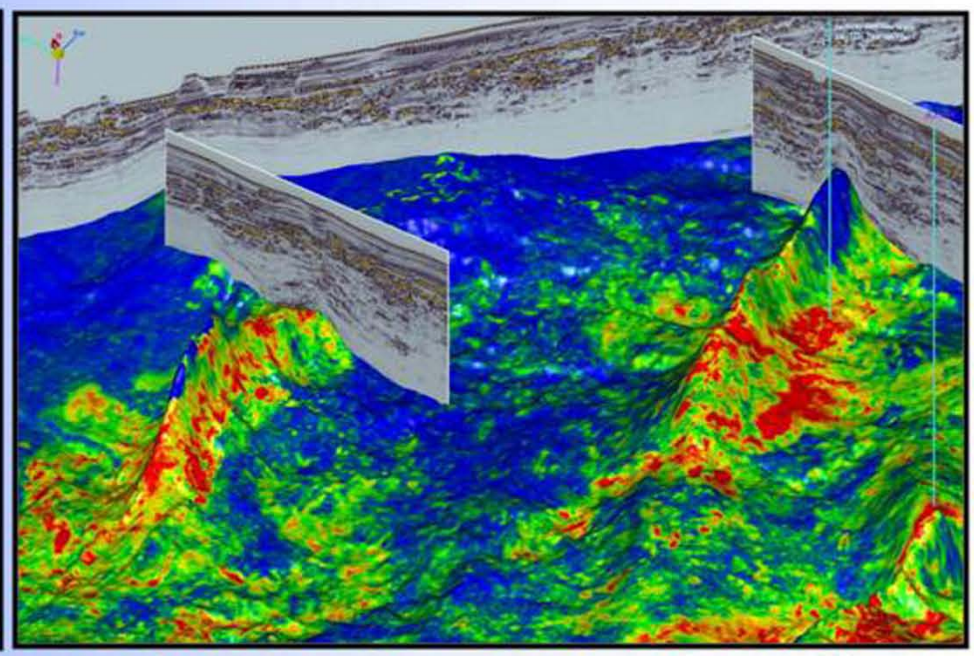
Comparison of Thrust Folds from the Western Lobe with Other Niger Delta Proven Thrust Fold



Eastern Niger Delta Thrust Fold Discovery
(Source: Geological Society of UK)



Deepwater Western Niger Delta Thrust Folds
"Outer fold and thrust belt"

- Remarkable similarity between existing Niger Delta Thrust fold example and Western fold features.
- Compressional tectonics have masked subtle turbidites channel features that were sourced from the Niger Delta.

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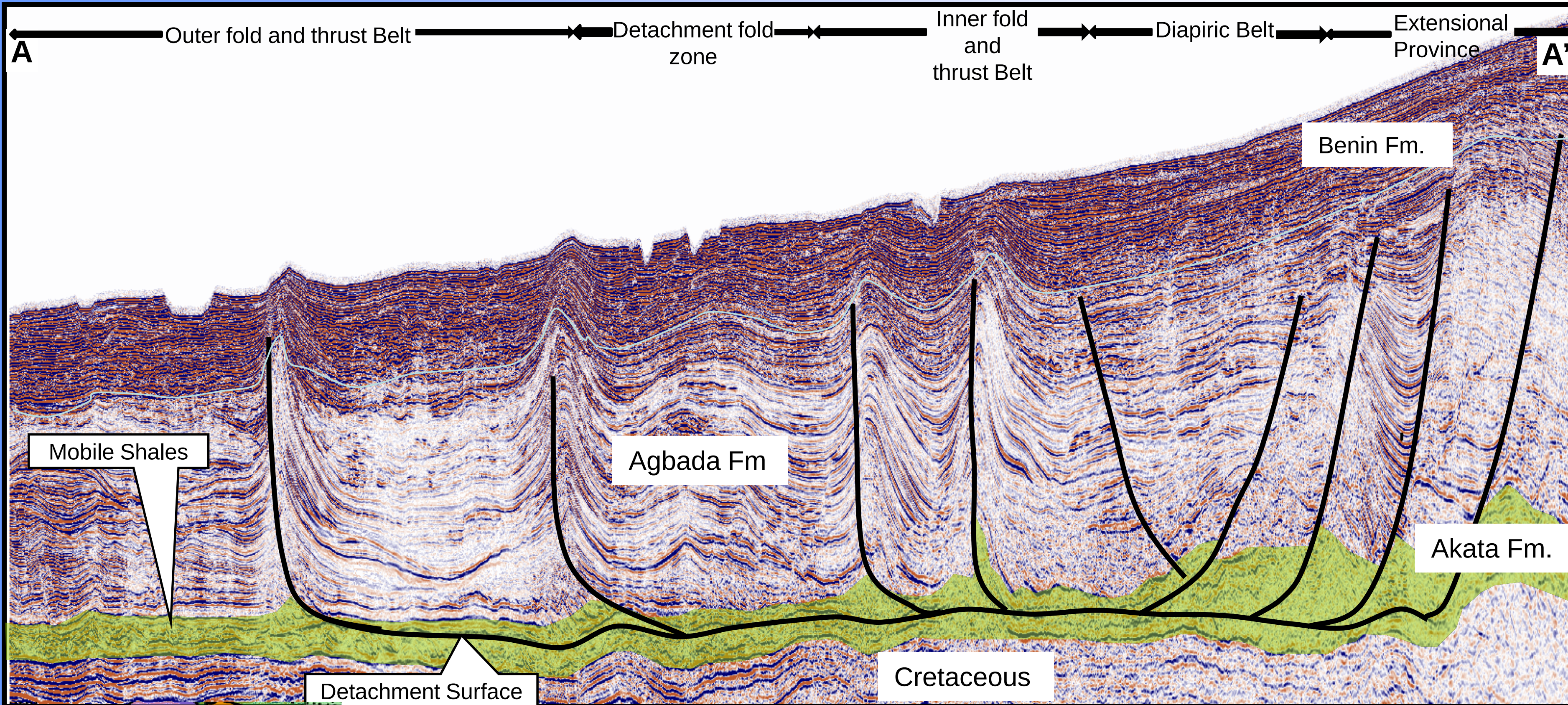
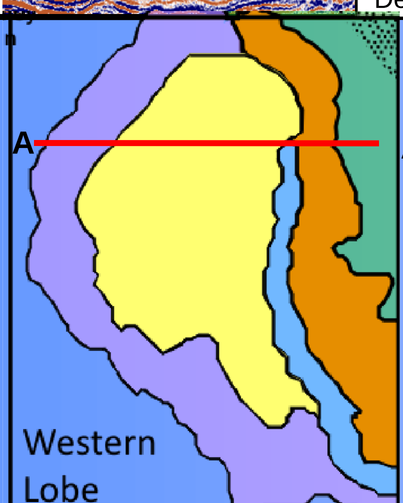
Notes by Presenter: At the base of the seismic data cube a surface has been interpreted showing the lower structure of the major fault, and a smaller one to the left.

Geo-seismic Interpretation of Line From Deepwater Western Niger Delta





Example TWT seismic line from deepwater Western Niger Delta showing the distribution of main structural provinces (based on 3D seismic data)

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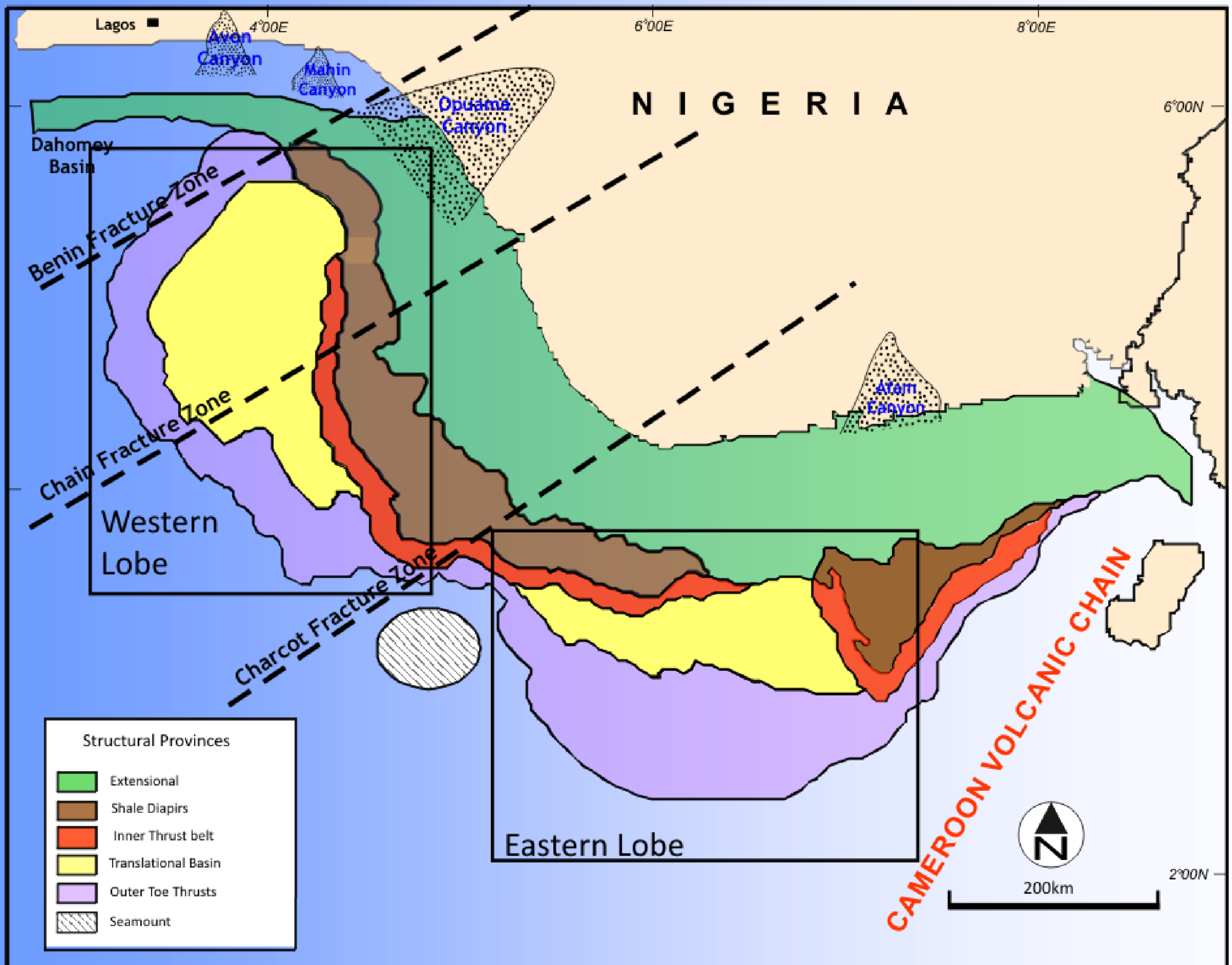

Map showing the distribution of main structural provinces based on regional 2D seismic data. Western Lobe modified after Corredor et all. based on 3D seismic data.

Implications for Trapping Mechanism

- Trap types: Structural, stratigraphic and combination.
- Thrust related traps :
  - Active with thrust faults emerging at the seafloor
  - Buried and inactive.
- Up-dip leakage of HC is a high risk especially in
  - Structural noses
  - Areas outside of 4-way closure
  - Channels running parallel to structural nose in stratigraphic traps
  - Thrust faults that have breached the trap especially in active thrust
- Sealing capacity of faults may be compromised by continued deformation thereby limiting retention capacity in fault dependent structures.

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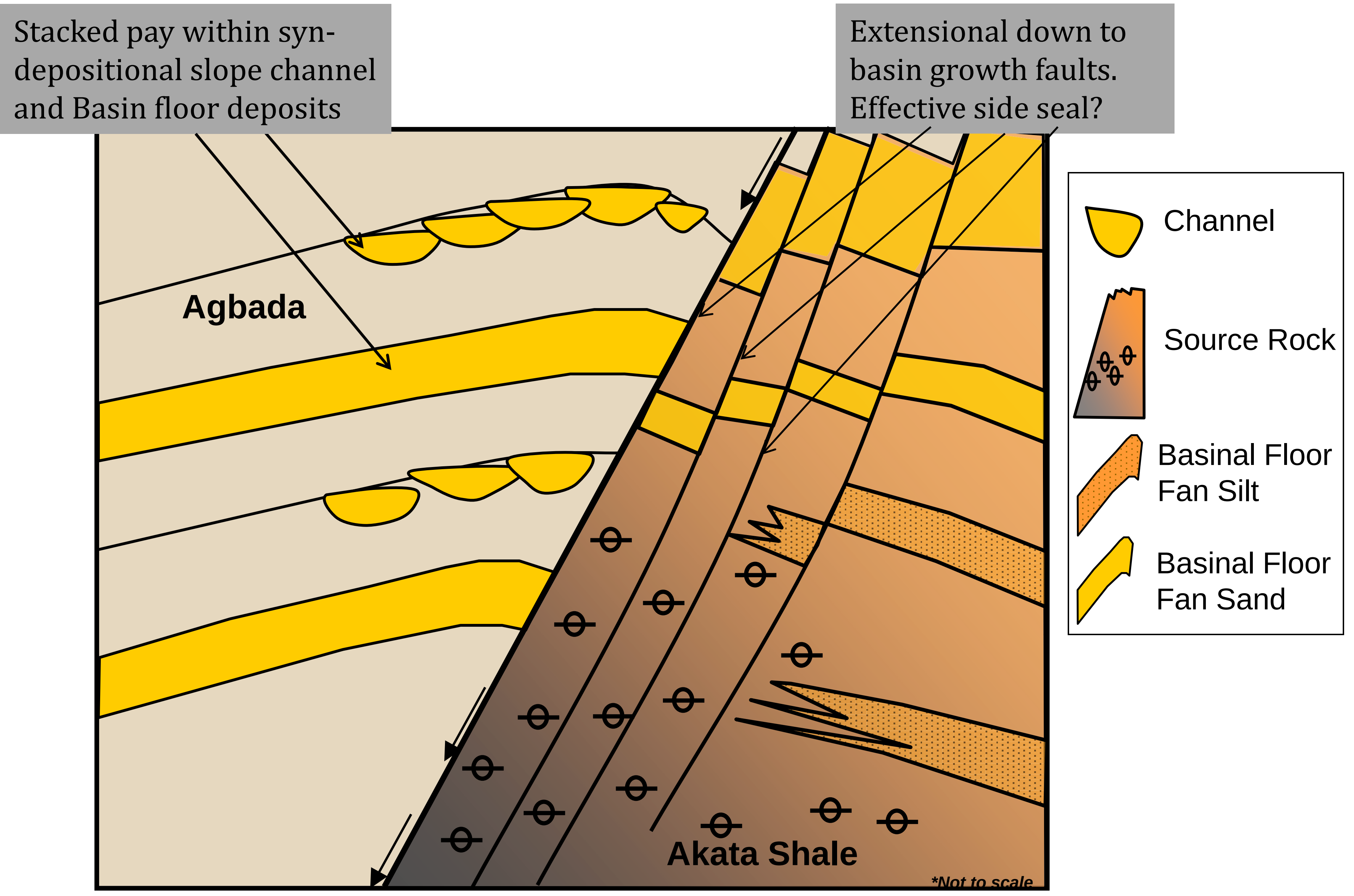
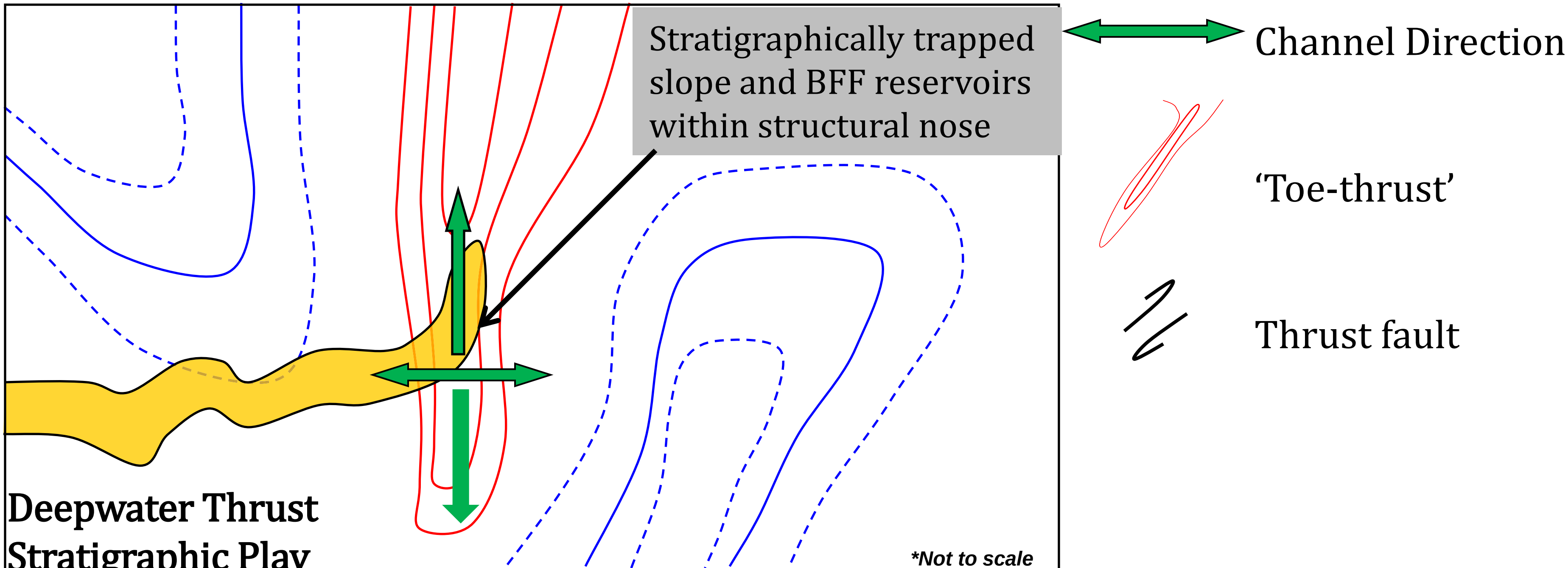
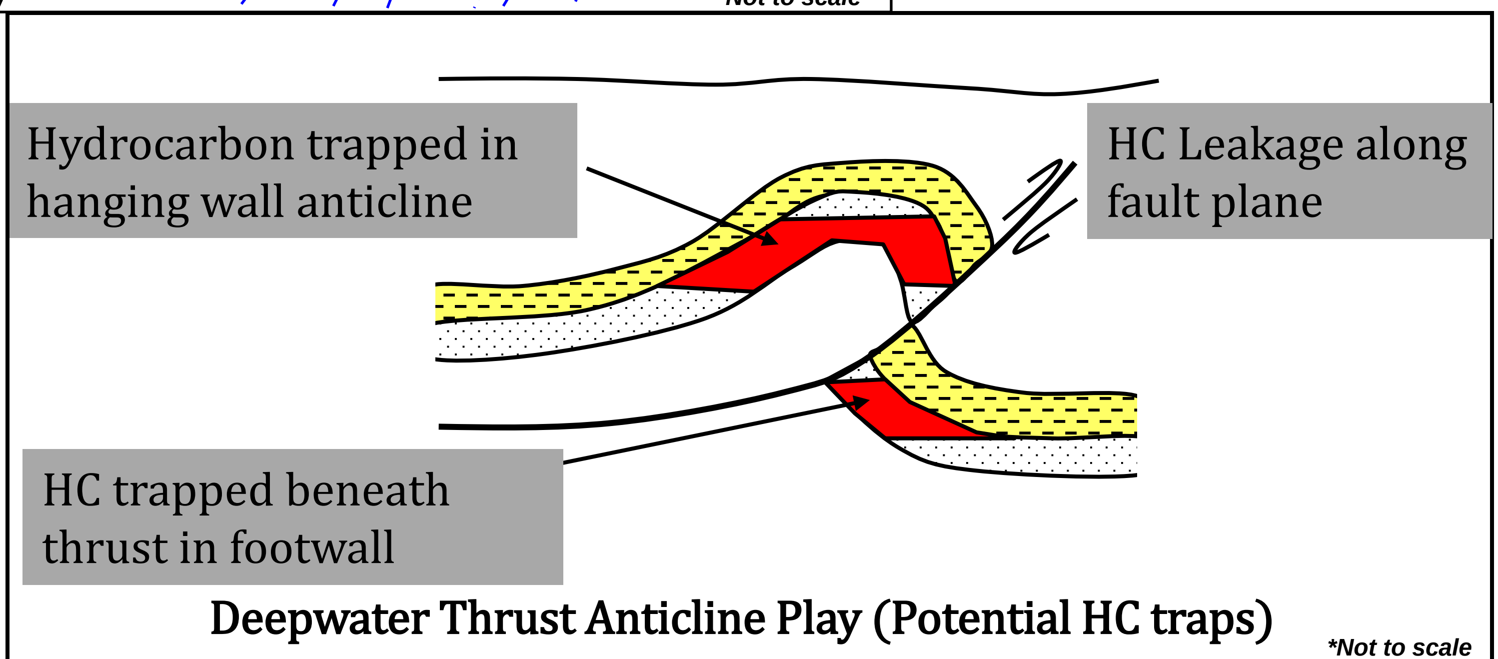


Deepwater Extensional Hanging Wall Play (Potential HC traps)

Trapping mechanism in the fold and thrust belts





Geologic Inferences

- Identified a transform fault which provides access to possible Pre-Tertiary source rocks.
- Complete structural regime typical of the deepwater Niger Delta can be replicated in the Western lobe.
- Similarity of thrust folds in the Niger Delta while some of the thrust folds north of the Benin transform fault have a different orientation.
- Implications of forcing regional models on local geology.

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Thanks for listening

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