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Integrated Seismic and Gravity Data Modeling: Basement Structure in the Gulf of Mexico

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ABSTRACT

Three mega-regional north-south transects, extending 300 mi (500 km) to over 500 mi (800 km) through the onshore and offshore parts of the northern Gulf of Mexico Basin, have been modeled by integrating gravity, seismic refraction, and composite seismic reflection data. The composite lines consist of long-offset Pre-Stack Depth Migrated (PSDM) marine streamer, legacy onshore, and Ocean Bottom Cable (OBC) data processed by GX Technology. The models indicate that the basin increases in depth to over 50,000 ft (15 km) offshore beneath the continental shelf and that a prominent basement high in the Keathley Canyon concession area rises over 9800 ft (3 km) above the surrounding basement. Detailed interpretations of the reflection seismic lines show that the basin structure and stratigraphy are affected by this basement architecture and are presented in a companion study.

Our results contribute to the understanding of the Gulf of Mexico Basin framework, and they are consistent with a recently proposed evolutionary model that requires a mantle plume eruption prior to sea-floor spreading in the basin. This evolutionary model suggests that prominent gravity anomalies over the Sigsbee Salt Nappe and center of the Gulf of Mexico are produced by hotspot tracks that were created as the basin opened, by counterclockwise rotation of the Yucatan block away from the North American Plate, over the mantle plume.

INTRODUCTION

Understanding the shape of the Gulf of Mexico Basin and deep basement structuring can contribute to the understanding of source rock distribution, salt mobilization, sediment loading, and basin evolution. Integrating gravity and seismic data to model basement geometries is a well-established method for studying sedimentary basin (Bird et al., 2005). This is because the depth to anomaly source ambiguity associated with gravity data can be reduced by depths from seismic data, and the localized nature of seismic data can be extrapolated away from acquisition locations using the areal coverage provided by gravity data.

The composite seismic data that were the basis for the modeled cross sections were reprocessed and depth imaged by GX Technology. The land data contributors were Geophysical Pursuit Inc. and Seismic Exchange Inc. The nearshore component of the composite lines is GX Technology OBC long-offset, long recording time data, and the deep water component is GX Technology's long-offset, marine streamer data.

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MODELING RESULTS

Three regional 2D gravity models, constrained by seismic reflection and refraction data, establish the shape of the northern Gulf of Mexico Basin from onshore to offshore (Figs. 1 and 2). The models extend south, from 124 mi (200 km) to over 248 mi (400 km) north of the coast, to the Sigsbee Escarpment. They were constructed along the composite seismic reflection lines. Gravity data were acquired in tandem with the long-offset PSDM (pre-stack depth migrated) section of the model, and it has been merged with open-file Decade of North American Geology gravity data (Tanner et al., 1988) for the remaining sections of the model. Refraction data, from published sources, were used to establish basement and Moho control points along the models (Antoine and Ewing, 1963; Cram, 1961; Ebeniro et al., 1988; Ewing et al., 1960; Hales et al., 1970; Ibrahim et al., 1981; Ibrahim and Uchupi, 1981; Keller et al., 1989).

To maintain consistency over the study area, the densities used for the modeled rock layers were held constant for the models (Table 1). Four sedimentary rock layers thicken to the south and include numerous salt bodies that were interpreted from the seismic reflection data. The crust is divided into two layers. Sources used to estimate rock properties for modeling and interpreting seismic refraction data include Carmichael (2000), Christiansen and Mooney (1995), Cordell (1973), Sykes (1996), and White et al., (1992).

Modeled Cross Section A-A’ is 564 mi (907 km) long and extends from near Dallas, Texas, to the Sigsbee Escarpment in the western part of the Keathley Canyon concession area. This cross section intersects, or is located close to, several seismic refraction lines (Antoine and Ewing, 1963; Ebeniro et al., 1988; Ewing et al., 1960; Hales et al., 1970). Results from the onshore study of Cram (1961) are located about 100 mi (160 km) to the southwest but along strike with the trend of the coast. Overall, the basement deepens from about 16,000 ft (5 km) to 50,000 ft (15 km) to the south. The crust thins to the south from over 130,000 ft (40 km) thick to less than 23,000 (7 km) thick. The prominent high amplitude gravity anomaly, about 70 mGal (milligals), is produced by a basement high that is interpreted from the seismic reflection data (Radovich et al., 2007). This basement structure has been interpreted from seismic refraction data as well (Ebeniro et al., 1988; Ewing et al., 1960). It rises over 9800 ft (3 km) above the basement and is rooted by thickened crust that depresses the upper mantle by about 9800 ft (3 km). To the north of this structure, the basement deepens to over 50,000 (15 km). Although thick salt exists in this part of the basin, the magnitude of the anomaly can only be modeled by deepening the basin, which further supports the interpreted basement structure in the southern part of the model. Shorter wavelength gravity anomaly lows, ranging from 39,000 ft (12 km) to 65,000 ft (20 km), along the model are produced by low-density salt. However, in some locations the salt produces short wavelength gravity anomaly highs. This is because salt density is nearly constant regardless of depth (about 2.16 g/cc), and at very shallow depths, salt is more dense than the surrounding rocks. The depth at which salt becomes more dense is typically around 5000 ft (1.5 km) below the water bottom.

Modeled Cross Section B-B’ is 417 mi (671 km) long and extends south from central Louisiana to the Sigsbee Escarpment in the eastern part of the Keathley Canyon concession area. It intersects one seismic refraction line and passes between two other refraction lines (Ibrahim and Uchupi, 1981). The sedimentary section, crust, and gravity anomalies related to salt are similar to Modeled Cross Section A-A’, including the rooted, basement structure at the southern end of the model. Note that several gravity anomaly highs are produced by salt that is above the cross-over depth and even produces bathymetric relief.

Modeled Cross Section C-C’ is the shortest model, 331 mi (533 km), and extends southward from about 43 mi (70 km) north of Lake Pontchartrain in eastern Louisiana to the Sigsbee Escarpment in the eastern part of the Walker Ridge concession area. It intersects one seismic refraction line at 169 mi (272 km) (Ibrahim and Uchupi, 1981). Like Modeled Cross Sections A-A’ and B-B’, the sedimentary section thickens to over 50,000 ft (15 km), and the crust to the south thins from continental to oceanic thicknesses. The prominent basement structure and gravity anomaly have both decreased in amplitude, less than 3300 ft (1 km) and 21 mGal respectively. However, a crustal root of over 6600 (2 km) must be modeled in this location. Also, similar to the other models, short wavelength gravity anomalies are interpreted to be produced by salt bodies.

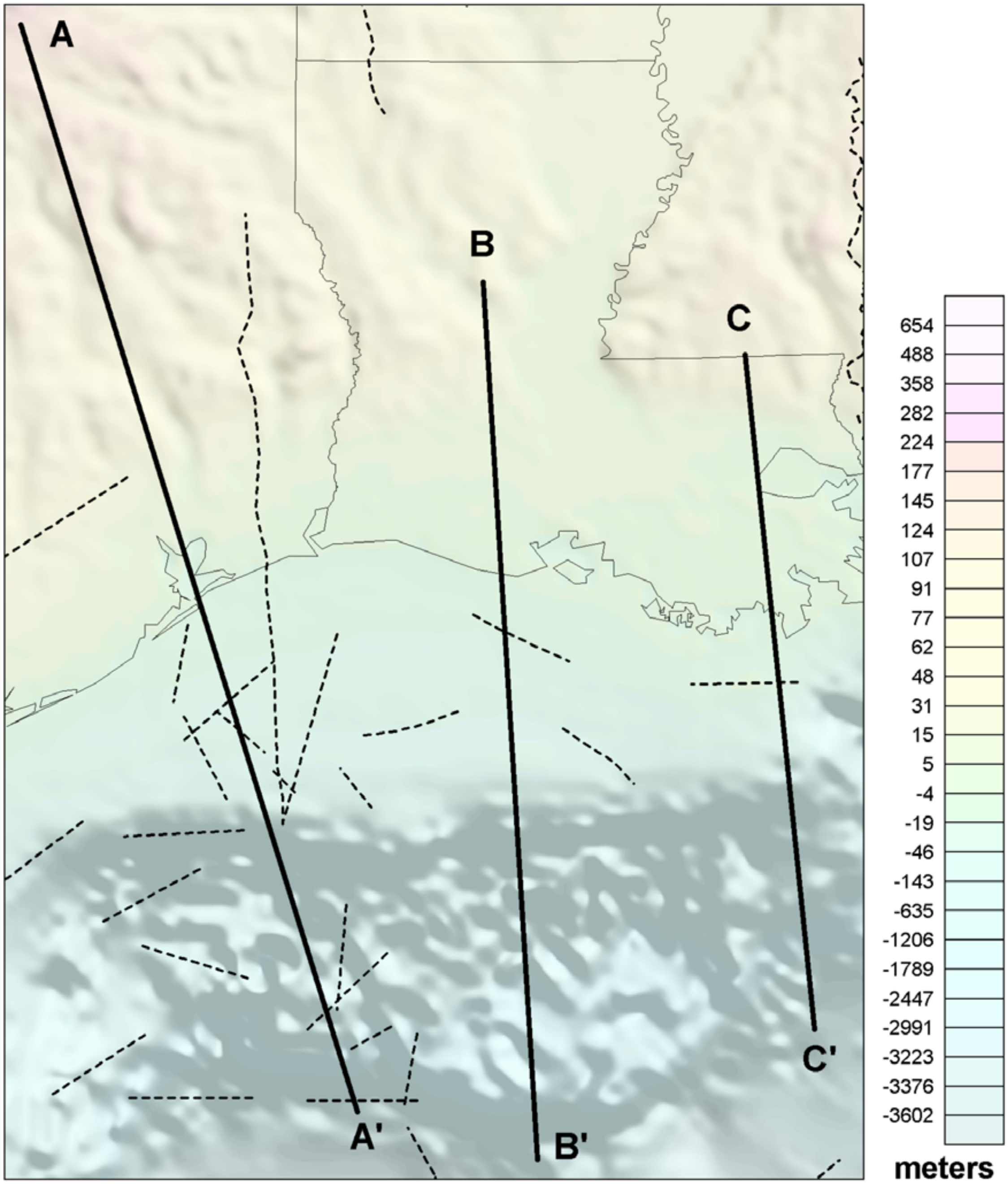

Figure 1. Topography. Solid lines = approximate GX Technology seismic reflection lines. Dashed lines = seismic refraction lines from published sources.

Table 1. Modeled cross section layer densities.

Layer	Density (g/cc)
Water	1.03
Sediments	2.10
Sediments	2.20
Sediments	2.40
Sediments	2.55
Upper crust	2.75
Lower crust	3.00
Upper mantle	3.30

DISCUSSION

The prominent, rooted basement structure in the southern part of the models has been interpreted to be a hotspot track that was created by a mantle plume during sea-floor spreading and the formation of the Gulf of Mexico (Bird et al., 2005). This evolutionary model proposed that:

- The Gulf of Mexico formed by approximately 40 degrees of total counterclockwise rotation of the Yucatan block about a pole located near Key West, Florida.
- Continental extension coincided with 20 degrees of rotation as the western edge of the Yucatan block moved south along a transform fault located just offshore eastern Mexico.
- Sea-floor spreading began with the eruption of a ridge-centered mantle plume in western Keathley Canyon followed by 10 degrees of rotation over 5 m.y., while two hotspot tracks were produced simultaneously on the North American Plate and the Yucatan block.
- Then, because the rate of sea-floor spreading decreased below the rate of North American motion over the mantle plume, the Yucatan block overrode the plume during the final 10 degrees of rotation for another 5 m.y.

Bird and Burke (2006) interpreted the formation of the Gulf of Mexico with respect to the Central Atlantic Ocean and Mexico. They reported that:

- Nearly every continental fragment that has broken away from the supercontinent Pangea has been preceded by a mantle plume.
- Eastern Mexico, the U.S. south of the Ouachita-Marathon suture, Florida, and the Yucatan block formed a contiguous Gondwanan block after North America broke away from Gondwana (ca. 180 Ma) and prior to the opening of the Gulf of Mexico.
- Two sea-floor spreading ridge jumps occurred in the Central Atlantic: ca. 170 Ma and 162 Ma, to the east and west respectively.

Bird and Burke (2006) suggested that the opening of the Gulf of Mexico may have occurred at the time of these ridge jumps. Finally they note, because the Yucatan block was bounded to the north, west and east by similar Gondwana terranes that a mantle plume is a probable explanation for opening the Gulf of Mexico.

CONCLUSIONS

Results from interpreting mega-regional modeled cross sections, integrated with seismic reflection and gravity data as well as refraction information from published sources, indicate that the basement deepens to over 50,000 ft (15 km) and that a prominent basement high exists in the Keathley Canyon and Walker Ridge concession areas. This basement structure further supports a recently proposed evolutionary model for the Gulf of Mexico in which a mantle plume erupted as sea-floor spreading began ca. 150 Ma (Bird et al., 2005).

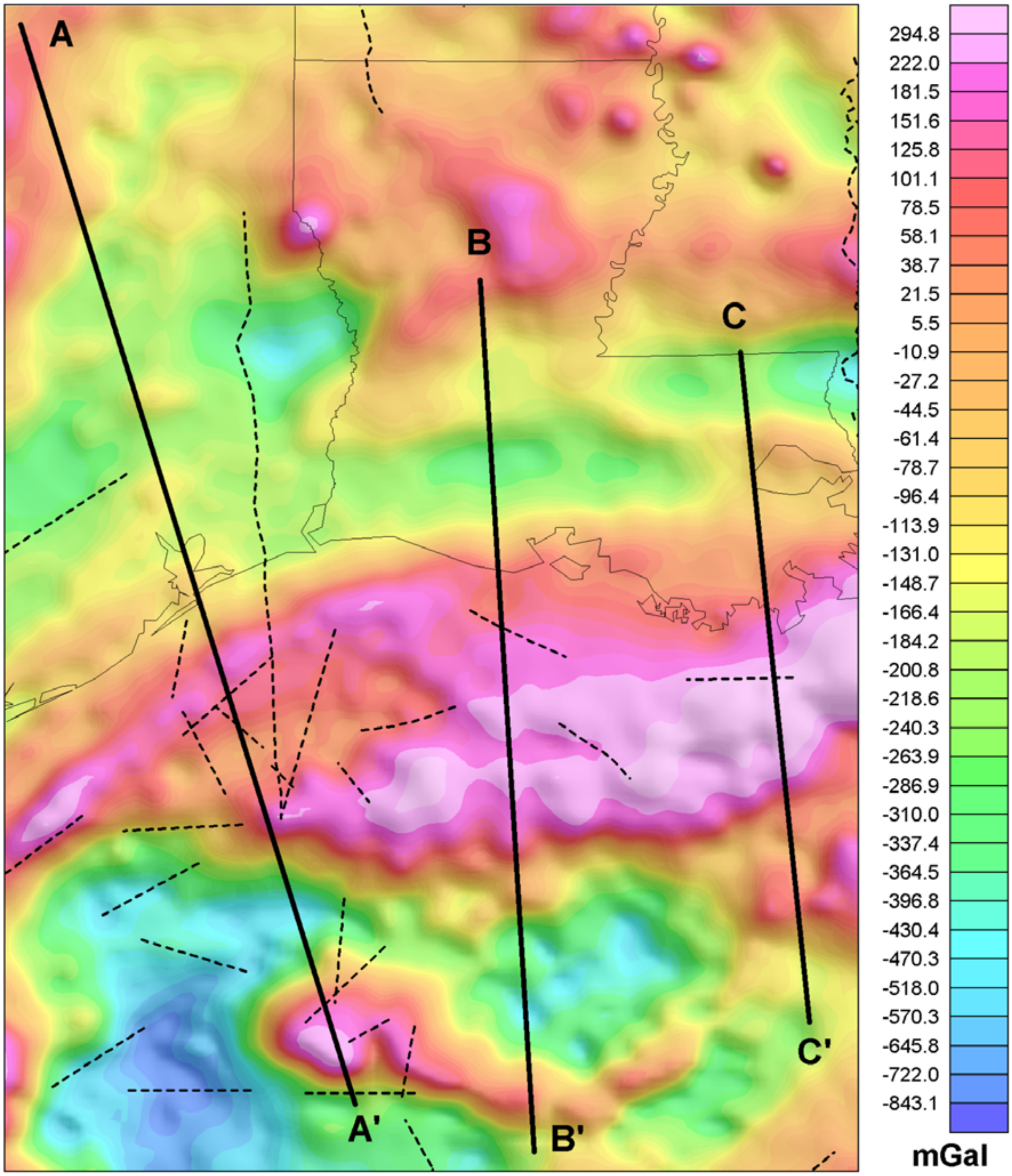

Figure 2. Gravity anomalies: Bouguer onshore and free air offshore. Solid lines = approximate GX Technology seismic reflection lines. Dashed lines = seismic refraction lines from published sources.

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