Recent High Resolution Seismic, Magnetic and Gravity Data Throws New Light on the Early Development of the Gulf of Mexico*

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Abstract

186,500 km of long (12 km) offset 2D marine seismic data, processed in time and depth, along with gravity and magnetic shipborne data (standard corrections applied) were acquired during 2015-16, covering the entire Mexican Gulf of Mexico (MGoM). These data tie into similar datasets in US waters and enable a better understanding of the deep structure of the entire GoM. The high resolution of the seismic data has allowed: 1. a correction of the GoM oceanic spreading transform fault locations, previously only diffusely identifiable on a Vertical Derivative version of the Sandwell Free Air Anomaly Map; 2. a study of transform zone width and angle of sediment wedges within the transform zone; and finally, 3. a refinement of existing models of the extinct Jurassic-early Cretaceous GoM spreading ridge locations by coupling the above with gravity and magnetic grids (themselves constructed using the transform faults as constraints) and profile plots of seismic depth (real and isostatically balanced) of top oceanic crust vs distance. The shipborne magnetic and gravity data were acquired in a direction slightly oblique to the transform ridges. However, the transform fault constrained magnetic anomaly and gravity maps have a broader frequency content than public magnetic and gravity (largely satellite derived) data. Because of thick sediment (up to 13 km) overlying the oceanic crust in the GoM, the magnetic anomaly signal and therefore the spreading anomaly pattern are more difficult to identify than those in younger and wider oceanic basins. Nonetheless, the location of the magnetic isochrons are readily identifiable by forward modelling of transform parallel transects within each spreading segment, and we are able to review existing models of oceanic opening time, rotation poles, and spreading rates. Finally we review spreading ages and bathymetry in a similarly small, but younger, oceanic spreading segment, the Gulf of Aden. This analysis leads us to conclude that, at the end of spreading, new GoM oceanic crust would have been some 1000 meters shallower than if standard age vs depth models (mostly based on wide spreading basins, such as the NW Pacific) were applied. This has important implications for salt deposition models in the entire GoM basin in the mid Jurassic.

^{*}Adapted from oral presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

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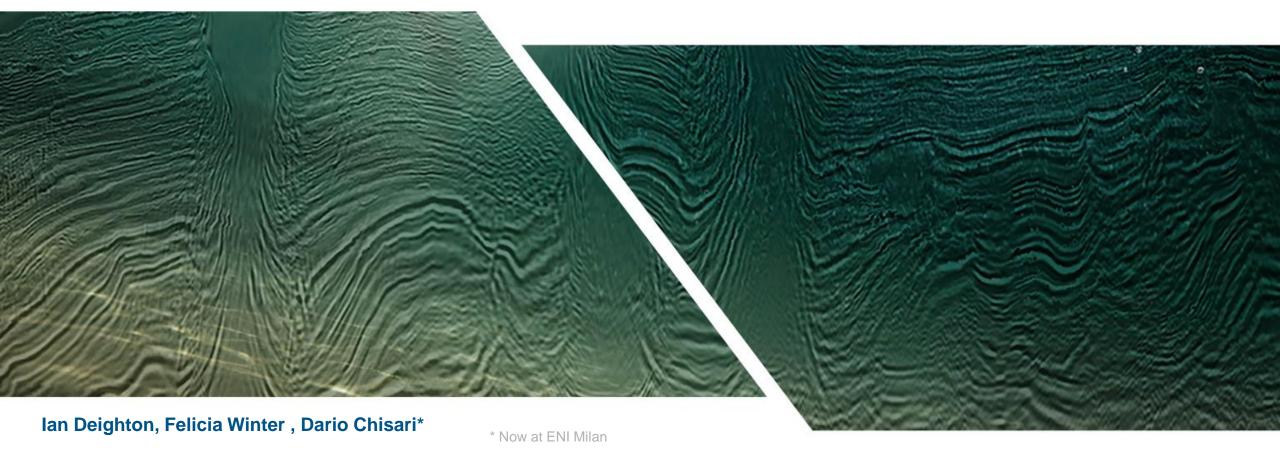
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Recent High Resolution Seismic, Magnetic and Gravity Data throws New Light on the Early Development of the Gulf of Mexico



Abstract

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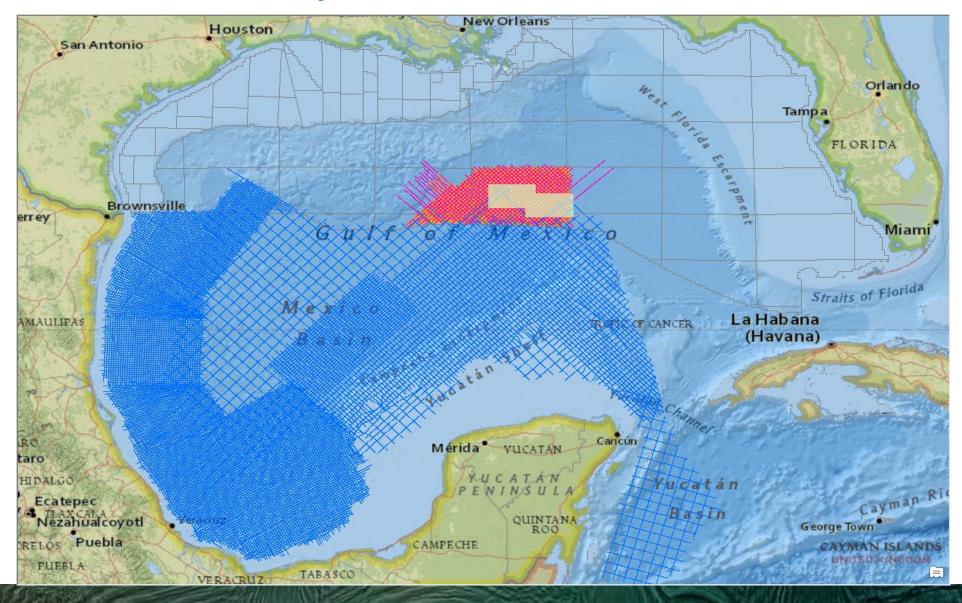
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Sandwell et al (2014). New global marine gravity from CryoSat-2 and Jason-1 reveals buried tectonic structure. Science

Introduction – Key Seismic Datasets



2D Data

Gigante (2017) – 191,000 km of long (12 km) offset 2D seismic data, processed in time and depth, with gravity and magnetic shipborne data

3D Data

Panfilo 3D (2015)

Overview

Study objective was to derive a paleo-bathymetric model for the oceanic crust in the Mexican Gulf of Mexico (MGoM) at the end of spreading.

- The tasks are:-
 - 1. Determine oceanic crust (OC) cooldown elevation at "end of spreading" time
 - 2. Refine the oceanic spreading model (pole and duration) for the Gulf of Mexico
 - Use "end of spreading" cooldown elevation and refined spreading model in GoM to derive the paleo-bathymetry
- Some statistics:-
 - The area of oceanic crust in the GoM stretches SW-NE with a maximum width of ~330 km and length of ~1300 km

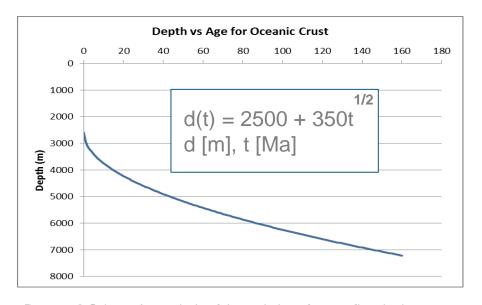
1. OC Elevation for "End of Spreading"

- Seems simple enough
- Use the age vs depth trend in present day oceanic crust right?
- Yes.. But which oceanic crust?
 - Mid Pacific?
 - But do we need something of a similar size?
- Assess present bathymetry of Red Sea/Gulf of Aden (GoA) as proxy for early GoM at end of spreading.

Size Comparison:

GoA: 500 km * 1300 km

GoM: 330 km * 1300 km



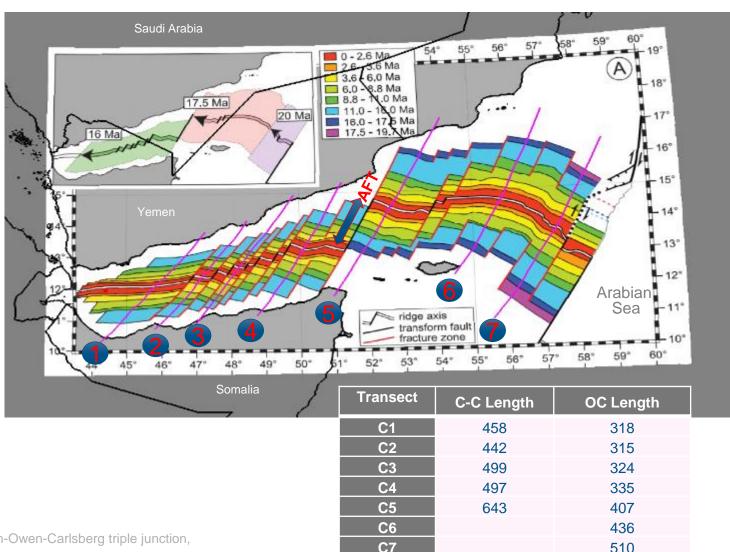
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GoA Transect Locations

Relatively recent research on GoA magnetic anomalies allowed some closer analysis:

- Age of oceanic crust goes back to 16 Ma, with spreading starting earlier (20Ma) further out
- ~20 ridge segments over 1300 km, (length variability 15-100 km)
- Segment offsets are generally less than 40 km, (except for the Alula-Fartak Transform (AFT) 200 km)
- Magenta transects are used for model analysis: C1→C7 (W→E)



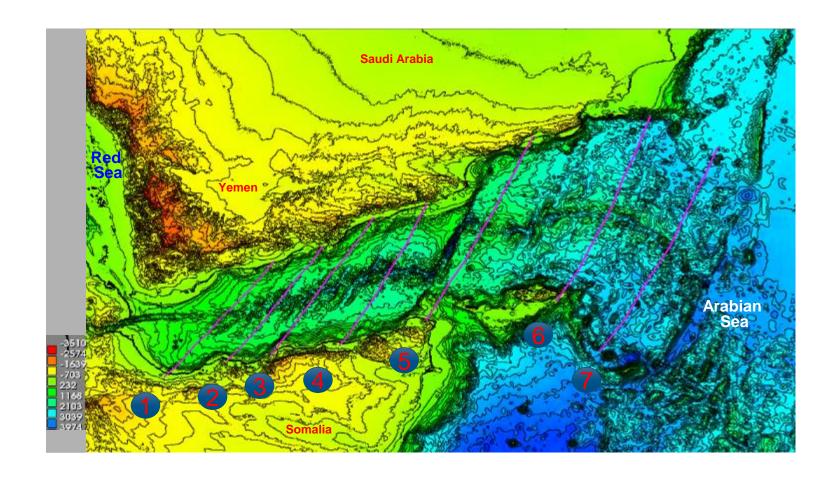
Fournier et al. (2010). Arabia-Somalia plate kinematics, evolution of the Aden-Owen-Carlsberg triple junction, and opening of the Gulf of Aden. *JGR*, *Solid Earth*

GoA Transect Bathymetry

SRTM30+ seabed bathymetry shows

- deepening of the ridge from W→E
- Variable presence of MOR valley
- Varying depths along transform zones
- MOR is not always perpendicular to transform faults

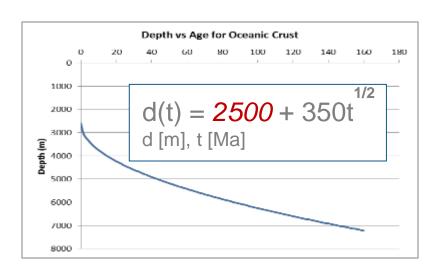
Transects C1-7 shown in magenta

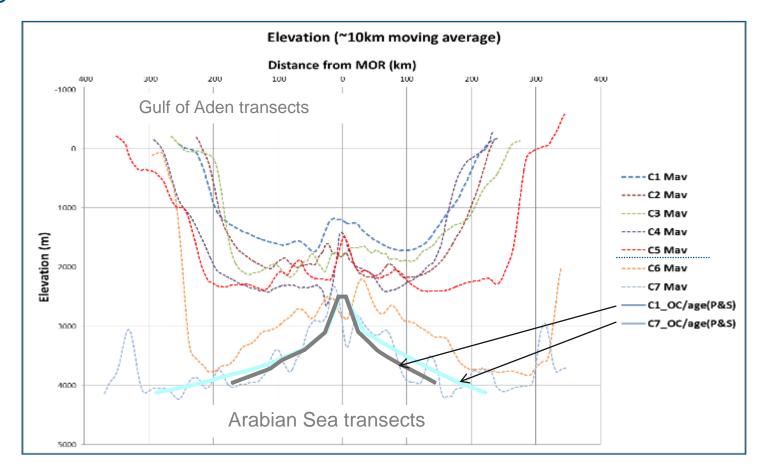


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Compare GoA OC Bathymetry with Parsons & Sclater (P&S) Model

- We use digitised age from Fournier et al (2010) map to calculate P&S depth of OC
- P&S trends for C1 and C7 are similar
- MOR elevation is a match for C7 but too deep for C1
- Solution is to change the initial MOR Elevation





2. Refine the GoM Spreading Model

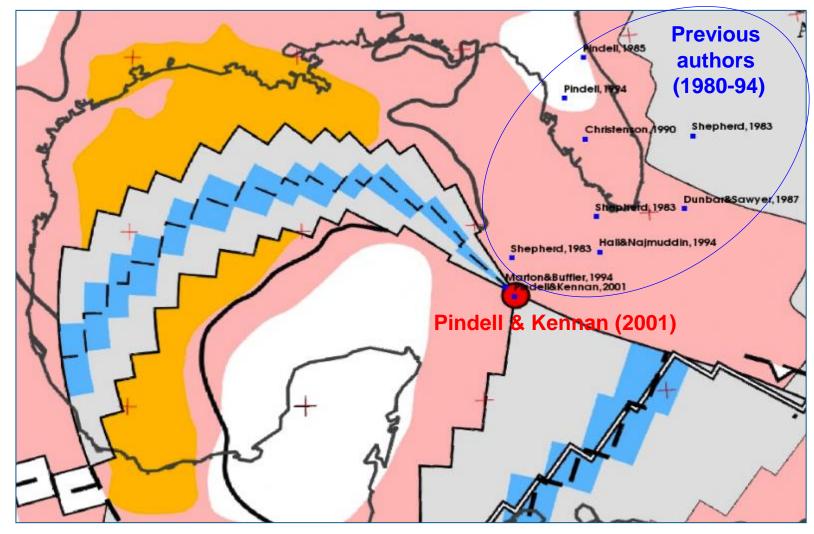
Starting with existing models from literature:-

- A. Refine transform fault interpretation
 - Literature review
 - Previous Rotation Poles
 - Impact of VGG
 - Change in location and orientation using seismic
 - Gigante 2D seismic basement
- B. Refine spreading ridge location
- C. Refine age model for spreading phase

Historical Locations of Rotation Poles

Over time the interpretation of the spreading direction has changed:

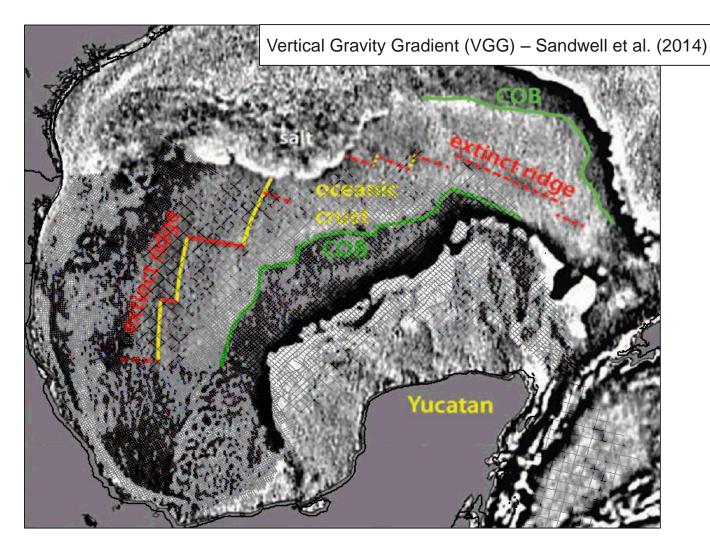
from NW-SE to N-S



Pindell and Kennan (2001). Kinematic Evolution of the Gulf of Mexico and Caribbean. Geol. Soc. Lond. Spec Pub 328

Refine Transforms – Literature Review

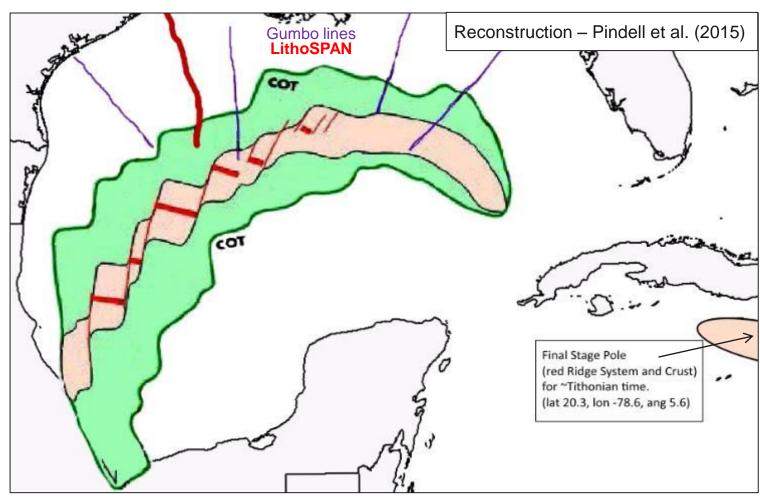
- Major breakthrough with interpretation of the Global gravity data set
- Vertical Gravity Gradient (VGG) map showed distinct ridge and transform features



Sandwell et al (2014). New global marine gravity from CryoSat-2 and Jason-1 reveals buried tectonic structure. Science

Refine Transforms – Literature Review

- The VGG model was used in conjunction with deep refraction and reflection lines by Pindell et al in 2015
- But resulted in a pole well to the east of previous interpretations



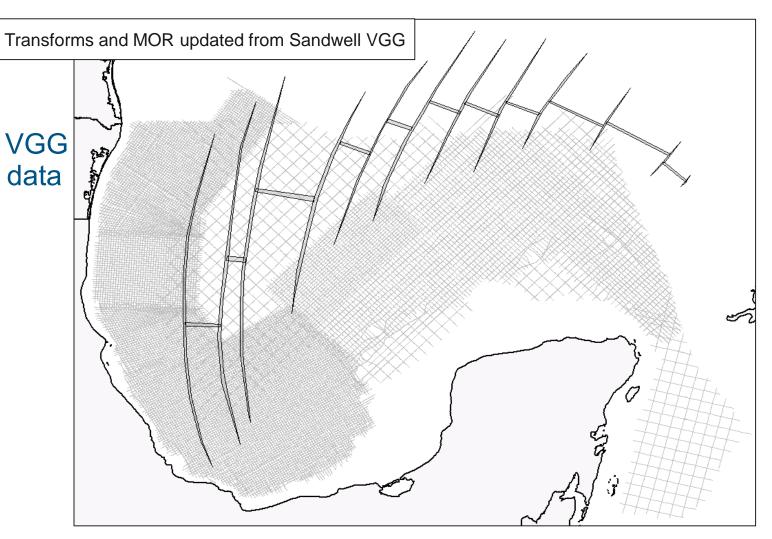
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TGS MGoM Transforms

Taking all this together:

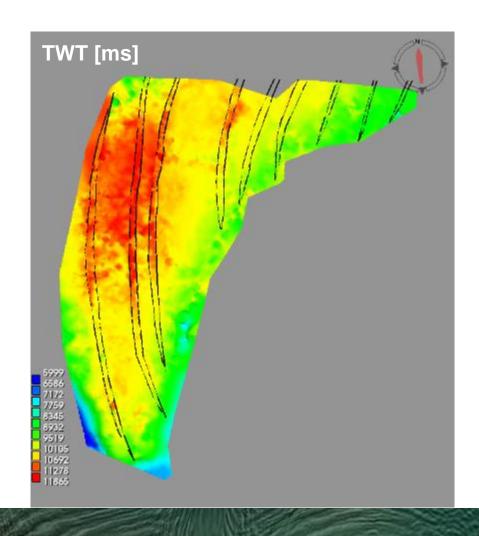
This was our starting point...

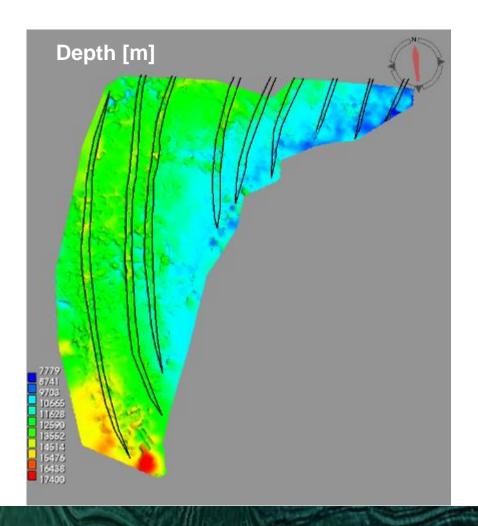
"updated Sandwell" model using VGG and TGS' Gigante survey gravity data



MGoM OC Basement Re-grid with Faults

Basement surfaces gridded with 'updated Sandwell' open faults

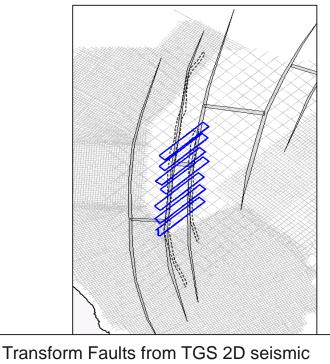


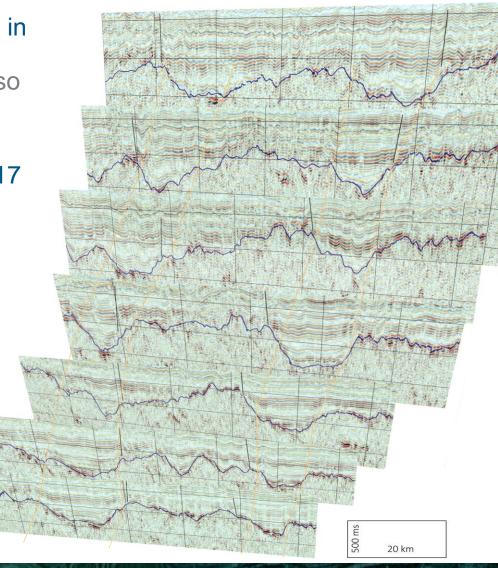


MGoM Transform Faults on TGS 2D Seismic

 TGS' 2D seismic clearly shows the transform fault troughs, in most cases coinciding with the "updated Sandwell" locations. At the ends of the transforms the imaging is not so supportive, mostly due to salt and folds in the overlying section

Further refinement awaits the depth processed data in 2017





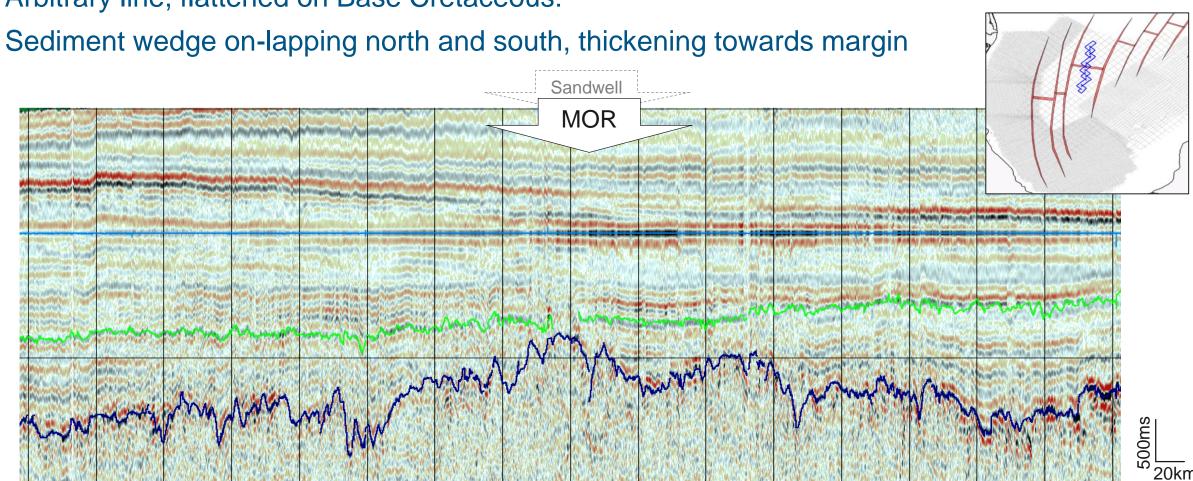
2. Refine the GoM Spreading Model

Starting with existing models from literature:-

- A. Refine transform fault interpretation
- B. Refine spreading ridge location
 - Test "updated Sandwell" location of MOR vs seismic location
 - Gigante 2D seismic
 - Panfilo 3D seismic
- C. Refine age model for spreading phase

MOR Identification - Gigante 2D Seismic

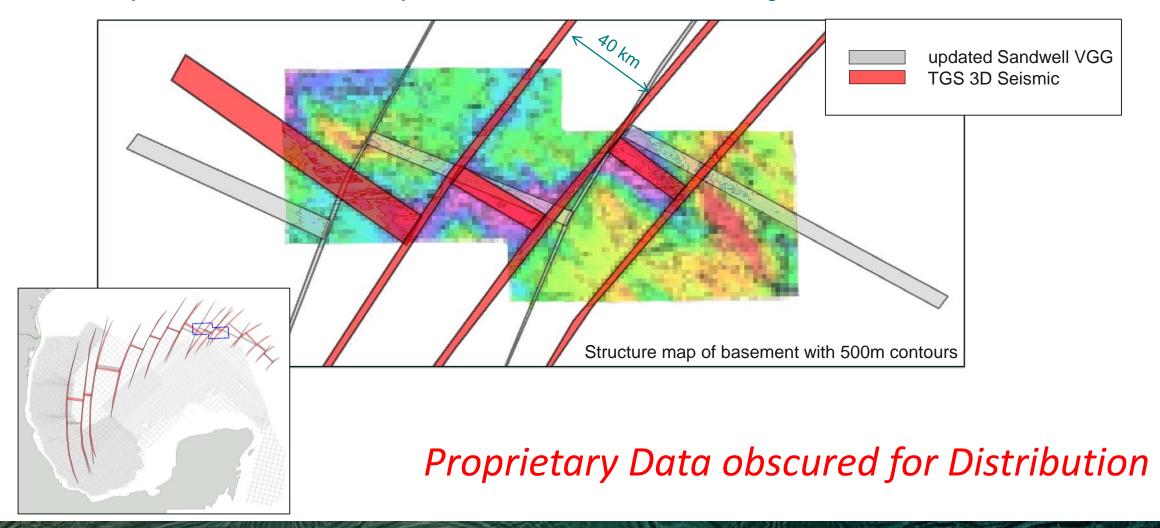
Arbitrary line, flattened on Base Cretaceous:



Note: no visible MOR valleys in most western segments...

MOR Identification - Panfilo 3D Seismic

MOR Valley identified in 3D survey, with different location and angles



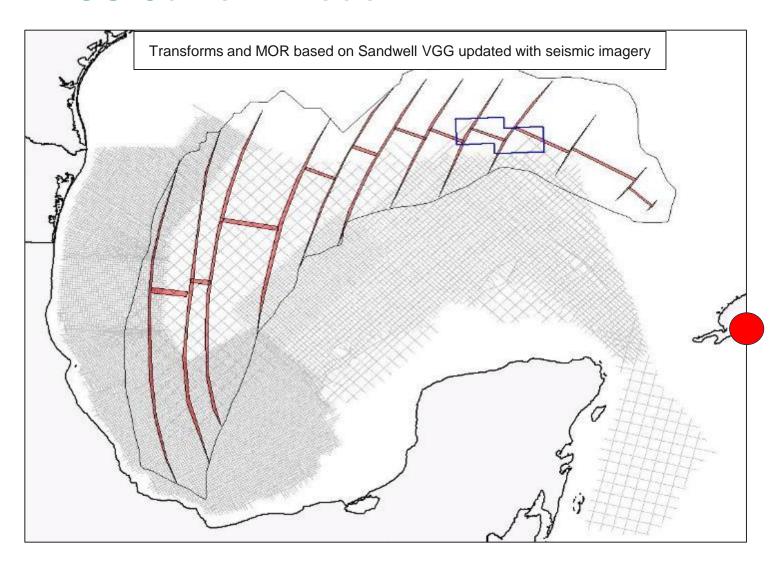
MGoM Transforms & MOR – TGS Current model

Taking all this together:

 This is our current model, with a pole located at

~83.8W, 21.9N

 Waiting on depth processing of Gigante 2D seismic data



2. Refine the GoM Spreading Model

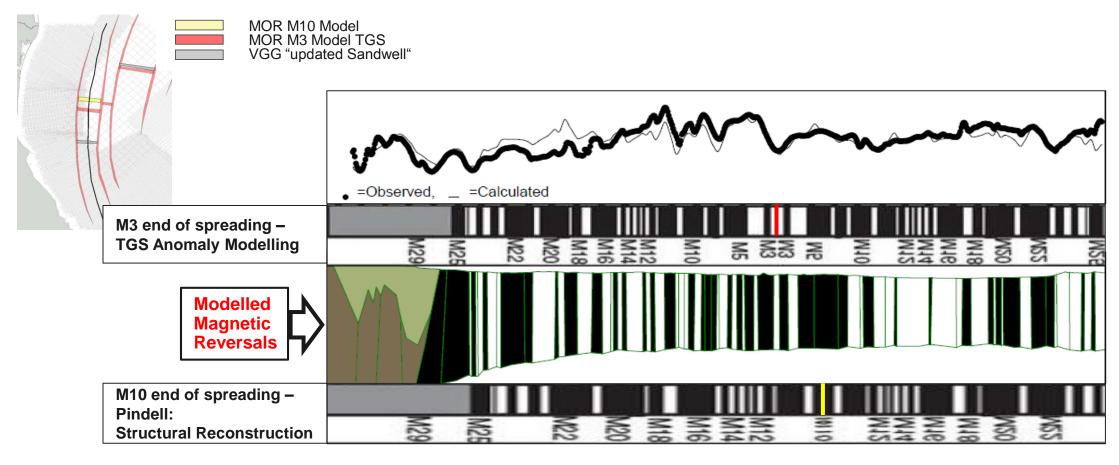
Starting with existing models from literature:-

- A. Refine transform fault interpretation
- B. Refine spreading ridge location
- C. Refine age model for spreading phase

Refine Age Model of Oceanic Spreading

- ~160-~140 Ma: Earlier versions of the GoM ocean spreading were based on rift/drift stratigraphic/structural interpretations on the margins
- ~150-134 Ma: Only one interpretation (Eskamani, 2014), located in the US GoM, was based on ship magnetics (Woods Hole survey)
- ~154-128 Ma: This version
 Gigante survey (including seismic, magnetics and gravity) was oriented roughly at 45° to the transform direction
 - 1. Regrid survey OC magnetic map using updated Transform faults and Ridges to see if magnetic anomaly trends show more apparent spreading patterns.
 - 2. Model arbitrary transects to determine a magnetic reversal pattern in the Gigante magnetic data.

Isochron identification and Spreading Location (West)

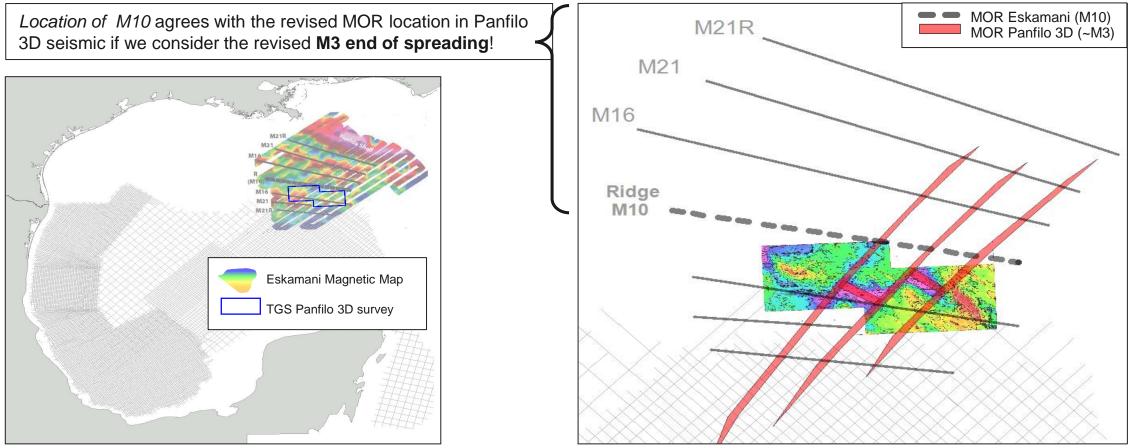


Pattern with M3 end of spreading shows a slightly better fit with the modelled/observed striping on the transect.

 \triangleright Chrons \sim M25-M3 = \sim 154-128 Ma = \sim 26 Ma of Oceanic Crust (OC), comparable with GoA

Isochron identification and Spreading Location (West)

- Eskamani (2014) model (M21R to M10 spreading) using Woods Hole data (1985)
- However the final MOR does not agree with TGS Panfilo 3D imaging



Eskamani (2014) . MSc thesis. Seafloor Spreading in the eastern Gulf of Mexico: New Evidence for Marine Magnetic Anomalies.. Colorado State University. Woods Hole R/V Farnella FRNL85-2 cruise [Lubinski and Twitchell, 1989]

3. Use cooldown and spreading model to derive early GoM paleo-bathy

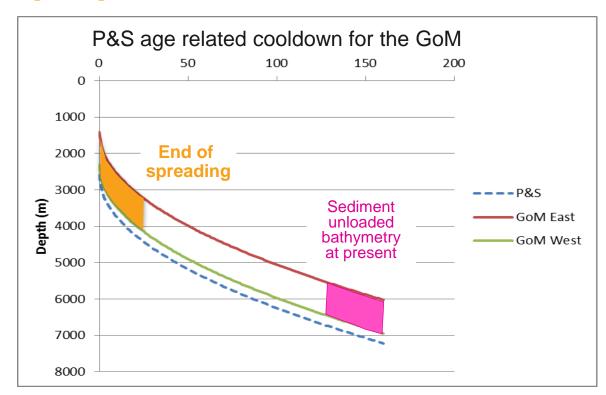
- Apply GoA OC cool down model and refined spreading model to derive GoM "end of spreading" bathymetry
- Apply new age frame for Gulf of Mexico to translate the OC basement relief at "end of spreading" time to derive the expected relief at "present day"

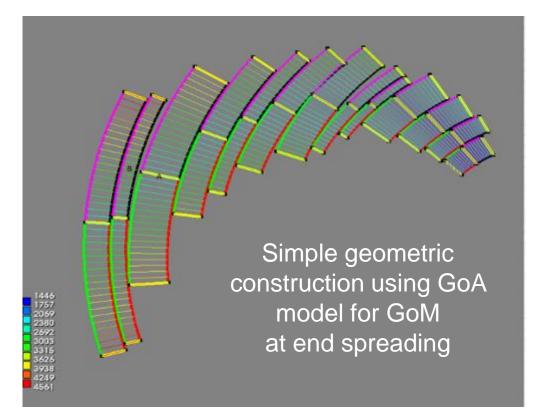
A Paleo-Bathymetry Model for the GoM

- We derive a sediment unloaded paleo-bathymetry at end GoM spreading using an age vs depth vs ocean length model from the above work.
- The figure below left shows the P&S age related cooldown (dashed) and that from the GoA restricted oceanic basin model.

Note that we are interested in the end of spreading in the GoM, so the relevant depths will be those in the

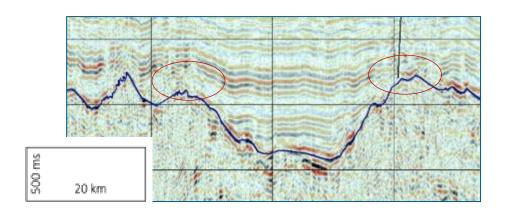
age range 0-26 Ma.

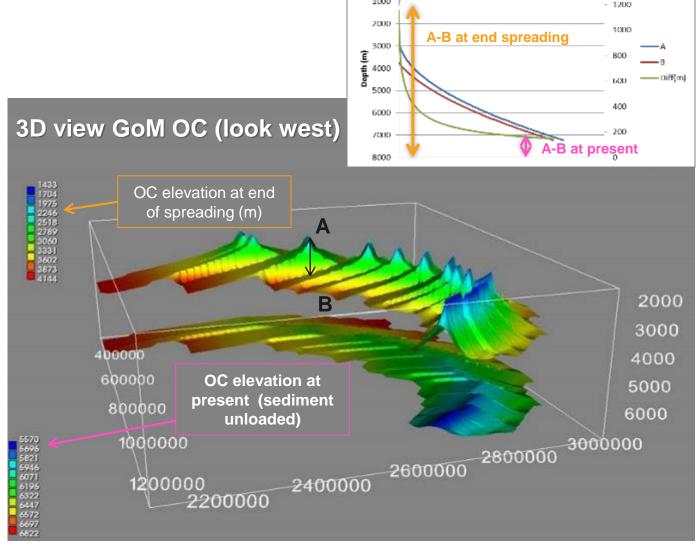




3D Paleo-Bathymetry Model for the Early GoM

- The cooldown model predicts a depth offset between segments at the transforms (because of different ages) - up to 1200m at end of spreading
- Even at present (further cooldown over the last 128 Ma), there is a 150m difference in elevation across a transform for the P&S half-space model (A-B, upper figure)
- Can we identify steps of the expected size/magnitude on the seismic data?
- The short answer is yes; but there are many reasons why it might not be there...





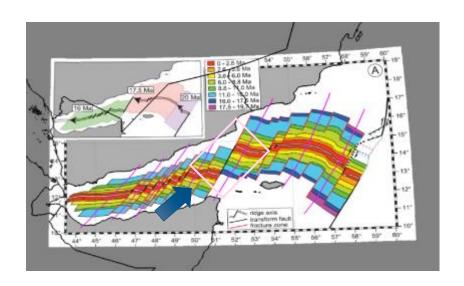
1000

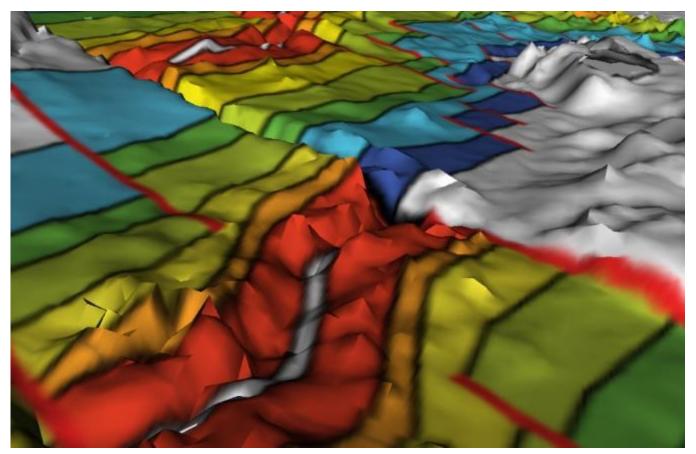
Difference in elevation across TF with 10 Ma age difference, at end spreading

Difference (m)

Why might there be no steps at Transforms?

- Most likely reason is lateral heat transfer at the end of the spreading segment, particularly for large offset ridge segments.. In the GoA 3D view below, the crust adjacent to the TF is elevated relative to that away further away
- Thus we are unlikely to see large sediment thickness variations across the transforms even when the final age difference is large





Conclusions

- In contrast to large ocean basins, magnetic isochrons in the Gulf of Mexico oceanic crust are blurred by thick sediments
- Long-offset, deep record seismic reflection data successfully images the location of transform faults, giving improved reconstructions of rotation poles for the opening of the GoM
- On the other hand, paleo-Mid Ocean Ridges may be harder to identify, for a variety of reasons
- Using the uniformitarian principle (i.e. analogy with the similar sized Gulf of Aden) leads to a ~1km shallower reconstruction of GoM oceanic crust at end of spreading in the early Cretaceous. Isostatic proof of this concept awaits better depth and density figures which will arrive with the Gigante depth processed data later this year

Thank you

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