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Continuous Coverage of Recent High Resolution Seismic and Magnetic Data gives New Insight into the Early Development of the Gulf of Mexico

I. Deighton* (TGS), F. Winter* (TGS)

Summary

Extensive coverage of the entire Mexican Gulf of Mexico (MGoM) by long offset 2D marine seismic data, processed in time and depth, along with gravity and magnetic shipborne data were acquired on an evenly space survey grid during 2015-16 and enable a better understanding of the deep structure of the entire GoM. 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 was carried out and a refinement of existing models of the extinct Jurassic-Early Cretaceous GoM spreading ridge locations was undertaken by coupling the above with gravity and magnetic grids and profile plots of seismic depth of top oceanic crust vs. distance. Due to 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.

Introduction

186,250 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; TGS, 2016) were acquired during 2015-16, covering the entire Mexican Gulf of Mexico (MGoM). The data ties into similar datasets in US waters and enables a better understanding of the deep structure of the entire GoM.

Many young oceanic basins, such as the northern North Atlantic, are well understood. Dense data coverage and continuously improved imaging allow analyses of sedimentary influx, syn-rift geology and the initiating structural processes, and the tectonic evolution of its margins. Historic seismic and magnetic data coverage of the MGoM did not permit a detailed ocean reconstruction based on spreading isochron analysis on a regional tectonic scale. Therefore, no evolutionary study for the entire basin, which focuses on a magnetostratigraphic approach in the MGoM, has been completed yet. The reconstruction by Pindell et al. (2015) used ION deep 2D data combined with magnetics, however, the restrictions of their data result in the model being best applied to the cross-border region. Our latest data greatly improves regional data density with the advantage of 2D seismic and magnetic data being acquired on an evenly spaced survey grid throughout the entire MGOM. Since the US GoM is well understood, this new and additional high quality data now allows us to better constrain the trends of Jurassic spreading in MGoM, estimate average spreading rates of the main segments in the west and ultimately draw conclusions for symmetry and geometry of the spreading dynamics.

Approach

This study undertakes a regional magnetic isochron identification for the MGoM by gridding magnetic anomaly data with updated transform fault polygons, which results in a magnetic anomaly map that better matches the tectonic faults and basement structures. The transform definition and fault-controlled gridding allows forward modelling of the anomalies on spreading transects (within a segment of oceanic crust wholly between a set of transform faults).

The high resolution of the seismic data has allowed us to:-

- Revise the location of the transform faults and so define the spreading segments.
  This is a refinement of the GoM oceanic spreading transform fault locations, which was previously only diffusely identifiable on a Vertical Derivative version of the public Free Air Anomaly Map (Sandwell et al., 2014). Along these transform faults the 2D seismic shows variable width of the transform fault zone and variable angles of sediment wedges within the transform zone (see Figure 2).
- Estimate the spreading centres and geometry of the basin opening.
  A refinement of existing mapped locations of the extinct Jurassic-Early Cretaceous GoM spreading ridge was undertaken by coupling the above mentioned transform zone revision with gravity and magnetic grids, themselves constructed using the transform faults as constraints. Seismic depth profiles of top oceanic crust were plotted against distance to identify a MOR like structure. With the time of spreading onset of the GoM taken from literature, a range of spreading ages was used to predict initially expected locations of magnetic reversals. The re-gridding of the 2D magnetic anomaly data using the revised transform fault locations and the newly located ridges results in a map indicating more apparent zones of magnetic intensity. Isochron patterns were then modelled along the western spreading segment to define the possible location of spreading anomalies and extinct ridge.

The palaeo-bathymetric modelling was based on a well-studied, small-width ocean analogue, the Gulf of Aden (GoA). The present bathymetry of the GoA was assessed quantitatively by plotting age vs. depth vs. ocean width to provide a first pass palaeo-bathymetry at the cessation of spreading in the GOM. The average GoA MOR elevation was plotted against the ocean basin width (values taken from the head of the GoA, Figure 1) and a trend was established for depth vs. GoA head distance (inset plot, Figure 1). The actual trend of the bathymetry vs. ridge offset in the GoA is complicated by sedimentation at distances greater than 100km from the MOR, but within MOR ± 100km a sub-parallel trend can be seen, which represents the cooling of oceanic crust (cooling subsidence rate ~600m at 100km distance). The actual depth of the GoA should be used as an initial case for a GoM palaeo-bathymetric model.

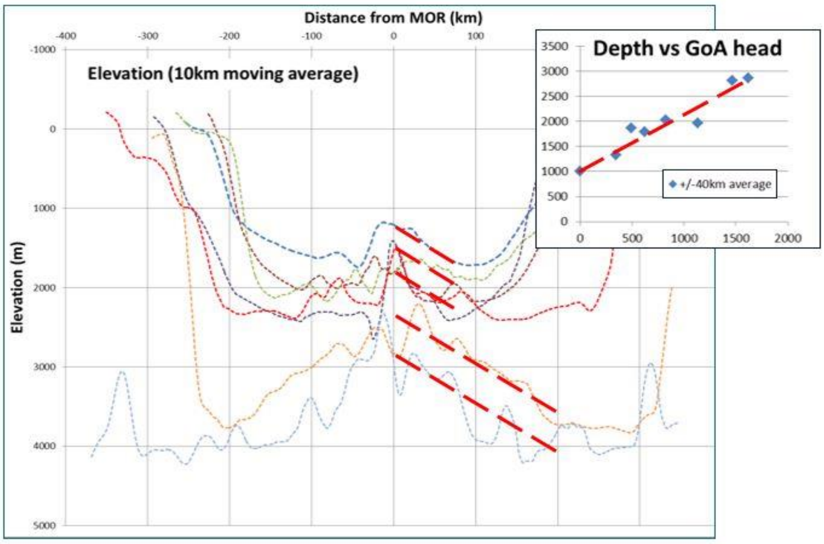

Figure 1 *Transects of oceanic basement depth analysis in GoA, extracted from Fournier et. al (2010).*

The analysis of this data leads to the conclusion that, at the cessation of spreading, the youngest oceanic crust in the GoM would have been some 1000 meters shallower than if standard age vs. depth models were applied (based on wider ocean basins, such as the NW Pacific). This would have important implications for salt deposition models in the entire GoM basin for the Mid Jurassic, such as volume calculations of sea-water available for Mediterranean-Messinian style desiccation models.

Results and Discussion

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 higher frequency content than public magnetic and gravity (largely satellite derived) data. Hence, our magnetic anomaly frequency content provides a much more robust ocean seafloor pattern than the publicly available data. Uncertainties remain though, because the magnetic anomaly signal and therefore the spreading anomaly pattern are challenging to visualise in the GoM due to the thick sediment overburden (up to 13 km) on oceanic crust, and are more difficult to identify than those in younger and wider oceanic basins.

The comparison of transform faults derived from current gravity vertical gradient (VDR) maps with the newly traced seismic oceanic basement surface allowed us to refine and extend the transform fault locations towards the northern and southern edges of the MGoM (Figure 2). Where the small scale troughs in the palaeo-seafloor relief approximately coincided with VDR fault locations, the published transform fault locations were adjusted, improving the magnetic grid. The improvement in pattern recognition can be seen in Figure 3; the gridded magnetic intensity (using the transform corrections) show a distinct quantitative banding from yellow to green to blue values on the map.

With the new and more confidently defined set of spreading segments, oceanic seafloor magnetic striping could more successfully be identified for most areas of the MGoM. A complete regional set of identified isochrons cannot be provided, the full set will be based on forward models. The identification of a magnetic pattern in the GoM remains challenging, since the unusually thick sediment cover of old post-rift sediments leads to a significant amount of compaction for the post-rift sequences which result in a low pass filter effect for the magnetic signal frequencies.

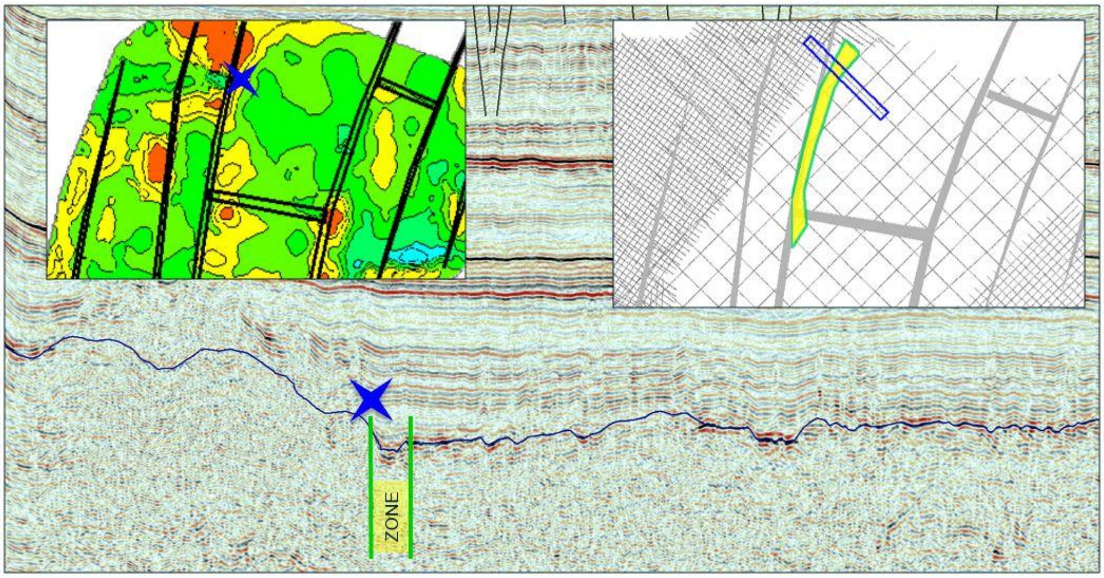

Figure 2 *Transform fault identified on seismic and reviewed on magnetic anomaly map, MGoM. The inset two maps show the VDR transform versions. The blue star indicates the better location of the transform fault, based on the high resolution 2D seismic data. The transform fault zone width is indicated in green/yellow on the seismic and inset basemap.*

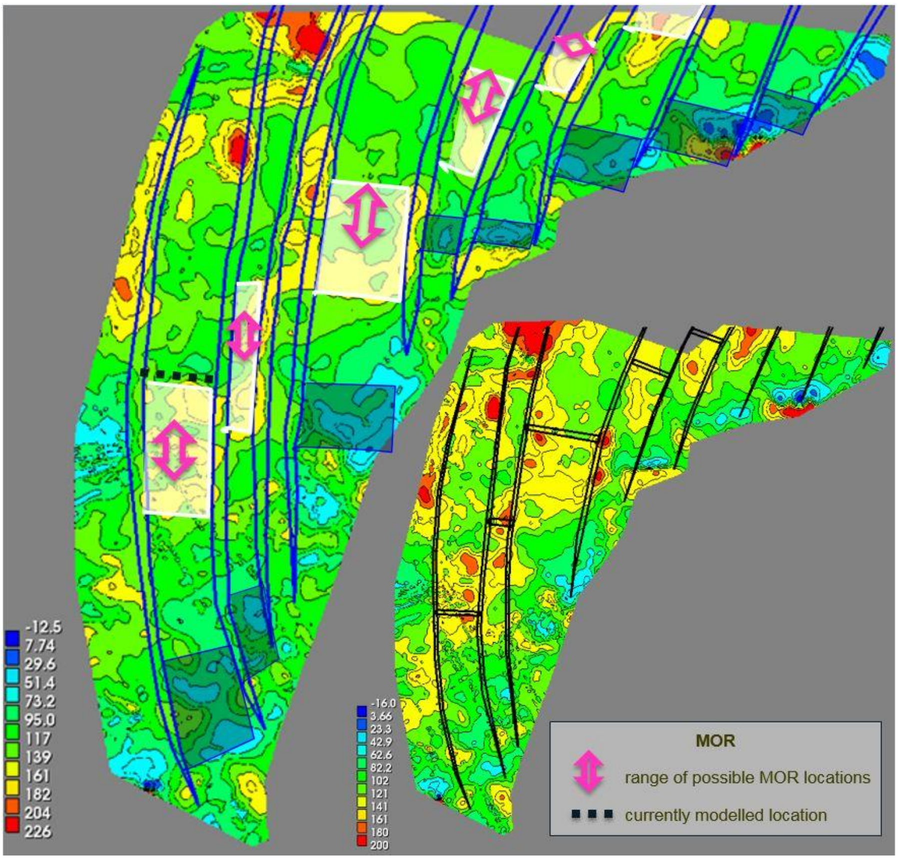

Figure 3 *Transform faults on an unrevised magnetic anomaly map of the MGoM (inset right) and transform corrected anomaly map with onset/cessation of spreading marked by blue/white polygons and the range of possible ridge locations indicated by pink arrow. Dashed black MOR is derived from the modelled transect (Figure 4).*

A magnetic anomaly profile was extracted from the revised magnetic grid for each segment, so that the observed and mapped anomaly pattern can be tied in with the magneto-stratigraphic time scale

(Walker et al., 2012). The transect in Figure 4 is a good example of the anomaly pattern, visualised on a profile within the western spreading segment (in direction of opening) the model suggests a reasonable fit of the magnetic isochron succession from roughly M25 (155Ma) to M1 (126Ma).

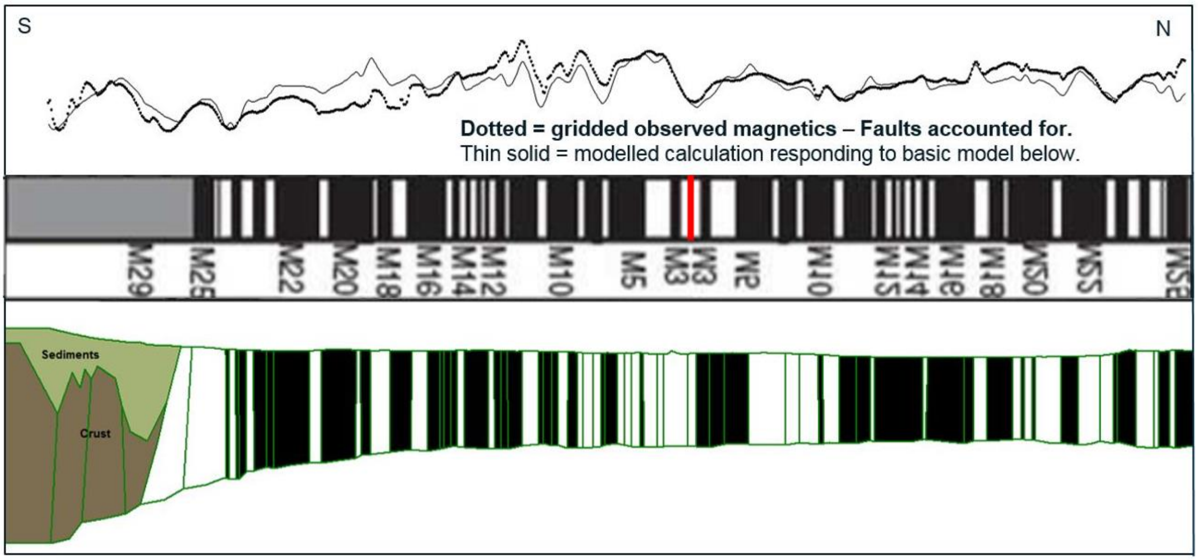

Figure 4 *Forward modelled magnetic profile along a transect in the western most spreading segment in the MGoM (Figure 3), isochron table taken from Walker et al. (2012).*

Conclusions

This approach of re-interpretation of observable oceanic transform faults in the high-resolution 2D seismic, combined with gridding, analysis and modelling of magnetic isochrons on the crustal segments between the transform faults provides us with a reasonably well defined oceanic spreading trend and an age framework for the early MGoM oceanic opening. This provides an important background for structural frameworks for interpretation and prospectivity studies.

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