Potential field evidence for a volcanic rifted margin along the Texas Gulf Coast

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ABSTRACT

Potential field data along the Texas portion of the Gulf of Mexico indicate a large-amplitude coast-parallel magnetic maximum and a smaller Bouguer gravity high. Models constrained by seismic-refraction data indicate that these maxima manifest a deeply buried volcanic rifted passive margin or other magnetic high in the outer transitional crust. Buried 12–15 km, the source is 220 km wide, similar to the Vøring Plateau in Norway and the U.S. East Coast. This margin, which formed during the opening of the Gulf of Mexico, differs in origin from the transform boundary of the northeast Mexico margin (Tehuantepec transform), and we infer a Jurassic triple junction related to the Borderland rift system, which is traceable as far as southeast California.

INTRODUCTION

Continent-ocean boundaries form by extension (e.g., central and North Atlantic; Red Sea) or transform or transtensional faulting (e.g., Gulf of California). Extensional boundaries form before and during the "rift-drift transition" of continental breakup by processes that range from passive, nonvolcanic (far-field lithospheric stresses) to active, volcanic rifting (asthenospheric upwelling or mantle plumes; Sengor and Burke, 1978). Continued extension leads to seafloor spreading and freezes the transitional crust in place, so the relative significance of passive versus active rifting is preserved in deeply buried units.

Nonvolcanic extensional continent-ocean boundaries form when little melting accompanies extension, such as the Galicia margin and the Gulf of Suez (Tucholke et al., 2007). Nonvolcanic transitional crust consists of stretched and thinned continental crust inboard and exhumed serpentinized mantle outboard. These boundaries are characterized by absence of lava, long duration (15 m.y. or longer), high stretching factor (β; increasing oceanward to ~5 or more), rotated fault blocks, and high-velocity (Vp ~7.2–7.7 km/s) outboard crust interpreted as serpentinized peridotite (Mjelde et al., 2007). Volcanic extensional boundaries, also known as volcanic rifted margins, form by rapid, voluminous emplacement of lavas, dikes, sills, and plutons observed as seaward-dipping seismic reflectors (SDRS), and several-kilometer-thick, high-velocity (Vp ~7.2–7.6 km/s) lower crust, interpreted as magmatic underplating (Mutter et al., 1984). Some models for volcanic rifted margins infer a mantle plume (e.g., White and McKenzie, 1989), but others invoke enhanced convective overturn of the asthenosphere (Mutter et al., 1988).

This report provides insight into the nature of the northwestern Gulf of Mexico, which lies beneath ~15 km of sediments. No consensus exists regarding the nature of this transitional lithosphere (cf. Skogseid, 2001; no volcanic rifted margin) versus Menzies et al. (2002; dominated by volcanic rifted margin). We present potential field data, accompanied by geologic evidence, that support the interpretation of a volcanic rifted margin beneath coastal Texas.

EARLY MESOZOIC DEVELOPMENT OF THE GULF OF MEXICO

Breakup of Pangea often exploited the suture between Laurasia and Gondwana (Ouachita orogen) and, on the eastern U.S. seaboard, was accompanied by basaltic volcanism (Olsen, 1997; McHone, 2000). Basalts of the Central Atlantic magmatic province from Georgia to maritime Canada yield Ar/Ar plateau ages of 200 ± 1 Ma (Hames et al., 2000; Marzolli et al., 2004). Central Atlantic magmatic province basalts were erupted in the Newark Series rift basins, which evolved over 30–40 m.y. in Late Triassic and Early Jurassic time (Olsen, 1997). Continued rifting formed a volcanic rifted margin (Kelemen and Holbrook, 1995). A thick (to 25 km) wedge of basalt and gabbro along the eastern North American margin is revealed by the East Coast magnetic anomaly and seismic-reflection studies (Talwani and Abreu, 2000). Seafloor spreading began in the central Atlantic perhaps as early as 185 Ma (Withjack et al., 1998) and certainly by 30–35 m.y. after formation of the Central Atlantic magmatic province (oldest magnetic anomaly is M40, ca. 167 Ma; Bird et al., 2007), which is presumably slightly younger than the East Coast volcanic rifted margin, which is otherwise undated. Limited direct evidence exists for early Mesozoic igneous activity in Texas. Late Triassic Central Atlantic magmatic province–like basalts occur in the Eagle Mills Formation in S Arkansas and NE Texas (Dawson and Callender, 1992) and may extend into east-central Texas (Moy and Traverse, 1986). No radiometric ages exist for Eagle Mills basalts, but associated sediments have been dated palynologically as mid- to late Carnian (early Late Triassic; Traverse, 1987). A flood of clastic sediments shed from central Texas in Late Triassic time (ca. 225 Ma; Fig. 1; Dickinson and Gehrels, 2008) suggests regional doming, possibly due to a mantle plume or other cause of buoyant mantle.

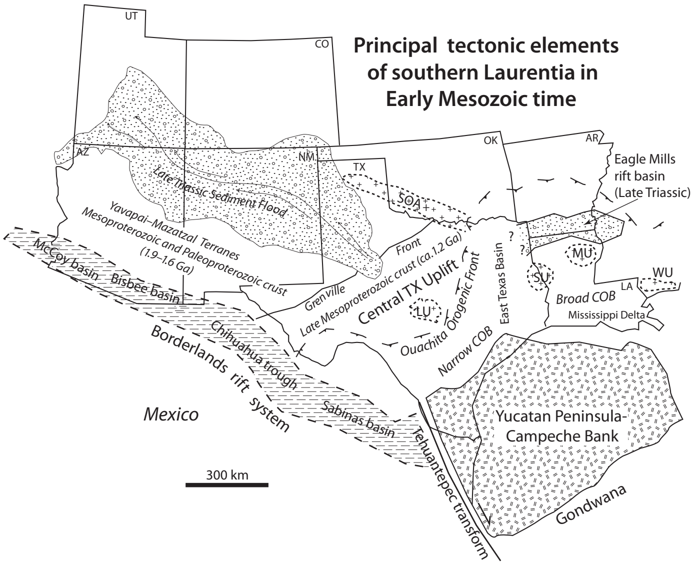

Figure 1. Early Mesozoic tectonic map of southwest Laurentia (modified from W.R. Dickinson sketch map, 2008, personal commun.). Borderlands rift system is defined by siliciclastic and carbonate trough of Jurassic age (Lawton and McMillan 1999; Dickinson and Lawton 2001). Buried uplifts: SU—Sabine Uplift, MU—Monroe Uplift, WU—Wiggins Uplift. Partially exposed uplift: LU—Llano Uplift, SOA—Southern Oklahoma aulacogen uplift. COB—Continent-ocean boundary.

Geology, May 2009; v. 37; no. 5; p. 387–390; doi: 10.1130/G25465A.1; 3 figures.

MAGNETIC AND GRAVITY EVIDENCE FOR A VOLCANIC RIFTED MARGIN

Bouguer gravity data were obtained from the Pan-American Center for Earth and Environmental Studies and the National Geophysical Data Center; aeromagnetic data were obtained from the U.S. Geological Survey (Bankey et al., 2002). Data were gridded, contoured, and color-scaled with a 45° sun angle to produce an aeromagnetic intensity and Bouguer gravity anomaly map (Figs. 2A and 2B).

The most prominent magnetic anomaly is a large-amplitude maximum that parallels the coastline from Mexico to Lafayette, Louisiana (anomaly 1, Fig. 2A). In contrast, the same region on the Bouguer gravity map is characterized by a small-amplitude maximum (anomaly 2, Fig. 2B). However, a large-amplitude Bouguer gravity anomaly (anomaly 3, Fig. 2B) parallels anomaly 1 and corresponds to a small-amplitude magnetic anomaly (anomaly 4) in the same region. The high-amplitude magnetic anomaly (anomaly 1, Fig. 2A) is similar in width (60–80 km) and amplitude (300–400 gammas) to some volcanic rifted margins, including Namibia (Corner et al., 2002). Other volcanic rifted margins (e.g., the U.S. East Coast; Talwani and Abreu, 2000) and the Vøring Plateau (Mjelde et al., 2007) have wider potential field anomalies. When the Texas Gulf Coast gravity and magnetic anomalies are integrated, they widen to ~180 km. To determine if this wider anomaly may be a volcanic rifted margin, a profile was constructed from the cratonic Llano Uplift to oceanic crust (Figs. 2A and 2B). The model includes seismic-refraction models (Cram, 1962; Dorman et al., 1972) for crustal thickness and velocity structure. Large-offset seismic profiles within the northwestern gulf (Ebeniro et al., 1988) constrain sediment thickness, average crustal thickness, and crust and upper-mantle velocities. The geometries of upper-crustal units (e.g., Ouachita facies, Paleozoic shelf sediments, Mesozoic and younger coastal plain sediments) were obtained from petroleum exploration studies (e.g., Nicholas and Rozendal, 1975), COCORP seismic-reflection profiles (Cullota et al., 1992), and similar lithospheric-scale profiles within the U.S. coastal plain (Mickus and Keller, 1992; Harry et al., 2003). Location of the oceanic crust was estimated from potential field studies by Bird et al. (2005), and densities of various bodies were estimated from seismic-refraction studies (Cram, 1962; Dorman et al., 1972), empirical relations between density and P-wave velocities (Christensen and Mooney, 1995), and comparison to similar gravity models (Mickus and Keller, 1992). Magnetic susceptibilities were estimated from other studies across passive margins (Talwani and Abreu, 2000; Mjelde et al., 2007). Depth, geometry, density, and magnetic susceptibility were varied within 20% of initial values to determine a final model that best matched the gravity and magnetic data.

The model (Fig. 3) contains bodies that produce anomalies matching both gravity and magnetic data except for the dashed, bolded line on top

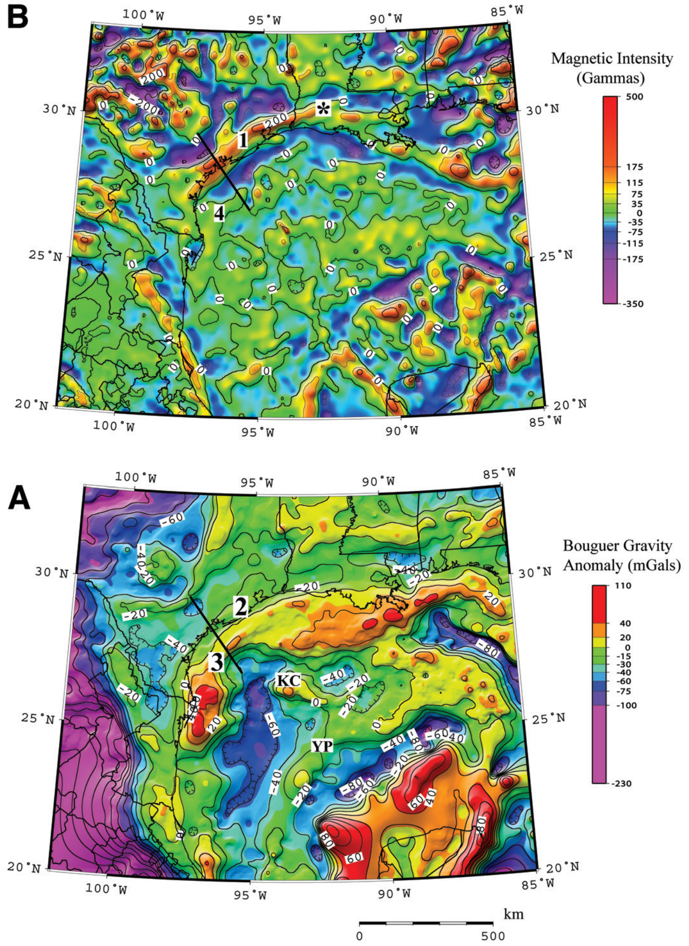

Figure 2. Bouguer gravity anomaly (A) and magnetic intensity map (B) of Texas Coastal Plain and surrounding regions. Contour intervals are 10 mGal and 100 gammas, respectively. Thick line represents location of gravity/magnetic model. Numbers correspond to anomalies mentioned in text. Asterisk, KC, and YP indicate locations of Lafayette, Louisiana, Keathley Canyon, and Yucatan parallel gravity maxima, respectively.

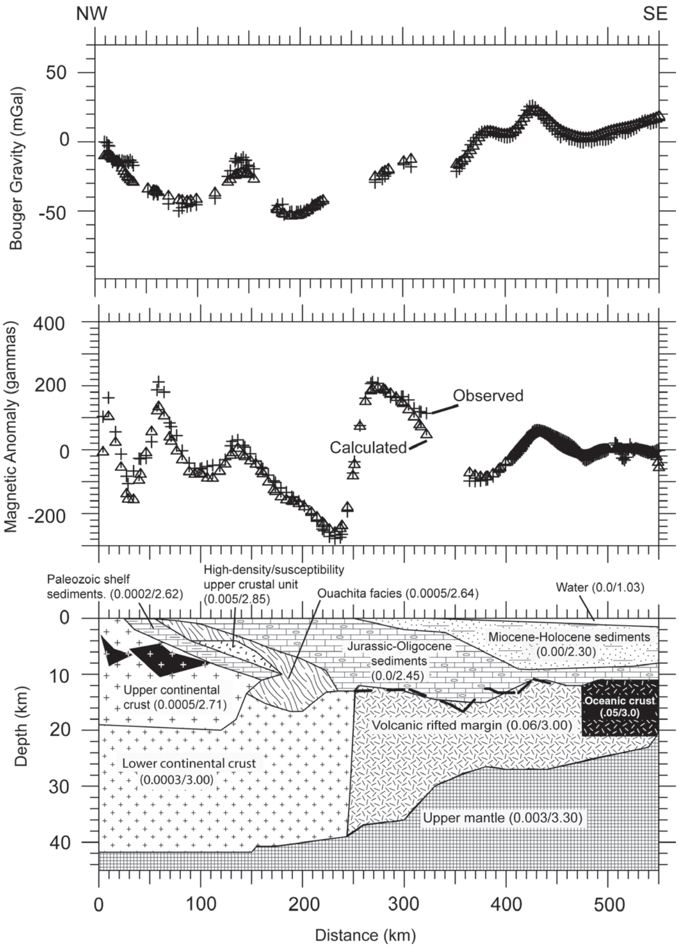

Figure 3. Texas Coastal Plain cross section with corresponding observed and calculated magnetic and gravity anomalies. Numbers in parentheses are magnetic susceptibility (emu) and density (gm/cm^3) of each body. Two unnamed bodies between 0 and 100 km are upper-crustal intrusions with magnetic susceptibility of 0.005 emu and densities of 2.77 and 2.71 g/cm^3. Bold line on top of volcanic rifted margin represents final gravity model.

of the volcanic rifted margin in the final gravity model. This final model fits a gravity maximum at 360 km that is not apparent on the magnetic profile. We assume that the source is within the volcanic rifted margin, but it may be caused by positive density contrasts in the sedimentary units above the volcanic rifted margin, e.g., younger volcanic rocks that are known from the region (Byerly, 1991). The final model contains tectonic elements that affected the southern margin of North America, including a Paleozoic passive margin, late Paleozoic Ouachita orogeny, Mesozoic rifts, and younger passive margin sediments. All these tectonic features are shown in the final model (Fig. 3), but the main focus here is the high density and magnetic susceptibility material along the Texas coastline. The magnetic anomalies between 240 and 320 km and 410 and 480 km were first modeled as individual bodies. When combined with the gravity data, one large body produced the best fit. Two individual bodies would have to be shallower and have higher density and magnetic susceptibility values than those shown in Figure 3. Given the known thickness of the Mesozoic and younger coastal plain sediments, such a model was ruled out.

DISCUSSION

The relatively high density (3.00 g/cm^3) and magnetic susceptibility (0.06 emu) for outer transitional crust suggest a large, deeply buried mafic igneous complex, probably a volcanic rifted margin. This interpretation is new, although seaward-dipping seismic reflectors have been seismically imaged in the eastern Gulf of Mexico (Imbert et al., 2001). Alternative hypotheses exist. Marton and Buffler (1994) suggested that the transitional crust of this region was formed by low-angle normal faulting along a south-dipping detachment. The asymmetrical distribution of different crustal types under the Louisiana sector of the basin and differences in the sedimentary record between the northern and southern gulf support a lithospheric simple-shear model for the evolution of the basin's conjugate passive margins. However, the nature of the transitional lithosphere varies markedly along strike; it is unlikely that the continent-ocean boundary from northeast Mexico to Louisiana has the same origin. The rifted zone in Texas from the Llano Uplift to the sea is relatively narrow (~250 km), but it is much broader (~500 km) in southern Arkansas and Louisiana (Fig. 1). In addition, the Sabine and other uplifts beneath Louisiana (Fig. 1) are buried continental tracts belonging to East Texas–Louisiana transitional lithosphere (Keller and Hatcher, 1999). The East Texas basin (Fig. 1) demarcates the boundary between these fundamentally different features. Also, Late Triassic uplift in central Texas adjacent to the narrow sector produced a northwestward-directed flood of clastic sediments about the same time that Eagle Mills rifting and basaltic activity occurred in southern Arkansas (Fig. 1). No evidence for a flood of clastic sediments shed from Arkansas-Louisiana is known.

Interpretation of the Texas continent-ocean boundary as a volcanic rifted margin provides a new perspective on the tectonic evolution of the western gulf region. A consensus exists that the NE Mexican margin is a transform continent-ocean boundary (Fig. 1), formed by the Jurassic Tehuantepec transform that allowed Yucatan to rotate counterclockwise away from Texas and Louisiana (Pindell, 1985; Dickinson and Lawton, 2001). Rifting of Yucatan (and Gondwanan fragments to the south) led to the formation of the northwestern Gulf of Mexico basin; this rotation occurred between ca. 160 Ma (Callovian) and 140 Ma (Valanginian) (Bird et al., 2005). Bird et al. (2005) inferred that a Late Jurassic mantle plume was involved with opening of the Gulf of Mexico in this region. Hotspot tracks today are marked by northwest-trending (Keathley Canyon) and southwest-trending (Yucatan parallel) gravity maxima (Fig. 2B) (Bird et al., 2005). The northern (Keathley Canyon) track originated near the South Texas boundary, which implies vigorous igneous activity during rifting.

Finally, the junction between the northwestern Mexico transform boundary and the Texas volcanic rifted margin is the terminus of the California-Coahuila rift, which can be traced ESE from southeast California (Fig. 1; Marton and Buffler, 1994; Lawton and McMillan, 1999). The Texas volcanic rifted margin, Tehuantepec transform, and California-Coahuila rift meet near the mouth of the Rio Grande at ~120° angles. This geometry is characteristic of a classic aulacogen, referred to as the Borderlands rift system.

CONCLUSIONS

We interpret potential field data for the Texas coast as a deeply buried volcanic rifted margin. This interpretation is consistent with regional sedimentary patterns and detrital zircon ages, which indicate that central Texas was strongly uplifted in Late Triassic time prior to rifting, and it is also consistent with Yucatan separating from Texas along this rift and the postulated fossil hotspot track in the western Gulf of Mexico. The Texas volcanic rifted margin contrasts markedly with the northeastern Mexico margin, defined by the Tehuantepec transform. We conclude that the Texas volcanic rifted margin changes strike into a transform boundary to the south, defining a triple junction, and gradationally changes to a nonvolcanic but still extensional boundary to the east along the Louisiana coast.

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