An Overview of the Structure and Evolution of the Ouachita Orogenic Belt from Mississippi to Mexico*

G. Randy Keller[1]

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Abstract

As part of our ongoing efforts to understand the structure and evolution of the Ouachita orogenic belt, we have complied and integrated a wide variety of data to produce a set of crustal scale transects from the continental interior to the Gulf Coast region. The key transect is based on deep reflection and refraction experiments that together extended from the Arkoma basin in Arkansas to the Sabine uplift in Louisiana. These data imaged the rifted margin of the craton that developed in the Cambrian and showed that it was not strongly deformed. It also revealed a thick mass of Ouachita facies sedimentary rocks above transitional or oceanic crust outboard of the rifted margin. Our integrated models and geologic constraints show that the Appalachian and Ouachita orogenic belts were formed during assembly of Pangea (by ~270 Ma), and were driven onto the rifted margin by collisions with arcs, exotic terranes, and other continents. They also show that the sinuous curves of the Appalachian-Ouachita orogen mimic the shape of the rifted margin and subsequent passive-margin shelf edge. Our results indicate that all around the Ouachita orogen, imbricated continental slope facies (in an accretionary prism at the leading edge of an arc complex) were thrust onto the continental shelf.

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An Overview of the Structure and Evolution of the Ouachita Orogenic Belt from Mississippi to Mexico

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Oklahoma Geological Survey

&

School of Geology and Geophysics

University of Oklahoma

Collaborators: Kevin Mickus, Bill Thomas, and many students

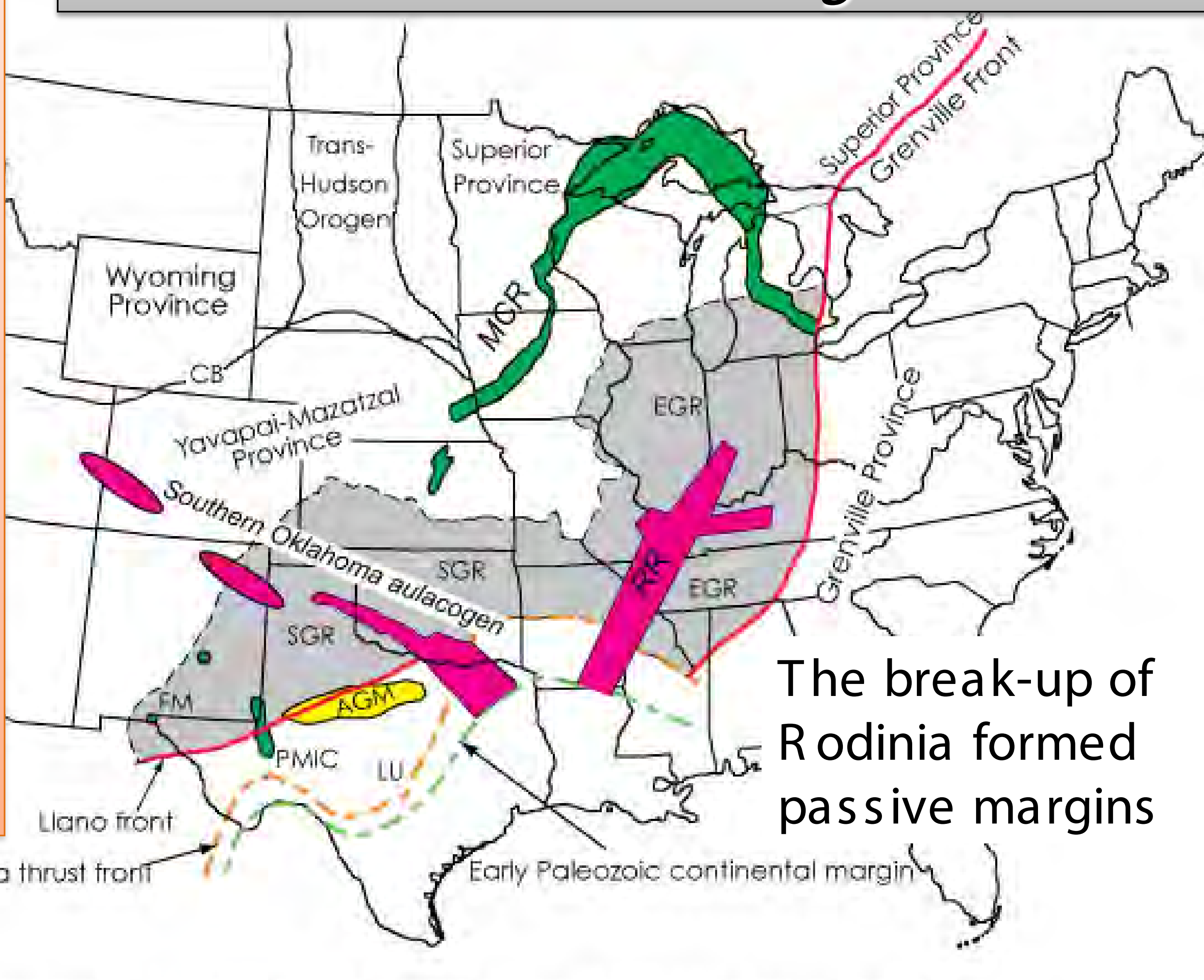
Precambrian Tectonic Evolution of the Mid-continent region

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

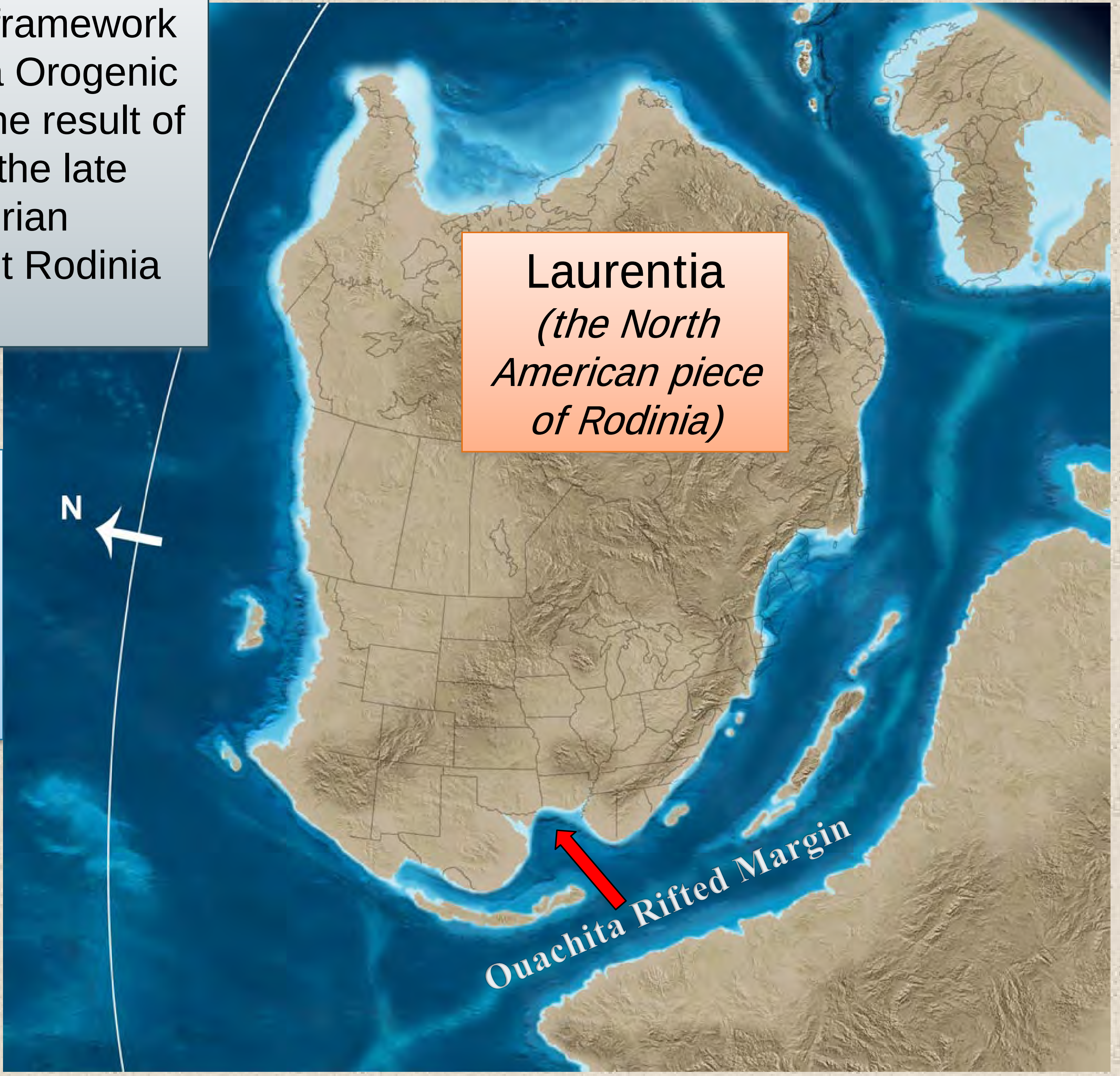


The break-up of Rodinia formed passive margins

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

The structural framework of the Ouachita Orogenic Belt is largely the result of break-up of the late Precambrian supercontinent Rodinia

Cambrian (~550 Ma) Paleo-geography

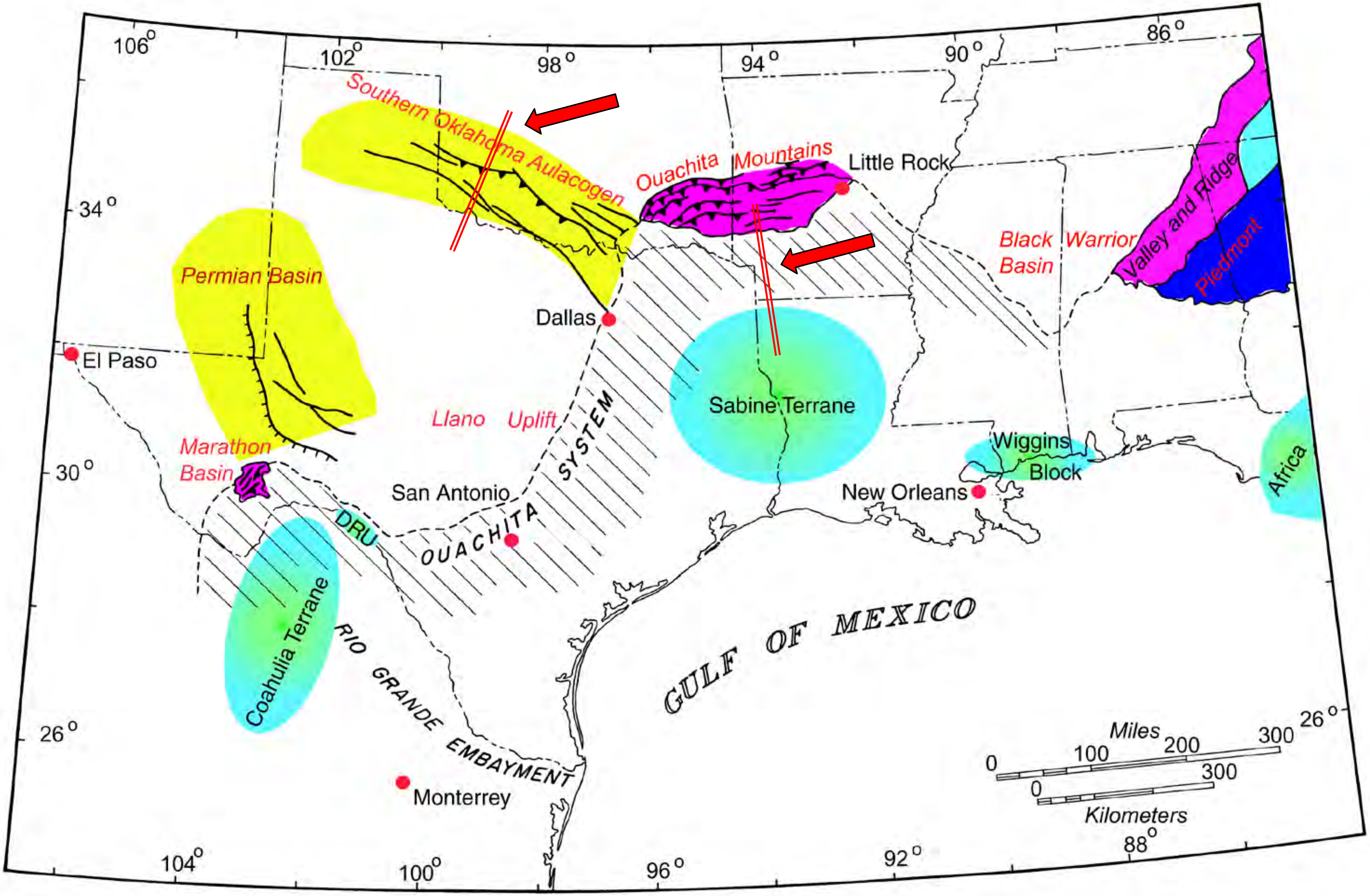


Ron Blakey

NAU

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

Ron Blakey, NAU



We have used the velocity models derived from the PASSCAL Ouachita and Wichita uplift seismic experiments, COCORP reflection profiles, gravity and magnetic data, along with drilling and geological data in an integrated analysis of the deep structure of this region.

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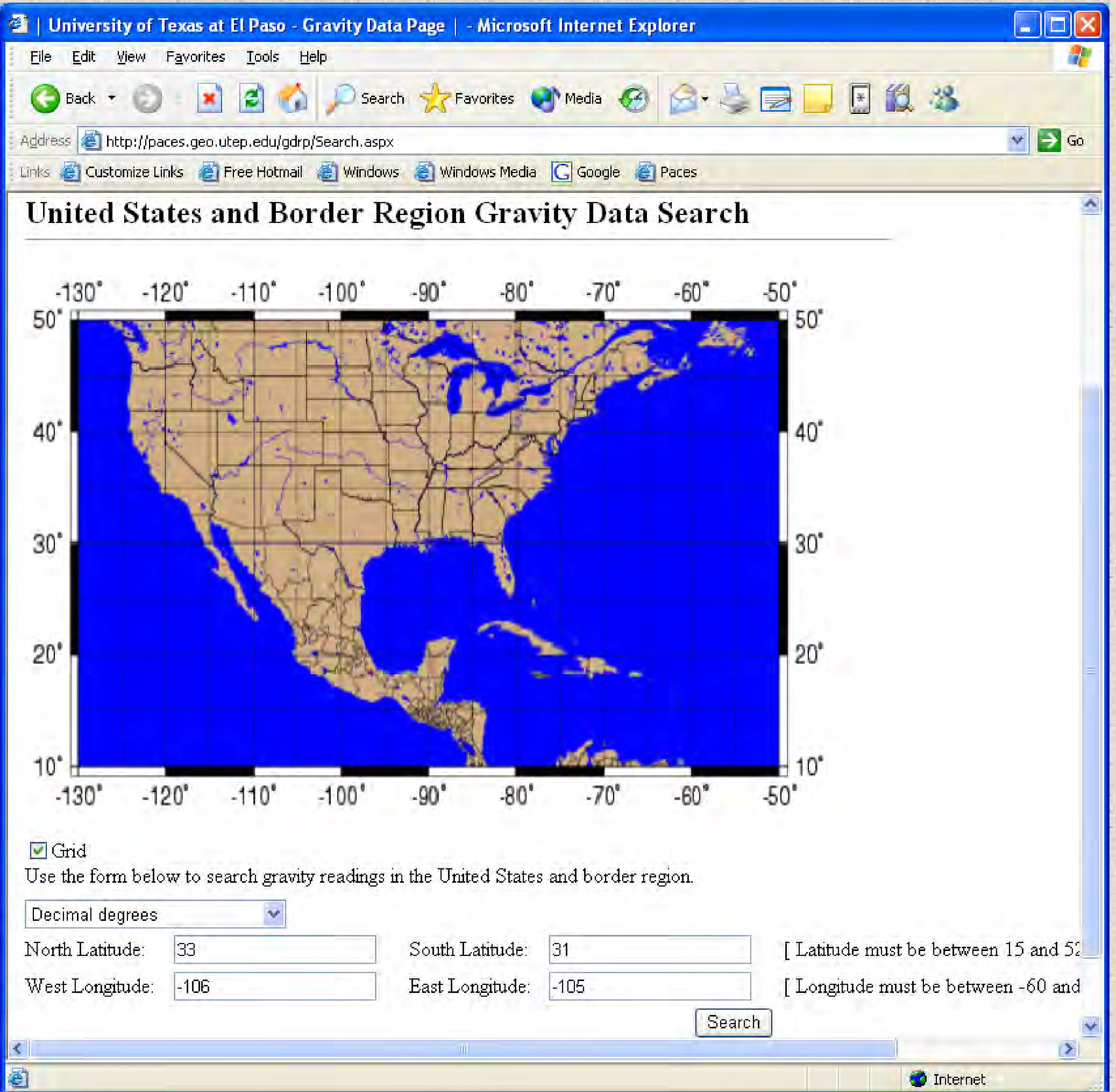
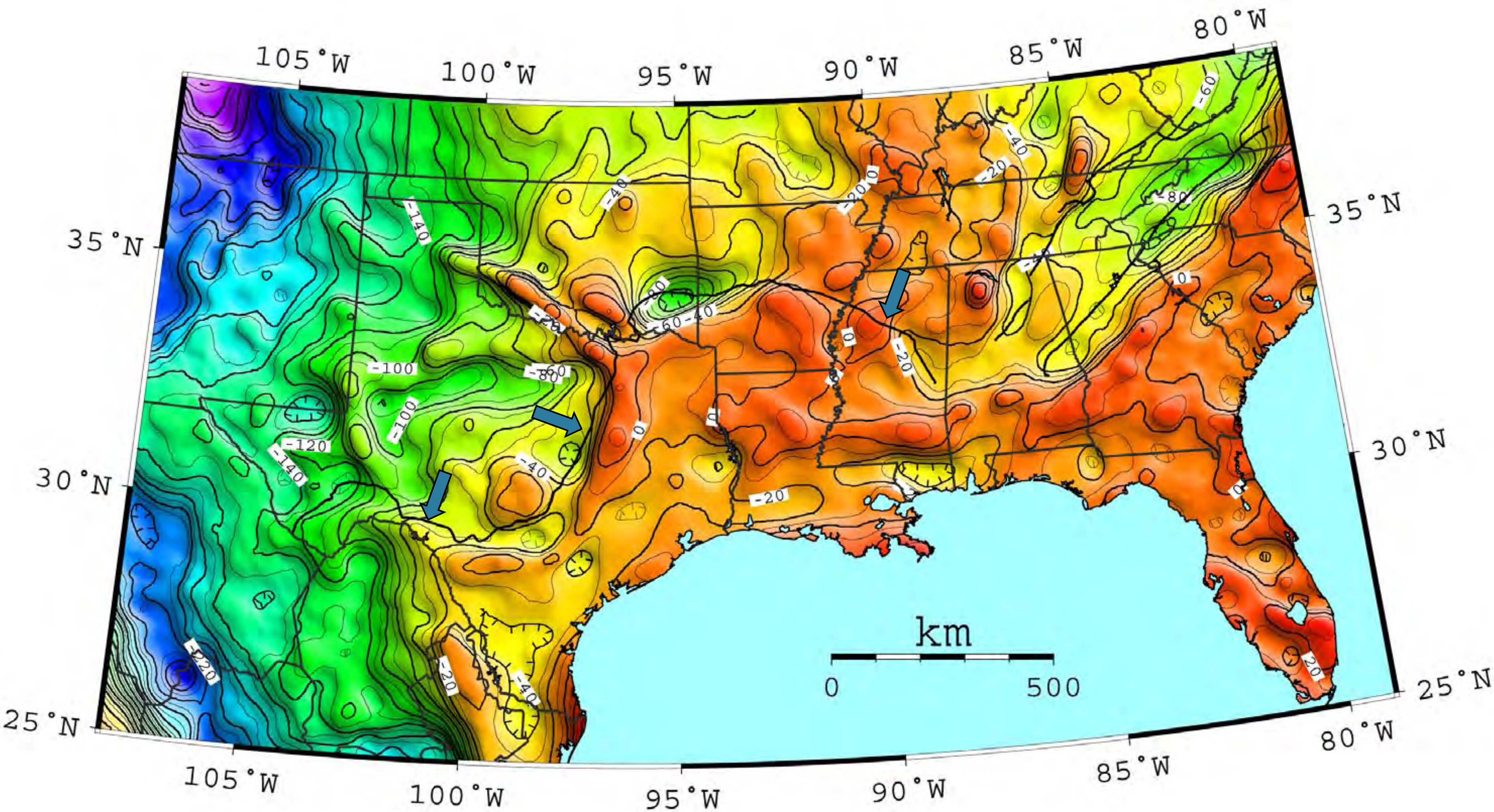


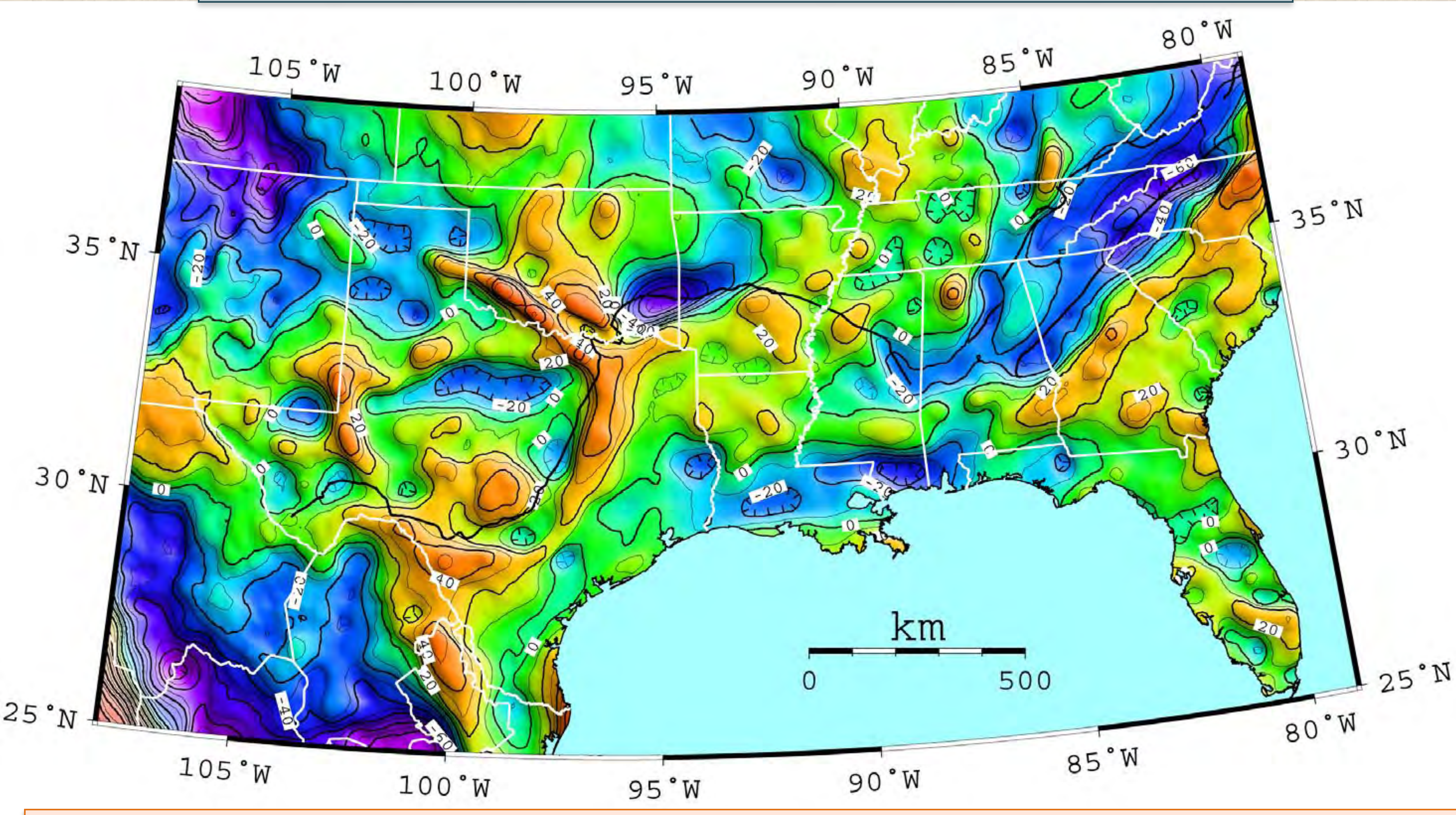
Search Engine

Bouguer gravity anomalies - Ouachita region



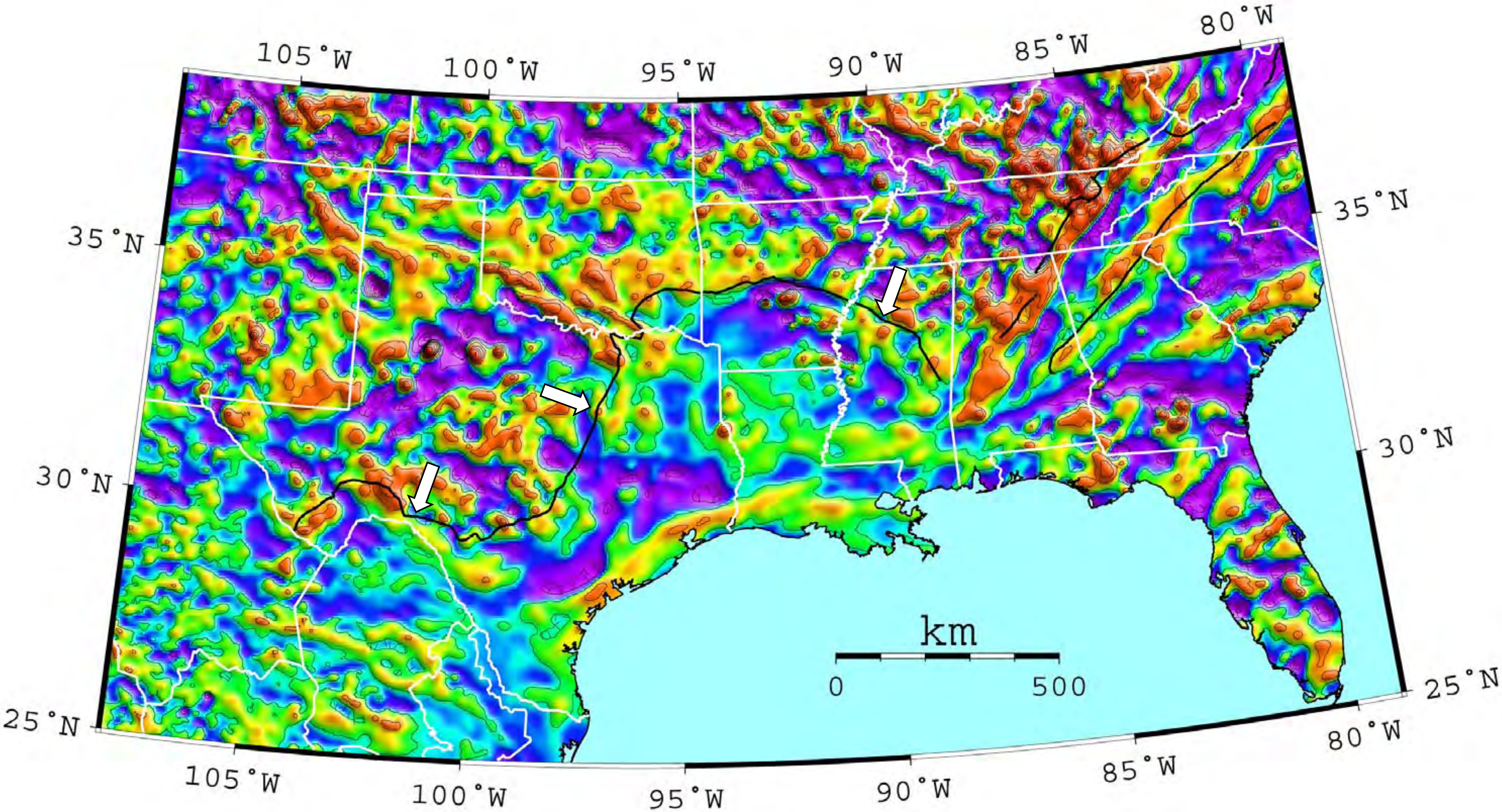
Bouguer gravity anomaly data were gridded and contoured (20 mGal interval). Bolded lines represent the Ouachita-Appalachian frontal thrust fault and the Brevard fault.

Filtered gravity anomalies - Ouachita region



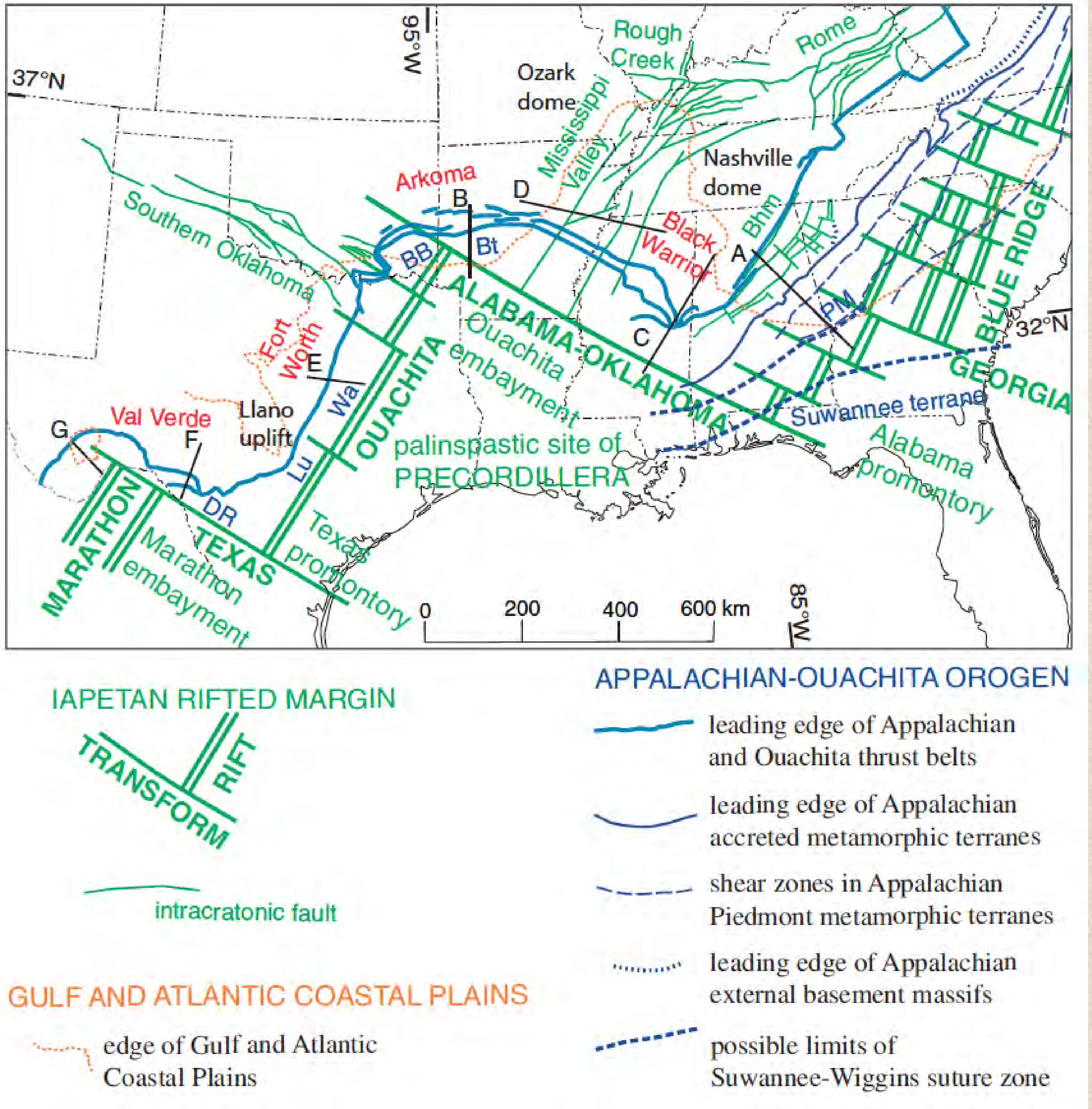
To better represent the gravity anomalies due to lithospheric density contrasts, a band-pass (150 and 15 km) filter was applied to the Bouguer gravity anomaly data. Prominent anomalies include a gravity maximum that roughly follows the Ouachita frontal thrust through Mississippi-Arkansas-Texas, gravity minima are associated with the foreland basins, the Wiggins Terrane (southern MS) and the Sabine Uplift, and gravity maxima associated with the Llano Uplift, and the southern Oklahoma aulacogen.

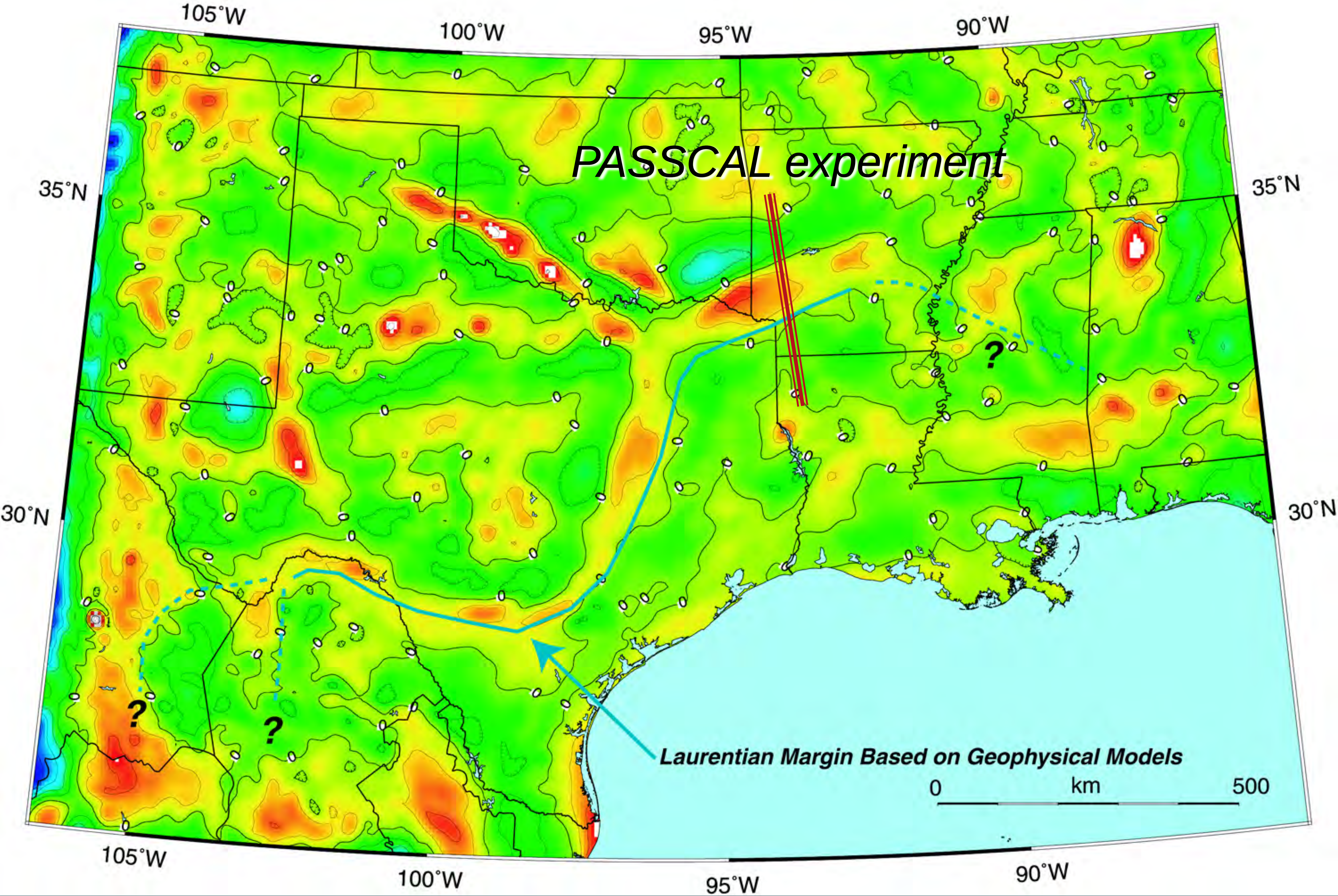
Aeromagnetic anomalies - Ouachita region



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 and Alabama suggest the presence of additional mafic intrusions.

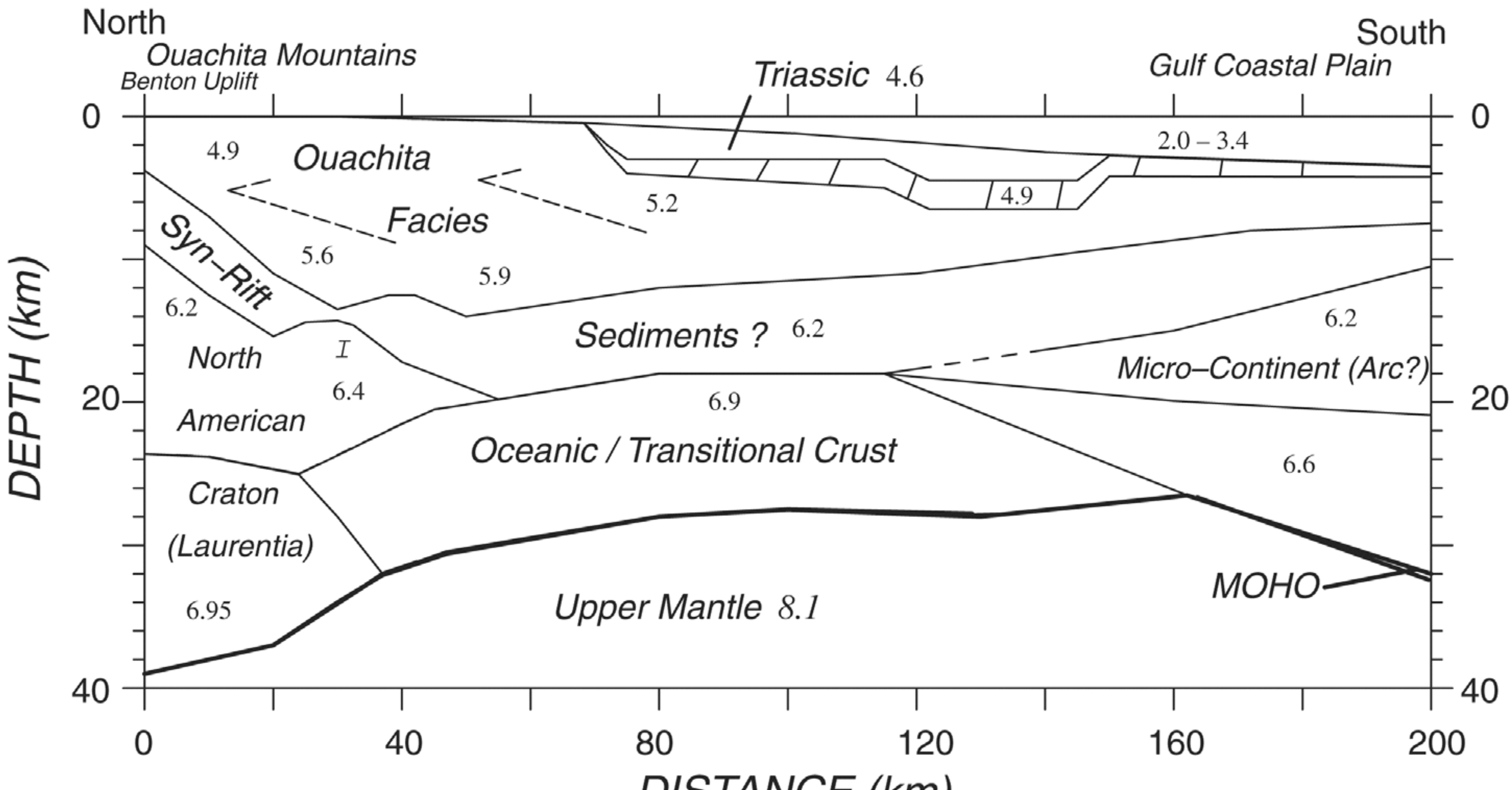
W. A. Thomas has long argued (1976-2011) that transform faults played a major role in the development of the Ouachita Orogenic Belt. However, we will see that the deep structure along the rifted margin is broadly similar from place to place.





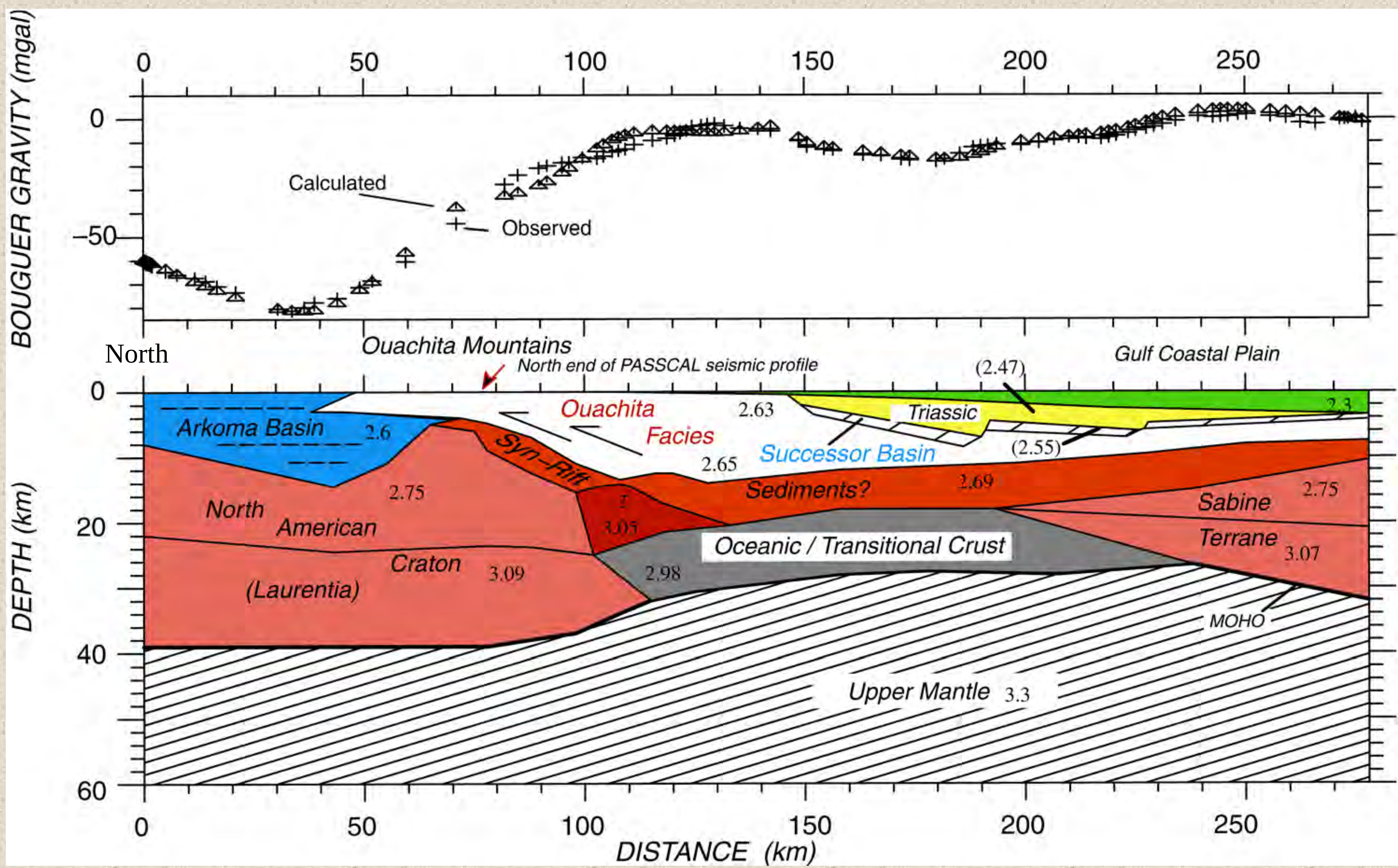
Regional Gravity Anomalies and PASSCAL Experiment Location

PASSCAL Experiment Seismic Model

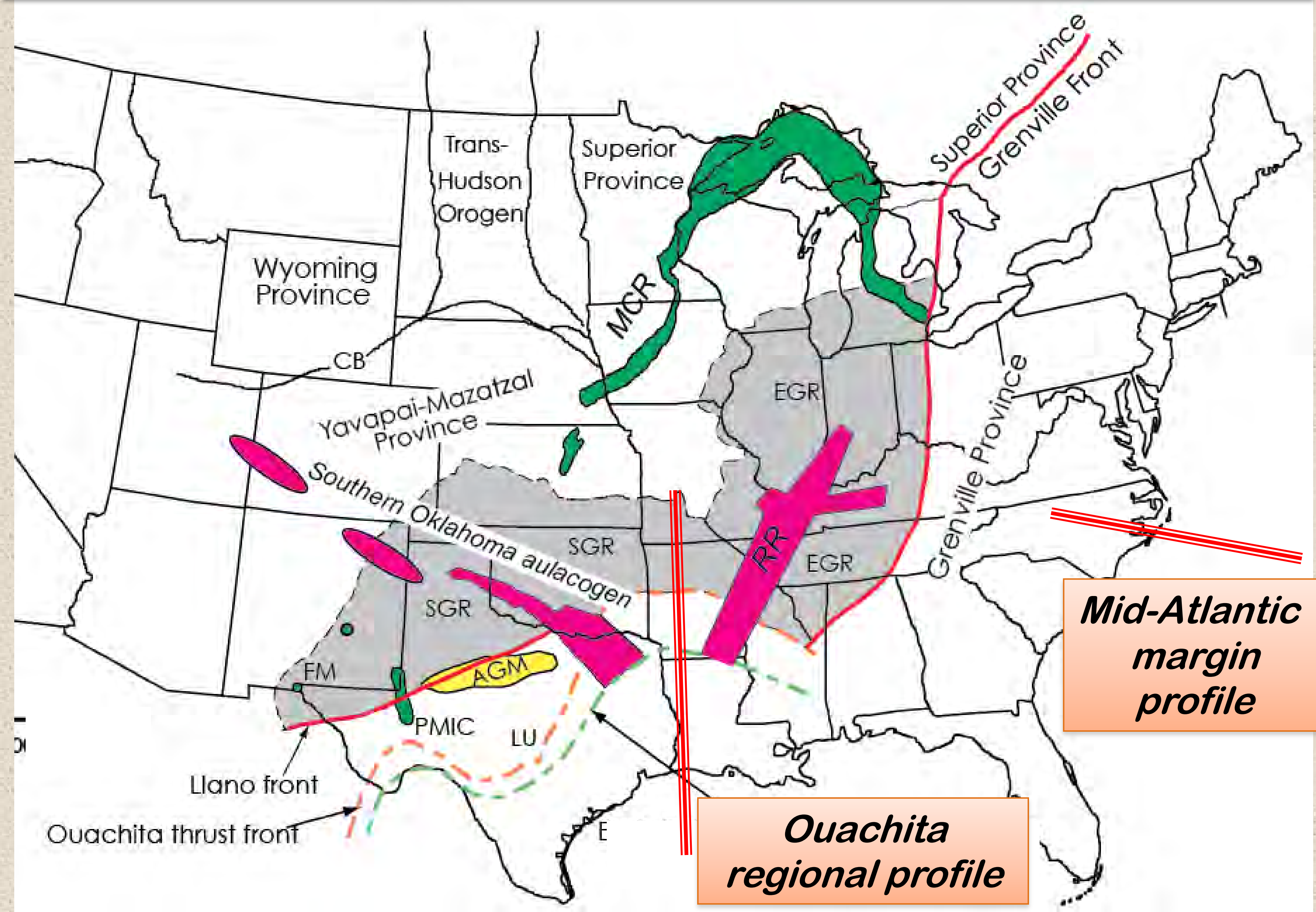


Modified from Keller and Hatcher (1999)

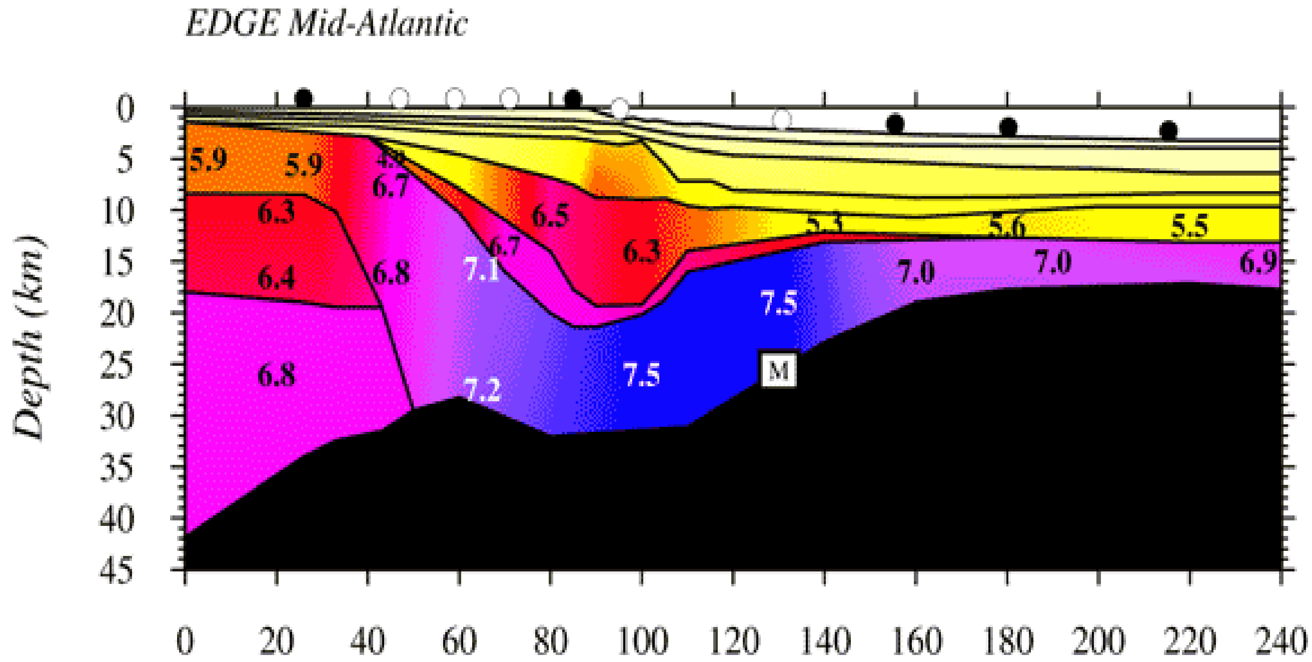
PASSCAL Experiment Integrated Model
The Cambrian Margin is largely intact

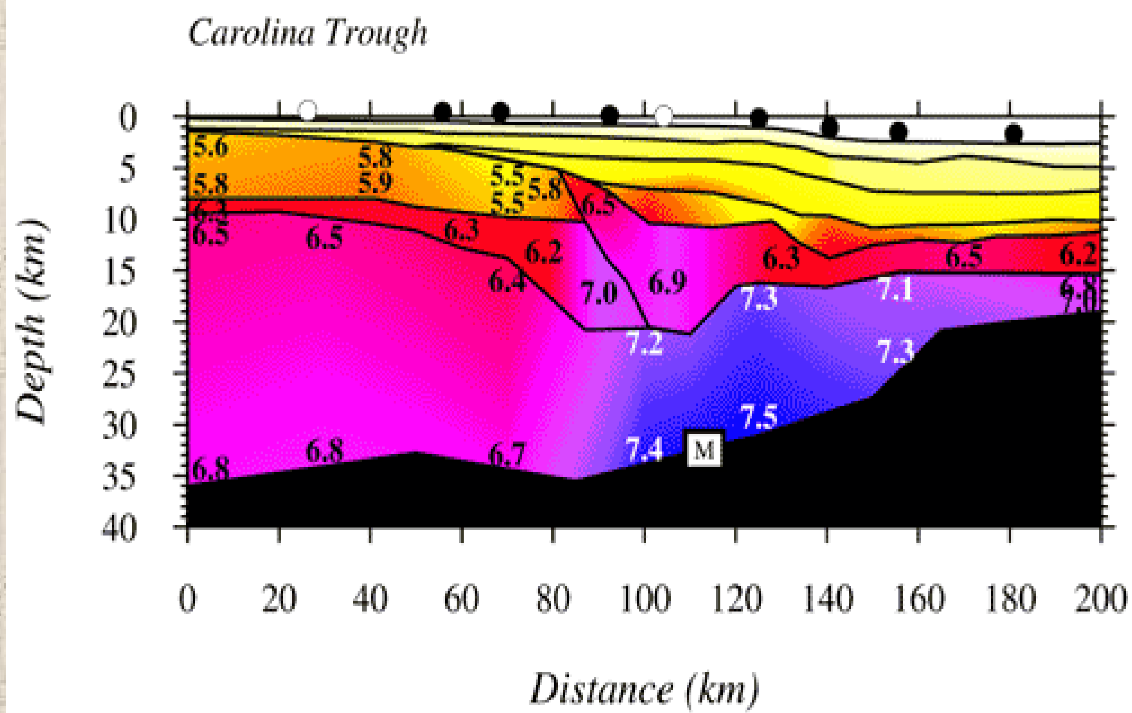


The modern passive margin of Laurentia, an analogy



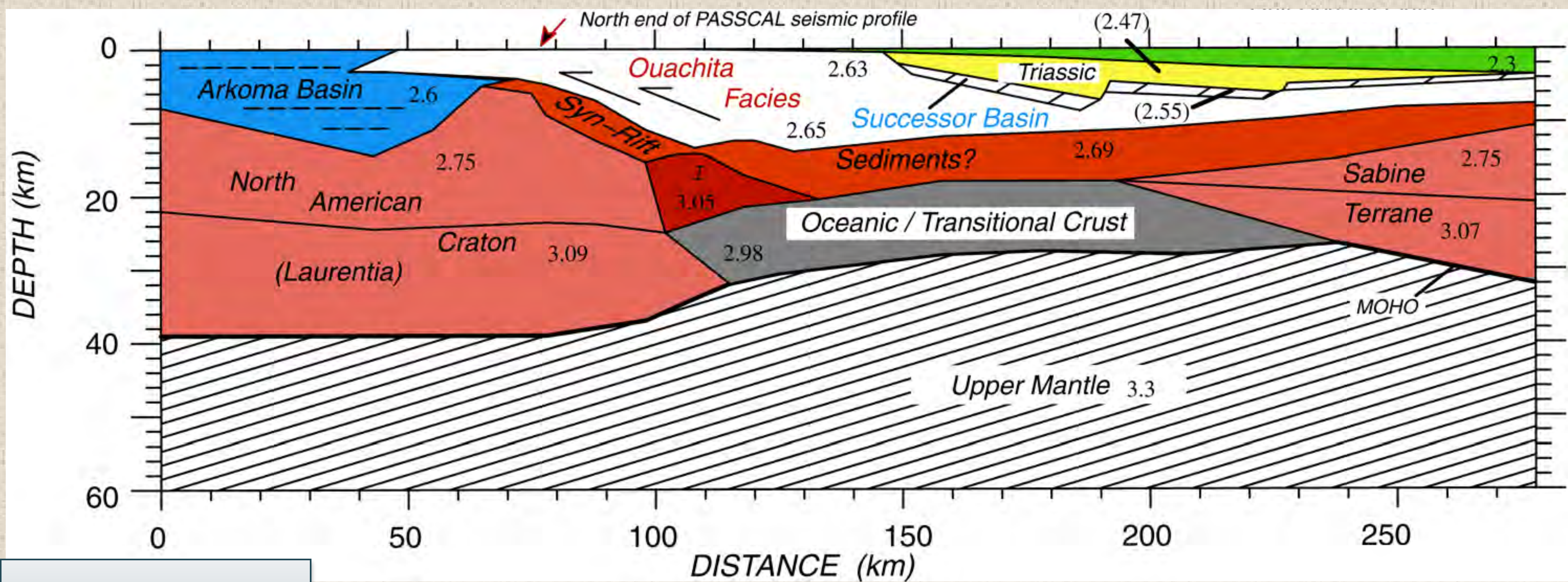
Seismic Models of the Modern Passive Margin of Laurentia



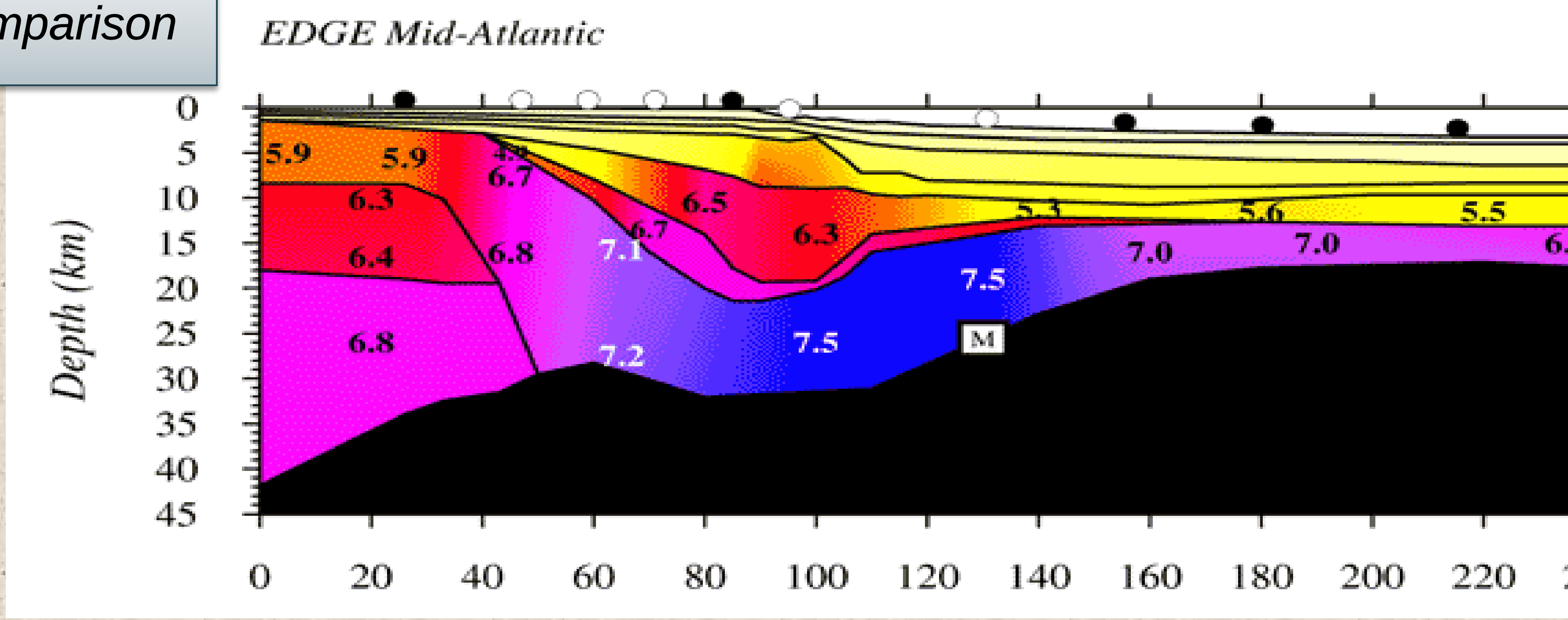


U.S. Mid-Atlantic Margin

(Provided by Steve Holbrook- Univ. of Wyoming)


North end of PASSCAL seismic profile
(2.47)
Arkoma Basin
2.6
Ouachita
Facies
2.63
Triassic
2.3
Syn-Rift
2.65
Successor Basin
(2.55)
2.75
North
American
Craton
(Laurentia)
3.09
3.05
Sediments?
2.69
Sabine
Terrane
2.75
3.07
Oceanic / Transitional Crust
2.98
MOHO
Upper Mantle 3.3
DEPTH (km)
DISTANCE (km)
0
20
40
60
0
50
100
150
200
250

Comparison


EDGE Mid-Atlantic
Depth (km)
0
5
10
15
20
25
30
35
40
45
5.9
5.9
6.7
6.3
6.4
6.8
6.8
7.1
7.2
6.7
6.5
6.3
7.5
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M
5.3
5.6
5.5
7.0
7.0
0
20
40
60
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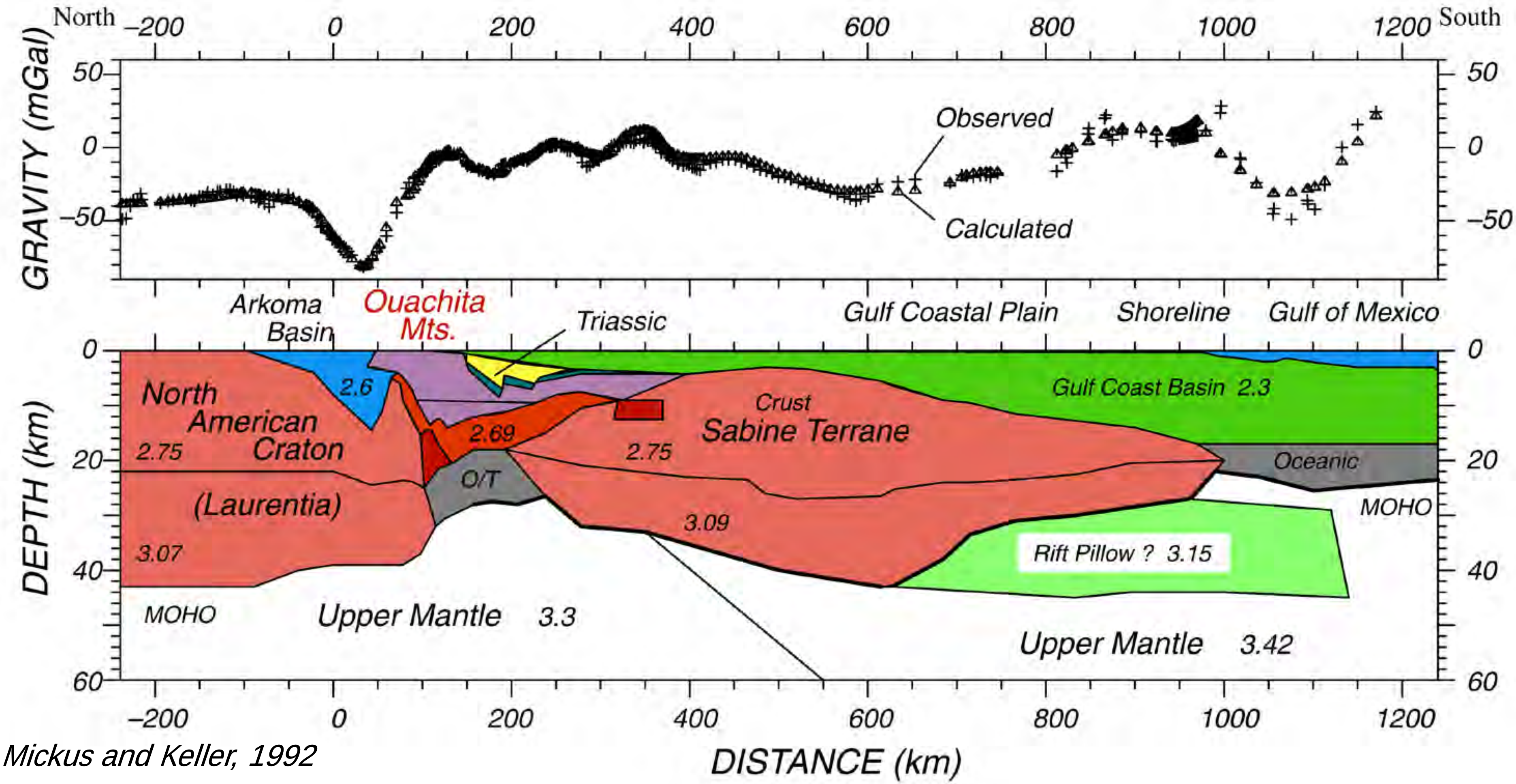
120
140
160
180
200
220

Craton to Gulf of Mexico Lithospheric Model

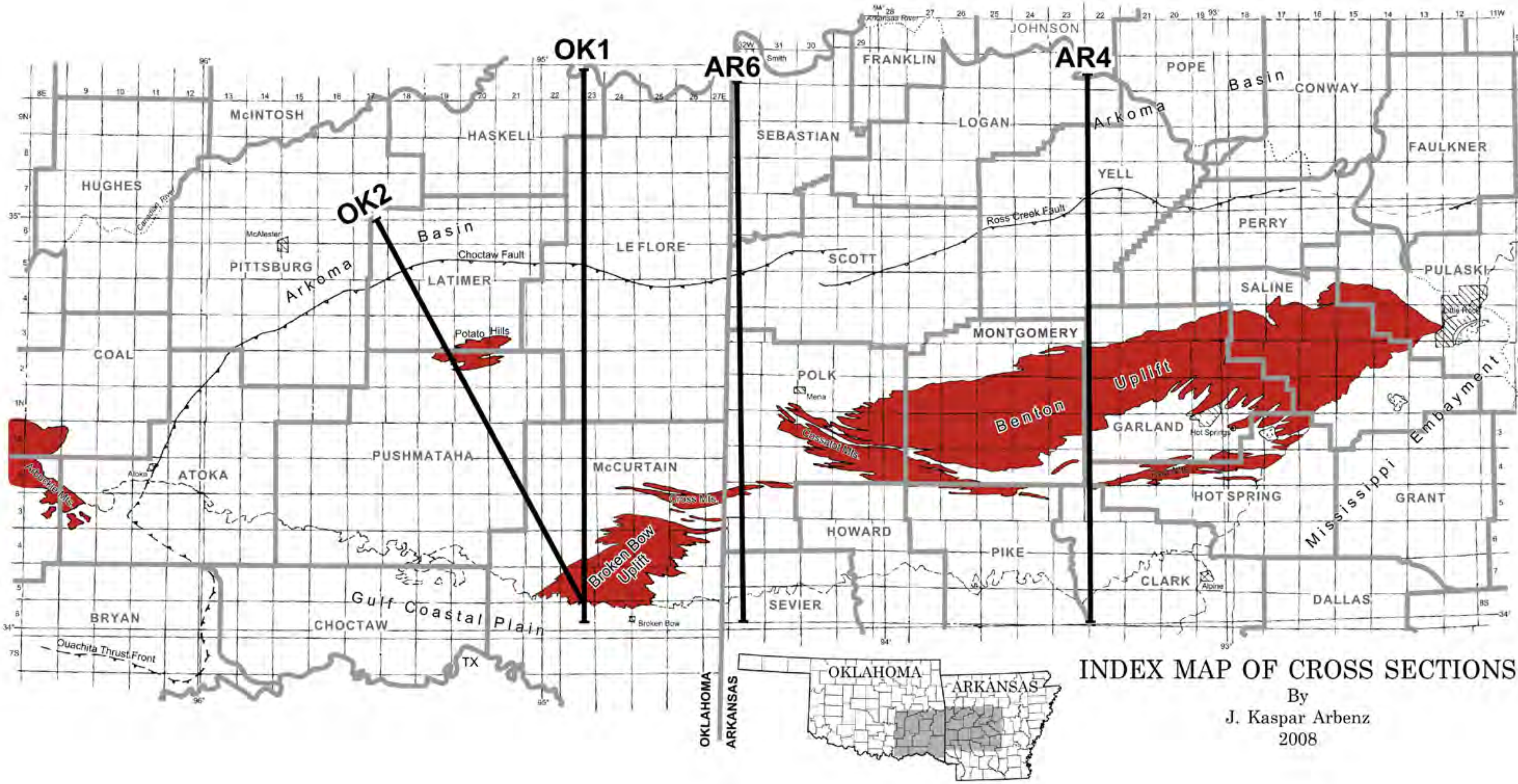
The Sabine Terrane may or may not be a piece of Laurentia

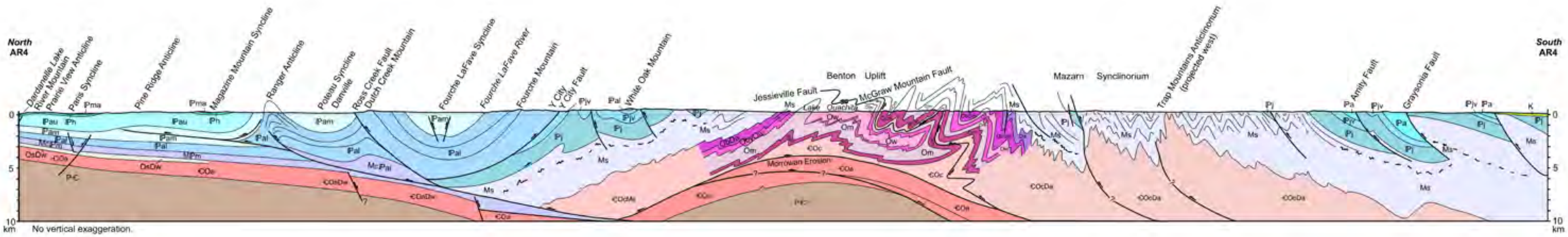


Mickus and Keller, 1992

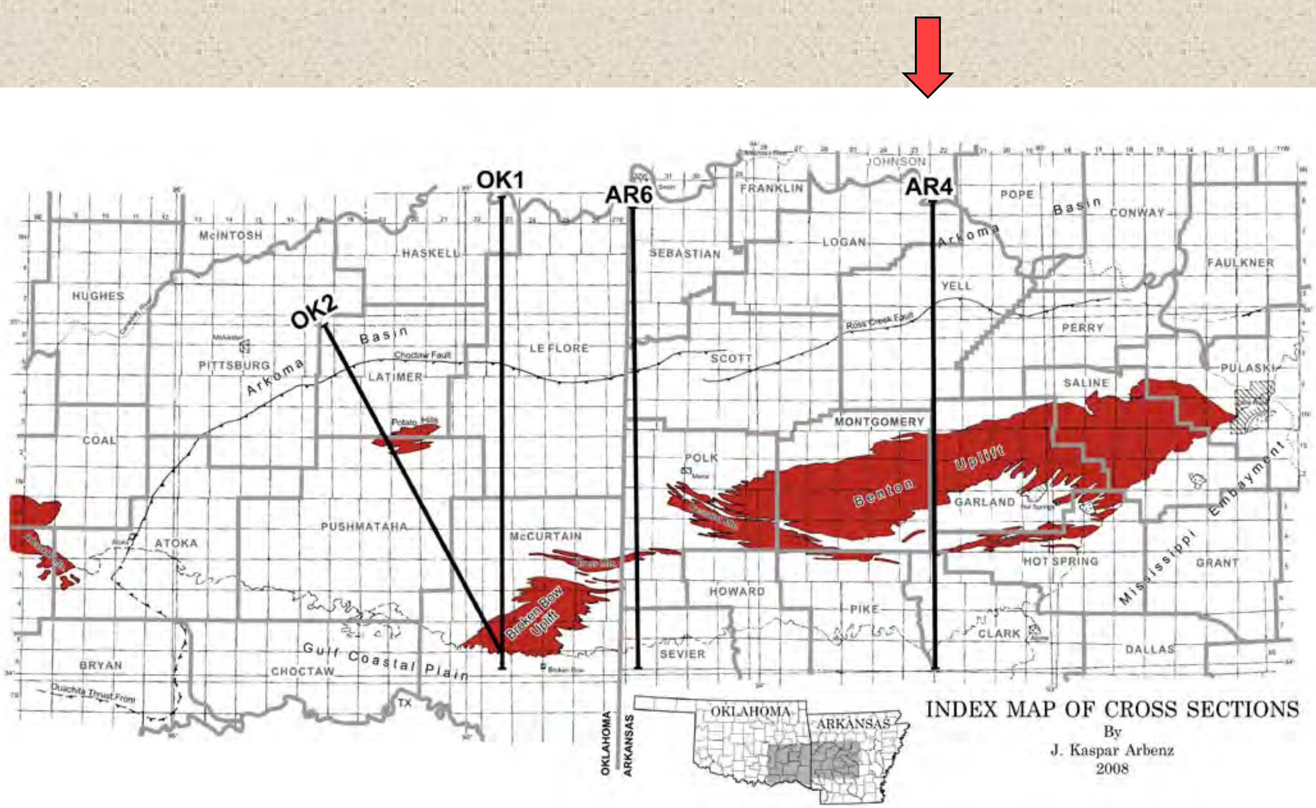
These images shows that the Ouachita orogeny involved a "soft collision" that preserved the Paleozoic margin strata. Are these strata all cooked?

Index map of cross-sections from Arbenz (2008) – OGS Circular 112A

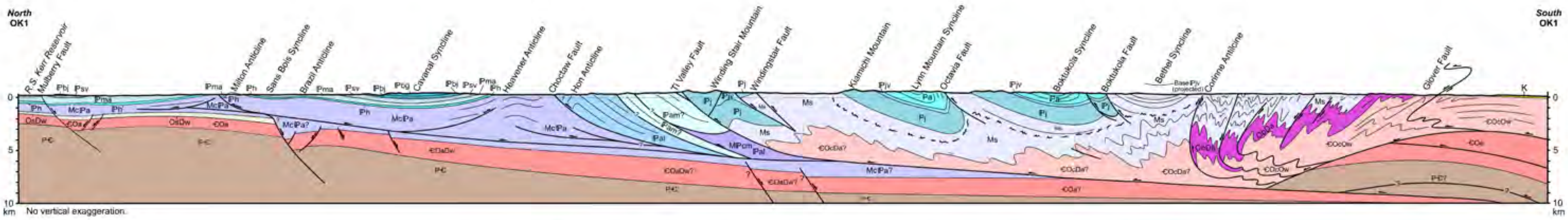




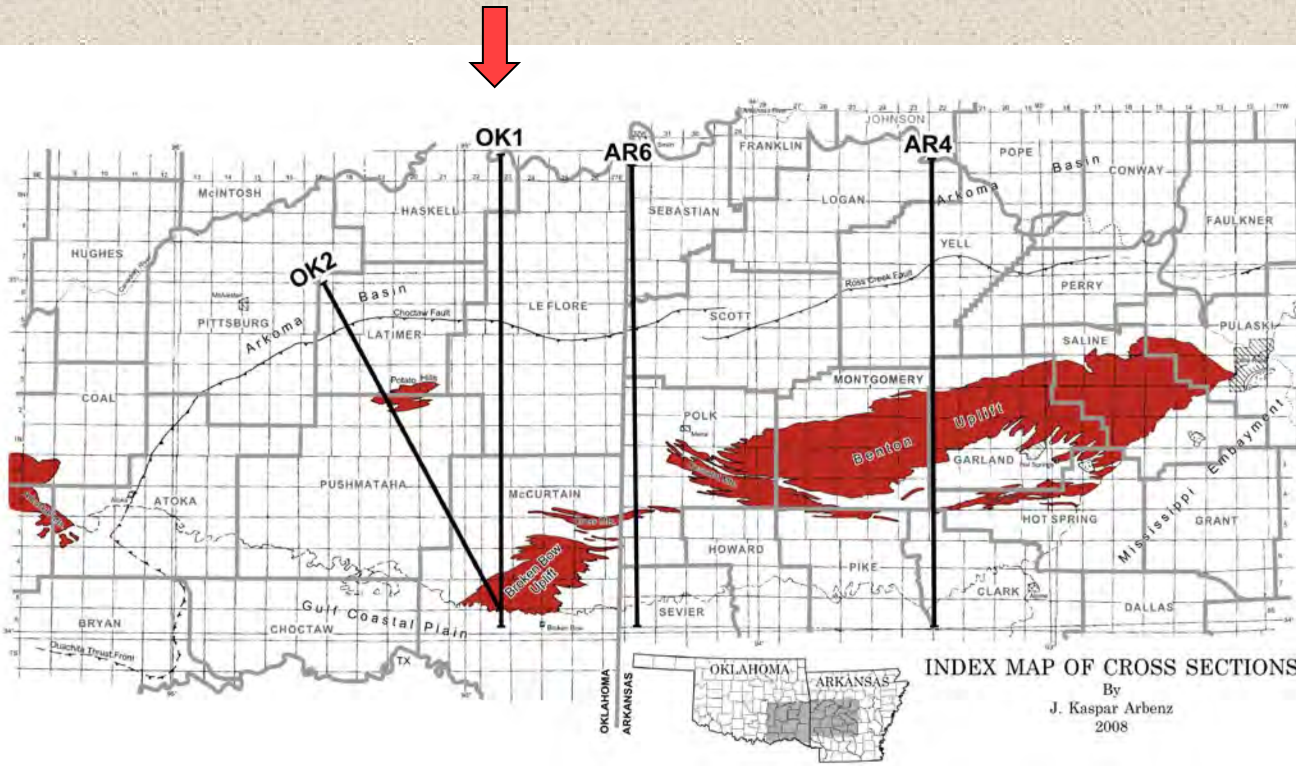
STRUCTURAL CROSS SECTION AR4 ACROSS THE ARKANSAS OUACHITA MOUNTAINS
By
J. Kaspar Arbenz
2008



INDEX MAP OF CROSS SECTIONS
By
J. Kaspar Arbenz
2008



STRUCTURAL CROSS SECTION OK1 ACROSS THE OKLAHOMA OUACHITA MOUNTAINS
By
J. Kaspar Arbenz
2008

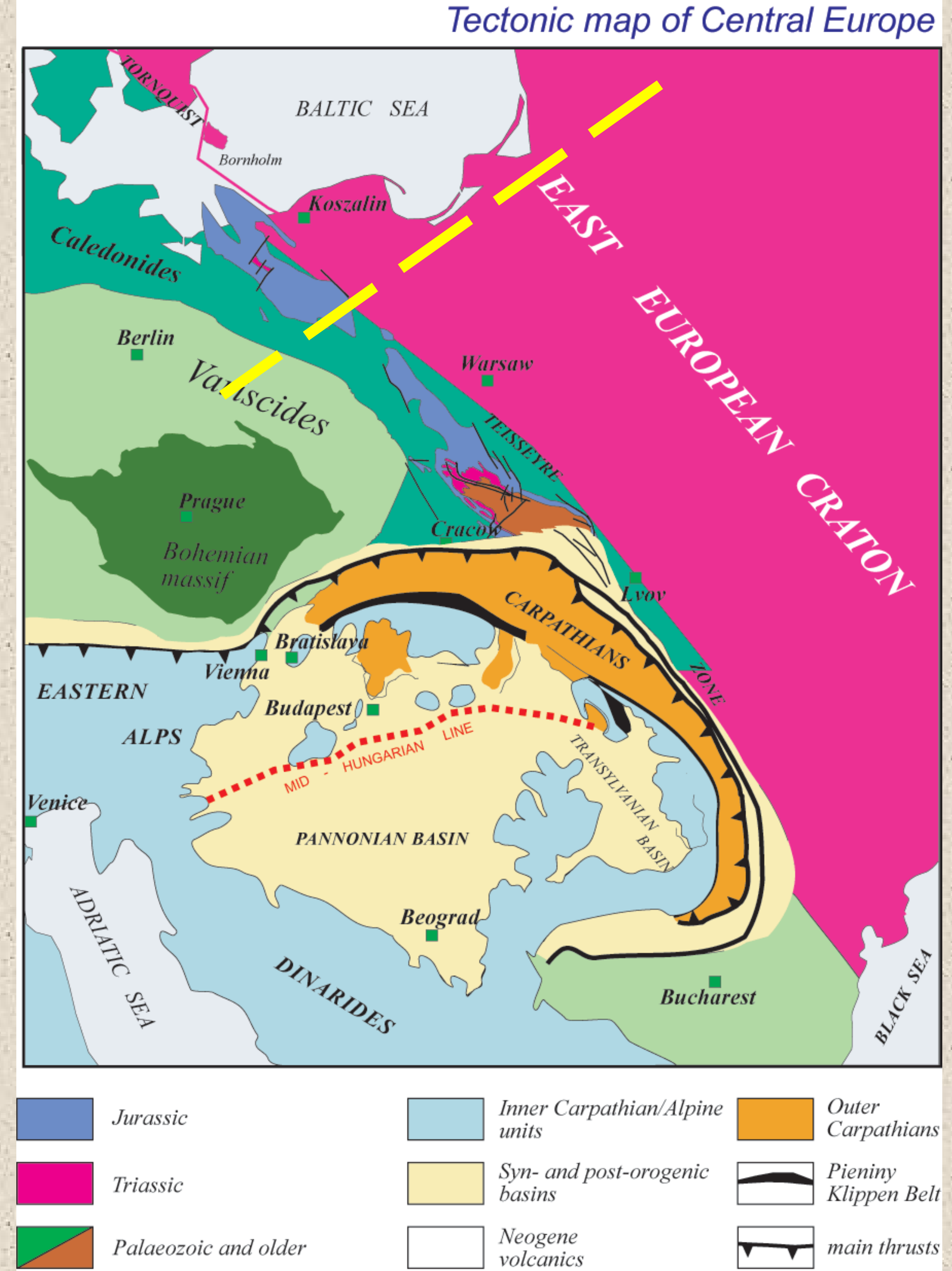


INDEX MAP OF CROSS SECTIONS
By
J. Kaspar Arbenz
2008

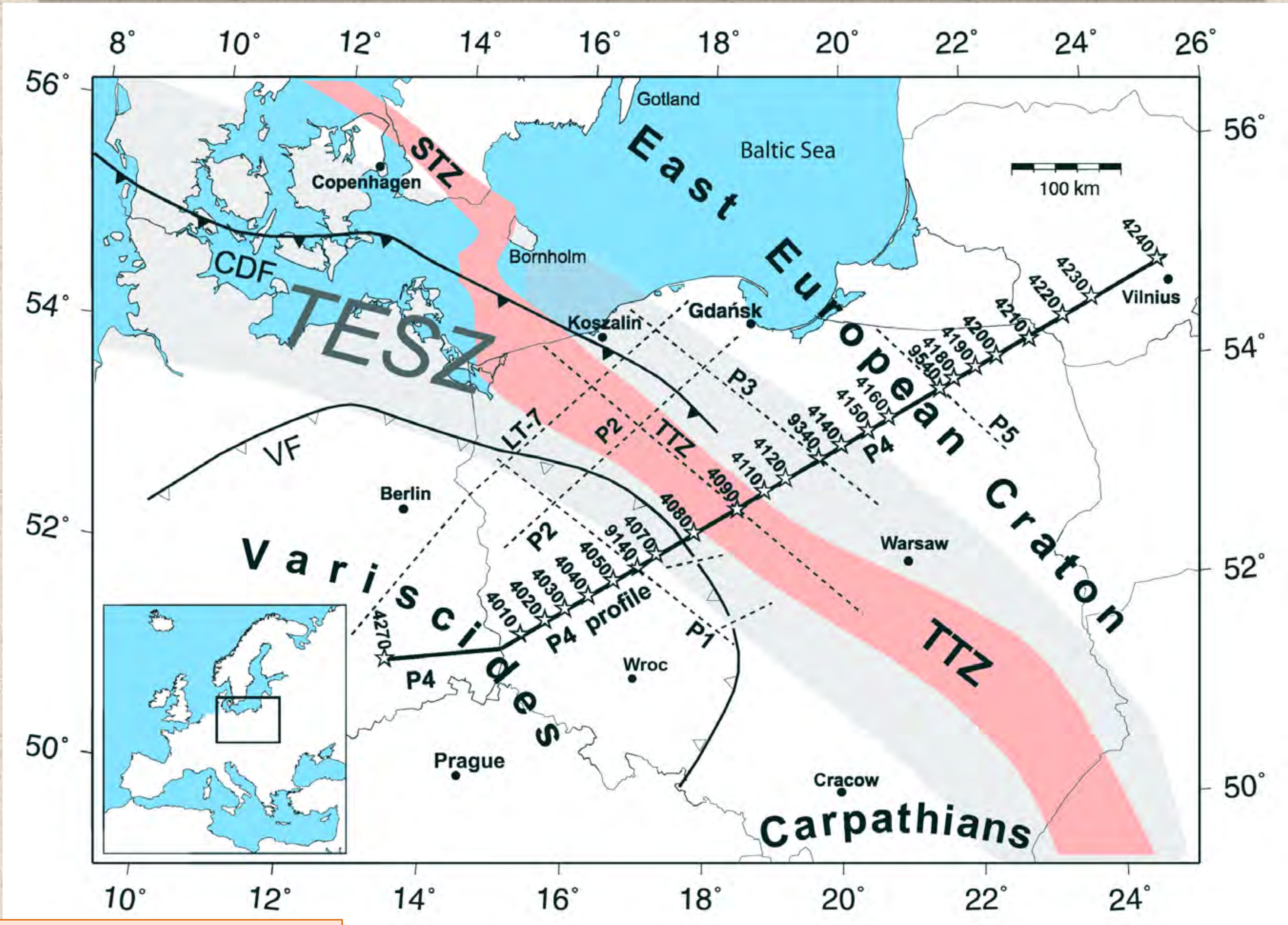
An European analogy

The Trans-European suture zone and Polish basin

Modified from Guterch, Grad, and Keller (2007)



POLONAISE' 97 Profile P4

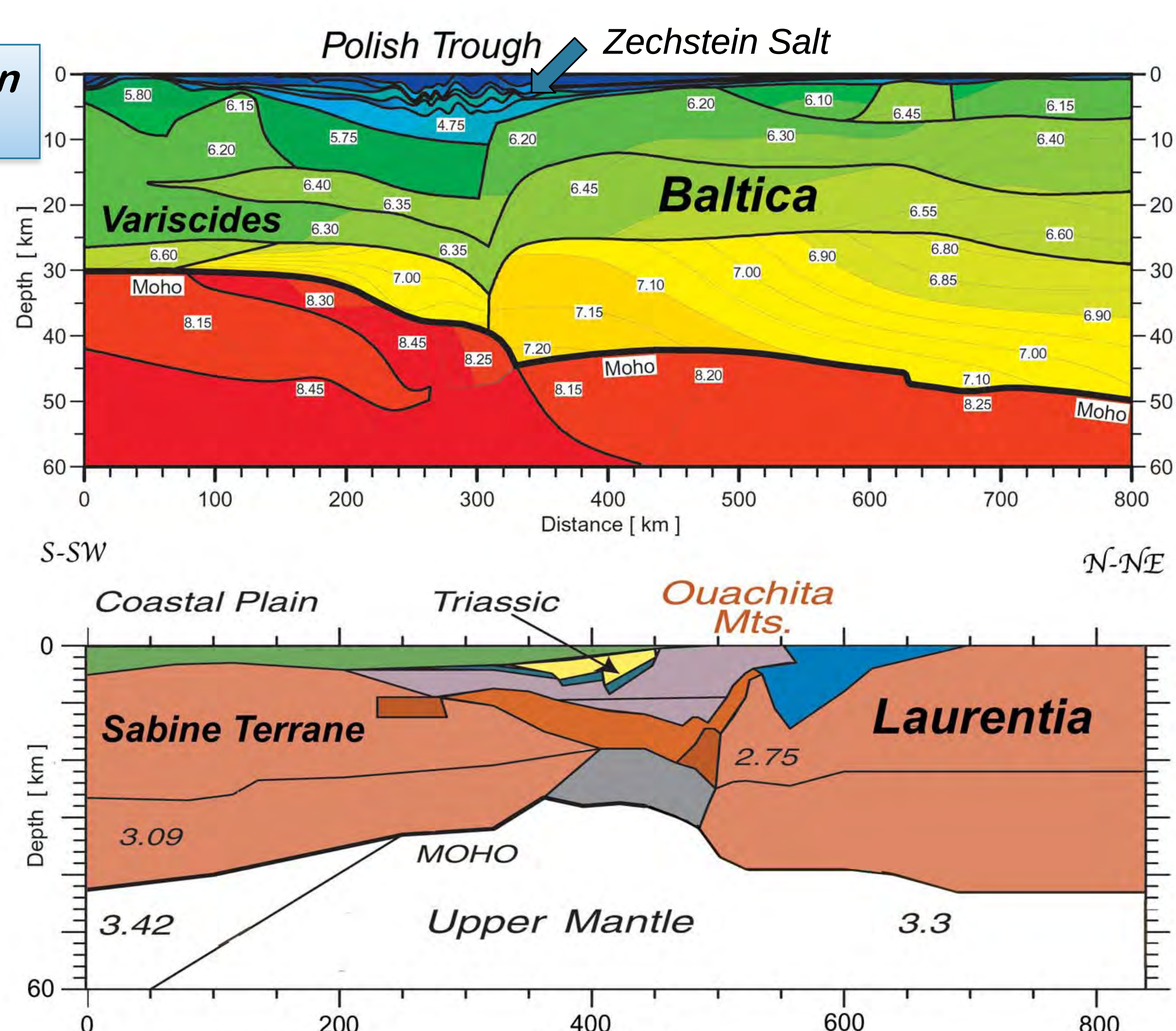


Grad et al. (2003)

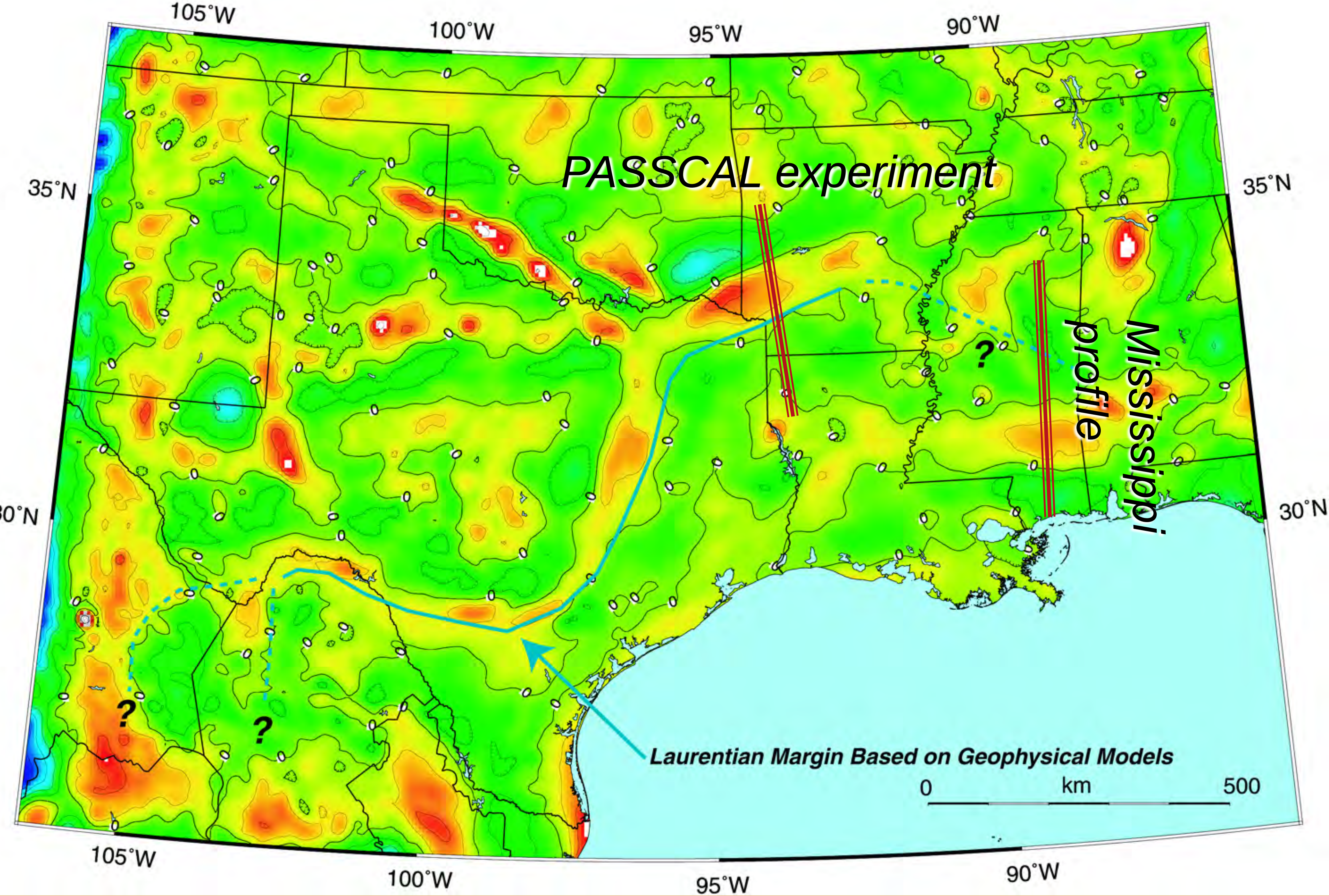
Baltican and Laurentian Margins Compared

Bohemian Massif

There are many geological similarities between the Ouachita and Variscan Orogenies, and now shale gas has been discovered in Poland.

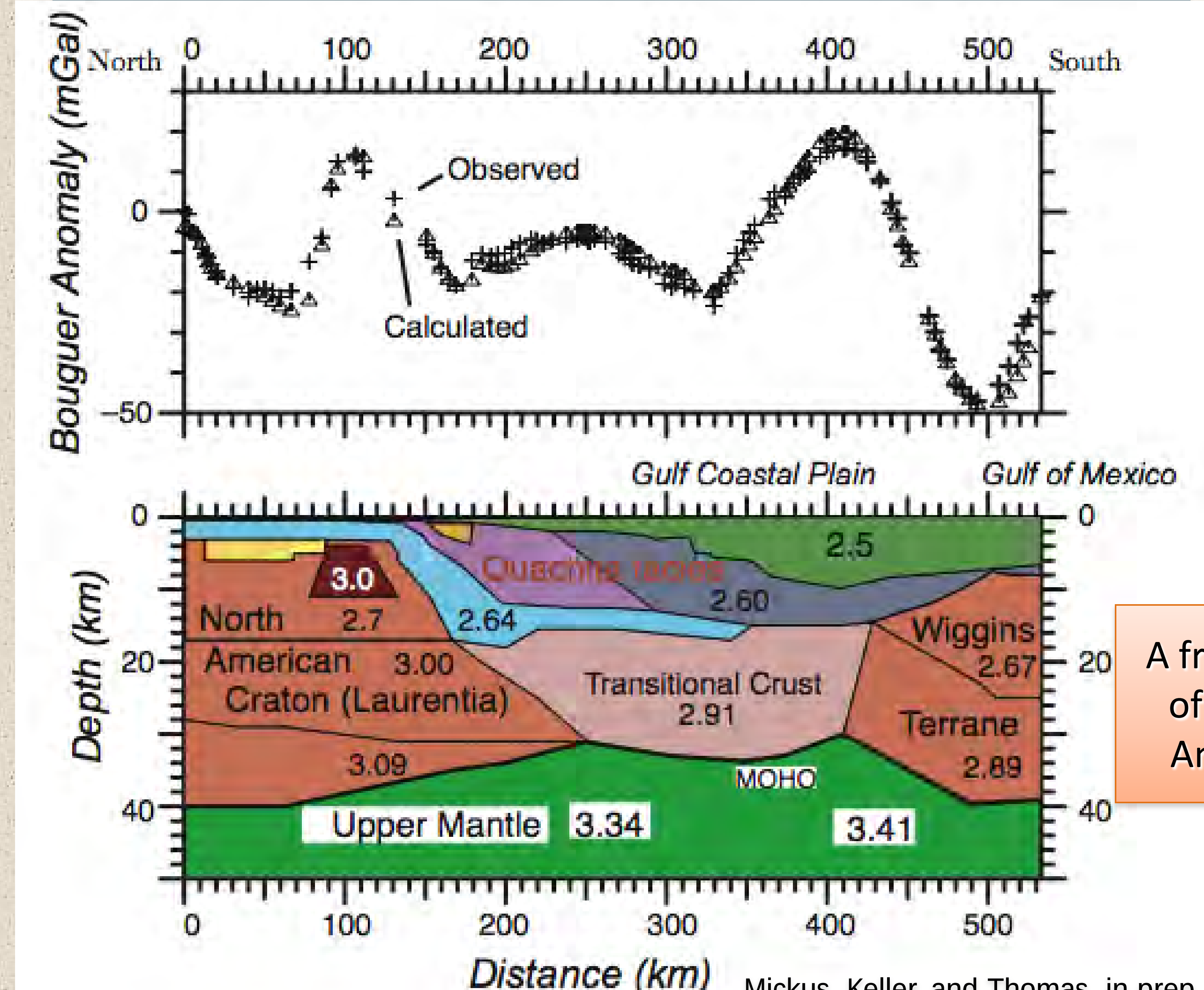


Keller (2009)



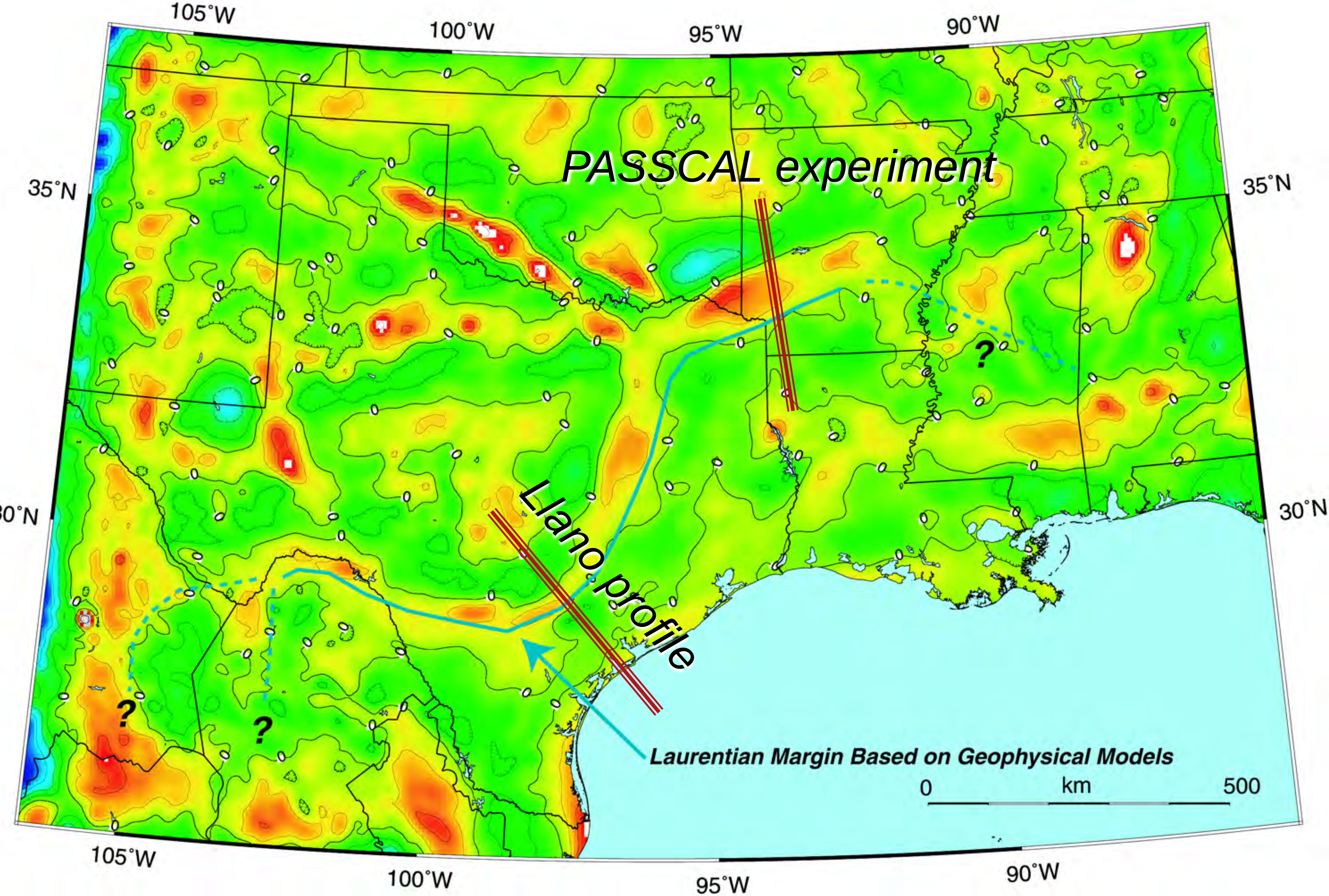
What about variations along the Ouachita orogenic belt?

Integrated model for the Mississippi profile



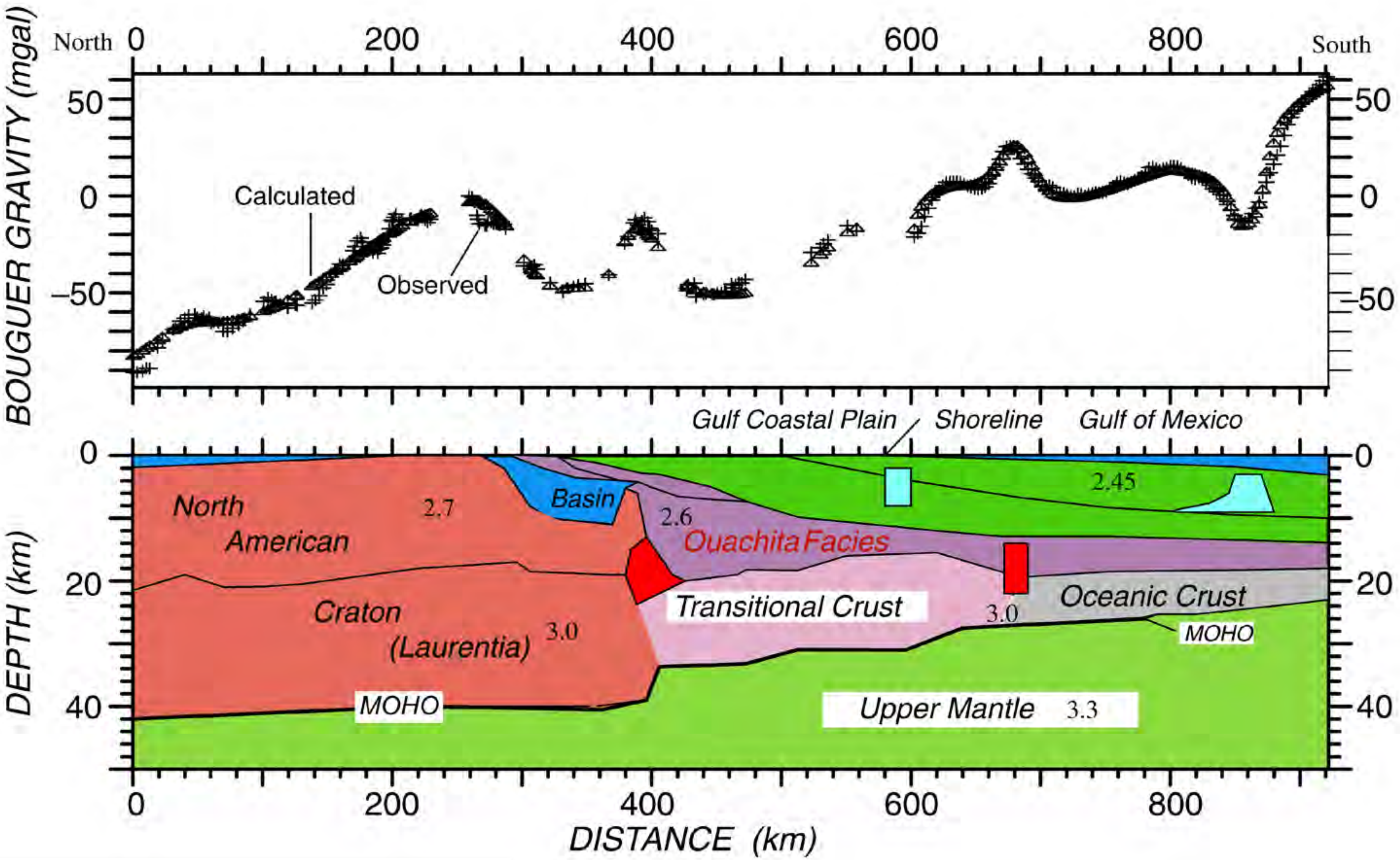
A fragment of North America

Mickus, Keller, and Thomas, in prep.



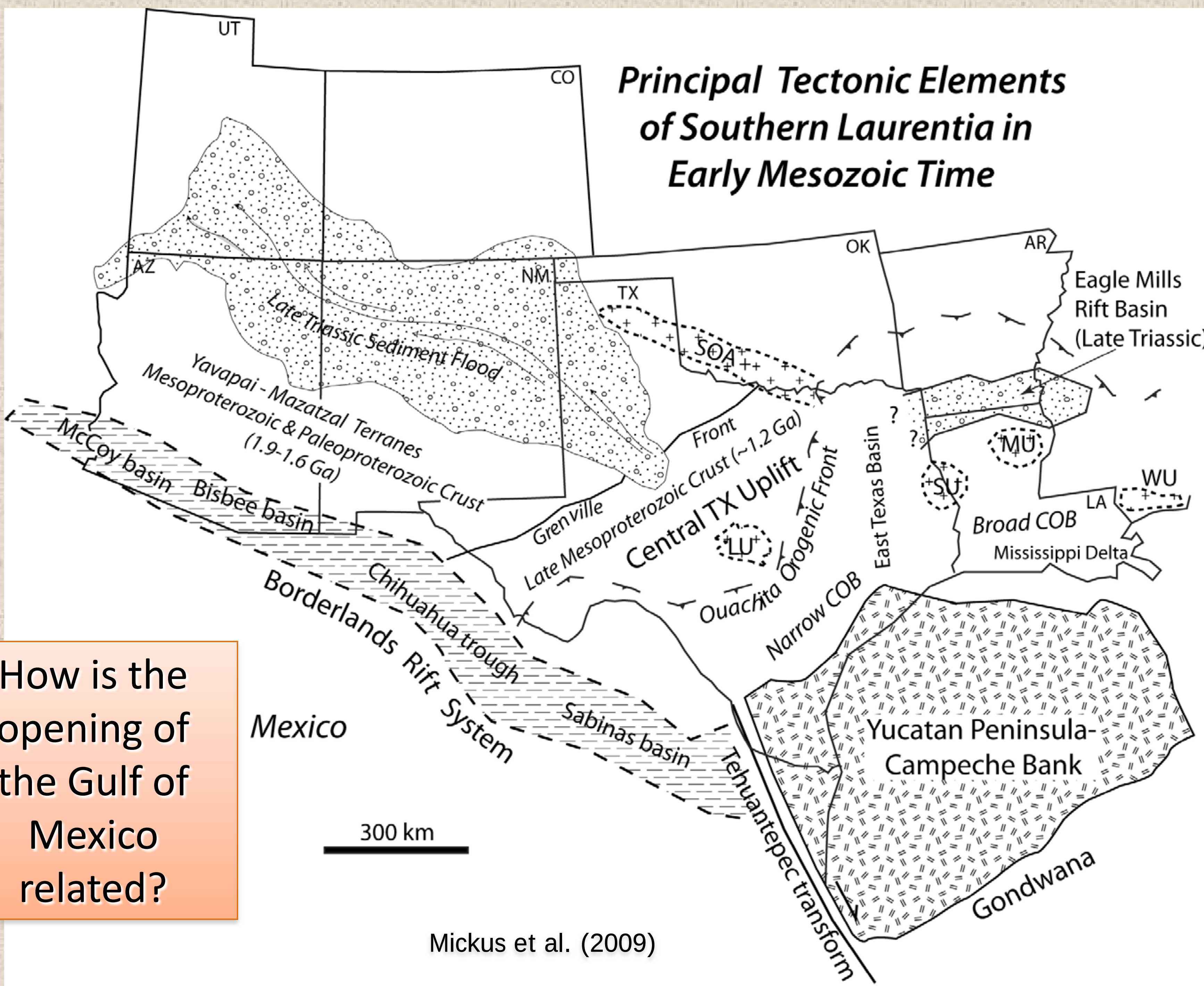
What about more variations along the Ouachita orogenic belt?

Integrated Model for the Llano Profile



Mickus, Keller, and Thomas, in prep.

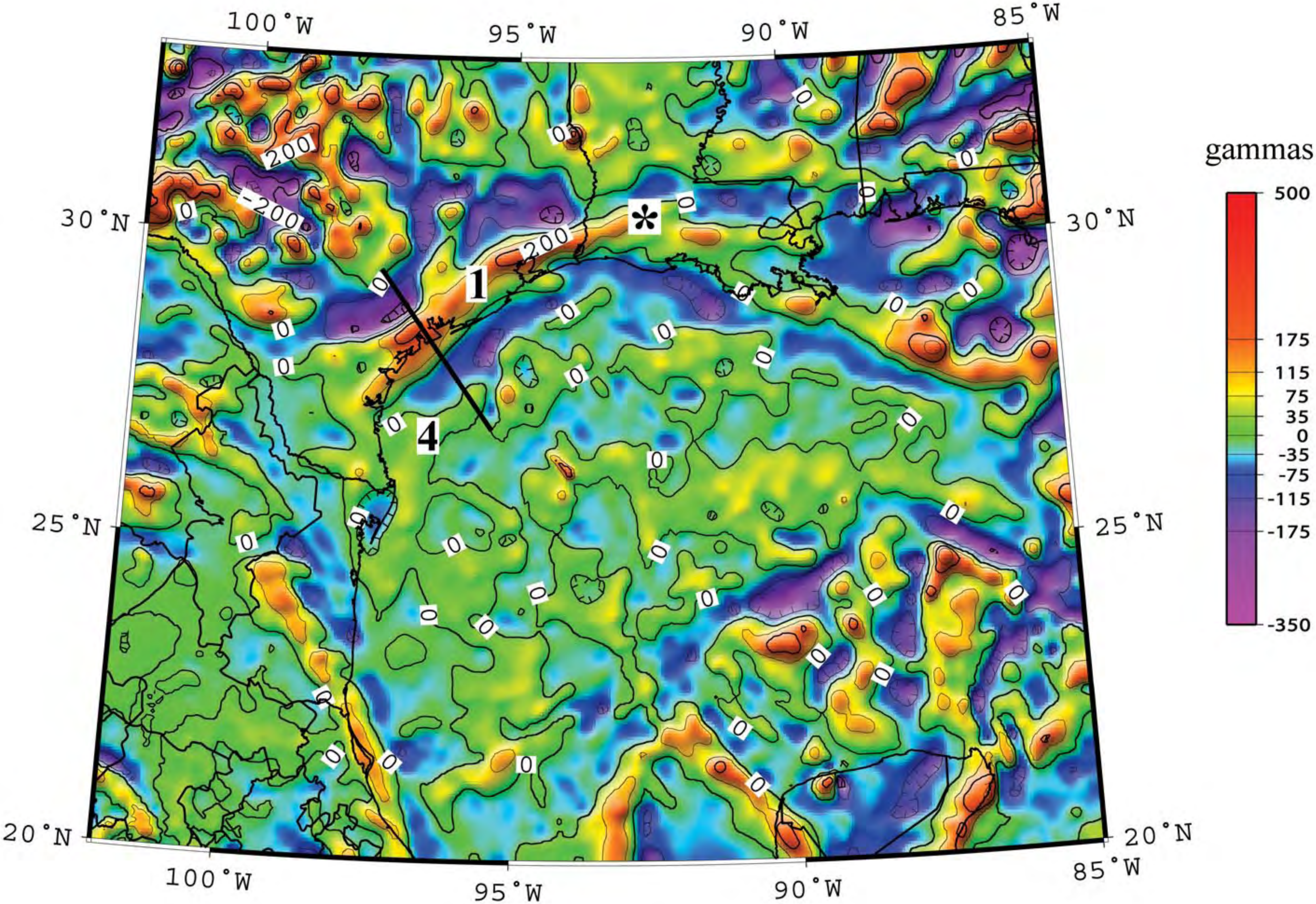
Yucatan



How is the opening of the Gulf of Mexico related?

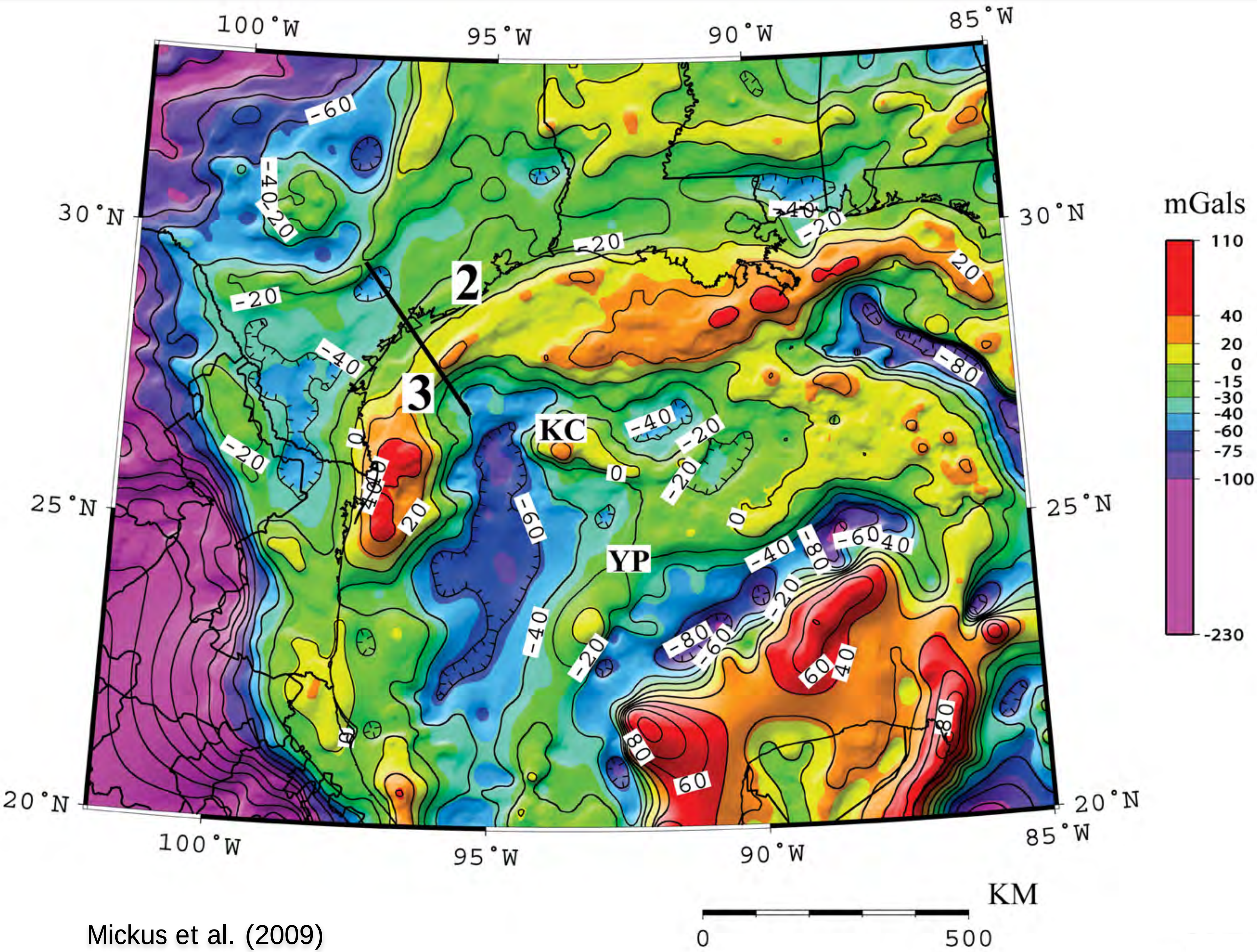
Mickus et al. (2009)

The prominent magnetic anomaly along the Gulf Coast has long been a puzzle, and ….

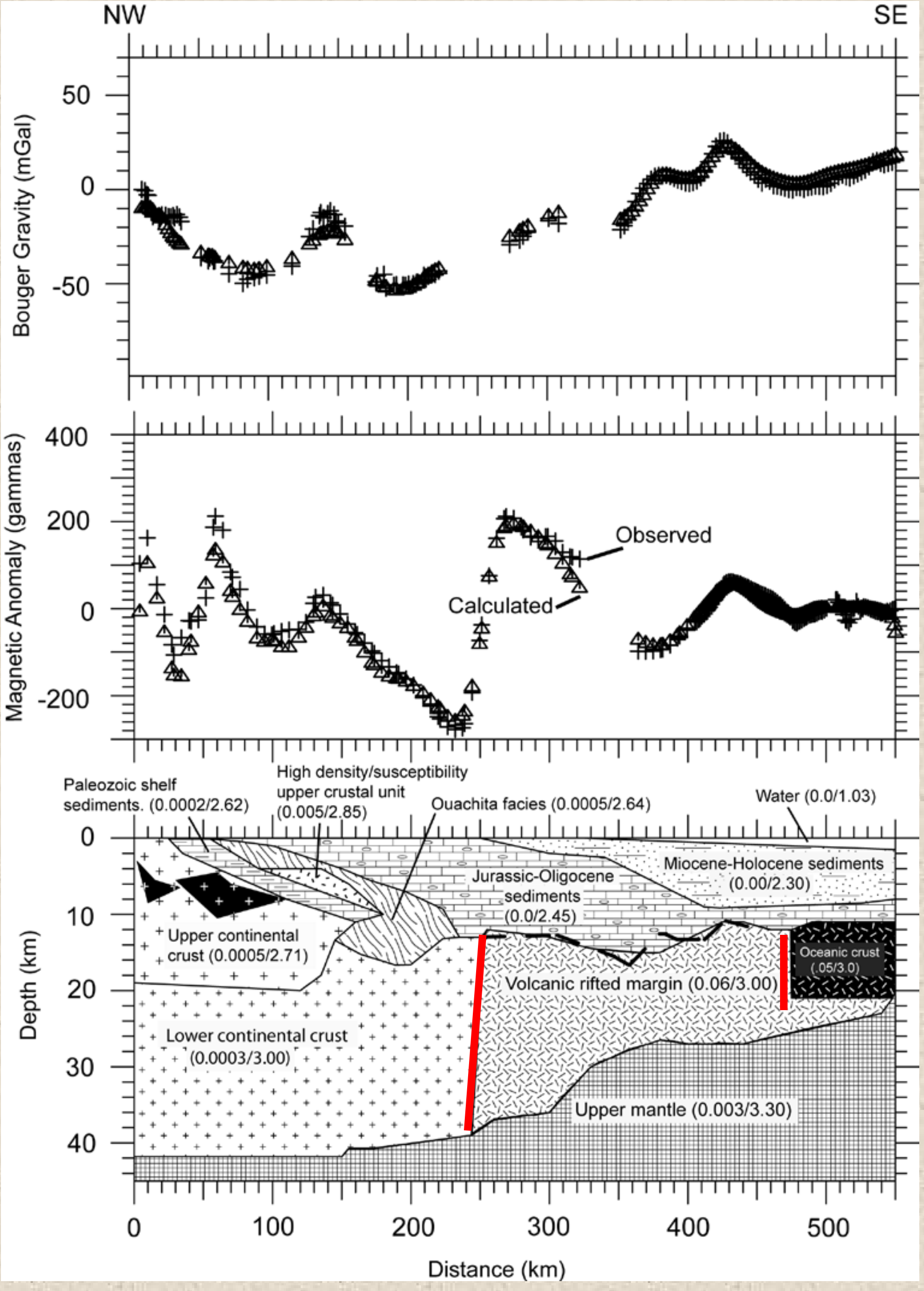


Mickus et al. (2009)

and the gravity anomaly along the coast is well offshore from the magnetic anomaly!



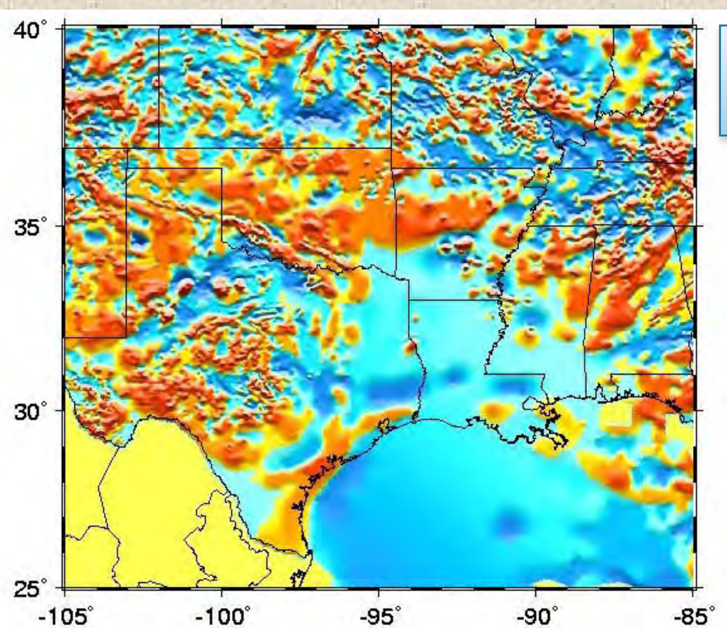
Mickus et al. (2009)



The answer to this riddle is that the Triassic rifting which originally formed along the Ouachita orogenic belt moved outboard and formed a volcanic margin whose magnetic signature is far more prominent than it gravity signature.

Mickus et al. (2009)

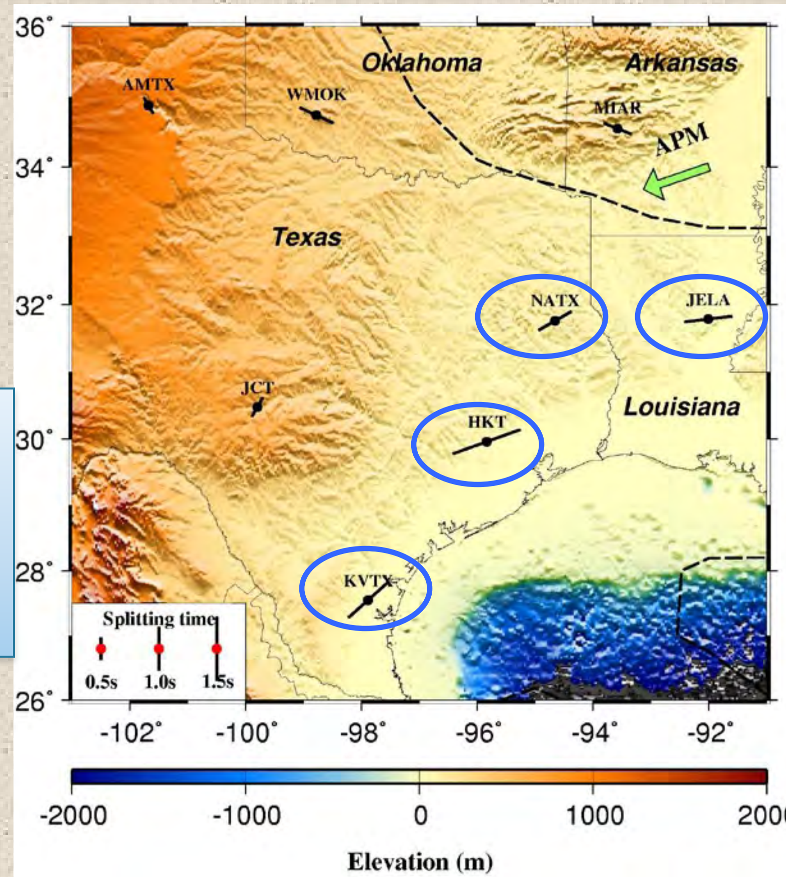
Possible causes of anisotropy in transitional crust: lithospheric dikes?

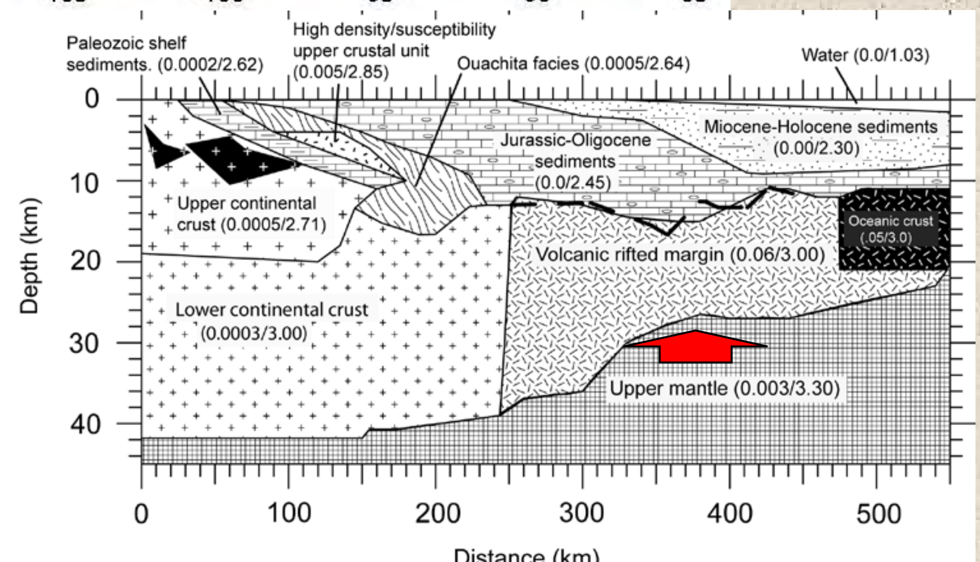


Magnetic anomalies

Shear wave splitting

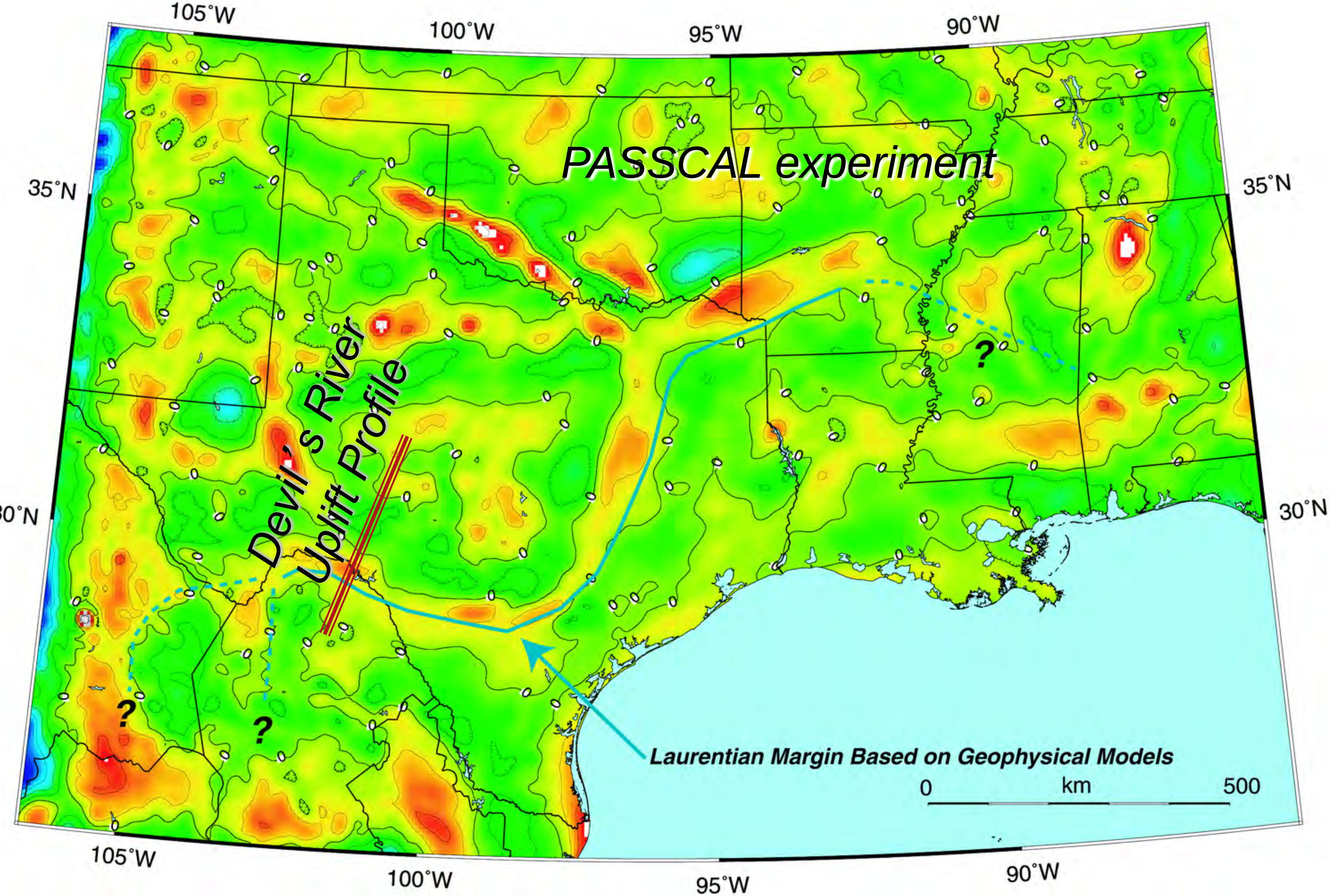
(Gao et al., 2008)





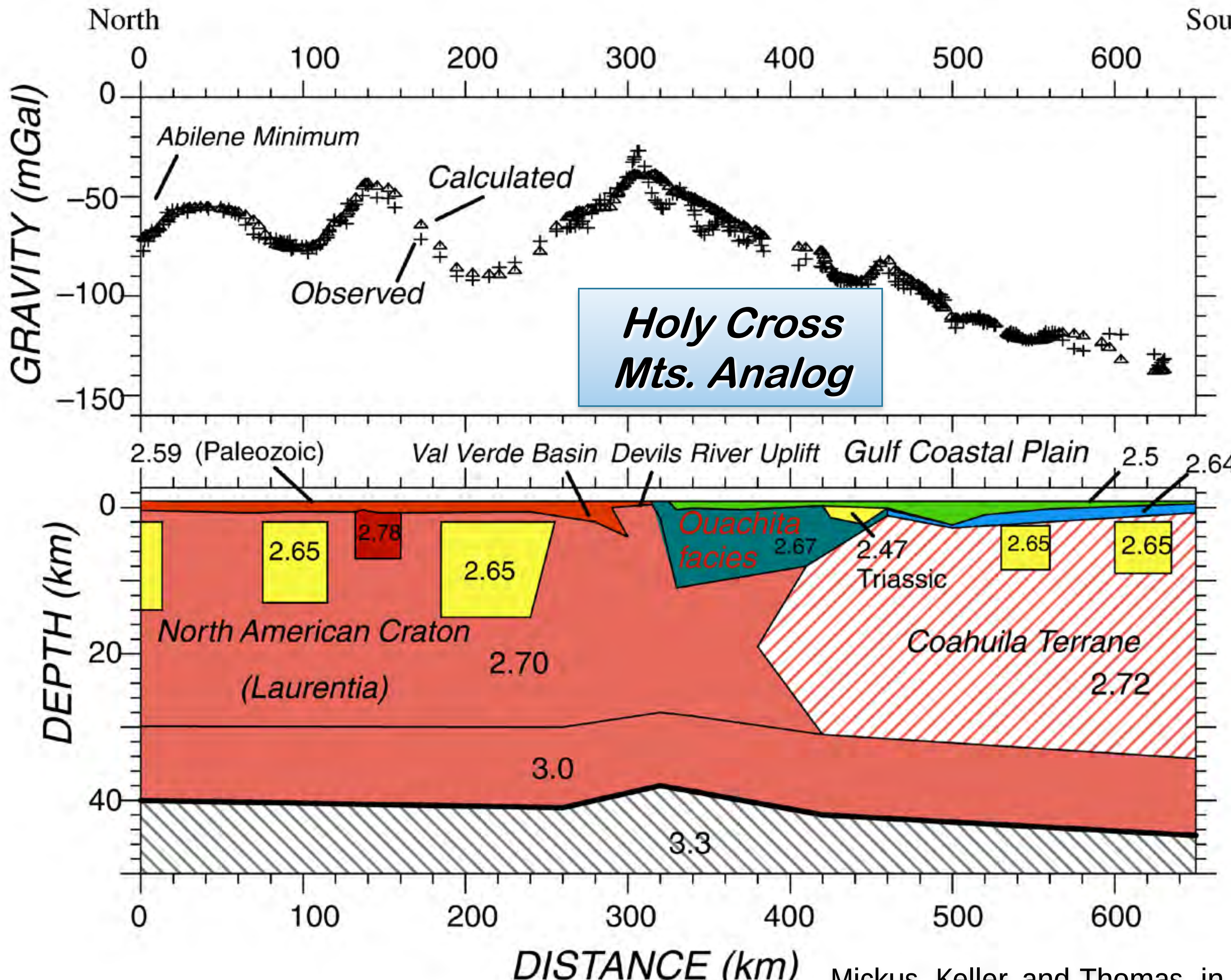
Margin-parallel magnetic high margin-parallel dikes

But this requires a large anisotropy of 6-10% for a 70-km thick lithosphere in order to produce the 0.9-1.7 s splitting



What about the Big Bend region and Mexico?

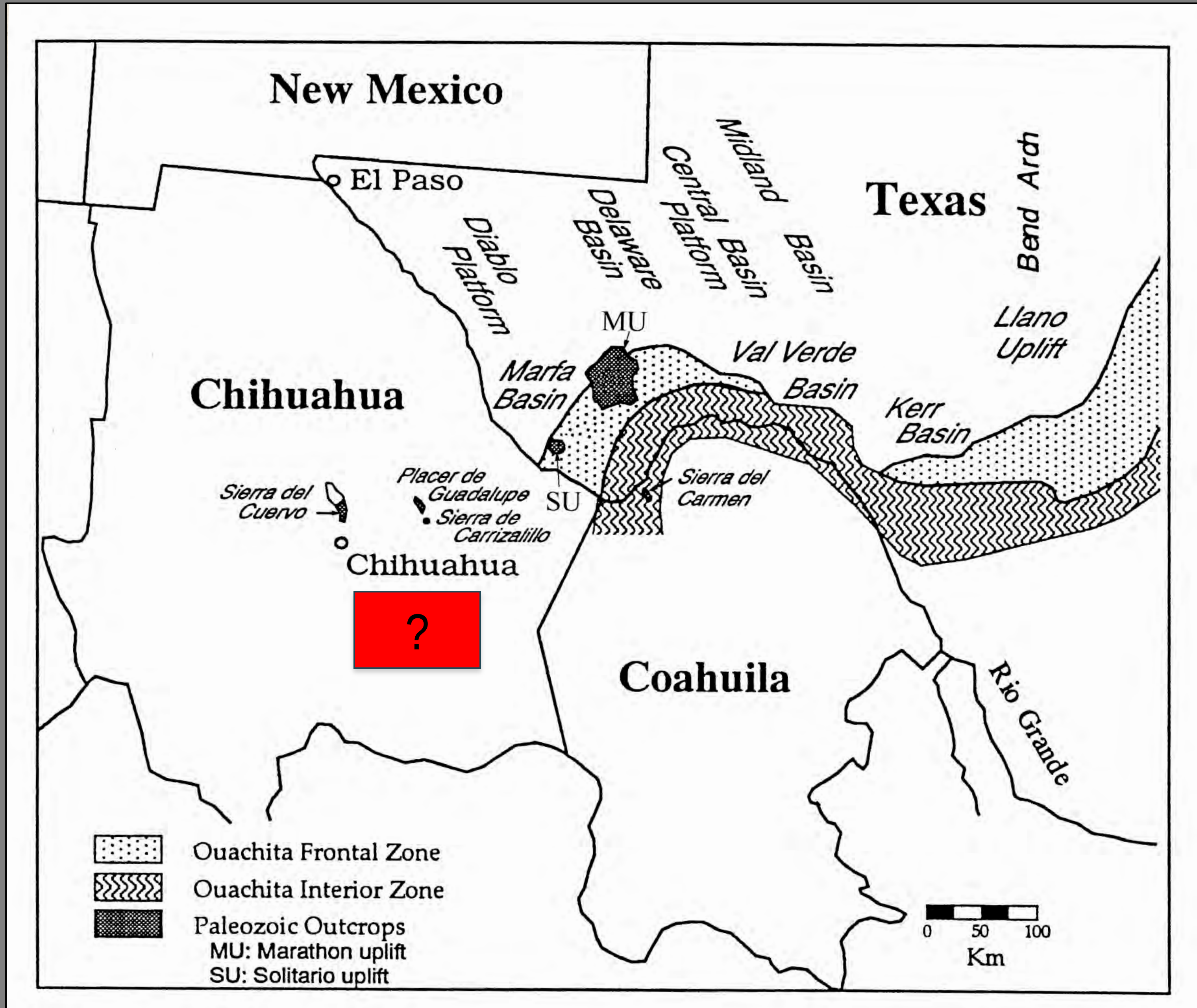
Integrated Model - Devil's River Uplift Profile



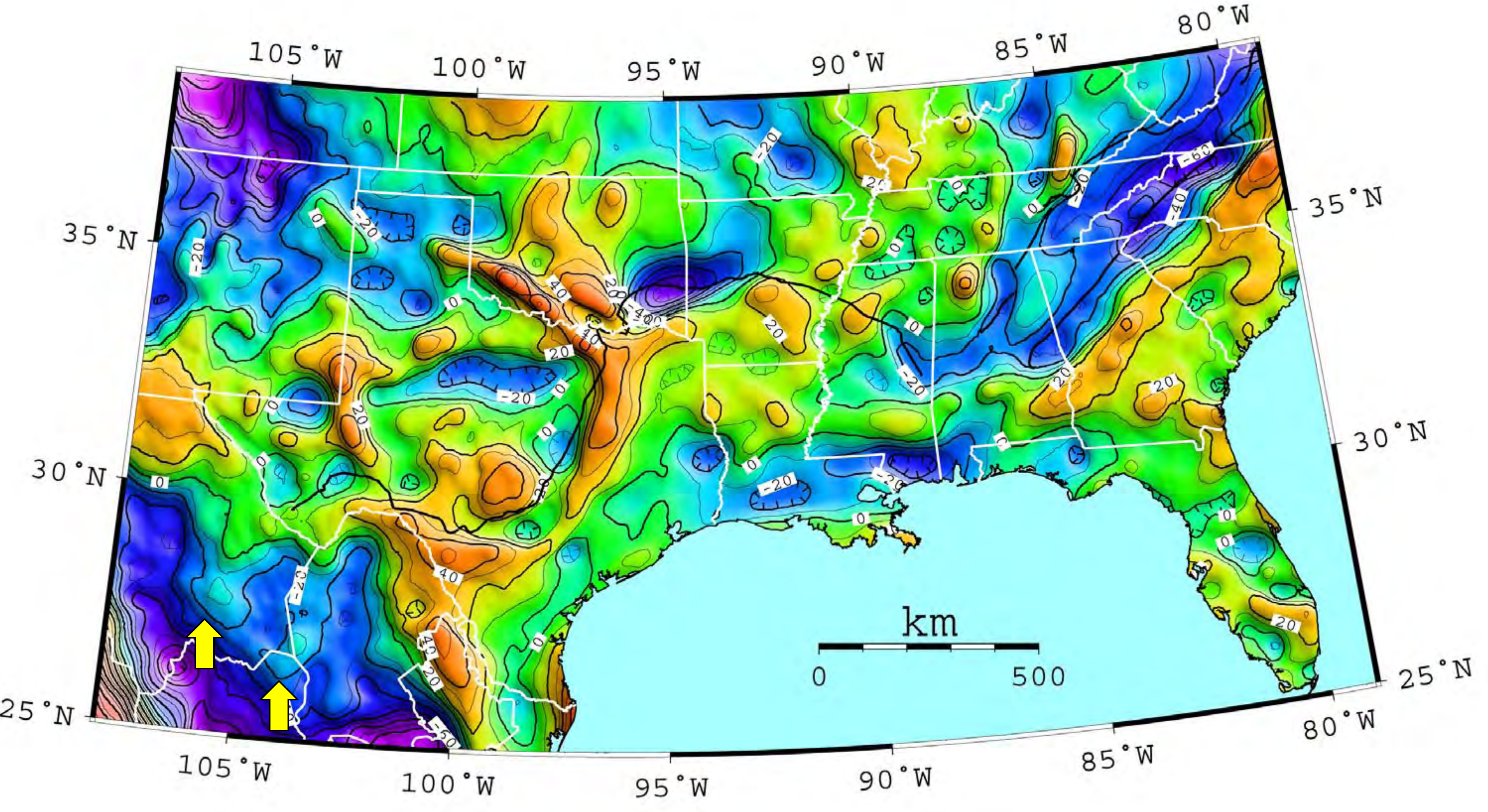
Mickus, Keller, and Thomas, in prep.

Here the Coahuila Terrane collided to drive the Ouachita Orogenic Belt but was not involved in the opening of the Gulf of Mexico.

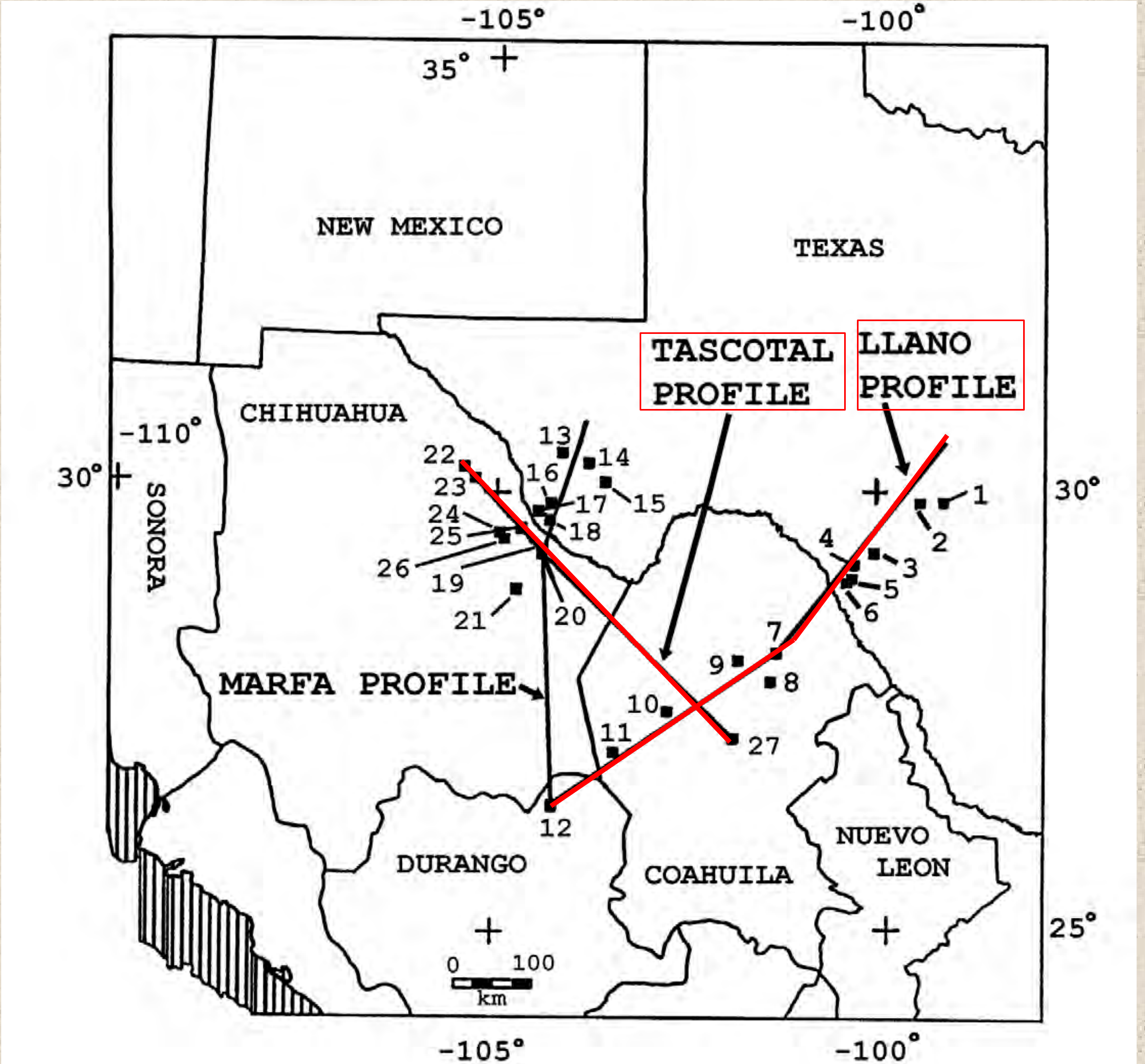
What happens in Mexico?

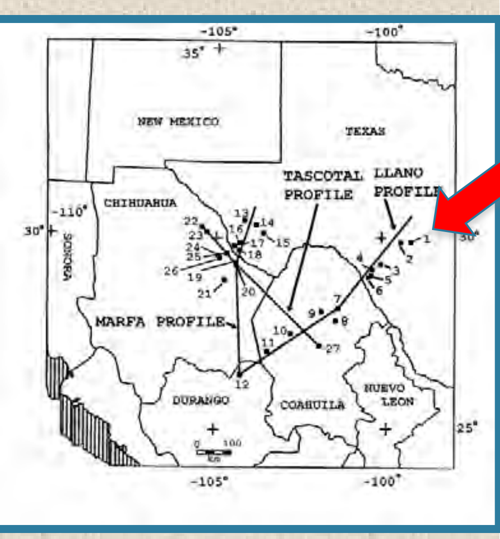


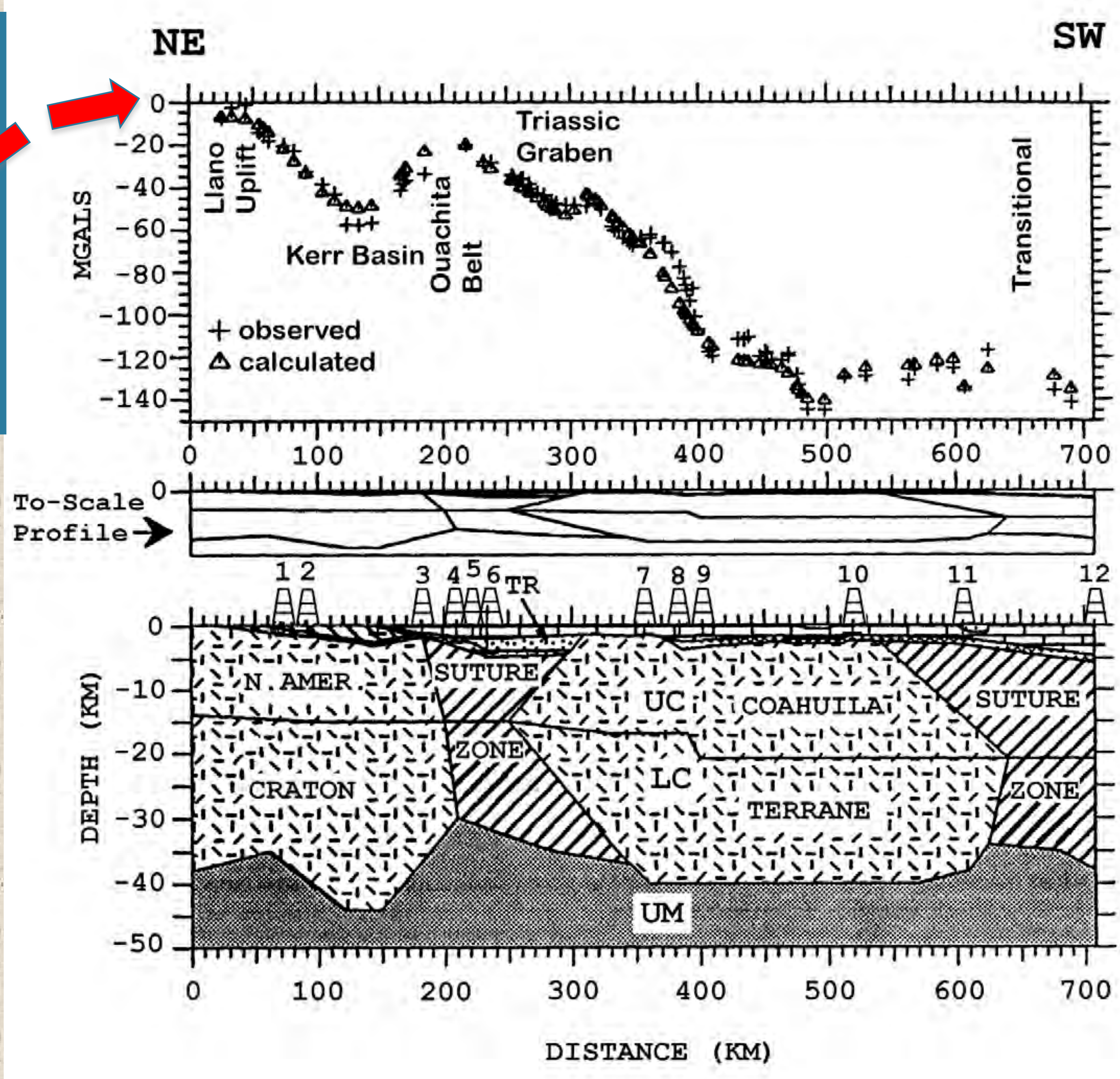
The traditional view is that the Ouachita orogenic belt trends south from Big Bend National Park, but ….



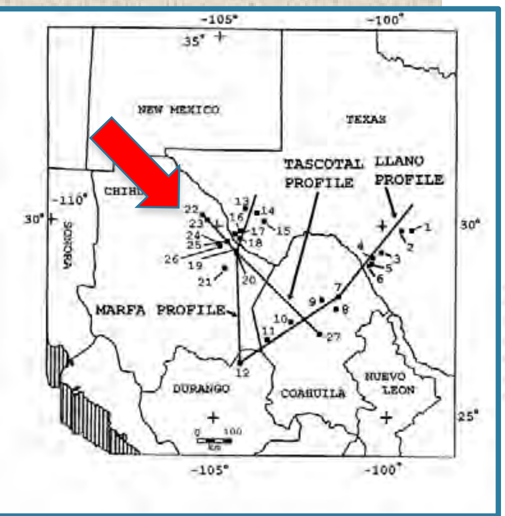
However, Moreno, Mickus, and Keller (2000) showed that the picture may be more complex.



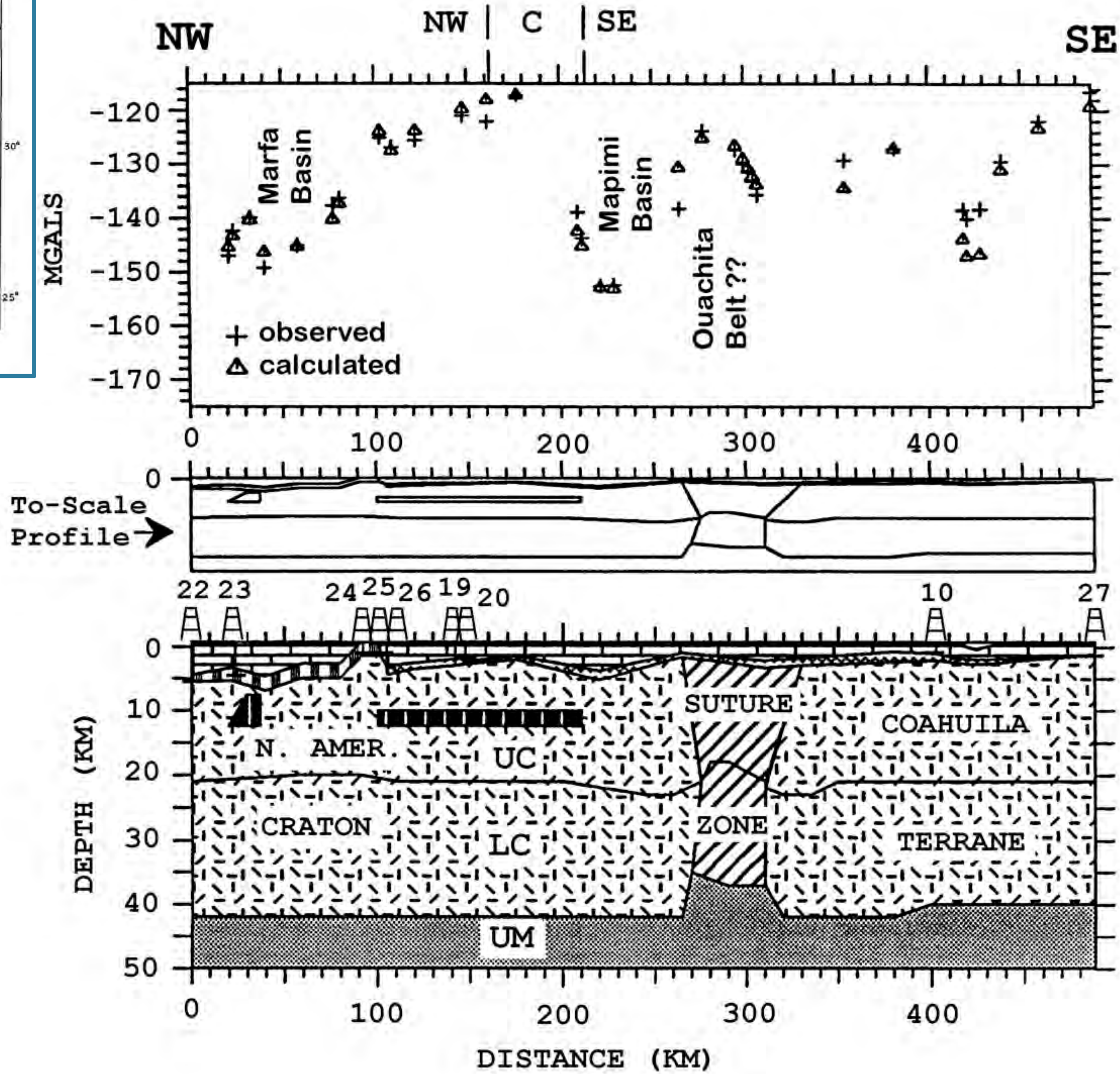


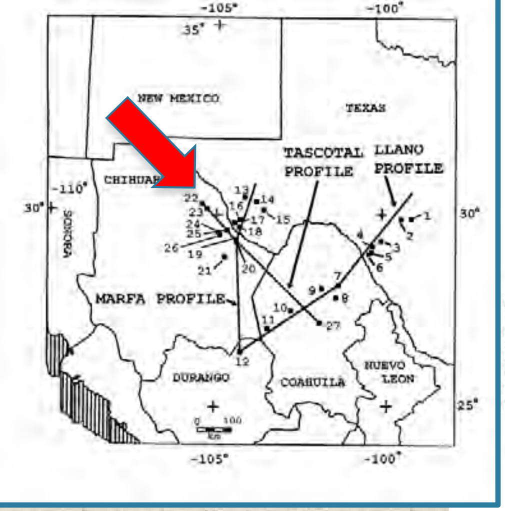


This profile crosses the Ouachita Orogenic Belt twice

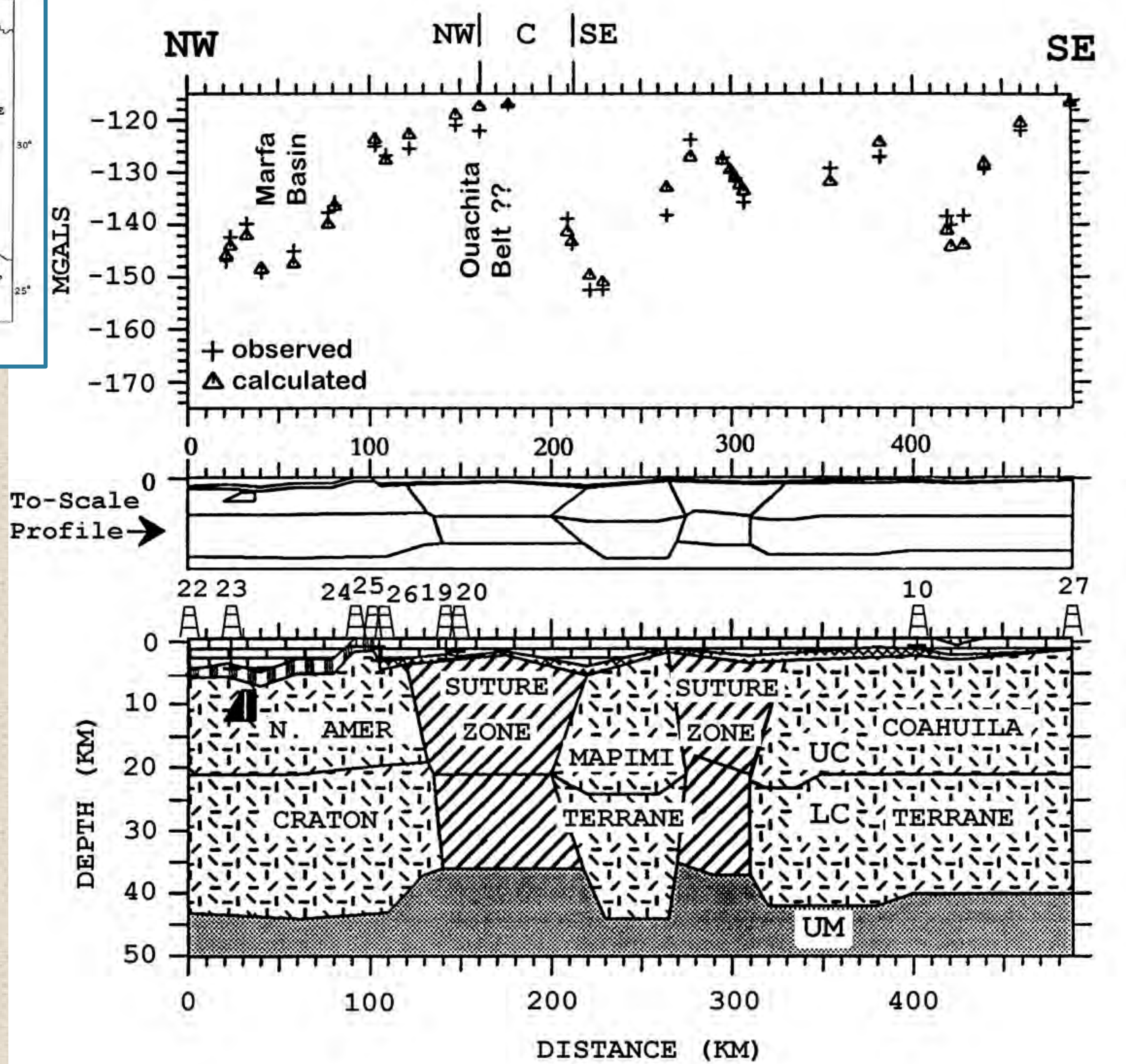


This profile can be modeled as crossing the Ouachita Orogenic Belt only once directly south of Big Bend National Park

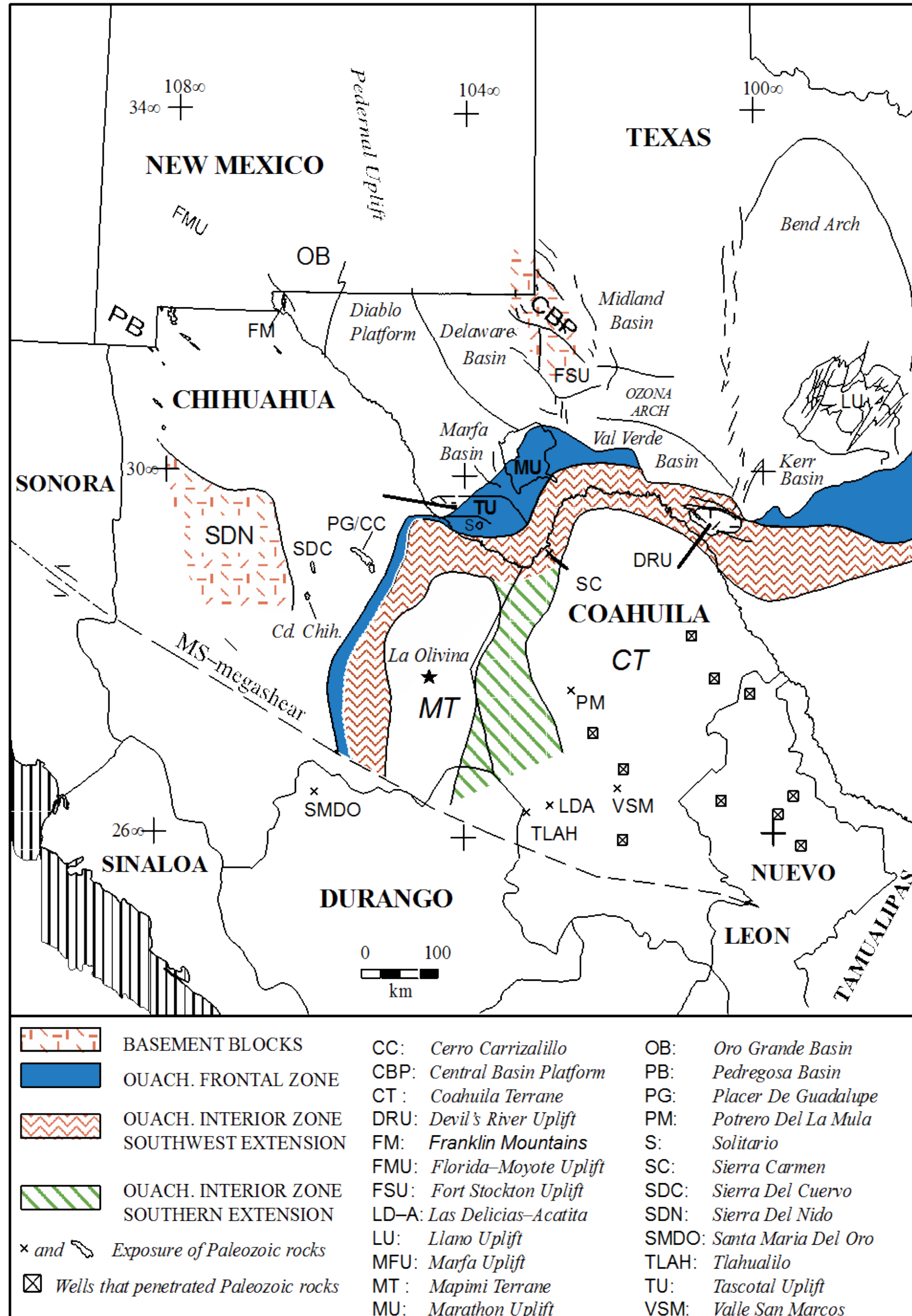




But, it can also be modeled as crossing the Ouachita Orogenic Belt twice which would match regional geochemical data better



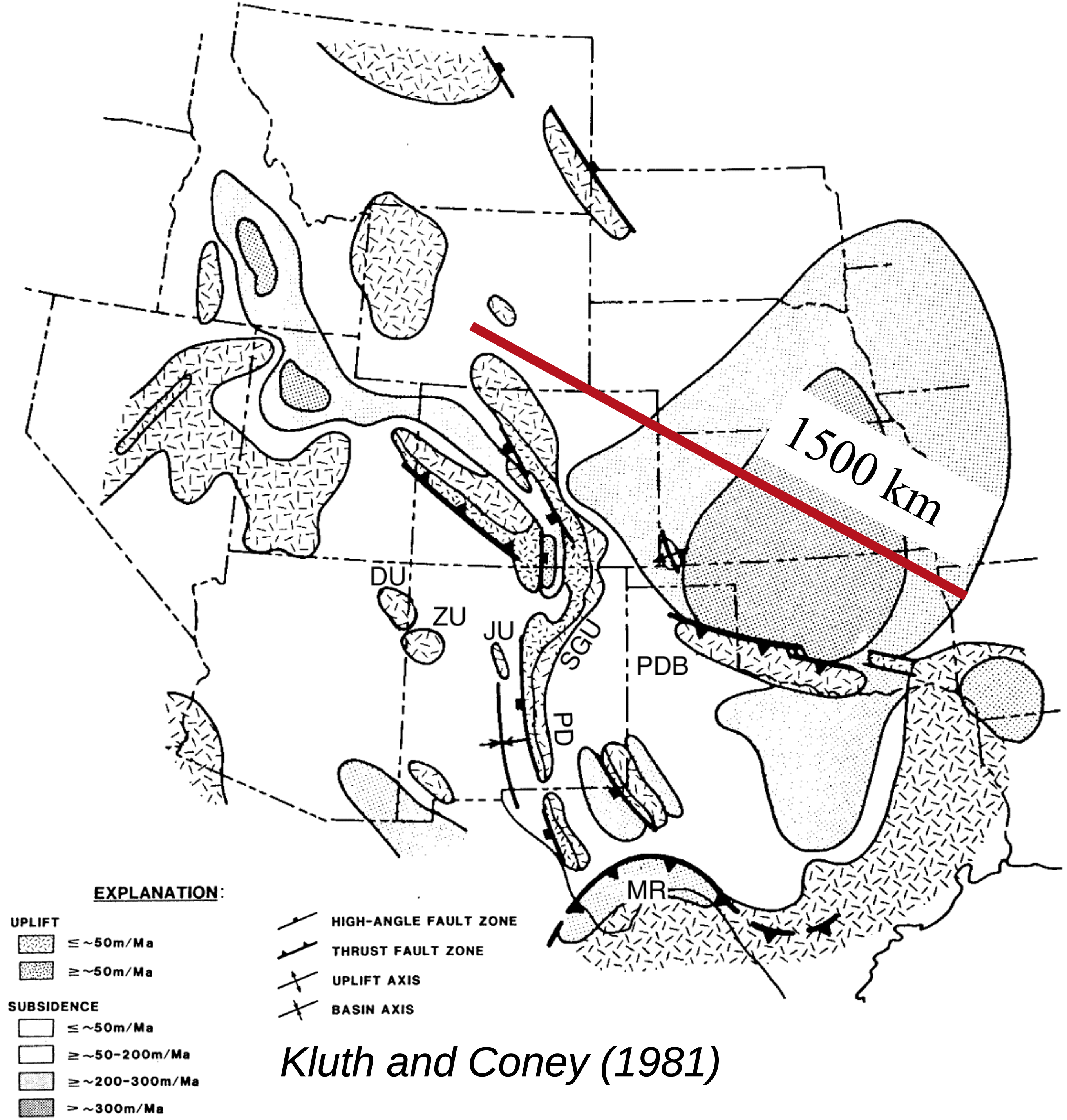
The addition of a Mapimi Terrane and a western arm of the Ouachita Orogenic Belt has implications for features such as the Marfa Basin



The Ancestral Rockies

This massive Late Paleozoic intraplate deformation generally cut across Precambrian tectonic trends

Collision along the Ouachita continental margin has long been the favored explanation for their development, but there is mounting evidence that the collision was "soft" along much of this margin.



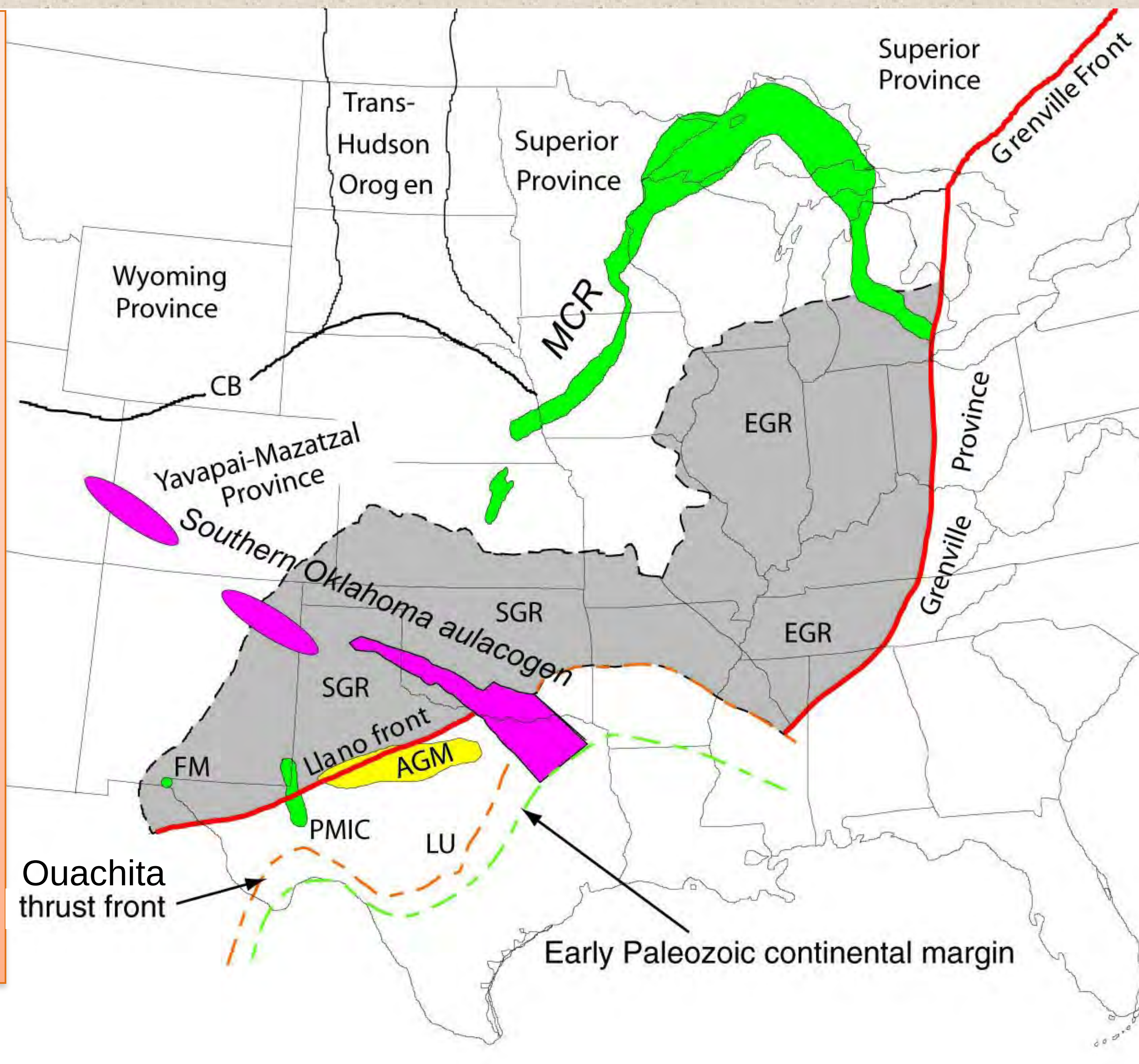
Kluth and Coney (1981)

Southern Oklahoma Aulacogen (the biggest ARM structure)

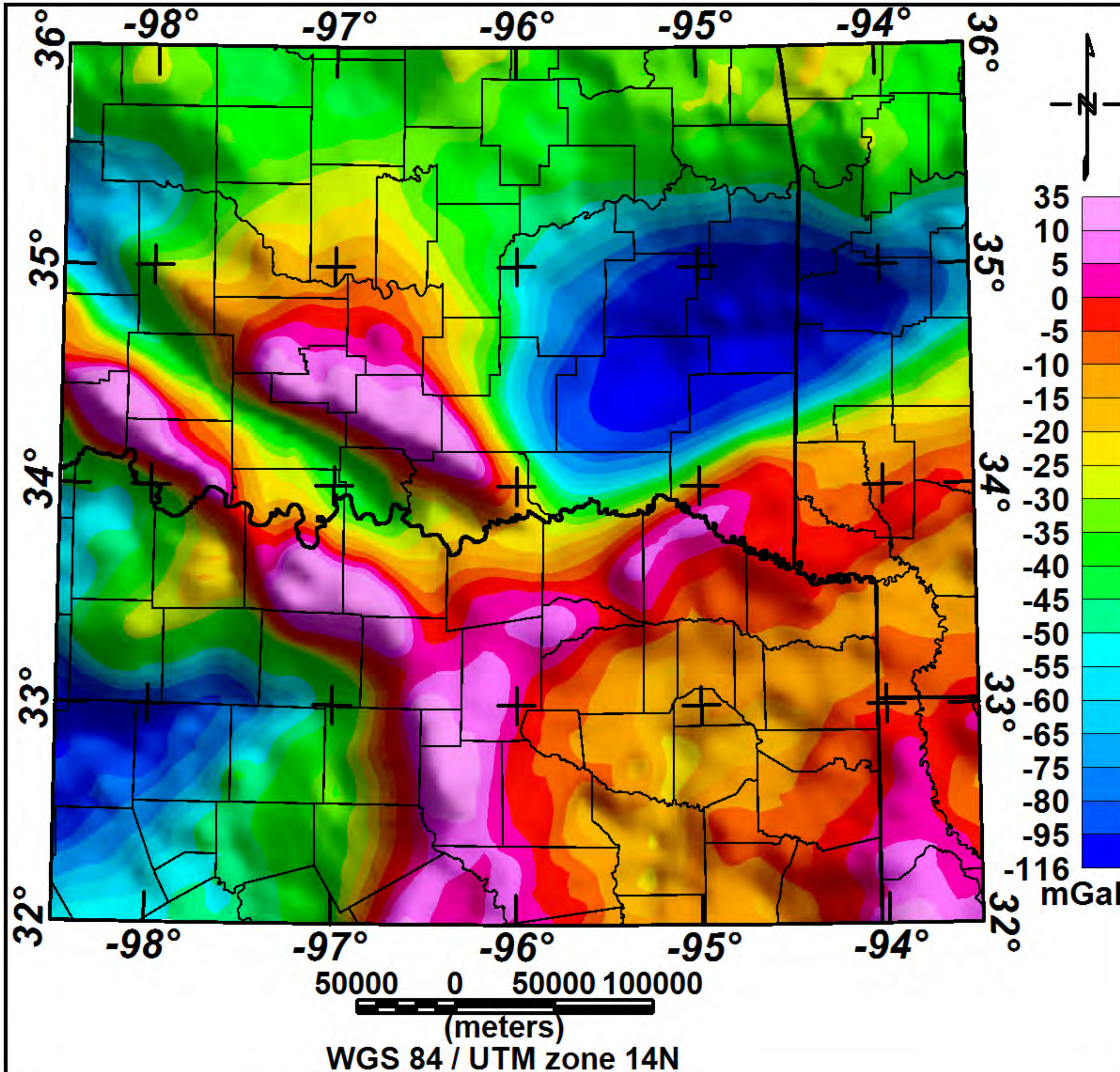
Magmatic modification of the crust is extensive and the outcropping igneous rocks have been studied extensively

Geophysical signatures of this modification are among the most prominent in the world (>100 mGal; 15 km of rift fill)

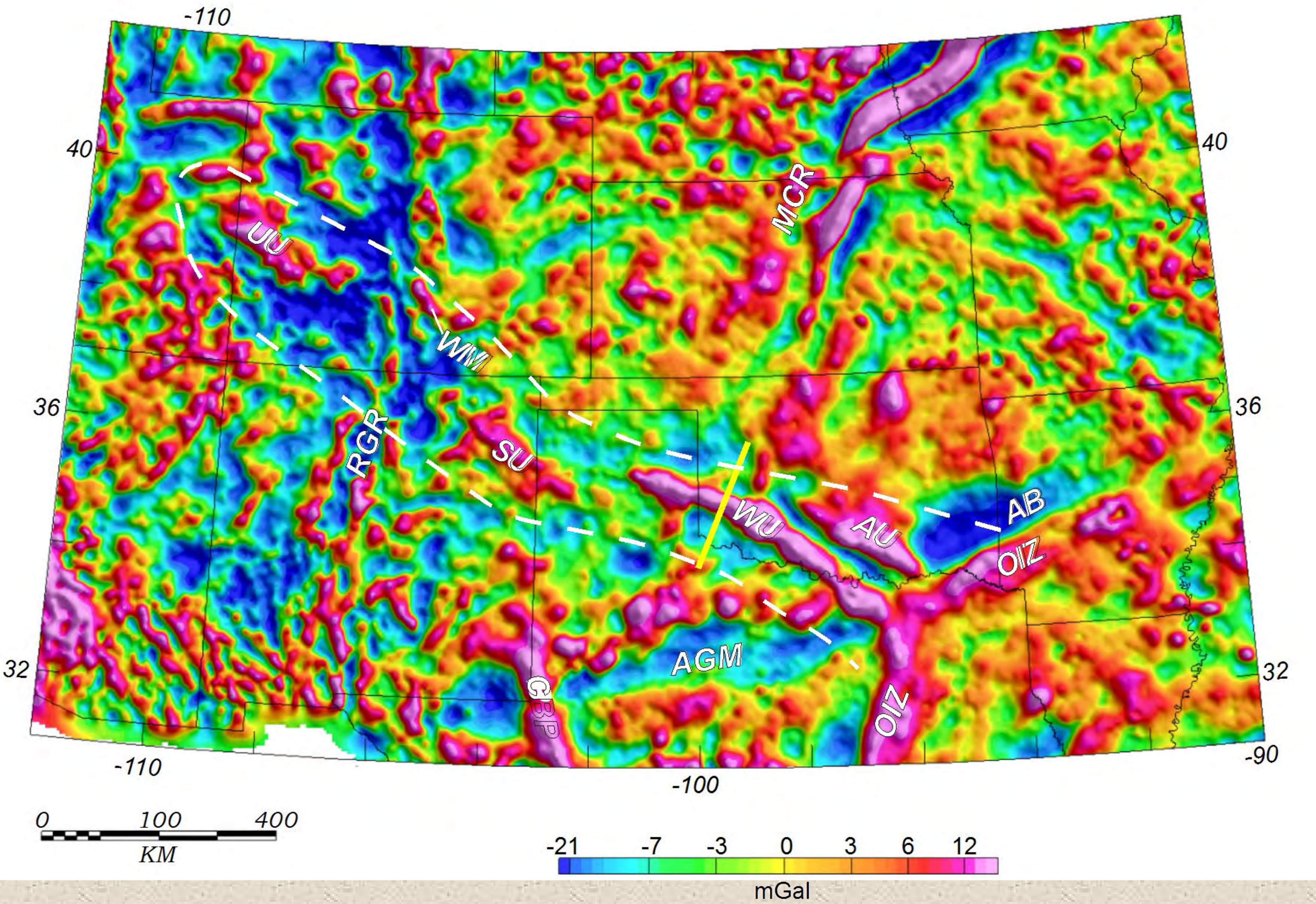
Inversion during the Late Paleozoic was massive, and produced >10 km of structural relief



The rift forms a classic triple junction with the Ouachita Orogen Belt in the vicinity of Dallas. The Late Paleozoic structures near this junction are very complex.



We can track the rift to the northwest via a series of gravity highs and outcrops of mafic igneous rocks

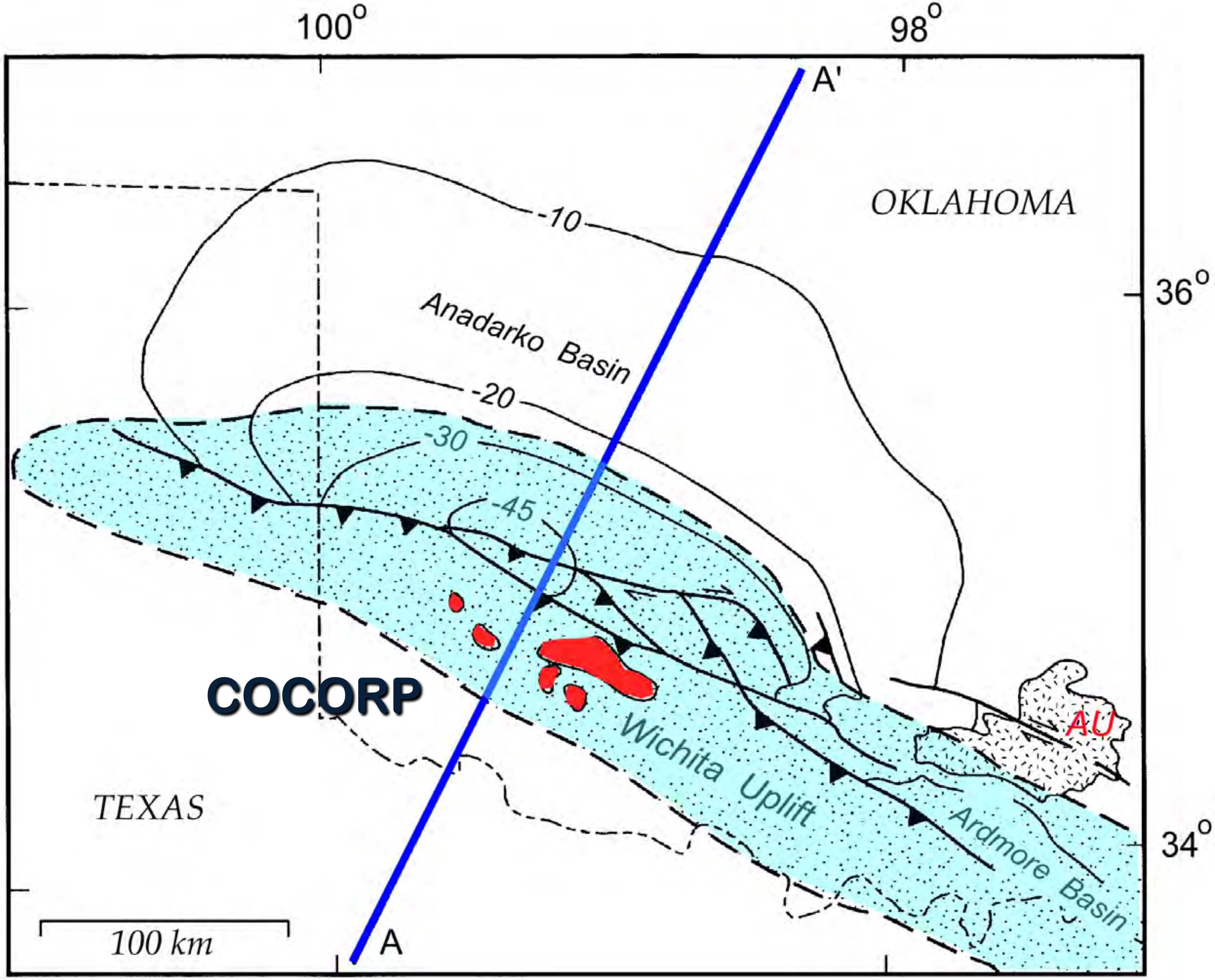


UTD-UTEP

Seismic experiment

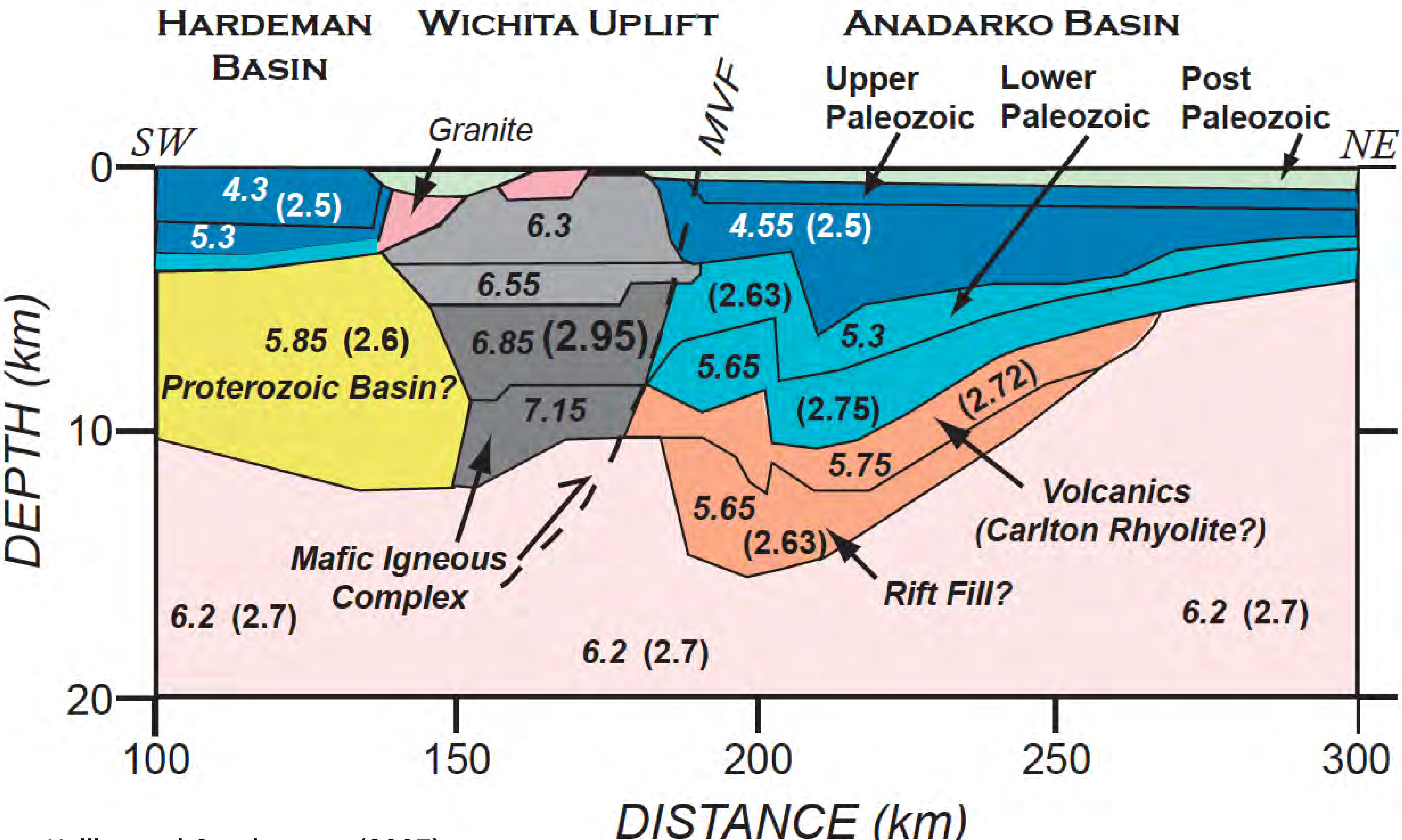
1600 recording stations

21 sources



Integrated crustal model

SOA Velocity Model of Upper Crust



Kelller and Stephenson (2007)

Summary

The Ouachita rifted margin (Cambrian) involved modest volcanism and is a classic passive margin that also involved considerable strike-slip motion during its formation.

This margin and the related inboard features set-up the structural framework of the southern Mid-Continent region.

The Late Paleozoic Ouachita/Ancestral Rocky Mountain orogeny reactivated many of the rift-related features and formed new ones.

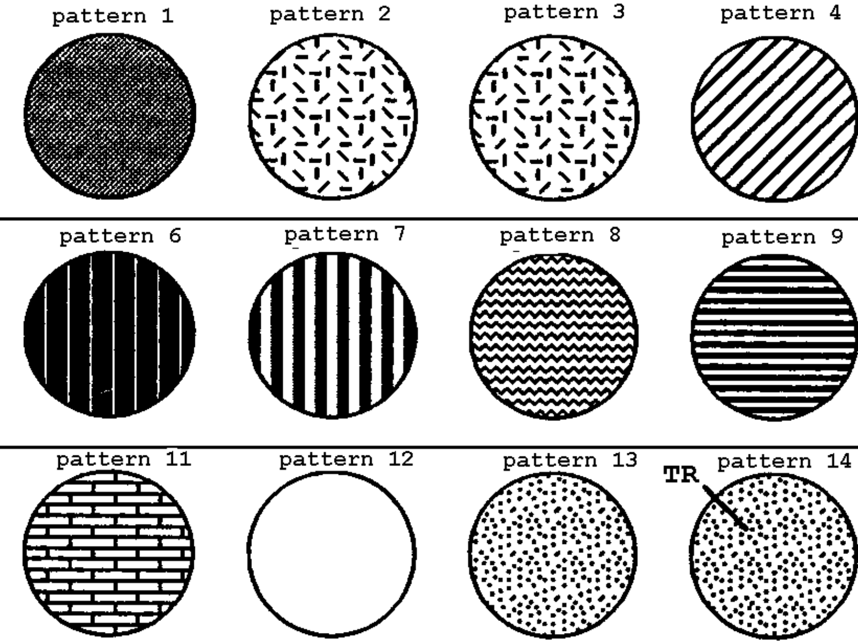
Appalachian/Caledonian orogenic events represent complete suturing of the colliding terranes but caused modest foreland deformation. The converse seems true for the Ouachita and Variscan (?) orogenies.

The Ancestral Rocky Mountains orogeny that is best documented along the Wichita-Amarillo uplift is a puzzling case of major intraplate deformation.

There are many possible sub-thrust and deep-basin plays to consider along the Ouachita Orogenic Belt, but the thermal regime needs to be better understood.

Thank You!

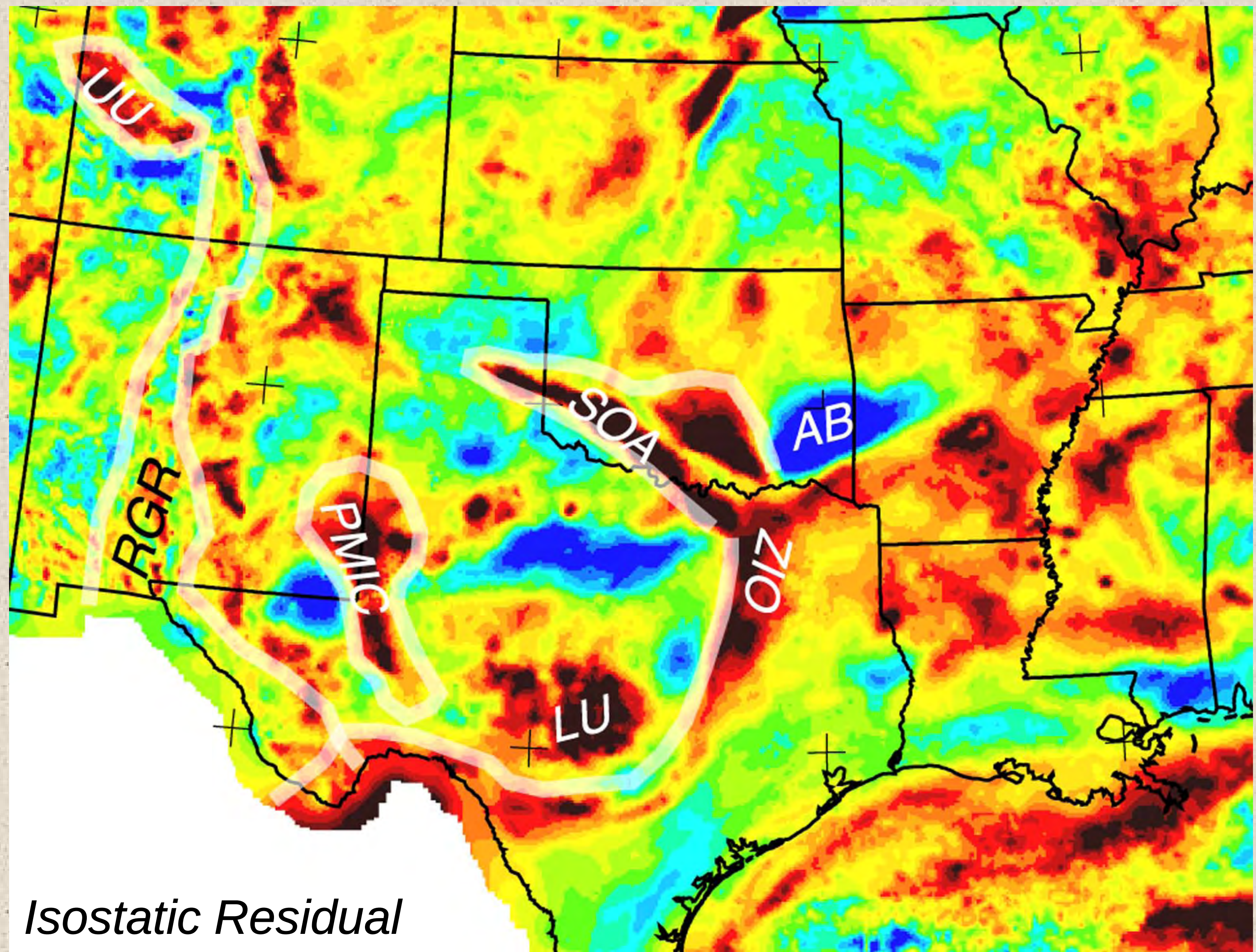
Appendix follows



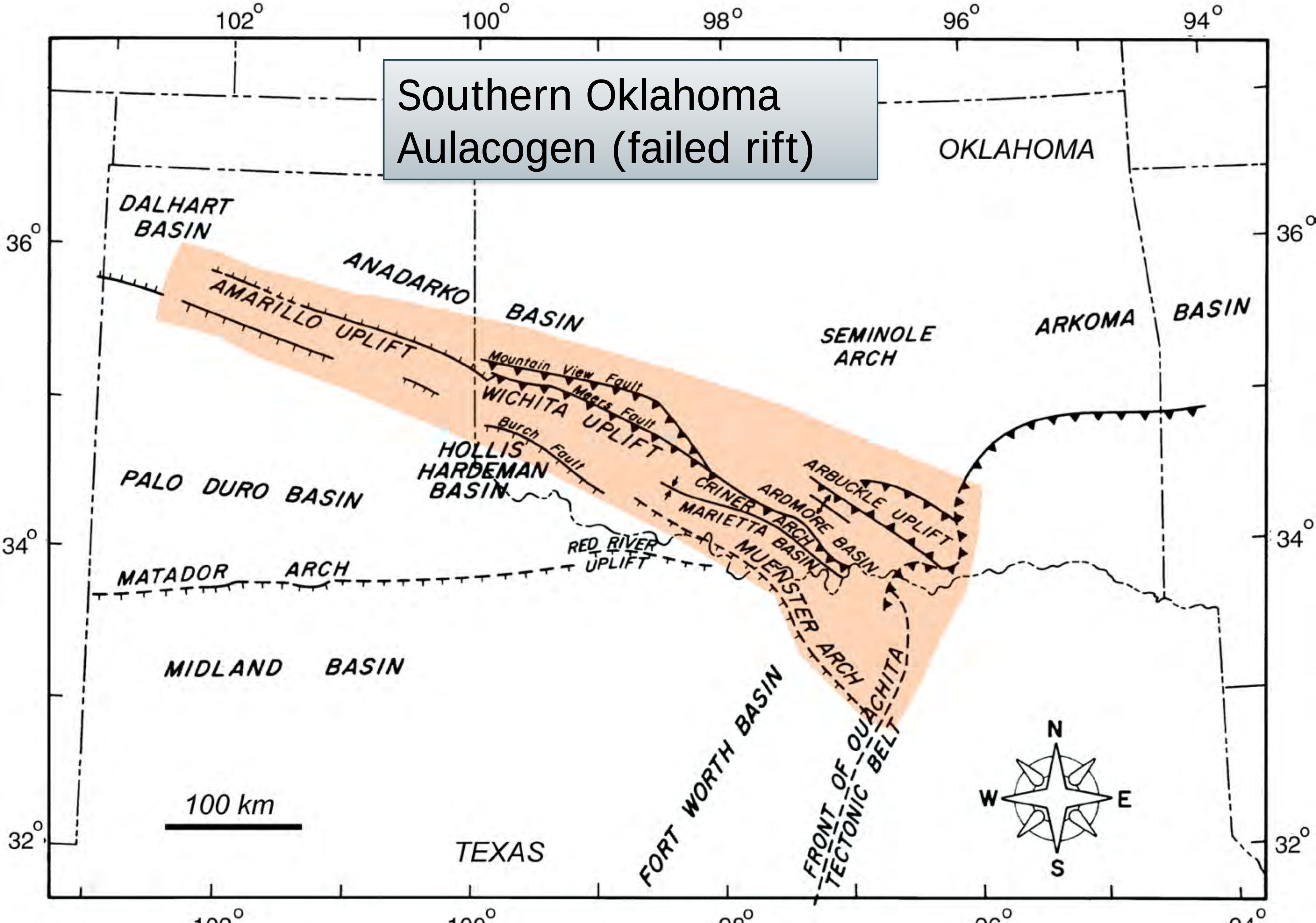
Unit Patterns and Density Values

DENSITY (gm/cc)	ROCK UNIT	PATTERN #
3.33	Upper mantle	1
3.00	Lower continental crust	2
2.70	Upper crust (Precambrian rocks)	3
2.69	Upper transitional crust	4
2.98	Lower oceanic/transitional crust	5
3.00	Mafic intrusive rocks	6
2.75	Upper Cambrian thought Lower Pennsylvanian; consists of carbonates, dolomites, metasedimentary and volcanic rocks	7
2.67	Paleozoic Ouachita facies rocks	8
2.67	Upper Cambrian through Lower Pennsylvanian and post Arbuckle rocks	9
2.60	Post Arbuckle Group, predominantly Mississippian through Permian Flysch	10
2.50	Cretaceous and Cenozoic sedimentary rocks	11
2.40	Tertiary volcanic rocks	12
2.00	Tertiary and Quaternary sedimentary rocks	13
2.47	Triassic graben fill sediments	14

Gravity map - SOA/ARM area

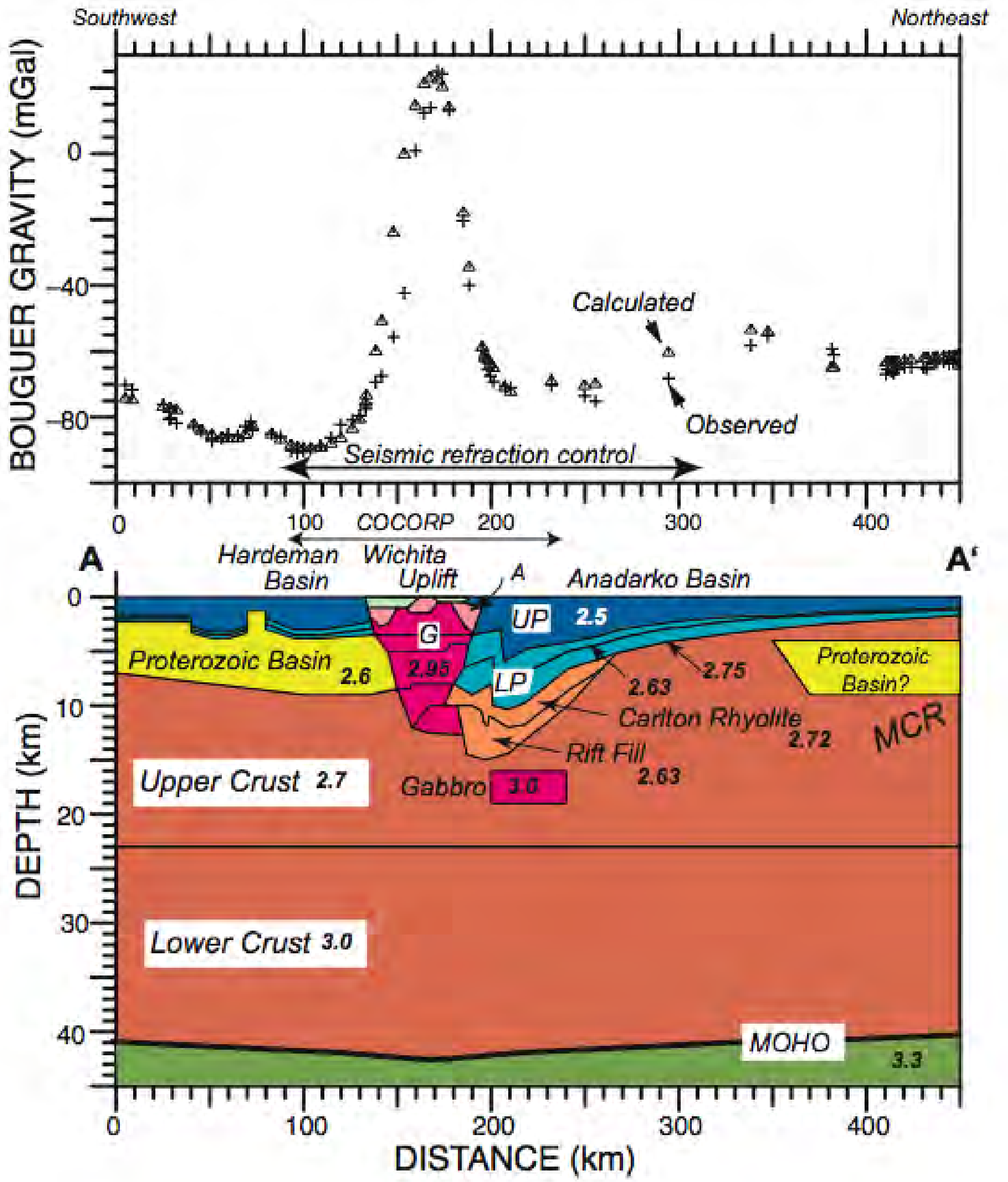


Southern Oklahoma Aulacogen (failed rift)

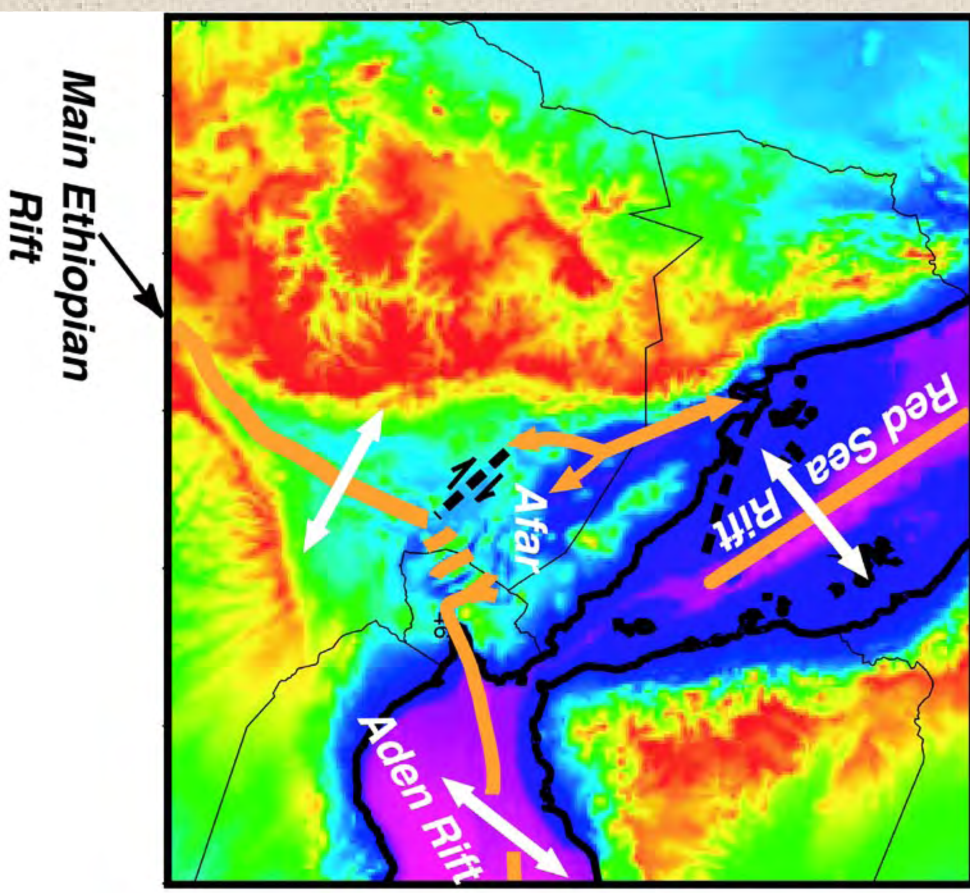


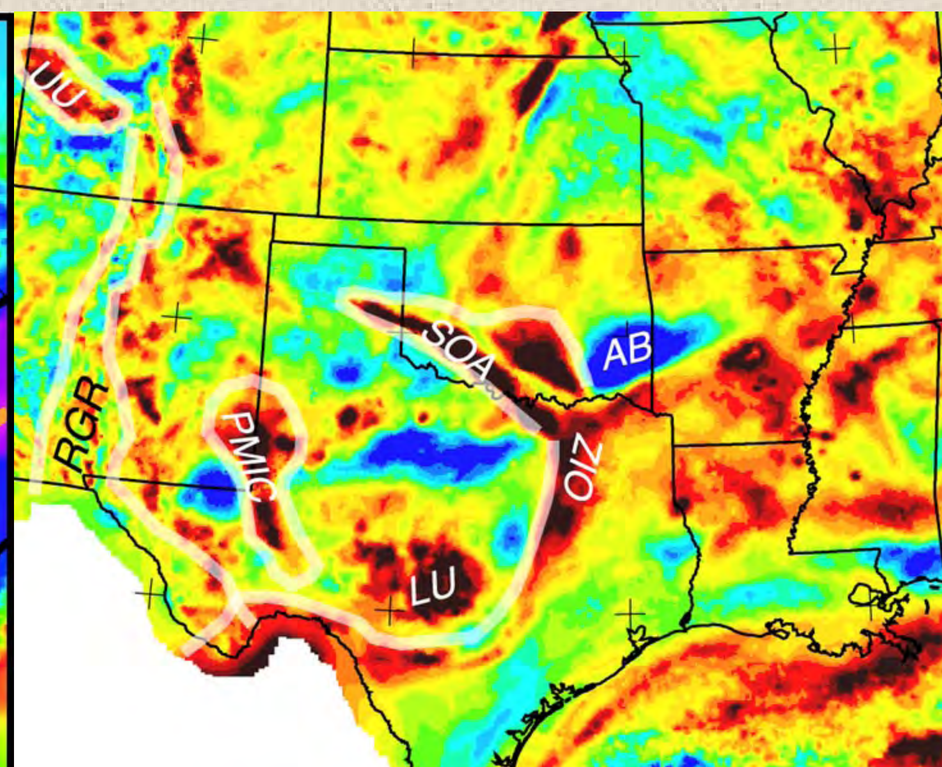
Crustal Model derived by integrated analysis of seismic, geologic, and gravity data

The mafic core of the Wichita uplift resides almost completely in the upper plate of the Mountain View thrust system

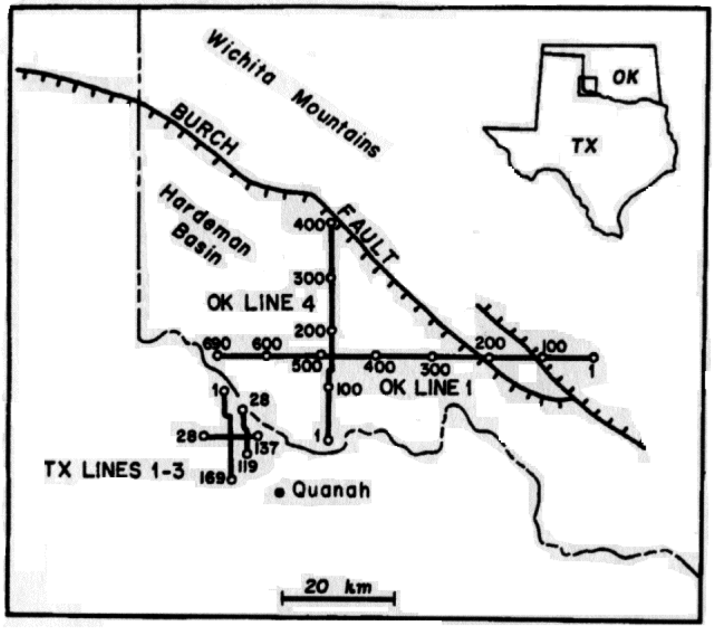


Afar vs. SOA Triple Junction

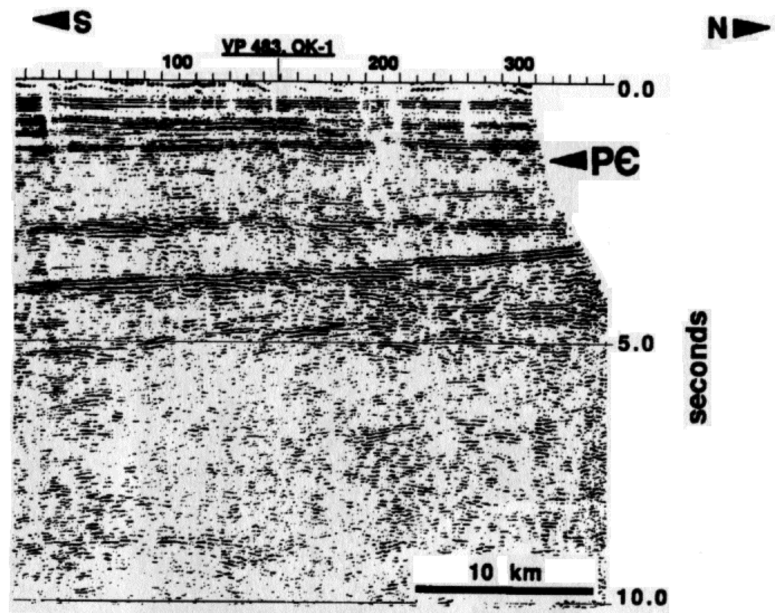




COCORP results



COCORP Oklahoma Line 4



COCORP Oklahoma Line 1