[PS]Raft-Related Structures of the Albian Madiela Formation, Offshore South Gabon*

Vernon M. Moore[1] and Robert H. Blanchard[1]

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Abstract

We investigate the raft-related turtle structures of the post-salt, mixed carbonate-siliciclastic Albian Madiela formation, located offshore south Gabon. Recent 3D broadband RTM seismic data shows the Madiela structures comprised of a Lower Madiela pre-rafting section, with overlying Mid-Upper Madiela and Cenomanian Cap Lopez formation syn-rafting growth stratigraphy. The lower Madiela section directly overlies the salt-related detachment and is isopachous, with footwall and folded hangingwall cut-offs observed at the edges of the raft blocks. Depo-centers predominantly stacked vertically to create symmetric structures as rafting continued during Mid-Upper Madiela deposition, although a few asymmetric structures are observed. The structures have an elongate map pattern that varies in orientation across the study area. Seismic facies vary across individual structures from high amplitude crests to low amplitude flanks. Inversion and turtle structure development caused crestal faulting, especially within the Cap Lopez section. Welding of the salt beneath the turtle structures is more extensive up-slope than down-slope in the study area. Map and section-view structural restorations indicate the maximum down-dip translation of the Lower Madiela rafts from a proximal setting varies from 25 km in the up-dip portion of the study area to 50 km down-dip. Structural restoration, adjacent well control, seismic facies transitions, and seismic attribute observations indicate inner neritic water depths during Albian deposition, deepening to outer neritic in the Cenomanian. Rafting initiated in the early Albian due to the effects of thermal subsidence and ongoing seafloor spreading on the margin. The variance in curvature of the raft trends near the Congo border mimics, and may be partially inherited from, the trend of the up-dip breakaway fault zone. The raft structures reach their present day positions in the study area during the Turonian. Inversion of the turtle flanks and basal welding initiated in the Turonian, with down building of the inter-raft salt diapirs continuing to the Paleogene-to-present across the area. Local submarine erosion of the Cap Lopez formation is due to local inter-raft salt diapir inflation associated with steepening of the margin during the late Cretaceous. The structures of southern Gabon vary from similar Albian structures in northern Gabon and Congo in burial history, thickness, and proximity to siliciclastic depo-centers.

References Cited

Bruckner, A., G. Rowlands, B. Riegl, S. Purkis, A. Williams, and P. Renaud, 2012, Khaled bin Sultan Living Oceans Foundation Atlas of Saudi Arabian Red Sea Marine Habitats: Panoramic Press, 262 p.

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Patterson, R., and J. Kinsman, 1982, Formation of diagenetic dolomite in coastal sabkha along Arabian (Persian) Gulf: AAPG Bulletin, V. 66, p. 28-43.

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Teisserenc, P., and J. Villemin, 1989, Sedimentary basin of Gabon—geology and oil systems: in J.D. Edwards and P.A. Santogrossi, eds., Divergent/passive margins: AAPG Memoir 48, p. 117–199.

Wonham, J., M. Cyrot, T. Nguyen, J. Louhouamou and O. Ruau, 2010, Integrated approach to geomodelling and dynamic simulation in a complex mixed siliciclastic-carbonate reservoir, N'Kossa field, Offshore Congo: in Jolley, S. J., Fisher, Q. J., Ainsworth, R. B., Vrolijk, P. J. & Delisle, S., eds., Reservoir Compartmentalization, Geological Society of London, Special Publication 347, 133–163.

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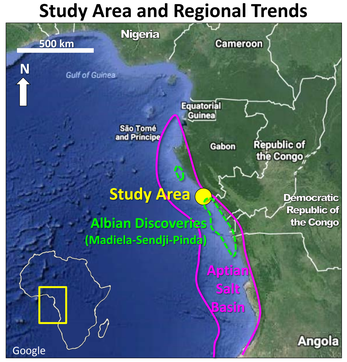
Madiela Overview

Study Area and Regional Trends

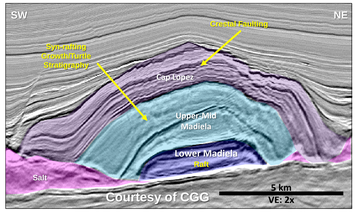


Stratigraphy of South Gabon

Age		Formation	Rift Phase	Lithology
Tertiary				
Cretaceous		Senonian	Post-Rift/Passive Margin	
	Turonian	Azile		
	Cenomanian	Cap Lopez		
	Albian	Madiela		
	Aptian	Ezanga	Transitional (Seafloor Spreading)	
		Gamba		
	Neocomian-Barremian	Dentale	Syn-Rift	
		Crabe-Melania		
		Lucina		
		Kissenda		
Basement			Pre-Rift	

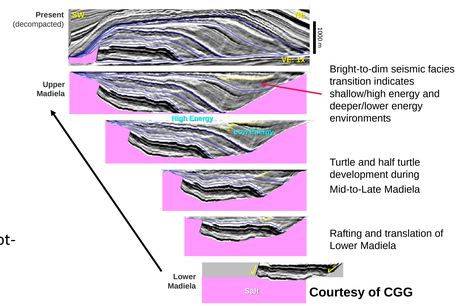
Modified from Liro and Coen (1995)

Madiela Raft-Turtle Structure

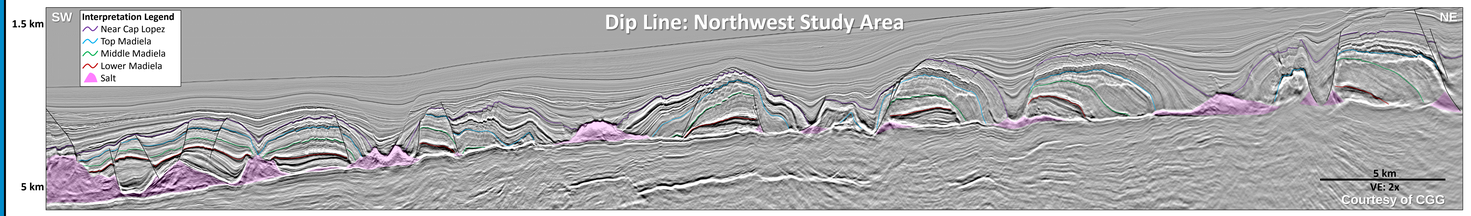


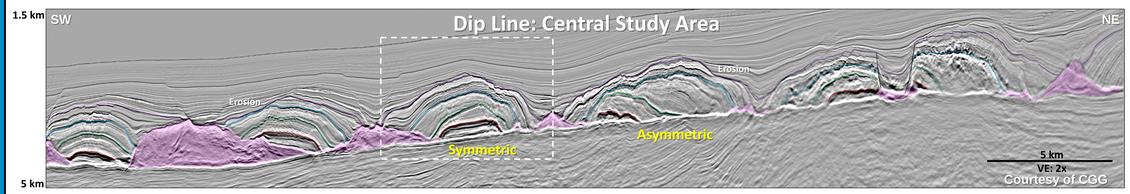
- Lower Madiela “rafts” on salt detachment with raft edge foot-wall and folded hanging-wall cut-offs
- Mid-Upper Madiela syn-rafting growth/turtle stratigraphy
- Cap Lopez post-rafting section, faulted and eroded

Raft-Turtle Structure Development



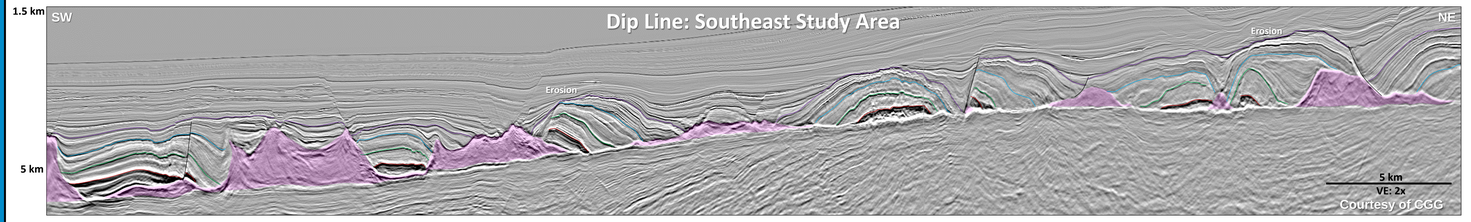
South Gabon Study Area

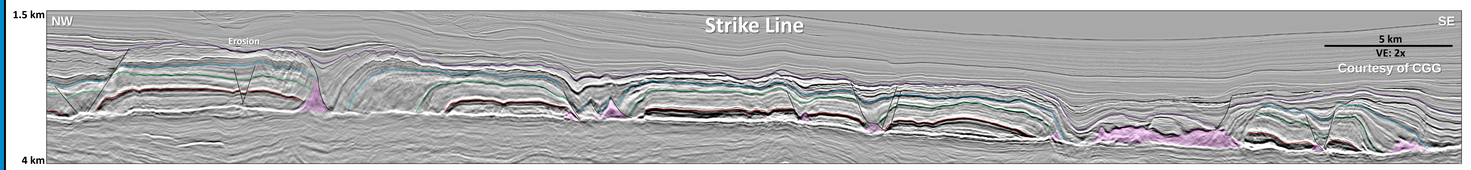




Observations

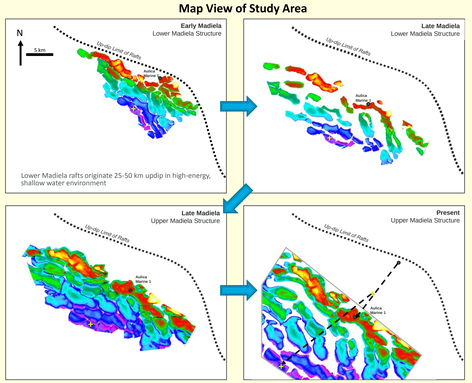
- High Amplitude, Isopachous, Lower Madiela rafts
- Both vertical stacking and lateral stepping of Mid-Upper Madiela depo-centers
- Crest-to-Flank seismic facies transitions in Middle and Upper Madiela
- Crestal faulting, onlap, and local erosion of Cap Lopez
- Down building of intra-raft salt diapirs from Late Cretaceous to Tertiary
- Basal welding is more complete up-slope than down-slope





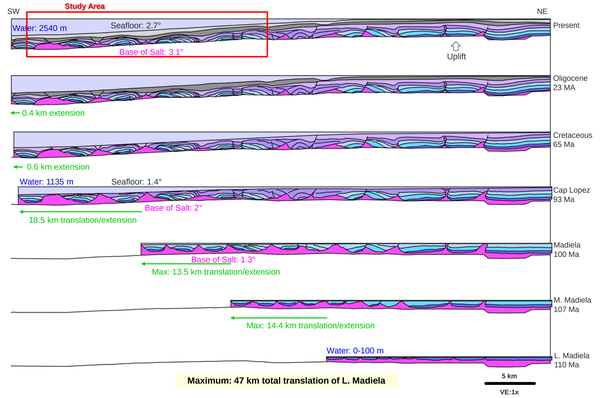
Madiela Extension

Map View of Study Area



Madiela Raft-Turtle Reconstruction

Decompacted with Isostatic and Thermal Subsidence Corrections



Summary

- Max translation of Lower Madiela rafts increases down-dip in study area (28km vs 47km)
- Base of salt continues to steepen after Madiela deposition
- Faulting at turtle crests suggests initiation of turtle inversion immediately after Cap Lopez
- Continued steepening of the margin causes local salt diaper rejuvenation and local erosion of Cap Lopez section
- Madiela raft movement ends in latest Cretaceous
- Basal welding of raft-turtle structures began during Late Madiela/Cap Lopez deposition at the earliest under the rafts center and continued to the Paleogene-to-present locally at the raft edges

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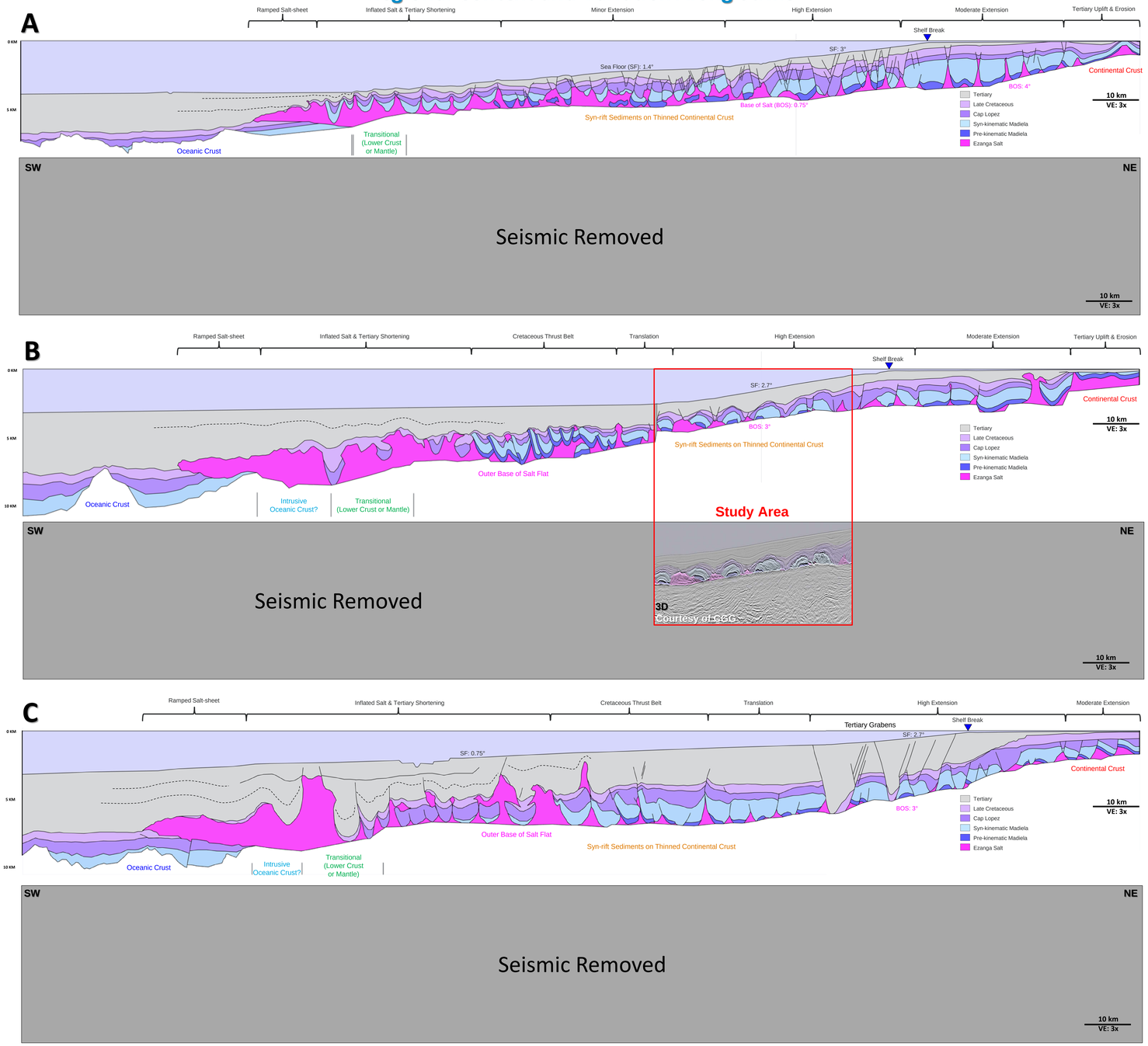
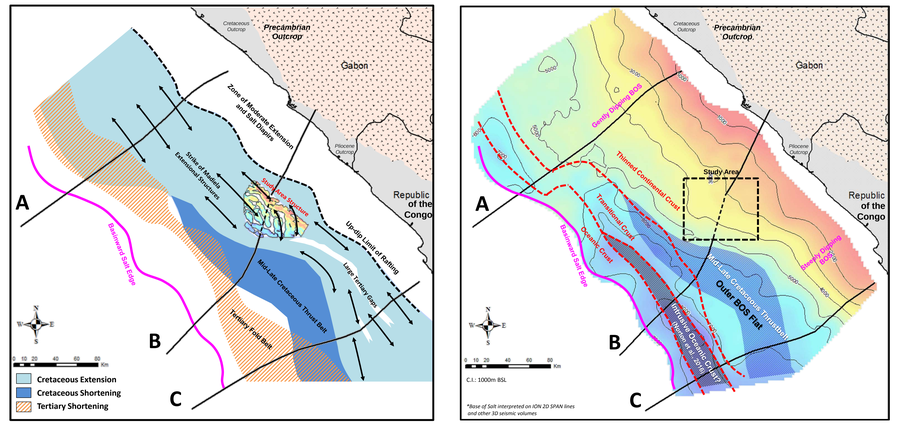
Regional Context and Variation Along Strike

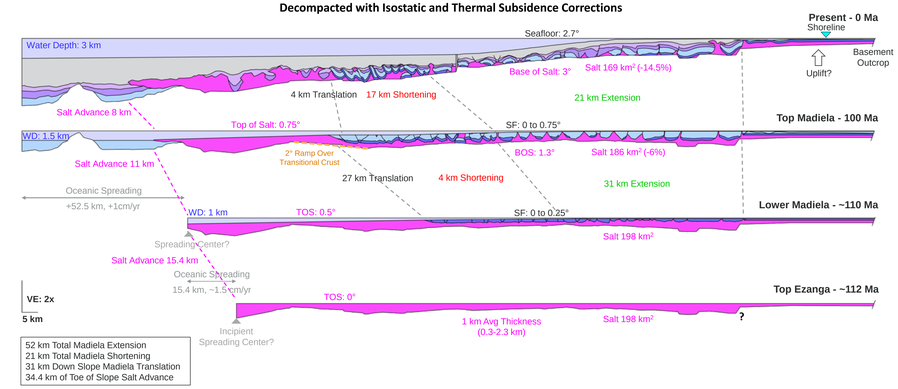


Madiela Structural Trends



- Discrete turtle-raft structures in the Madiela are unique to Study Area (see Transect B)
- Variation in raft strike across study area is influenced by:
  - Reentrant in the up-dip limit of rafting or break-away fault zone
  - Rotation during the Tertiary due to extension along strike to the south (compare Transects B & C)
- 2 episodes of shortening are recognized, one in the Mid-Late Cretaceous and one in the Tertiary
- Mid-Late Cretaceous thrust belt coincident with slope inflection and outer flat on the base of salt

Madiela Extension, Salt Tectonics, and Sea Floor Spreading



- Down slope translation and extension of Madiela influenced by:
  - ~1° increase in base of salt tilt
  - Widening of the salt/rift basin during late Ezanga and early Madiela deposition (see Norton et al., 2016)
  - Advance of salt over oceanic crust (31 km translation ≈ 34.4 km salt advance)
- A base of salt ramp over transitional crust localized shortening inboard of the basinward salt edge during the Cretaceous.
- Further tilting (~2°) of margin during Tertiary caused a fold belt at the basinward salt edge.

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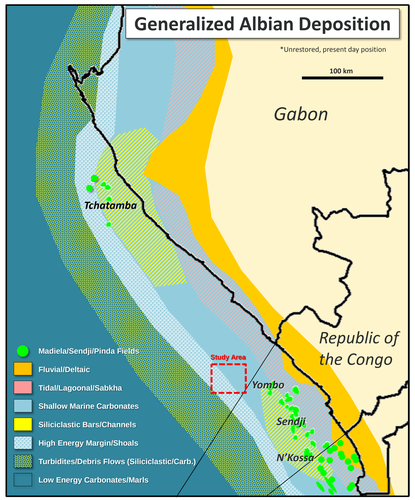
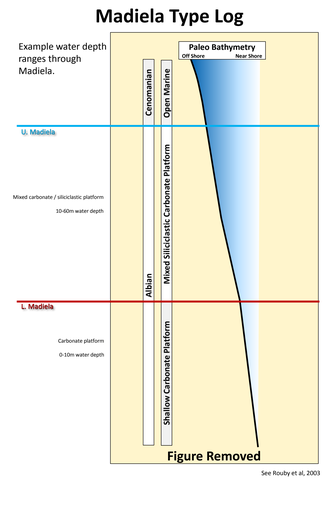
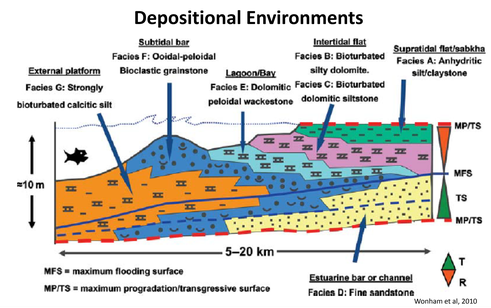
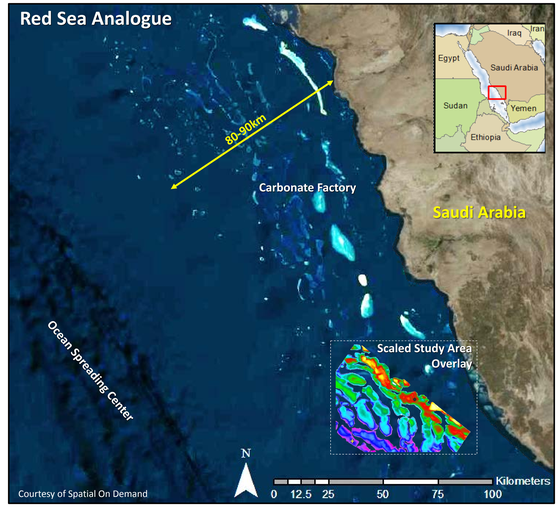
Madiela Deposition







- Madiela was deposited in a mixed siliciclastic-carbonate platform influenced by salt tectonics during the establishment of a passive margin extending from North Gabon to Angola. The clastic component increases with proximity to fluvial-deltaic axes.
- Water depth increases during deposition from sabkha and tidal facies in the Lower Madiela to inner neritic (up to 60m) in the Upper Madiela.
- Fields are productive from stacked reservoirs with a mix of environments, including oolitic shoals, dolomitic tidal flats, and siliciclastic bars and channels.
- High energy carbonate reservoir facies would have been localized by bathymetric highs related to Madiela turtle structures and salt diapirs.

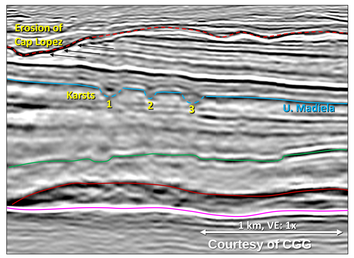


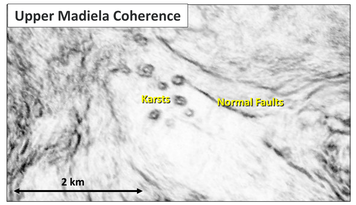
Red Sea Rift Basin Analogue - "Farasan Banks"

- Active Rift Basin with ongoing salt movement
- *Carbonate Factory* offshore produces wide variety of depositional styles in complex island chains where water depths range from 0-40m and are separated by deep marine channels (Bruckner et al, 2012)
- Depositional patterns influenced by active salt movement and faulting
- Shallow water at crest, deepening off the flanks of structures
- Platform width of 80-100km comparable to study area
- Nearby ocean spreading center to Southwest
- Scale of structures similar to study area (see inset)

Seismic Evidence for Shallow Reservoir Facies

Karst / Erosion





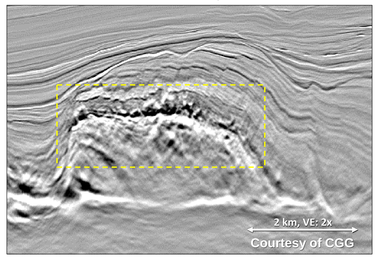
Observations:

- Periodically spaced discontinuities with downward curvature
- Map view – features are circular with diameter of 100-200m

Interpretation:

- Karst surface with collapse features
- Possible subaerial exposure within study area through late Madiela

Chaotic "Popcorn"



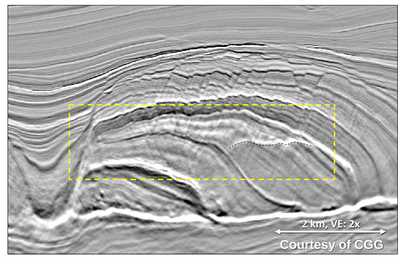
Observations:

- Disorganized, incoherent bedding
- Variable seismic amplitudes (high-low)
- Located up-dip within study area
- Primarily observed within Upper Madiela, but amplitudes locally extend to lower Cap Lopez
- U. Madiela fractured dolomite in offset wells
- Circular down-cutting features

Interpretation:

- Subaerial exposure surface with karsts
- Intra-to-supra tidal water depths
- Dolomite formed diagenetically (*Patterson & Kinsman, 1982*), then fractured during turtle formation
- Continued dolomitization along permeable faults into Cap Lopez

Reflective Boundary



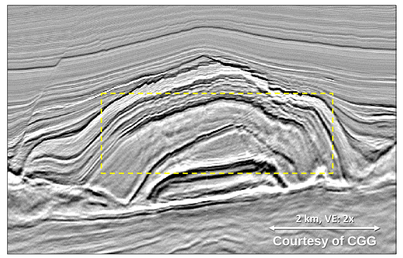
Observations:

- Pronounced reflection (always a trough – decrease in acoustic impedance)
- Higher amplitudes on crest, lower amplitudes on flanks of structures
- Continuous bedding crosses reflection
- Reflection is sub-horizontal with local bend/curves
- Stronger reflection in Upper Madiela; weaker reflection in Middle Madiela
- Reflection not penetrated by wells

Interpretation:

- Change in lithology: Depositional or Diagenetic
- Trough indicates a transition from dolomite or limestone overlying softer limestone or shale
- Possible burial or water flushing depth indicator
- Expect shallow water grading to deeper water on flanks (lagoon?)

Gradational Transition



Observations:

- Subtle amplitude transition from crest (higher amplitude) to flank (lower amplitude)
- Bedding is continuous across the transition
- Occurs in both Middle and Upper Madiela

Interpretation:

- Gradual facies transition from shallow platform limestones (shoals, reefs) to slightly deeper water limestones
- Porosity changes of a few percent

Conclusions

Syn-depositional extension during the Albian Madiela resulted in combination early raft and subsequent turtle structures over the south Gabon study area. The Albian extension was likely driven by the interplay of an initial increase in dip of the slope of the salt detachment after rifting and the advance of the down-dip salt sheet over and towards the oceanic crust. Extension during the early Madiela may have also been influenced by rifting of the salt basin and initial sea floor spreading (e.g., Norton et al., 2016). Extension along the strike of the margin did not produce similar, discrete Madiela turtle structures, likely due to differing magnitudes and rates of deposition, extension, and salt evacuation during the Mid-Upper Madiela. Within the study area, both vertical stacking and lateral stepping of Madiela depocenters are observed, resulting in symmetric and asymmetric turtle geometries. Structures in the study area reached their present day positions by the Turonian.

Extension was linked to a thrust belt that was localized, well inboard of the down-dip salt front, by an inflection in the base of salt detachment that is represented today by a wide flat on the base of salt. The margin continued to steepen after the Albian, resulting in adjustments of the Madiela structures and down-dip salt edge foldbelts that are more pronounced along strike to the northwest and southeast than in the study area. Variations in the strike of the structures across the study area were influenced by a reentrant in the "break away" fault and possibly rotation due to Tertiary extension to the southeast.

Despite the present day deep water position of the Madiela raft-turtle structures, the Madiela is an exploration target expected to have reservoir potential in the study area. The structures were originally deposited in a proximal, high energy environment conducive to reservoir quality facies and were subsequently displaced 25-to-50km down-dip. Well control within the study area indicates zones with 15-20% porosity in the Mid-Upper Madiela limestones and dolomites. There are no adequate penetrations of the Lower Madiela rafted section. Seismic observations of potential local karsting and high amplitude-to-low amplitude variations across the individual structures also indicate a much shallower water and reservoir prone depositional environment. High energy reservoir facies would have been localized by bathymetric highs related to turtle structures and salt diapirs, much like that observed in the Farasan Banks of the Red Sea.

Acknowledgements

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References and Further Reading

Bruckner, A., G. Rowlands, B. Riegl, S. Purkis, A. Williams, and P. Renaud (2012) Khaled bin Sultan Living Oceans Foundation Atlas of Saudi Arabian Red Sea Marine Habitats. Panoramic Press, pp. 262.

Dupre, S., Bertotti, G., Cloeting, S., 2007, Tectonic history along the South Gabon Basin: Anomalous early post-rift subsidence: Marine and Petroleum Geology, v. 24, p. 151–172.

Gilmore, L., 1996, Evolution and hydrocarbon potential of the Madiela carbonate platform, Offshore Gabon, West Africa, Master's thesis, Baylor University, Waco, Texas, 131 p.

Liro, L., R. Coen, 1995, Salt deformation history and postsalt structural trends, offshore southern Gabon, West Africa, in M. Jackson, D. Roberts, and S. Snelson, eds.: Salt Tectonics: A Global Perspective: AAPG Memoir 65, p. 323-331.

Norton, I., D. Carruthers, and M. Hudec, 2016, Rift to drift transition in the South Atlantic salt basins: A new flavor of oceanic crust: Nature, v. 44, p.55-58.

Patterson, R., J. Kinsman, 1982, Formation of diagenetic dolomite in coastal sabkha along Arabian (Persian) Gulf: AAPG Bulletin, V. 66, p. 28-43.

Rouby, D., F. Guillocheau, C. Robin, R. Bouroullec, S. Raillard, S. Castelltort :and T. Nalpas, 2003: Rates of deformation of an extensional growth fault/raft system (offshore Congo, West African margin) from combined accommodation measurements and 3-D restoration: Basin Research, v. 15, p. 183-200.

Teisserenc, P., and J. Villemin, 1989, Sedimentary basin of Gabon—geology and oil systems, in J. D. Edwards and P. A. Santogrossi, eds., Divergent/passive margins: AAPG Memoir 48, p. 117–199.

Wonham, J., M. Cyrot, T. Nguyen, J. Louhouamou and O. Ruau, 2010, Integrated approach to geomodelling and dynamic simulation in a complex mixed siliciclastic-carbonate reservoir, N'Kossa field, Offshore Congo, in Jolley, S. J., Fisher, Q. J., Ainsworth, R. B., Vrolijk, P. J. & Delisle, S., eds., Reservoir Compartmentalization, Geological Society of London, Special Publication 347, 133–163.