Can a Propagating Rift Model Finally Explain all the Peculiarities of the Rift Drift Evolution in the South Atlantic and in the Gulf of Mexico Basins?*

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Abstract

At continental scale, a propagating rift model implies that at a given time, different margin segments occur in a different stage of rift development. In the direction of propagation, the rift is getting younger. Thus, it is possible that in the area where the propagation initiated the rift is already developed into a deep oceanic basin, while at the tip of the propagation the rift is still in the early stage of development and occurs above sea level. Clearly, at a given time, paleogeographic conditions along rifted continental margins, such as paleo water depth, can be very different. A common work hypothesis, for example, in the Gulf of Mexico, is that salt represents the last syn rift deposits and that no autochthonous salt was deposited over oceanic crust. We propose that the presence of autochthonous salt only tells us that the paleogeographic conditions were favorable for salt deposition along a given margin segment. More specifically, the paleogeographic requirements for salt deposition are a) intermittent saltwater supply resulting in a restricted basin and b) subsidence below paleo sea level, providing accommodation space for salt deposition. In simple terms, the salt has no knowledge about the nature of the underlying basement rocks, but it is very sensitive to the paleogeographic conditions. The “salt deposition window” is a well-defined time interval when salt can form along a margin. We propose that the amount of salt observed along a continental margin is directly related to the accommodation space available during the salt deposition window. In the Gulf of Mexico, proceeding from the west towards the east, and in the South Atlantic from the south to the north, we observe decreasing amounts of salt. At the end of the spectrum in the Southeastern Gulf of Mexico and in the South Atlantic north of Gab on we observe no salt at all. A natural interpretation is that in these salt free areas the evolving continental rift had not subsided yet below paleo sea level during the salt deposition window. This salt deposition window in the Gulf of Mexico occurred approximately in the Bathonian Callovian and in the South Atlantic in the Aptian. The salt deposition ceased in both cases because of the end of restriction and not because oceanic crust formation had started. Rift propagation provides a natural explanation for the observed differences in salt thickness. During the Gulf of Mexico oceanic crust formation, the Yucatan block rotated counterclockwise about 42 degrees around a pole just north of Cuba. The breakup undoubtedly occurred in the Western Gulf perhaps as early as in the Bathonian. This was also the beginning of salt deposition in this basin. Thus, in the Western Gulf and in the Bay of Campeche we likely have Louann salt deposited over coeval (Bathonian/Callovian) oceanic

crust. The tip of the rift propagated towards the east and curved down into the area of the Southeastern Gulf of Mexico. In the Eastern Gulf the amount of salt is significantly less, indicating relatively less available accommodation space during the salt deposition window. In the Southeastern Gulf of Mexico, we explain the lack of salt with insufficient tectonic subsidence in the Callovian. In other words, the Southeastern Gulf of Mexico “missed” the Callovian salt deposition event. Further rotation, rift propagation and oceanic crust formation continued in the Gulf of Mexico till at least the Berriasian. During the Oxfordian to Berriasian period, although the Southeastern Gulf of Mexico also subsided below paleo sea level, open marine circulation was established in the whole basin and paleogeographic conditions became unfavorable for salt deposition.

In the South Atlantic, south to north rift propagation is well documented. Rifting started at the southern tip of Africa in the Upper Jurassic and it reached the Equatorial Atlantic only in the Albian. In the South Atlantic the “salt deposition window” occurred in the Aptian and only occurred north of the Walvis ridge, a volcanic hot spot chain which provided a deep seal and restricted circulation for the Cretaceous Brazilian and Angolan salt basins. Careful cross-sectional salt area measurements along the Angolan margin show a monotonously decreasing amount of salt from the south in the Benguela basin towards the north in the Kwanza and Lower Congo basins. North of the Ascension FZ in Gabon there is no mobile salt observed. In the Benguela basin we have evidence that autochthonous salt exists in marine magnetic lineation M3 (Barremian). In other words, there, autochthonous salt was deposited in an already opening deep oceanic basin. The only way to explain the lack of salt north of Gabon is that that the South Atlantic rift was still propagating towards the north and the rift was still above paleo sea level during the Aptian salt deposition window. Final separation between Africa and South America occurred in the Albian, during which time open marine circulation was established (restricted marine conditions ceased) along the full length of the Central and Equatorial Atlantic. In conclusion, we propose that the occurrence of salt, or lack of salt is controlled by the paleogeographic conditions along passive margins. The duration of marine restriction controls the length of the “salt deposition window”. The amount of salt, on the o the r hand, is related to the available accommodation space. In an already opening oceanic basin (drift stage) a significant amount of accommodation space is available for salt deposition and large salt thickness can develop. On the other end of the spectrum, in front of the tip of the propagator (earlier in the synrift stage) the margin can occur above paleo sea level, where no (marine) salt deposition is possible. In general, salt deposition is not directly related to any of the rifting stage. In a propagating rift setting the same age salt can occur over oceanic crust or only over continental crust, depending when the breakup occurs along the margin segment relative to the “salt deposition window”.

References Cited

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E.R. Lundin and A.G. Doré, 2017, The Gulf of Mexico and Canada Basin: Genetic Siblings on Either Side of North America: GSA Today.

Marton, G.L., 1995, Jurassic evolution of the Southeastern Gulf of Mexico: PhD dissertation, The University of Texas, Austin, Texas, 275 p.

Can a propagating rift model finally explain all the peculiarities of the rift-drift evolution in the South Atlantic and in the Gulf of Mexico basins?

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Geology and Hydrocarbon Potential of the Circum-Gulf of Mexico Pre-salt Section

10 historical GOM oceanic crust distribution in the literature (Marton Ph.D. Dissertation 1995)
Lack of good constrains is obvious in these early works .

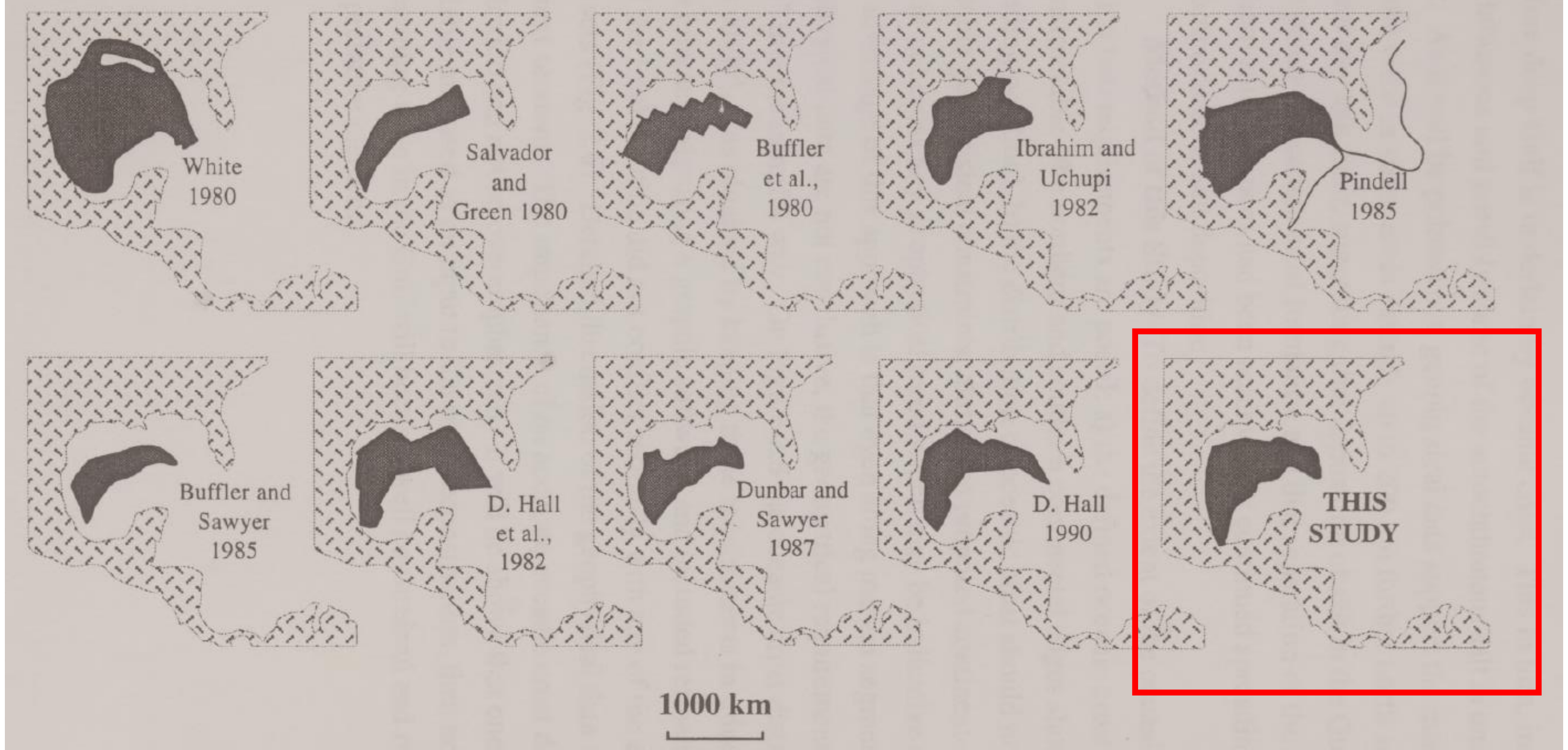


Fig. 2.5 Different oceanic crust definitions from the literature. Dark gray areas represent the inferred distribution of oceanic crust in the Gulf of Mexico Basin.

Rigid plate reconstruction results in conspicuous gaps and overlaps in GOM reconstructions(Marton Ph.D. Dissertation 1995)

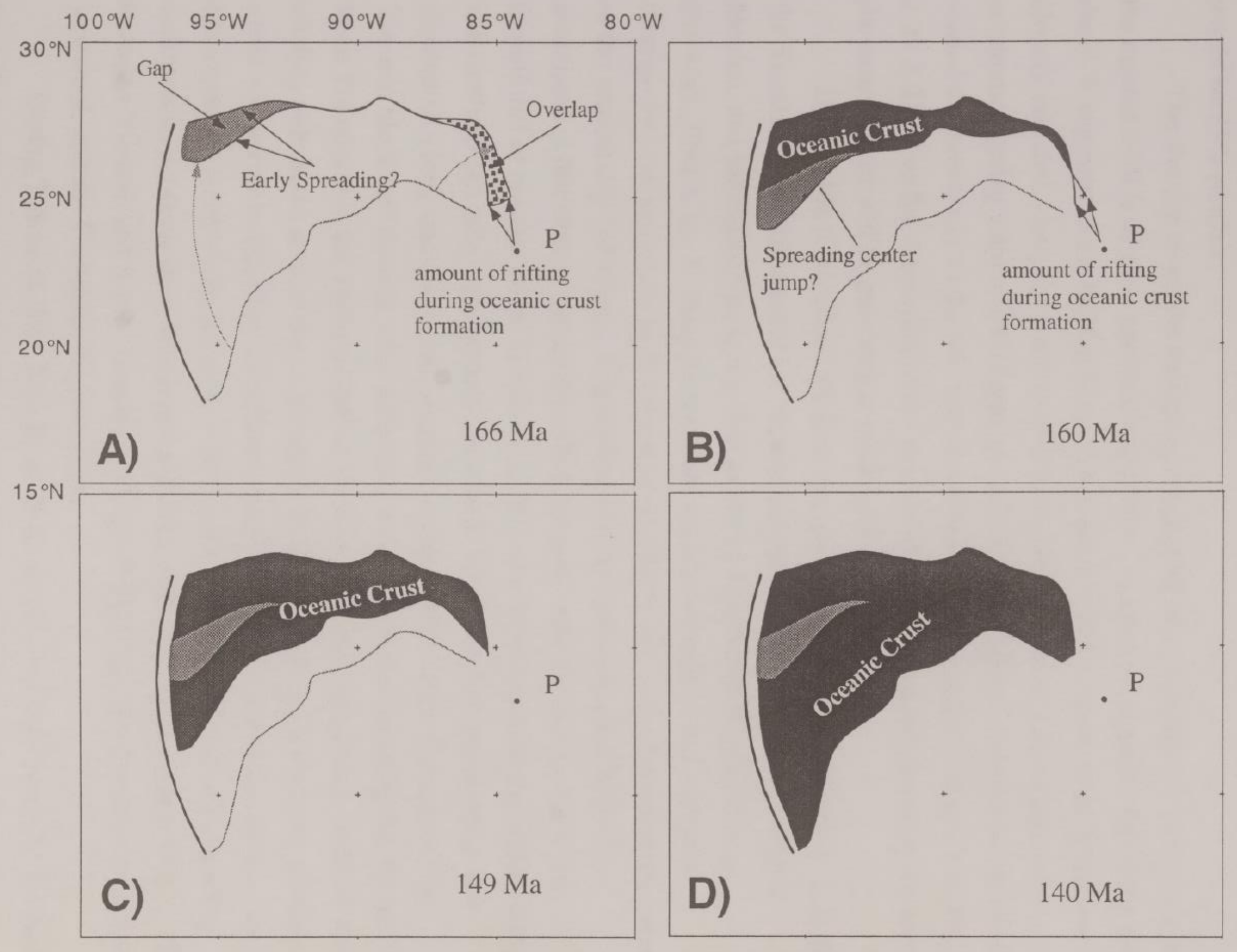
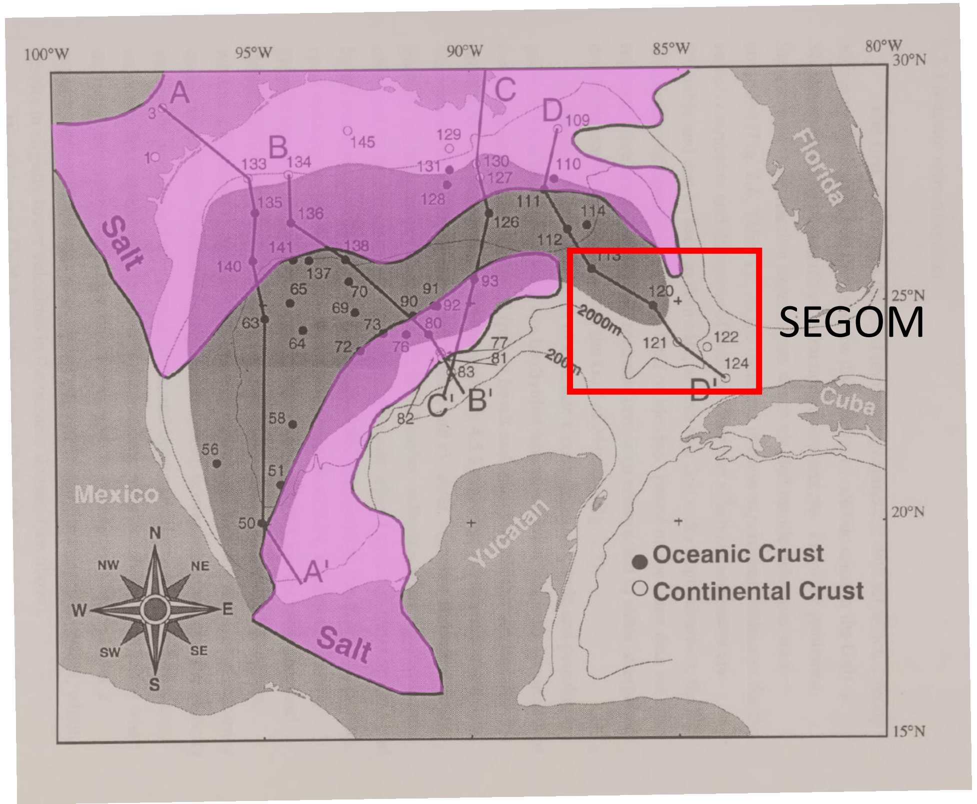


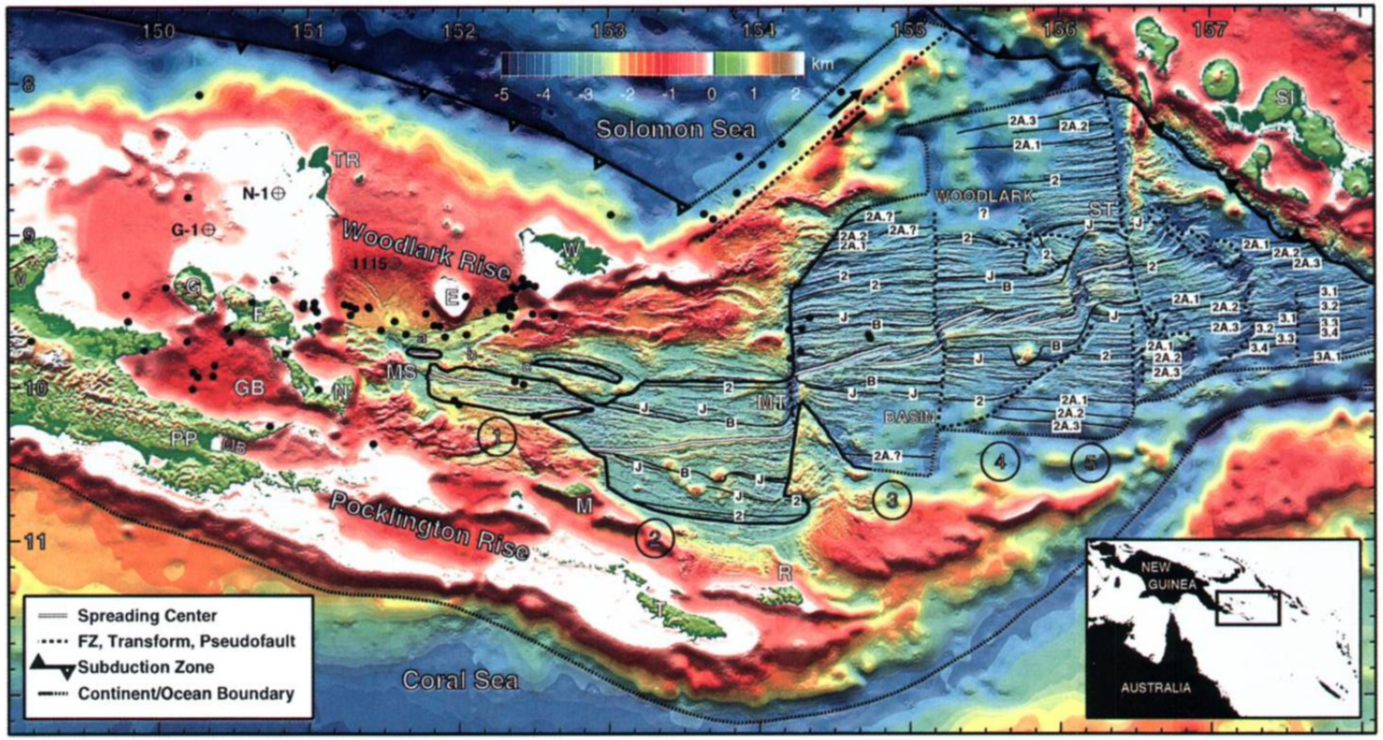
Fig. 2.23 Kinematics of oceanic crust formation in the Gulf of Mexico. P=rotation pole.

Depositional setting of the Louann and Campeche Salt basins. Explanation for the lack of Salt in the SEGOM margins lacking (Marton Ph.D. Dissertation 1995)



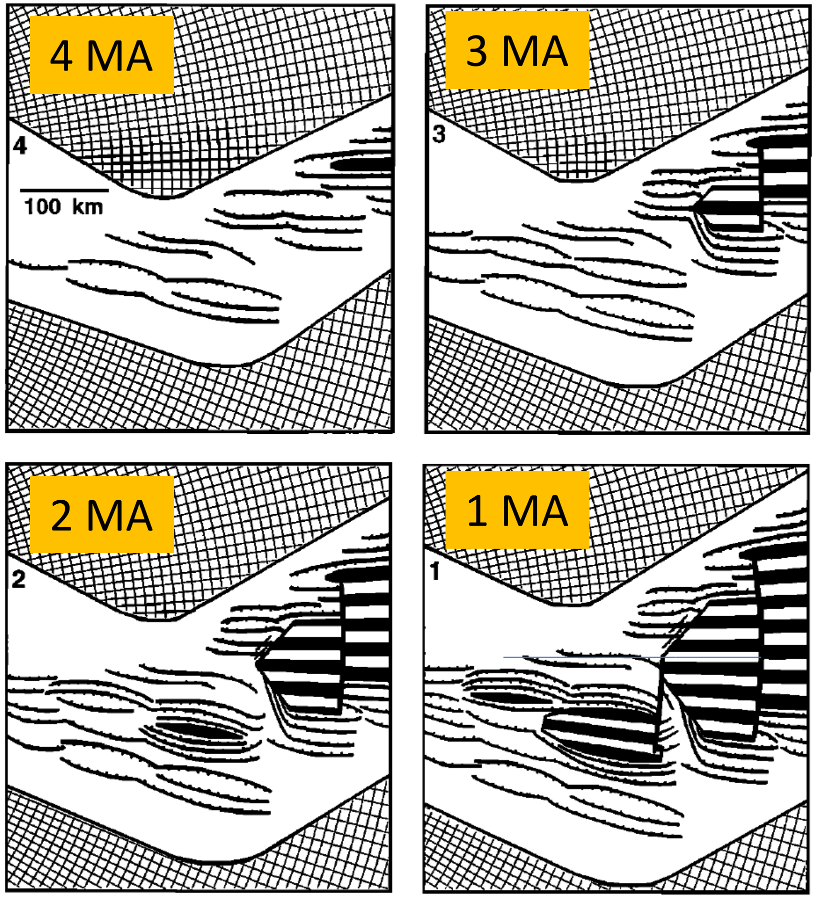
The Woodlark basin in the western Pacific provides an excellent modern-day analogue for tectonic processes and resulting features in continental breakup. Rift propagation and time-transgressive nature of oceanization is clearly documented in this superb example (Taylor et al, 1999)

Ridge propagation ~ 140km/My



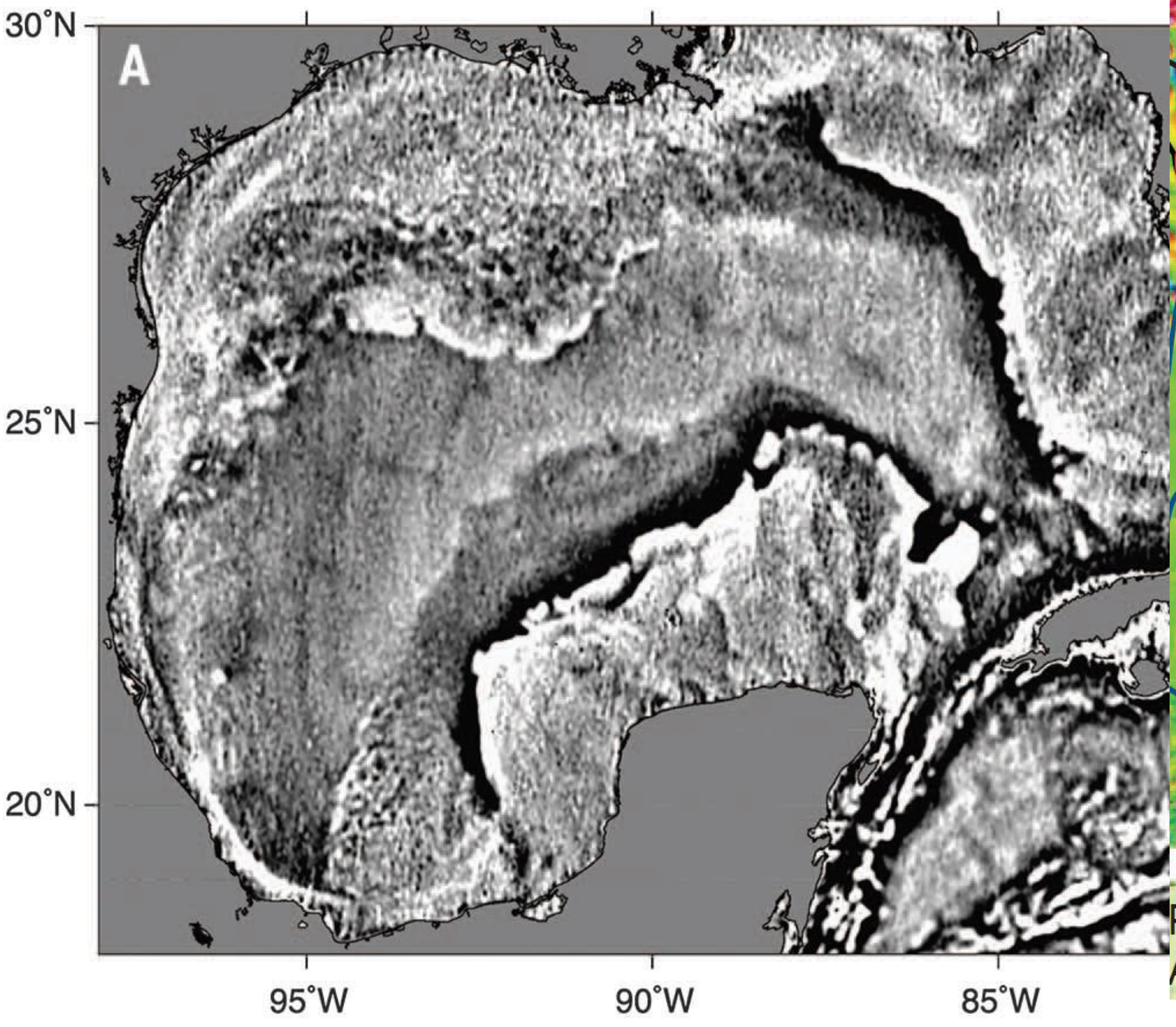
How continents break up: Insights from Papua New Guinea

Brian Taylor, Andrew M. Goodliffe, and Fernando Martinez
School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu

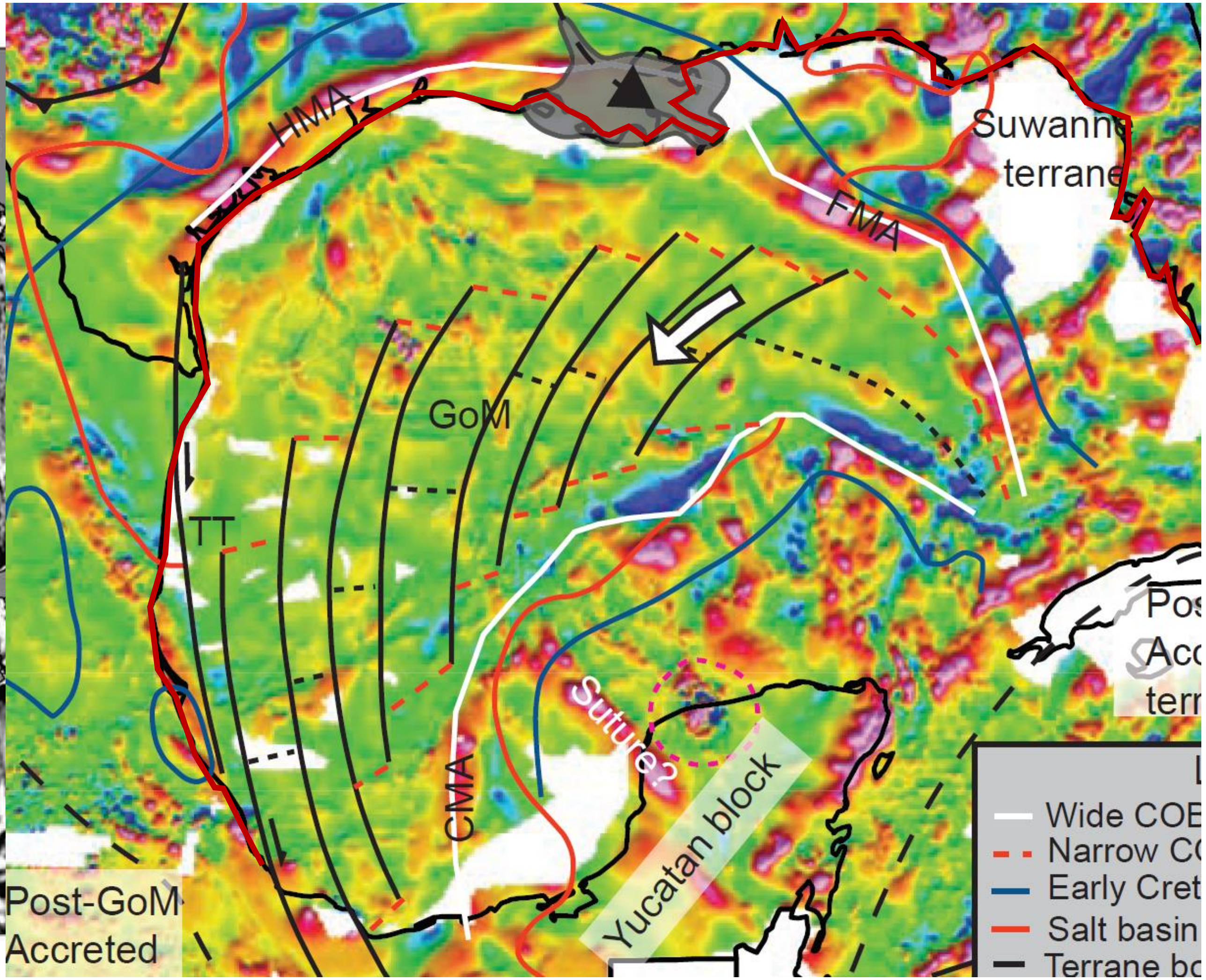


Reconstruction of the Woodlark basin (4-1 Ma)

Modern Gravity and magnetic data puts better constrain on the distribution of oceanic crust in the GOM.
We propose that a propagating rift model can explain both the distribution of oceanic crust and salt in the basin!

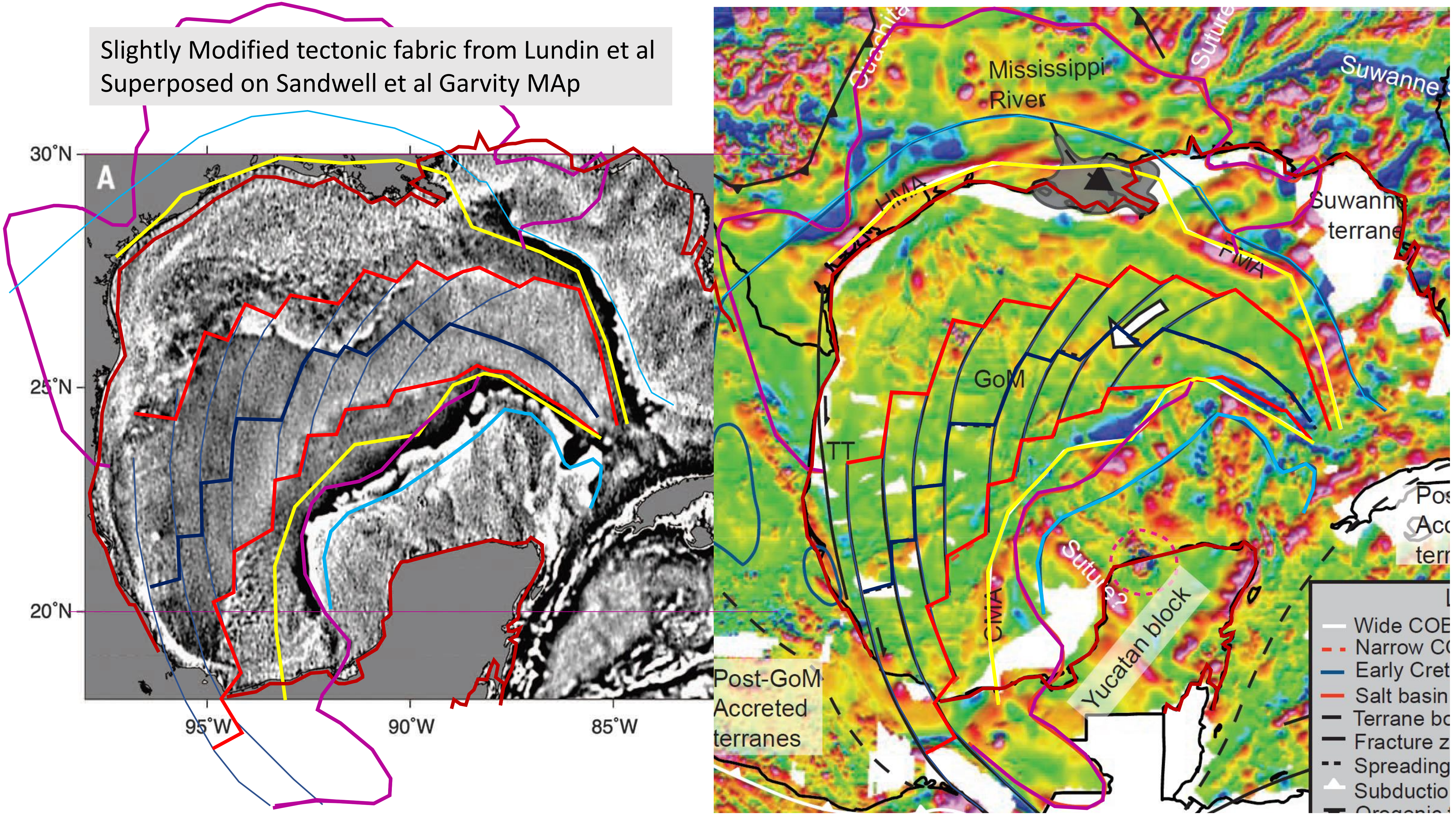


Gravity gradient Map with Oceanic fabric overlay
(Sandwell et al 2014)

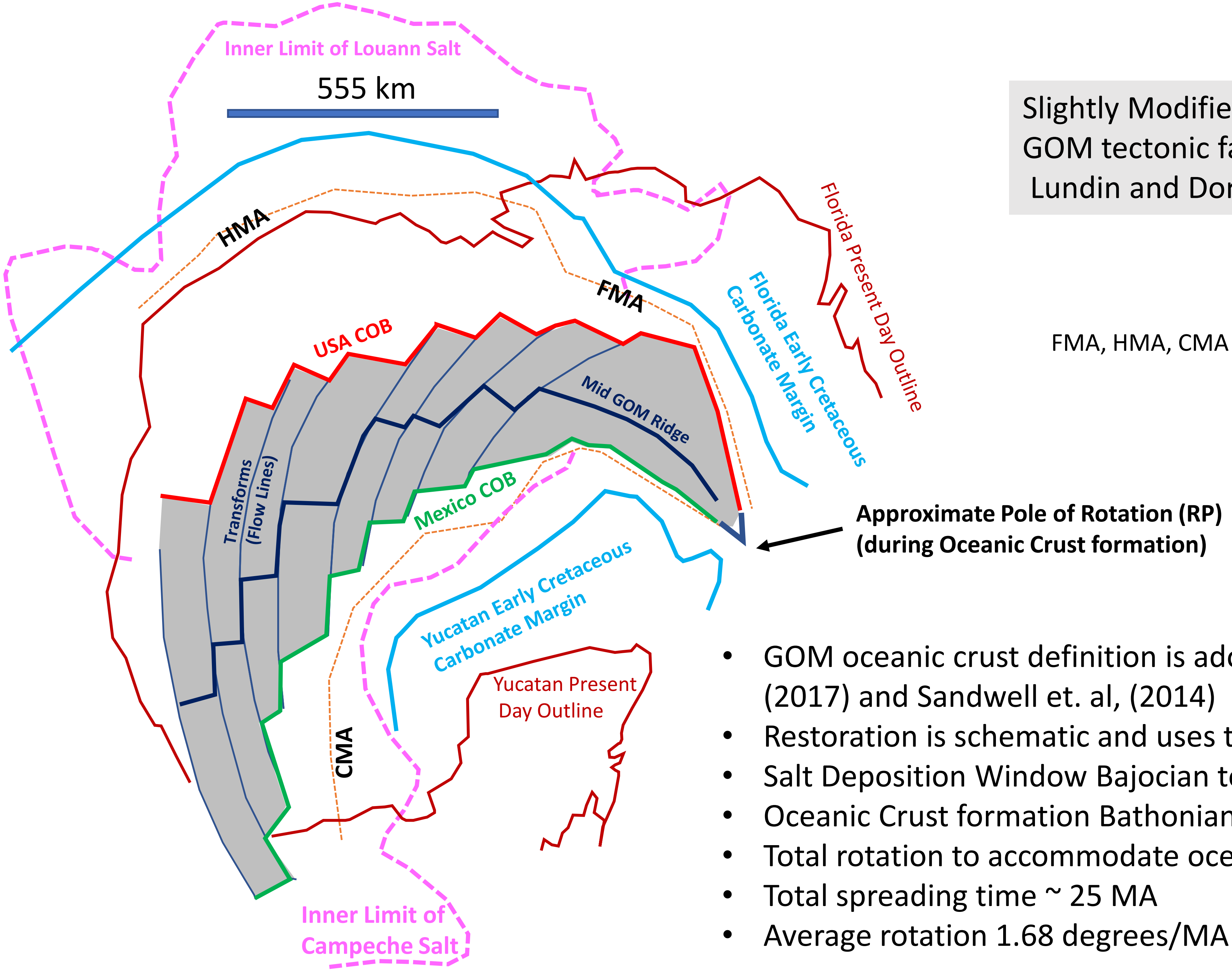


USGS Magnetic map + oceanic fabric interpretation
(Lundin et al 2016)

Slightly Modified tectonic fabric from Lundin et al
Superposed on Sandwell et al Garvity MAp



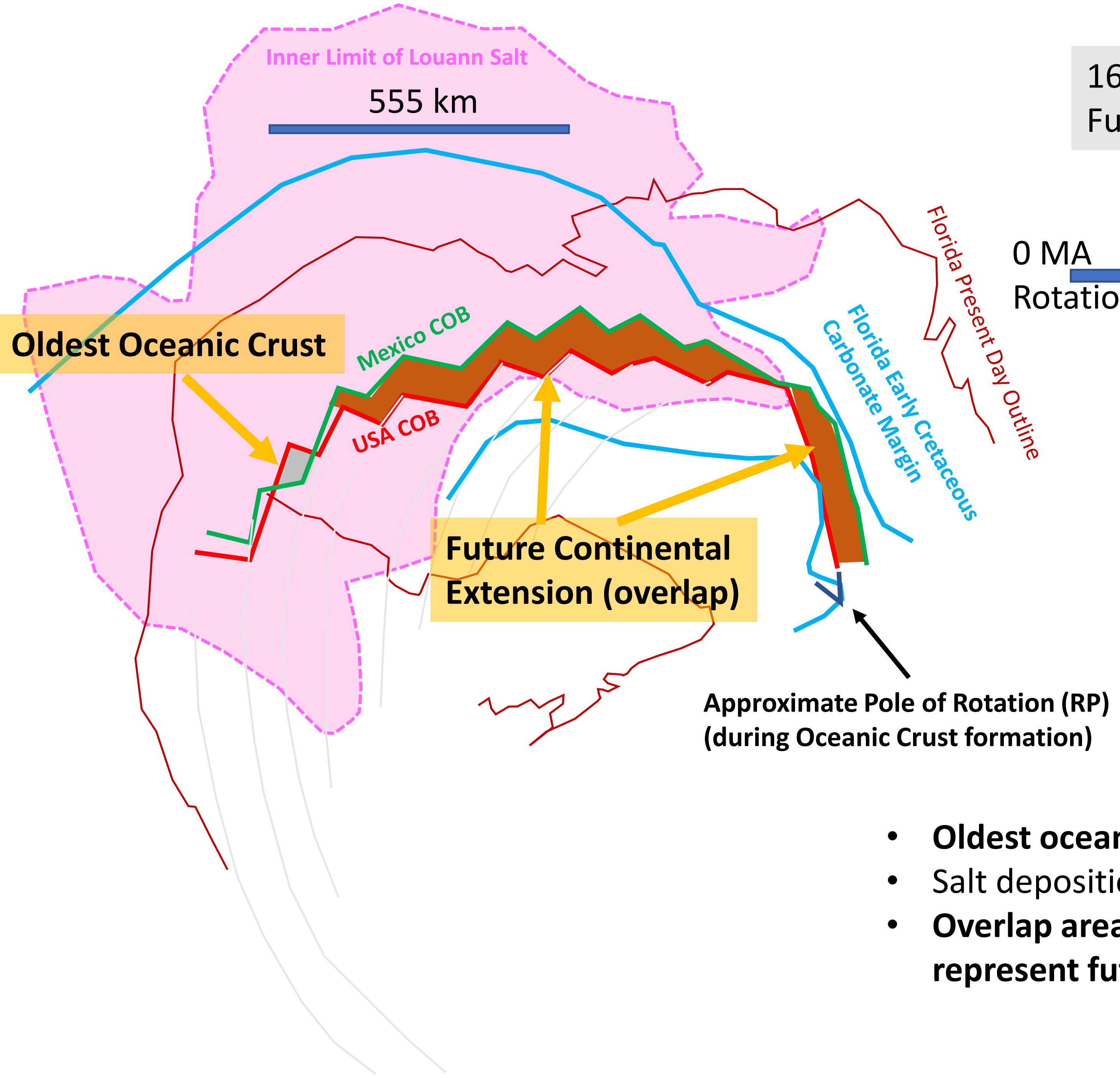
Slightly Modified Present Day GOM tectonic fabric from Lundin and Dore (2017)



FMA, HMA, CMA → Magnetic Anomalies

- GOM oceanic crust definition is adopted from the Lundin and Dore (2017) and Sandwell et. al, (2014)
- Restoration is schematic and uses the following boundary conditions:
- Salt Deposition Window Bajocian to Early Oxfordian)
- Oceanic Crust formation Bathonian/Callovian to Berriasian/Valanginian
- Total rotation to accommodate oceanic crust ~ 42 degrees
- Total spreading time ~ 25 MA
- Average rotation 1.68 degrees/MA

165 MA (Bathonian/Callovian)
Full closure/overlap (by 42 degrees clockwise rotation)

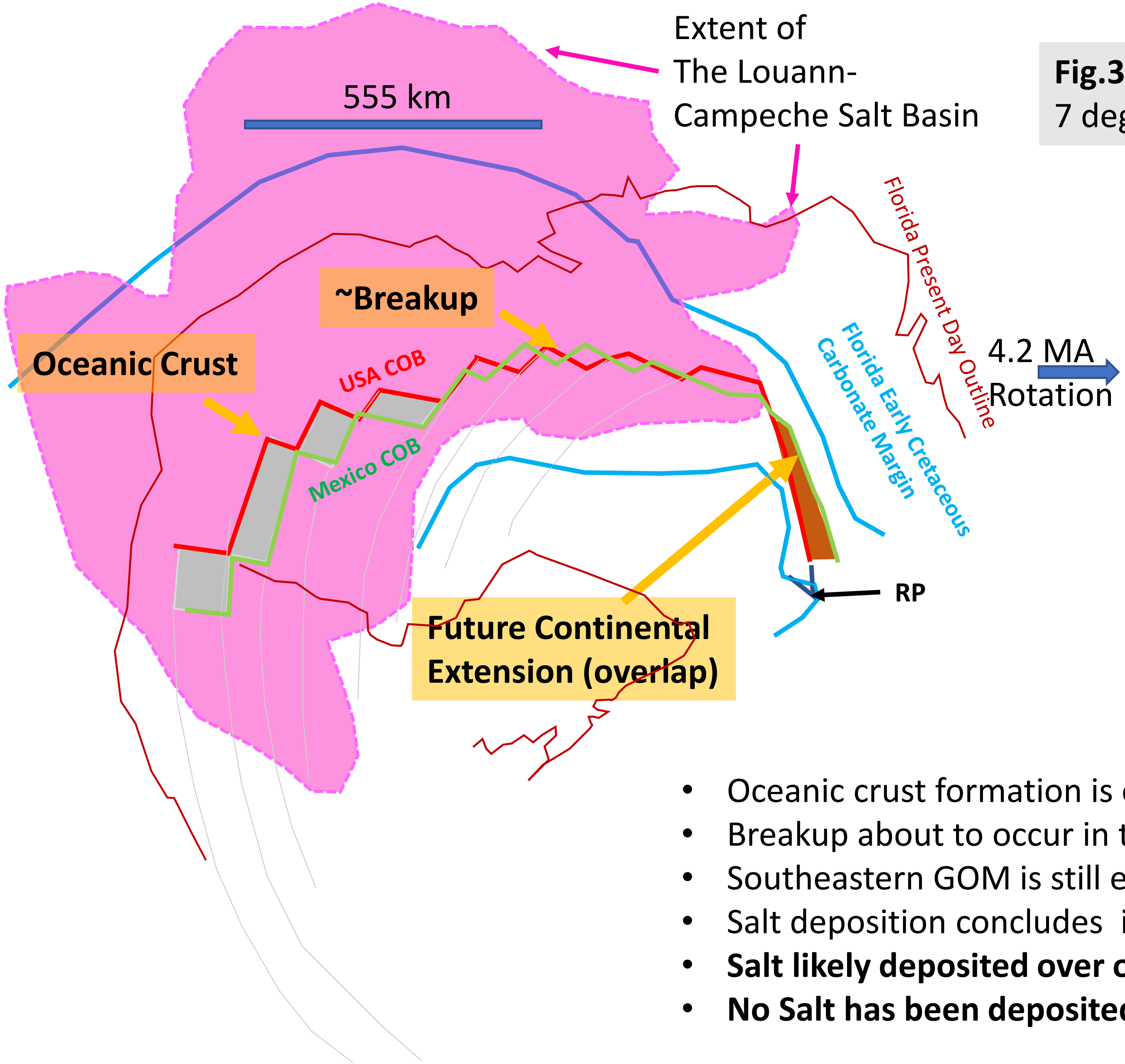


0 MA Rotation

AGE	MA	Yuacatan Rotation	Salt Deposition
Bathonian/Callovian	165	0.0	
Callovian			
Callovivian/Oxfordian	161	6.7	
Oxfordian			
Oxfordian/Kimmeridgean	156	15.1	
Kimmeridgean			
Kimmeridgean/Tithonian	151	23.5	
Tithonian			
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

- **Oldest oceanic crust forms in the Western GOM**
- Salt deposition is already on-going
- **Overlap areas in the Central-Eastern-Southeastern GOM represent future continental extension (likely emergent land)**

Fig.3) 160.8 MA (Early Oxfordian)
7 degrees Counterclockwise Yucatan Rotation



AGE	MA	Yuacatan Rotation	Salt Deposition
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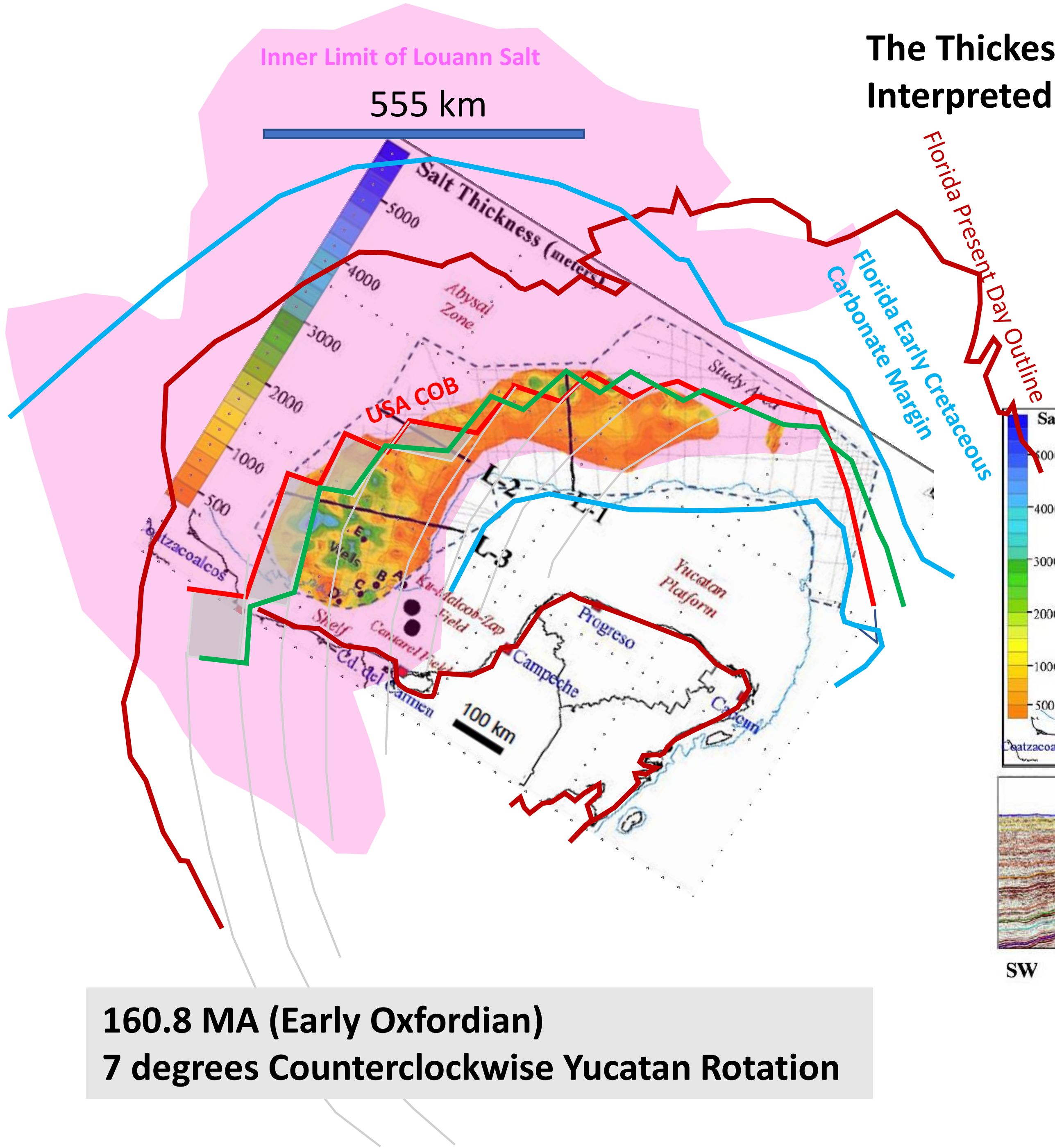
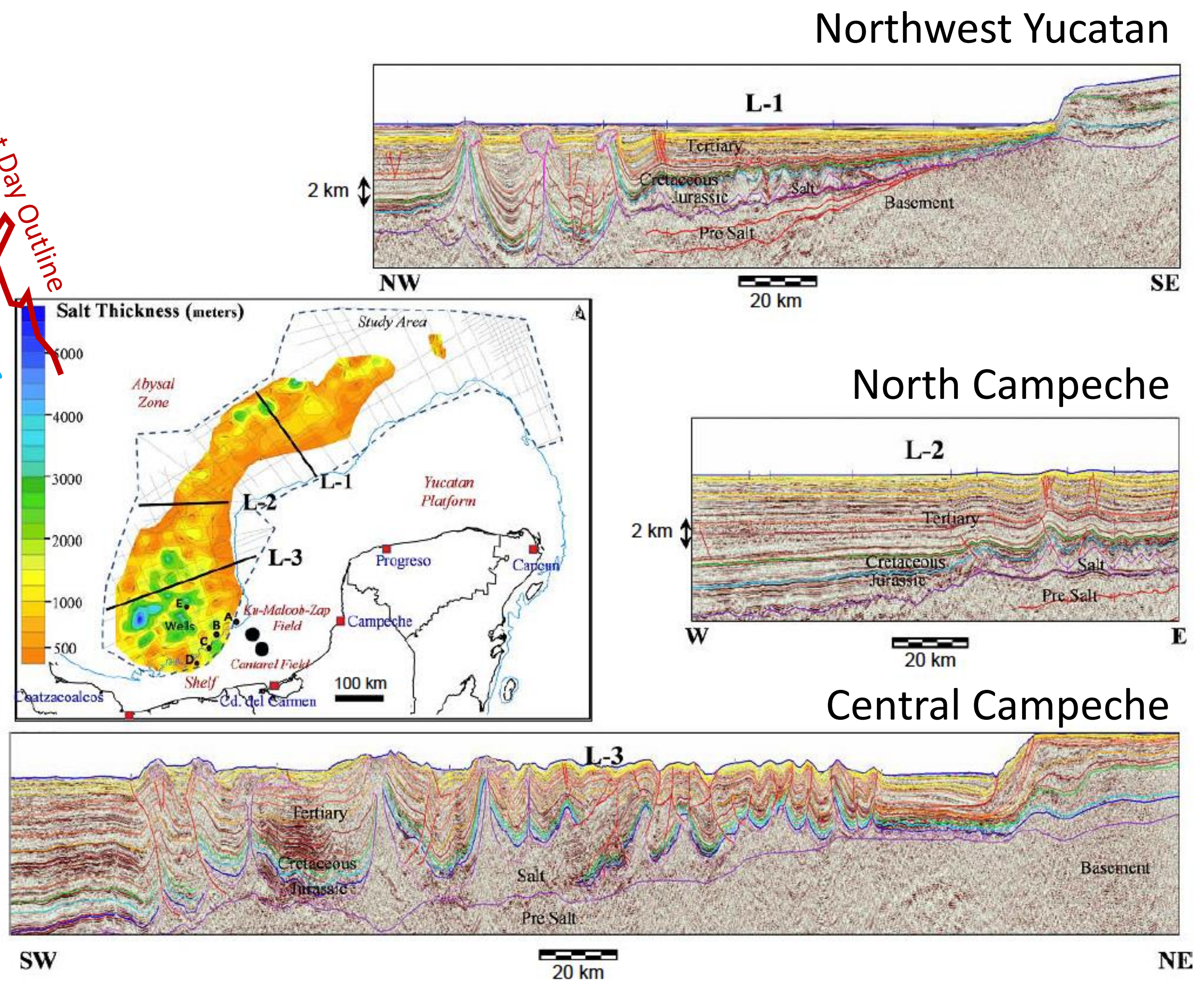
Kimmeridgean/Tithonian	151	23.5	
Tithonian			
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

- Oceanic crust formation is ongoing in the Western GOM (Drift Stage)
- Breakup about to occur in the Central and Eastern GOM (Breakup Stage)
- Southeastern GOM is still emergent (Overlap area) (Rifting Stage)
- Salt deposition concludes in submerged areas
- **Salt likely deposited over oceanic crust in the Western GOM**
- **No Salt has been deposited in the SEGOM (emergent land)**

The Thickest salt in Campeche is observed where the basin is Interpreted to be partially opened by the Early Oxfordian!

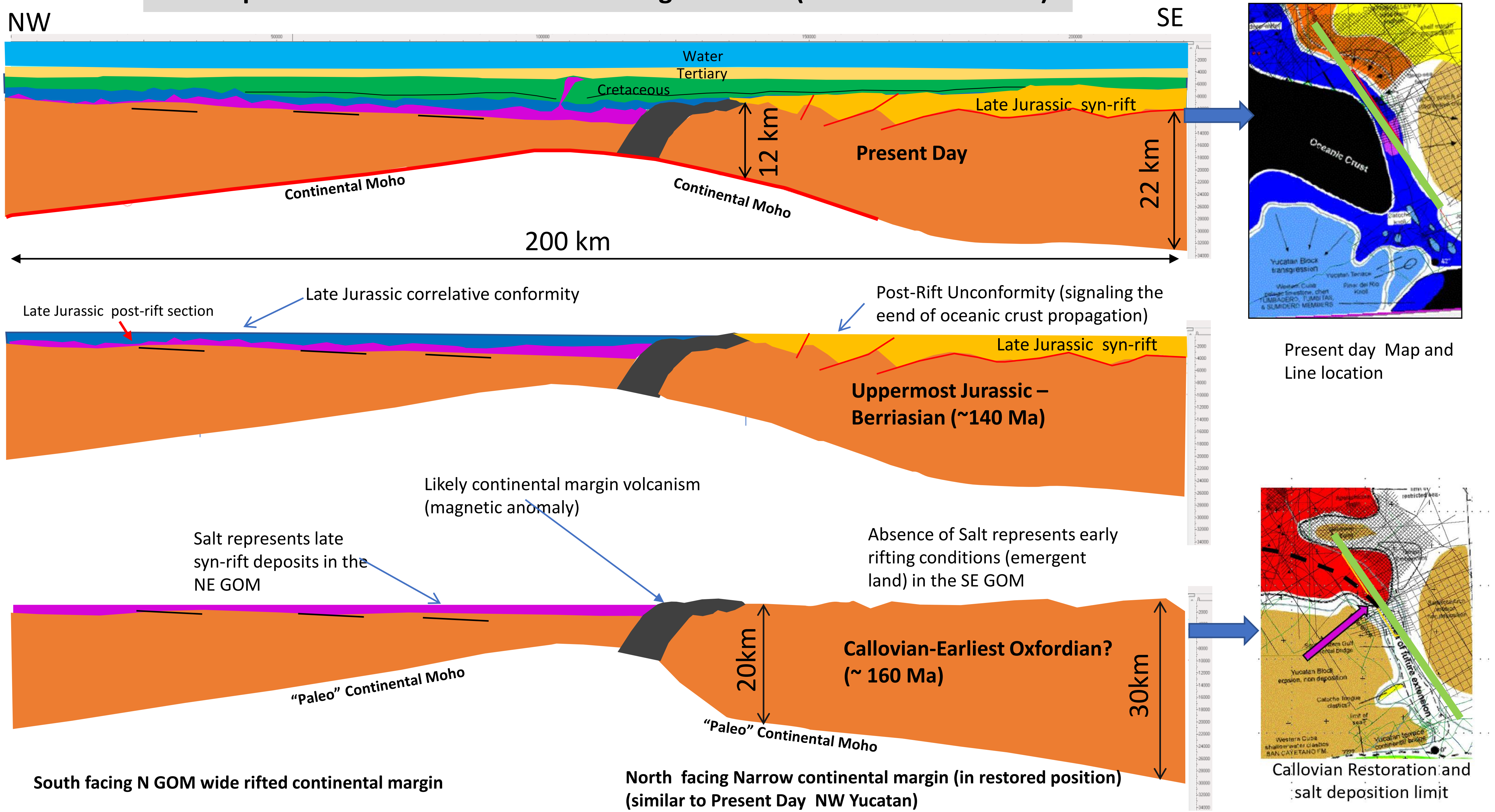


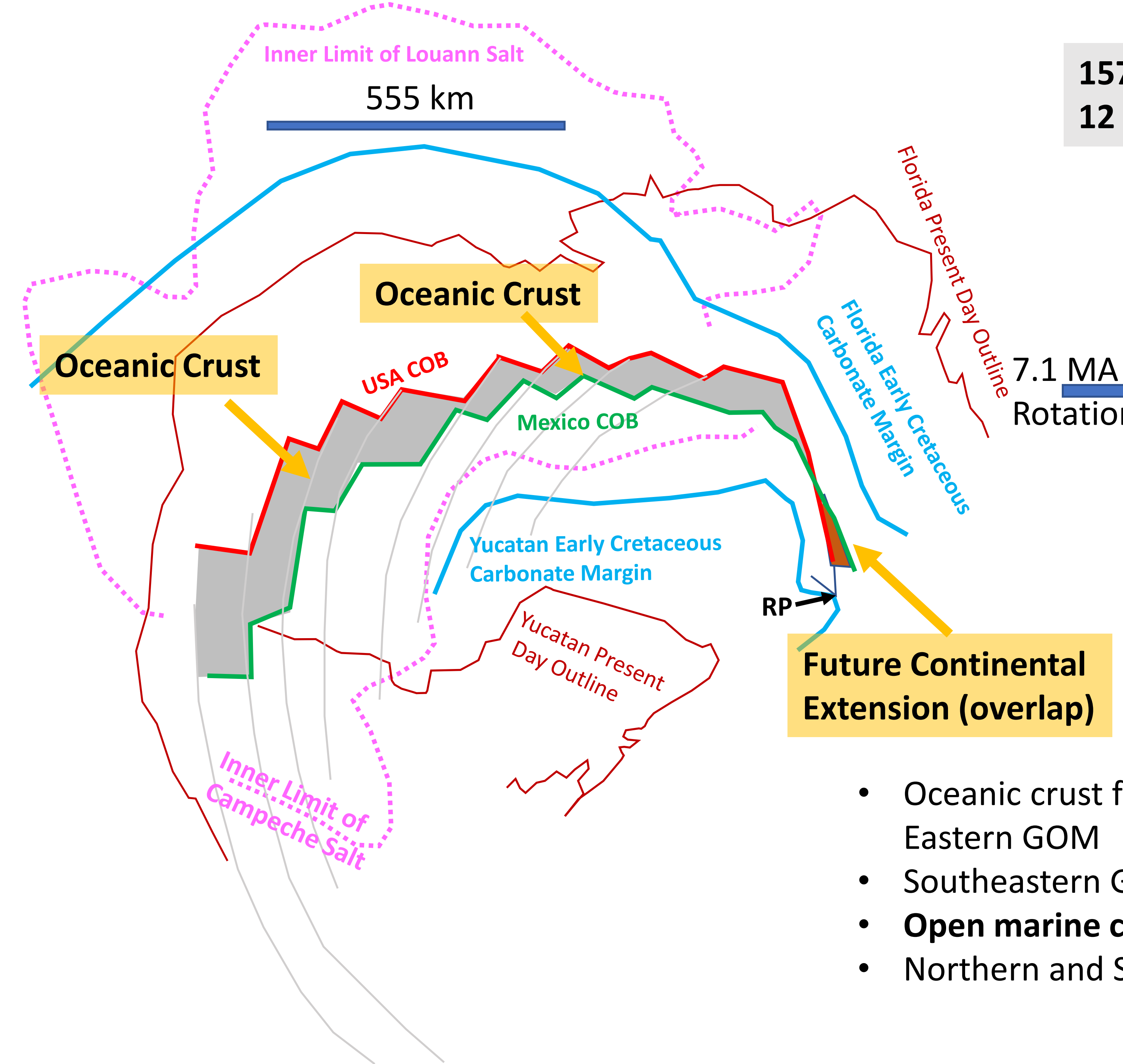


160.8 MA (Early Oxfordian)
7 degrees Counterclockwise Yucatan Rotation

Rodriguez, 2013

Semi-quantitaive restoration of NW-SE regional line (off the Florida Shelf)





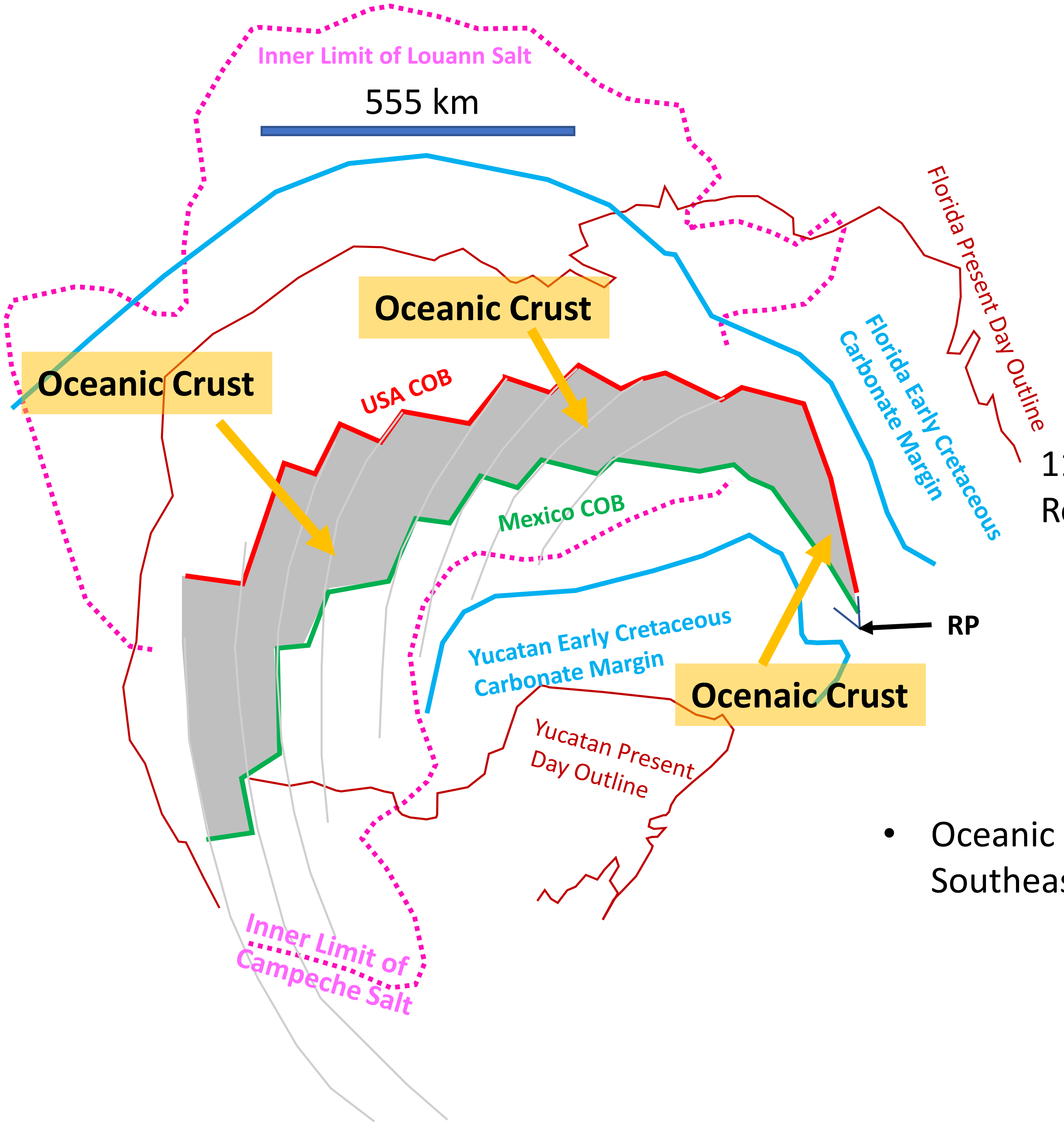
157.9 MA (Late Oxfordian)
12 degrees Counterclockwise Yucatan Rotation

7.1 MA Rotation

AGE	MA	Yuacatan Rotation	Salt Deposition
Bathonian/Callovian	165	0.0	
Callovian			
Callovivian/Oxfordian	161	6.7	
Oxfordian			
Oxfordian/Kimmeridgean	156	15.1	
Kimmeridgean			
Kimmeridgean/Tithonian	151	23.5	
Tithonian			
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

?

- Oceanic crust formation is ongoing in the Western, Central and Eastern GOM
- Southeastern GOM is likely flooded (Overlap area).
- **Open marine circulation in the whole GOM**
- Northern and Southern salt provinces got terminally separated



153.1 MA (Kimmeridgean)
20 degrees Counterclockwise Yucatan Rotation

11.9 MA Rotation

AGE	MA	Yuacatan Rotation	Salt Deposition
Bathonian/Callovian	165	0.0	
Callovian			
Callovivian/Oxfordian	161	6.7	
Oxfordian			
Oxfordian/Kimmeridgean	156	15.1	
Kimmeridgean			
Kimmeridgean/Tithonian	151	23.5	
Tithonian			
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

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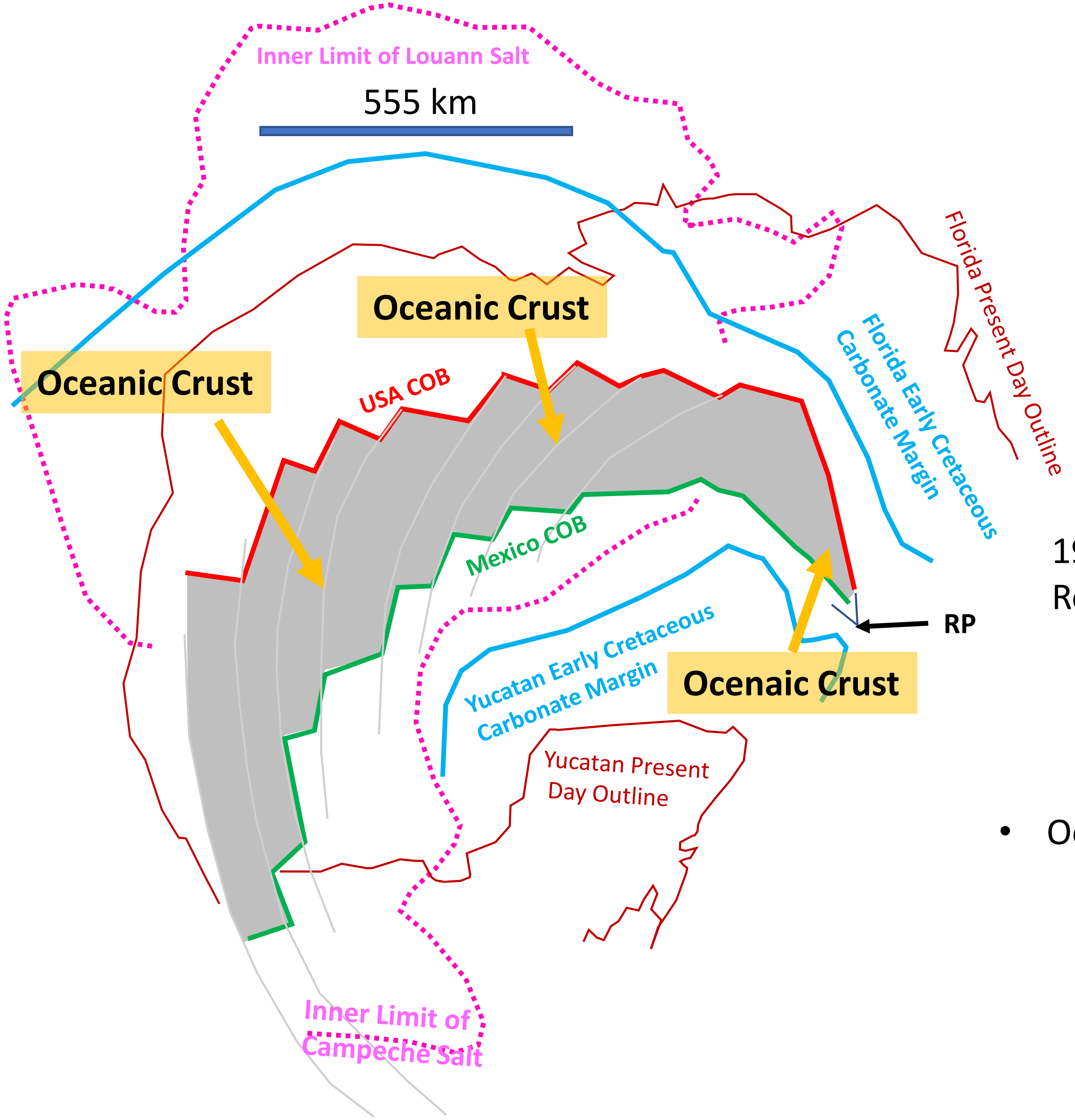
- Oceanic Crust formation propagated further south into the Southeastern GOM

146 MA (Latest Tithonian)
32 degrees Counterclockwise Yucatan Rotation



19 MA Rotation

AGE	MA	Yuacatan Rotation	Salt Deposition
Bathonian/Callovian	165	0.0	
Callovian			
Callovivian/Oxfordian	161	6.7	
Oxfordian			
Oxfordian/Kimmeridgean	156	15.1	
Kimmeridgean			
Kimmeridgean/Tithonian	151	23.5	
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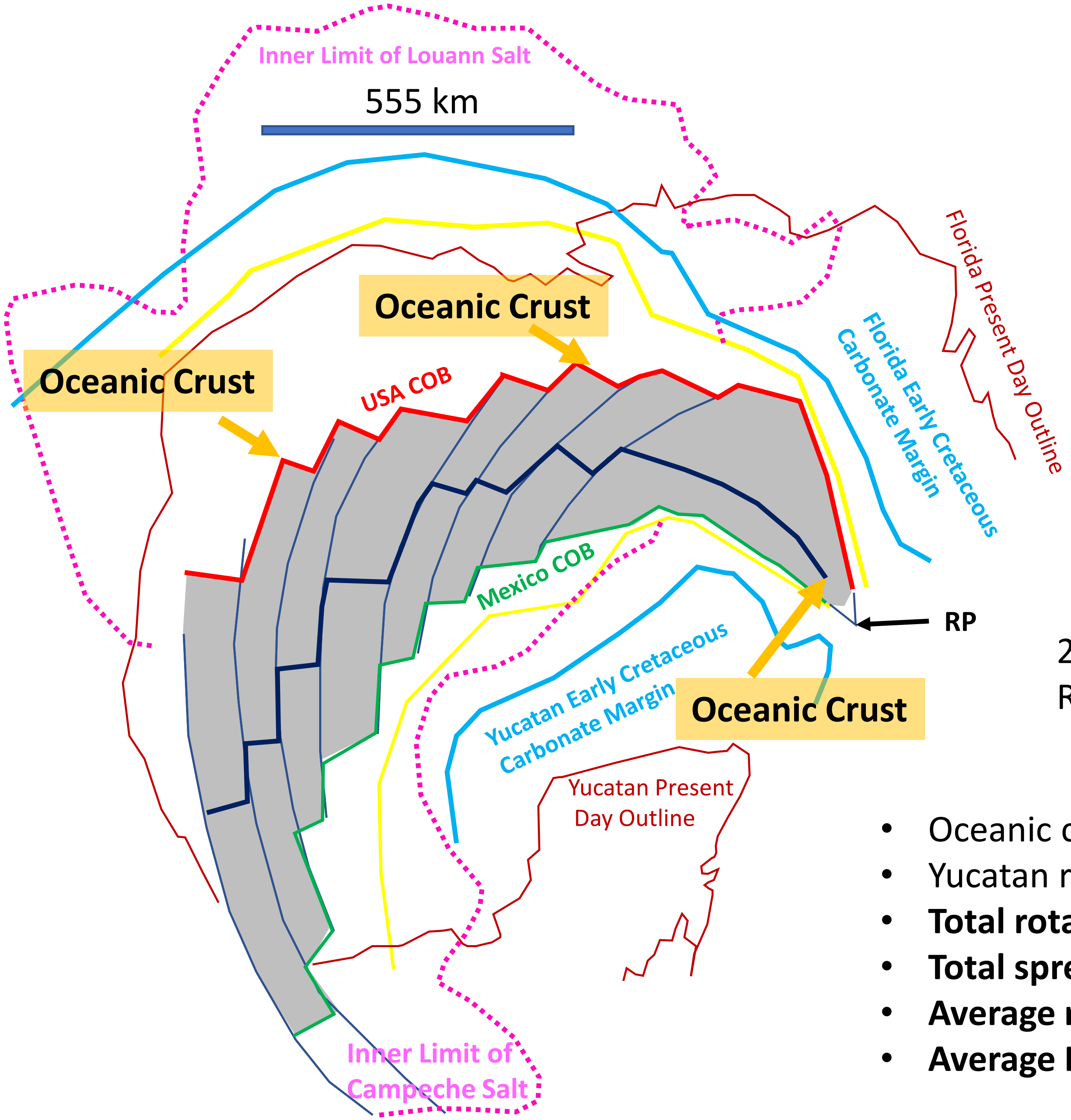
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

?

- Oceanic crust formation is ongoing in the whole GOM



140 MA (Berriasian/Valanginian)
42 degrees Counterclockwise Yucatan Rotation

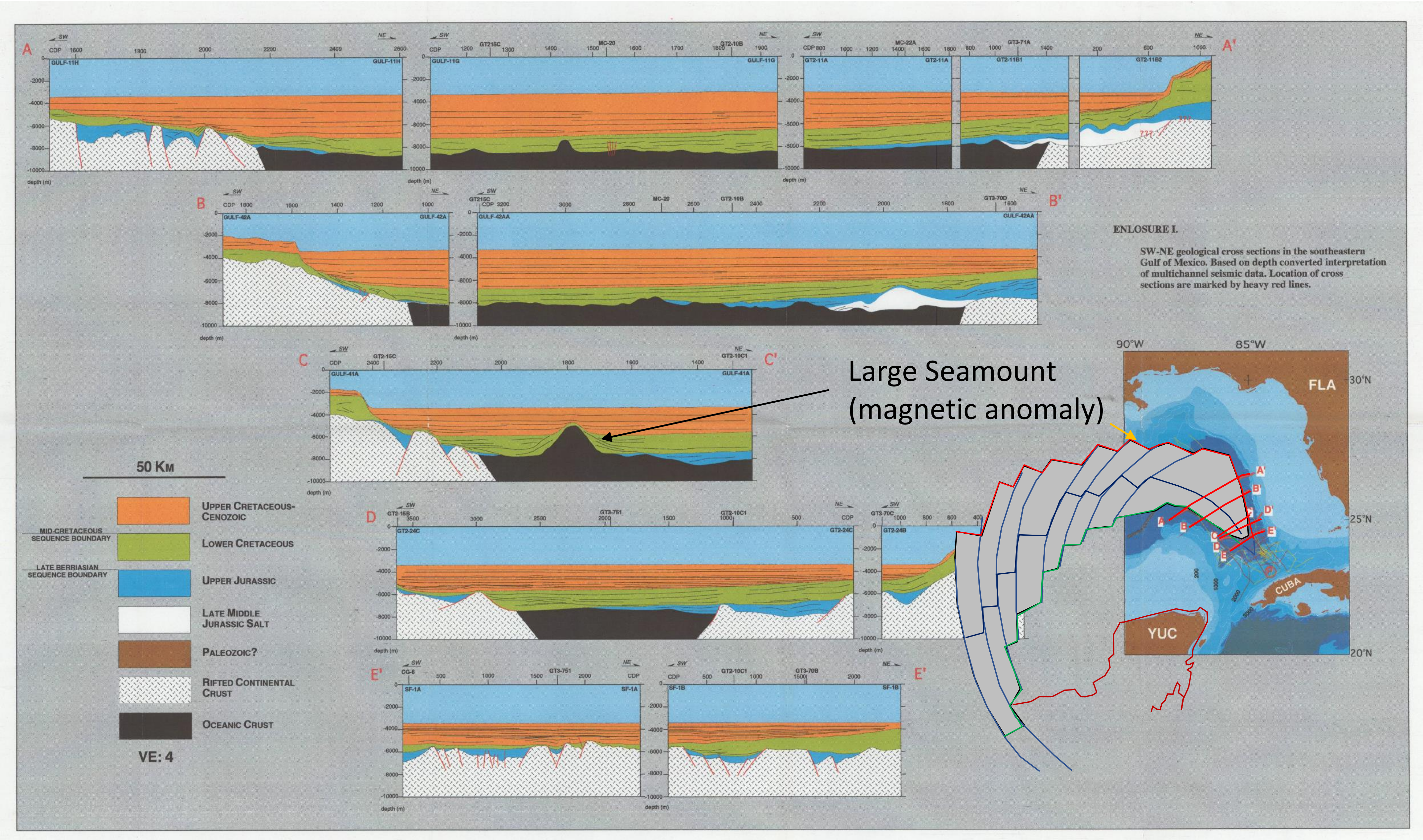
AGE	MA	Yuacatan Rotation	Salt Deposition
Bathonian/Callovian	165	0.0	
Callovian			
Callovivian/Oxfordian	161	6.7	
Oxfordian			
Oxfordian/Kimmeridgean	156	15.1	
Kimmeridgean			
Kimmeridgean/Tithonian	151	23.5	
Tithonian			
Tithonian/Berriasain	145.5	32.8	
Berriasian			
Berriasaina/Valanginian	140	42.0	
Valanginian			
Valanginian/Hauterivian	134		

?

25 MA Rotation

- Oceanic crust formation has been completed in the GOM
- Yucatan reached its present position relative to North America
- **Total rotation to accommodate oceanic crust ~ 42 degrees**
- **Total spreading time ~ 25 My**
- **Average rotation 1.68 degrees/My**
- **Average Ridge propagation ~ 44 km/My**

Rift Propagation and diachronous oceanic crust formation and lack of mobile salt in the SEGOM is clearly documented on the available academic data (Marton Ph.D. Dissertation, 1995)



Semi Quantitative Gulf of Mexico (GOM) Opening Model

Main observations:

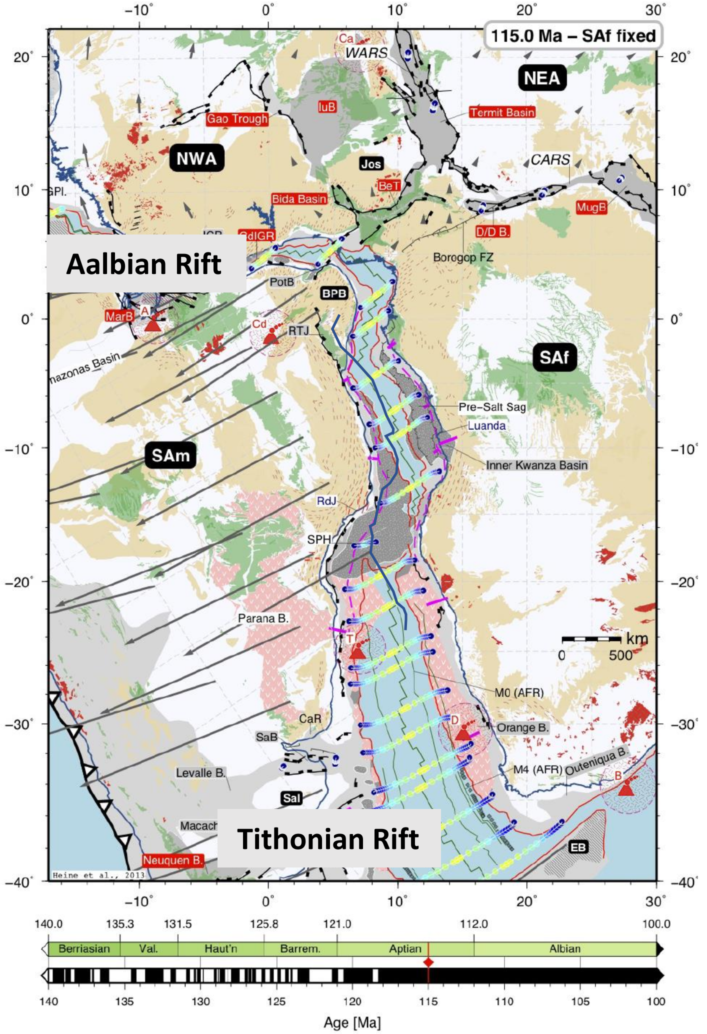
- GOM oceanic crust can’t be restored without significant gaps and overlaps. → propagating rift model can easily resolve reconstruction problems
- Breakup occurred diachronously in the GOM. Rift propagation progressed from West to East
- Salt deposition concluded in the Early Oxfordian (161 MA) in a partially opened Oceanic basin
- The thickest salt is observed in the Western Gulf (Plenty of accommodation space)
- Relatively less salt is observed in the Eastern GOM (off Florida)
- The Southeastern GOM was still an emergent land during Callovian time! (No accommodation space available)
- **Salt thickness variations reflect available accommodation space in a propagating rift setting!**
- **Salt got deposited “post-rift” in the Western GOM and “late syn-rift” in the Eastern GOM** → propagating rift model also explain the observed distribution (and lack) of salt along the GOM margins

ANGOLAN PROPAGATING RIFT / SALT

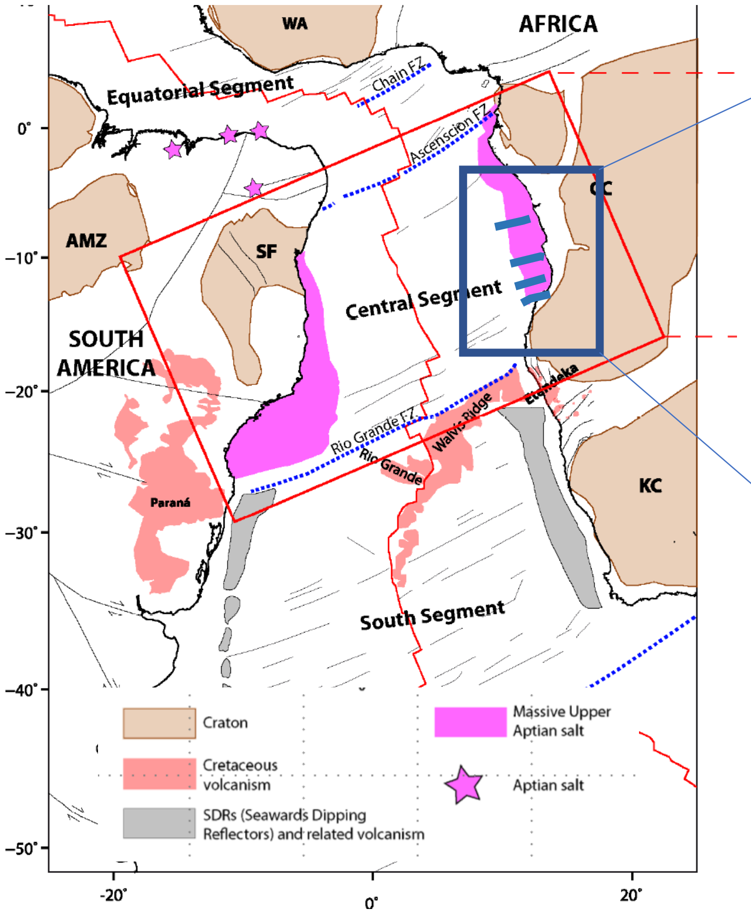
The South Atlantic
Is a very large example of a "propagating" rift
(115 MA restoration)

Aptian Salt occurs between the Rio Grande FZ (south) and the Ascencion FZ (north)

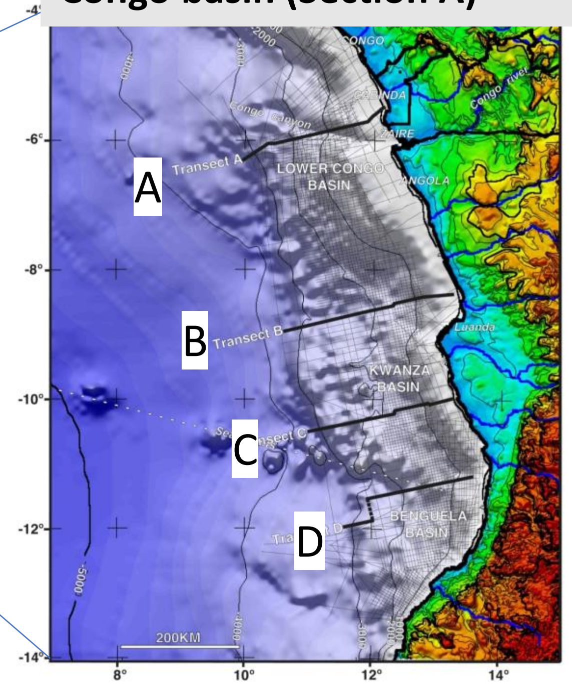
Salt Crossectional area decreases monotonously from the Benguela basin (section D) to the Lower Congo basin (Section A)



Kinematics of the South Atlantic rift
Heine et al, 2013

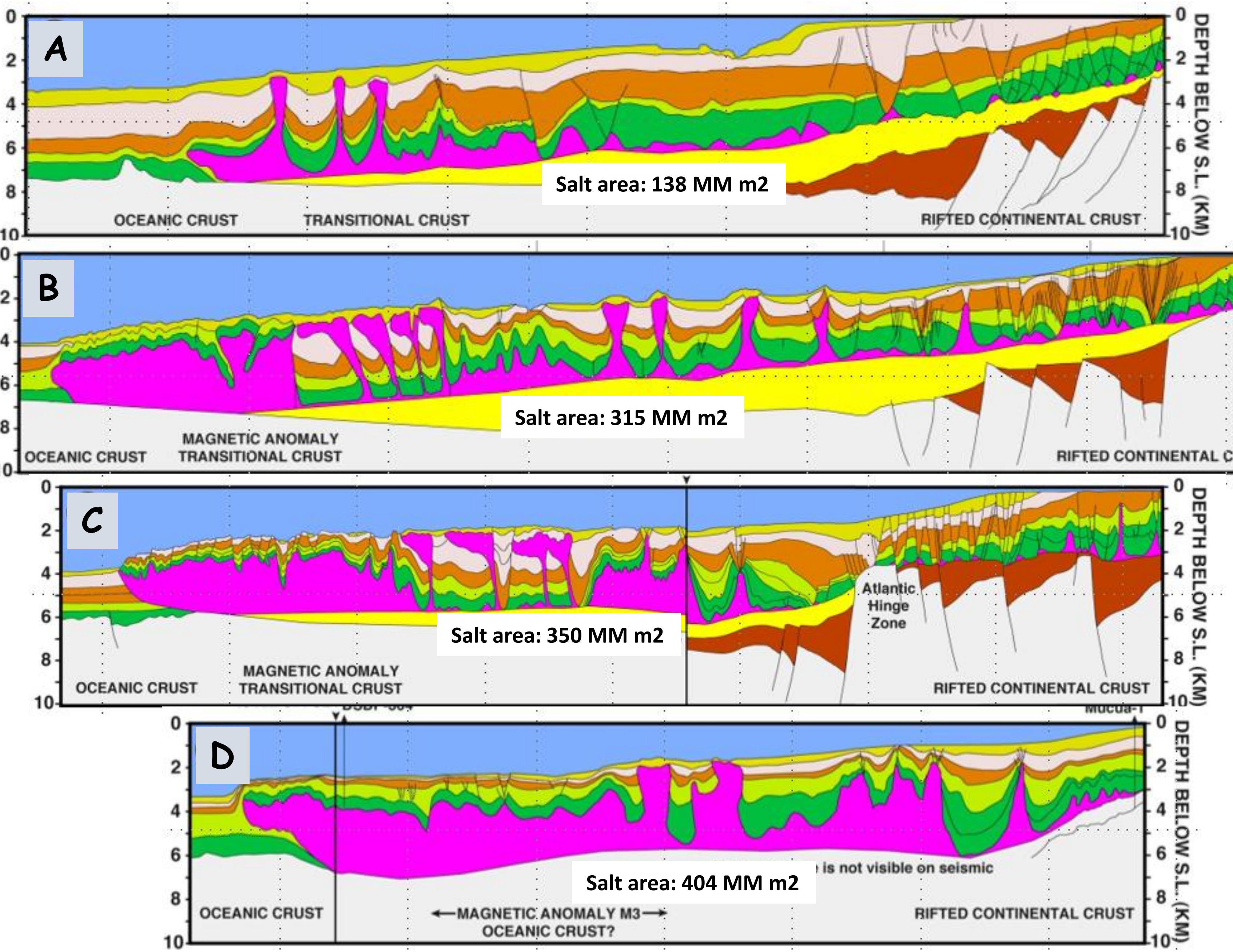


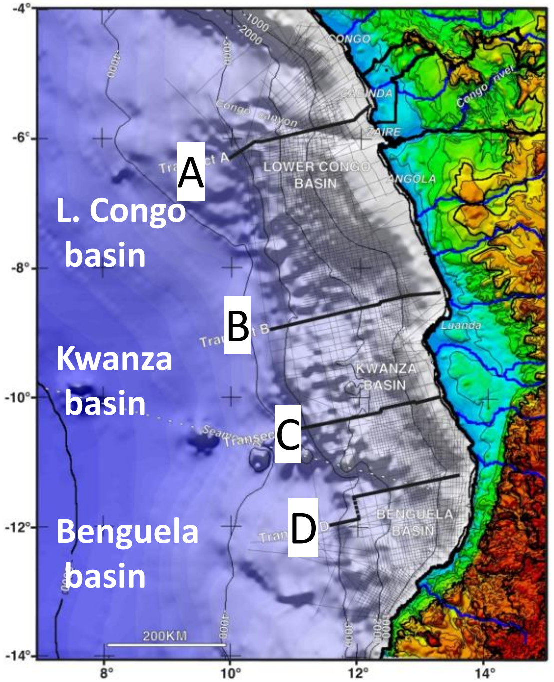
The Aptian evaporites of the South Atlantic: a climatic paradox? Chaboreau et al, 2012



Salt basins occurred in the area of restriction, N of the Walwis Ridge
Salt deposition ceased when open marine circulation got established in the Albian

Depth Cross Sections along the Angolan Passive Margins. Salt area measured in GeoSec (Marton and Tari, 2001)





In the Benguela basin the outer salt may have deposited over oceanic crust. Cross sectional area is the largest here → Largest accommodation Space
In the Lower Congo basin salt deposited over continental crust only. Salt cross sectional area is the third → less accommodation space
In N Gabon the salt is absent → rift was still propagating here in the Aptian (emergent land)

Analogue Study in the South Atlantic (SA)

Main observations:

- The South Atlantic restorations also have significant gaps and overlaps. → Propagating rift model is obviously relevant in this basin
- Breakup occurred diachronously in the SA. Rift propagated from South to North
- Salt deposition occurred in the Barremian?-Aptian in a partially opened Oceanic basin in Southern Angola
- The thickest salt is observed in the Benguela basin (Plenty of accommodation space)
- Relatively less salt is observed in the northern Lower Congo basin
- The area north of Gabon was still in the early phase of rifting in the Aptian and was likely an emergent land (No accommodation space available)
- **Salt thickness variations reflect available accommodation space in a propagating rift setting!**
- **Salt got deposited "post-rift" in the Benguela basin and "late syn-rift" in the Lower Congo basin**→ propagating rift model also explain the observed salt-thickness variations and lack of salt north of Gabon