Paleogene Yucatan back-arc basin in the northern Caribbean: Ridge and fracture zone geometry in oceanic crust, depth-to-Moho, and Cenozoic sedimentary fill

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Summary

Based on the interpretation of gravity, magnetic, and 6,000 km of 2D seismic reflection data, the presence of a spreading ridge system in the Yucatan basin associated with the formation of a back-arc basin during the Paleogene related to the collision of the Caribbean Plate with the North American Plate was identified. This first recognition of the system allows broadening the understanding of the evolution of the Caribbean plate since the Paleocene and the formation of oceanic crust east of the Yucatan Peninsula.

Introduction

The Yucatan basin is a triangular ocean basin located between the Cayman Trough, Cuba, and the eastern edge of the Yucatan Peninsula in Mexico (Figure 1). This basin is an important tectonic and sedimentary record of the evolution of the northern Caribbean Plate and its interaction with the North American Plate since the Late Cretaceous.

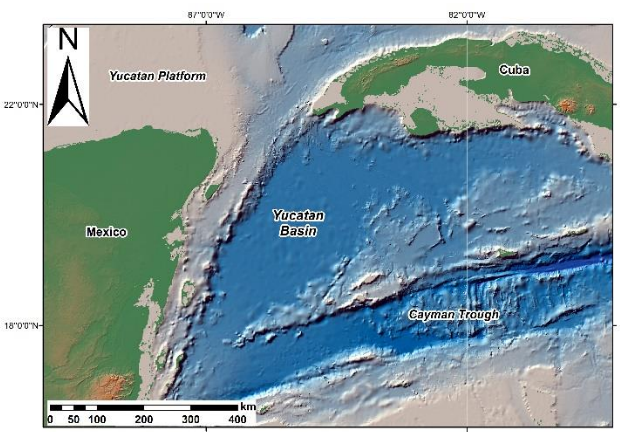


Figure 1. Location of the Yucatan basin in the NW Caribbean Sea with a maximum water depth of 5,000 m.

This area has undergone a complex evolution involving the collision of the northern segment of the Great Caribbean Arc (GAC) against the Bahamas platform and the coeval development of Paleogene back-arc opening and strike-slip faulting.

Previous regional studies of the area based on seismic reflection have shown the main crustal types and basement architecture of the Yucatan Basin (Rosencrantz, 1990) while land studies of northwestern Cuba interpreted the termination of the left-lateral Yucatan strike-slip fault (Gordon et al., 1997). Additionally, recent results based on 3D gravity modeling inversion of the Gulf of Mexico (Lin et al., 2019) have revealed the presence of oceanic crust underlying the sedimentary sequences in the Yucatan basin.

Methodology

For this study, we have used different data sources to carry out the interpretation of the spreading ridge system in the Yucatan basin. These methods include interpretation of tilt-angle gravity of the Sandwell free-air gravity dataset and magnetics to analyze density and magnetic anomalies associated with changes in crustal composition. Additionally, the interpretation of 6.000 km of 2D seismic data in depth was conducted.

The seismic lines were used to interpret the basement fabric in the Yucatan Basin, sediment thickness, sedimentary sequences, depth-to-Moho, and depth-to-basement surfaces.

Results

Defining the back-arc pattern of Paleogene spreading ridges and fracture zones

This study defines the location of an extinct spreading ridge system within a 60,000 km^2 area of Paleogene oceanic crust in the western Yucatan Basin, northwestern Caribbean. These extinct and buried NNW-trending spreading ridges that total 220 km in length are linked by right-lateral transform faults and adjacent fracture zones (Figure 2).

The northern spreading ridge is 42 km in length and is linked by the Los Palacios pull-apart basin in coastal northwestern Cuba. The 065-striking Pinar fault extends 305 km on land in western Cuba and is known from previous studies to have been active during the early Eocene (Gordon et al., 1997). The 83-km-long central spreading ridge is bounded by a transform and fracture zone trending parallel to the 070-striking Varadero fault that exhibits a 21-km left-lateral offset of the thrust front of northwestern Cuba (Cruz-Orosa et al., 2012). The 73-km-long southern spreading ridge is terminated on its southern edge and northern edges by right-lateral faults, while the shortest spreading ridge of 20 km in the southwestern corner of the Yucatan Basin is terminated by a left-lateral fault that aligns with the left-lateral La Trocha fault that offsets the thrust front by 26 km in central Cuba (Rosencrantz, 1990).

This overall pattern of progressive, clockwise deformation in the Yucatan back-arc basin is consistent with the detachment of elongate microplates from the Caribbean plate and their transfer to the North American plate (Gordon et al., 1997). Additionally, these spreading ridges are flanked by normal faults that dip inwardly towards the axial valley. The trend of the extinct spreading supports the idea that the Yucatan basin opened in an east-northeast direction (Figure 2).

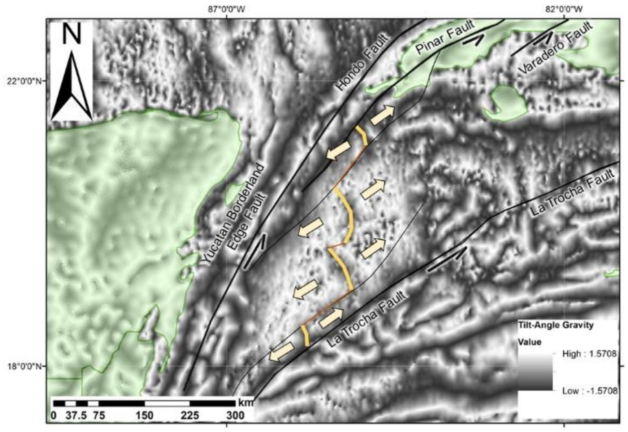


Figure 2. NWW-trending spreading ridges over tilt-angle gravity of the Sandwell v30.1 free-air gravity dataset

Characteristics of oceanic crust underlying the western Yucatan basin

Depth-converted seismic reflection data were used to interpret the top of the Moho in the study area. These data show that the Moho is much shallower (10-12 km) beneath the thinner oceanic crust of the Yucatan basin than at the thicker basin margins (16 km) (Rosencrantz, 1990).

In the area where the spreading ridges were interpreted, it is observed that the top of the Moho is at a shallower depth, which is characteristic of these zones of oceanic crust generation due to the ascent of asthenospheric material. Along these ridges, the top of the Moho was found at depths less than 11 km.

An interpretation of the crustal thickness in the Yucatan basin shows that the spreading ridges are surrounded by oceanic crust with a thickness of 6-7 km, a characteristic value for this type of crust. In the areas where the ridges were previously interpreted, the thickness of the oceanic crust is less (3-5 km), which supports the interpretation of these structures throughout the basin.

Sedimentary sequences of the western Yucatan basin

Based on the interpretation of the seismic reflection grid, the sedimentary sequence in the Yucatan basin reaches a thickness of up to 4 km in the major depocenters. These thicker zones are directly related to the location of the axial valleys of the spreading ridges where the top of oceanic basement top is at greater depth and therefore allows for greater accommodation space.

The sedimentary thickness of the basin decreases to the structural highs formed by large but now inactive, left-lateral strike-slip faults that form the northwestern margin of the basin (Figure 2). The average sediment thickness over the oceanic crust is greater than 1.5 km.

Using heat flow to constrain the Paleogene age of the Yucatan basin

Heat flow values were published in the early 1970s for the Yucatan basin (Epp et al., 1970; Erickson et al., 1972) .These results show a higher heat flow value right where a spreading ridge was interpreted (119 mW/m2) while the other values along the Yucatan Basin are in the range of 50-69 mW/m2 typical for oceanic crust.

These reported heat flow values support the interpretation of the existence of extinct spreading ridges because the highest heat flow values are in the area of the extinct spreading ridge where the oceanic crust is thinnest (3-5 km) as known from the Moho seen on seismic reflection lines.

Age and origin of the Yucatan Basin

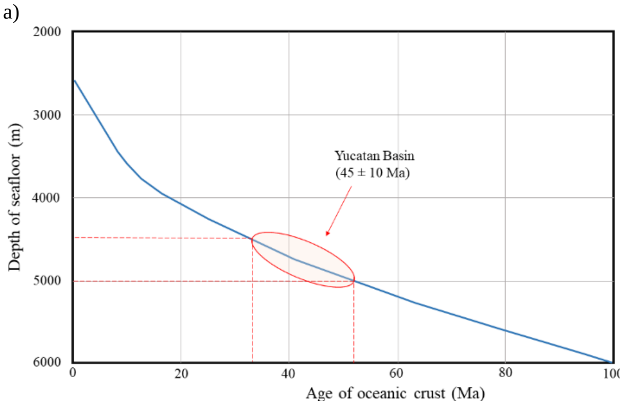
Because the study area has not been previously drilled by oil exploration or academic deep-sea drilling, the age of the oceanic basin was calculated based on its water depth and the measured heat flow.

Previous studies interpreted the opening of this basin for the early Eocene related to a phase of collision of the Caribbean Plate against the Bahamas Platform to the NE and sinistral faulting along the Pinar fault zone during this period that produced the opening of this back-arc basin (Gordon et al., 1997). Other authors have also interpreted the formation of oceanic crust in this Yucatan basin for the Paleocene – middle-to-late Eocene based on the age of the NE thrust and deformation belt in Cuba that led to the extension present southward of the collision zone.

We used the Cooling Plate Model (1977) to calculate an Early to Late Eocene age (55-35 Ma) of the oceanic crust of the Yucatan basin based on the depth of seafloor along the basin (Fig. 3a). As an additional constraint on the age of the oceanic crust, we used a heat flow value for the western Yucatan basin that was included in the Plate Model and Half-Spaced Cooling Model (Korenaga and Korenaga 2008). The average heat flow value yielded an Eocene age (55-40 Ma) (Figure 3). These calculated values are similar to previously proposed ages for the formation of the Yucatan basin in the NW Caribbean by Rosencrantz (1990), Gordon et al. (1997), and Cruz-Arosa et al. (2012).

Origin of the Yucatan back-arc basin in the northern Caribbean

a)



b)

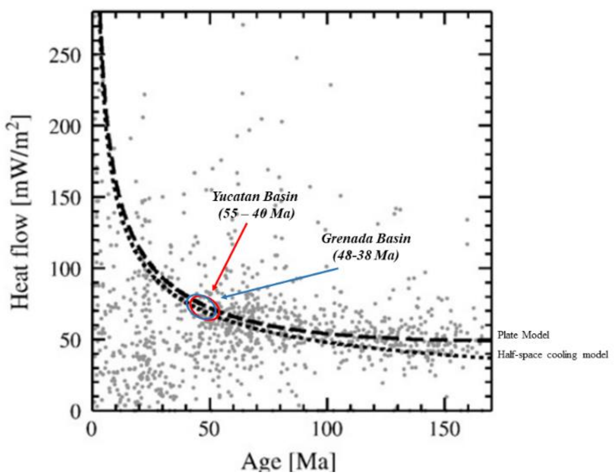


Figure 3. a) Comparison of the depth of seafloor in meters vs. age of oceanic crust (Ma) as a constraint for a 45±10 Ma age (Early to Late Eocene) for the Yucatan Basin. b) Heat flow (mW/m^2) vs. age of oceanic crust (Ma) showing Middle Eocene (45 Ma) age for the Yucatan basin. The plot is modified from Korenaga and Korenaga, (2008). A similar age of Middle Eocene has been inferred from heat flow for the Grenada basin which is another segment of the backarc basin adjacent to the Great Arc of the Caribbean.

Based on these results, we conclude that the Yucatan basin formed during the Paleogene as a back-arc basin adjacent to the Cuban segment of the GAC. The Yucatan basin formed along a parallel series of left-lateral strike-slip faults that were terminated when the Great Arc of the Caribbean collided with the Bahamas carbonate platform (Figure 4). A similar age back-arc basin formed adjacent to the Lesser Antilles arc but was not affected by the collision with the Bahamas carbonate platform (Garrocq et al., 2021)

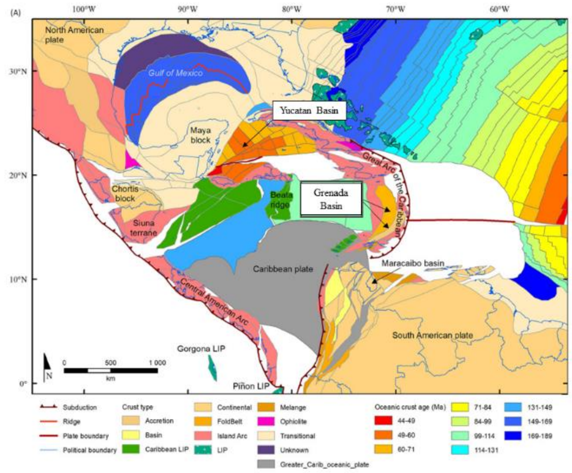


Figure 4. Middle Eocene plate reconstruction for the Gulf of Mexico and Caribbean from (Escalona et al., 2021) showing the Middle Eocene Yucatan and Grenada back-arc basins adjacent to the Great Arc of the Caribbean.

Conclusions

The western Yucatan basin is underlain by an oceanic crust of Paleogene age with an average thickness of 6-7 km that is overlain by 1-4 km of Cenozoic, deep-marine clastic sedimentary rocks. This basin shows gravity, magnetic, and seismic reflection evidence for a slow-spreading ridge and associated fracture zones with a west-northwest opening direction. The extinct spreading axis exhibits an axial valley with a 4-km-thick sedimentary fill, higher heat flow values, and a thinner (3-5 km) oceanic crust as seen from the underlying Moho as imaged on the seismic reflection grid. The seafloor depth (4.5-5 km) constrains the age of the oceanic crust from Early Eocene to Early Oligocene in age (45±10 Ma) while the heat flow constrains an age of Early to Late Eocene (55-40 Ma). The calculated age of Eocene for the Yucatan basin overlaps with the more protracted Paleocene-Late Eocene (65-37 Ma) age for the collision of the Cuban segment of the Great Arc of the Caribbean with the Bahamas carbonate Platform (Gordon et al., 1997; Cruz-Orosa et al., 2012)

Acknowledgments

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