An Overview of the Structure and Tectonic Evolution of the Gulf Coast Region of Texas and Louisiana

G. Randy Keller[1], Jay Pulliam[2], Harold Gurrola[3], and Kevin Mickus[4]

[1]201 Vanderpool Lane, #2, Houston, Texas 77024

[2]Baylor University, One Bear Place #97354, Waco, Texas 76798

[3]Texas Tech University, Box 41053, Lubbock, Texas 79409

[4]Department of Geography, Geology and Planning, Missouri State University, 901 S. National Ave., Springfield, Missouri 65897

GCAGS Explore & Discover Article #00070*
http://www.gcags.org/exploreanddiscover/2016/00070_keller_et_al.pdf
Posted September 13, 2016.

*Article based on an extended abstract published in the *GCAGS Transactions* (see footnote reference below), which is available as part of the entire 2016 *GCAGS Transactions* volume via the GCAGS Bookstore at the Bureau of Economic Geology (www.beg.utexas.edu) or as an individual document via AAPG Datapages, Inc. (www.datapages.com), and delivered as an oral presentation at the 66th Annual GCAGS Convention and 63rd Annual GCSSEPM Meeting in Corpus Christi, Texas, September 18–20, 2016.

EXTENDED ABSTRACT

The Gulf Coast Plain (GCP) of Texas and Louisiana is a Jurassic rifted margin covered by a thick sedimentary sequence (Fig. 1). Over the northern Gulf of Mexico ocean-to-continent transition (OCT), a broad and thick sedimentary succession has built upward and seaward. Because of the great thickness of these sediments, there is considerable uncertainty about the nature and location of the transition from craton to extended continental crust to oceanic crust in this region. Our lack of understanding about the deep structure of the Gulf Coast is particularly striking since the sedimentary package there is likely the most intensely geologically investigated regions in the USA thanks to extensive drilling and geophysical surveys. An important consideration is that understanding the structure and tectonic evolution of the Mesozoic and Cenozoic GCP is a key in attempts to understanding Paleozoic tectonic events and vice versa.

Perhaps the biggest ambiguity in interpreting crustal models in this region is the difficulty in separating the geophysical signatures of features due to: (1) Eocambrian rifting to form the sinuous southern margin of the cratonal interior of North America that extends across Texas; (2) Paleozoic plate convergence and interaction that is manifested by the Ouachita orogenic belt; and (3) Mesozoic rifting and crustal stretching that open the Gulf of Mexico.

Key constraints in attempts to understand the geophysical signatures are deep seismic refraction (Cram, 1962; Hales et al., 1970; Dorman et al., 1972; Ewing, M., et al., 1955; Ewing, J., et. al, 1960), surface wave dispersion (Keller and Shurbet, 1975), and broad-band seismic investigations (Gurrola et al., 2016, <http://www.gcags.org/exploreanddiscover/2016/00124_gurolla_et_al.pdf>) indicate that the upper crust or basement beneath the GCP is very thin (10–15 km). Thus generally, the crustal-scale structure has been interpreted to be attenuated continental crust caused by rifting in either the early Mesozoic or the early Paleozoic or both (e.g., Bartok, 1993; Harry and

Originally published as: Keller, G. R., J. Pulliam, H. Gurrola, and K. Mickus, 2016, An overview of the structure and tectonic evolution of the Gulf Coast region of Texas and Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 66, p. 785–788.

Londono, 2003; Bird et al., 2005). In addition, the integration of a regional seismic refraction profile along the Texas-Louisiana border integrated with gravity and offshore refraction profiles (Ebeniro et al., 1988) indicates the presence of an upper mantle low velocity anomaly that is consistent with a depleted mantle or a rift pillow (Mickus and Keller, 1992). This observation supports the interpretation of this region as severely attenuated continental crust overlain by 10 to 20 km of Gulf Coast sediments (Fig. 2, upper model). Another possibility is that the transitional lithosphere is a volcanic rifted margin, analogous to the Greenland-Norway margin or East Coast of the U.S. (Mickus et al., 2009), (Fig. 2, lower model).

Because structures due to Paleozoic and Mesozoic tectonic events are a key understand the structure and evolution of the GCP, we have undertaken an integrated analysis of a broad range of geological and geophysical data aimed at advancing our understanding of the deep structure and tectonic evolution of the region, as well as, the thermal regime of the region due to events such as the formation of the Balcones Igneous Province. This igneous province approximately follows the interior zone of the Ouachita system (Fig. 1). Our analysis is focused on understanding two proposed models of the crustal structure from the craton, as exposed in the Llano Uplift, across the buried Ouachita system that covers the rifted Eocambrian margin, across the coastal plain where thin crystalline crust has been documented, to the Gulf of Mexico. Both models are based gravity data, drilling results, and available deep seismic data modeling results. The lower model (modified after Mickus et al., 2009) is also constrained by magnetic data. A linear magnetic high follows the coast of Texas and is offset from the parallel gravity high that lies approximately 50 km offshore. This model suggests that the continental margin in this area may be a volcanic margin (Mickus et al., 2009).

Both models are based on the integration of gravity data, drilling results, and available deep seismic data. The lower model (modified after Mickus et al., 2009) is also constrained by magnetic data. A linear magnetic high follows the coast of Texas and is offset from the parallel gravity high that lies approximately 50 km offshore. This model suggests that the continental margin in this area may be a volcanic margin (Mickus et al., 2009). A recent marine seismic reflection profile (GUMBO 1; Avendonk et al., 2015) that extends from the coastline just north of the models in Figure 2 provides a more detail image of the crustal structure offshore. The interpretation of Avendonk et al. (2015) is that rifted continental crust extends offshore for ~250 km before the oceanic crust of the Gulf of Mexico is encountered.

...

An overview of the structure and tectonic evolution of the Gulf Coast region of Texas and Louisiana

G. Randy Keller
University of Oklahoma (Emeritus)

Jay Pulliam
Baylor University

Harold Gurrola
Texas Tech University

Kevin Mickus
Missouri State University

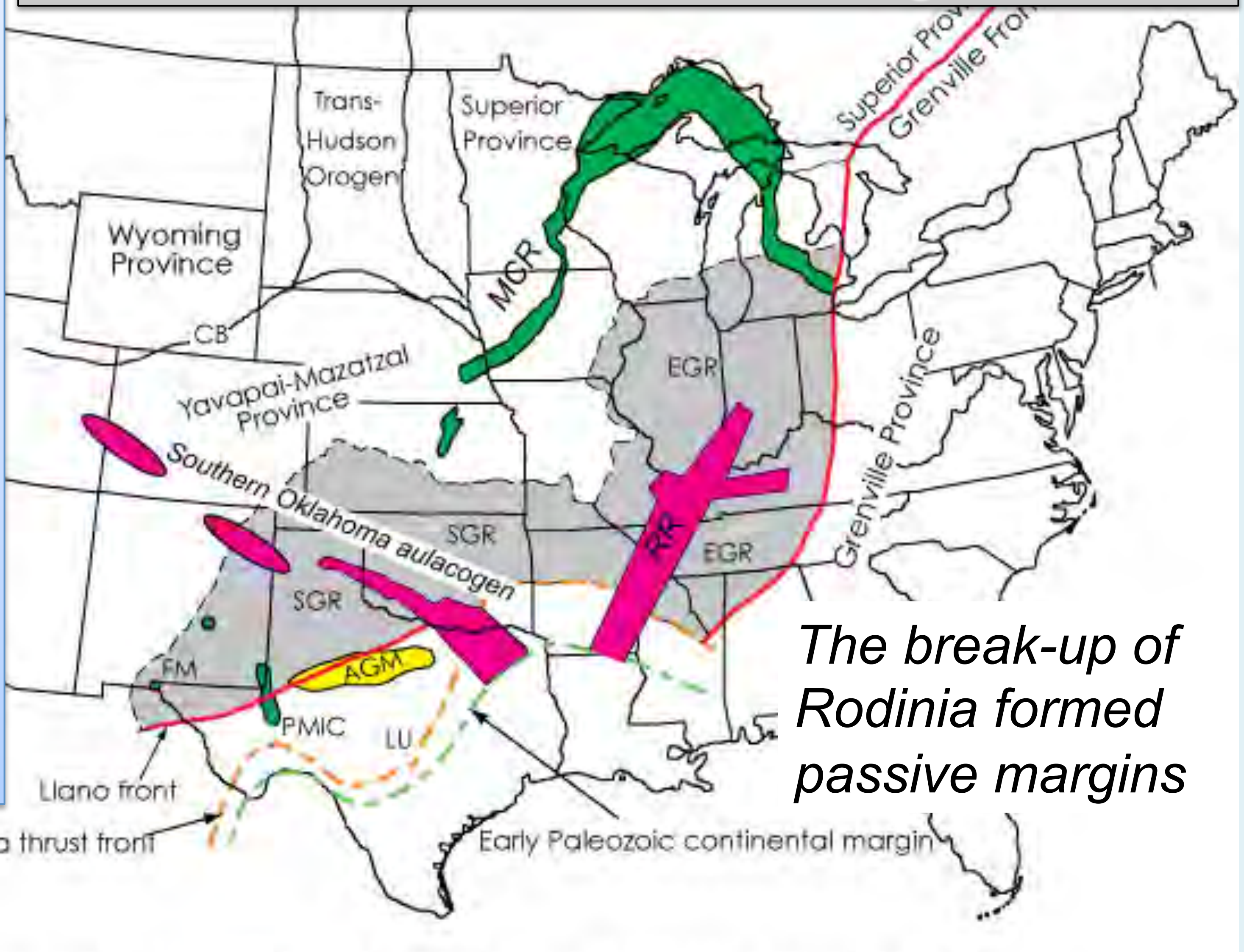
Precambrian Tectonic Evolution of the Mid-continent region – the first step in the Tectonic evolution of the Gulf Coast region

The crust of the southern Mid–continent region formed 1.7 to 1.1 billion years ago

A huge pulse of volcanism covered the area at ~1.4 Ga

Extensive rifting and the Grenville Orogeny occurred at ~1.1 Ga

The continent then began to break up

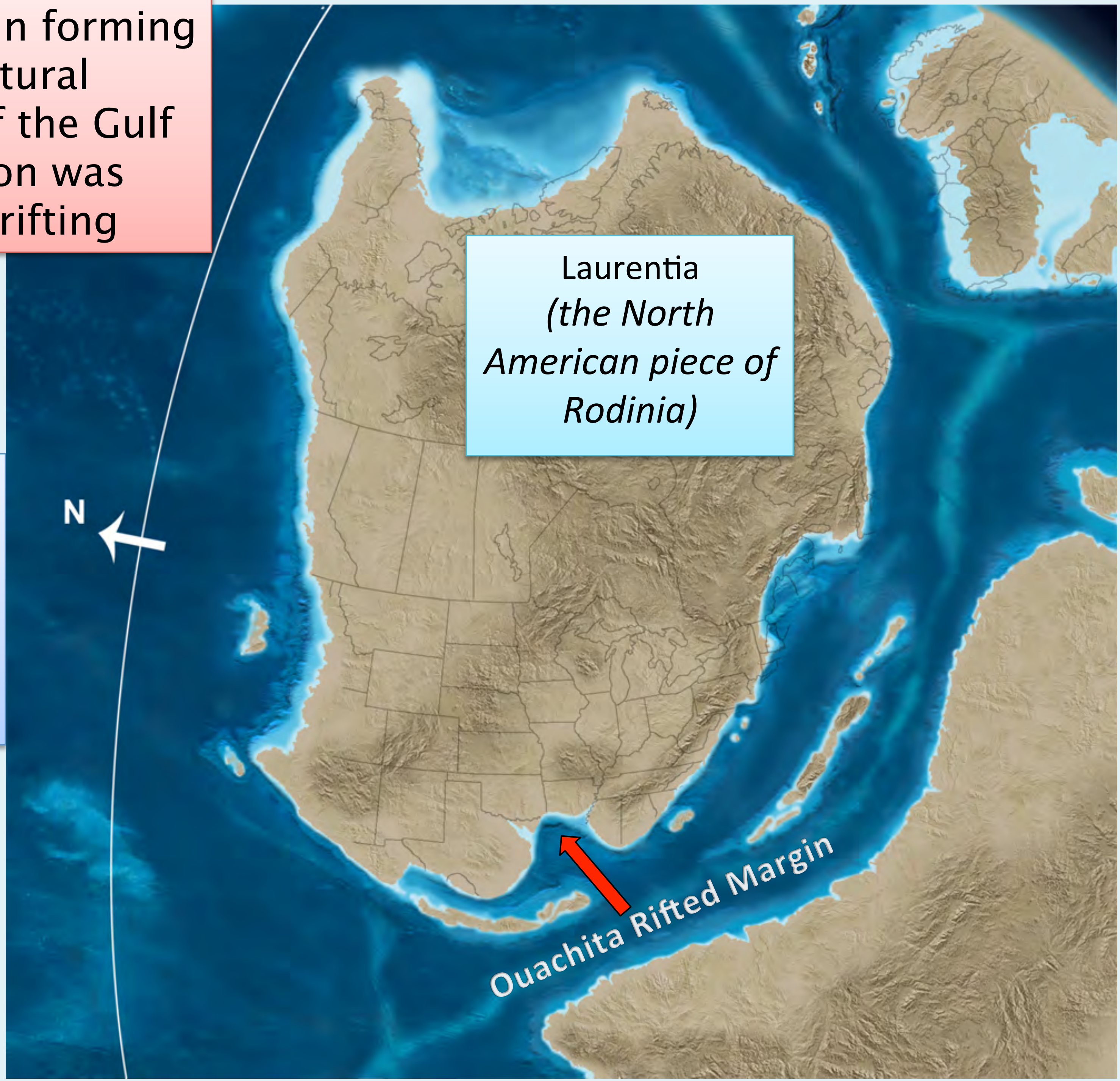


The break-up of Rodinia formed passive margins

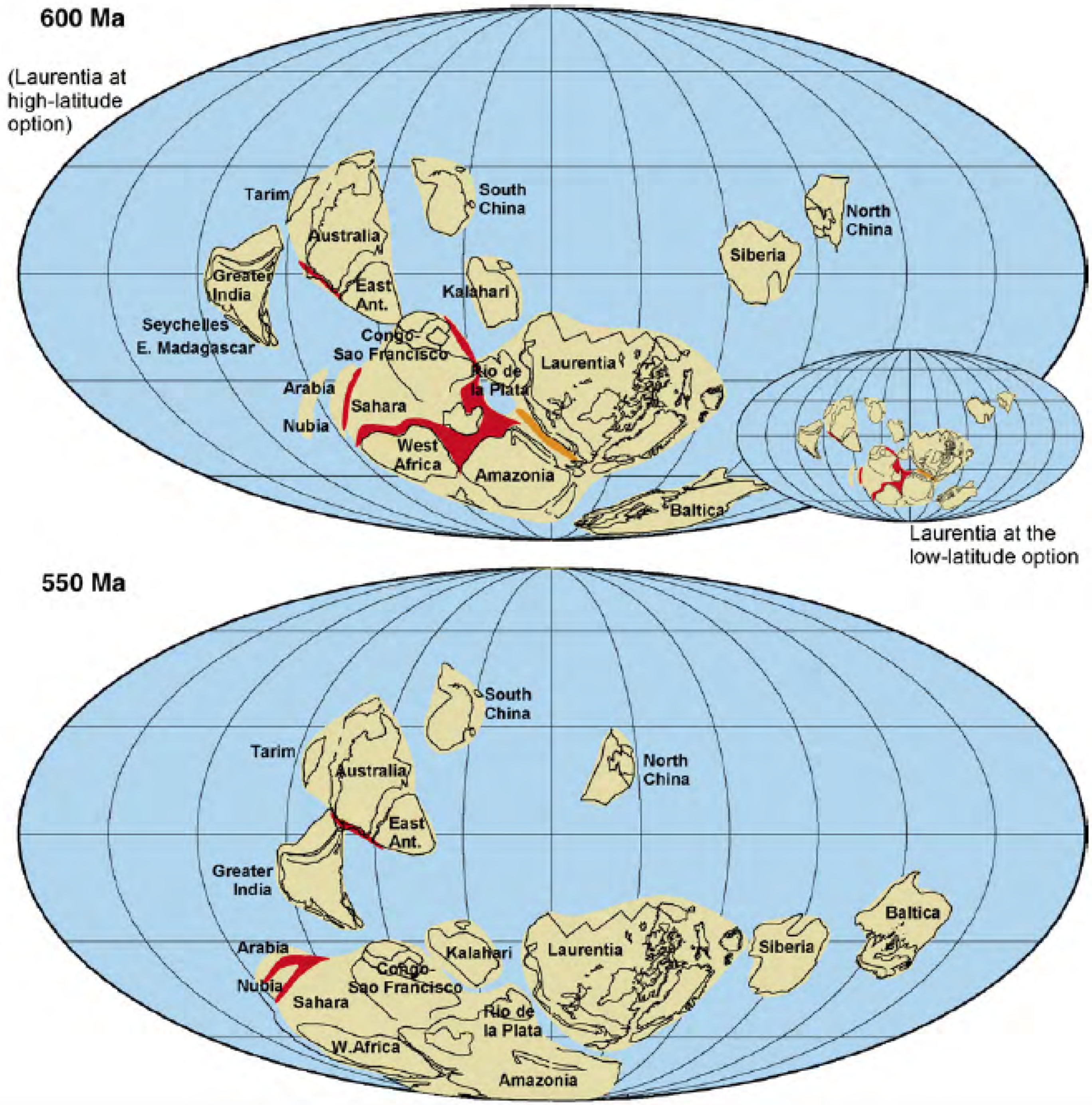
(modified from Barnes and others, 1999, originally modified from Van Schmus and others, 1996).

The first step in forming the structural framework of the Gulf Coast region was Cambrian rifting

Cambrian (~550 Ma) Paleo-geography



Ron Blakey
NAU



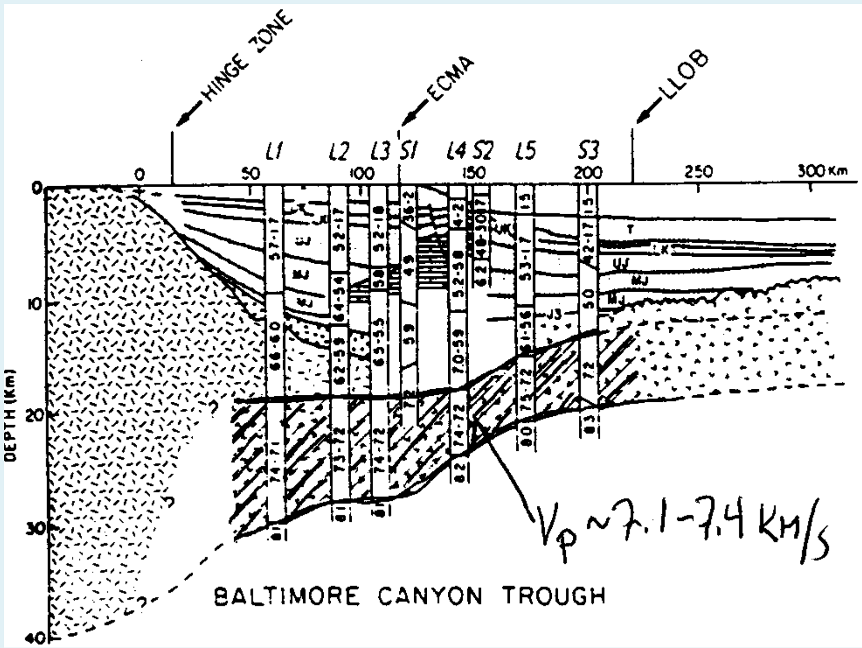
A recent Rodina reconstruction (Li et al., 2008)

What rifted off of North America to form the sinuous margin?

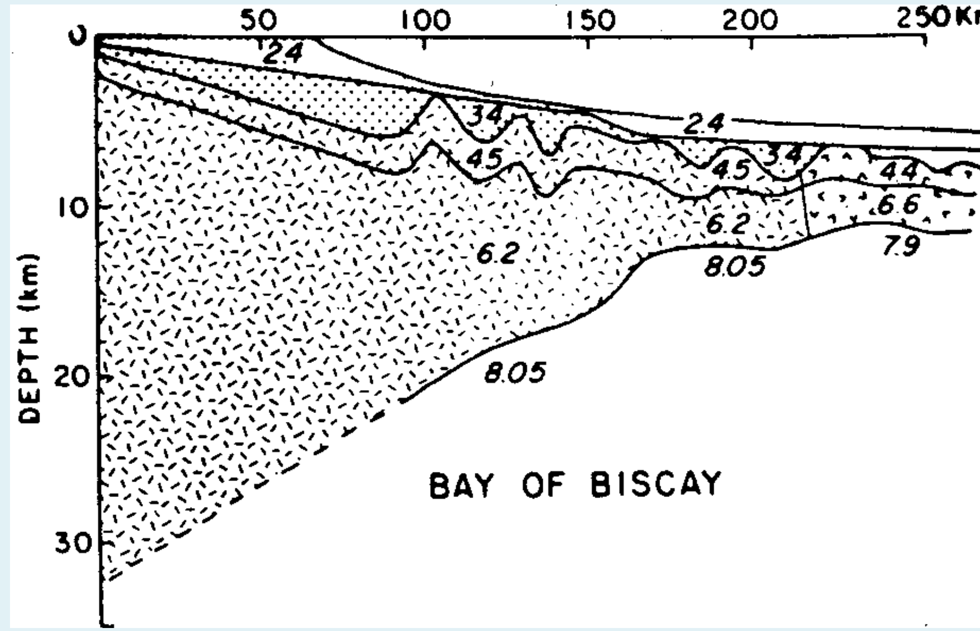
Is a piece in the Southern Andes?

Were some pieces (crustal blocks) left behind?

P-wave velocity structure: Volcanic versus stretched margin



Volcanic Passive Margin (VPM)



Rifted Passive Margin (RPM)

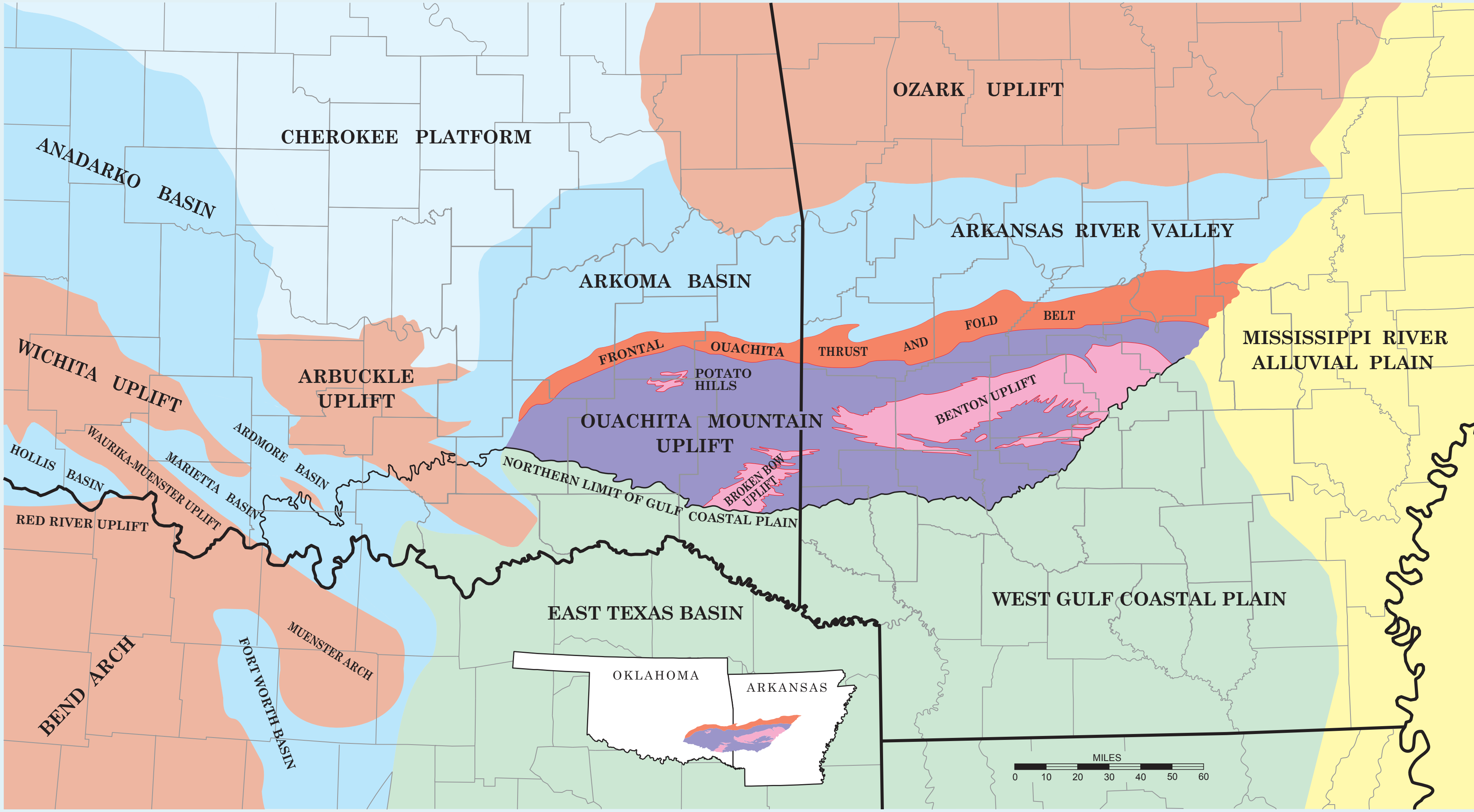
What was the rifted margin alike initially?

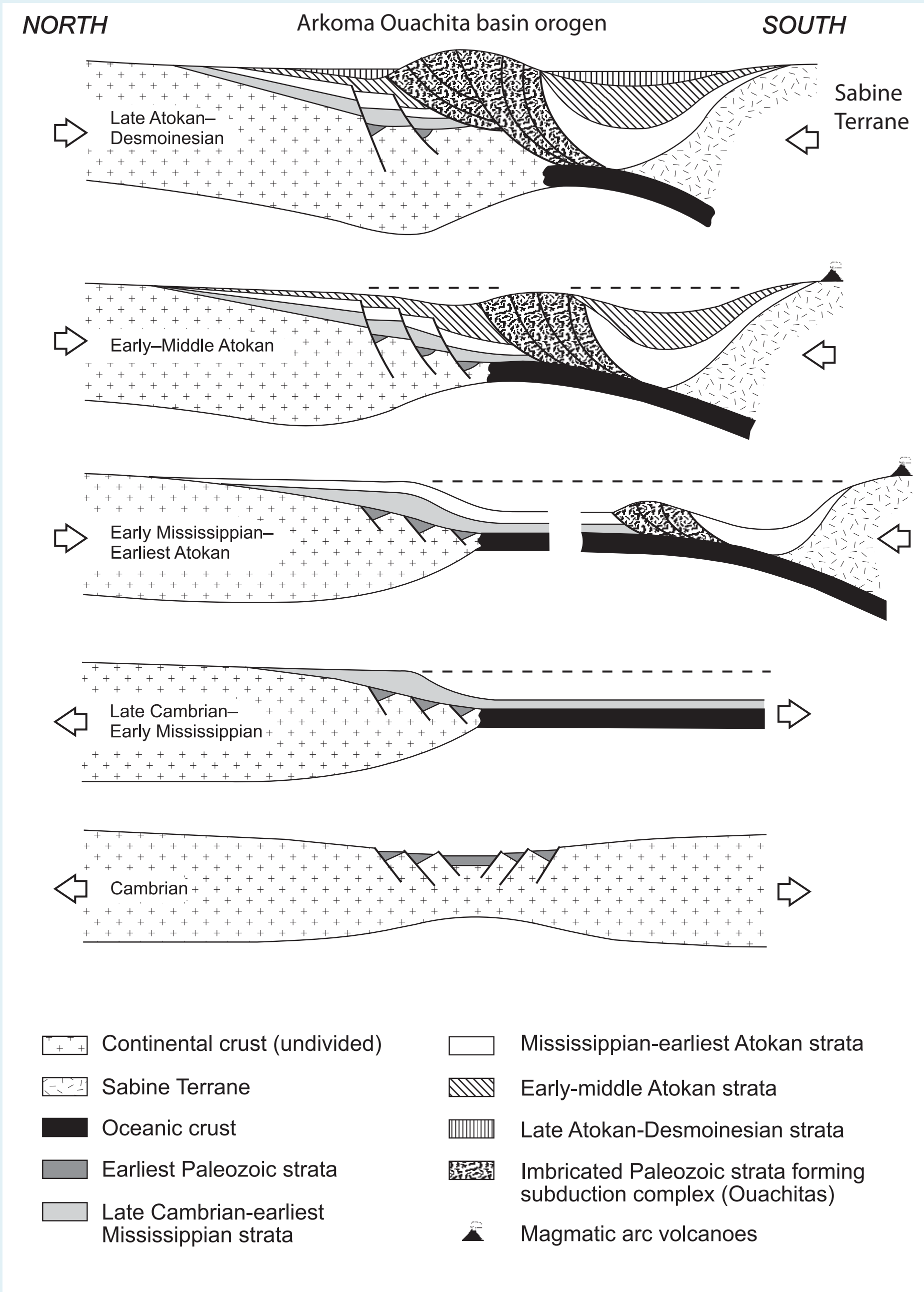
Moores & Twiss 1995

After this break-up, passive margins formed around the region, and then came the Ouachita/Ancestral Rocky Mountain Orogeny

Ron Blakey, NAU
(A great website)

The classic Ouachita orogenic belt outcrops in Oklahoma and Arkansas





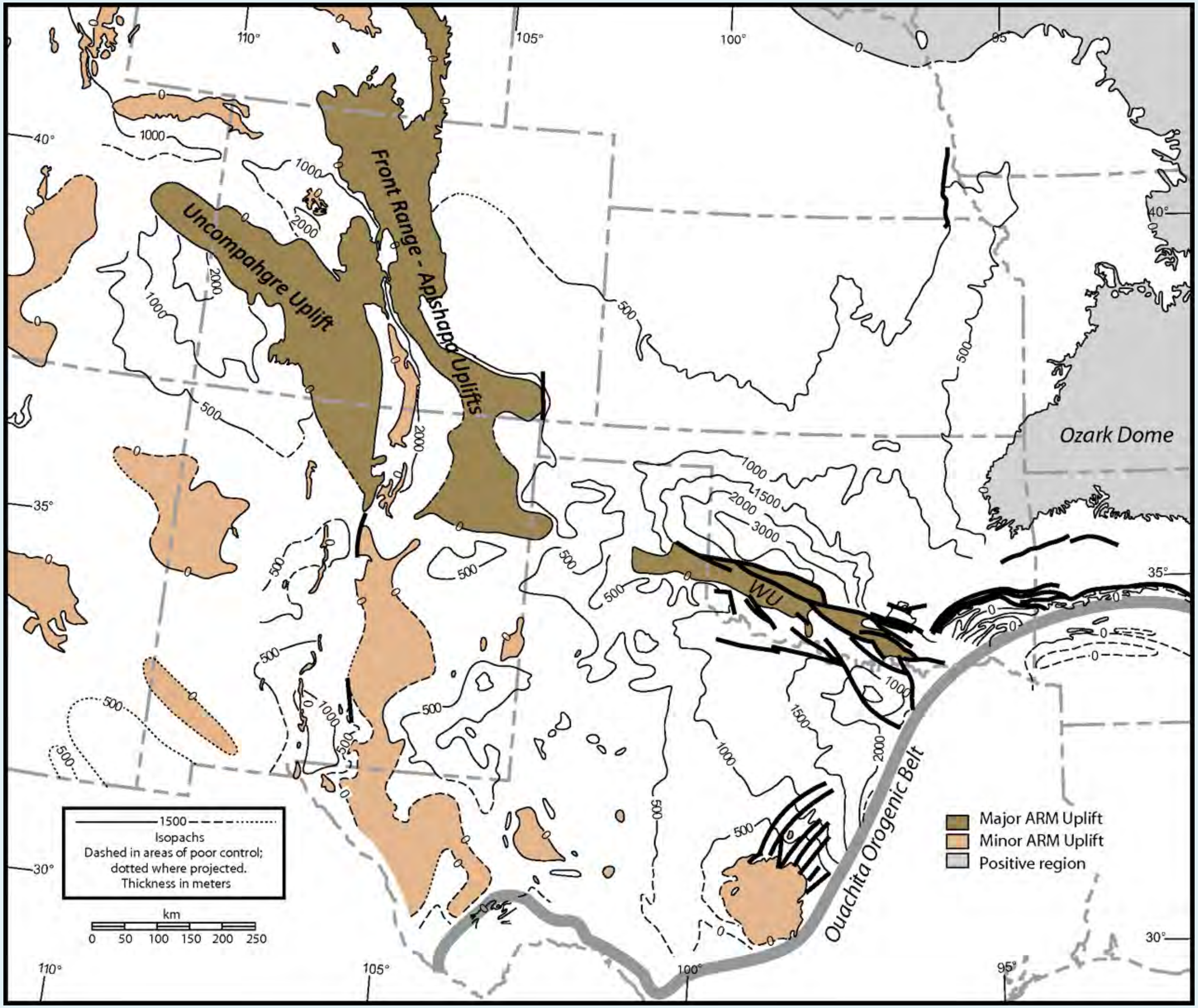
The tectonic evolution in eastern Oklahoma and western Arkansas (modified from Houseknect, and Matthews, 1985)

A classic "Wilson Cycle"

Rifting breaks up the continent and forms an ocean basin that in turn closes to form an orogenic belt.

The Ancestral Rocky Mountains

What caused this extensive intraplate deformation that correlates temporally with the Ouachita orogeny?

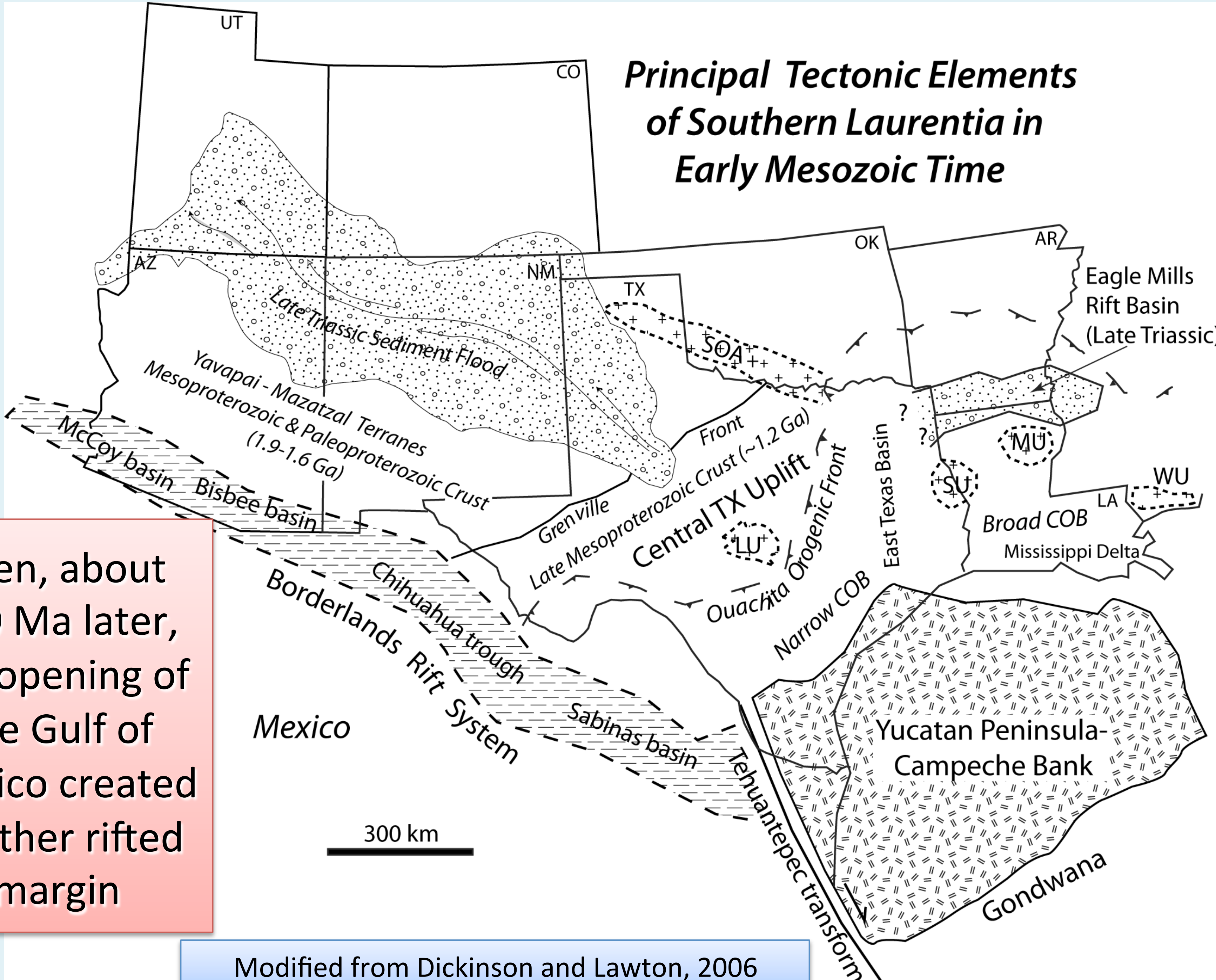


Isopach map showing preserved Pennsylvanian strata

Soreghan et al. Geosphere (2012)

©2012 by Geological Society of America

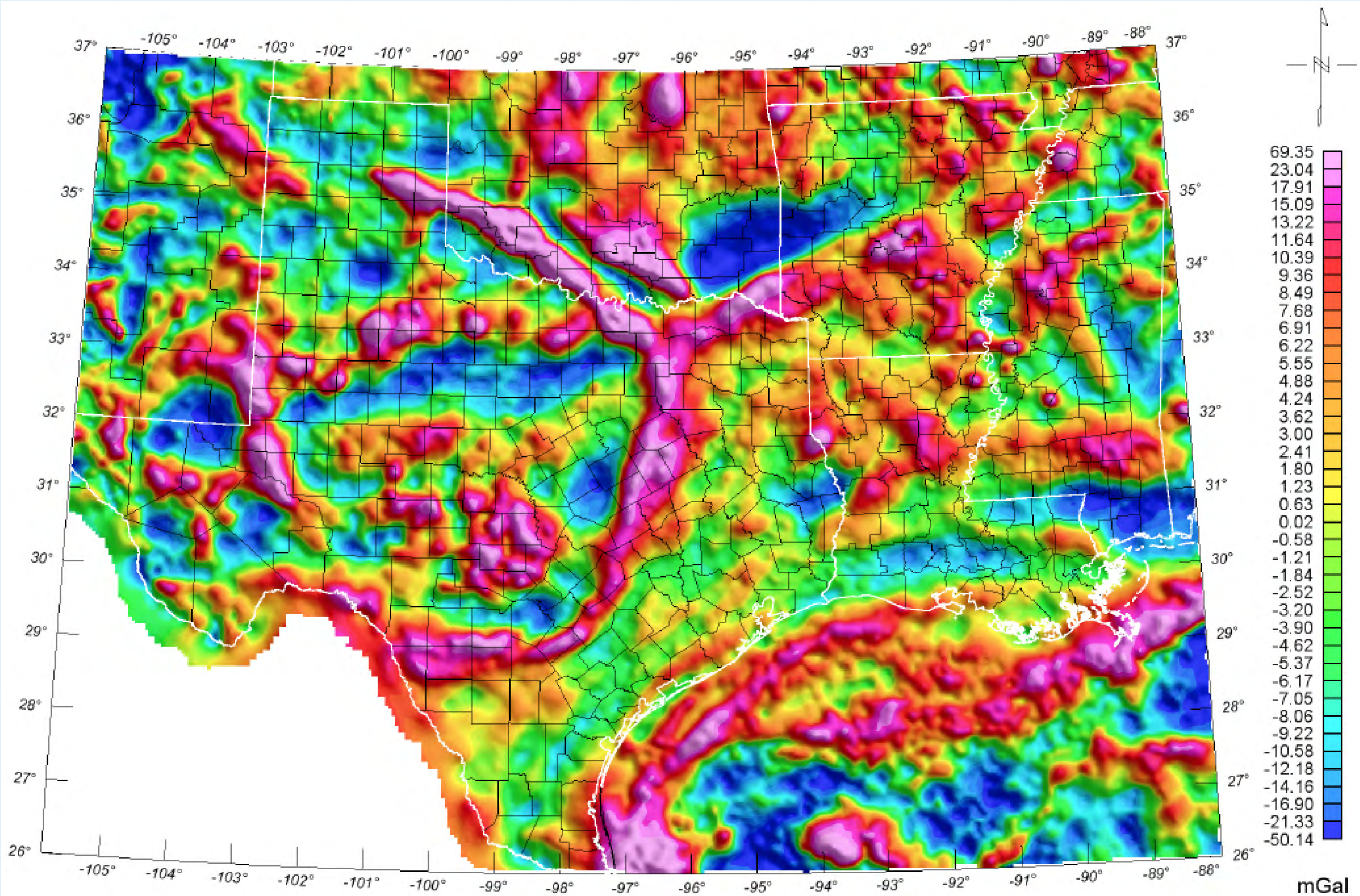
THE GEOLOGICAL SOCIETY OF AMERICA

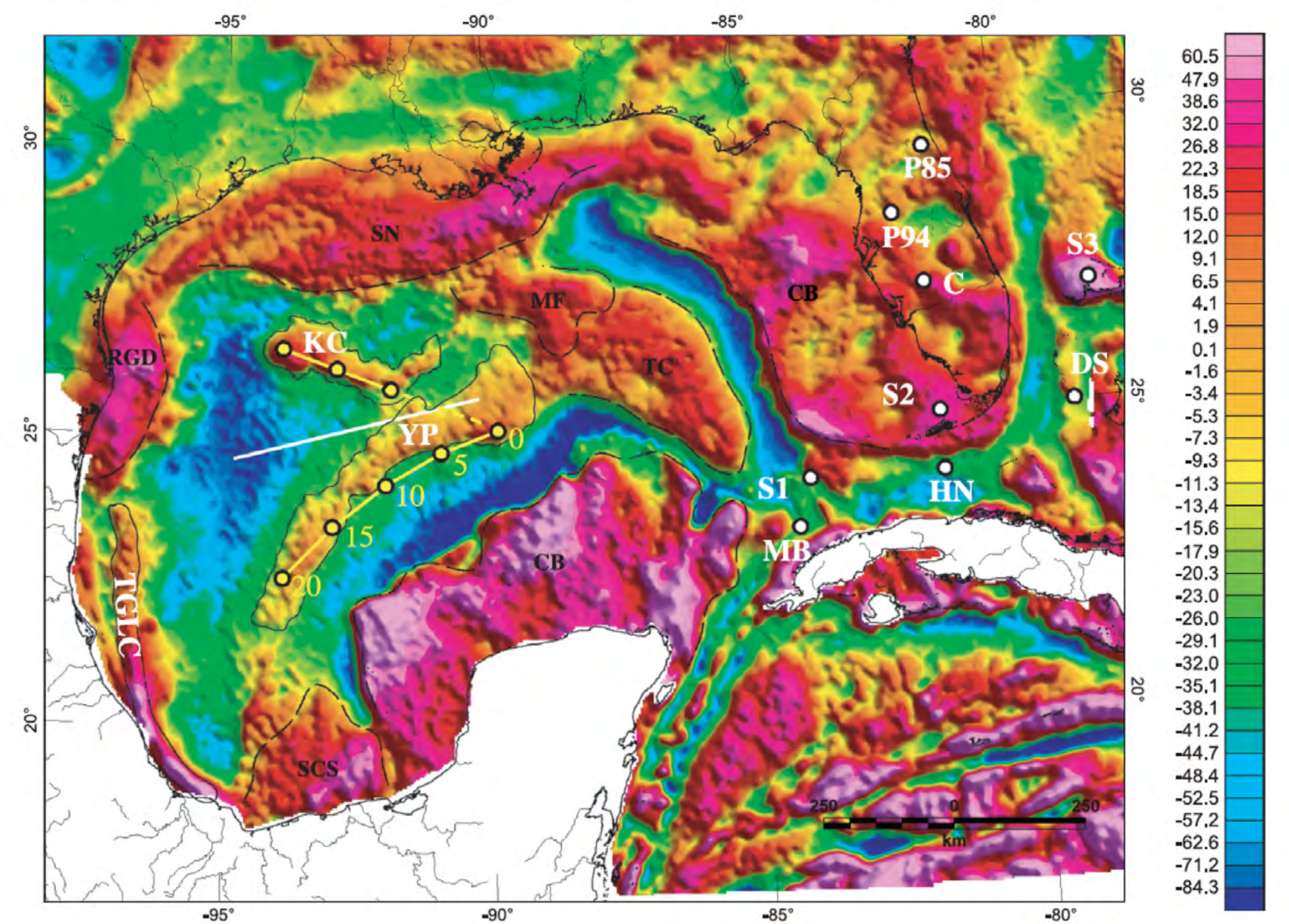


Then, about 200 Ma later, the opening of the Gulf of Mexico created another rifted margin

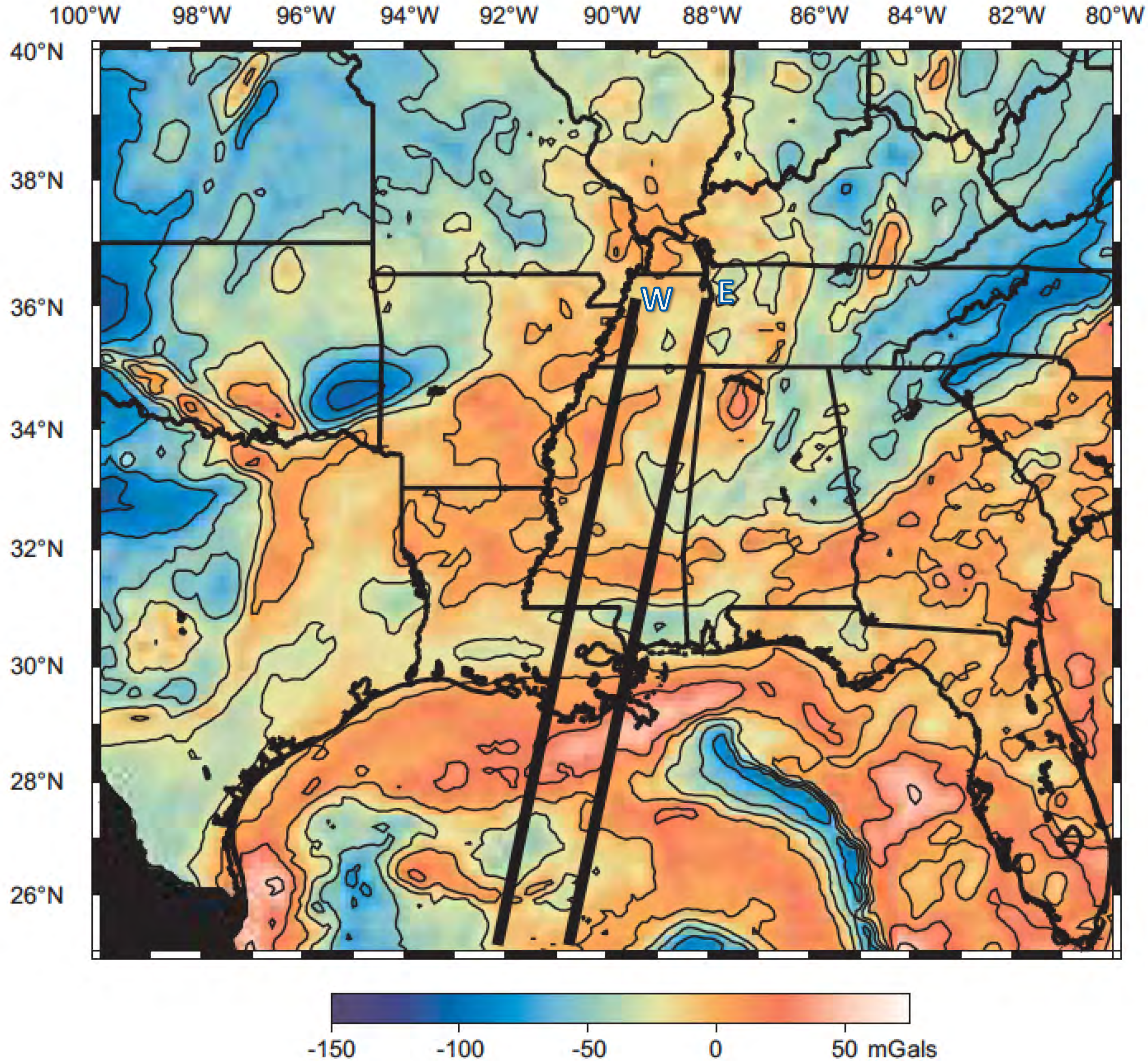
Modified from Dickinson and Lawton, 2006

A simple residual gravity anomaly showing linear gravity highs that mark the edges of the Cambrian and Mesozoic continental margins along the western Gulf Coast



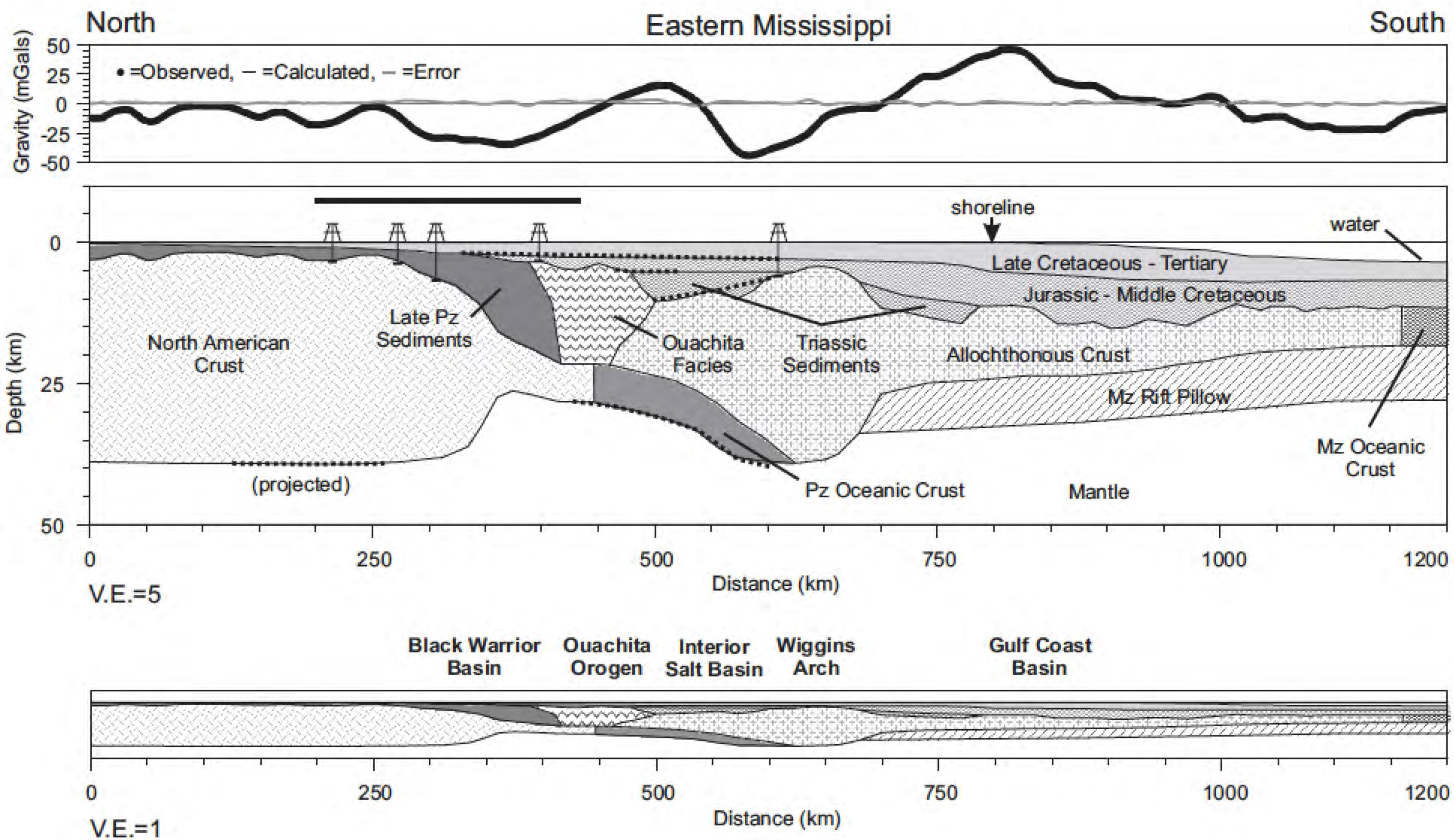


Gravity data over the Gulf of Mexico includes onshore Bouguer gravity anomalies compiled by the Society of Exploration Geologists and the U.S. Geological Survey and offshore satellite-derived free-air gravity anomalies. Global satellite-derived gravity data have been calculated from satellite altimetry data acquired during the Geosat Geodetic Mission and the European Remote-Sensing Satellite (ERS-1) Geodetic Phase along closely spaced satellite tracks (Sandwell and Smith, 1997). The reported data resolution is about 5 mGal in amplitude over 20-km (12.4-mi) wavelengths. (Dale E. Bird, Kevin Burke, Stuart A. Hall, and John F. Casey, 2005).

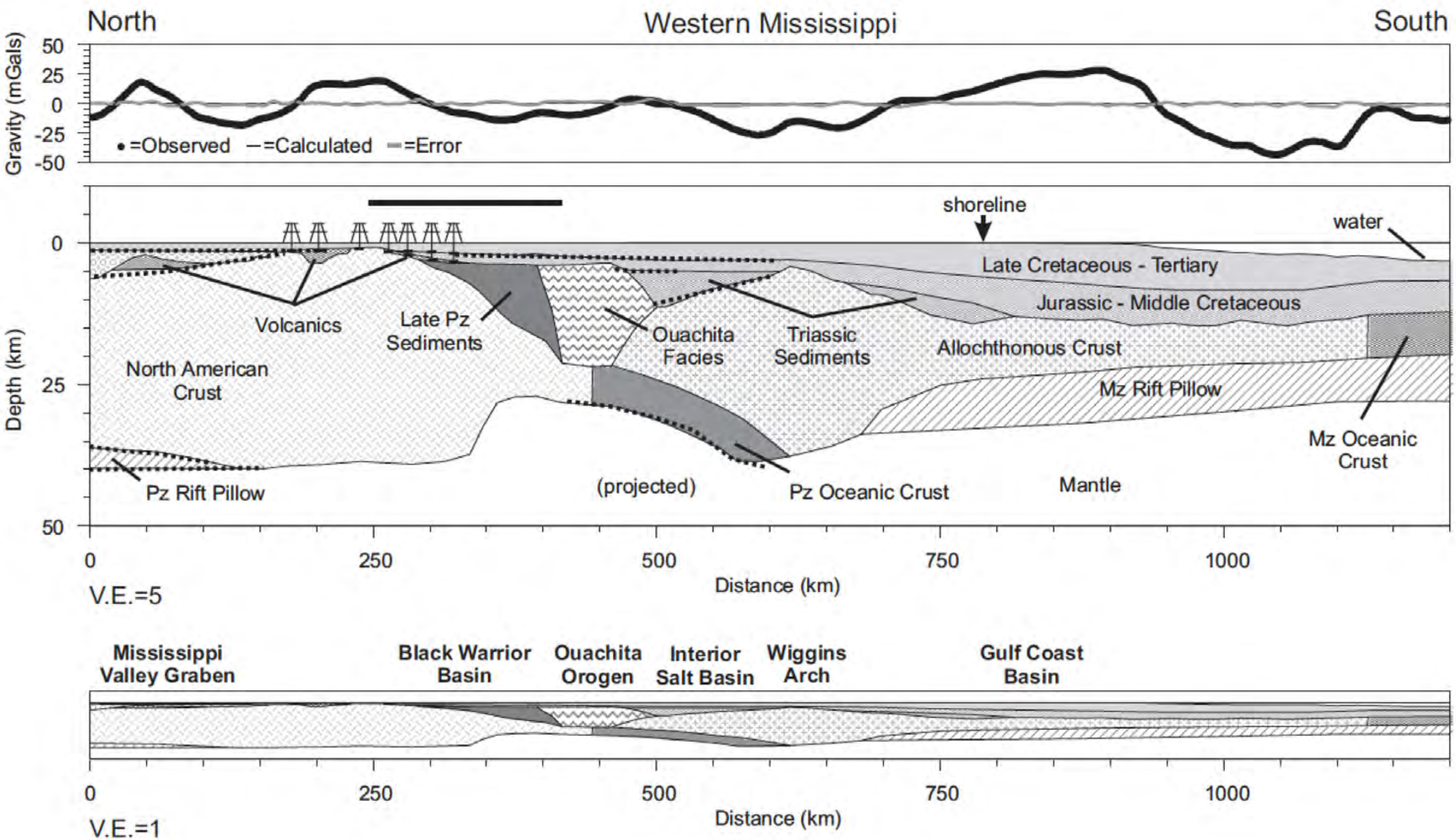


Crustal cross sections Mississippi into the Gulf of Mexico

D.L. Harry, J. Londono, and A. Huerta (2003)

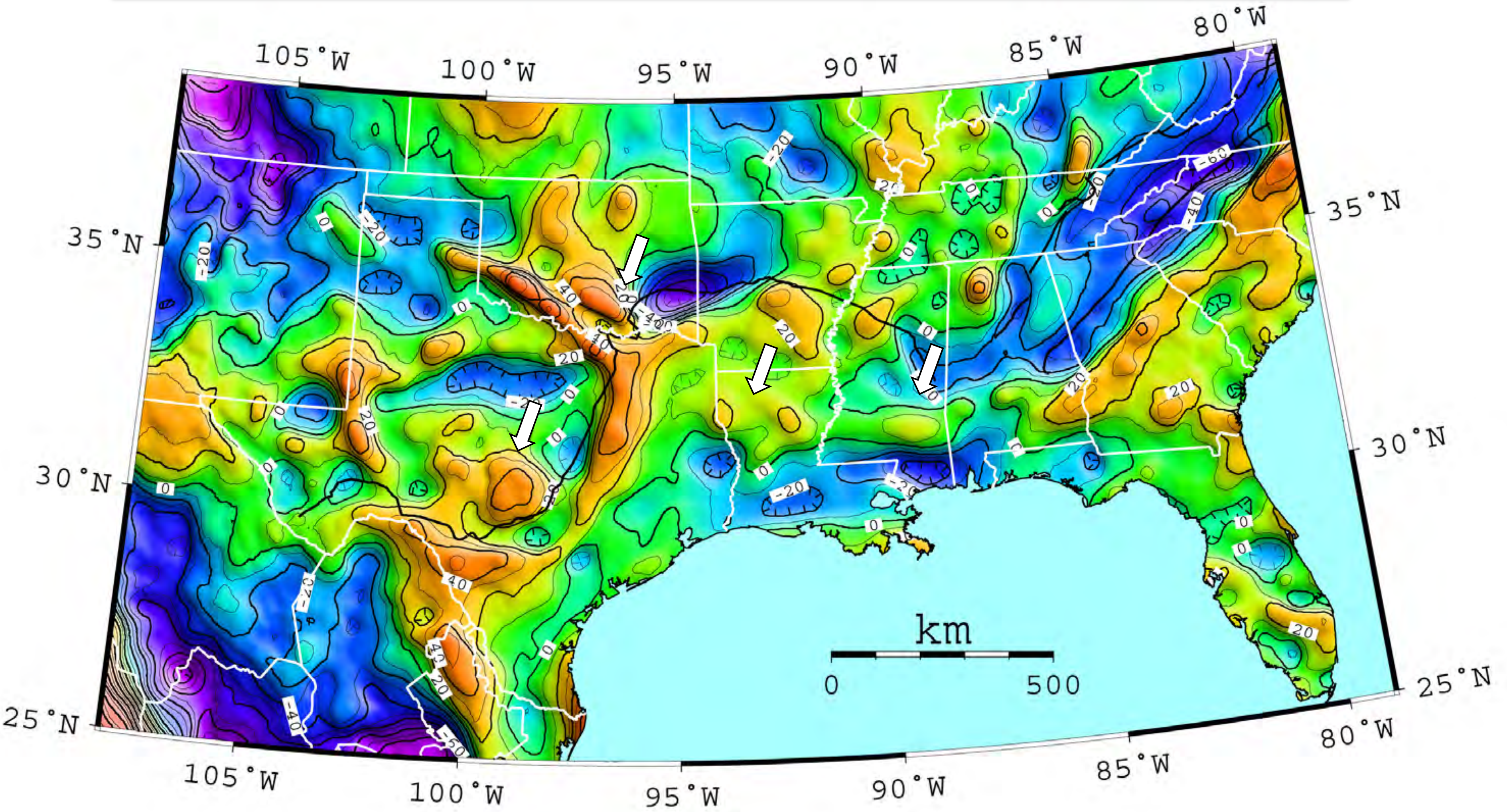


North
Eastern Mississippi
South
Gravity (mGals)
• =Observed, — =Calculated, — =Error
shoreline
water
Late Cretaceous - Tertiary
Jurassic - Middle Cretaceous
Late Pz Sediments
North American Crust
Ouachita Facies
Triassic Sediments
Allochthonous Crust
Mz Rift Pillow
Mz Oceanic Crust
(projected)
Pz Oceanic Crust
Mantle
Depth (km)
Distance (km)
V.E.=5
Black Warrior Basin
Ouachita Orogen
Interior Salt Basin
Wiggins Arch
Gulf Coast Basin
V.E.=1



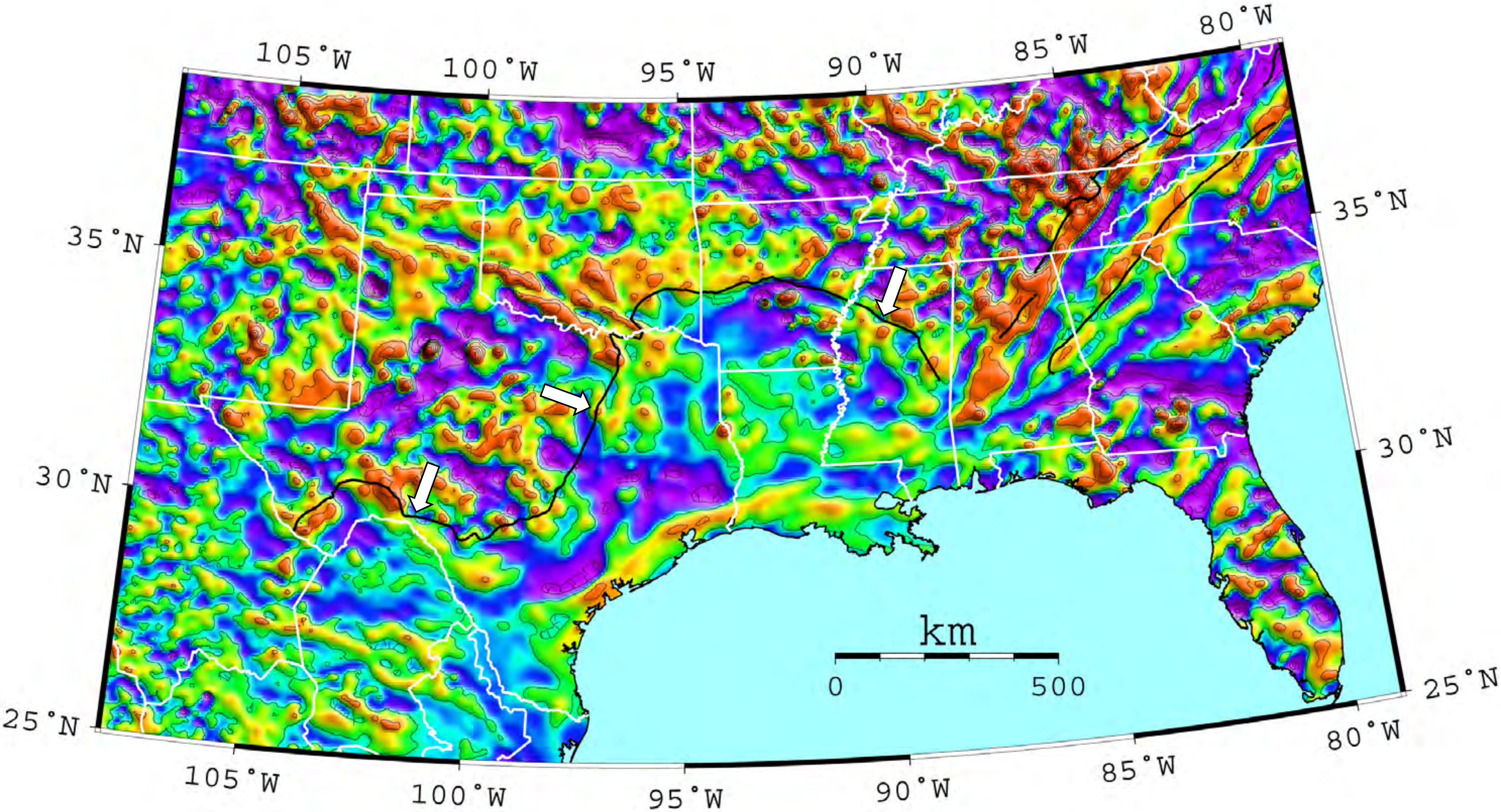
North
Western Mississippi
South
Gravity (mGals)
50
25
0
-25
-50
• =Observed — =Calculated — =Error
shoreline
water
0
Late Cretaceous - Tertiary
Jurassic - Middle Cretaceous
Volcanics
Late Pz Sediments
Ouachita Facies
Triassic Sediments
Allochthonous Crust
North American Crust
Mz Rift Pillow
Mz Oceanic Crust
Depth (km)
25
Pz Rift Pillow
(projected)
Pz Oceanic Crust
Mantle
50
0
250
500
750
1000
Distance (km)
V.E.=5
Mississippi Valley Graben
Black Warrior Basin
Ouachita Orogen
Interior Salt Basin
Wiggins Arch
Gulf Coast Basin
0
250
500
750
1000
Distance (km)
V.E.=1

Filtered gravity anomalies – Ouachita orogenic belt region



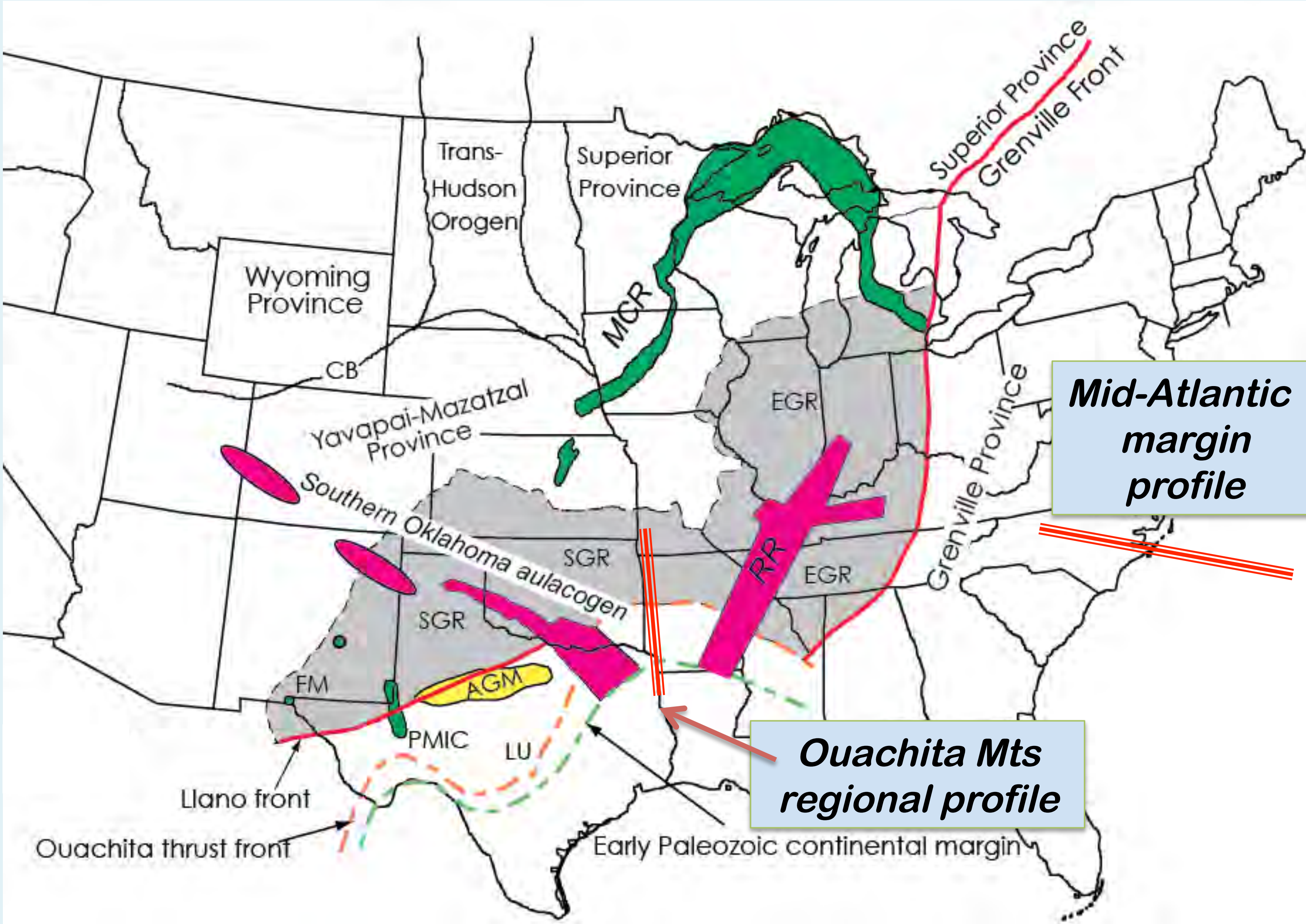
To better represent the gravity anomalies due to crustal density contrasts, a band-pass (150 to15 km) filter was applied to the Bouguer gravity anomaly data. Prominent anomalies include a gravity maximum following the Ouachita frontal thrust through MS-AK-OK-TX-MX, **gravity minima** are associated with the foreland basins and the Wiggins Terrane (southern MS), the Sabine Uplift (LA), the Llano Uplift (LU), and the southern Oklahoma aulacogen (SOA) are **maxima**.

Aeromagnetic anomalies – Ouachita region

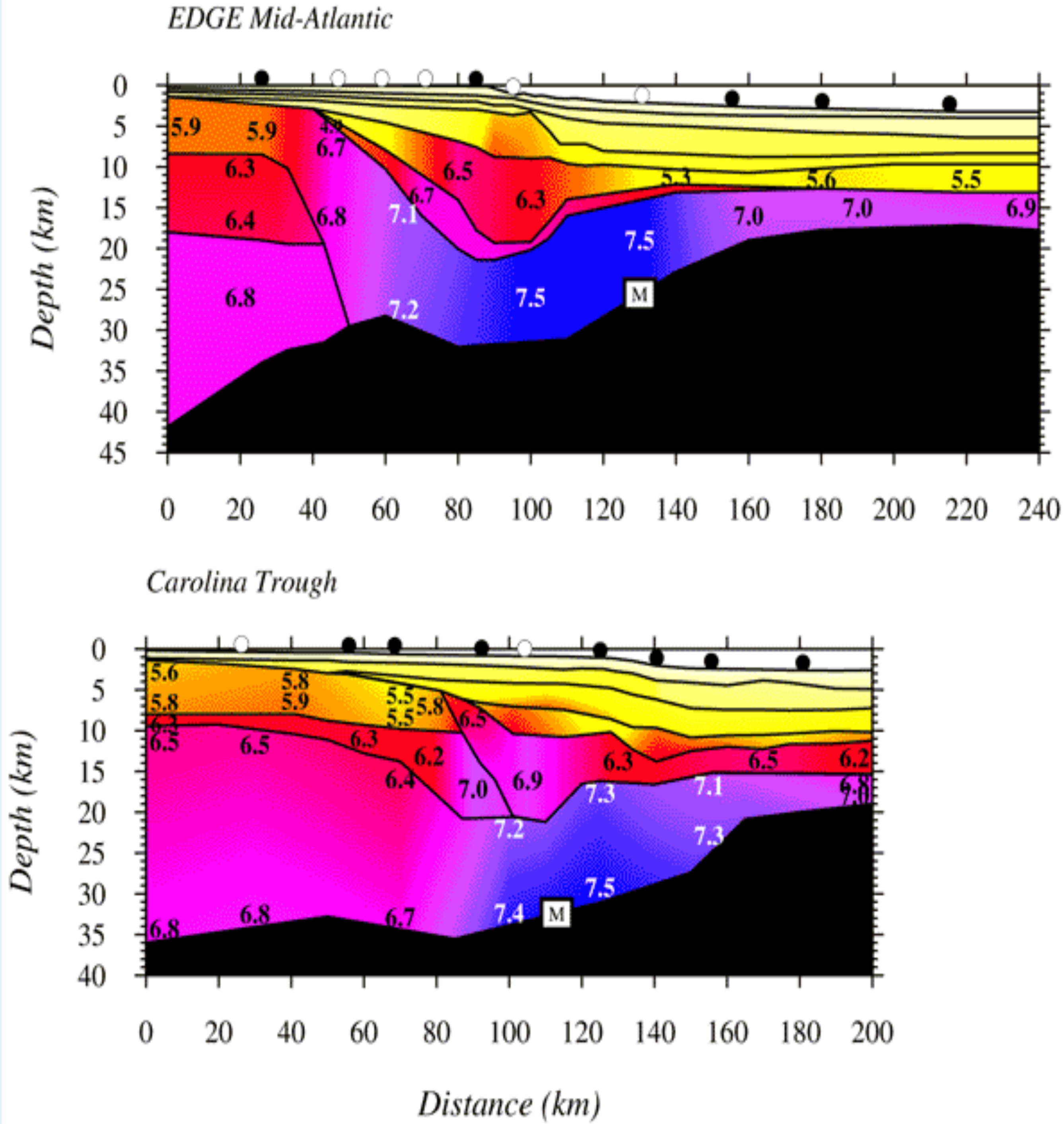


Aeromagnetic data are commonly used in conjunction with gravity data to interpret the geology of a region. The Ouachita Orogenic Belt is marked by a change in wavelength. Numerous high amplitude, short wavelength anomalies in northern Mississippi, western Louisiana, and Alabama suggest the presence of additional mafic intrusions. **What is going on along the Texas-Louisiana coast**?

We do have some deep seismic reflection and refraction profiles to constrain interpretations

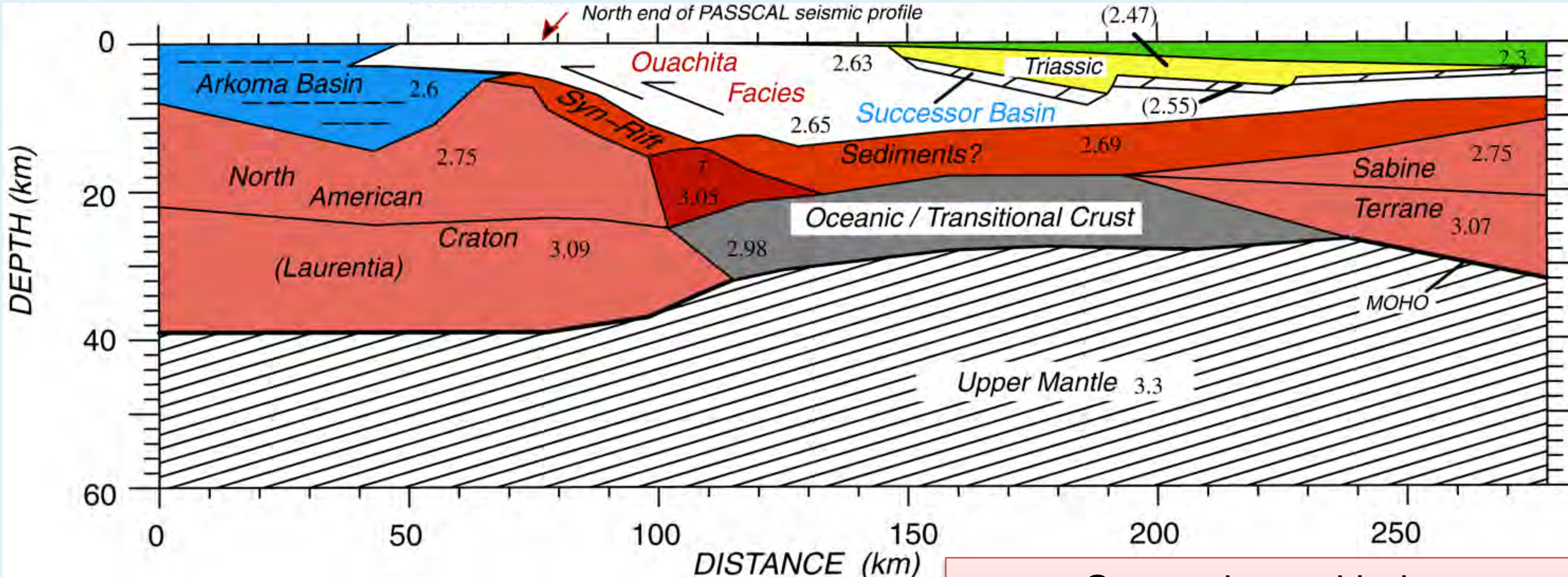


The Modern passive margin of the Eastern U.S.

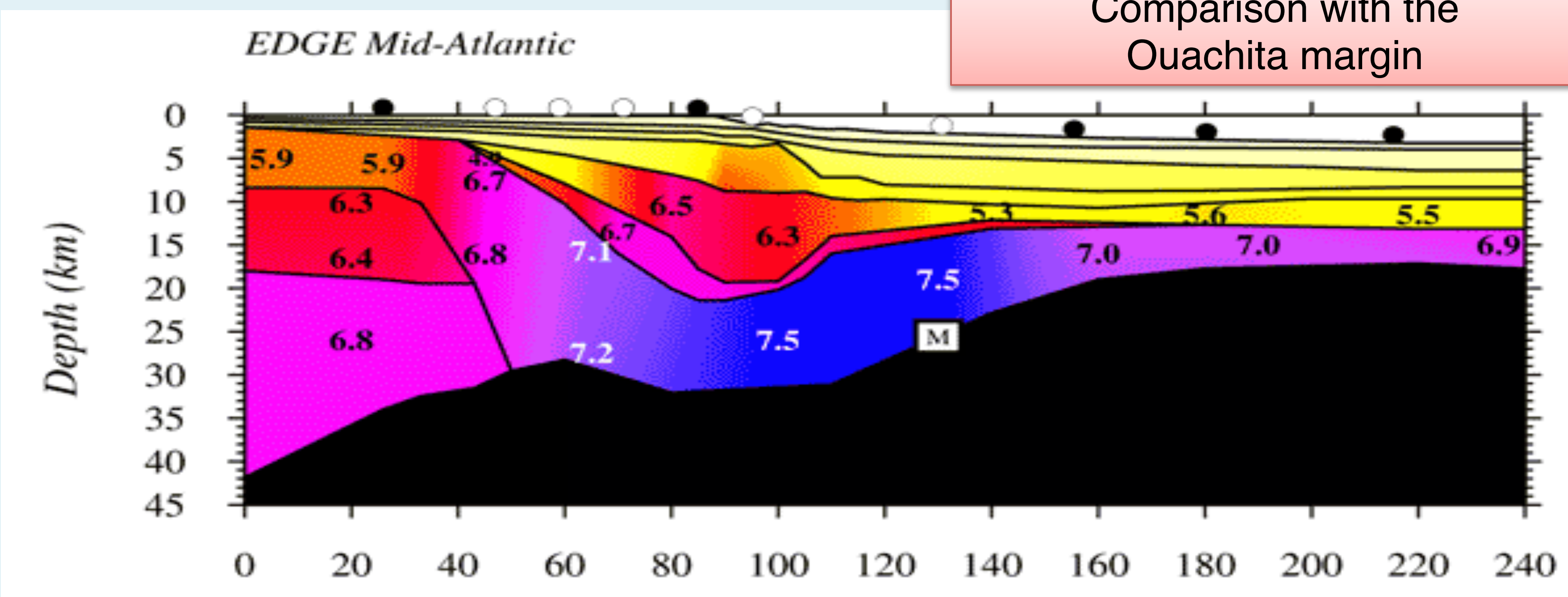


U.S. Mid-Atlantic Margin

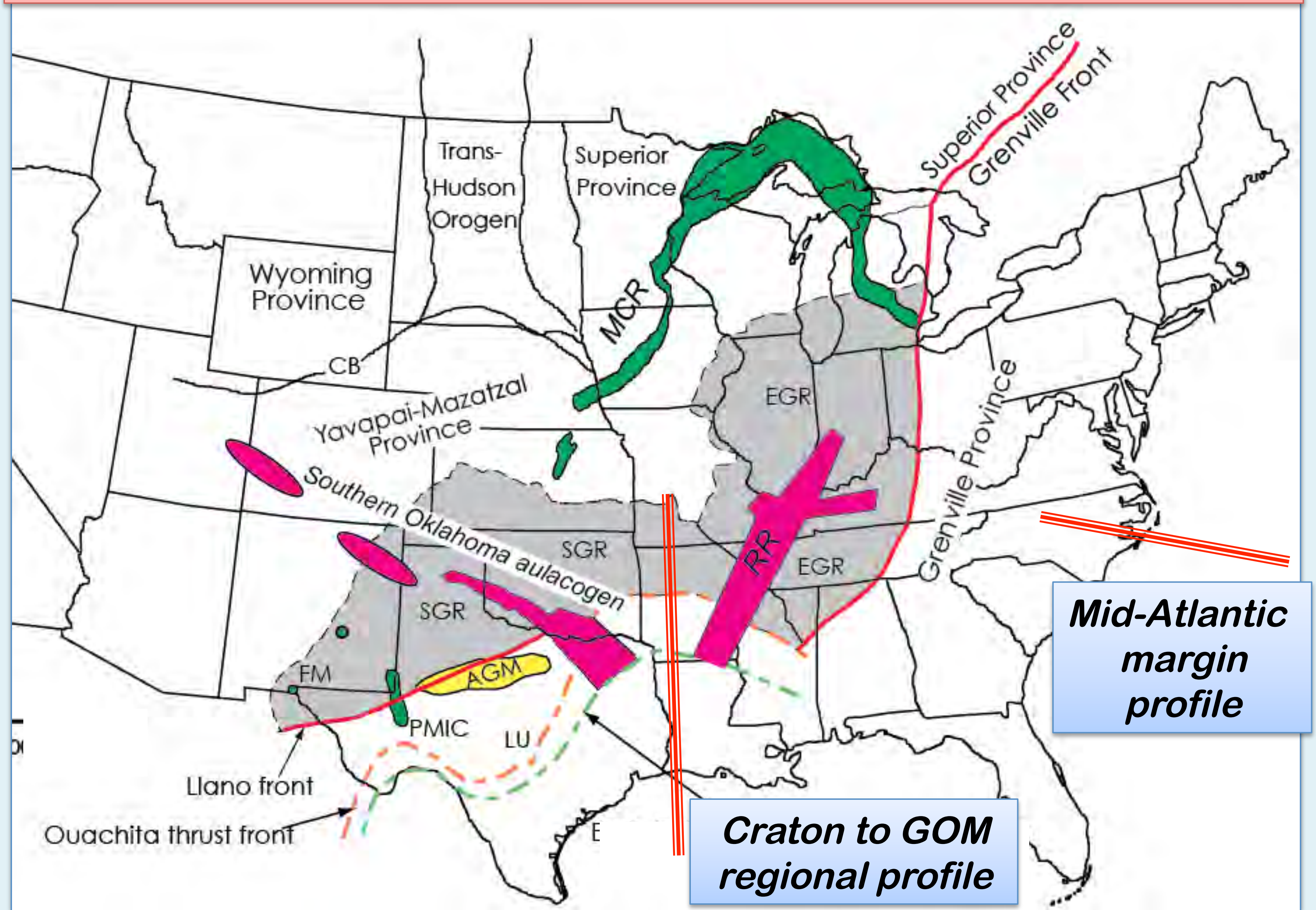
(Provided by Steve Holbrook- Univ. of Wyoming)



Comparison with the Ouachita margin

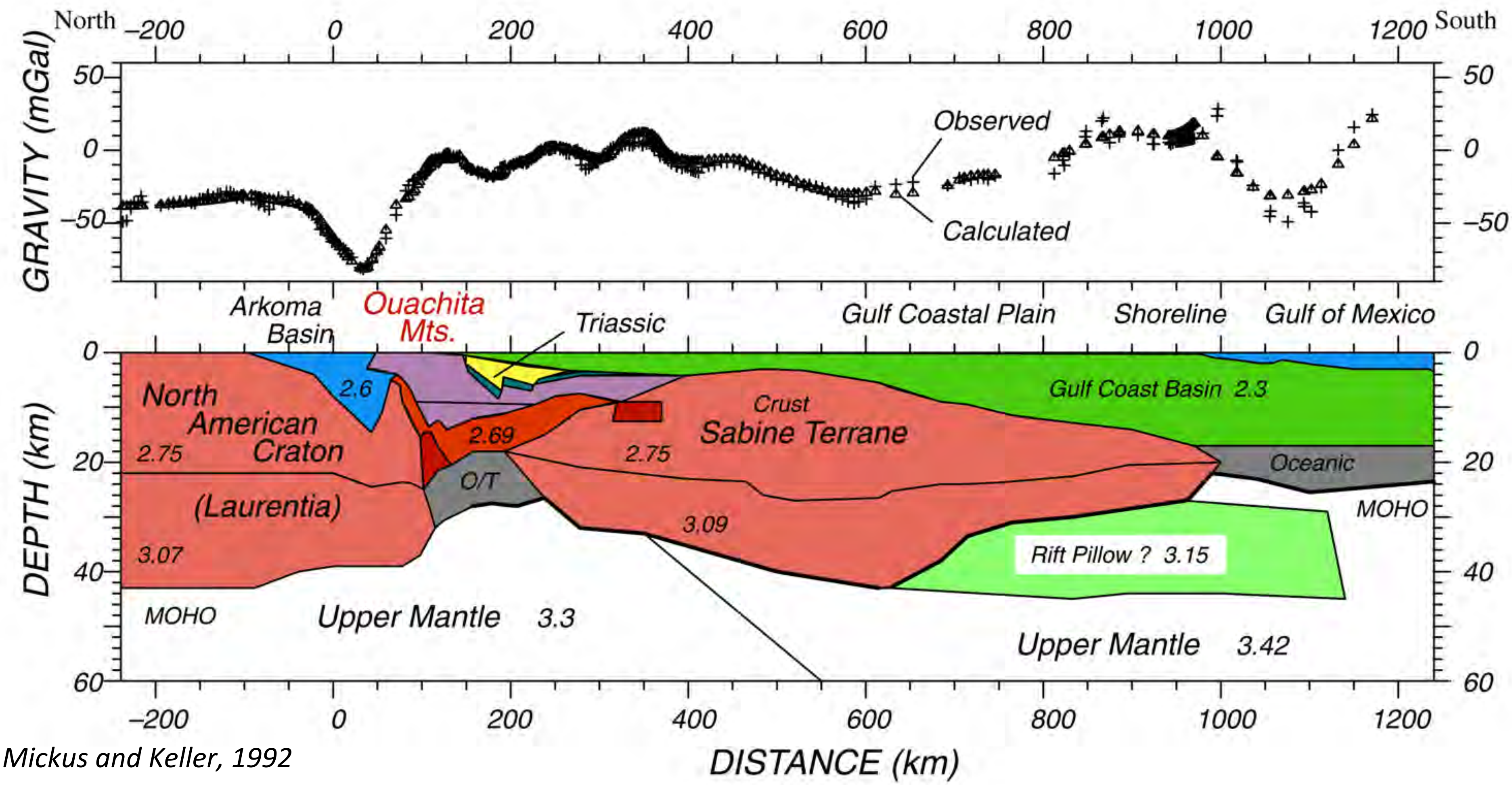


Craton to Gulf of Mexico lithospheric model across the Sabine Uplift



Craton to Gulf of Mexico Lithospheric Model

The Sabine Terrane may or may not be a piece of Laurentia



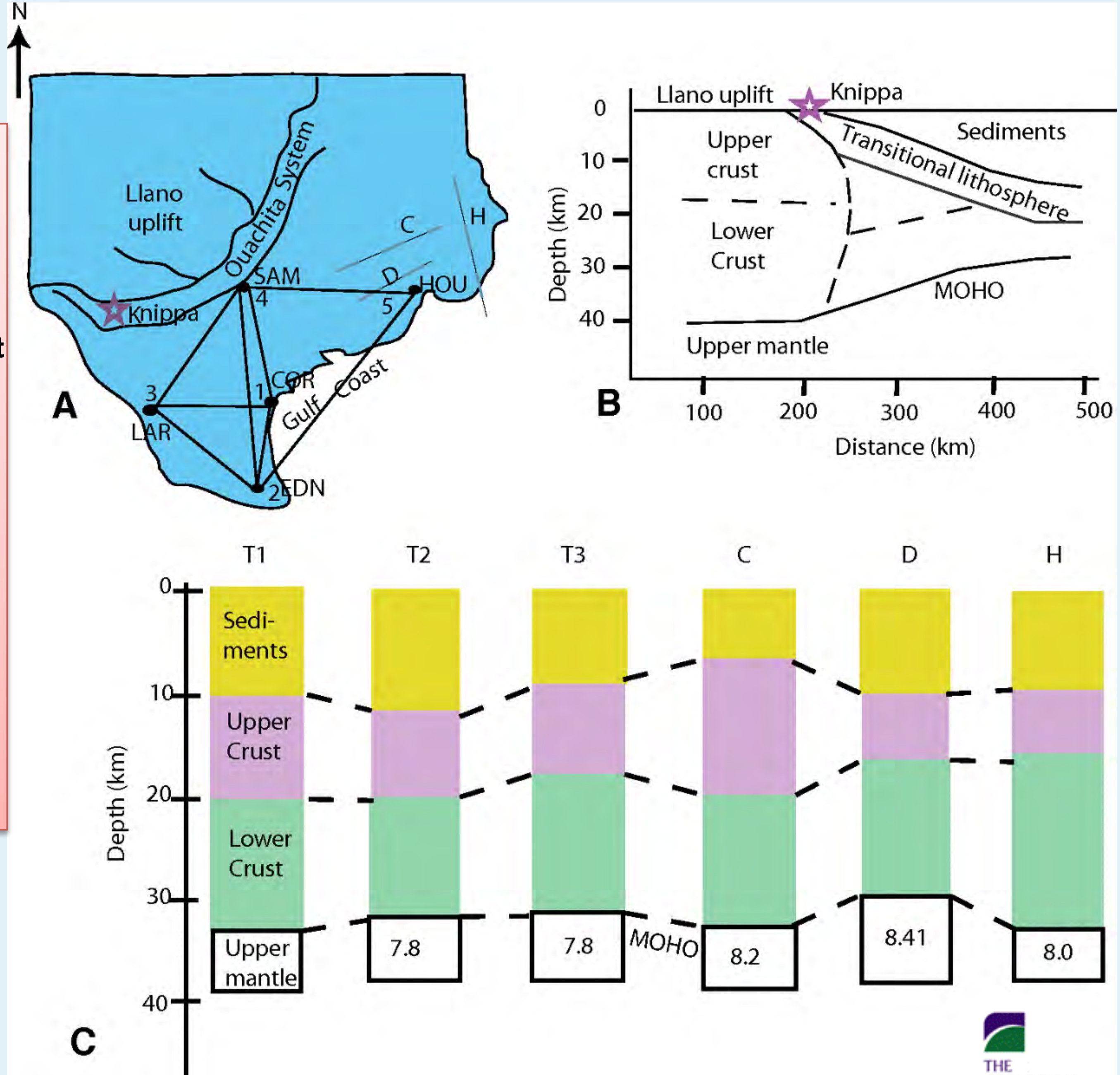
Mickus and Keller, 1992

This images shows that the Ouachita orogeny involved a "soft collision" that preserved the Paleozoic margin strata. Are these strata all cooked?

A: Index map showing Knippa (star), seismograph stations: LAR—Laredo, COR—Corpus Christi, EDN—Edinburg, SAM—San Marcos, HOU—Houston (Keller and Shurbet, 1975), C—Cram (1961, 1962), D—Dorman et al. (1972).

B: Generalized crustal structure model proposed by Keller and Shurbet (1975).

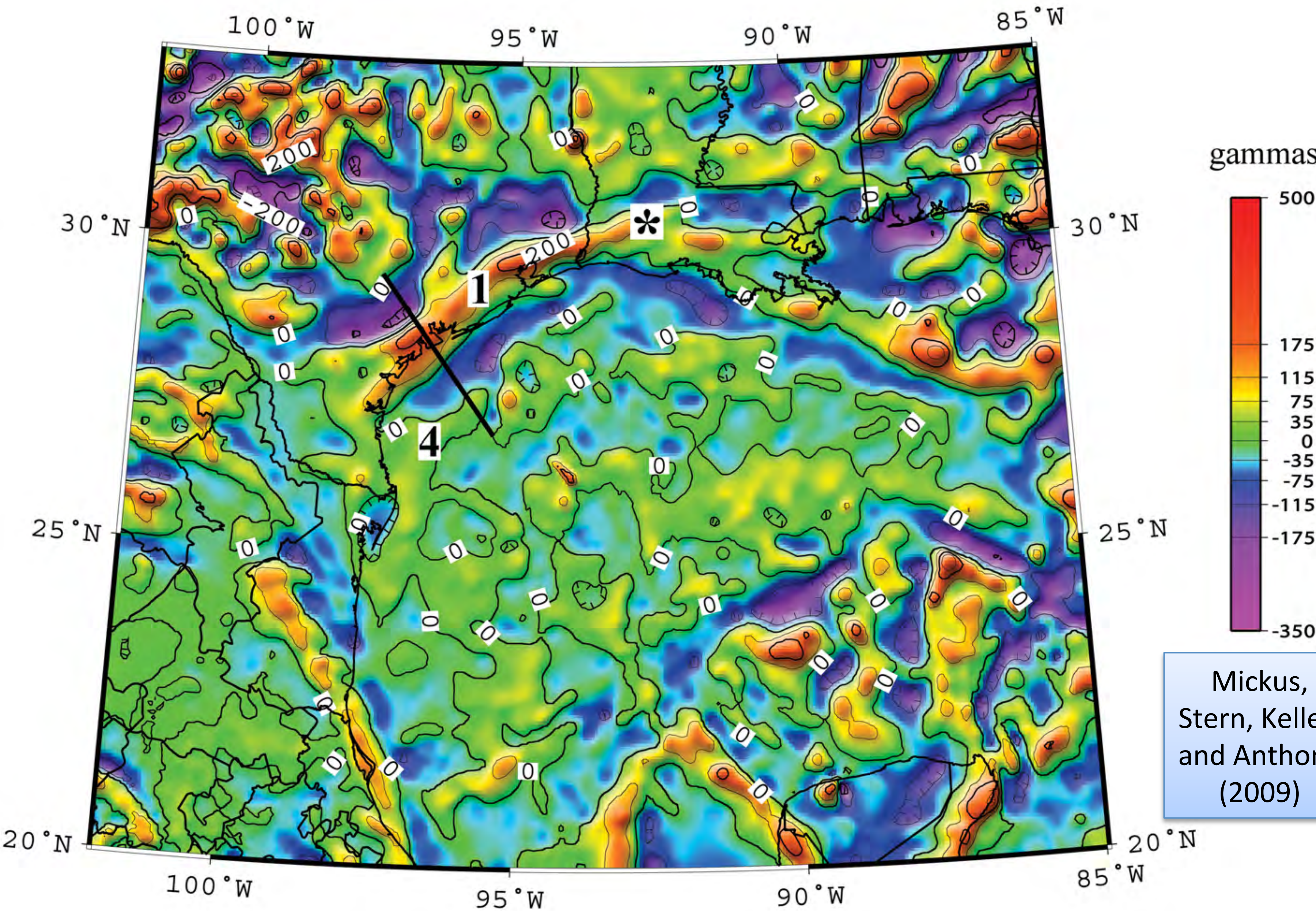
C: Crustal structure as interpreted from seismic velocities. Our calculated upper mantle seismic velocity agrees well with those velocities obtained from geophysical experiments.



Raye et al. Geosphere 2011;7:710-723

©2011 by Geological Society of America

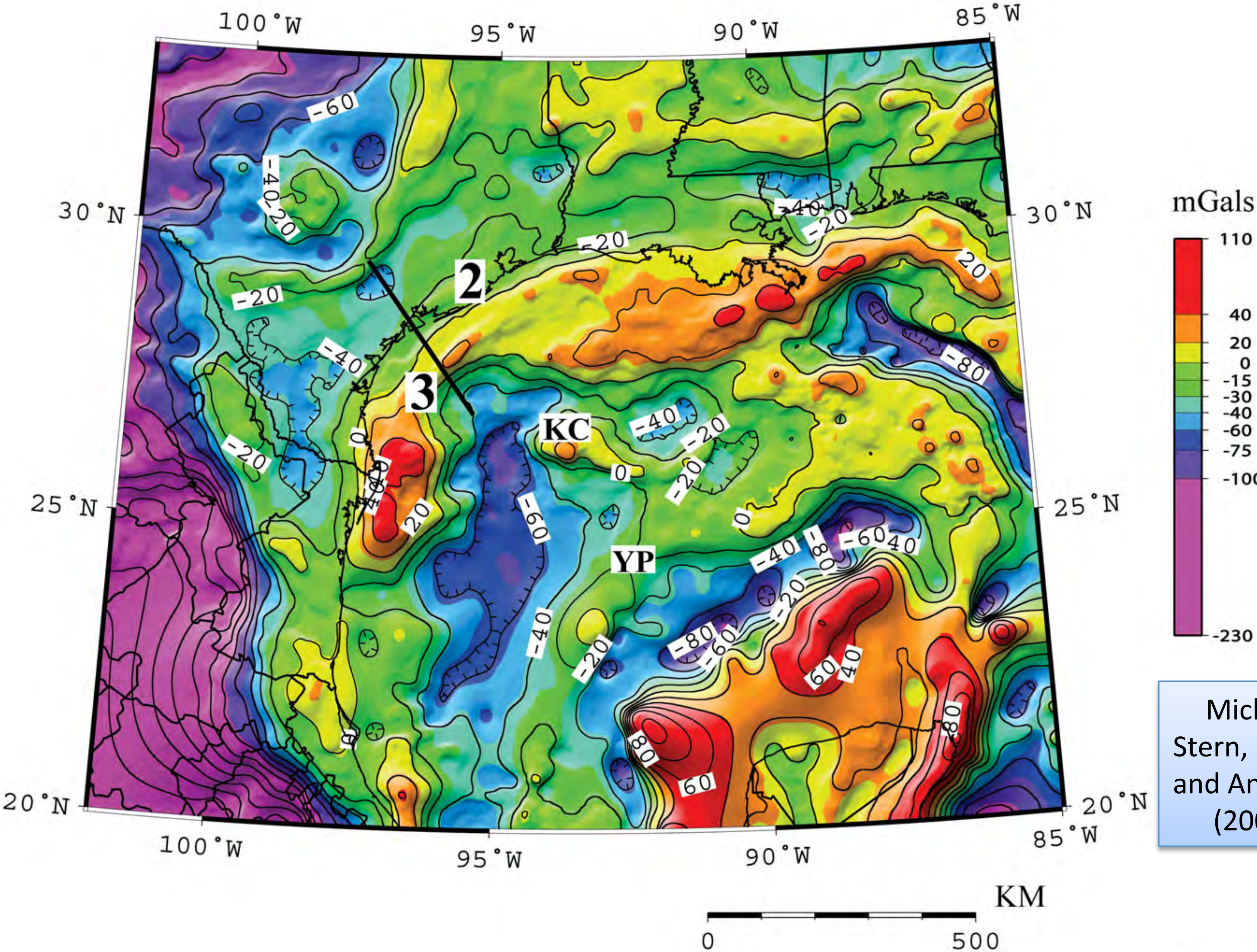
The prominent magnetic anomaly along the Gulf Coast has long been a puzzle



Mickus, Stern, Keller, and Anthony (2009)

Mickus et al. (2009)

And the gravity anomaly along the cost is well offshore from the magnetic anomaly!



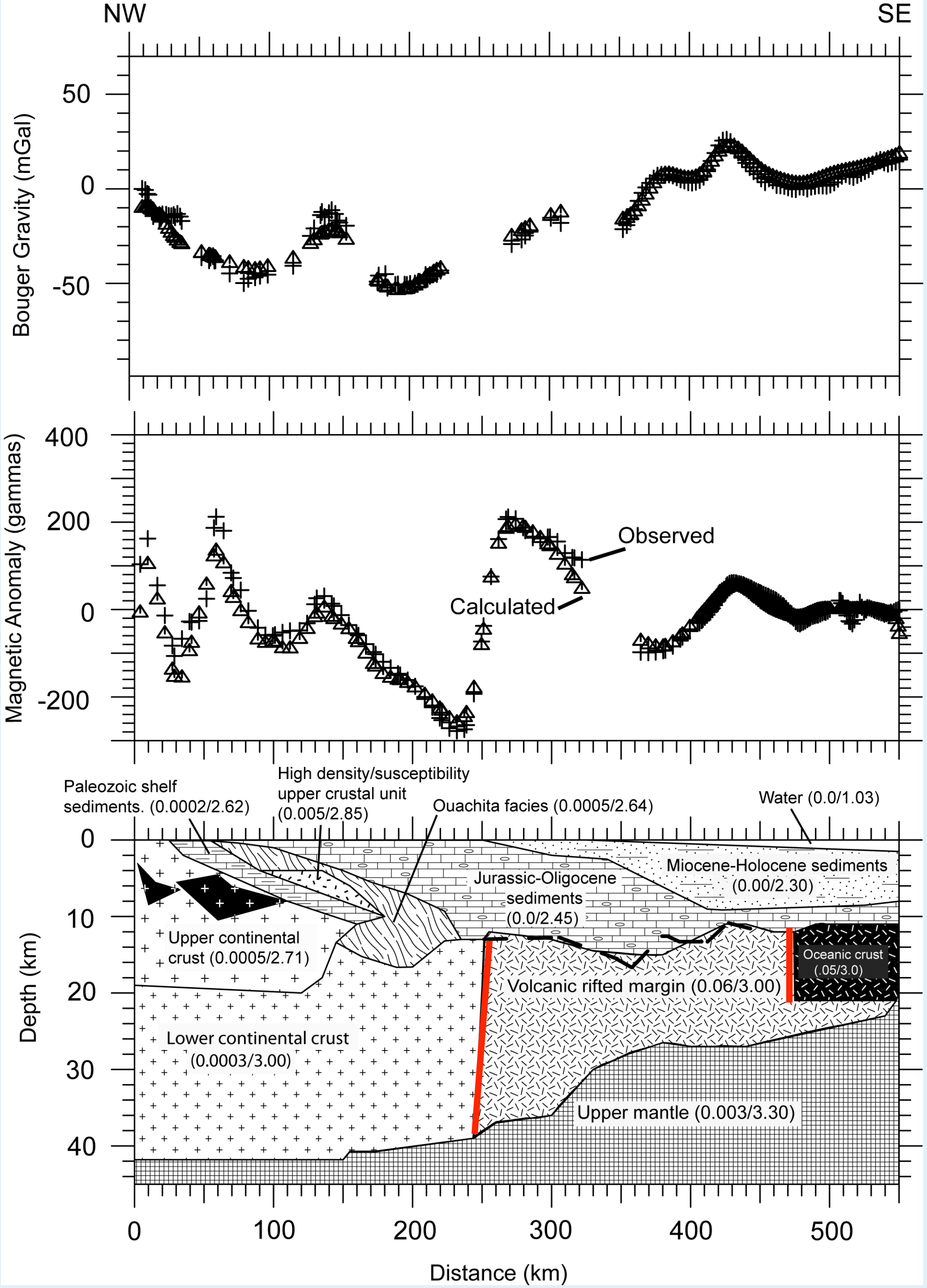
Mickus, Stern, Keller, and Anthony (2009)

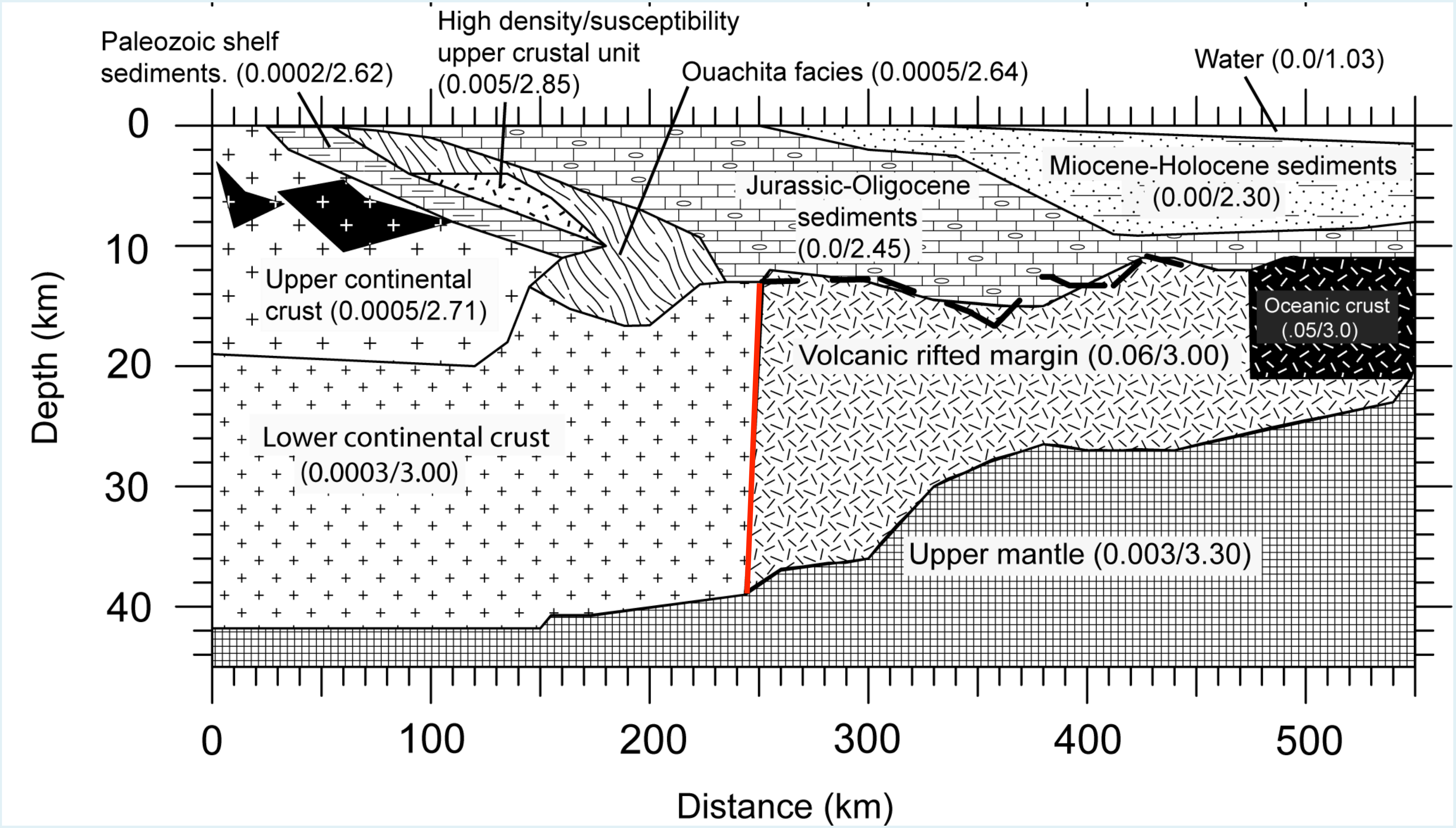
Integrated geophysical model along the black line crossing the Mesozoic margin. This model is based on a volcanic margin scenario that:

1) Fits both the gravity and magnetic anomaly data.

2) Honors the deep seismic data in the region.

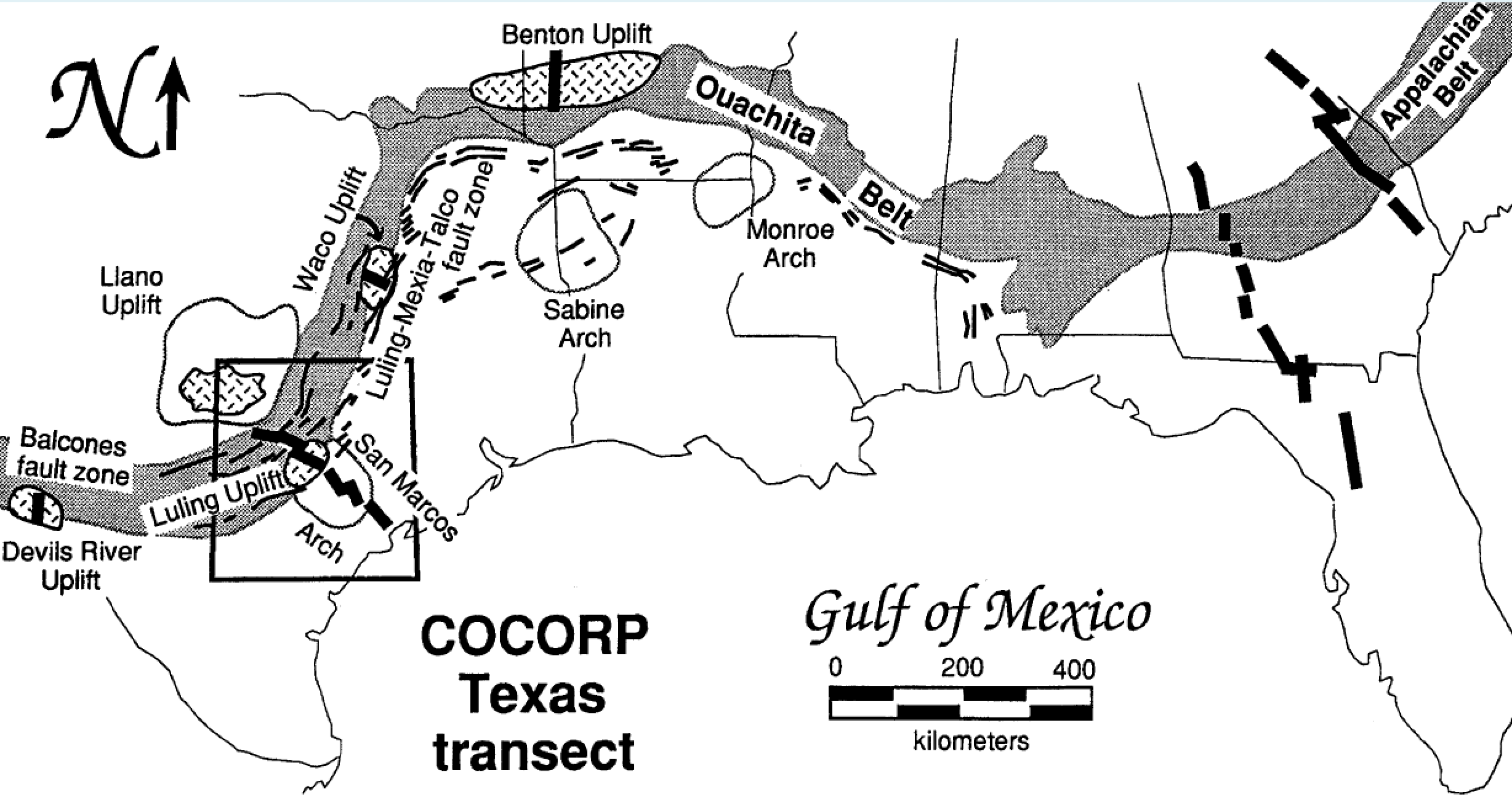
Mickus, Stern, Keller, and Anthony (2009)

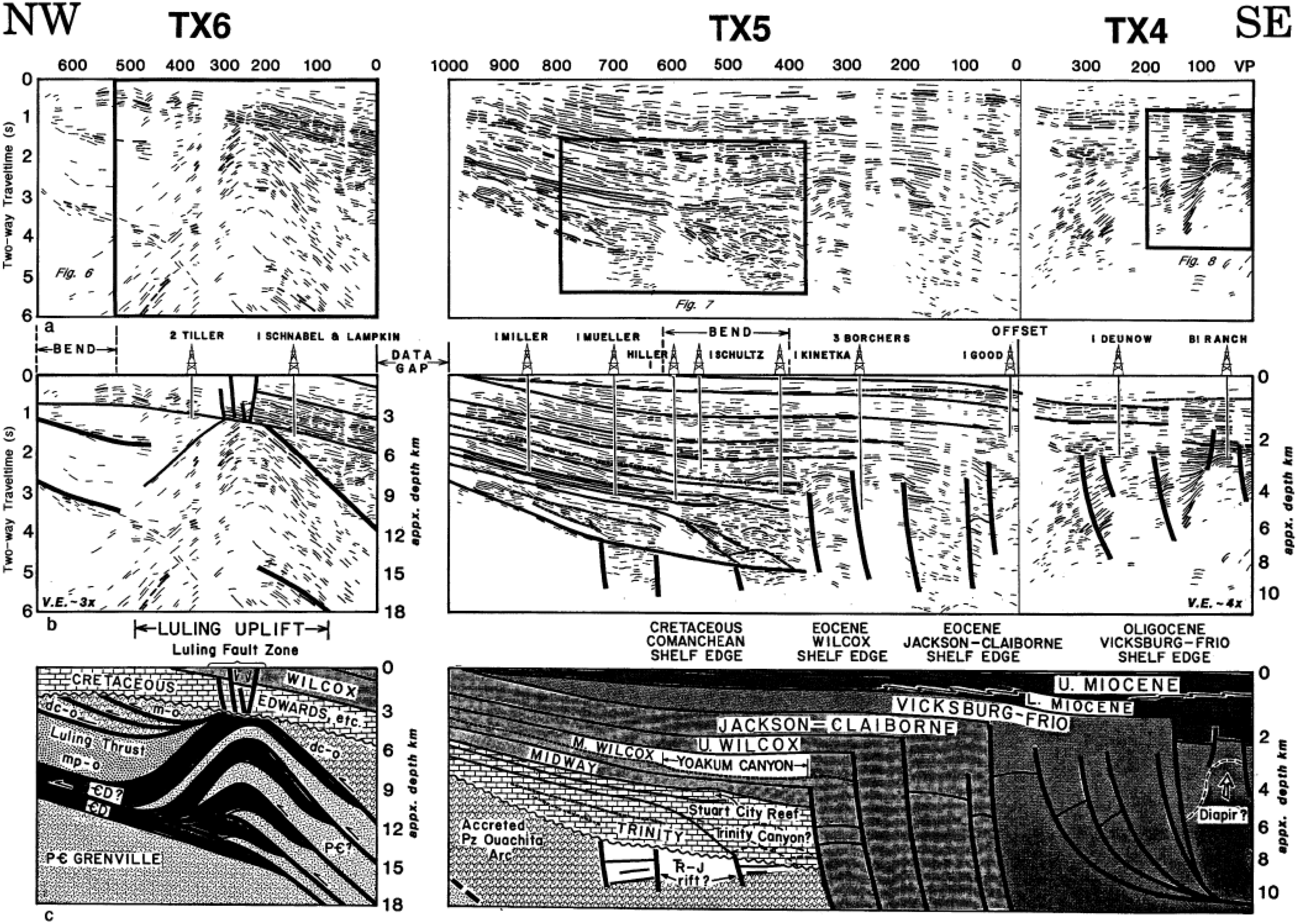




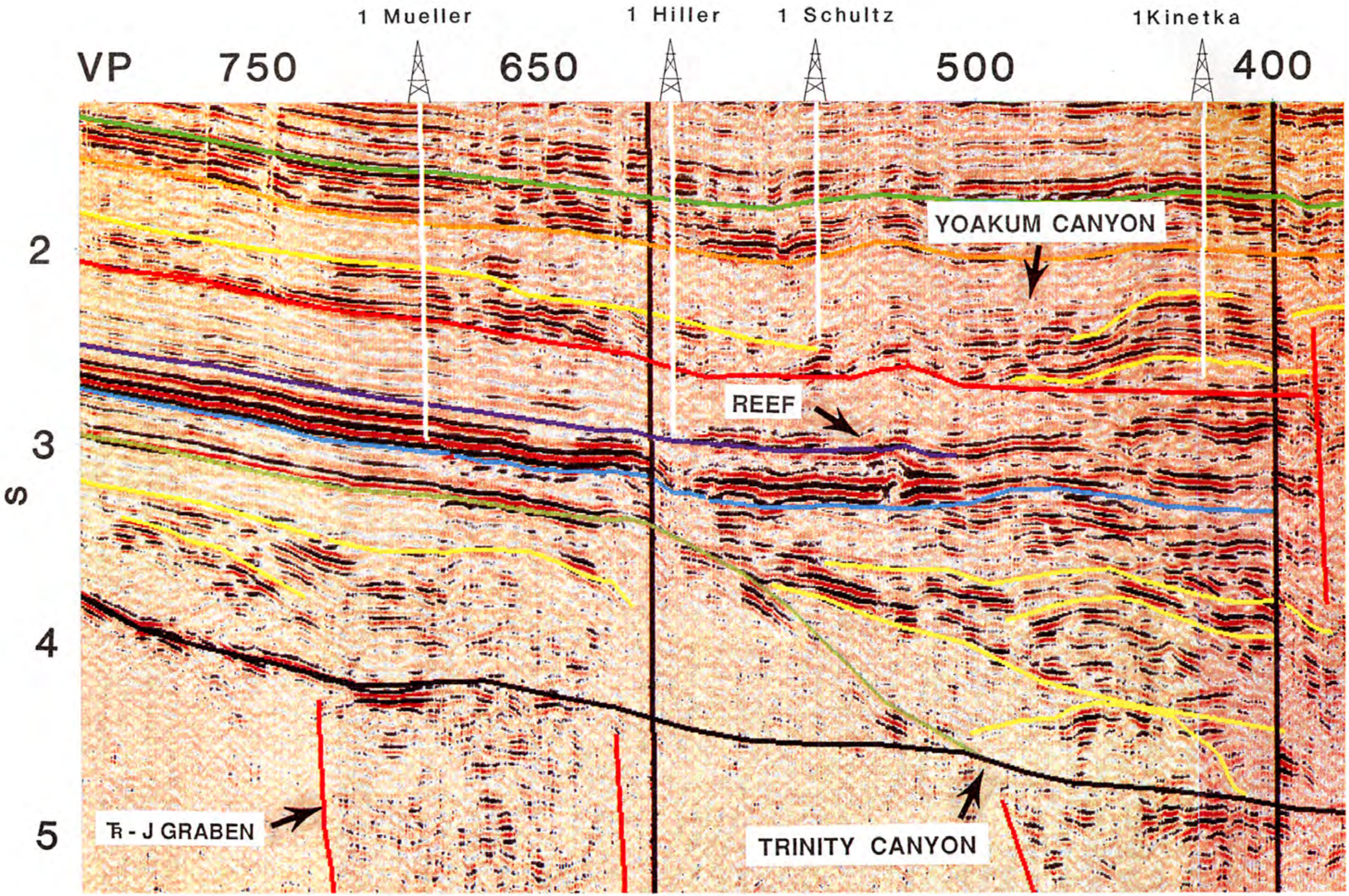
Mickus, Stern, Keller, and Anthony (2009)

We do have some seismic reflection lines to constrain the regional models

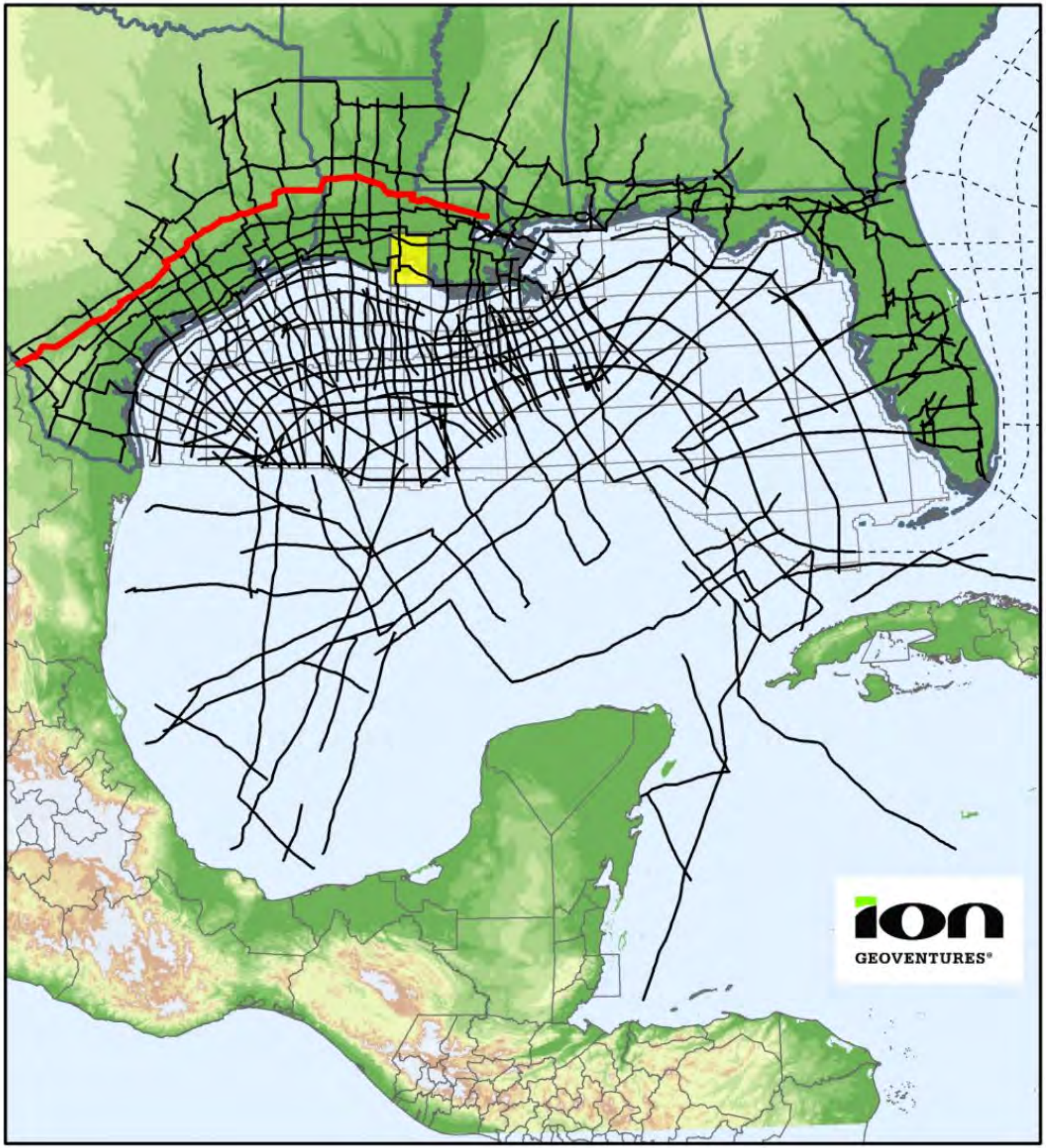


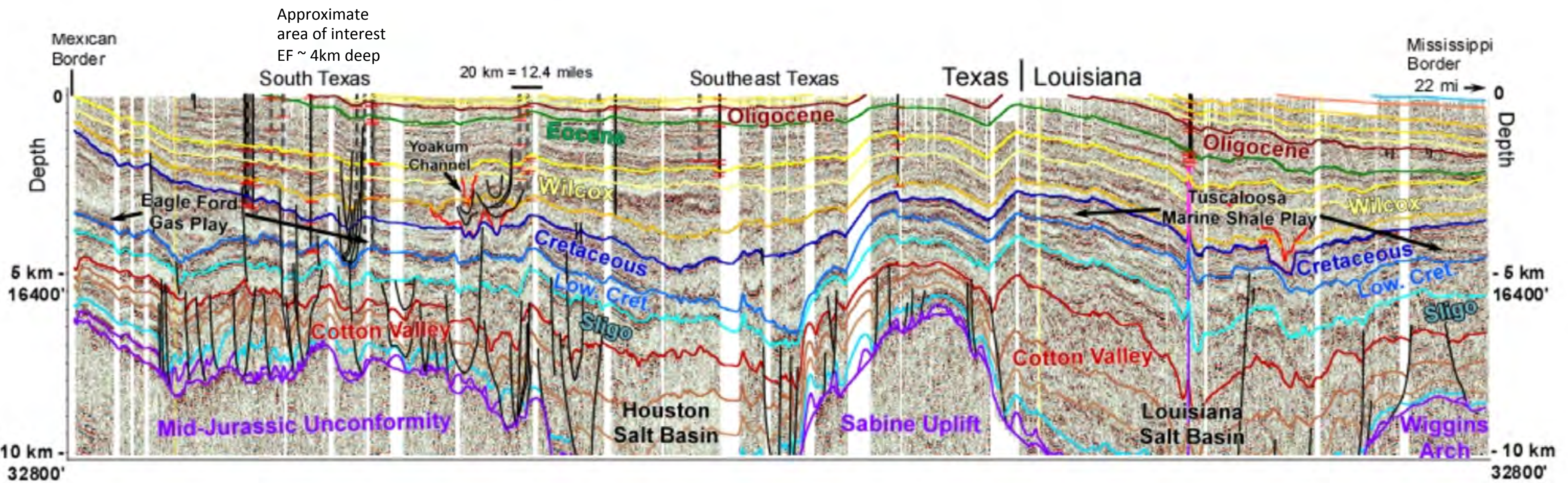


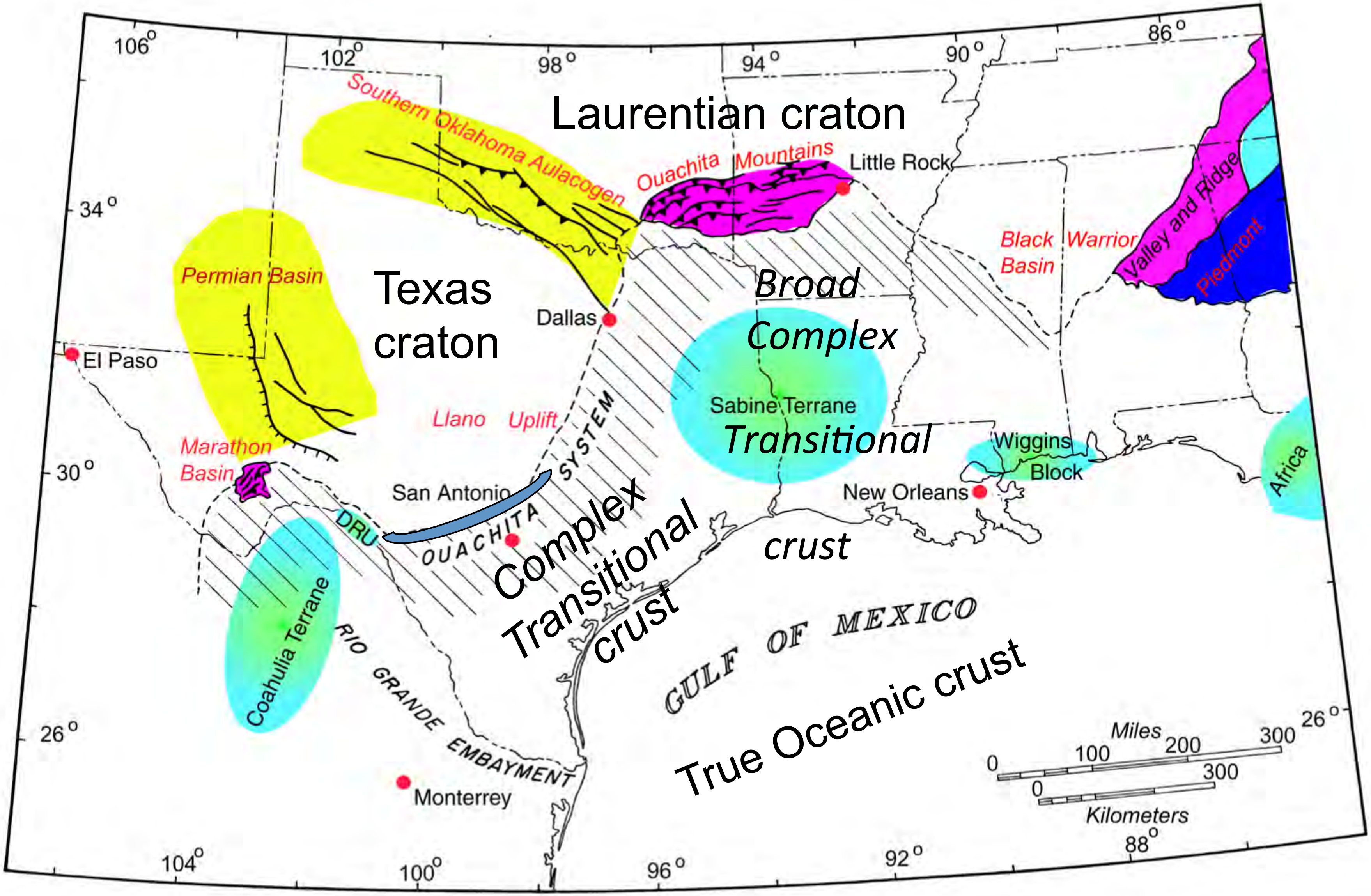
NW
TX6
TX5
TX4
SE
Two-way Traveltime (s)
Fig. 6
Fig. 7
Fig. 8
a
BEND
2 TILLER
I SCHNABEL & LAMPKIN
DATA GAP
I MILLER
I MUELLER
HILLER I
I SCHULTZ
I KINETKA
3 BORCHERS
I GOOD
OFFSET
I DEUNOW
BI RANCH
appx. depth km
V.E. ~3x
V.E. ~4x
b
LULING UPLIFT
Luling Fault Zone
CRETACEOUS COMANCHEAN SHELF EDGE
EOCENE WILCOX SHELF EDGE
EOCENE JACKSON-CLAIBORNE SHELF EDGE
OLIGOCENE VICKSBURG-FRIO SHELF EDGE
CRETACEOUS
WILCOX
EDWARDS, etc.
dc-o
m-o
Luling Thrust
mp-o
€D?
€D
P€?
P€ GRENVILLE
c
U. MIOCENE
L. MIOCENE
VICKSBURG-FRIO
JACKSON-CLAIBORNE
M. WILCOX
U. WILCOX
MIDWAY
YOAKUM CANYON
Stuart City Reef
TRINITY
Trinity Canyon?
Accreted Pz Ouachita Arc
Ʀ-J rift?
Diapir?


1 Mueller
1 Hiller
1 Schultz
1Kinetka
VP
750
650
500
400
2
3
S
4
5
YOAKUM CANYON
REEF
TR - J GRABEN
TRINITY CANYON

Seismic profile along red line follows

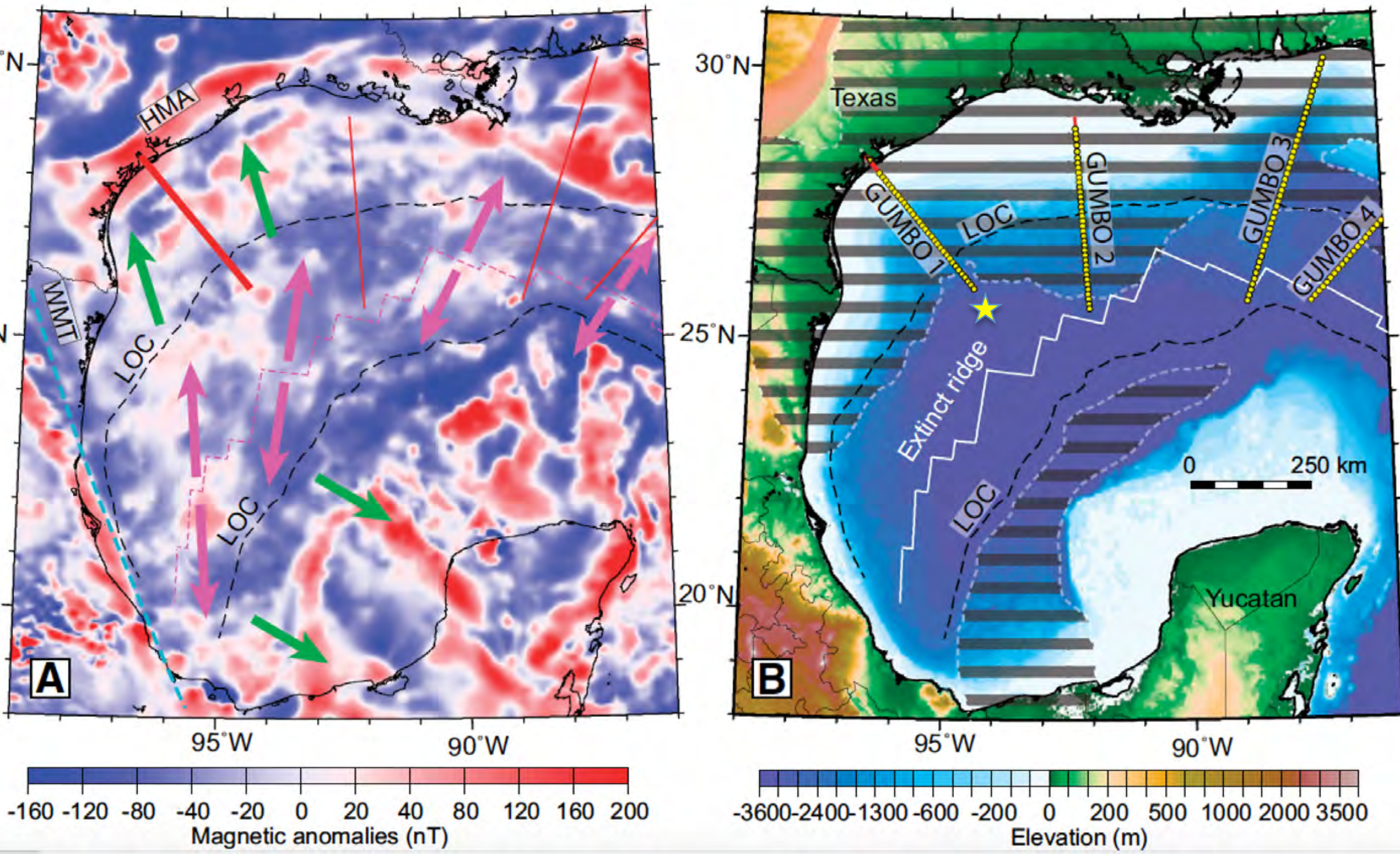



Approximate
area of interest
EF ~ 4km deep
Mexican
Border
South Texas
20 km = 12.4 miles
Southeast Texas
Texas | Louisiana
Mississippi
Border
22 mi
0
Depth
Oligocene
Eocene
Yoakum
Channel
Wilcox
Eagle Ford
Gas Play
Tuscaloosa
Marine Shale Play
Cretaceous
Low. Cret.
Sligo
Cotton Valley
Mid-Jurassic Unconformity
Houston
Salt Basin
Sabine Uplift
Louisiana
Salt Basin
Wiggins
Arch
5 km
16400'
10 km
32800'

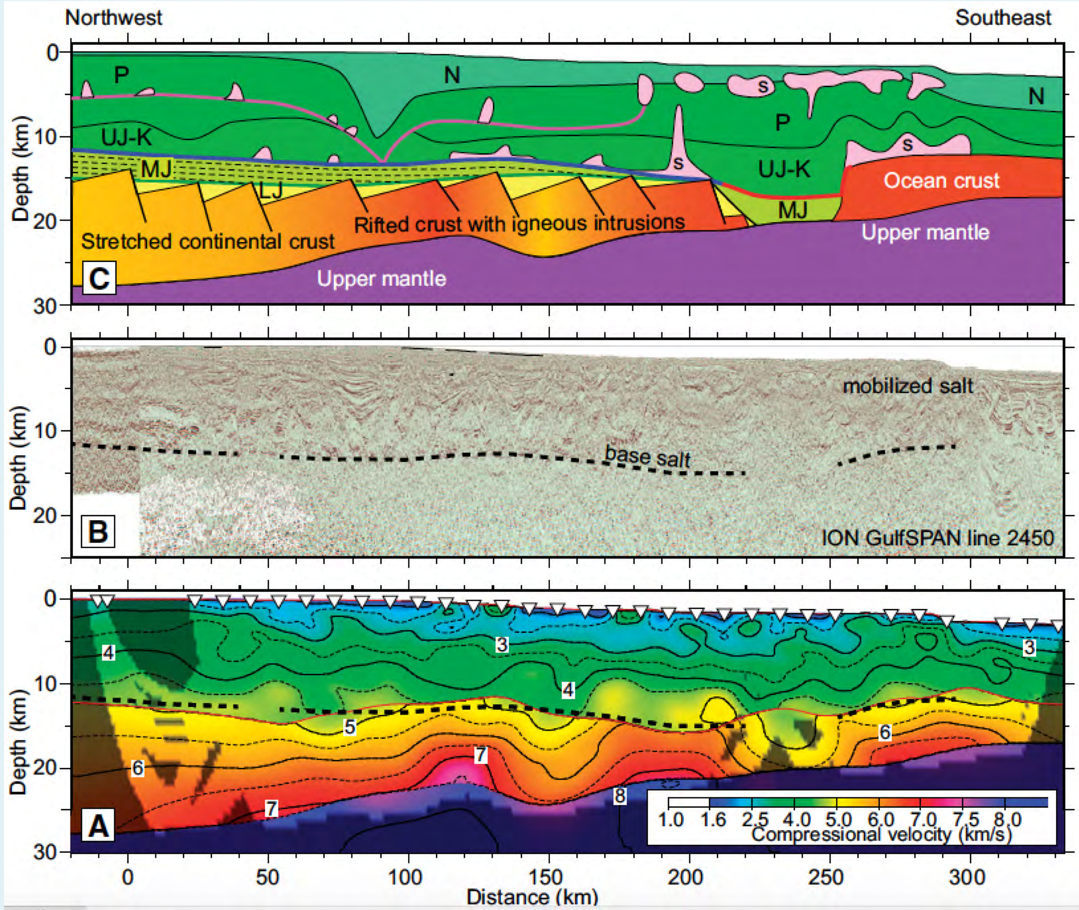


The different behaviors of the Texas and Louisiana sectors of transitional crust (highly extended continental crust) that formed during early Mesozoic rifting is reflected in width and nature of the transitional crust

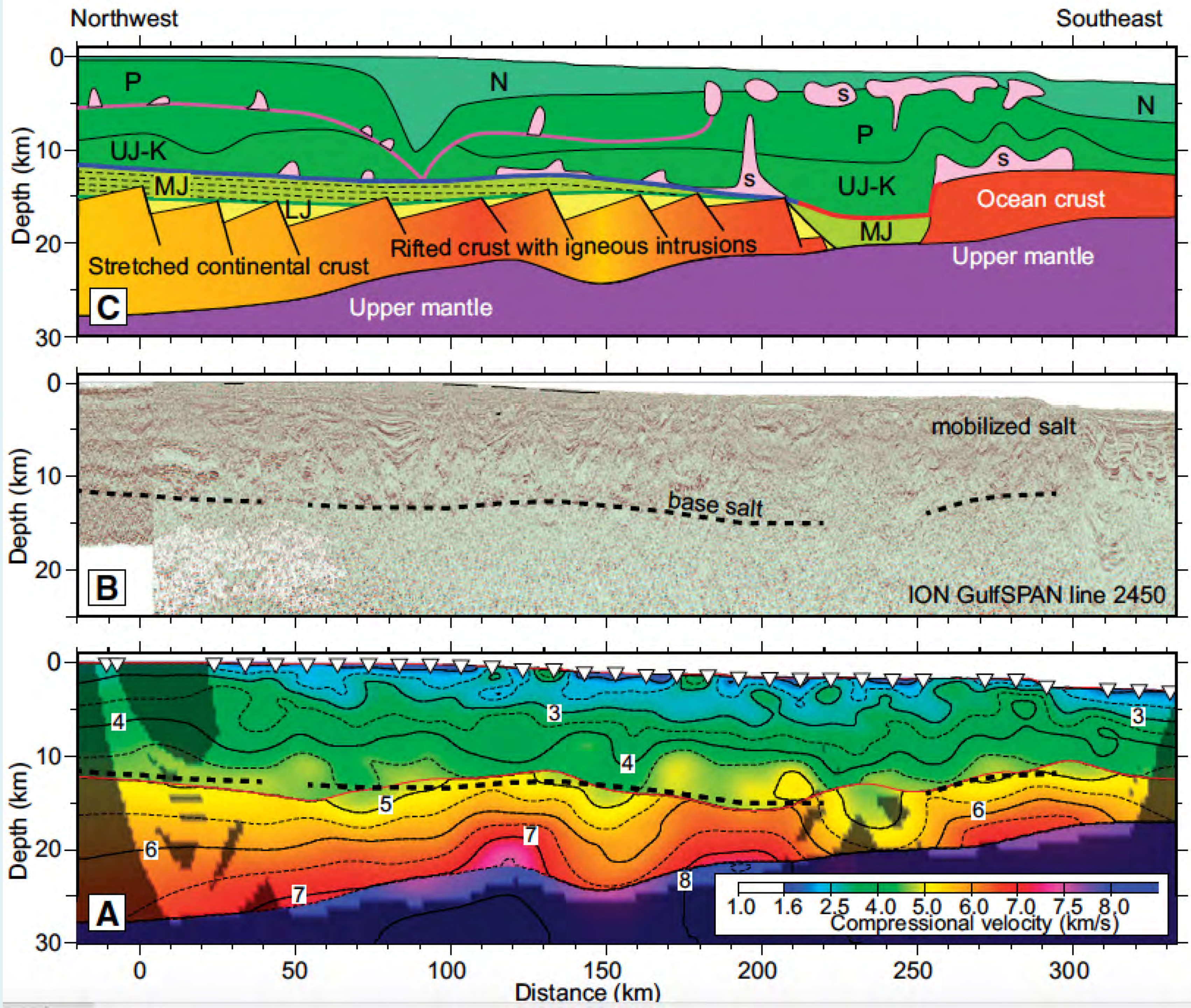
The GUMBO Project (Univ. of Texas Institute for Geophysics) has provided important new images of the crust of the Gulf just off the coast.



Harm J. A. Van Avendonk, Gail L. Christeson, Ian O. Norton, and Drew R. Eddy (2015)



- A: Seismic velocities image for Gulf of Mexico Basin Opening (Gumbo) line 1. Distance is measured from the coast. Red lines show model boundaries in the tomographic inversion. The thick black dashed line indicates the base of salt interpreted in seismic reflection data.
- B: Pre-stack depth migration of seismic reflection data from ION Geophysical GulfSPAN line 2450 approximately in the location of GUMBO line 1.
- C: Interpretation of the seismic velocity and reflection images.



Northwest
Southeast
P
N
N
P
s
s
s
UJ-K
UJ-K
MJ
MJ
LJ
Ocean crust
Rifted crust with igneous intrusions
Stretched continental crust
Upper mantle
Upper mantle
C
mobilized salt
base salt
B
ION GulfSPAN line 2450
A
Compressional velocity (km/s)
1.0 1.6 2.5 4.0 5.0 6.0 7.0 7.5 8.0
Depth (km)
Distance (km)

My Conclusion:

We still have a great deal to learn about the structure and tectonic evolution of the Gulf Coast region

Thank You for Your Attention!