Structural Deformation, Traps and Reservoir Distribution in Deepwater Southern Equatorial Guinea: A Tale of Two Basins*

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Abstract

The area of Block K in the southernmost part of Equatorial Guinea is an emerging exploration province, with proven plays to the north and south. The area straddles two basins, the Rio Muni Basin and the North Gabon Basin within the block. In the northern part, reservoirs and structures are typical of the adjacent Rio Muni Basin. Paleocene and Turonian reservoirs consist of relatively flat-lying, undeformed toe of slope submarine fans analogous to the deepwater Campos Basin of Brazil. Play extension of channelized Senonian reservoirs from producing fields such as Ceiba and Okume to the north is focused on analogous compressional anticlines formed by sliding on salt. Uplift events in the platform and onshore in the Middle Eocene tilted the basin, and caused sliding and thrusting. As much as 2-4 km of overthrusting of undeformed Upper Cretaceous section is evidenced.

The southern half of Block K is radically different than the north. It is actually an extension of the North Gabon Basin, with much more movement of salt nappes than within Gabon. Multiple uplifts in the platform and onshore have driven a radial pattern of downslope movement of two spectacular salt nappes, which have been transported 20-40 km into the deepwater emerging exploration area from a source area on the present-day continental shelf. Upper Cretaceous marine as well as Lower Cretaceous rifted sequences below the salt nappes never had autochthonous salt. Sub-salt structural traps in the Upper Cretaceous represent a new deepwater play for the country, and could provide significant volume potential. Traps in the Lower Cretaceous rift sequence, which one would normally call “pre-salt”, are, in fact, beneath allochthonous salt and an Albian-Turonian marine sequence. These “pre-salt” traps differ from pre-salt traps in northern and central Gabon, which are overlain by autochthonous salt. Gamba and pre-Gamba fluvial-lacustrine sandstone reservoirs are present in nearby wells and represent potential reservoirs in southern Equatorial Guinea. In this untested area of Block K, Equatorial Guinea, the diversity of trap types, reservoirs and salt tectonics are quite different that the rest of the Rio Muni Basin, as well as the Northern Gabon Basin. It is an untested deepwater emerging play area.

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AAPG ICE, Cartagena de Indias, Colombia
Theme 5: Deep Water Exploration & Production: Emerging Global Deep Water Provinces

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University of Southern California

Outline

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- Megaregional setting and emerging plays.
- Basin boundary and local plays
- Rio Muni segment of study area: plays and structure; lines and visualization
- Northern Gabon Basin segment of study area: plays and salt tectonics
- Synrift play in Northern Gabon Basin segment.
- Conclusions

Block K: Intersection of Emerging Plays

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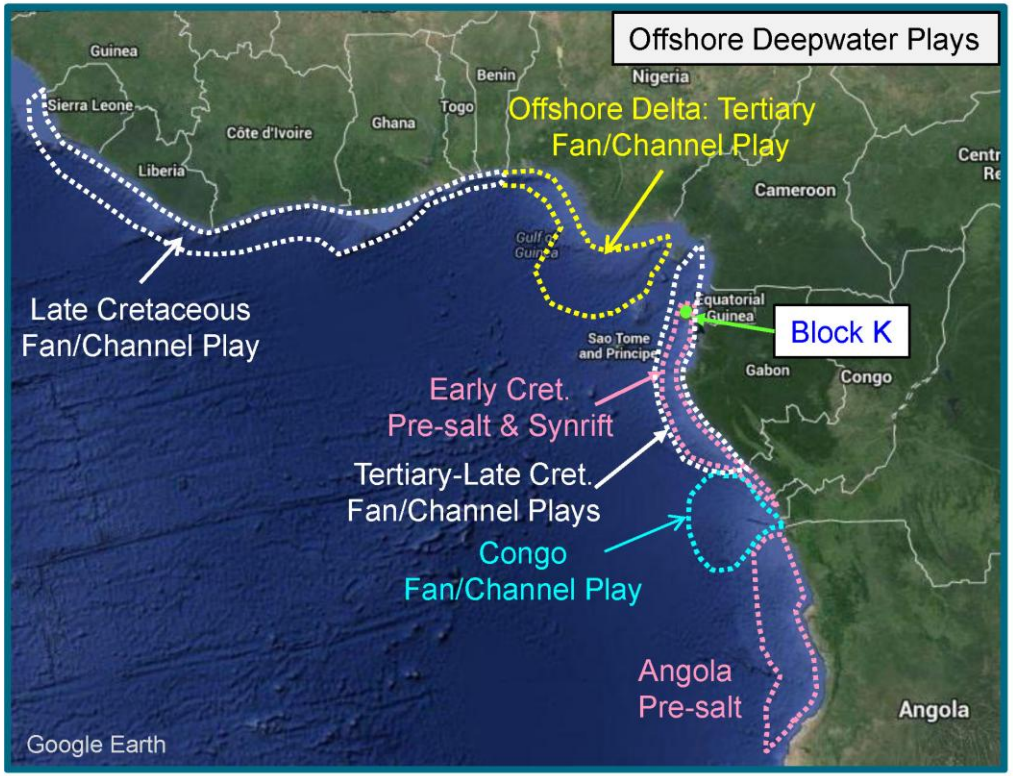

Presenter's notes: Let us look at the emerging plays in deepwater in West and Northwest Africa. PanAtlantic's Block K in Equatorial Guinea is here in this green dot. To the north we have the Late Cretaceous Fan/Channel Play which has had some giant discoveries in recent years in Ghana. To the south of that is the Niger and Rio de Rey delta with Tertiary fan and channel plays. In Cameroon to the Congo Tertiary-Late Cretaceous fan and channel plays are structural, stratigraphic or combination traps. The Early Cretaceous Pre-salt and Synrift play extends from Equatorial Guinea to the southern Congo. To the south of that is the Congo Fan/Channel Play. Finally we have the Angola Pre-Salt Play which has both sandstone and carbonate reservoirs.

Fracture Zones: Former Transform Faults

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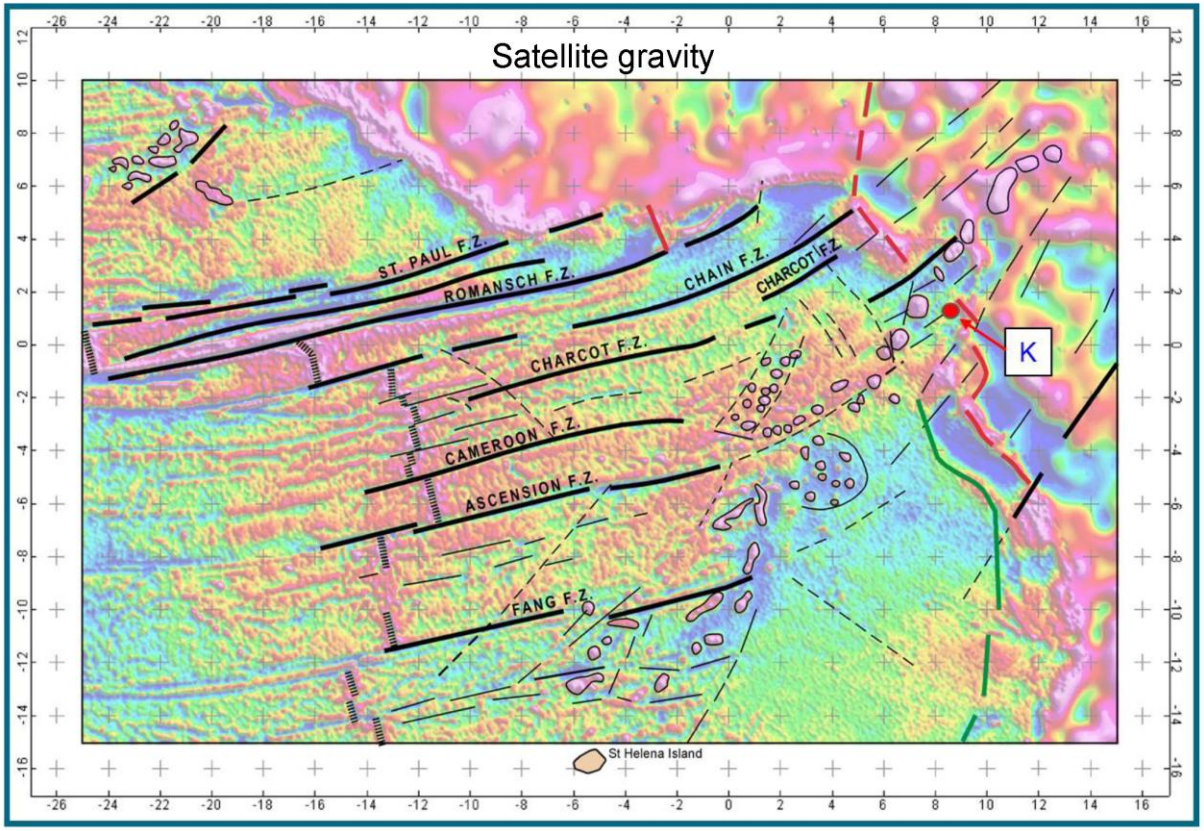

Presenter's notes: This is a satellite gravity map of the offshore and onshore. Fracture zones are usually inactive, away from the transform parts that separate the spreading Mid-Atlantic Ridge. Let me point out the Fracture Zones, like the Ascension Fracture Zone, which extends into Block K. Notice how the Ascension is segmented and offset near Block K.

Filling in Holes in the Pre-salt Rifts

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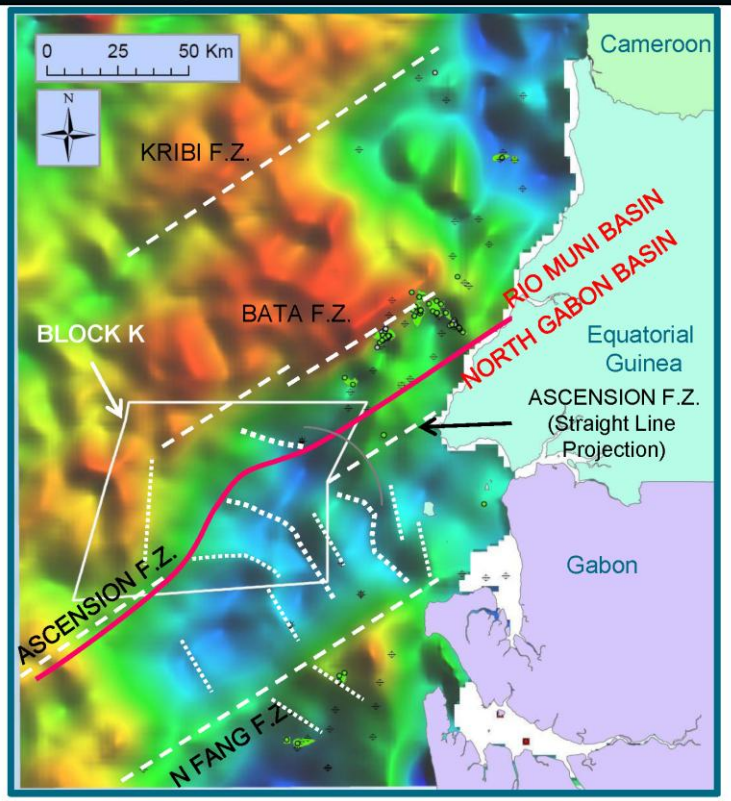
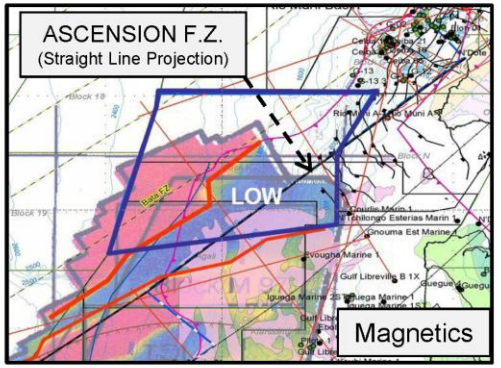


Isostatically Corrected Gravity

- Blue = gravity low
- Red = gravity high
- Basin boundary is really a broad zone, not a line



Gravity Data from GeTech, Wells and Fields from IHSEnergy and Geography from ESRI sources

Presenter's notes: Two types of potential field maps help us see the basement structure and the Aacension Fracture Zone. To the lower right is a magnetics map, with a straight-line projection of the Asuncion Fracture Zone. The magnetics show a broad low, with an irregular outline. The isostatically corrected Ascension is not simple. If you put on a straight line projection, you do not see it, because these secondary patterns suggest subsequent transpression. Gravity, on the left, is really interesting for basement structure: the holes that we fill after breakup with synrift sediments are later inverted. Several well defined fracture zones are expressed by the gravity data: the Kribi, Bata and North Fang, but not the Ascension. Secondary trends reflect inversion and transpression.

Stratigraphic Cycle Chart

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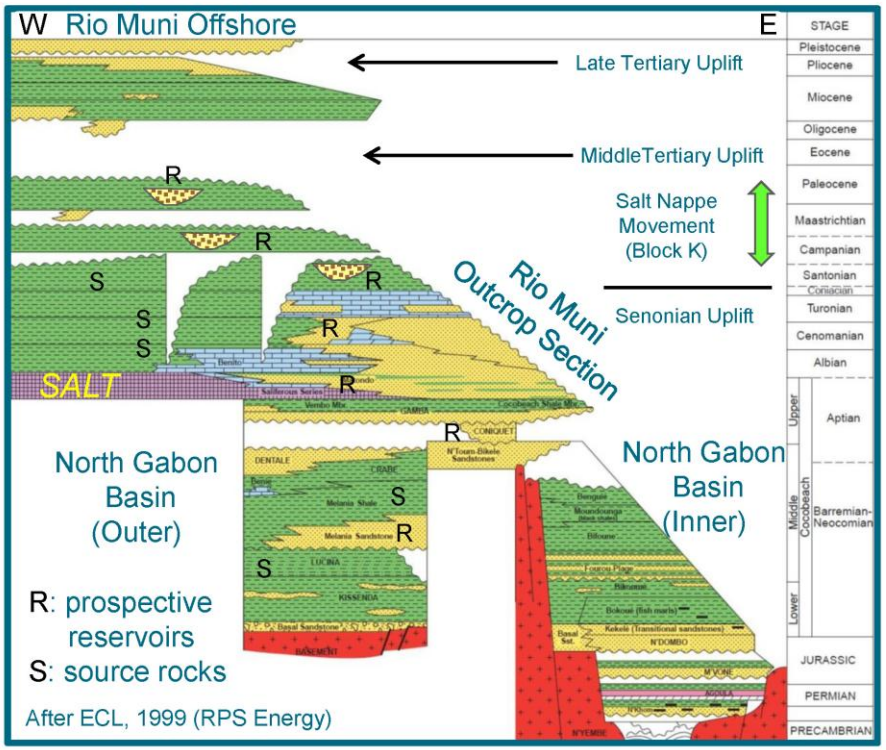
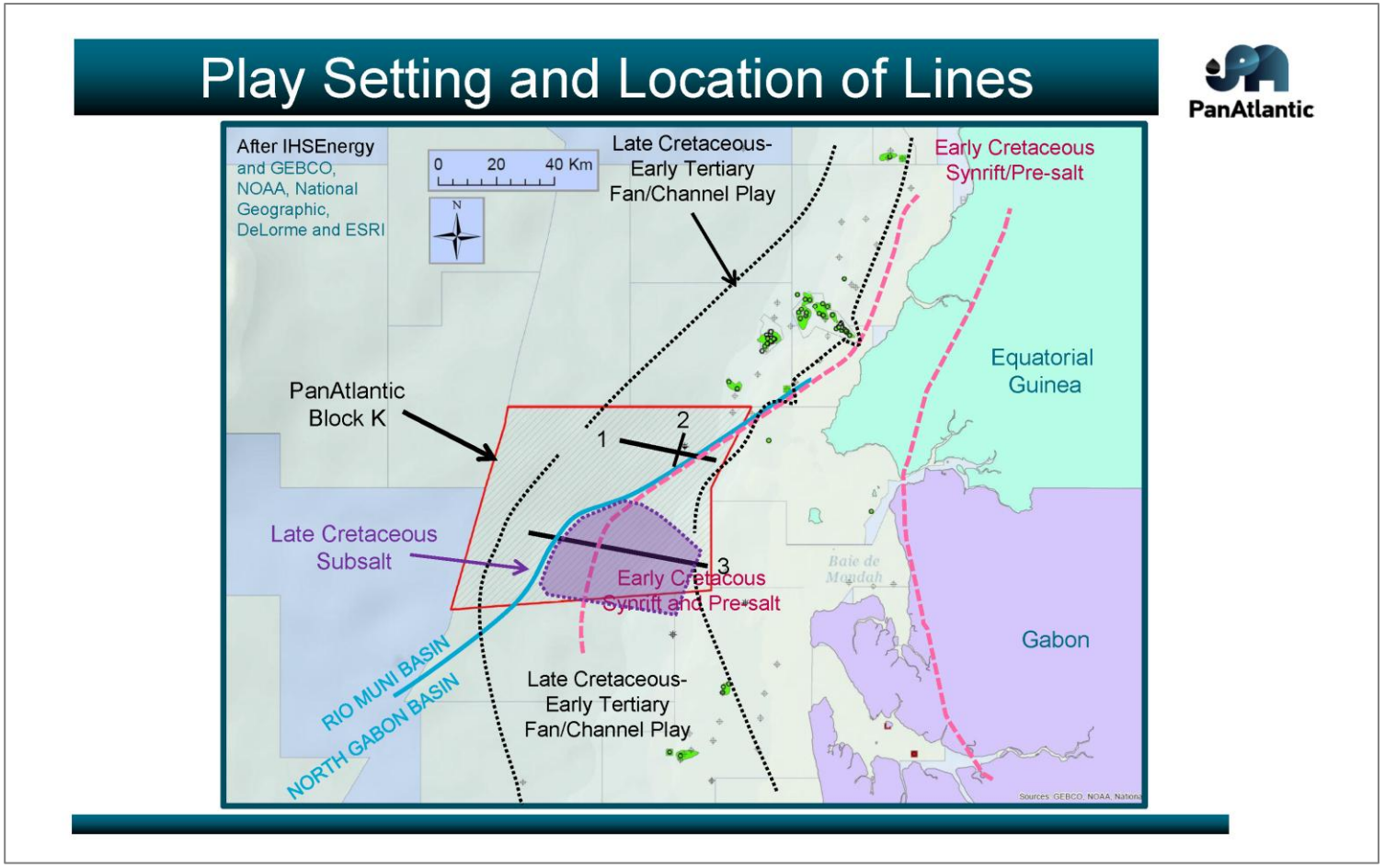
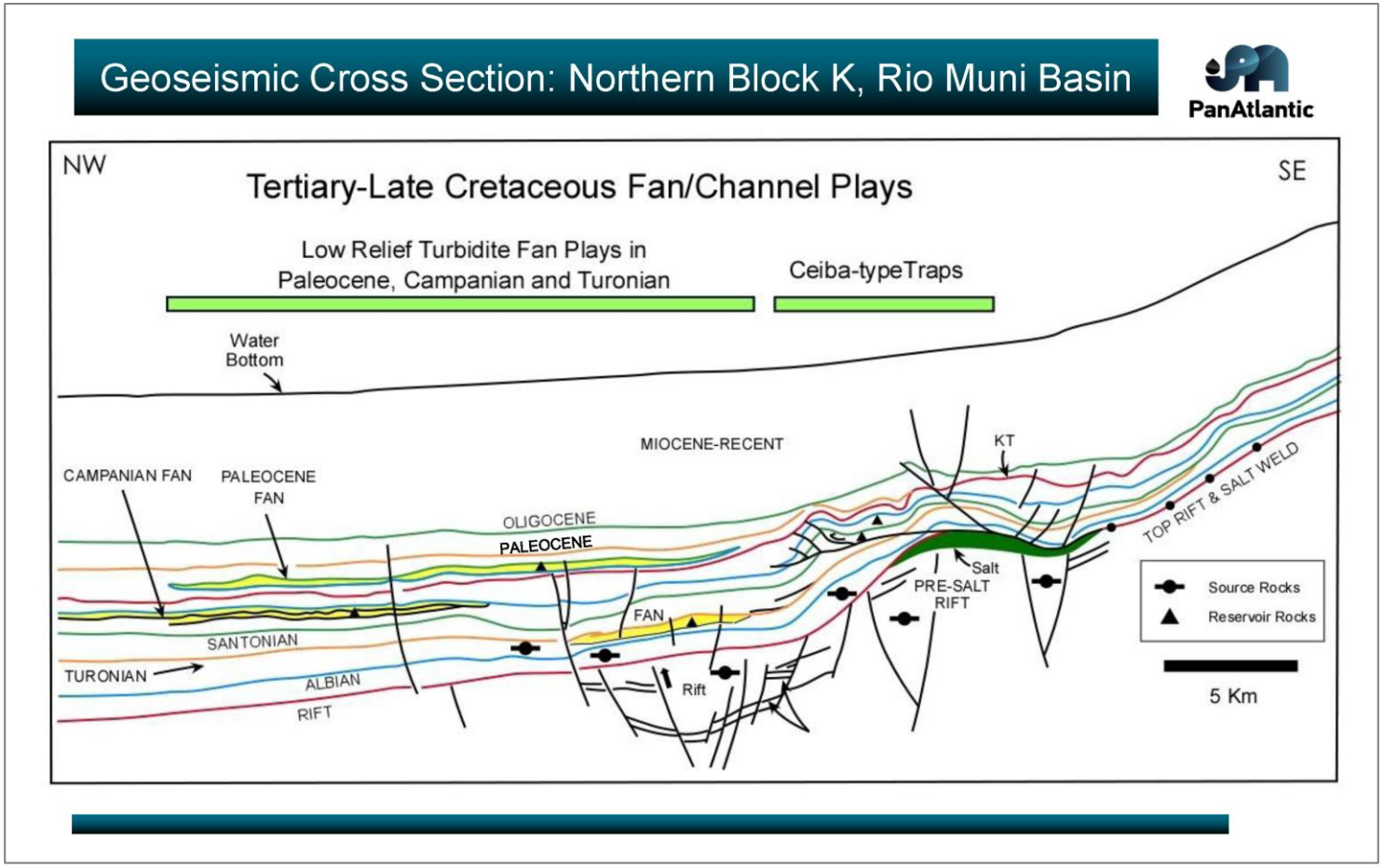


Presenter's notes: This stratigraphic cycle chart shows our expected section in the region, from west to east. R means prospective reservoirs, S means proven source rocks. First of all, notice the salt below the Albian marine section. Above that we have significant sandy reservoirs in the Paleocene, Campanian, and Santonian/Coniacian. The Turonian, Cenomanian and Albian are very sandy in the Northern Gabon Basin area of the study. Significant tectonic activity has caused movement of salt and formation of structures and traps. The Senonian Uplift, widespread in Africa and very well documented in the shallow shelf and onshore is here. Salt nappe movement in our area mainly occurred from the Santonian to the Middle Paleocene. We also have a Middle Tertiary Uplift and a Miocene to Pliocene uplift.

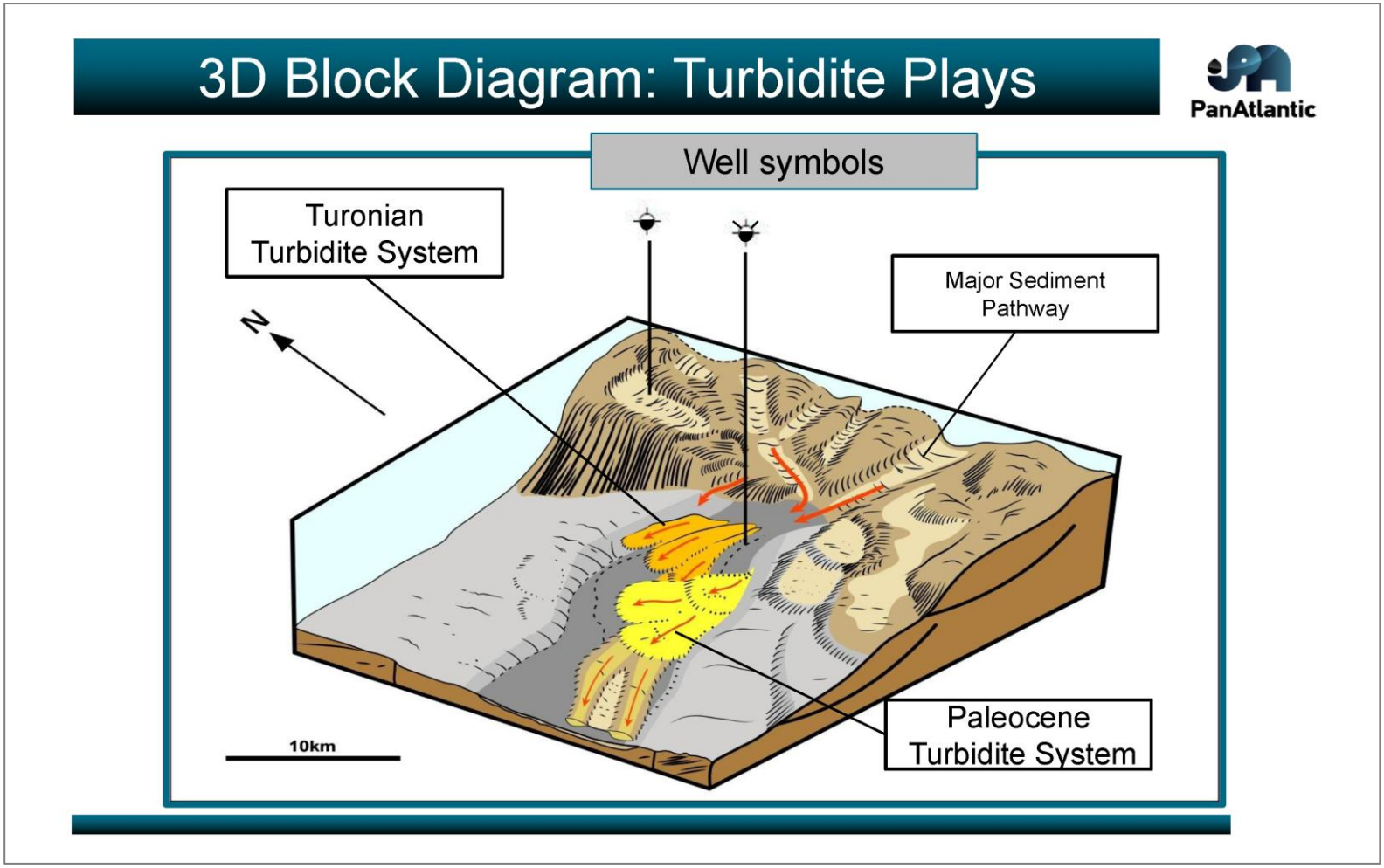


Presenter's notes: Let us look at the Play Setting and the location of lines and Geoseismic Cartoons we will show. Here is the PanAtlantic Block K. Fields and wells are from HIS Energy. We will show cartoons and seismic lines here at 1, 2 and 3. Note that the Early Cretaceous Synrift/Pre-Salt Play fairway extends into are large part of the SE of Block K, and extends a long ways into Gabon and further south. The Late Cretaceous-Early Tertiary Fan/Cannel Play extends from the Santonian oil fields of Ceiba and Okume north of Block K to the Campanian Oil Discoveries in Tullow's block in Gabon.

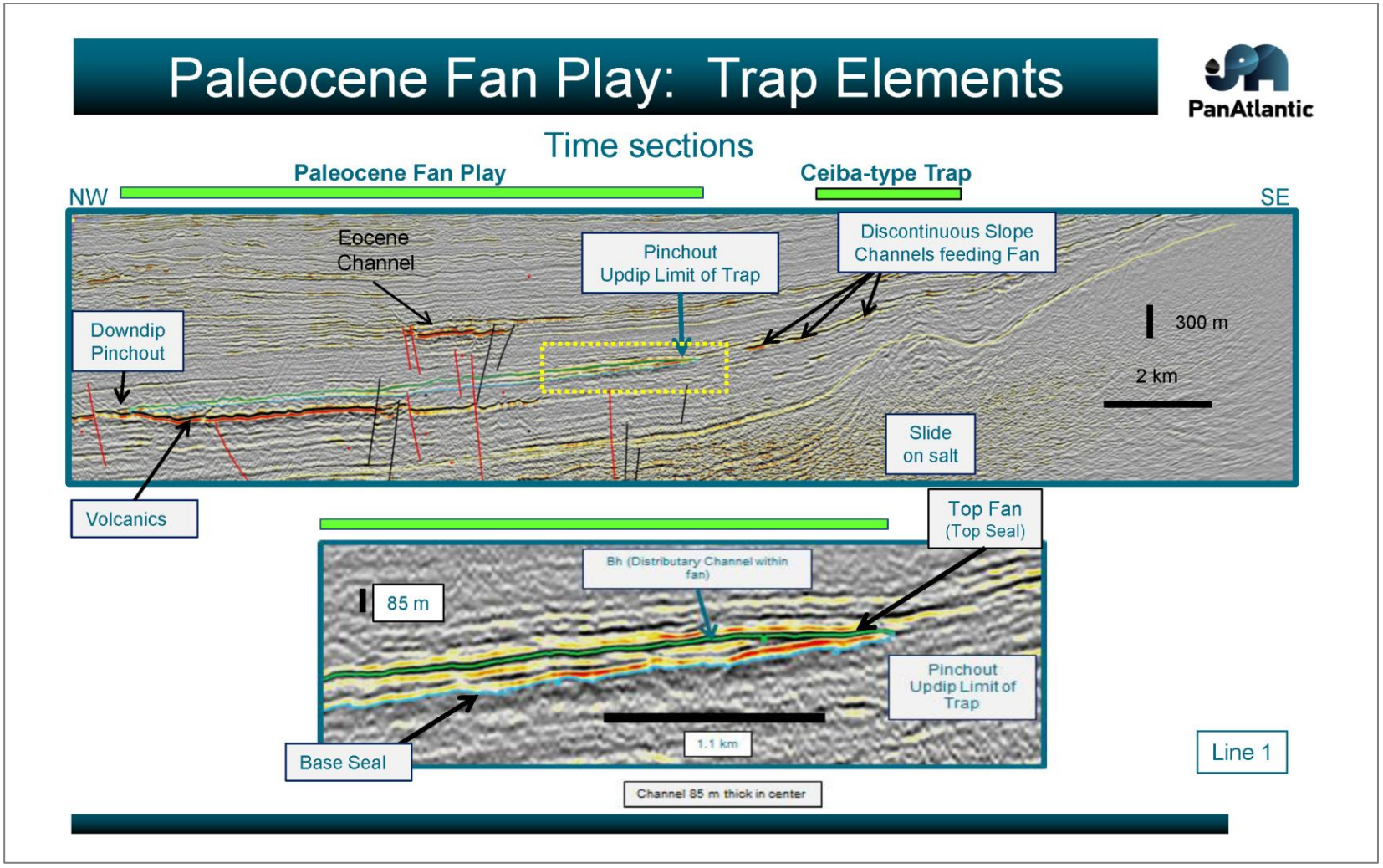
Finally, we have a Late Cretceous Subsalt Play in purple which likely will have reservoirs in the Upper Cretaceous.



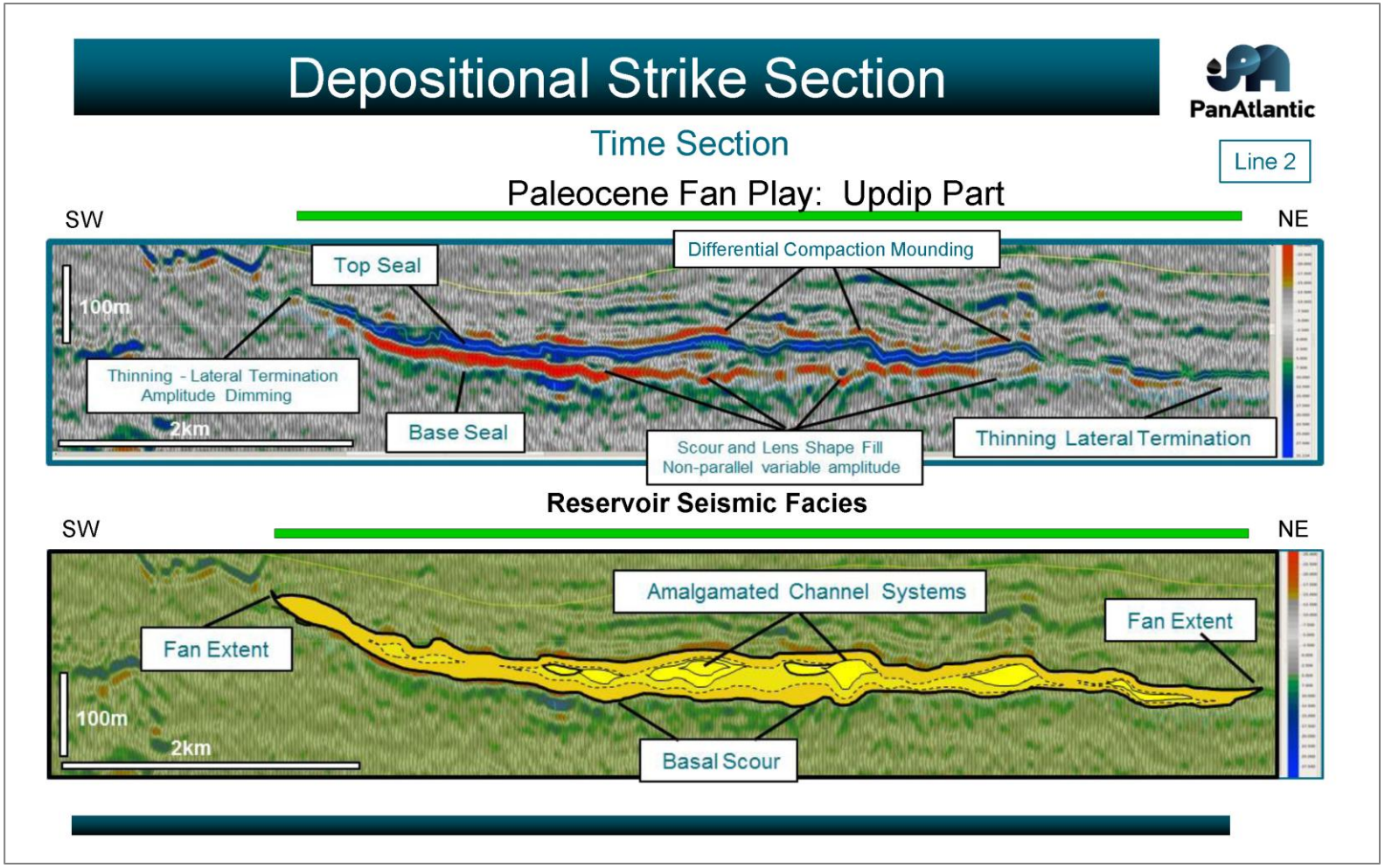
Presenter's notes: This is a geo-seismic cross section, or cartoon of the Rio Muni Basin part of this study, which was based on a time line. Note the horizon, which will be in other lines and sections. Rift, Albian, Turonian, Santonian, Campanian and Paleocene. Note the symbols for source rocks and reservoir rocks. We have two play areas, with traps on the section, the Ceiba-type Traps in the east. These consist of anticlines formed by sliding on salt, which have combination trapping potential in Late Cretaceous reservoirs. To the northwest, we have interpreted very low relief submarine fans in the Turonian, Campanian and Paleocene. In the fan play area there are deep-penetrating faults penetrating to the rift. The Paleocene Fan is quite similar to mostly stratigraphic traps in the deepwater Campos Basin of Brazil that I have examined, like the giant Marlim Field.



Presenter's notes: Let us look at the Turonian and Paleocene turbidite plays in a block diagram interpreted from our seismic interpretation. Note the direction of north. The major sediment pathway, a submarine canyon we believe has been in the same position from the Albian to present-day, and has some branches. Here is the Turonian turbidites system, which was not penetrated in this well, although minor sand was found. The Paleocene turbidite system has two fans and also was not penetrated in this well, which was on a basement rift high. Note the low angle thrust faults here, caused by sliding on salt.



Presenter's notes: This time line (near 5-15) shows both the Ceiba-type trap as well as the Paleocene Fan Play. Near the downdip pinchout, extensive volcanics occur in the section. Note the updip pinchout, base seal and discontinuous slope channels which feed this fan.



Presenter's notes: Here is a depositional strike section about 2 km downdip from the updip fan pinchout. It is a time section with depth conversions on the left. In the amplitude section at top, this is an abrupt pinchout on the southwest and a more subtle pinchout on the northeast. The top of the fan shows mounding caused by differential compaction. Note the excellent scour and fill, with chaotic seismic facies in this area. On the bottom, we see general seismic facies in yellow. The brighter yellow amalgamated channels systems likely have the highest net to gross, but we think there is high lateral connectivity of sands throughout this yellow area.

Transfer Faults and Tertiary Fan Play

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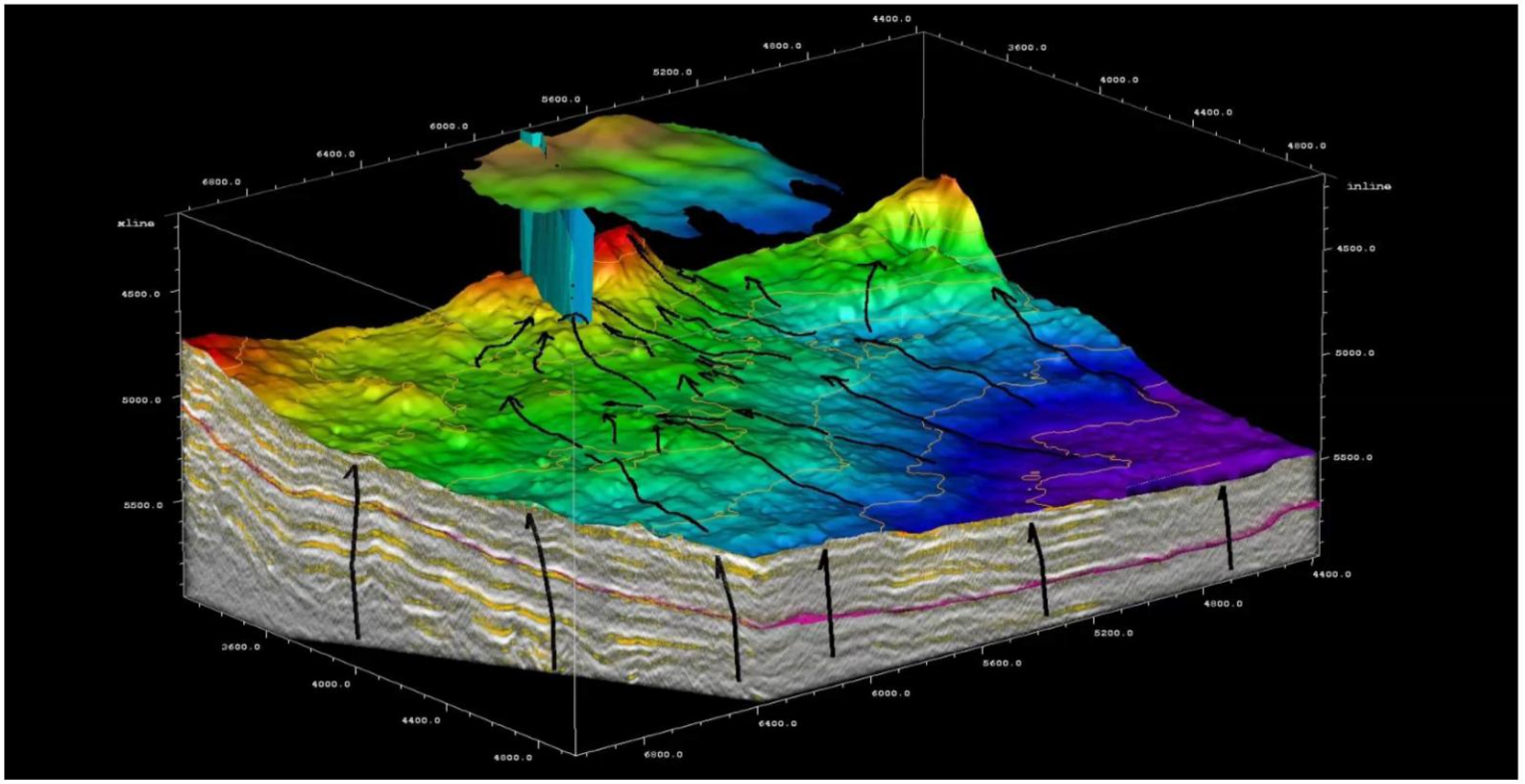

Presenter's notes: The geobody at the top is the Tertiary Fan Play and the colored surface is the top of the Albian. Vertical bodies between them are faults correlated in a weighted coherence/full stack volume. The rose colored horizon is the top Turonian. Transfer faults below the Albian surface can act as migration conduits to hydrocarbon charge.

Voxel Amplitude Visualization of Turbidite Systems

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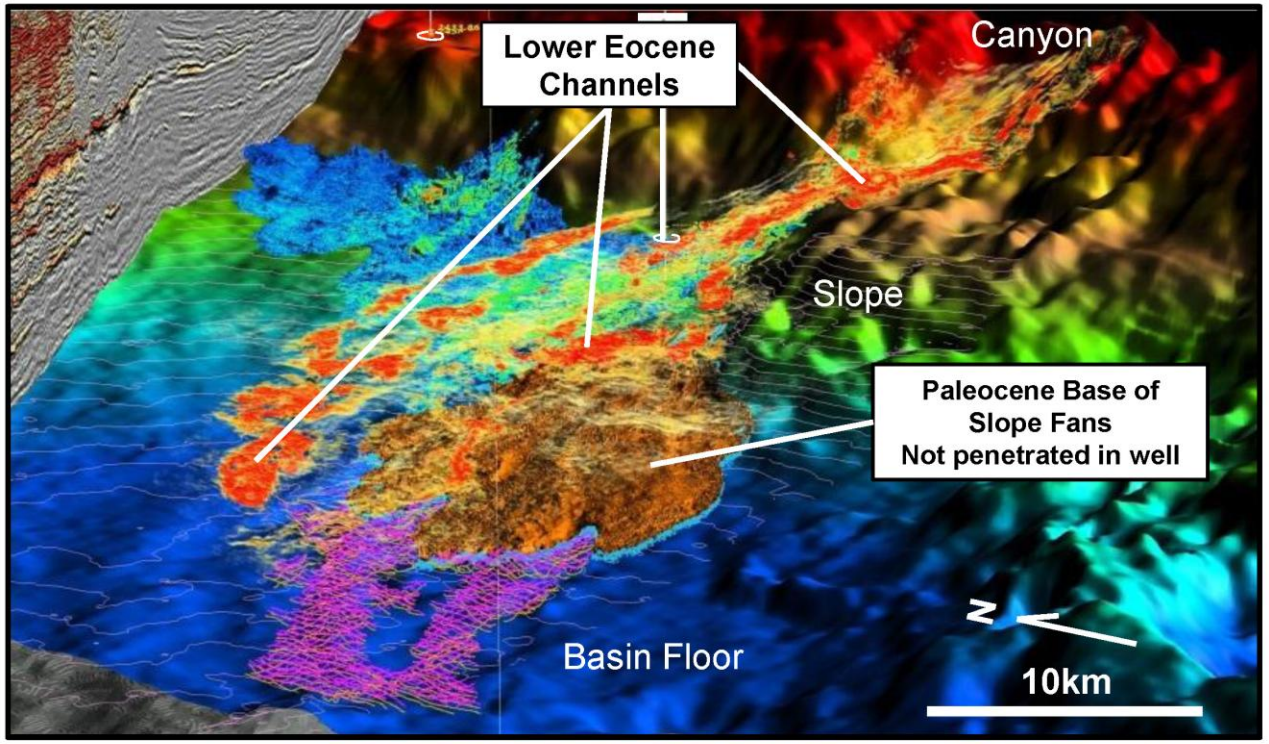

Presenter's notes: Note the north area and scale in lower right. The well penetrates very good Eocene channel sands, but is off to the side of the Paleocene Fan. The lower horizon is the regional Albian surface, and a conventional dip line is to the upper left. The canyon, slope and basin floor are well visualized. We think this canyon has been in place since the Albian, and is still active, just like the Ceiba Canyon. The brown surface is the Paleocene Fan we just showed, and the purple grid is an older Paleocene fan. The overlying Eocene channel system confined to channels with large shaly inter-channel areas.

Subsalt Play Setting and Location of Lines

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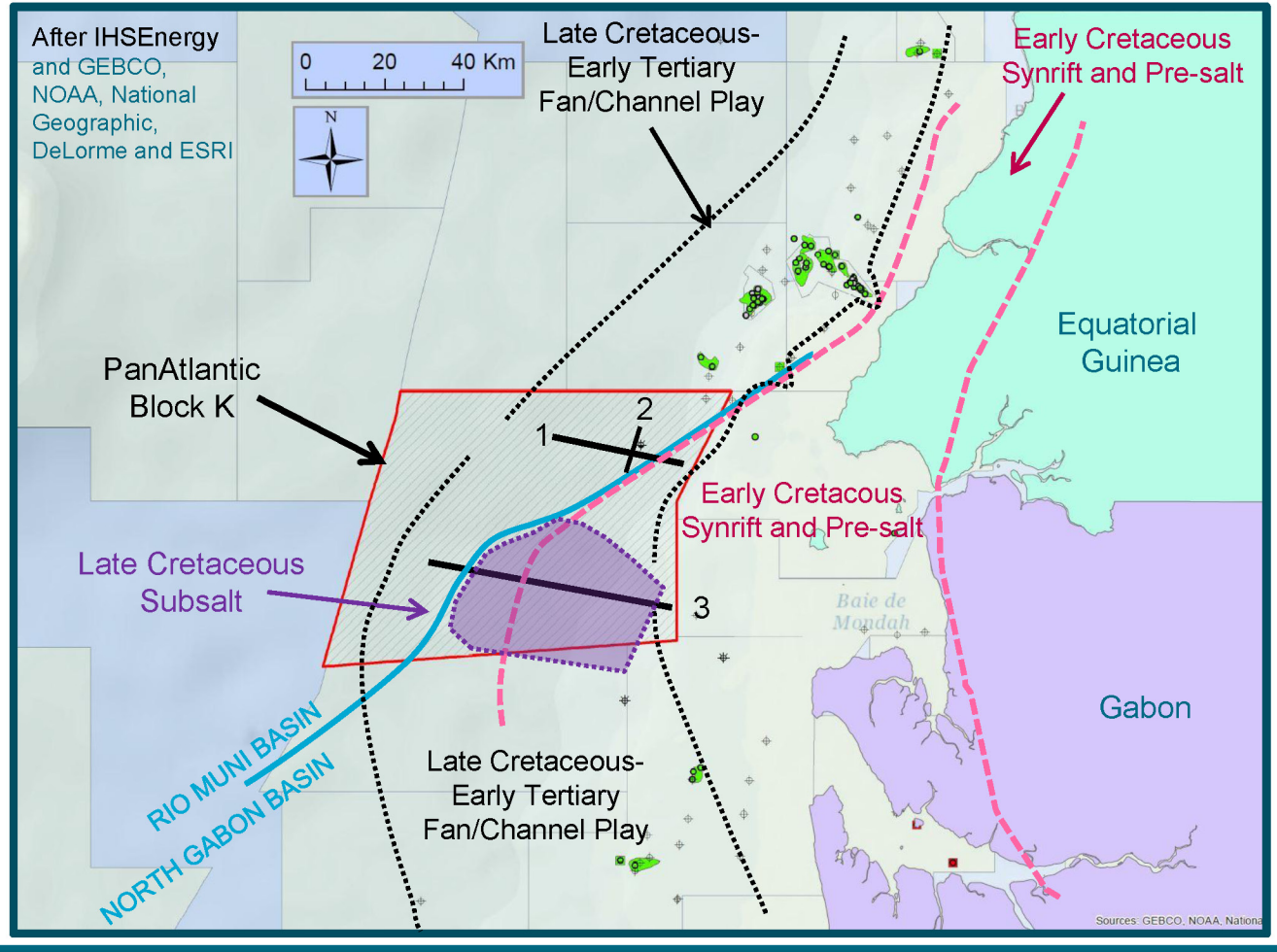

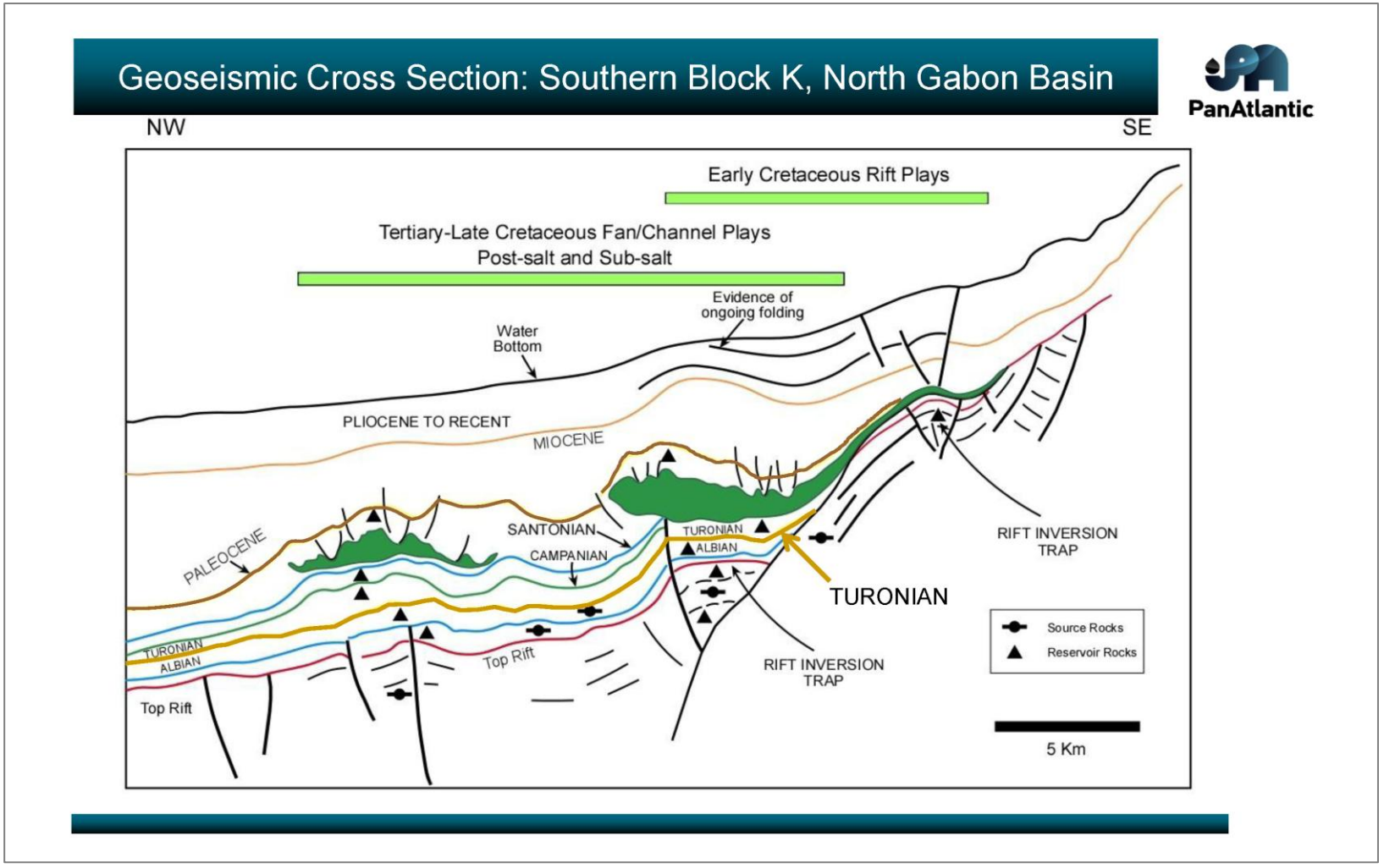

Presenter's notes: This geo-seismic cross section is based on a time section, and contains the same named horizons and symbols as before. Note the location of the two play fairways. Please note first the rift inversion traps below the salt, which we interpret are capped by Albian marine sediments. They are salt nappes displaced from up to 50 km away from the Southeast. The Subsalt Play is in the marine section below the salt with probable reservoirs in Albian, Turonian and Santonian in different trapping configurations. Note the folding on top of the salt, which is still occurring.

Semblance and Amplitude Rendering

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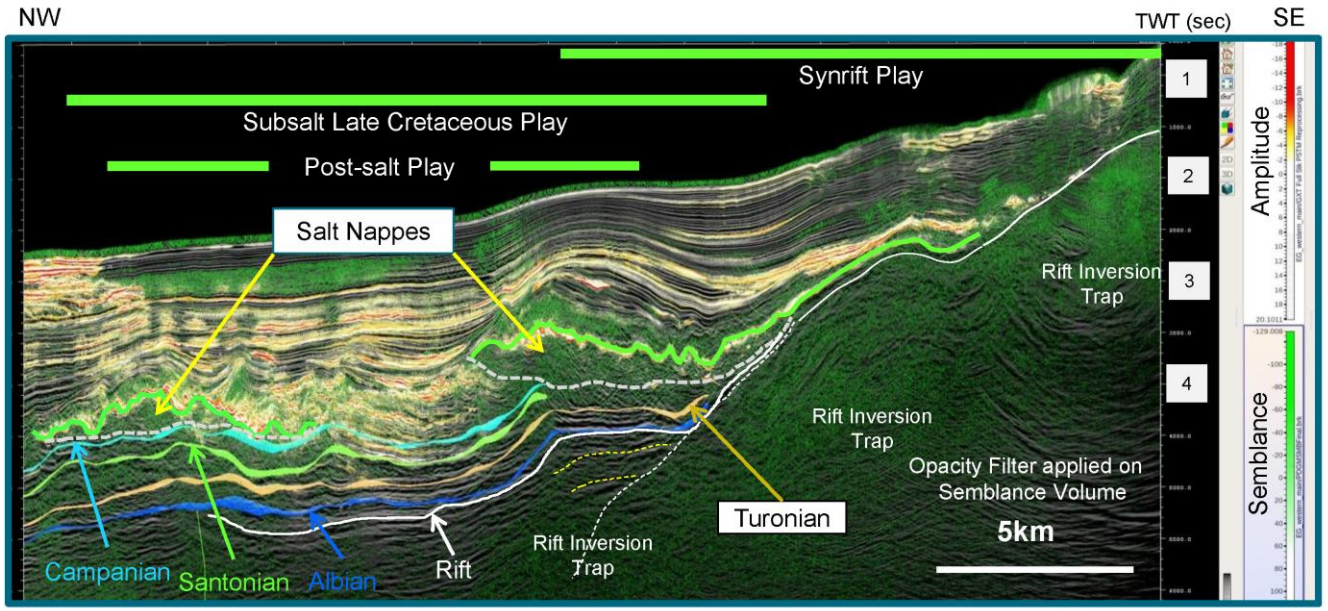
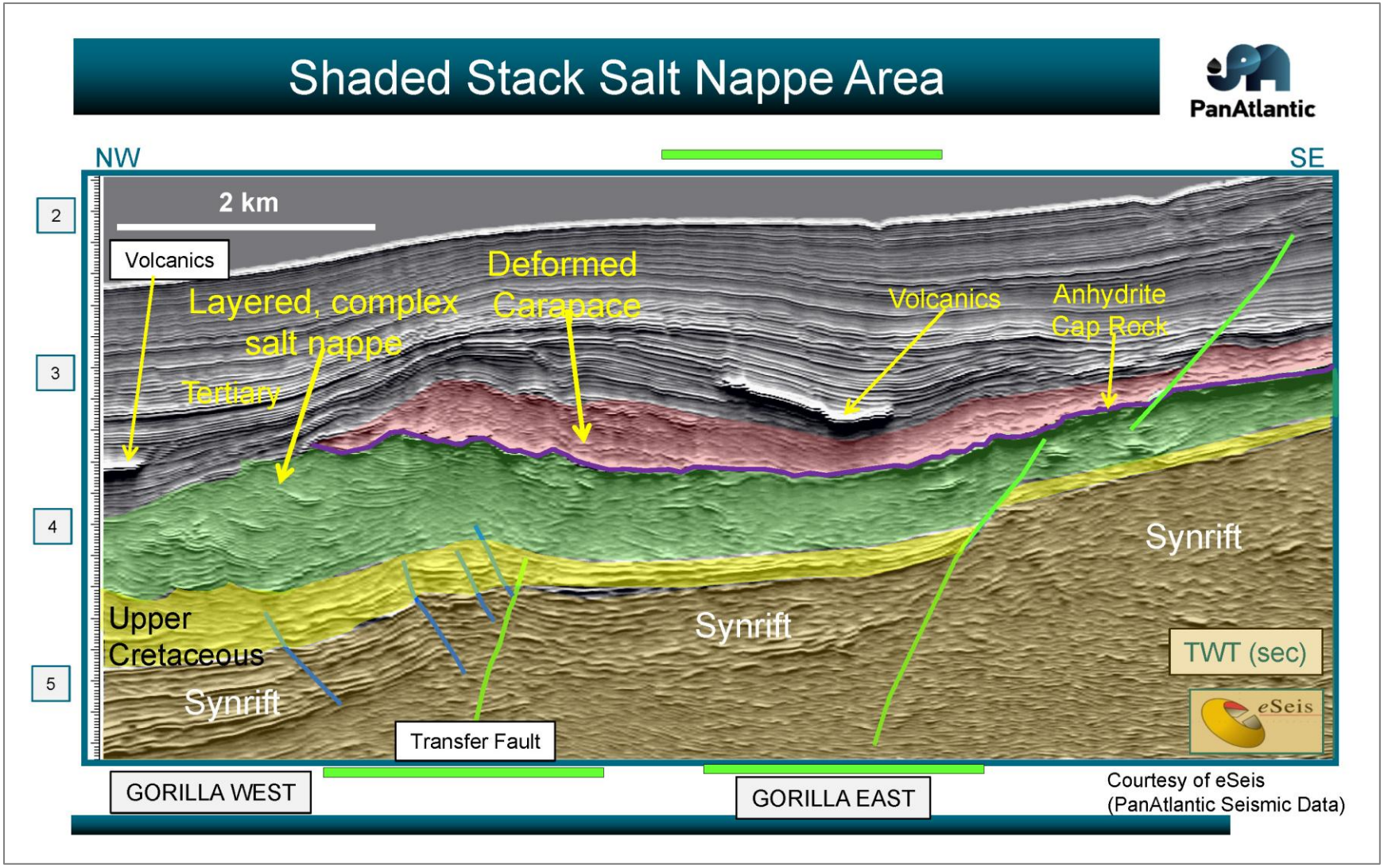
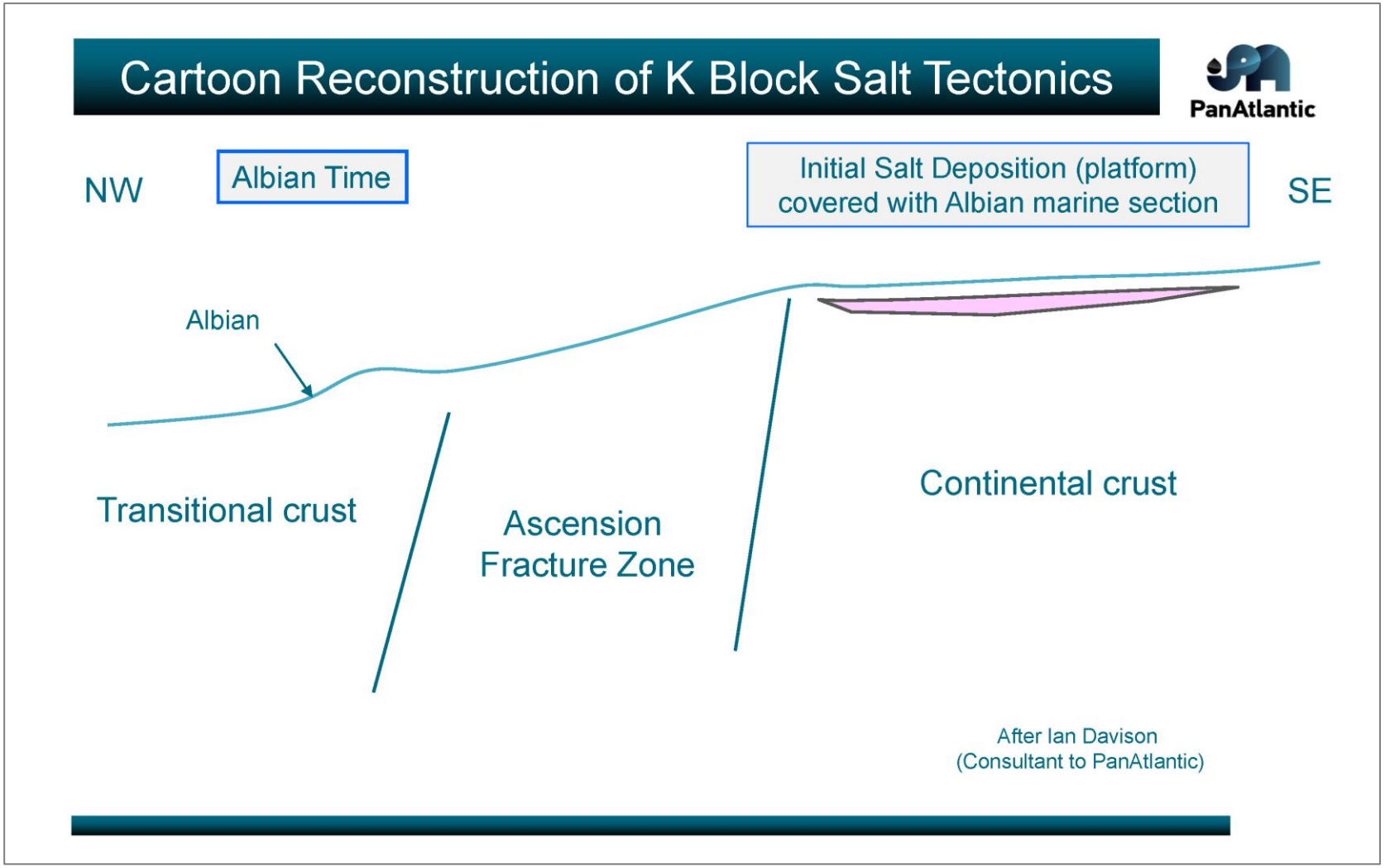
Optically stacked (40 lines)



Presenter's notes: Let us look at the salt area in seismic expression. This data is merged in Voxel Geo with semblance and amplitude volumes, then optically stacked over 40 lines. This enhances the data beneath salt, as well as potential post-salt sections. Please note the horizons, in particular the top rift in white, the Turonian in light brown and the top salt in bright green. The Synrift Play is located in these three areas where rift inversion has occurred. The salt extends from a thin salt over this rift inversion to thin, corrugated nappes. The top of the nappes have tight folds and faults likely caused by interbedded carbonates. Overlying the nappes is a very deformed zone which could possibly also contain some thin evaporites, as well as shale. Note the bright amplitudes in the post-salt play.

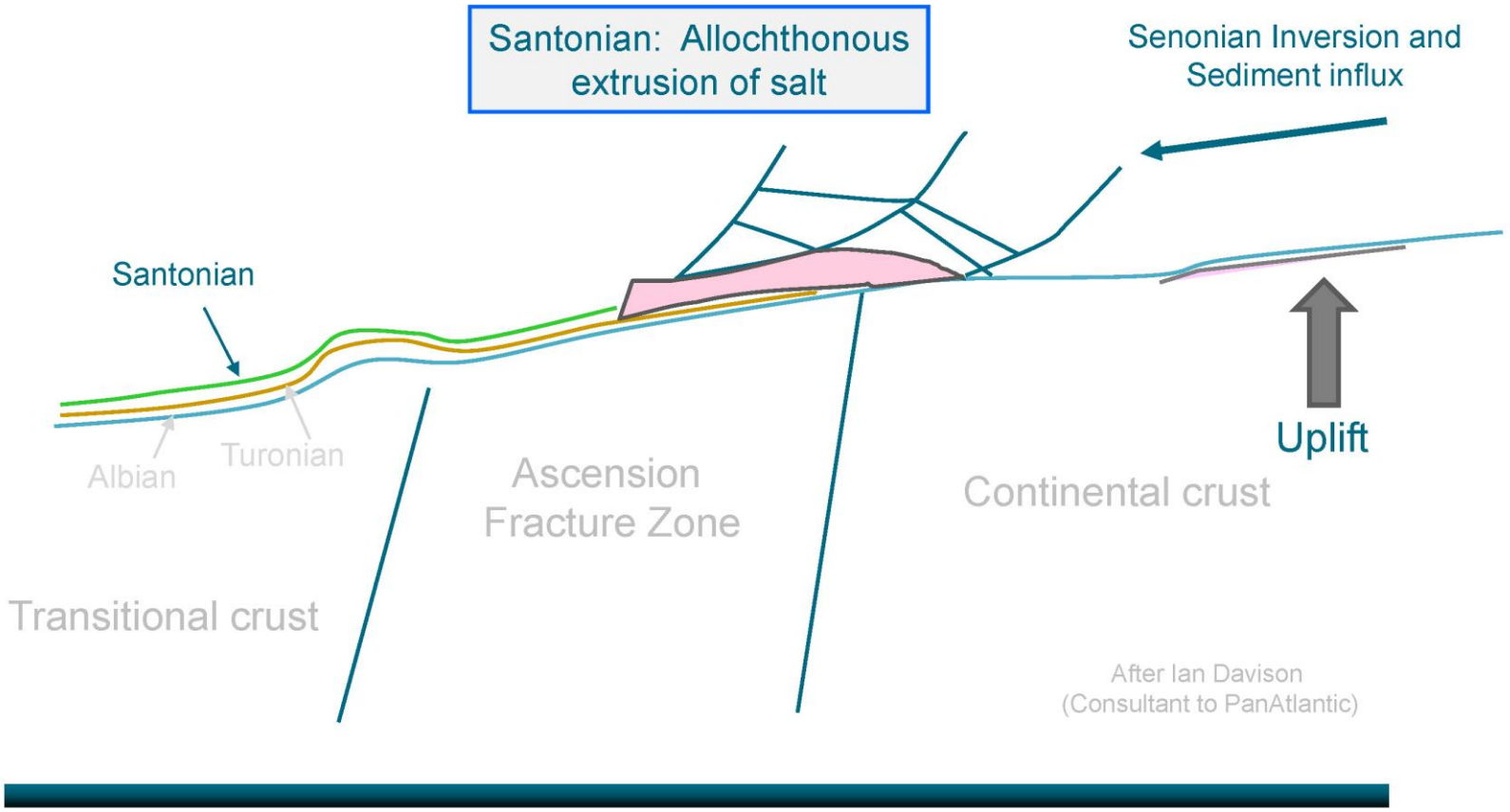


Presenter's notes: Shaded stacks of this older date really help to define the salt better. The salt complex is layered and contains thrusts and folds. The Upper Cretaceous and Synrift sequences are also better expressed. The deformed carapace may also have some evaporites in it, as well as brittle carbonates.



Presenter's notes: Let us look at cartoons which should show our model of how these spectacular nappes form, from southeast to northwest. The cartoon shows the Albian in a thin layer has covered the salt to the right, which was deposited in what was very shallow water in southernmost Equatorial Guinea and northern Gabon on continental crust. Here is the broad Ascension Fracture Zone, and further Northwest transitional crust.

Salt Extrusion Begins



Presenter's notes: In the Santonian considerable uplift occurred in the area, as well as throughout Africa during the Senonian. Downslope movement of salt was caused by a combination of this uplift plus sediment influx.

Multiple Salt Sheets Formed

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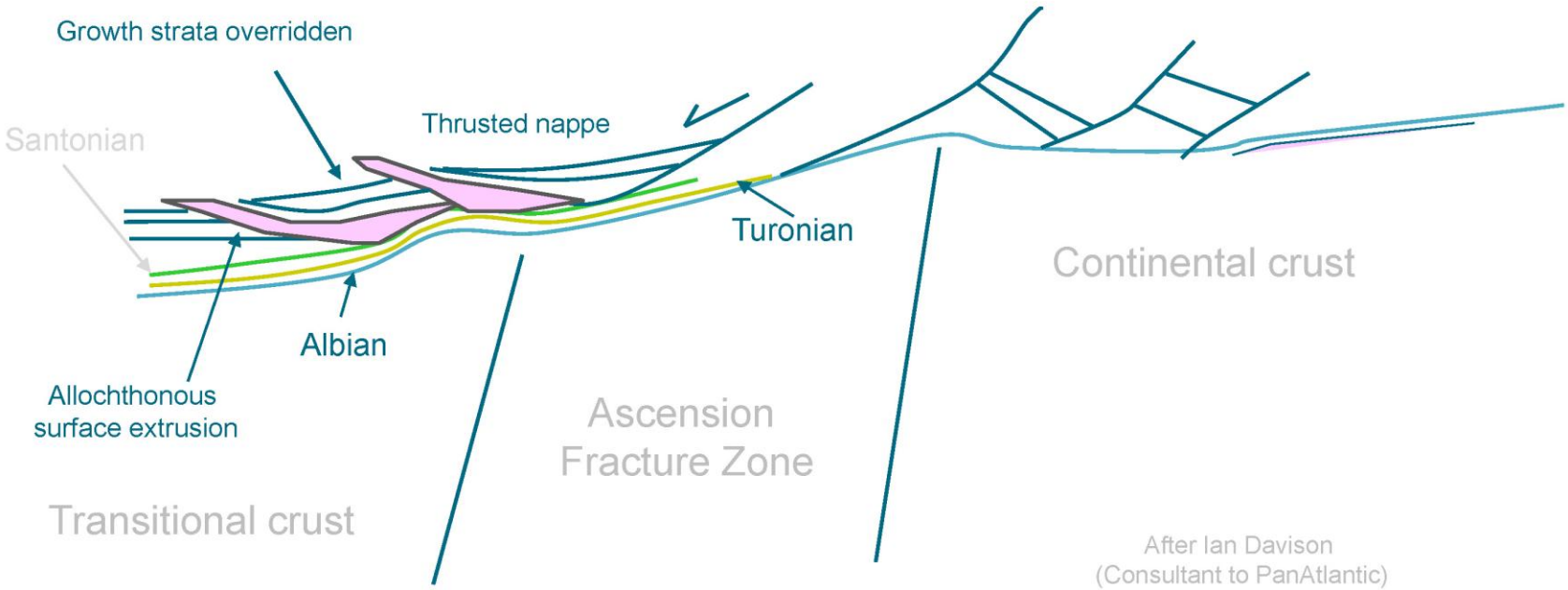
Paleocene-Eocene: Sheet is segmented and thrusted at break in slope.



Presenter's notes: The salt sheet is segmented after the outer nappe begins to be damned by sediment. It cannot move further, so the salt thrusts over sediment. Two nappes are formed.

Post Salt Deposition

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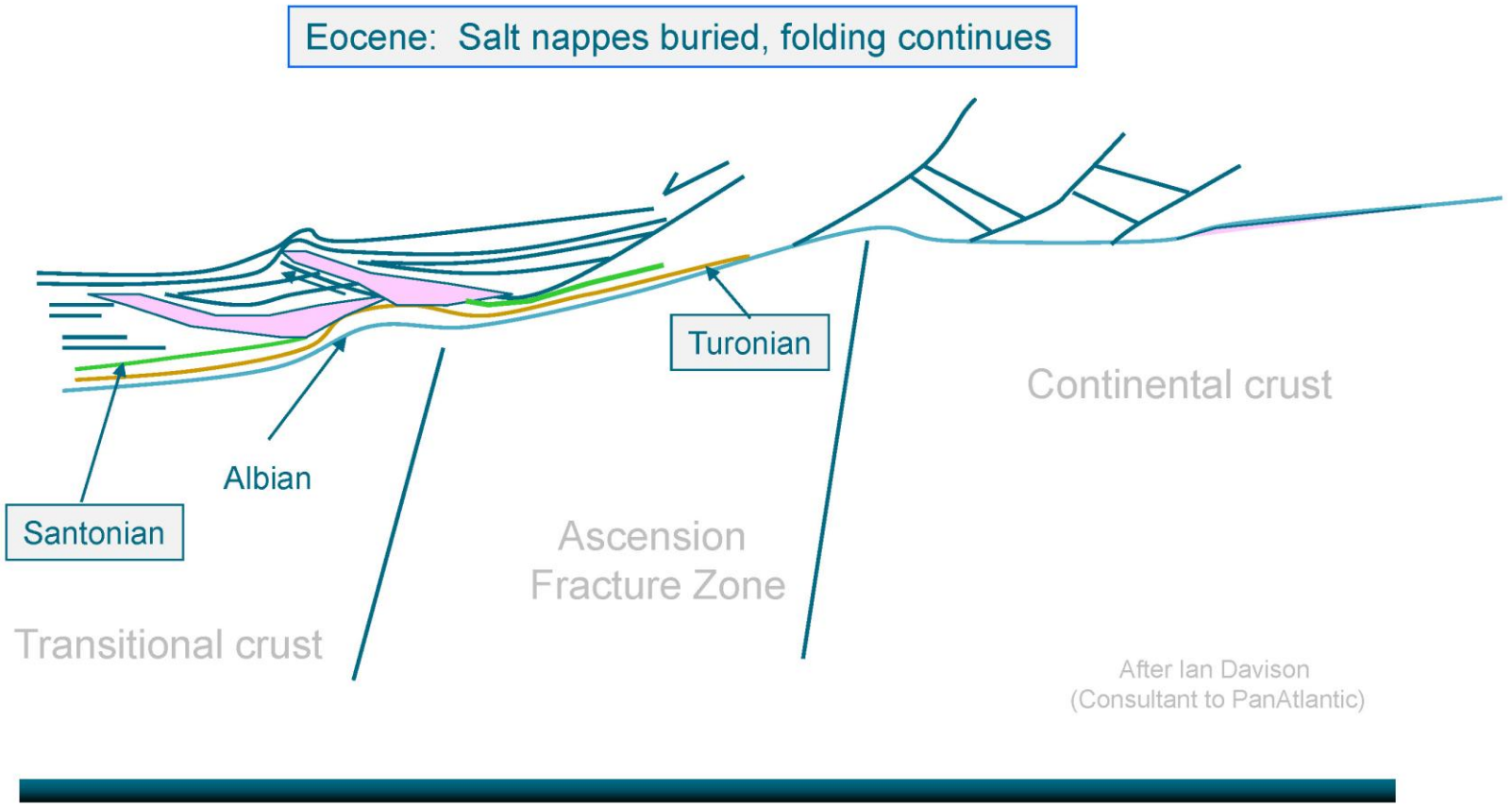

Presenter's notes: In the Paleocene and Early Eocene, the nappes are buried, but folding continues over both nappes. Note position of the Santonian sub-salt, as well as the Turonian.

Sediment Thickening and Folding

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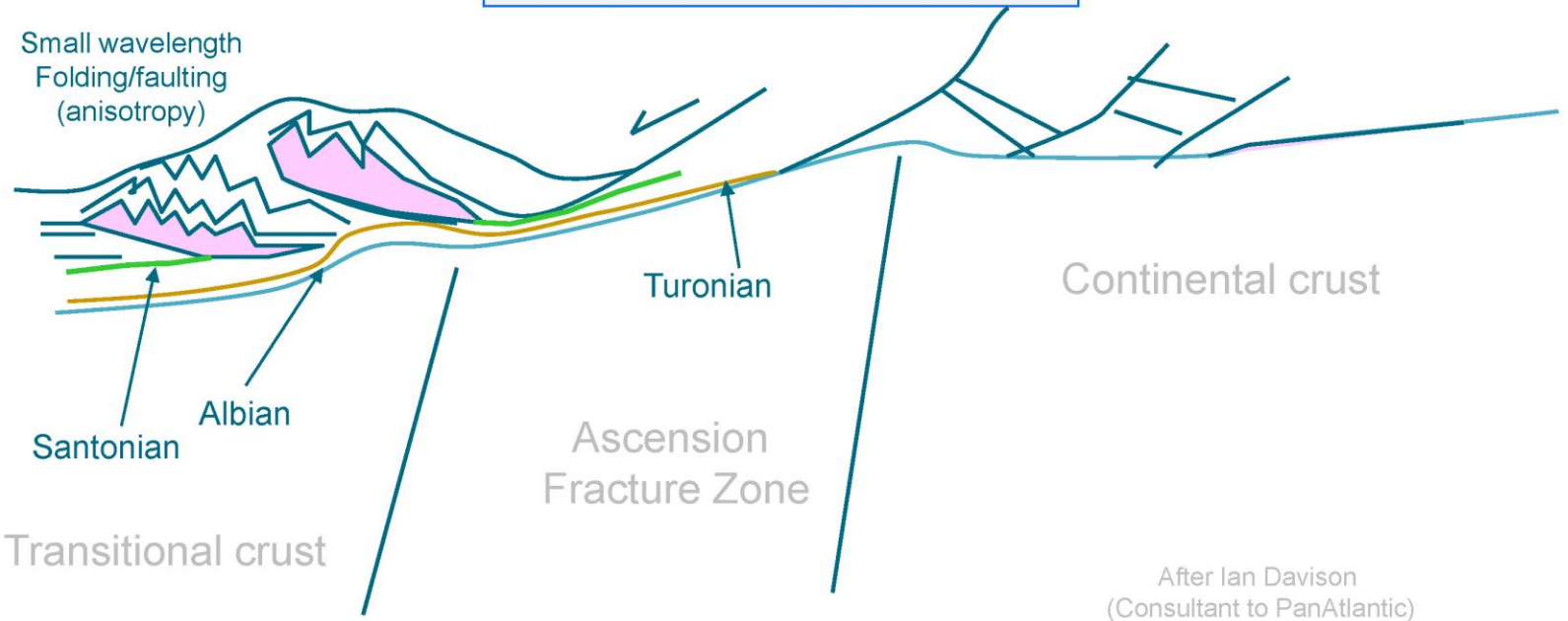
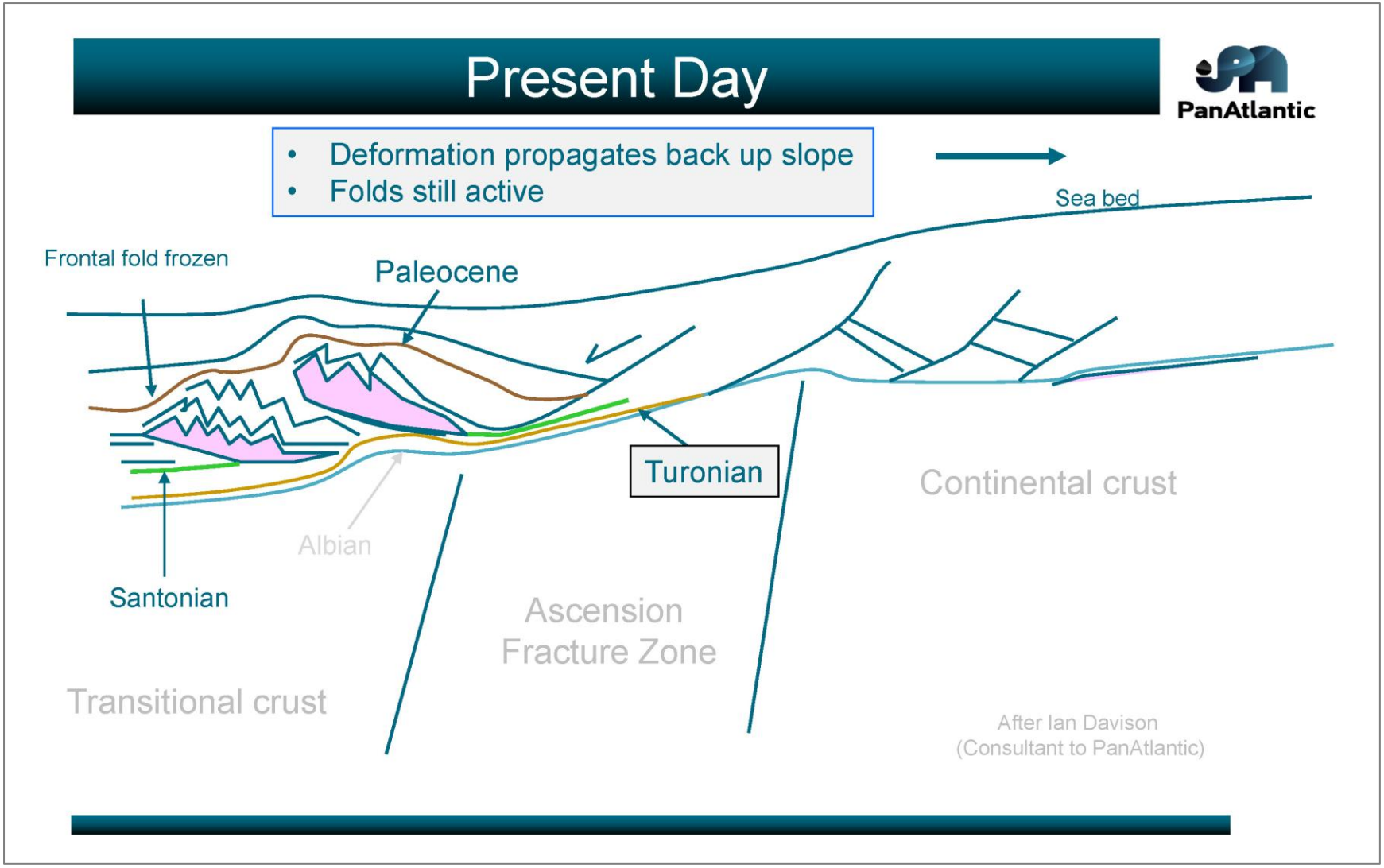
Oligocene-Miocene:
- Salt nappes thicken.
- Very active folding in Miocene



Presenter's notes: Folding is very active in the Miocene, which continues to segment the Santonian, as well as deforming the upper salt and post-salt which rides on it.



Presenter's notes: Folding continues to present day. Note the folds within the Paleocene in the post-salt play. Now deformation progrades landward.

Synrift Play Setting and Location of Lines

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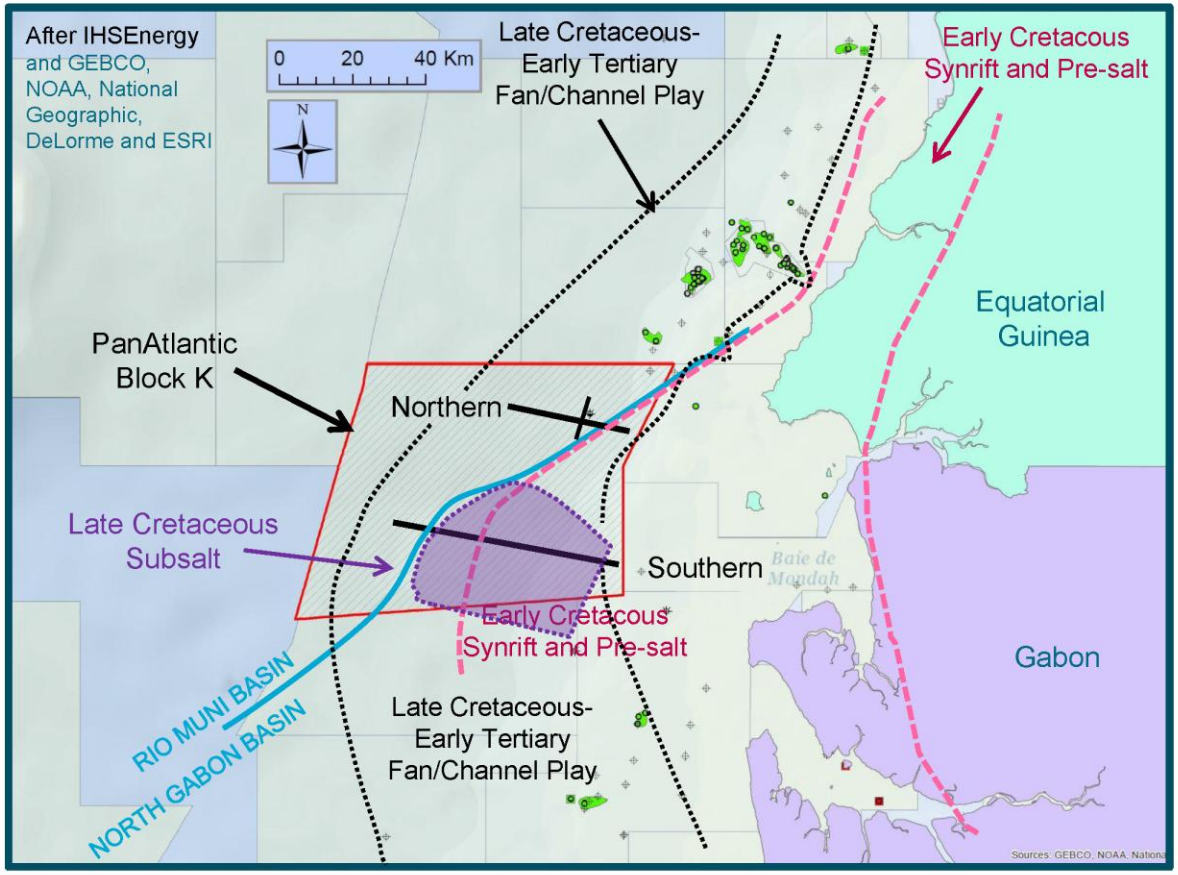

Presenter's notes: Let us look at some more at the Early Cretaceous synrift and pre-salt.

Late Synrift Plays Extend into Equatorial Guinea

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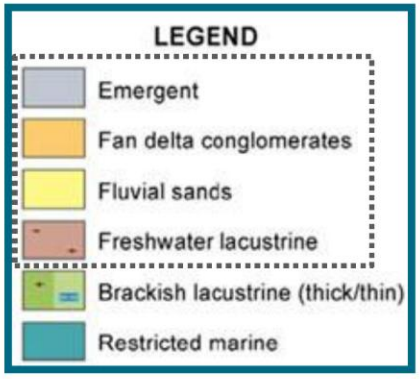
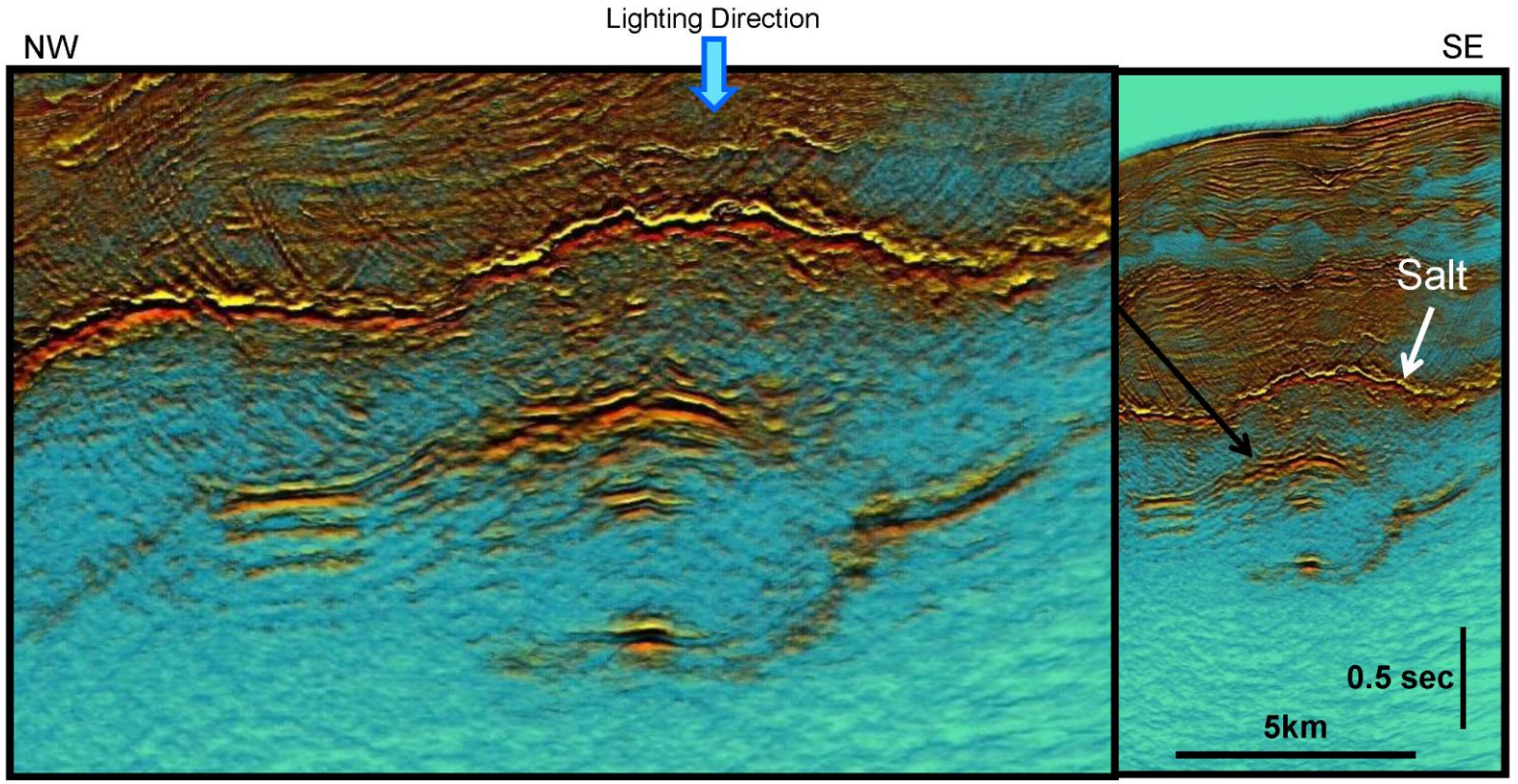
- Rift section extends from Gabon into Equatorial Guinea
- Potential reservoirs are fluvial lacustrine sandstones in wells adjacent to block



Courtesy of Martin et al (CGG Veritas), 2009, GeoExpro, Issue 6

Presenter's notes: In this figure the late synrift section extends throughout the South Atlantic Basin, and well into Equatorial Guinea. We would expect fluvial/lacustrine freshwater lacustrine sediments are present in all wells in the brown region.

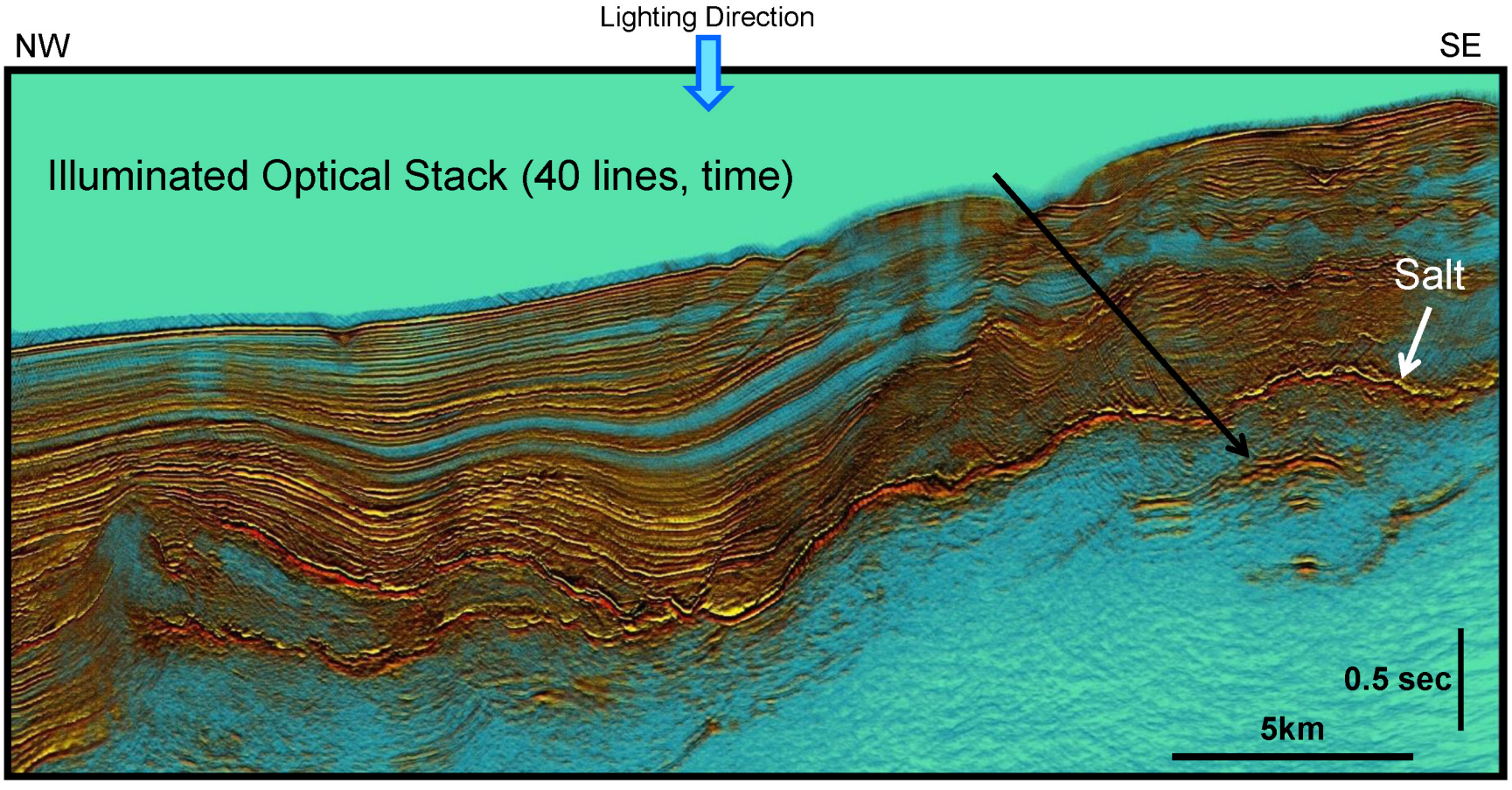
Looking for Synrift Traps



Presenter's notes: To see the synrift, we have to use some sophisticated geophysical technology to enhance the poor-quality deeper data. Here we see the salt nappe area, as well as thinner up-dip salt. Excellent faulted 3-way and 4-way traps are interpreted.

Looking for Synrift Traps

PanAtlantic



Conclusions

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- Very different structural styles and play types in the two basins in the study area.
- Salt is *allochtonous*, slid downslope at distances of 15-50 (?) km: nappes not canopies.
- Sub-salt play is frontier: undrilled in West Africa in nappe setting.
- Synrift sandstone play is not explored in deep water in Equatorial Guinea and just beginning to be drilled in Gabon. *Emerging play*.

Acknowledgements

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Thanks to Peter Gibbs, CGG Veritas and GEO ExPro for permissions to show figure.

Thanks to RPS Energy for permissions to show figure.