

Central and South Atlantic Conjugate Margin Pre- and Post-Salt Successions: Implications to Rift Models and Petroleum Systems*

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Search and Discovery Article #30081 (2009)

Posted April 16, 2009

*Adapted from poster presentation at AAPG International Conference and Exhibition, Cape Town, South Africa, October 26-29, 2008.

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Abstract

Basins along the Nova Scotian-Moroccan (non-volcanic/transitional) and Brazilian-West Africa (volcanic) conjugate margins reveal stratigraphic sequences beneath late synrift salt lying above the unconformities defining rift onset, and below the breakup unconformity. They are proximal to basin margin hinge lines in shallow water; in deep water are at the distal basin margins out into the abyssal plain. Recent deep crustal and regional seismic lines have improved resolution of these pre-salt features as well as post-salt troughs controlled by basement-involved faults. In shallow water, they are seen as isolated salt evacuation synclines and half-grabens containing fluvial and playa redbed sediments. Unusual deep water structures, seen as highly rotated fault blocks with growth geometries, have alternative interpretations of continental or oceanic, synrift or post-rift features. Once interpreted as structural relief on magnetically-quiet oceanic crust, internal geometries and presence below the assumed breakup unconformity suggest the basement may not be oceanic. Some evidence supports the presence of attenuated, serpentinized mantle in these areas. The thick pre-salt sedimentary sequences are probably related to rift shoulder uplift at the continental border and future rift spreading axis just prior to rifting. Rapid sedimentation was directed towards the main salt depocentres on both the South and Central Atlantic conjugate margins. Sediments underlying salt in deep waters are not rotated by synrift faults. Their depocenter lies above a deep seismic reflector which may correspond to the Moho or to lower crust detachments. Recognition of these features, identification of basement type, definition and age of breakup events and their interpreted temporal and tectonic association, has implications to different styles of rifting, salt tectonics and basin petroleum systems.

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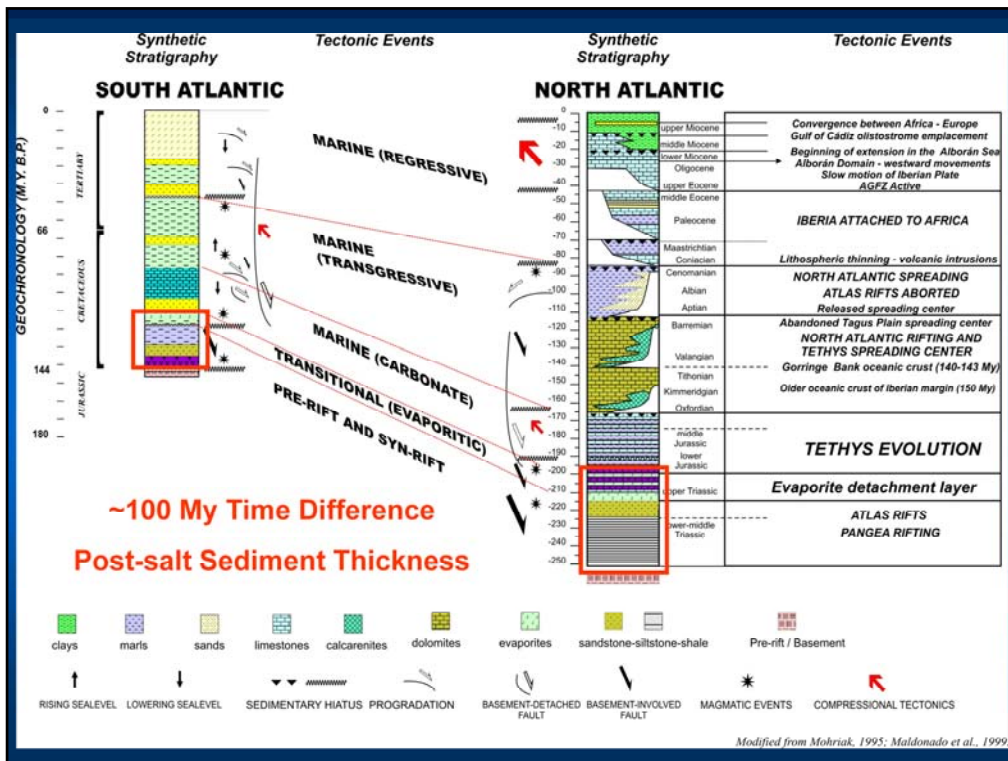
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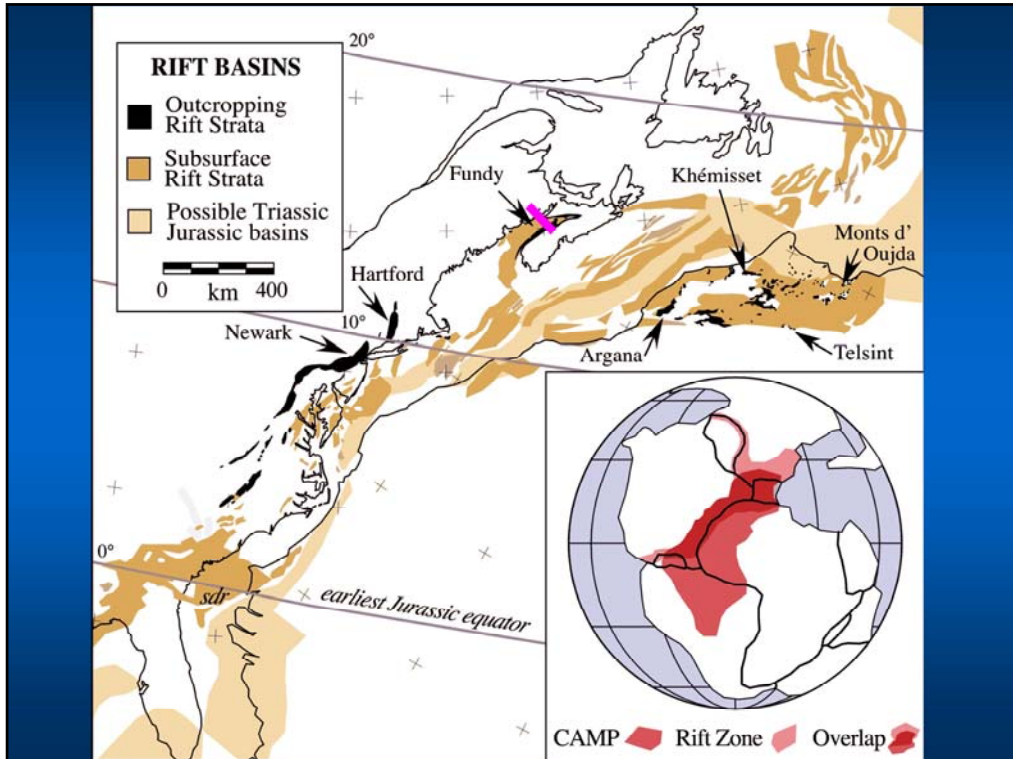
OVERVIEW

- Conjugate Margins
- Pre-Salt Features
 - Half Grabens
 - Sag Basins
- Post-Salt Features
 - Salt Evacuation Synclines
 - Highly Rotated Fault Blocks
- Observations / Implications



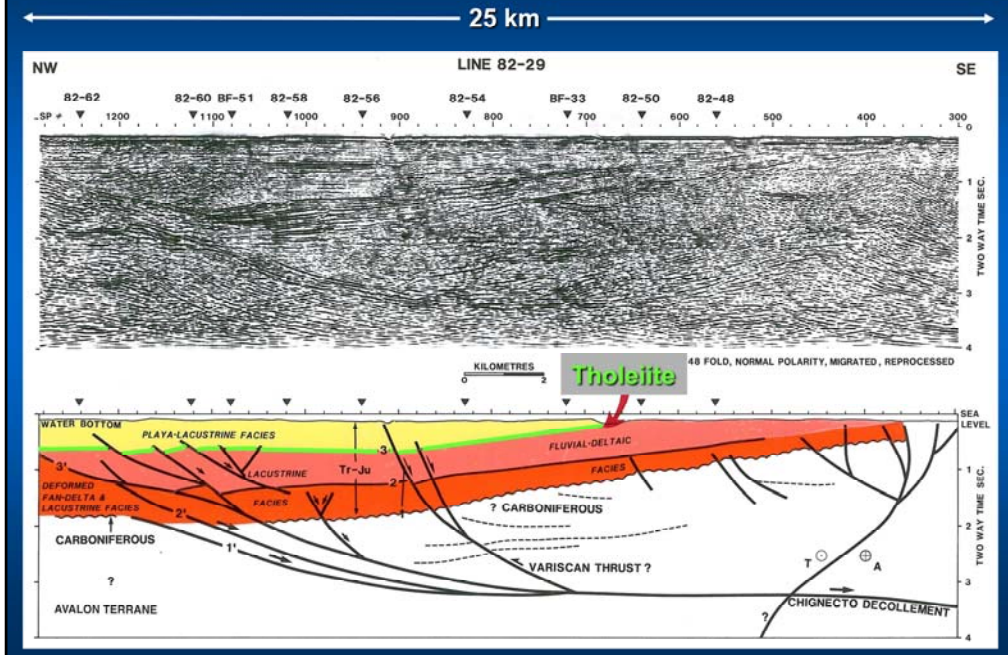
Comparison of the Central and North Atlantic synthetic stratigraphies. While the successions are broadly similar, note that the Central Atlantic is at least 100 million years older and over twice as thick.

PRE-SALT **Half Grabens**



Distribution of Central Atlantic Late Triassic – Early Jurassic Newark Supergroup and related synrift basins (via Paul Olsen, LDEO – used with permission). Note that some basins (Newark, Fundy) contain exclusive continental successions and are well exposed, whereas those proximal to the rift axis are deeply buried and may contain some paralic marine strata.

Half Graben - Fundy Basin



Seismic Line 82-29 across the Late Triassic – early Jurassic Chignecto Subbasin, Bay of Fundy region, Canada. Colour key: Dark Orange = Wolfville formation (Carnian) / fluvial-lacustrine; Light Orange = Blomidon formation (Norian-Rhaetian) / playa-lacustrine; Light Green = North Mountain formation (earliest Hettangian) / tholeiitic basalt flows; Yellow: McCoy Brook formation (Hettangian-?Aalenian) / fluvial, playa, lacustrine. Note the high amplitude laterally continuous reflections to the left indicative of lacustrine facies. A gravity low corresponds to this area. A major normal fault is about 300 metres west of the line with early Paleozoic volcanics and intrusives comprising the footwall (Avalonian “Caledonia Terrane”) with a relief of up to 400 metres. Underlying succession interpreted as the eastward-prograding Pennsylvanian coal measures of the Nova Scotian Cumberland Basin.

30m+ Eolian Dune Field



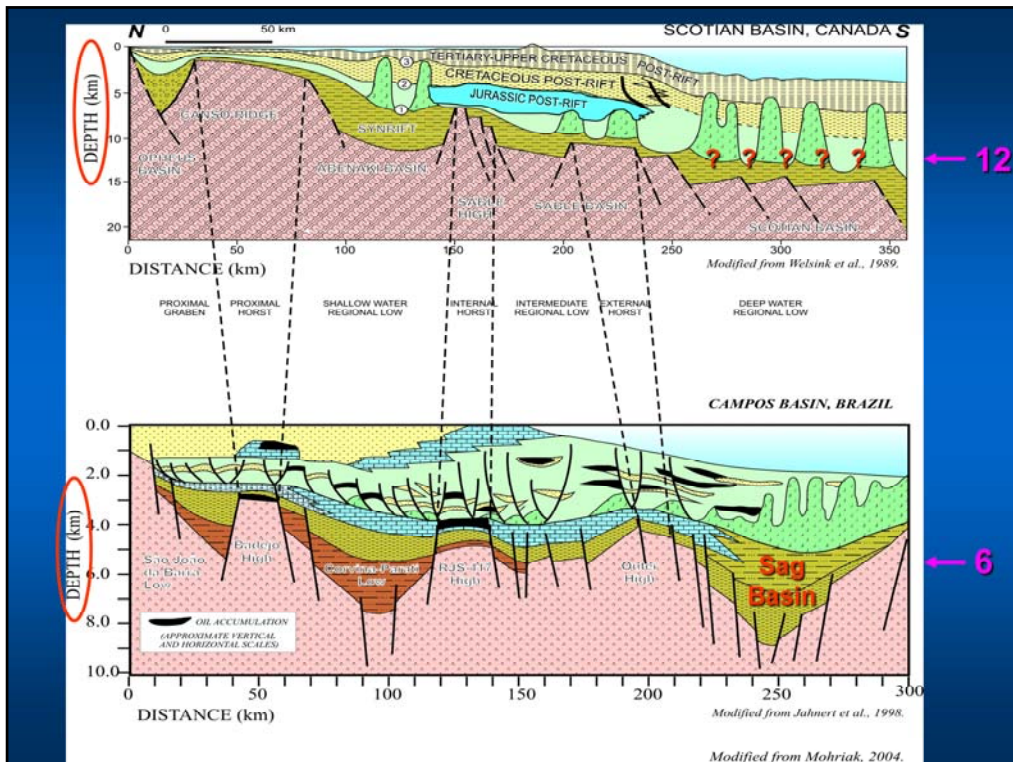
Internal dip view of stacked barchan dunes at the base of the Late Triassic (Norian-Rhaetian) Blomidon formation, Five Islands Provincial Park, Nova Scotia. Playa facies of the Blomidon conformably overlie the eolian sediments. Photo copyright: David E. Brown.

Attributes

- Fluvial-lacustrine-playa closed basin successions; rich source rocks
- Volcanics: single ~650 ky episode at 200 Mya
- Location: distal - intra-terrane boundaries; proximal - attenuated crust along rift axis
- Distribution: inboard of basin hingeline margin; deeply buried in sag basins?
- Tectonic driver: initial rift and extension phase
- Extensional reactivation of Variscan thrust faults
- Known petroleum systems, rare commercial discoveries

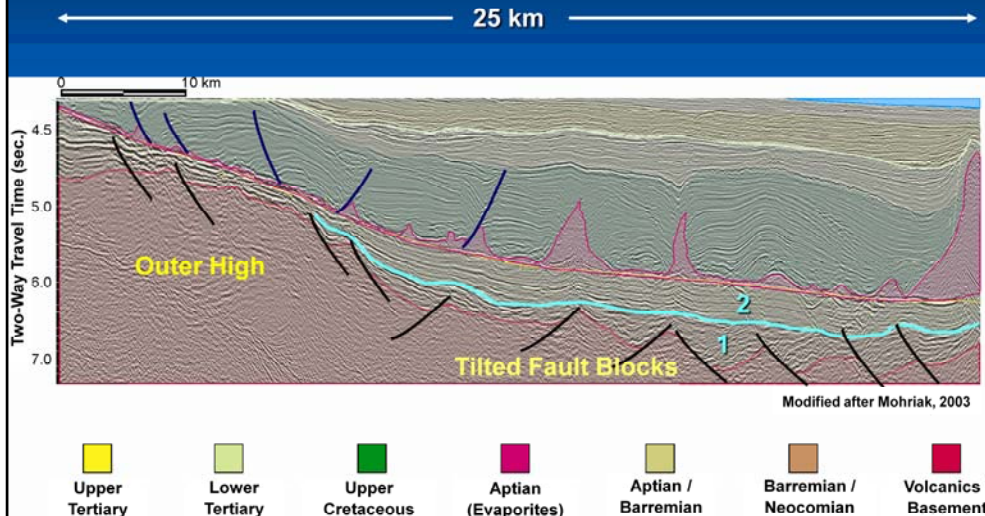
PRE-SALT

Sag Basins



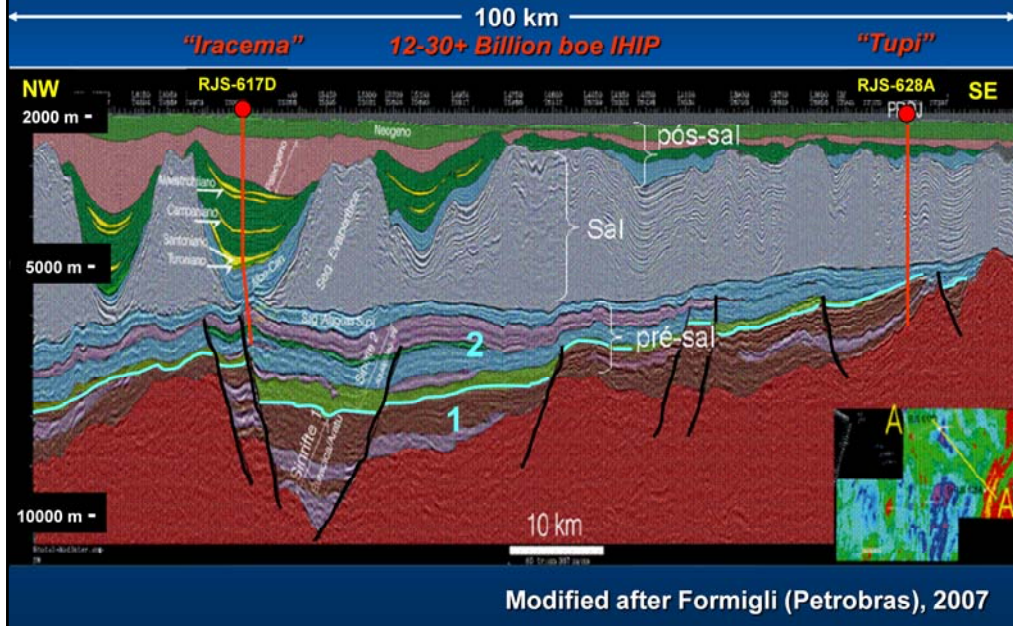
Correlation of features (similarity, basin width) / thickness of salt basin.
 DEPTHS – Scotian Basin succession almost twice as thick.

Sag Basin – Campos Basin



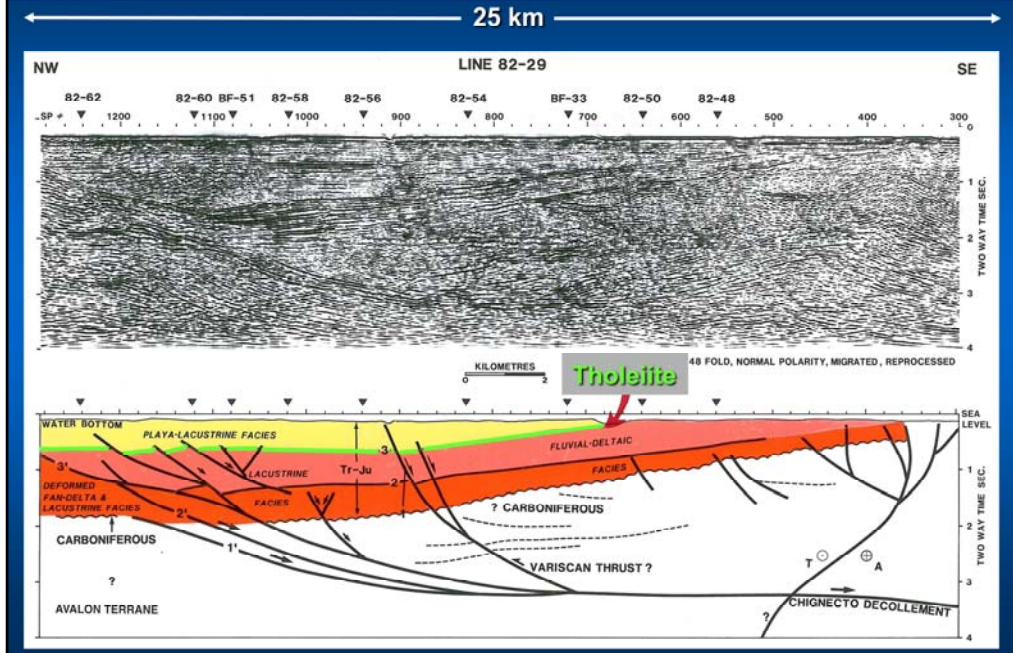
Blue line indicates two syn-rift packages; the lower fluvial and alluvial, the upper fluvial and lacustrine.

Santos Basin – Pre-salt



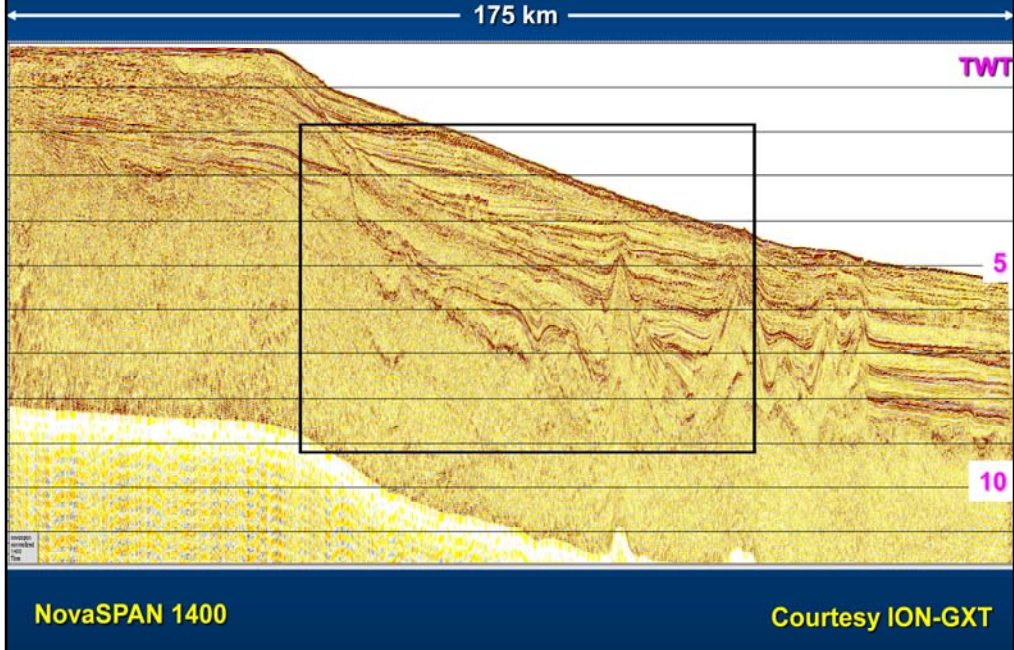
Guaratiba Formation – lacustrine siliciclastics and limestones – coquinas (reservoirs), lacustrine shales (source). Lower succession fluvial sandstones, conglomerates and playa mudstones. The Iracema and Tupi discoveries are estimated to be a single accumulation containing 12-30+ billion BOE initial hydrocarbons in place (IHIP).

Half Graben - Fundy Basin



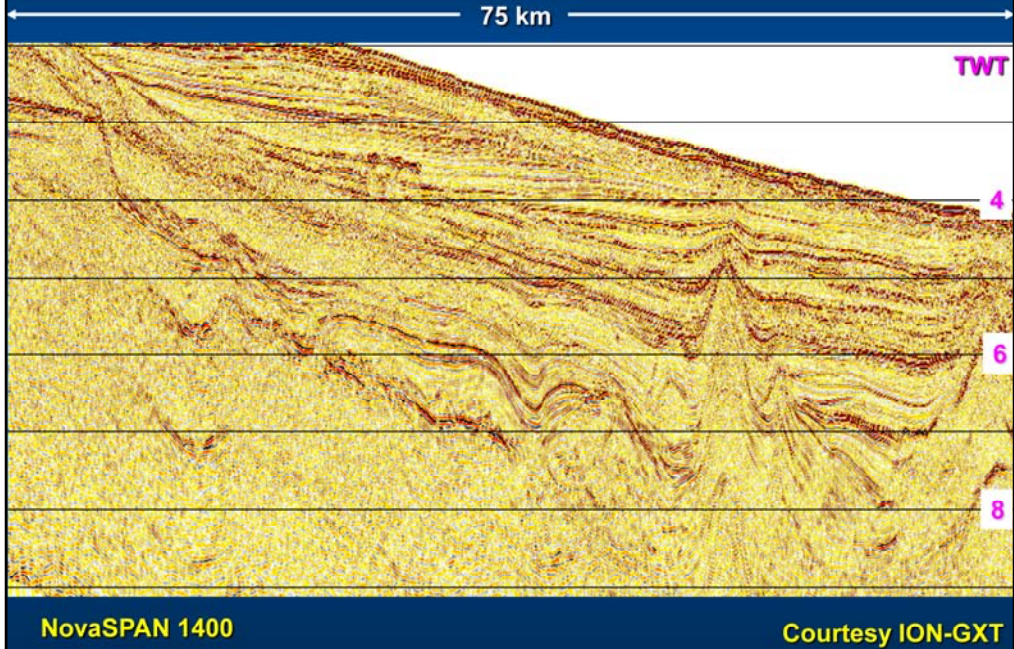
The half graben architecture and general stratigraphy of the continental Chignecto Subbasin is similar to that of the Tupi depocentre but without the salt. Salt-capped half grabens may though exist deeper in the Scotian Basin (e.g. Orpheus Graben).

Sag Basin? – Scotian Basin



Example of a portion of the southwestern Scotian Basin that may have an underlying sag basin. Thick overlying Tertiary to Jurassic successions are considered to be masking a series of possibly interconnected, deeper basement features that acted as loci for Argo formation (Hettangian) salt deposition. The black outline is the area shown on the next slide.

Sag Basin? – Scotian Basin



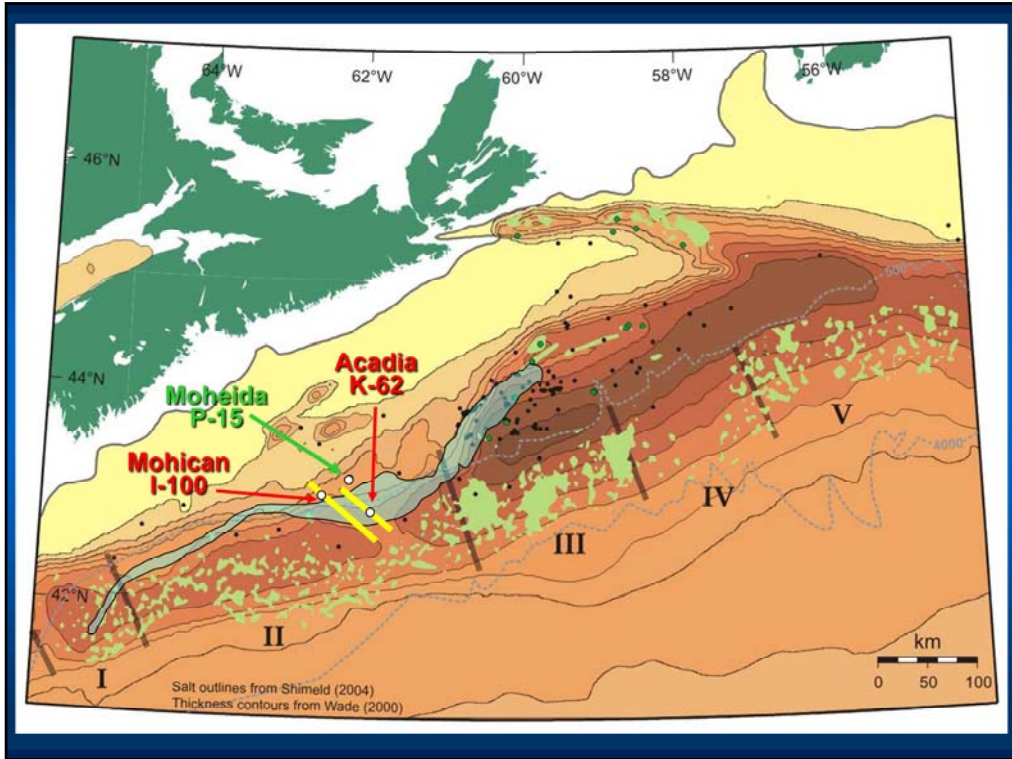
Detail of the previous slide. The thickness of the overlying Tertiary, Cretaceous and Jurassic succession may be masking deeper Late Triassic fluvial-lacustrine strata in half grabens. Salt is ubiquitous along the entire margin, and its distribution and morphologies suggest similarities with portions of the the Brazilian Campos and Santos basins.

Attributes

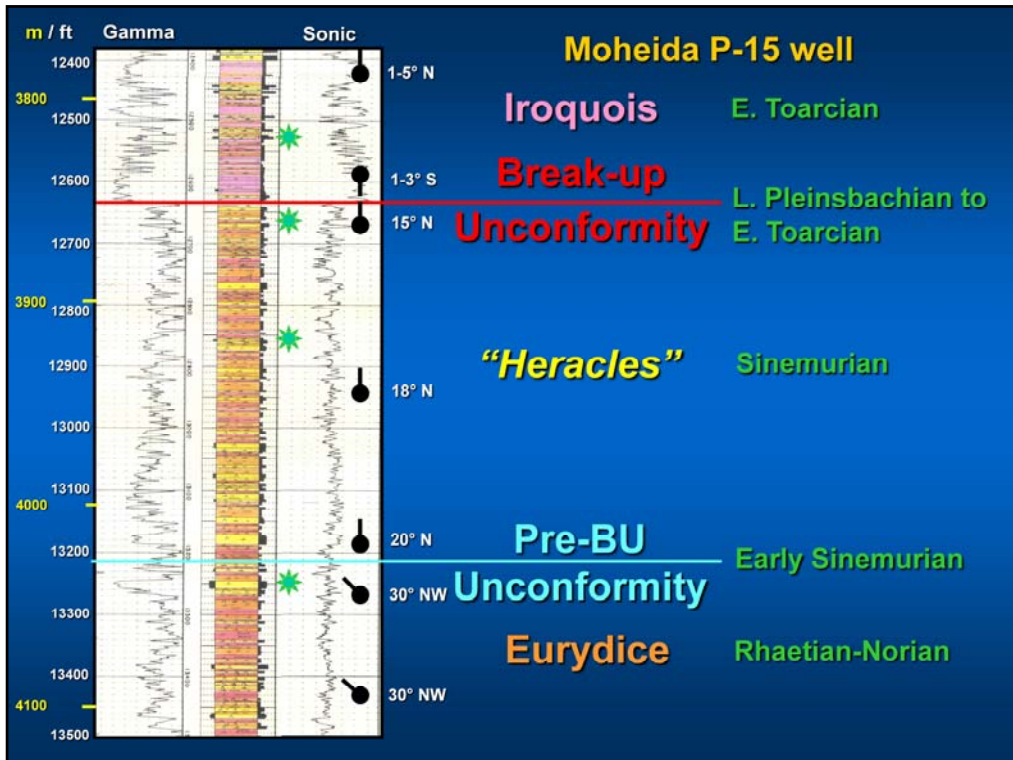
- Fluvial-lacustrine (clastic-carbonate) successions (South Atlantic); unknown (Central Atlantic)
- Location: thinned, fractured attenuated crust
- Distribution: distal of basin hingeline, proximal to continental-ocean crust transition
- Tectonic driver: rift extension; thermal subsidence
- Region of greatest subsidence
- Confirmed petroleum system and discoveries

POST-SALT

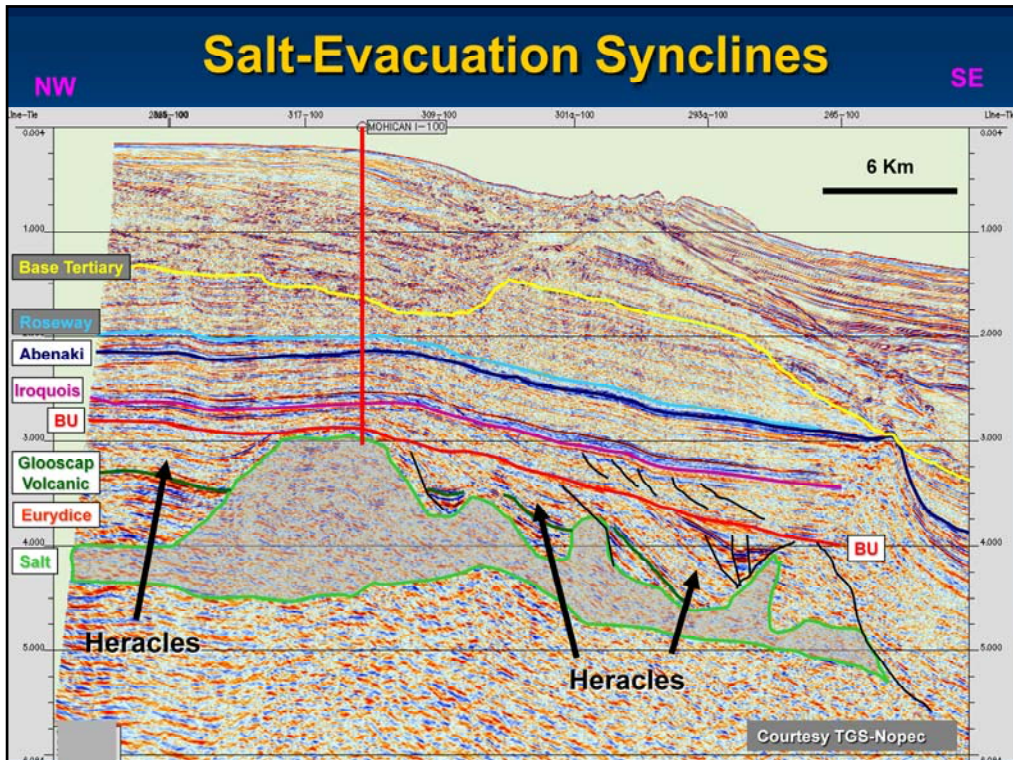
Salt-Evacuation Synclines



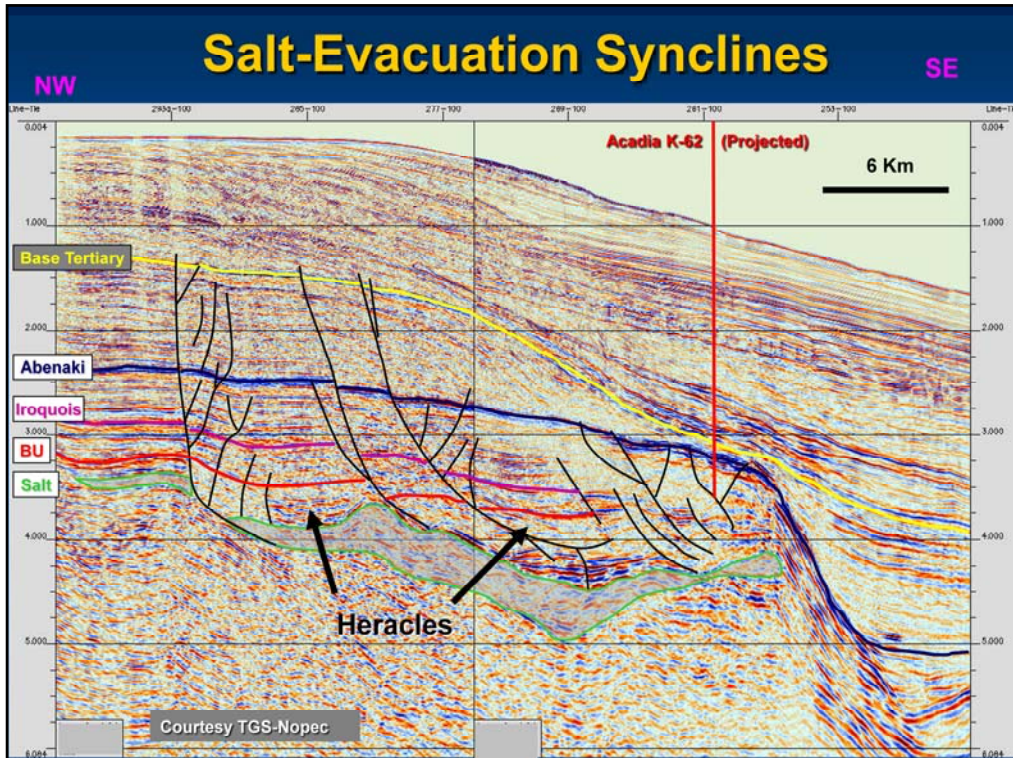
Salt (green) and Abenaki carbonate bank margin (light blue). Well locations and yellow lines indicate locations of the following slides within and at the edge of the Mohican Graben. Roman numerals define the salt provinces interpreted by Shimeld (2004).



Portion of the Canstrat log for the Moheida P-15 well. Dip logs and palynostratigraphy confirm the presence of two unconformities within the well: 1. the late Pleinsbachian to Early Toarcian Breakup Unconformity (BU), and older Pre-BU Unconformity. The latter event is interpreted to be a response to rift shoulder uplift related to a final thermal pulse prior to the creation of true oceanic crust. The Heracles Unit is the sedimentological response to rift shoulder uplift and seaward-directed deposition directly over Argo formation salts and subsequent deformation.



Seismic line in the southwestern part of the Scotian Basin (mouth of the Mohican Graben) illustrating the early Sinemurian age post-salt / pre-breakup “Heracles” fluvial-lacustrine succession. Note that there is very little thickening of the Jurassic Abenaki carbonate succession across the margin confirming that the underlying salt sequence and features were essentially dormant or ‘locked’ for a considerable period of time. High amplitude reflections are interpreted and lacustrine facies. The Glooscap volcanics are Hettangian-aged tholeiitic basalts that are probably equivalent to the North Mountain formation volcanics in the Fundy Basin. High amplitude reflections to the east are thought to be lacustrine in origin as there is an absence of a magnetic anomaly.

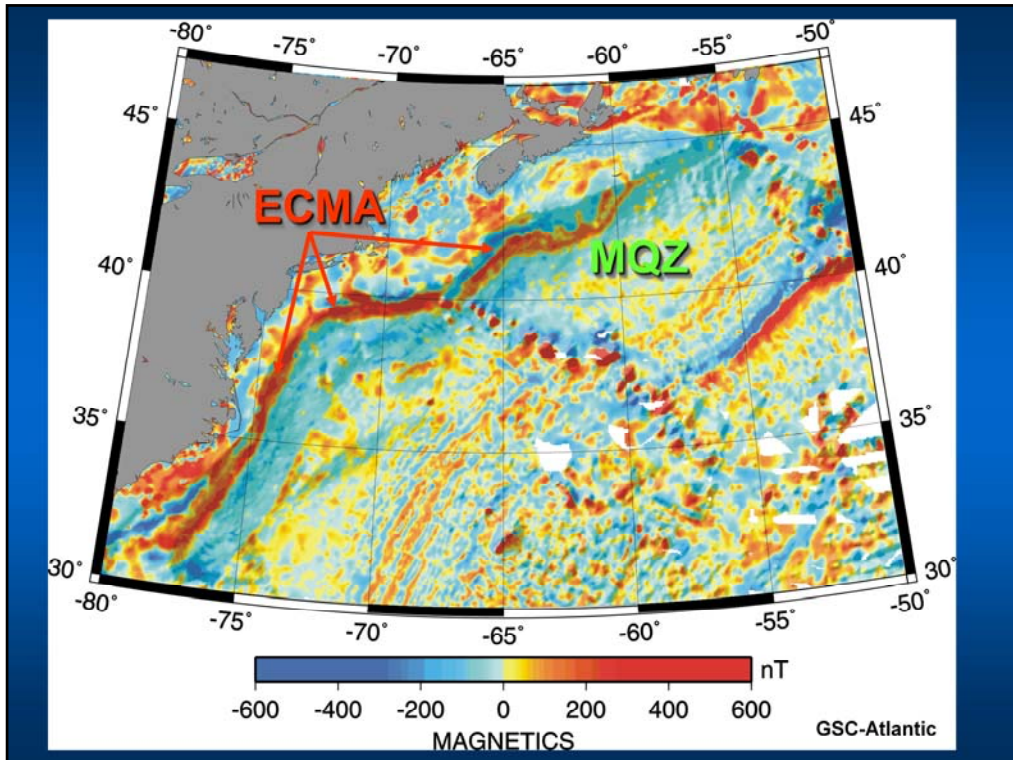


Seismic line in the southwestern part of the Scotian Basin (mouth of the Mohican Graben) illustrating the early Sinemurian age post-salt / pre-breakup “Heracles” fluvial-lacustrine succession. High amplitude reflections are interpreted and lacustrine facies. Note the late-stage faulting that penetrates into the lower Tertiary strata. It is thought that this might be the response on the margin to the Early Eocene (50.5 Mya) Montagnais impact event on the self about 100 km to the west.

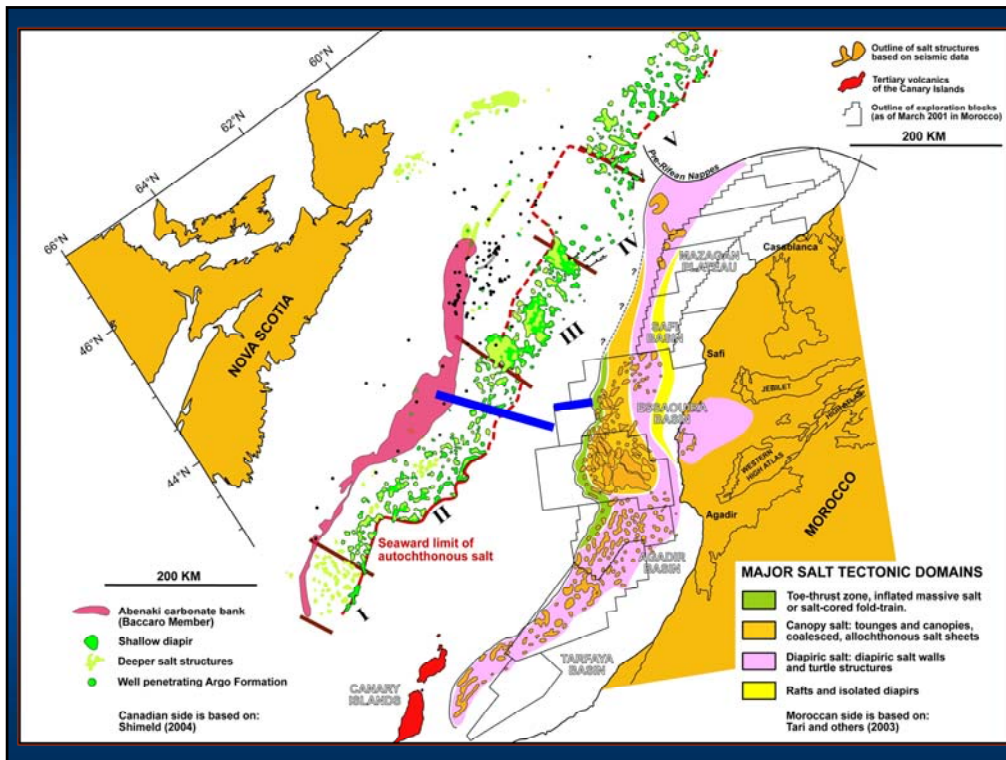
Attributes

- Seaward-directed progradational succession
- Fluvial-playa (lacustrine?) facies
- Location: inboard (straddling?) basin hingeline
- Distribution: subbasins; embayments with salt
- Tectonic driver: rift-shoulder uplift
- Potential reservoirs, sources & traps

POST-SALT
Highly Rotated Fault Blocks

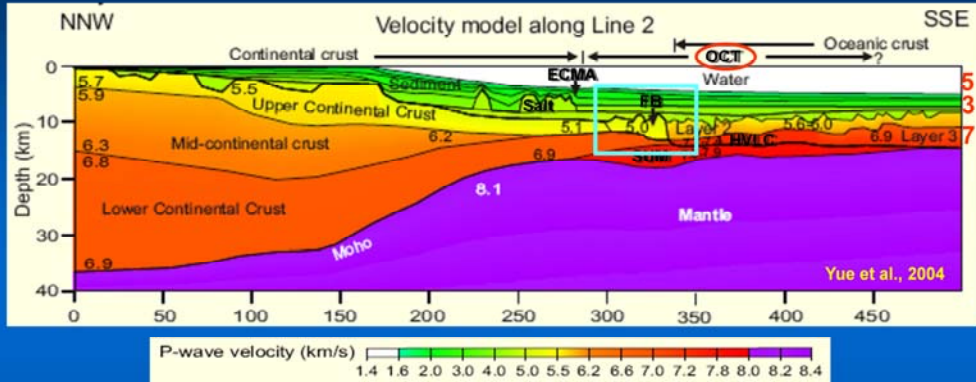


ECMA = East Coast Magnetic Anomaly; MQZ = Magnetic Quiet Zone. The Highly Rotated Fault Block (HRFB) features are located on the MQZ that was originally interpreted as oceanic crust but is now believed to be highly attenuated serpentinized upper mantle.



Salt and basin locations, Nova Scotian and Moroccan margins. Blue lines indicate the location of two conjugate seismic lines that reveal the presence of Highly-Rotated Fault Blocks (HRFB) on interpreted attenuated mantle, not oceanic, crust.

AGC 88-1 / 88-1A



FB – Highly Faulted Basement Blocks

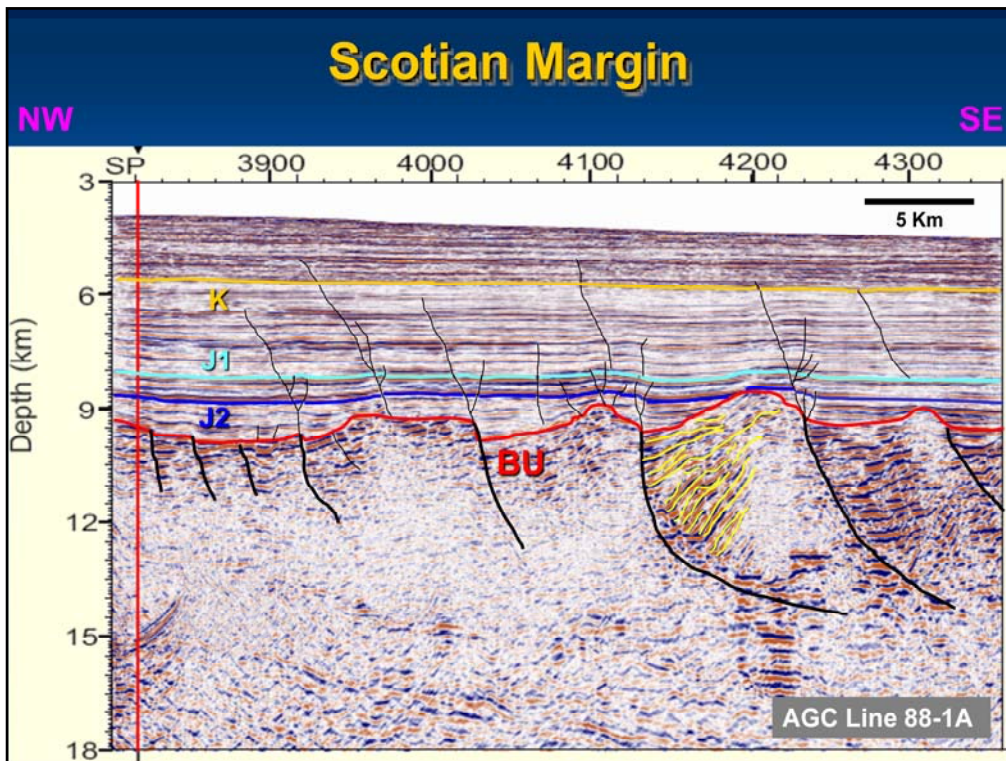
ECMA – East Coast Magnetic Anomaly

OCT – Ocean-Continental Transition

HVLC – High Velocity Lower Crust

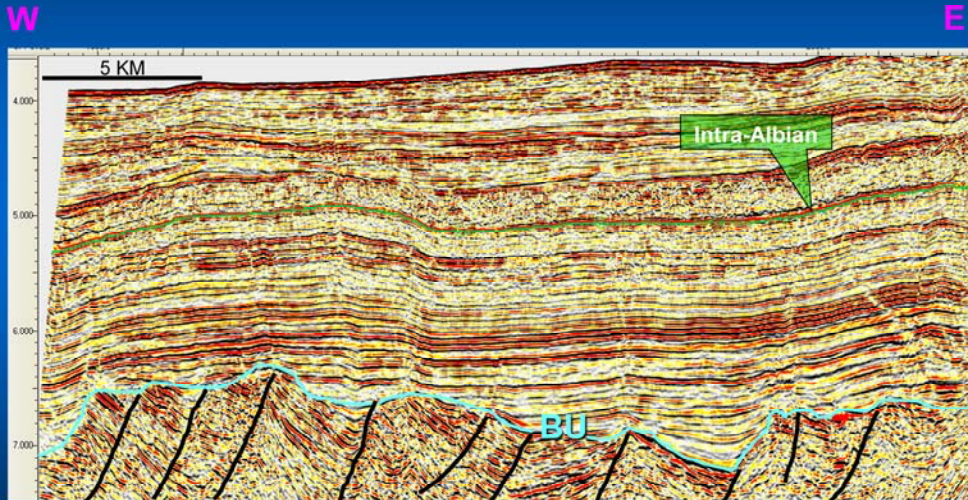
SUM – Serpentinized Upper Mantle

Note thicknesses of water, sediments and crust. Blue box outlines the area illustrated in the seismic line of the next slide.



Highly-rotated fault blocks. Note the internal architecture with reflections expanding towards the fault strongly inferring a sedimentary origin. The Sinemurian age Breakup Unconformity is above the blocks that in turn confirms that the underlying crust cannot be oceanic and thus believed to be highly attenuated serpentinized mantle in the magnetic quiet zone (MQZ).

Moroccan Margin



From Tari and Zizi (2007). Seismic data courtesy GSI

Highly Rotated Fault Blocks on the Moroccan conjugate margin. Note their landward-dipping character and internal geometries indicative of concurrent sedimentation extensional faulting. Tertiary to early Jurassic successions overly the HRFBs.

Attributes

- Geometries > sedimentary (fluvial-alluvial?)
- Landward-directed progradational succession
- BU on rugose surface > very late syn-rift
- Decrease towards central salt basin (landward)
- Location: highly attenuated lower crust
- Distribution: limited, distal, adjacent to rift axis
- Tectonic driver: rift axis thermal uplift - BU
- Unknown petroleum potential

POST-Salt: Highly Rotated Fault Blocks – Attributes.

Observations - Rifting Process

PRE-SALT:

- Basinward-directed sedimentation
- Rift-shoulder uplift (half grabens)
- Central rift extension (sag basins)
- Little to no(?) contribution from rift axis
- Entire rift margin - inherited basement
- Initial rifting thermal uplift

POST-SALT:

- Basinward-directed sedimentation
- Dominant: rift shoulder (salt synclines)
- Subordinate: rift axis (rotated fault blocks)
- Limited distribution: imprinted rift topography
- Pre-breakup thermal uplift

Observations – Petroleum Systems

PRE-SALT:

- Significant lacustrine deposition
- High TOC source rocks
- Lacustrine clastic and carbonate reservoirs
- Later salt provides seals, migration pathways
- Petroleum source for younger strata
- Discoveries – Brazil, GOM

POST-SALT:

- Lacustrine sequences unknown
- Fluvial-dominated reservoirs
- Limited seals
- Potentially breached traps - BU

Acknowledgements

- **Menno Dinkelman – ION-GXT**
- **Kim Abdallah – TGS-NOPEC**
- **Paul Einarsson – GSI**
- **Sonya Dehler – Geological Survey of Canada**
- **Keith Loudon – Dalhousie University**
- **Wu Yue – Shell**
- **Our colleagues and respective employers**

Selected References

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