A Regional Overview of Southern Oklahoma Structures

(and some stuff about recent earthquakes)

G. Randy Keller

Oklahoma Geological Survey

School of Geology and Geophysics

University of Oklahoma

(with the help of many students and colleagues)

MEWBOURNE COLLEGE OF EARTH&ENERGY THE UNIVERSITY OF OKLAHOMA

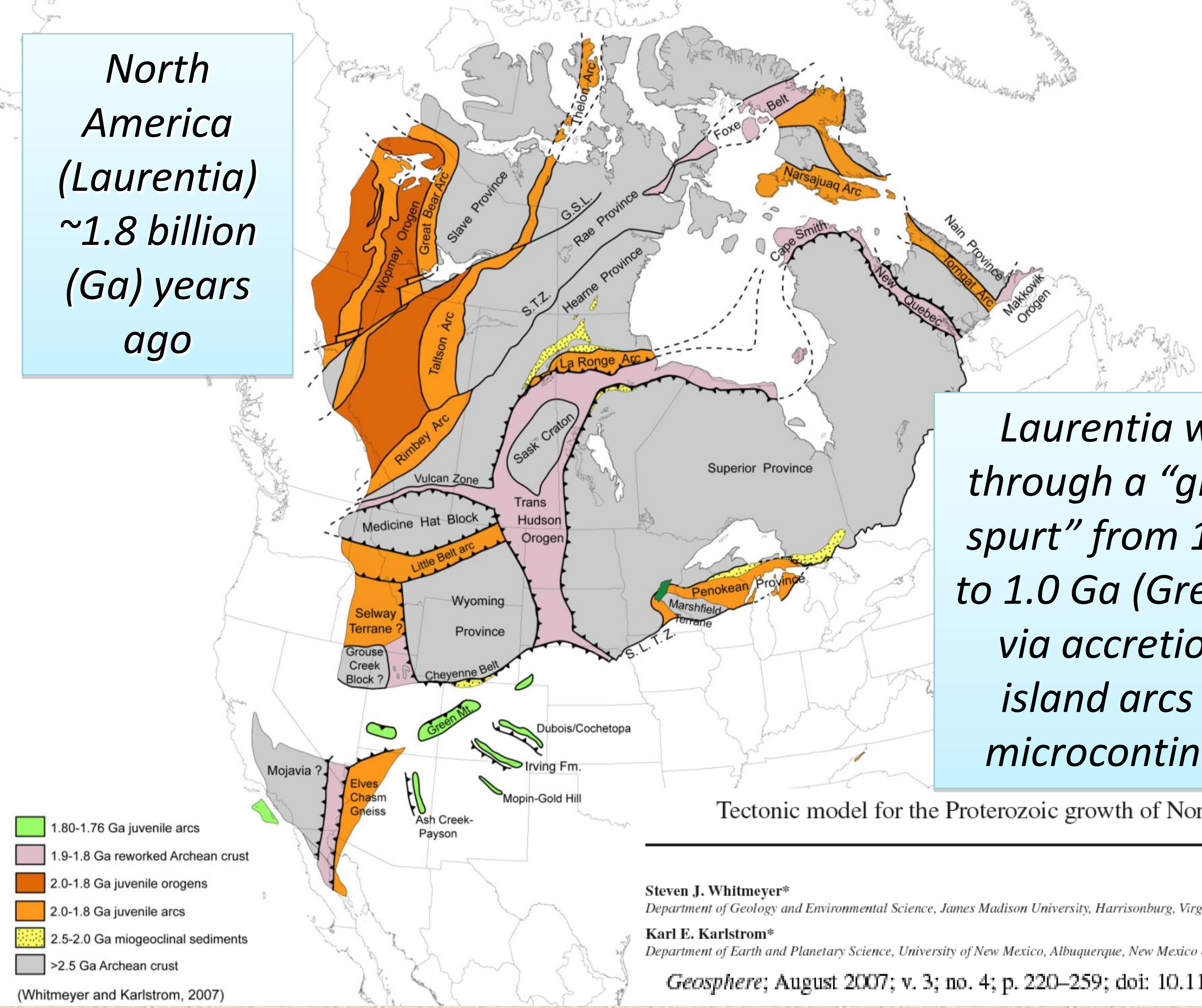
OKLAHOMA GEOLOGICAL SURVEY 1908

NSF

The big tectonic events that affected Oklahoma and surrounding areas

1. ***The formation of the continental crust in the Proterozoic (1.8 to 1.4 Ga)***
2. *The Mid-continent rift (1.1 Ga)*
3. *The break-up of the continent in the Cambrian*
4. *The Ouachita orogeny and formation of the Ancestral Rocky Mountains*

North America (Laurentia) ~1.8 billion (Ga) years ago



Laurentia went through a "growth spurt" from 1.8 Ga to 1.0 Ga (Grenville) via accretion of island arcs and microcontinents.

Tectonic model for the Proterozoic growth of North America

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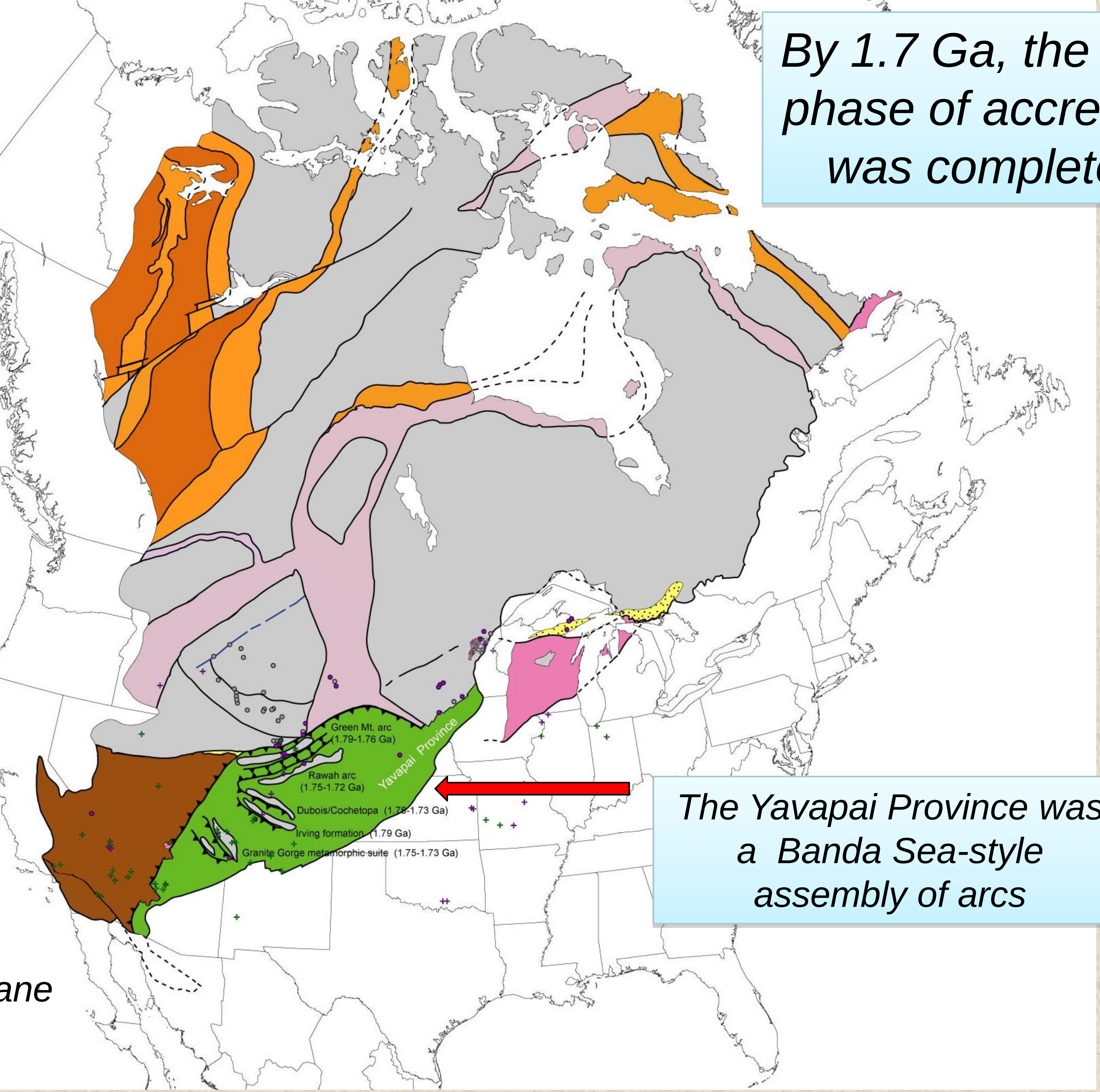
Department of Earth and Planetary Science, University of New Mexico, Albuquerque, New Mexico 87131, USA

Geosphere; August 2007; v. 3; no. 4; p. 220–259; doi: 10.1130/GES00055.1

By 1.7 Ga, the first phase of accretion was complete.

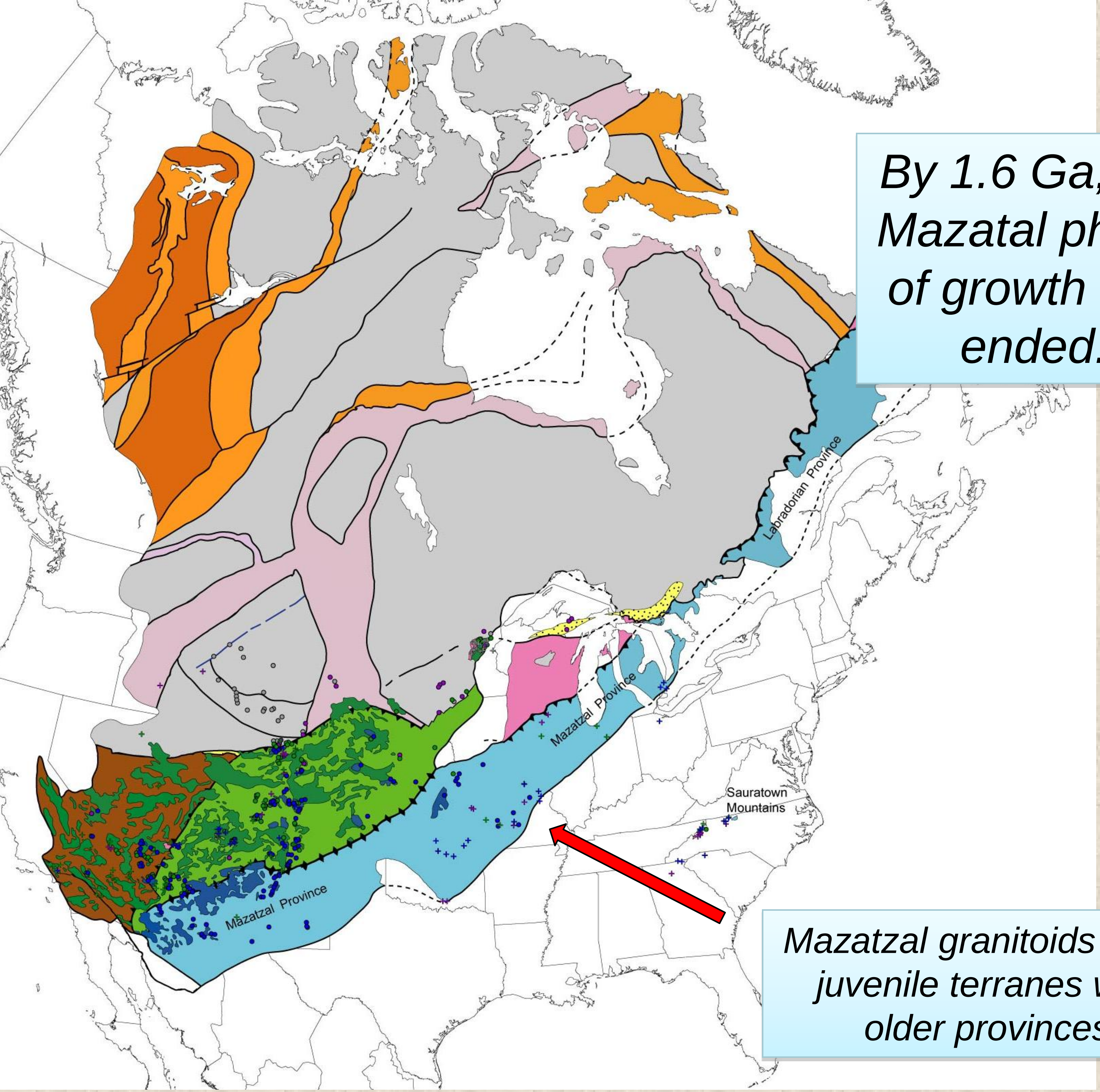
Proterozoic growth of Laurentia



The Yavapai Province was a Banda Sea-style assembly of arcs

Juvenile terrane accretion

Proterozoic growth of Laurentia



By 1.6 Ga, the Mazatal phase of growth had ended.

Granitoid intrusion

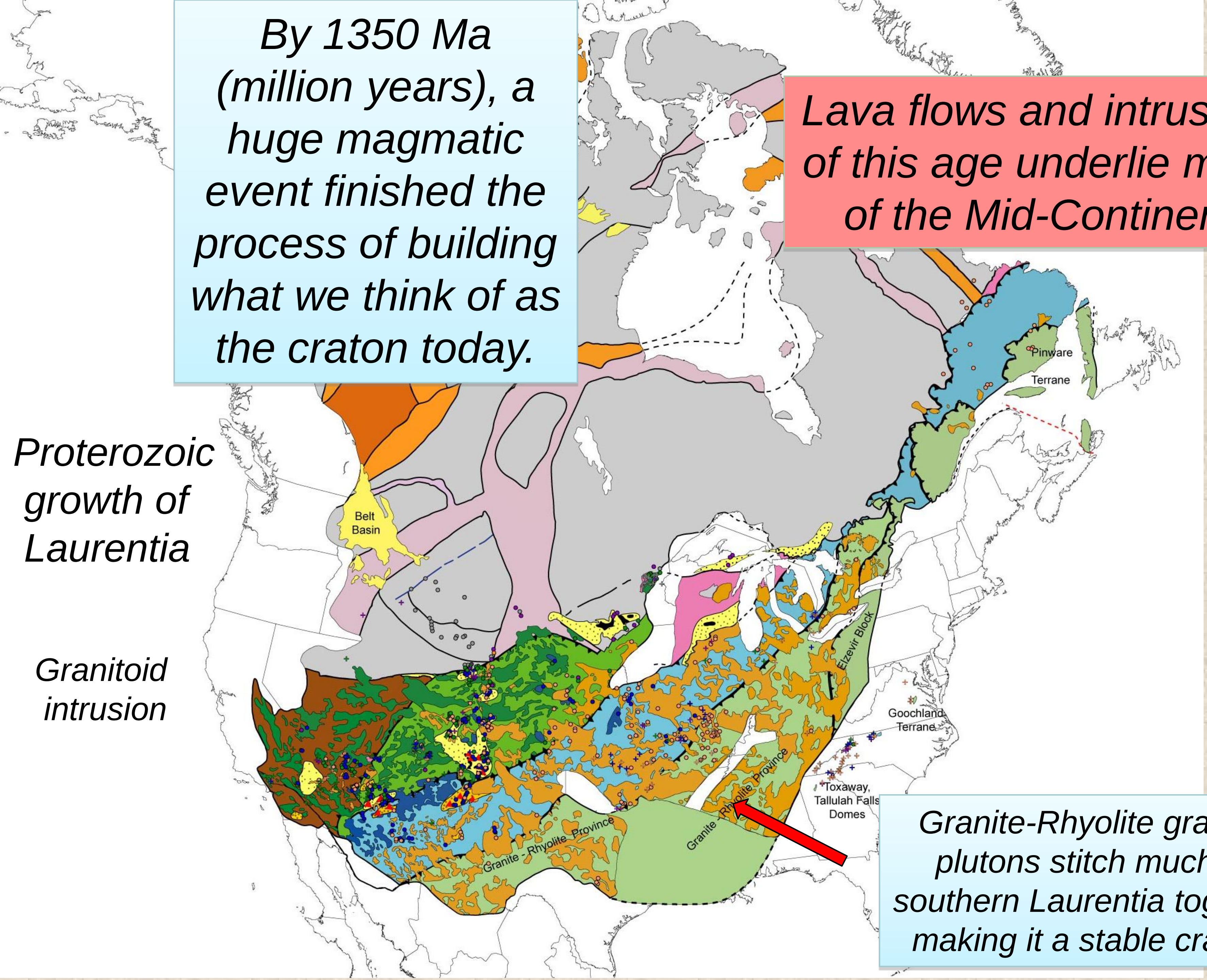
Mazatzal granitoids stitch juvenile terranes with older provinces

By 1350 Ma (million years), a huge magmatic event finished the process of building what we think of as the craton today.

Lava flows and intrusions of this age underlie much of the Mid-Continent.

Proterozoic growth of Laurentia

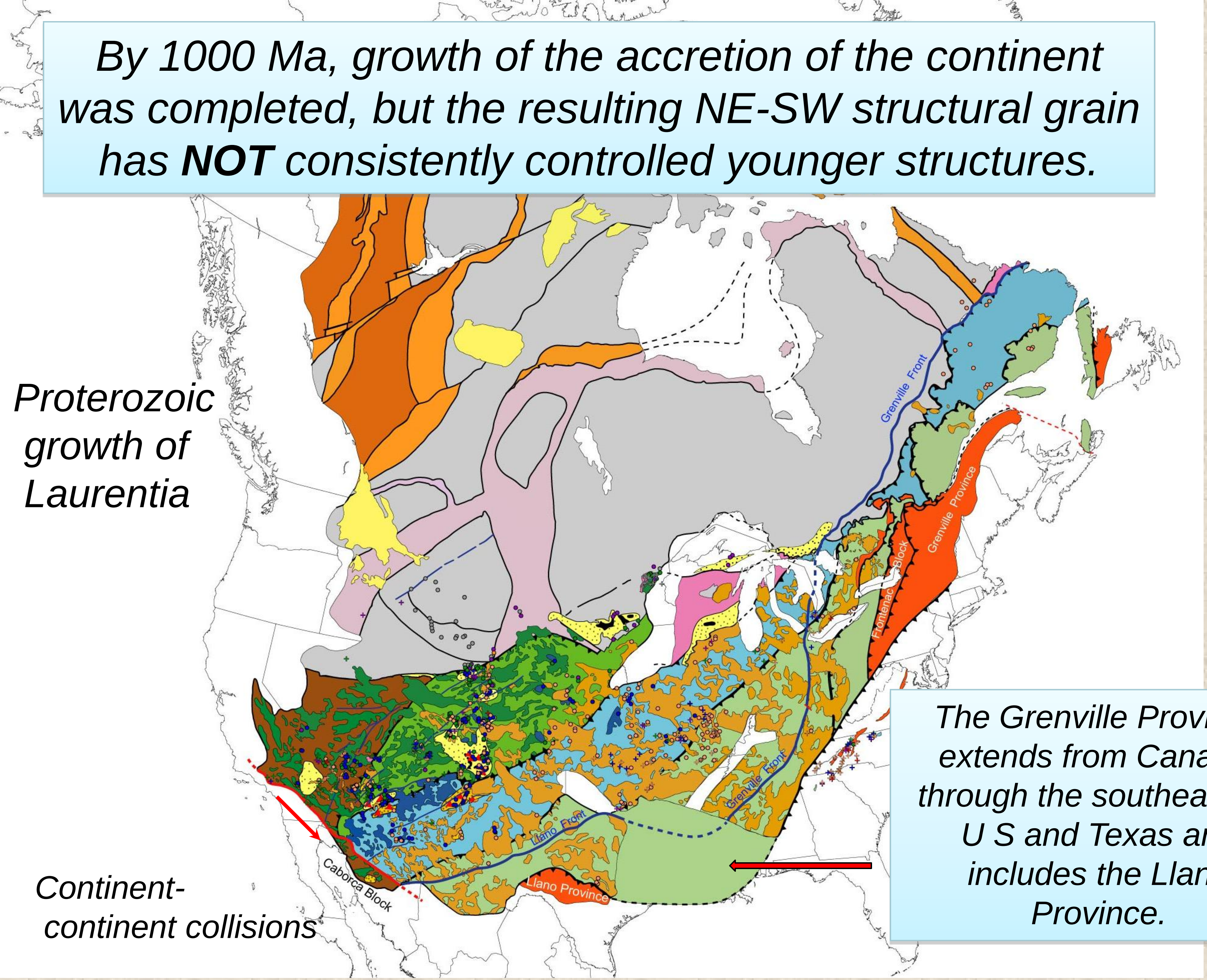
Granitoid intrusion



Granite-Rhyolite granitic plutons stitch much of southern Laurentia together making it a stable craton.

By 1000 Ma, growth of the accretion of the continent was completed, but the resulting NE-SW structural grain has **NOT** consistently controlled younger structures.

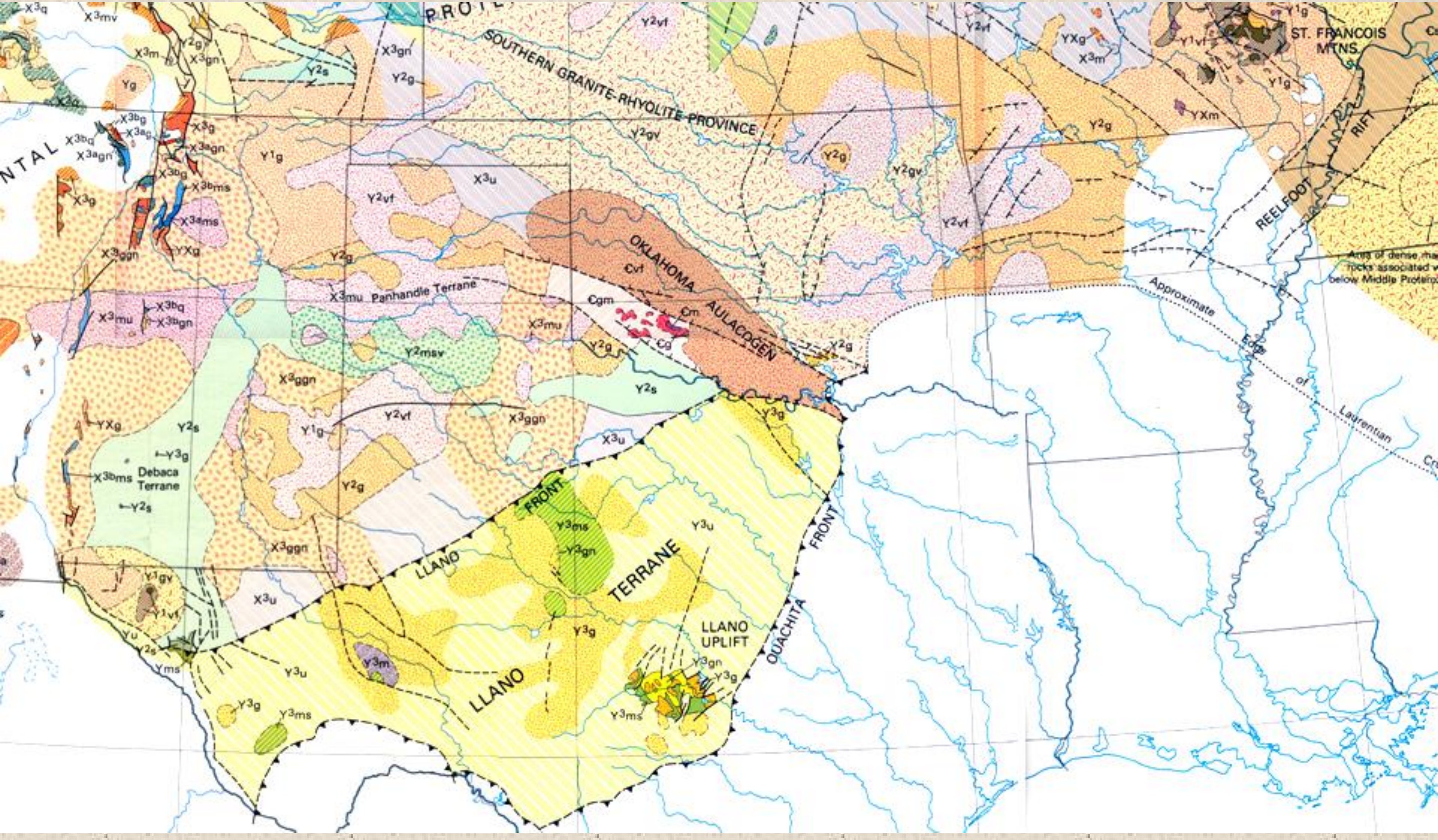
Proterozoic growth of Laurentia



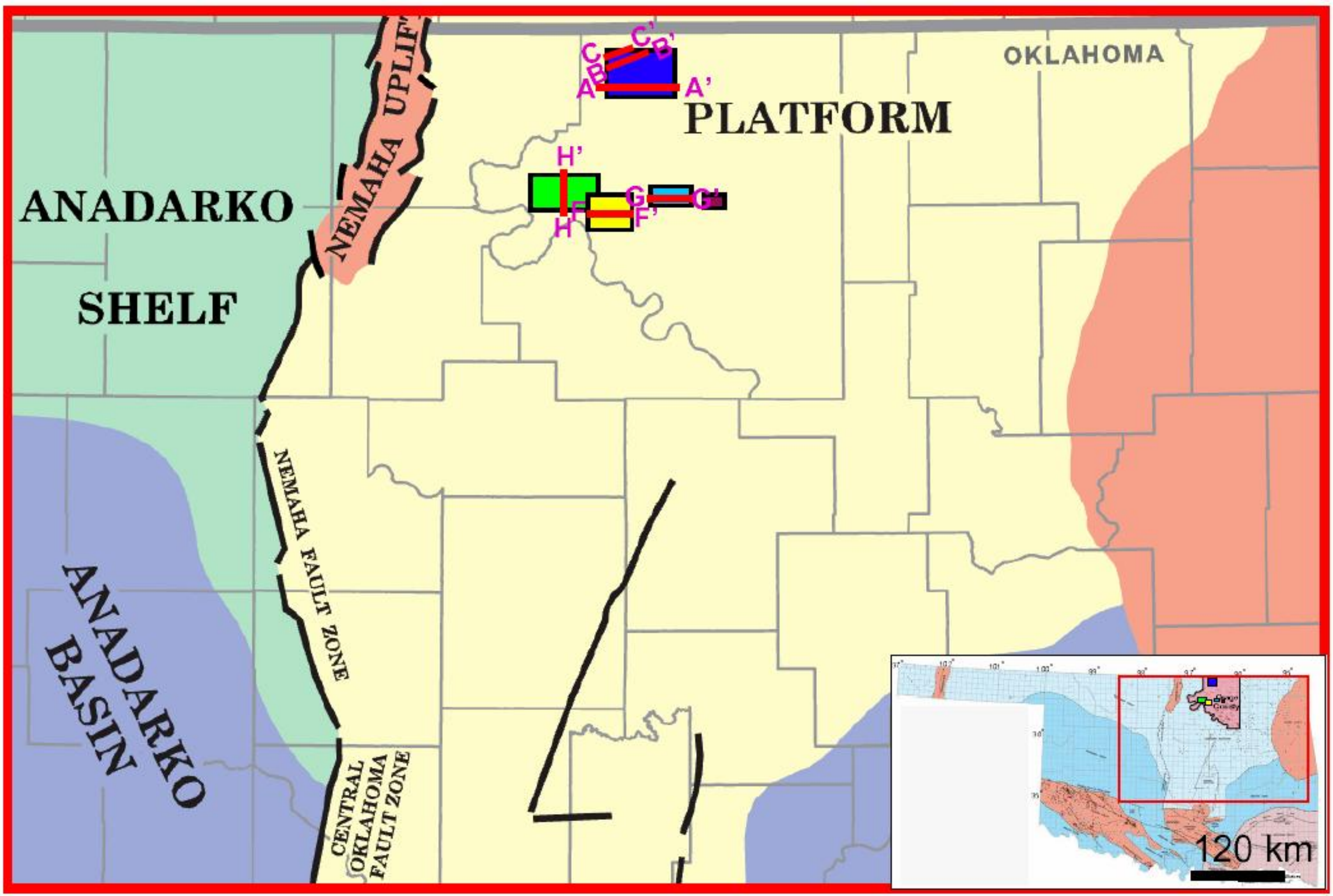
Continent-continent collisions

The Grenville Province extends from Canada, through the southeastern U S and Texas and includes the Llano Province.

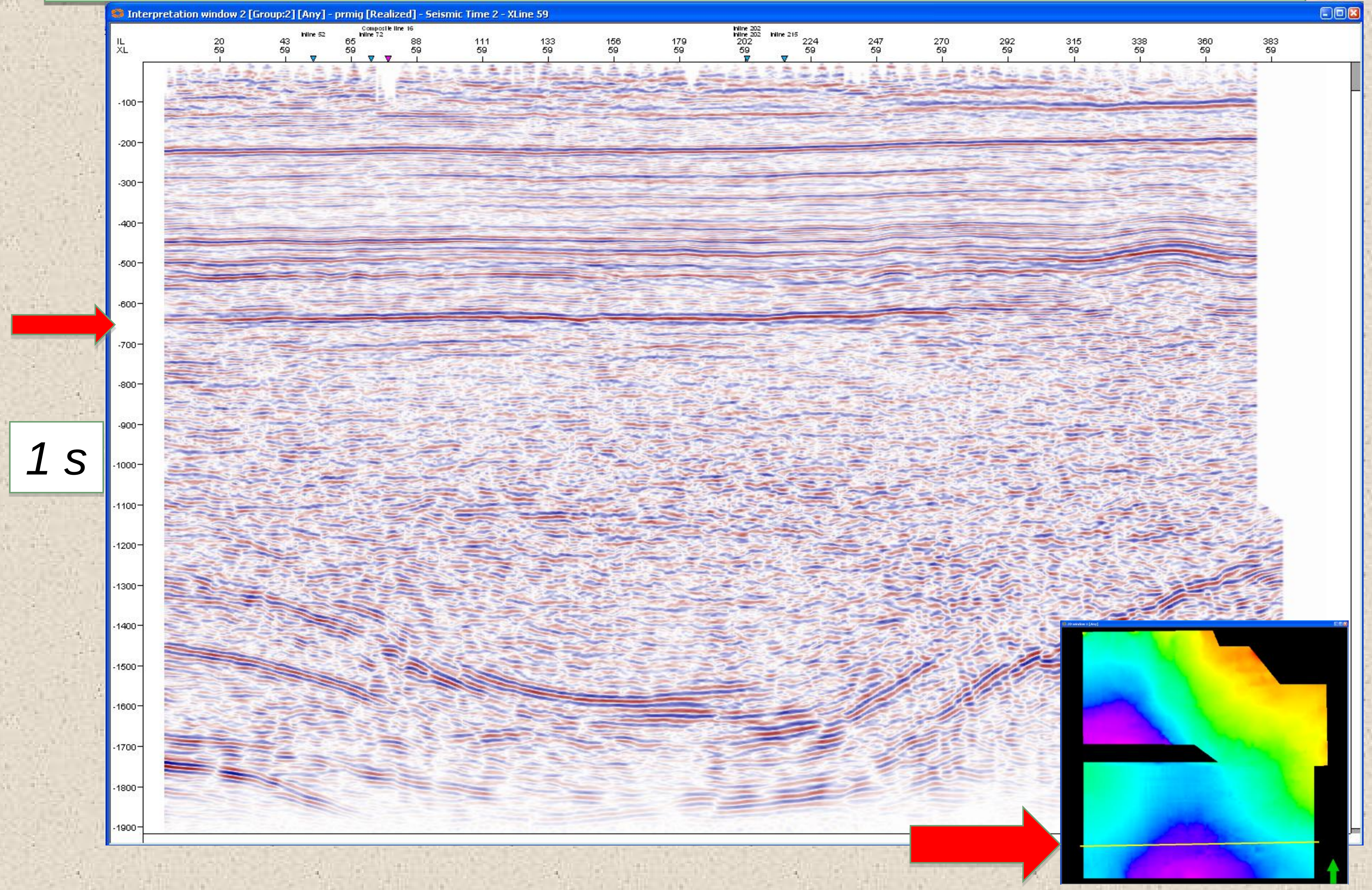
Oklahoma-Texas region basement



3-D seismic reflection surveys in Osage County, OK

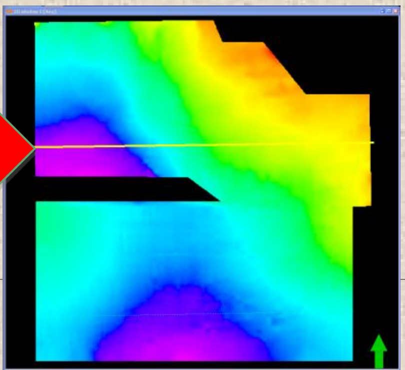


The deep (basement) structure is far from simple



This looks like a modern extensional basin that is buried beneath a layer of 1.4 Ga volcanics

1 s



The big tectonic events that affected Oklahoma and surrounding areas

1. *The formation of the continental crust in the Proterozoic (1.8 to 1.4 Ga) due to accretionary events*
2. ***The Mid-continent rift (1.1 Ga)***
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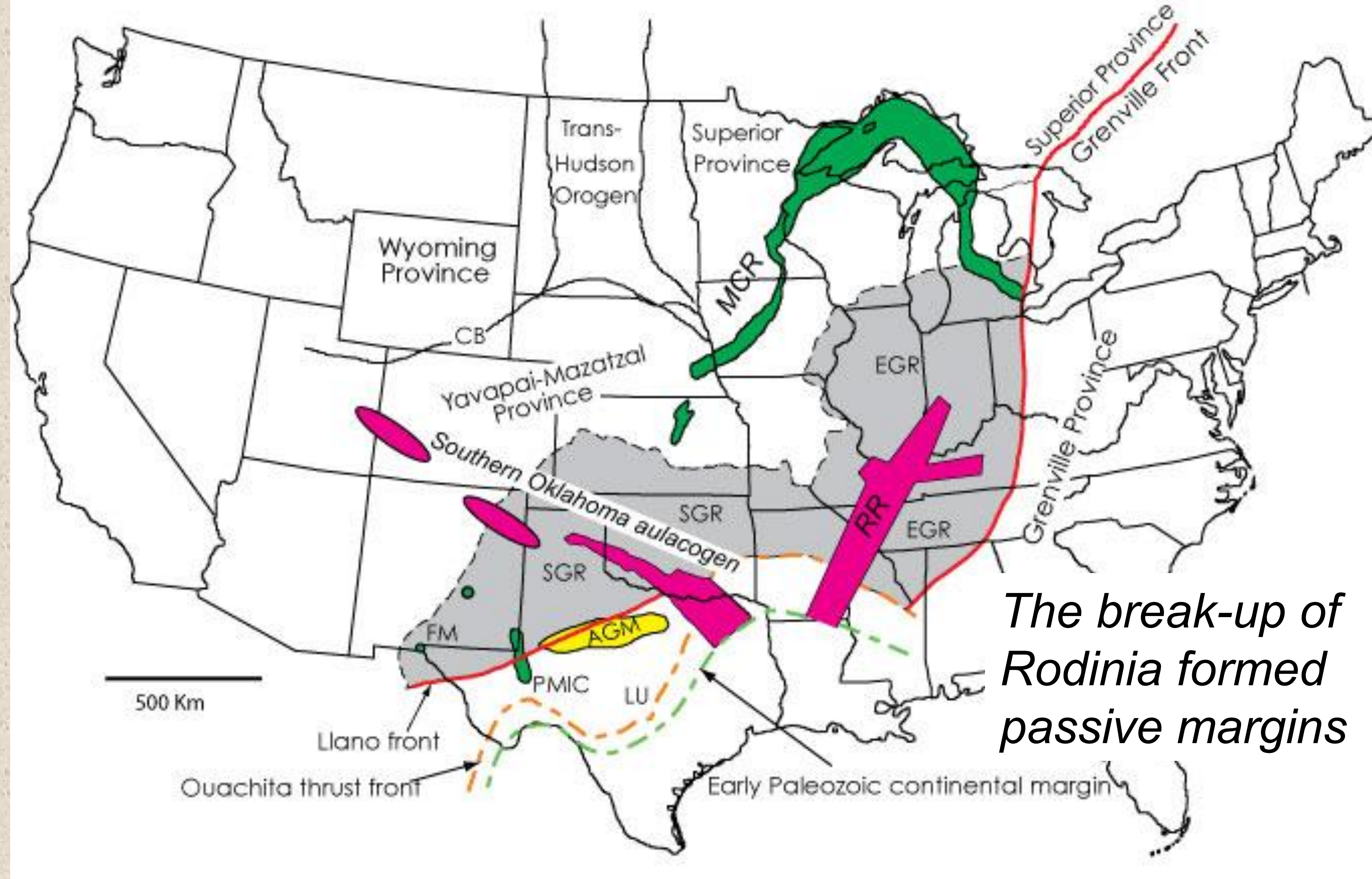
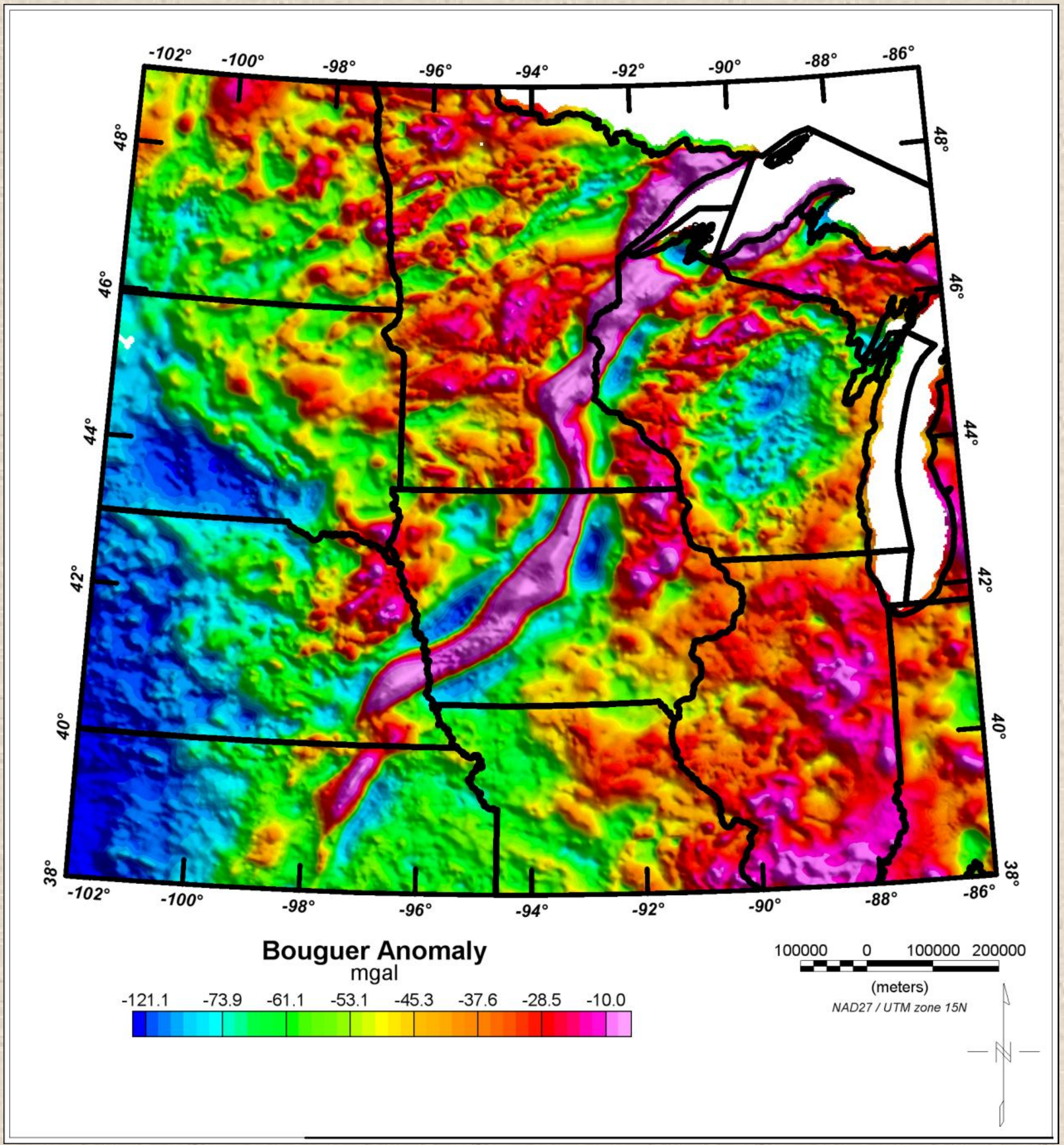
Central U. S. Late Precambrian Structural Framework (1.1 Ga and Cambrian rifts)



The break-up of Rodinia formed passive margins

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



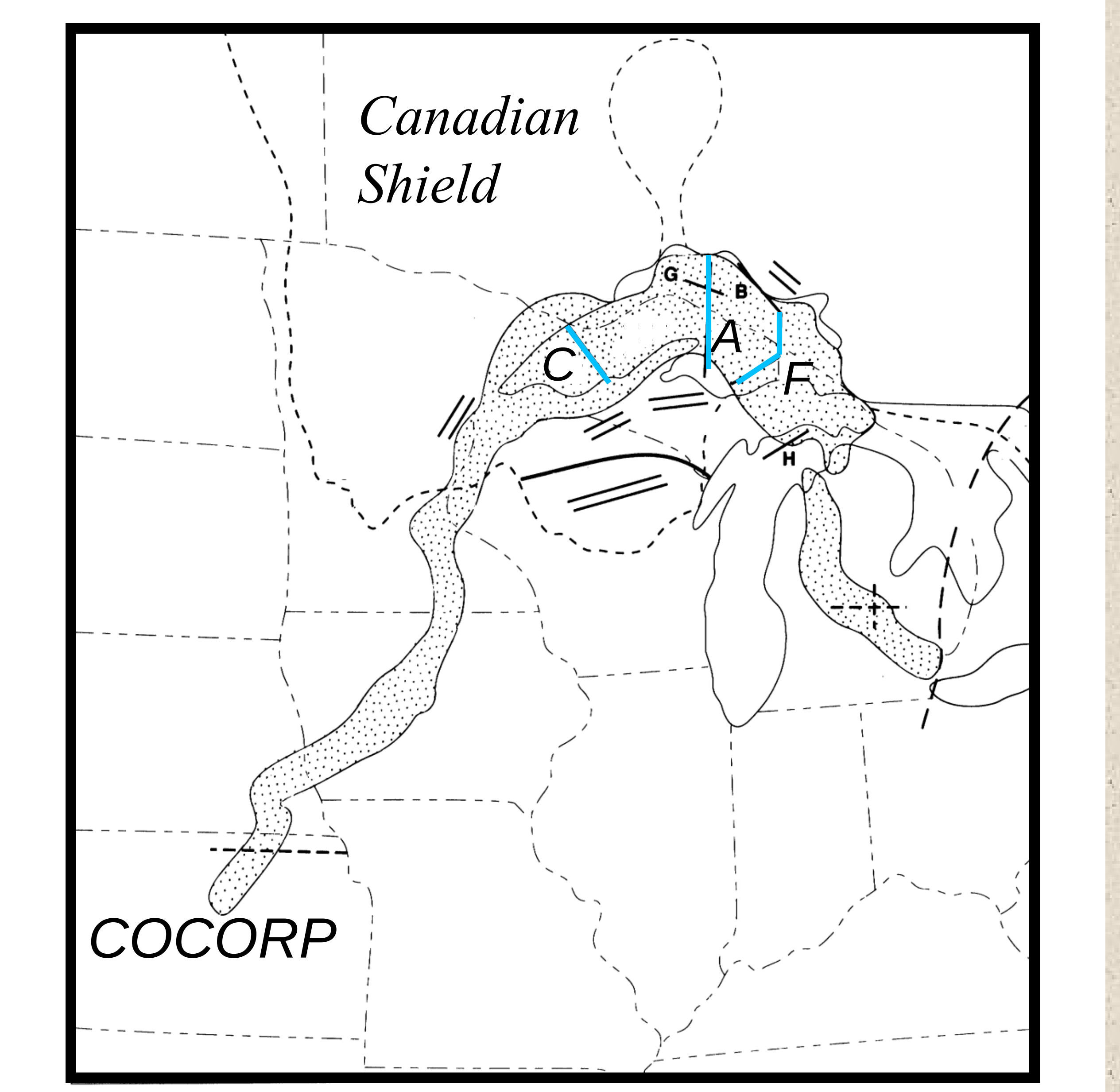
Complete Bouguer Anomaly Map of the Northern Mid-Continent Region.

The 1.1-Ga Mid-Continent Rift is the dominant feature.

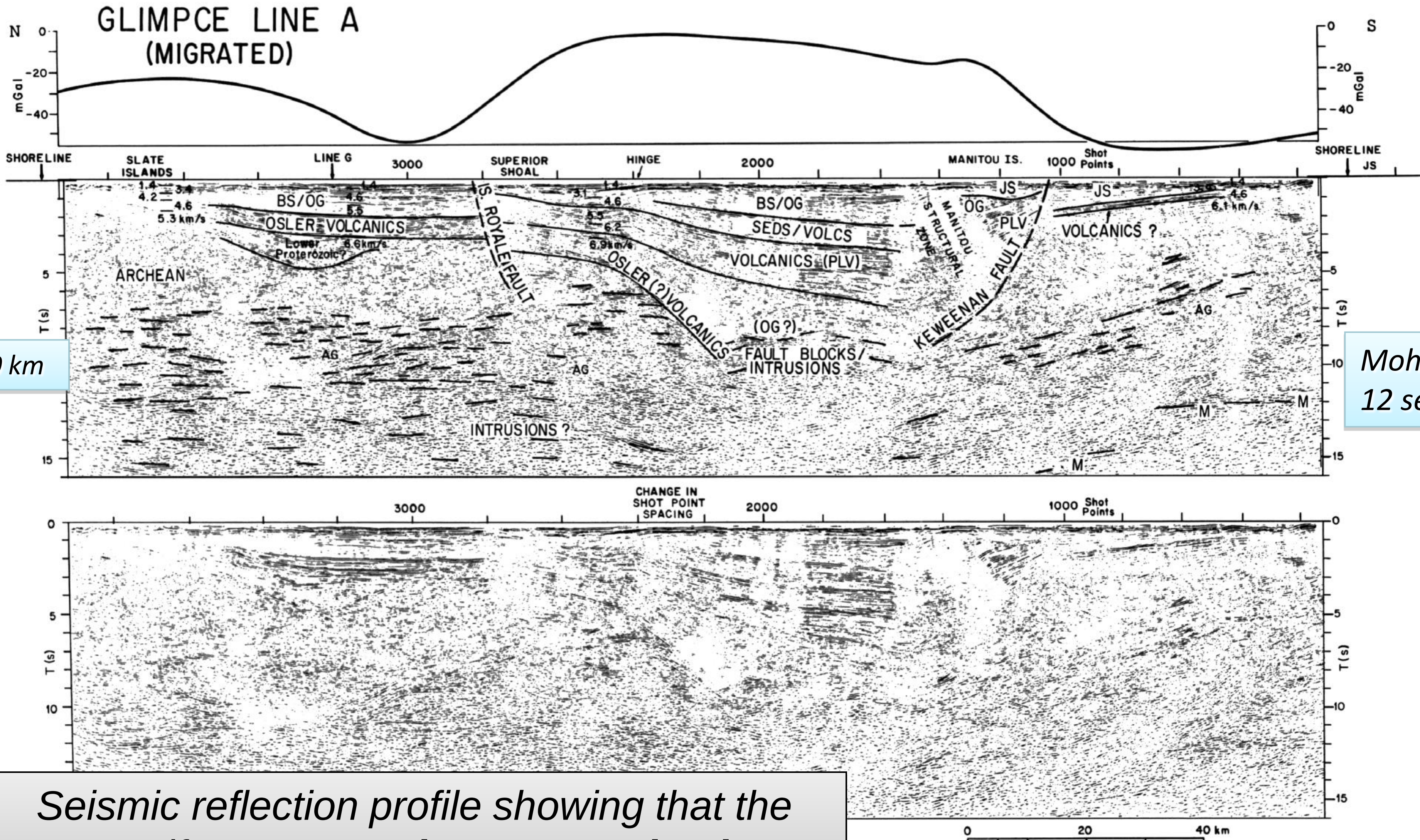
This event overlaps the Grenville Orogeny in time to some extent.

GLIMPSE Experiment Index Map

GLIMPSE was a large international cooperative seismic experiment that featured the acquisition of multi-channel reflection data in the Great Lakes



GLIMPSE – Line A

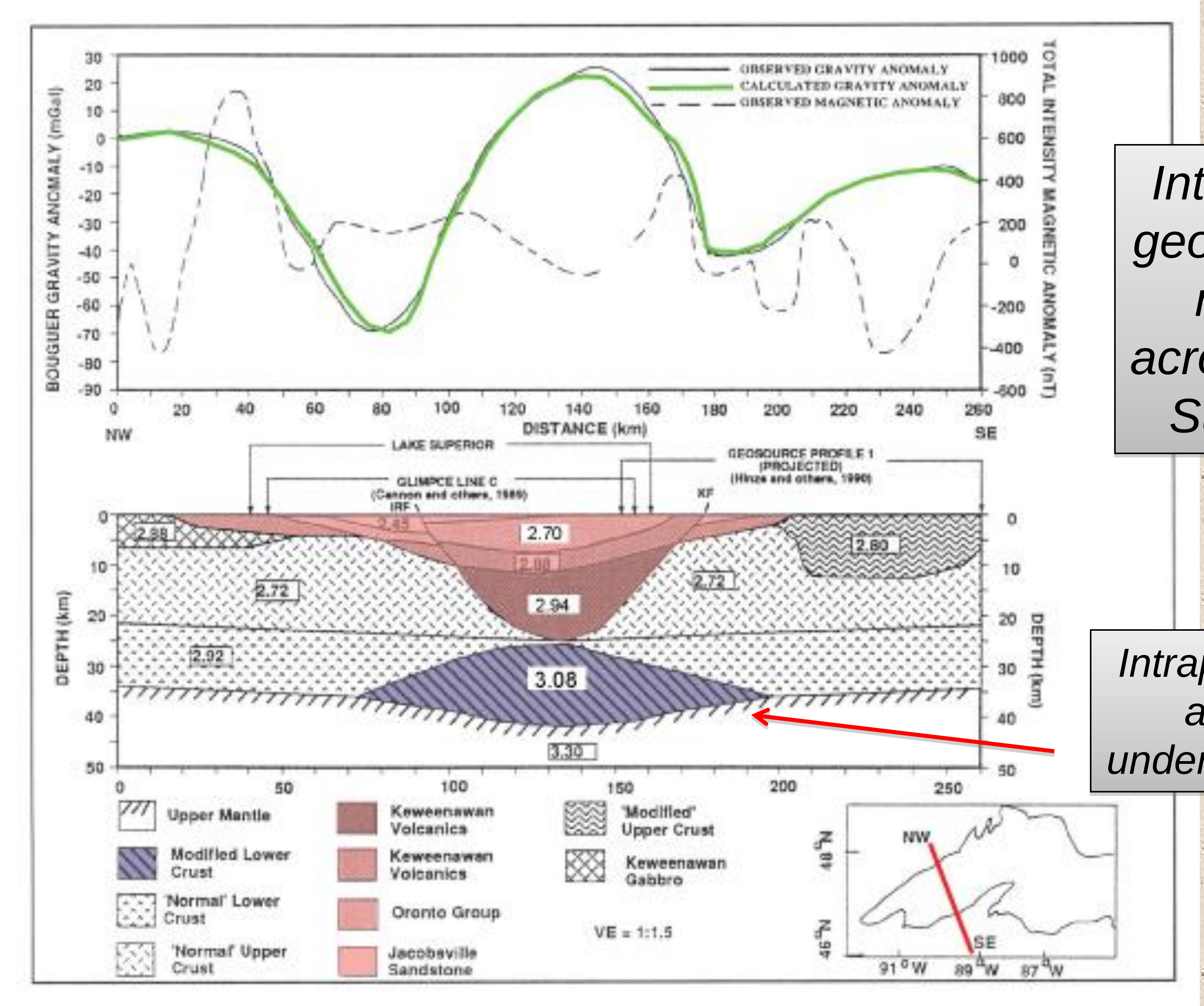


30 km

Moho 12 sec

*Seismic reflection profile showing that the pre-rift crust was **almost completely destroyed**. However, the rift failed. **Why?***

Provided by Bill Cannon (USGS)



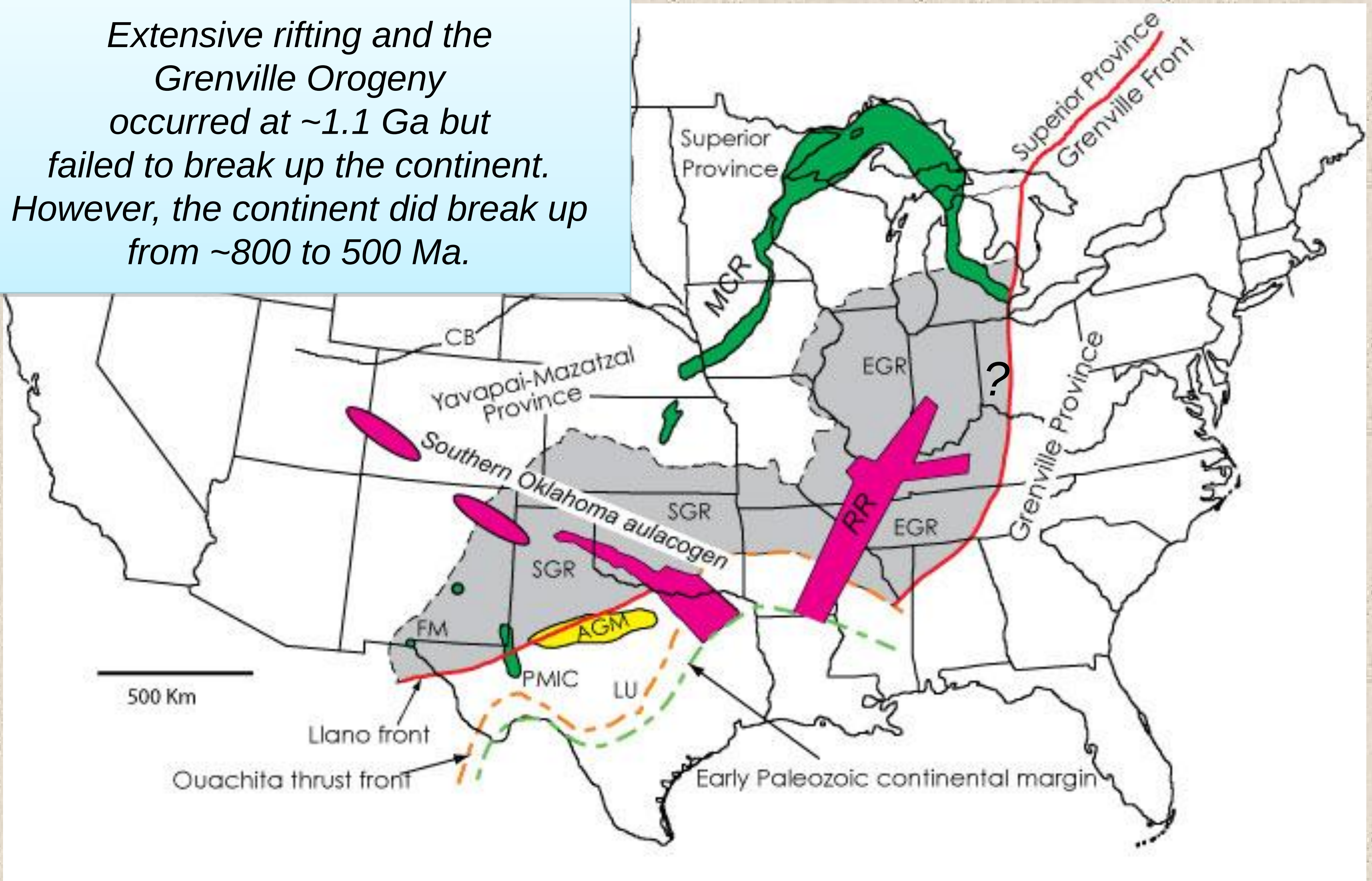
Integrated geophysical model across Lake Superior

Intraplating and underplating

Hinze et al. (1997)

What Happens to the East and Further South?

Extensive rifting and the
Grenville Orogeny
occurred at ~1.1 Ga but
failed to break up the continent.
However, the continent did break up
from ~800 to 500 Ma.



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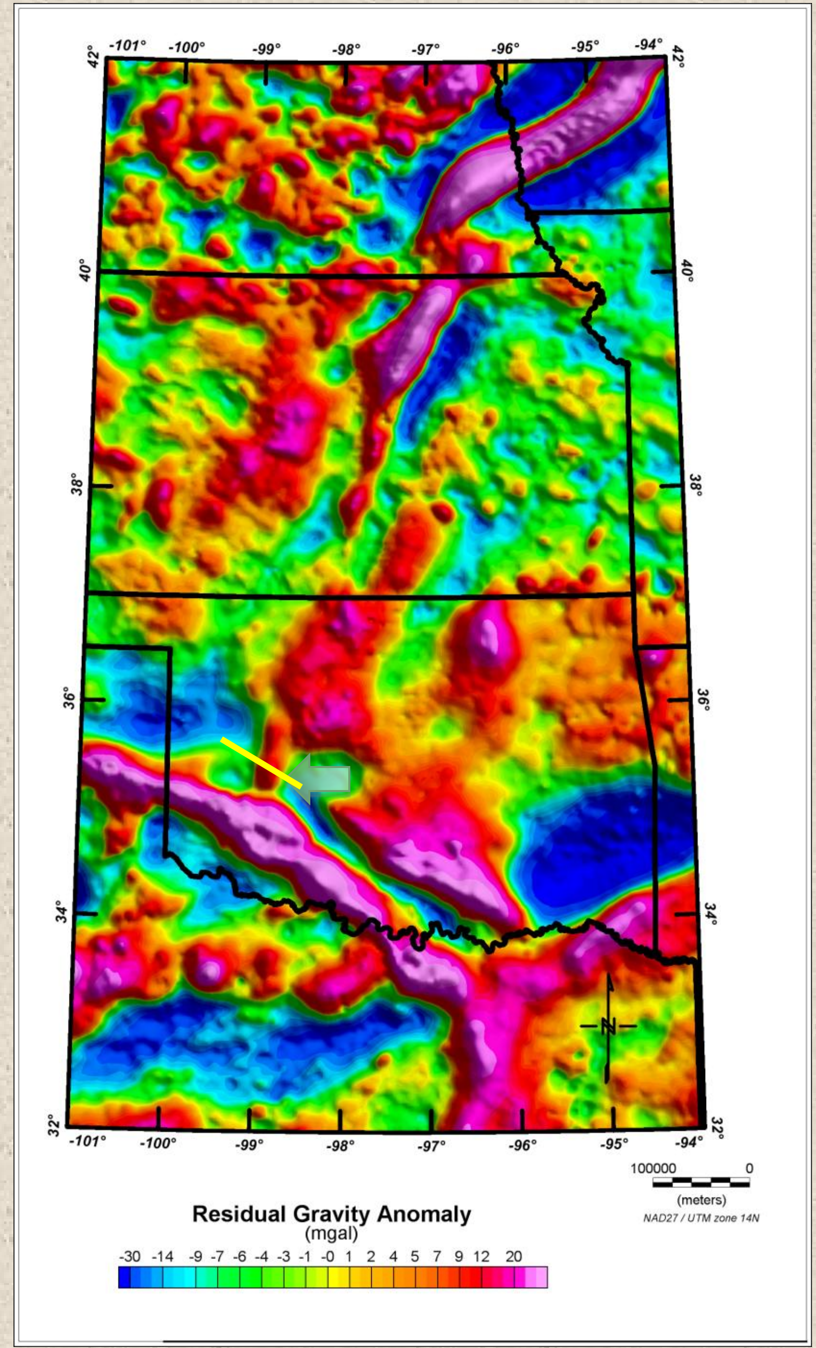
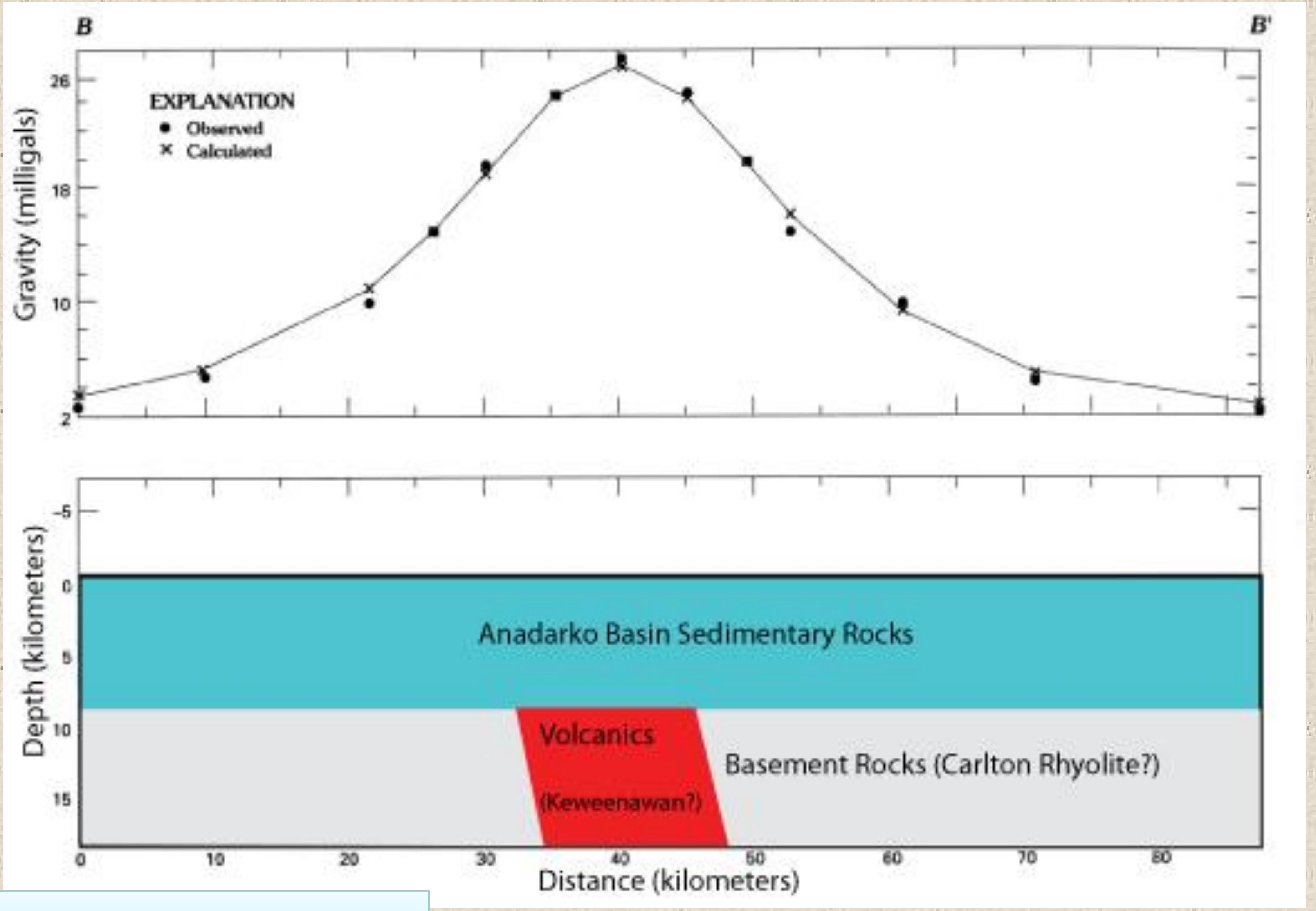


Residual Gravity map

This map enhances some shorter-wavelength features. It clearly suggests that the Mid-Continent rift system extends across southern Kansas and northern Oklahoma.

The gravity relief across the N-S trending anomalies in Oklahoma is still 25 mGal, and these anomalies mask the effect of the Anadarko basin!

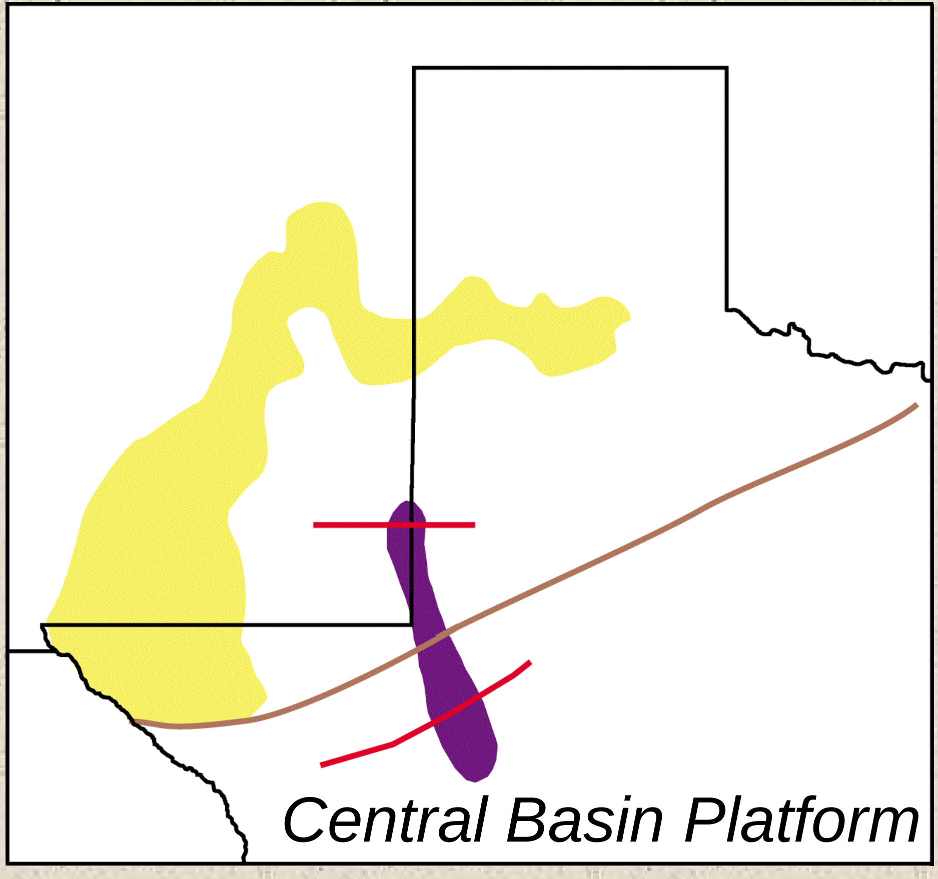
Southern Extension of the MCR?

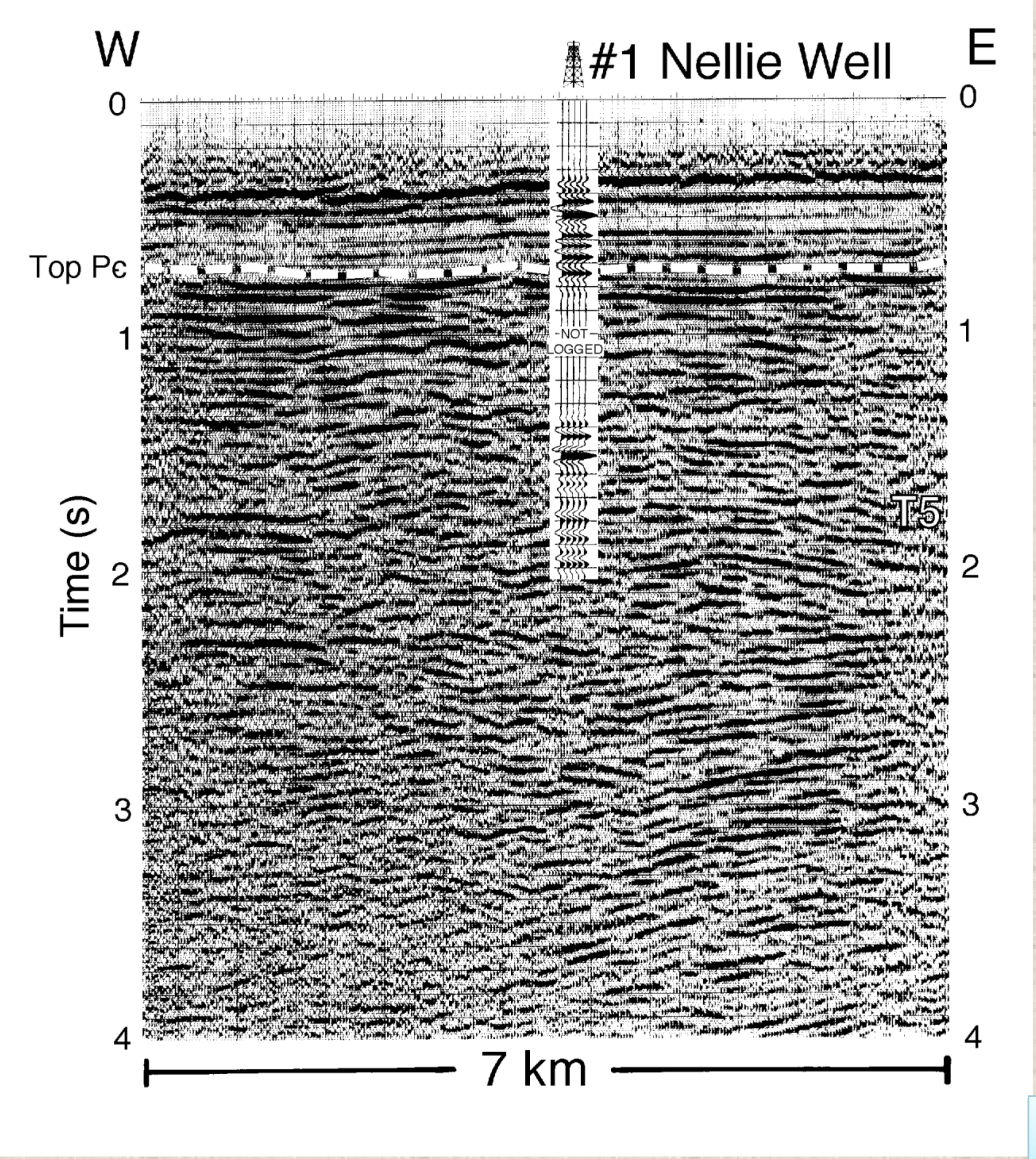


Robbins and Keller (1992)

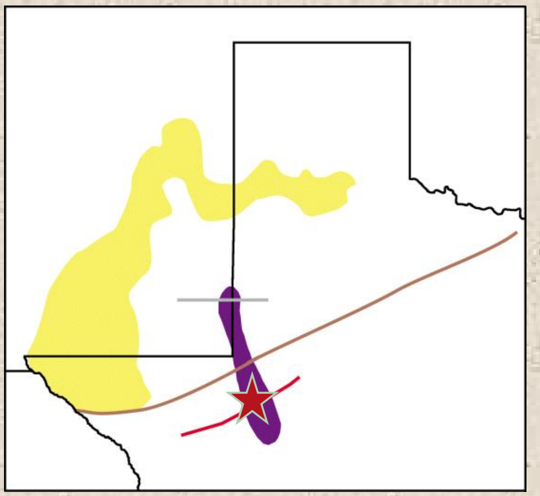
Did it go even further south?
Pecos Mafic Intrusive Complex (the core of the Central Basin Platform)

- A buried layered igneous complex
- ~1.1 Ga in age
- Seismic layering - a response to cumulate layering
- Gravity models constrain size of the complex
- Acted as the core of the Central Basin platform





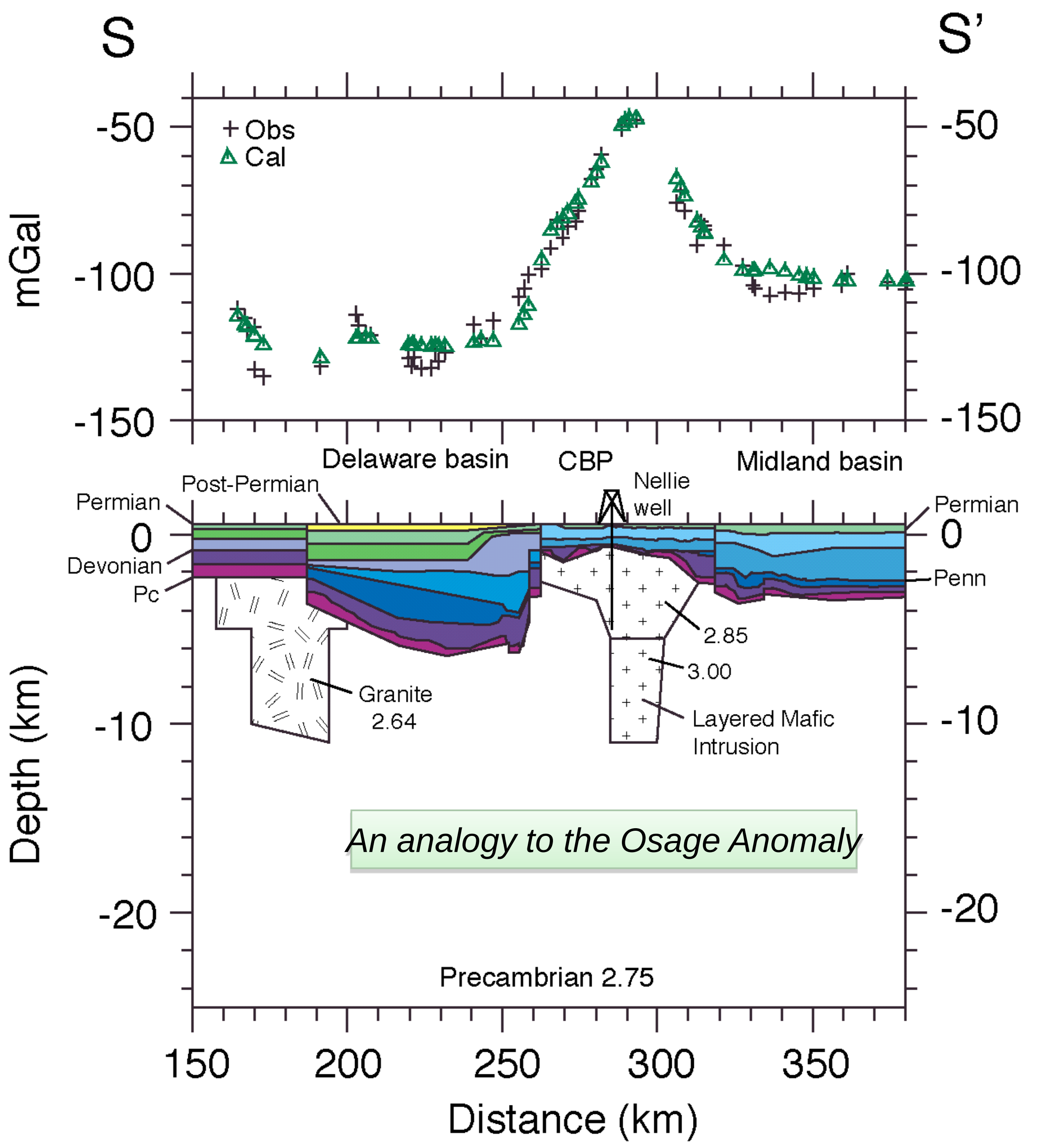
#1 Nellie Well



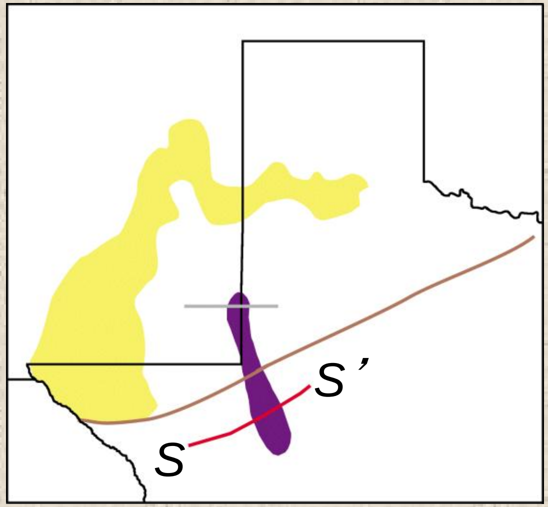
A cautionary tail; all layered sequences are not sedimentary

Adams and Miller, 1995

PMIC Gravity Model

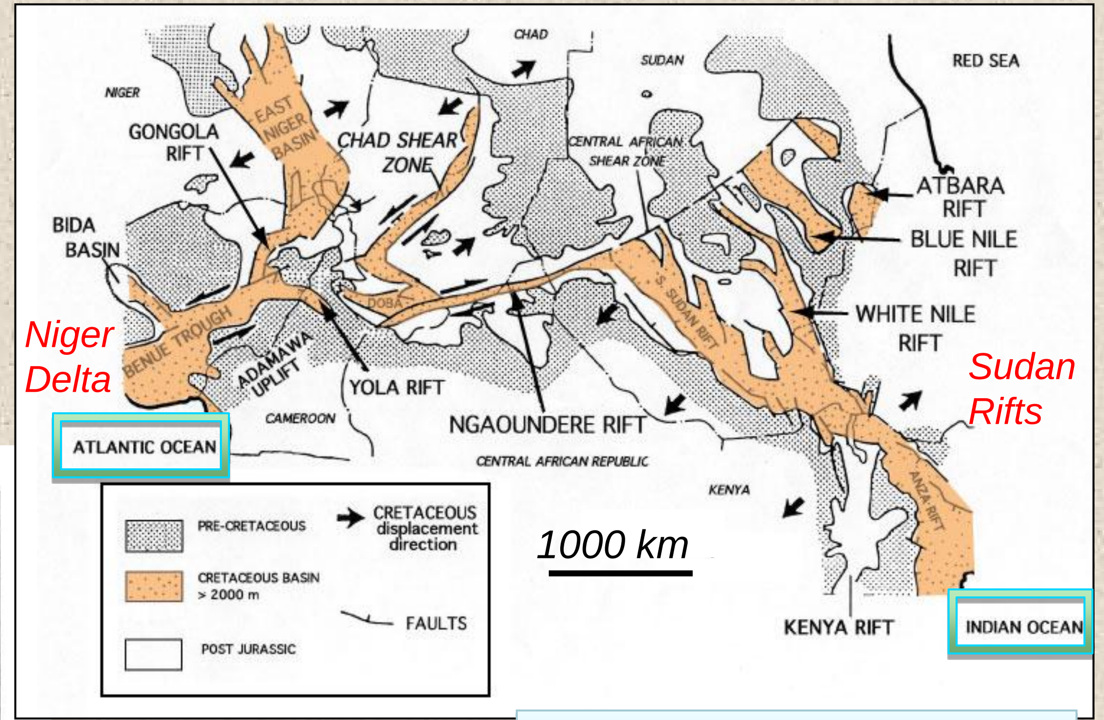


An analogy to the Osage Anomaly

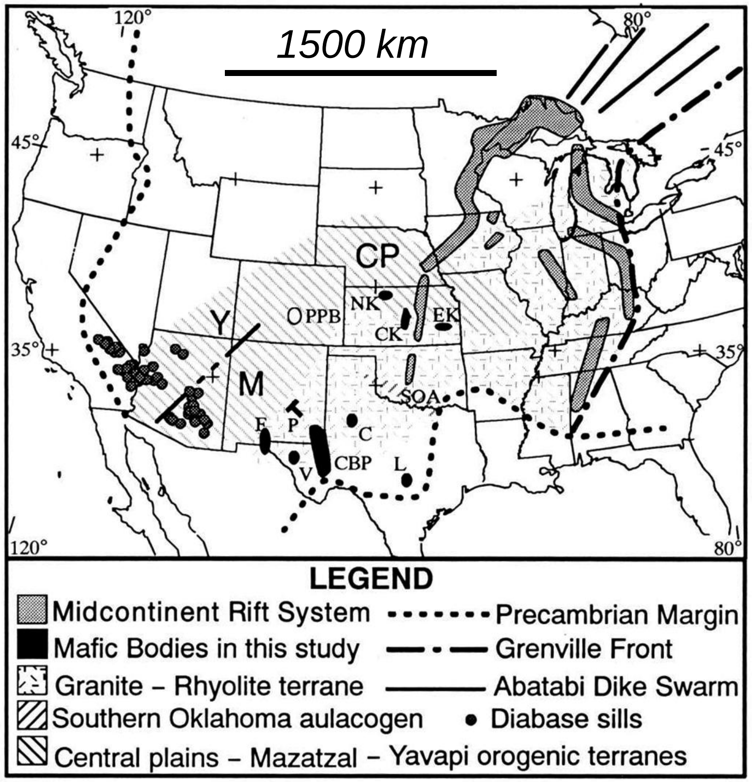


Adams and Keller 1996

Mid-Continent and West and Central Africa Rift Systems



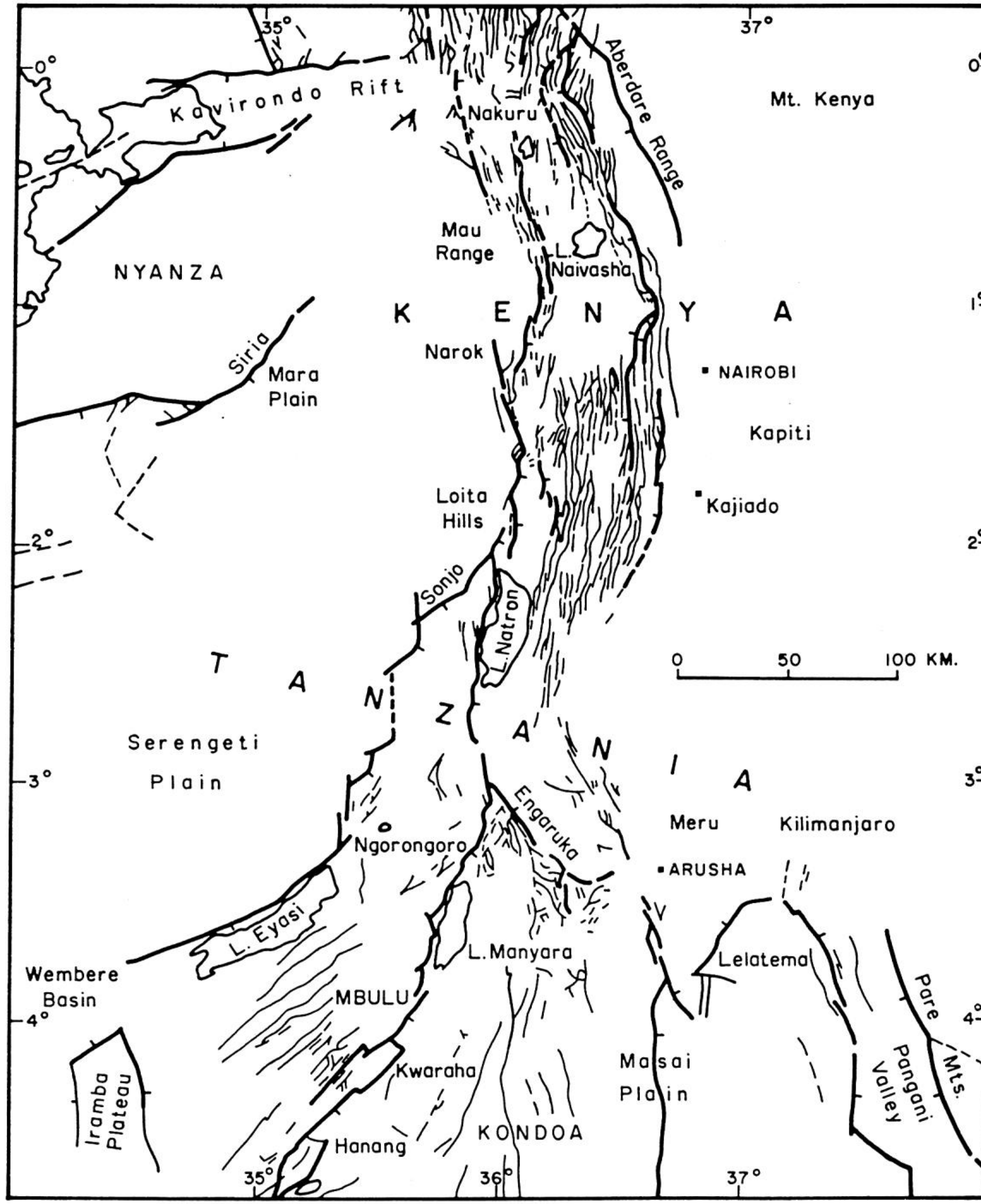
Fairhead and Green (1989)



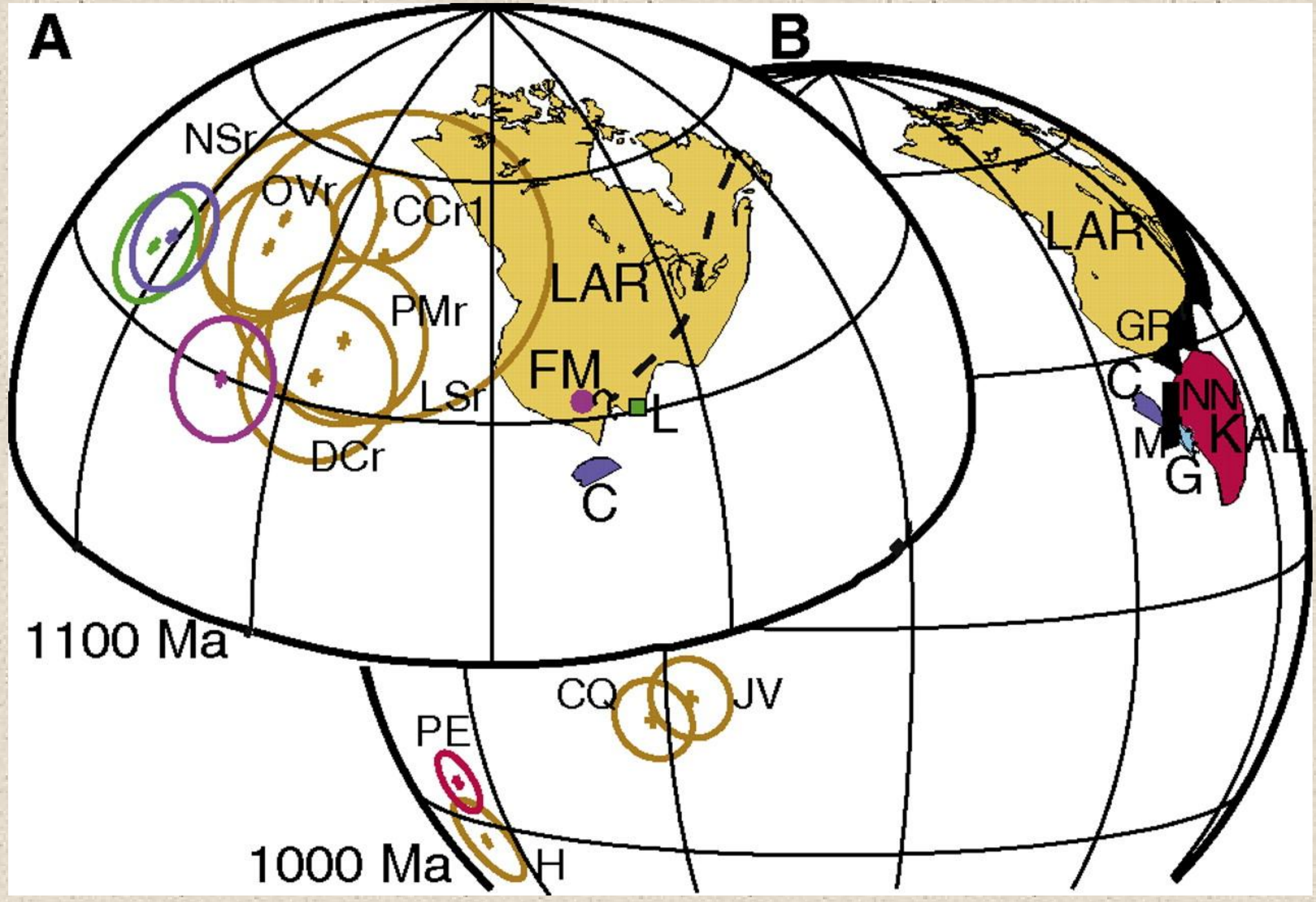
Adams and Keller (1994)

WCARS provides an interesting analog for the Mid-Continent Rift. Both are of similar scale and nearly tore their respective continents apart.

What the deep structure in Kansas and Central Oklahoma might have looked like 1100 million years ago!



*Reconstructions in present-day North American coordinates demonstrating general compatibility of paleomagnetic data. **A**: With geological restoration of Coats Land crustal block against southern Laurentia (LAR) near the southwestern termination of Midcontinent rift system ca. 1100 Ma (dashed black line shows approximate position of future Grenville front;. **B**: With inferred juxtaposition of Kalahari (KAL) and LAR–Coats Land across the Maud belt ca. 1000 Ma. C (dark blue)—Coats Land crustal block; FM (red dot)—Franklin Mountains; L (green square)—Llano. Poles are color coded with continent or terrane of origin.*



Loewy et al. (2011) Geology

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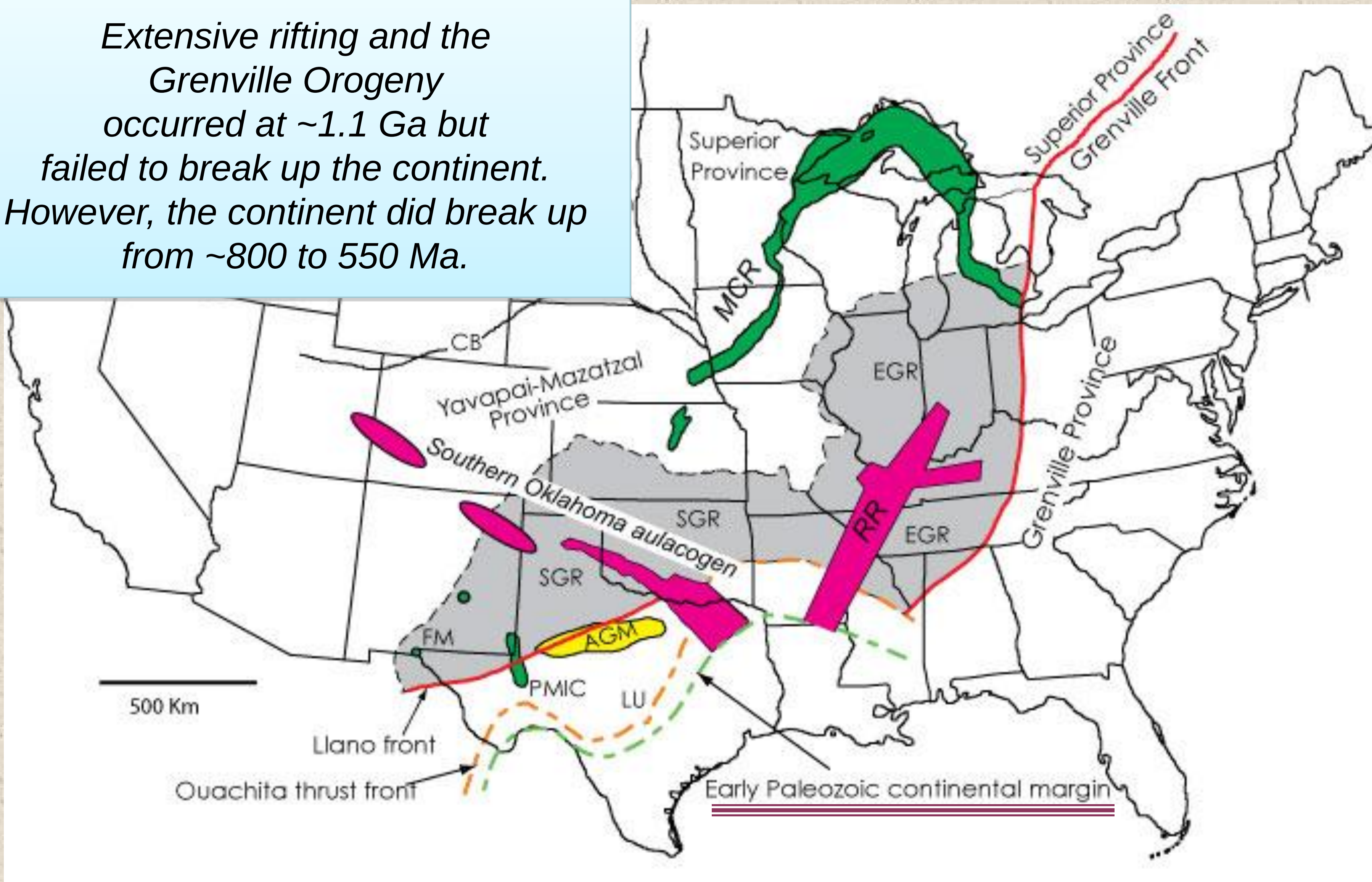

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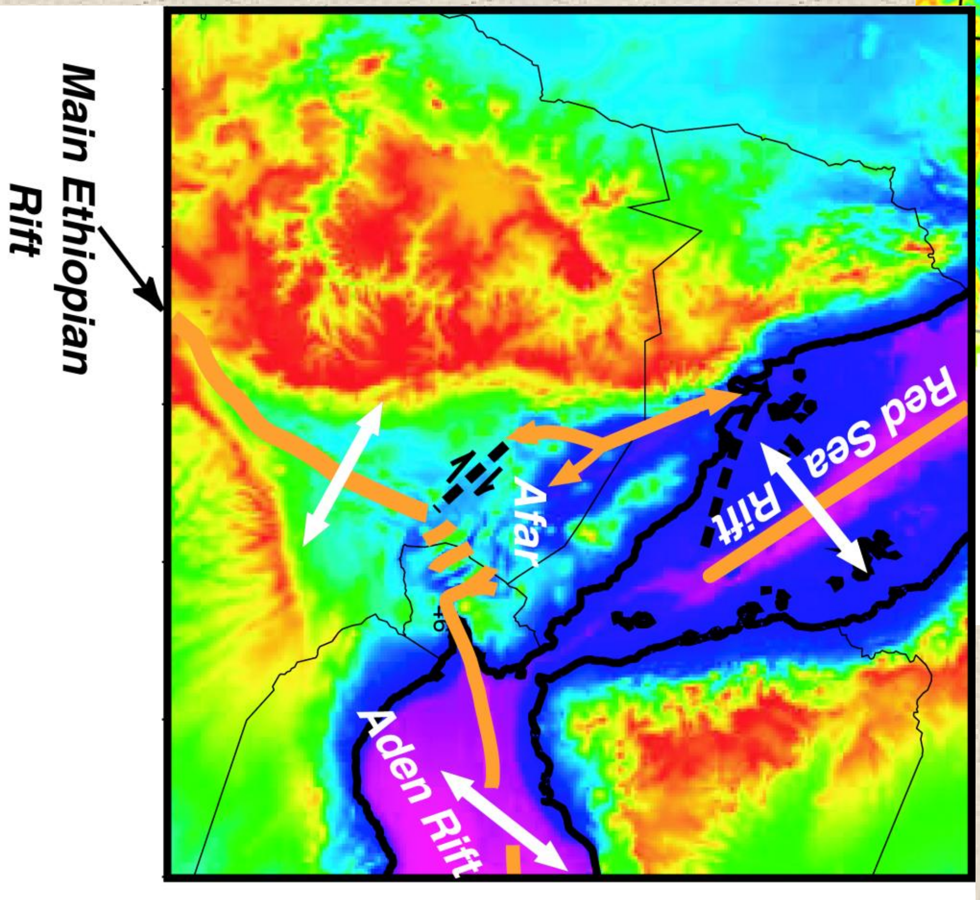
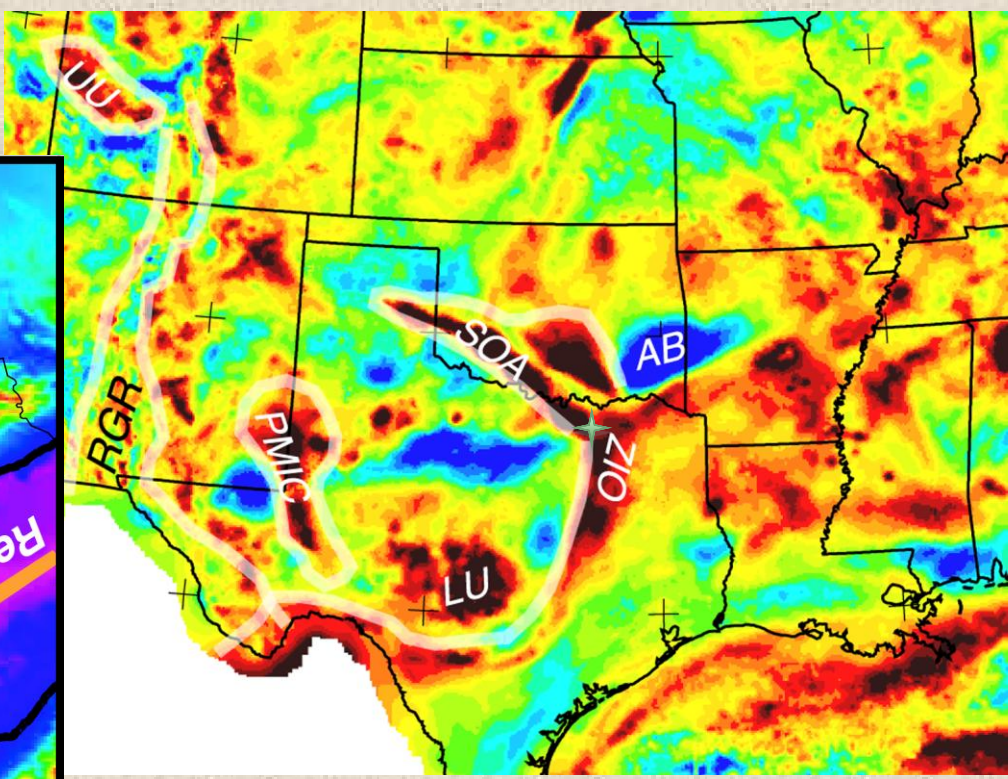
Afar vs. SOA Triple Junctions

The scales are approximately the same

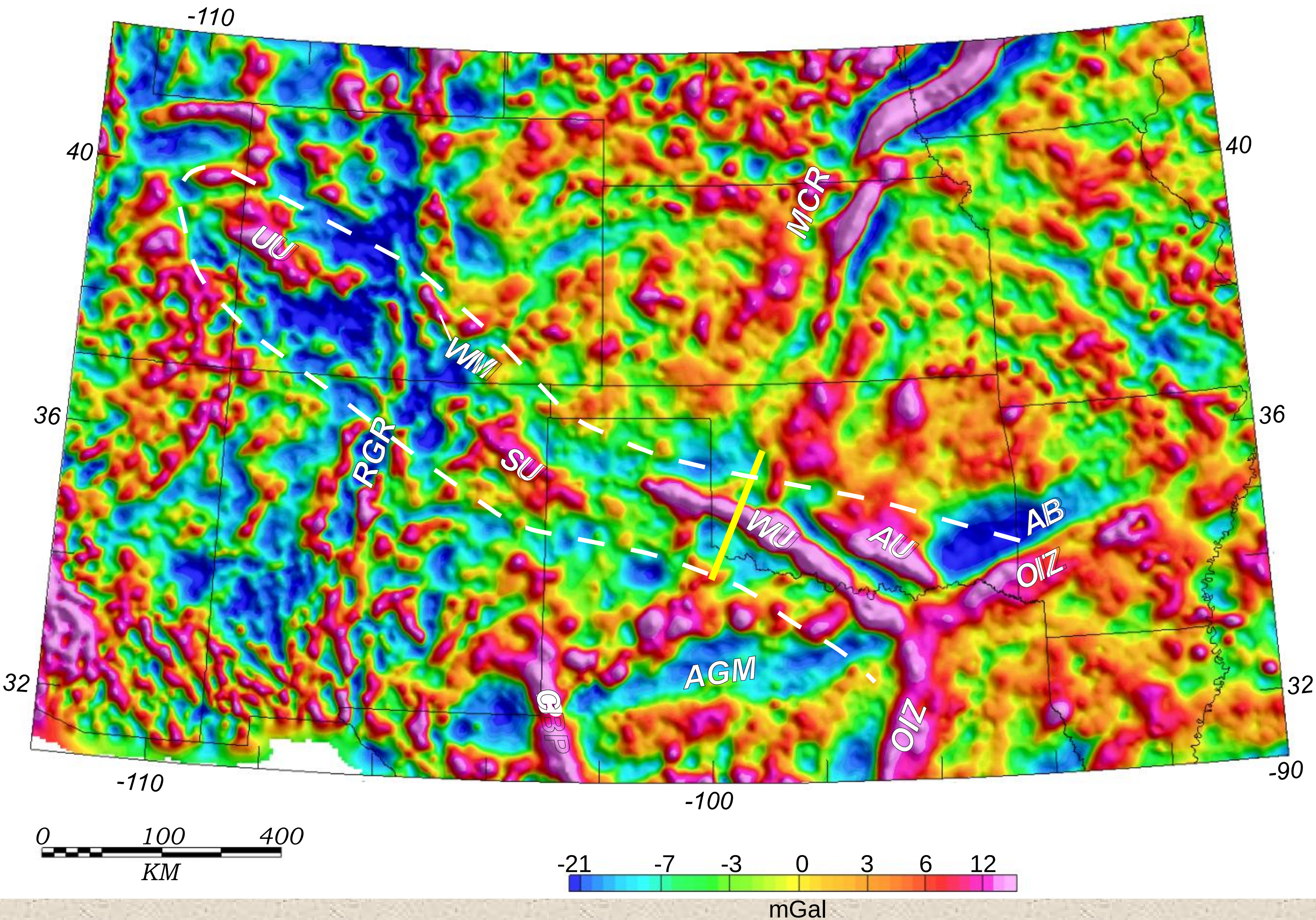
From the mouth of Afar to Tanzania ~1500 km





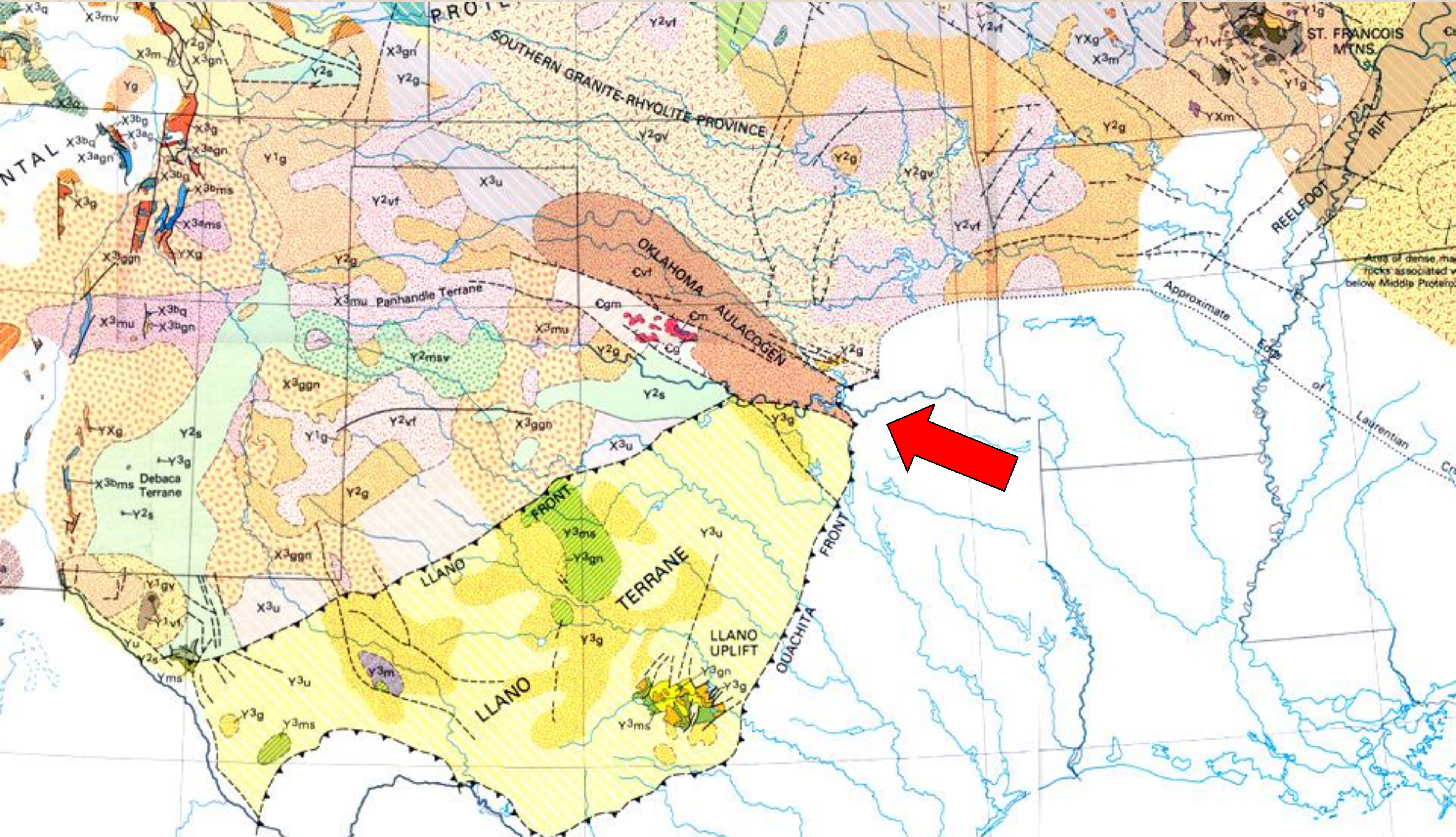
From the SOA triple junction to the UU ~1500 km

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




N
Ron Blakey-NAU

Oklahoma-Texas region basement



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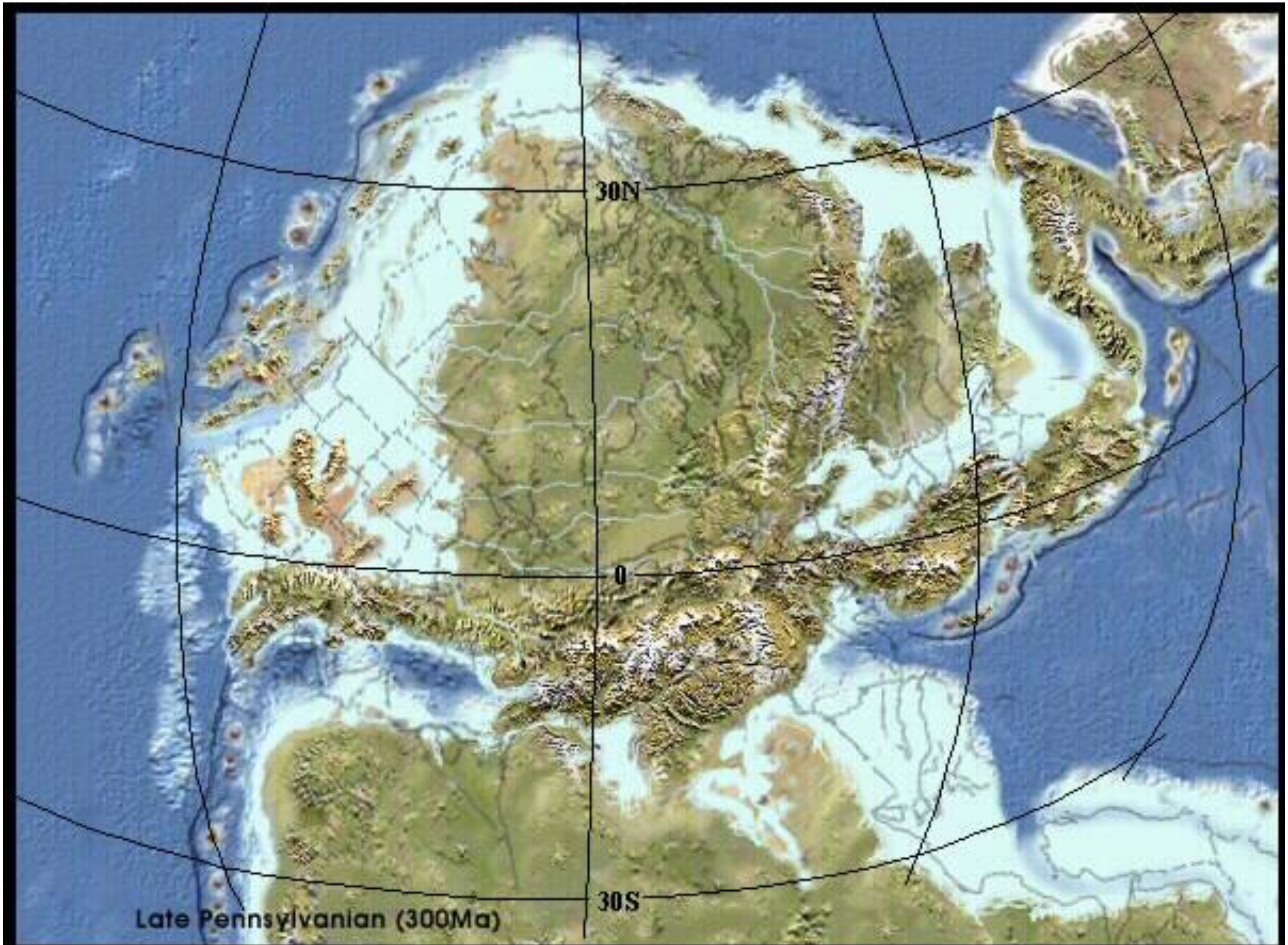
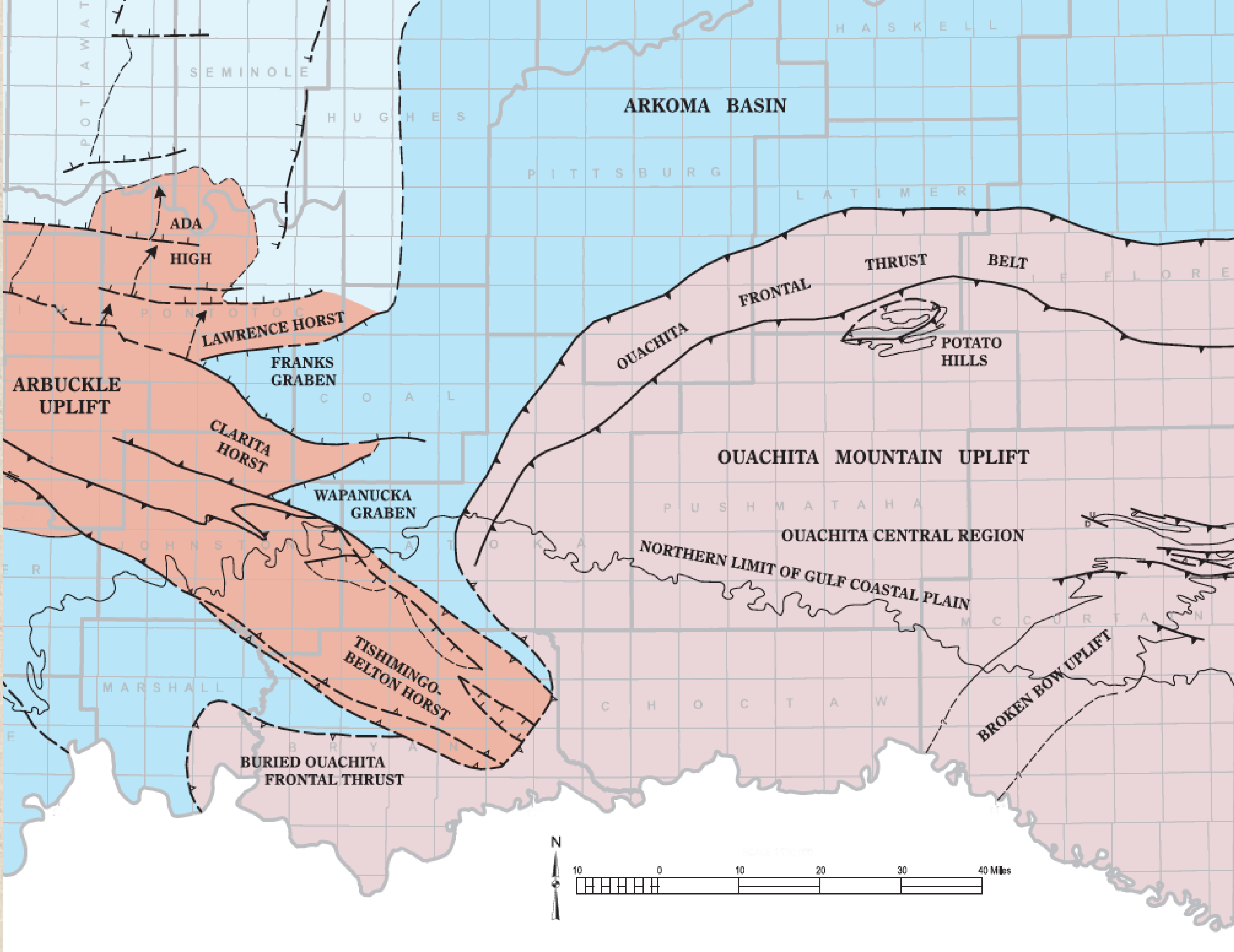
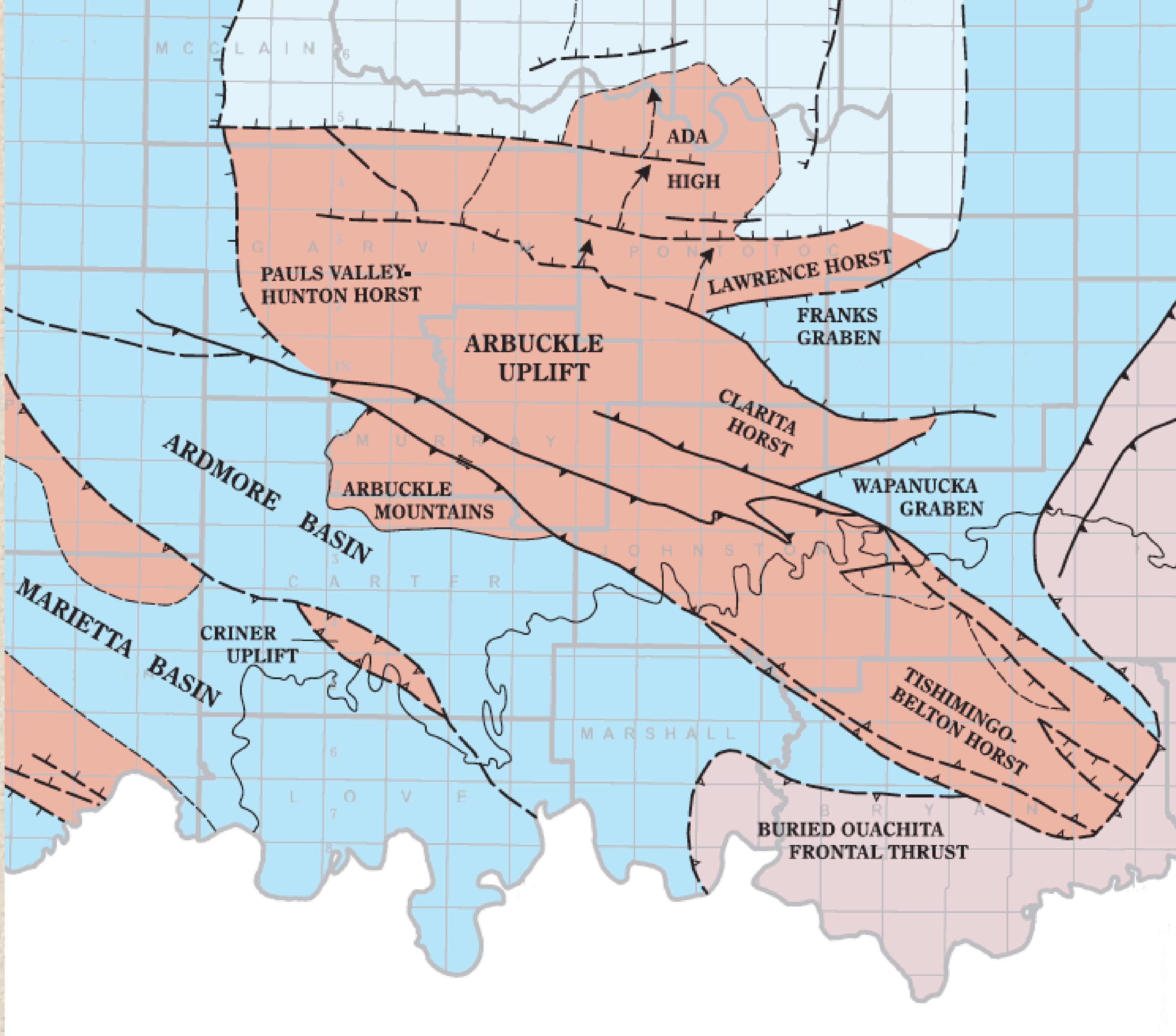
Appalachian - Ouachita - ARM Orogeny



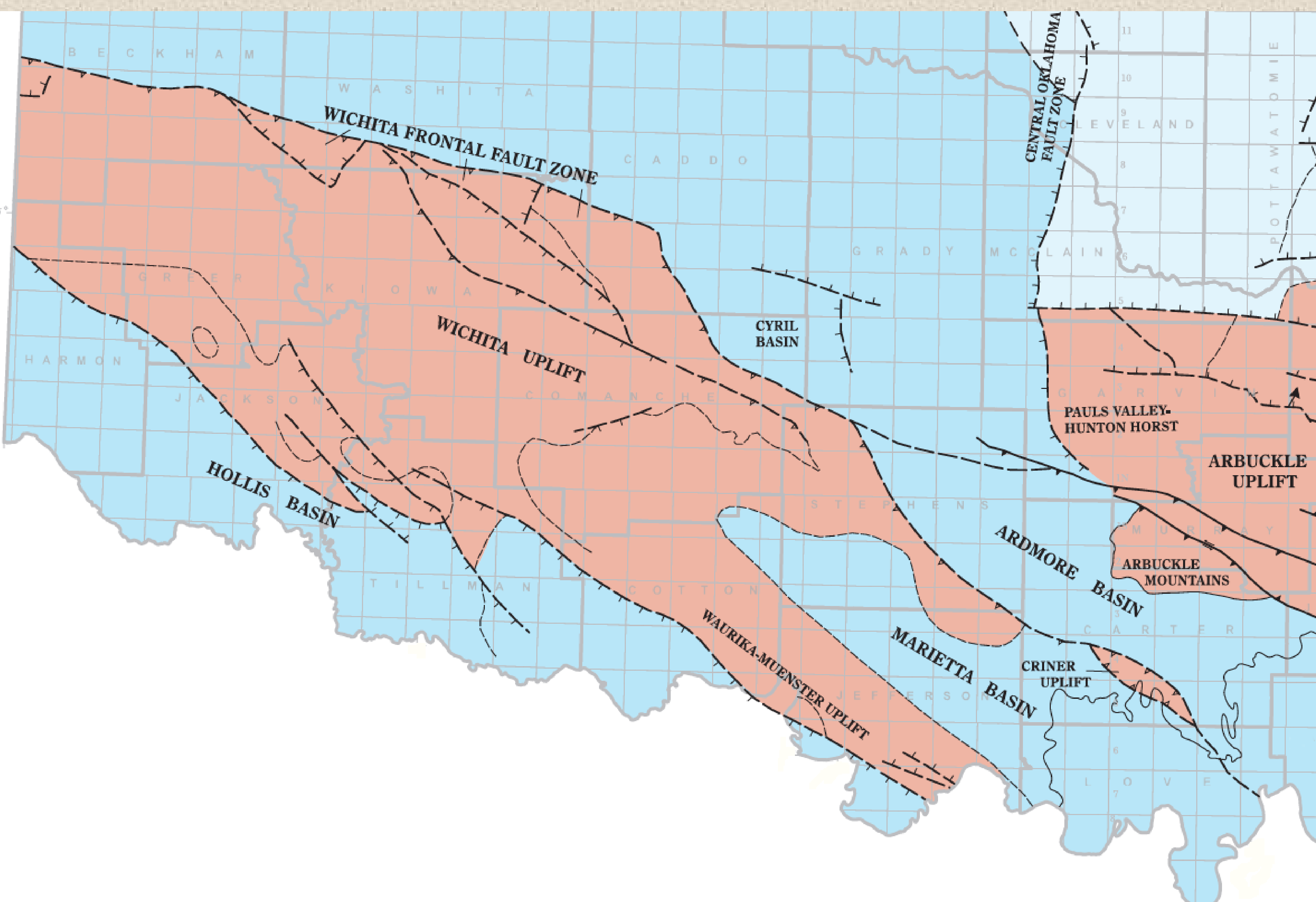
Ron Blakey NAU



ARKOMA BASIN
HASKELL
SEMINOLE
POTTAWATOMIE
HUGHES
PITTSBURG
LATIMER
LE FLORE
PONTOTOC
COAL
ATOKA
JOHNSTON
MARSHALL
BRYAN
CHOCTAW
PUSHMATAHA
MCCURTAIN
ADA
HIGH
LAWRENCE HORST
FRANKS
GRABEN
ARBUCKLE
UPLIFT
CLARITA
HORST
WAPANUCKA
GRABEN
TISHIMINGO-
BELTON HORST
BURIED OUACHITA
FRONTAL THRUST
OUACHITA FRONTAL THRUST BELT
POTATO
HILLS
OUACHITA MOUNTAIN UPLIFT
OUACHITA CENTRAL REGION
NORTHERN LIMIT OF GULF COASTAL PLAIN
BROKEN BOW UPLIFT
N
10 0 10 20 30 40 Miles



MCCLAIN
ADA
HIGH
GARVIN
PONTOTOC
PAULS VALLEY-
HUNTON HORST
LAWRENCE HORST
FRANKS
GRABEN
ARBUCKLE
UPLIFT
CLARITA
HORST
MURRAY
ARDMORE
BASIN
ARBUCKLE
MOUNTAINS
WAPANUCKA
GRABEN
JOHNSTON
CARTER
MARIETTA
BASIN
CRINER
UPLIFT
TISHIMINGO-
BELTON HORST
MARSHALL
LOVE
BRYAN
BURIED OUACHITA
FRONTAL THRUST

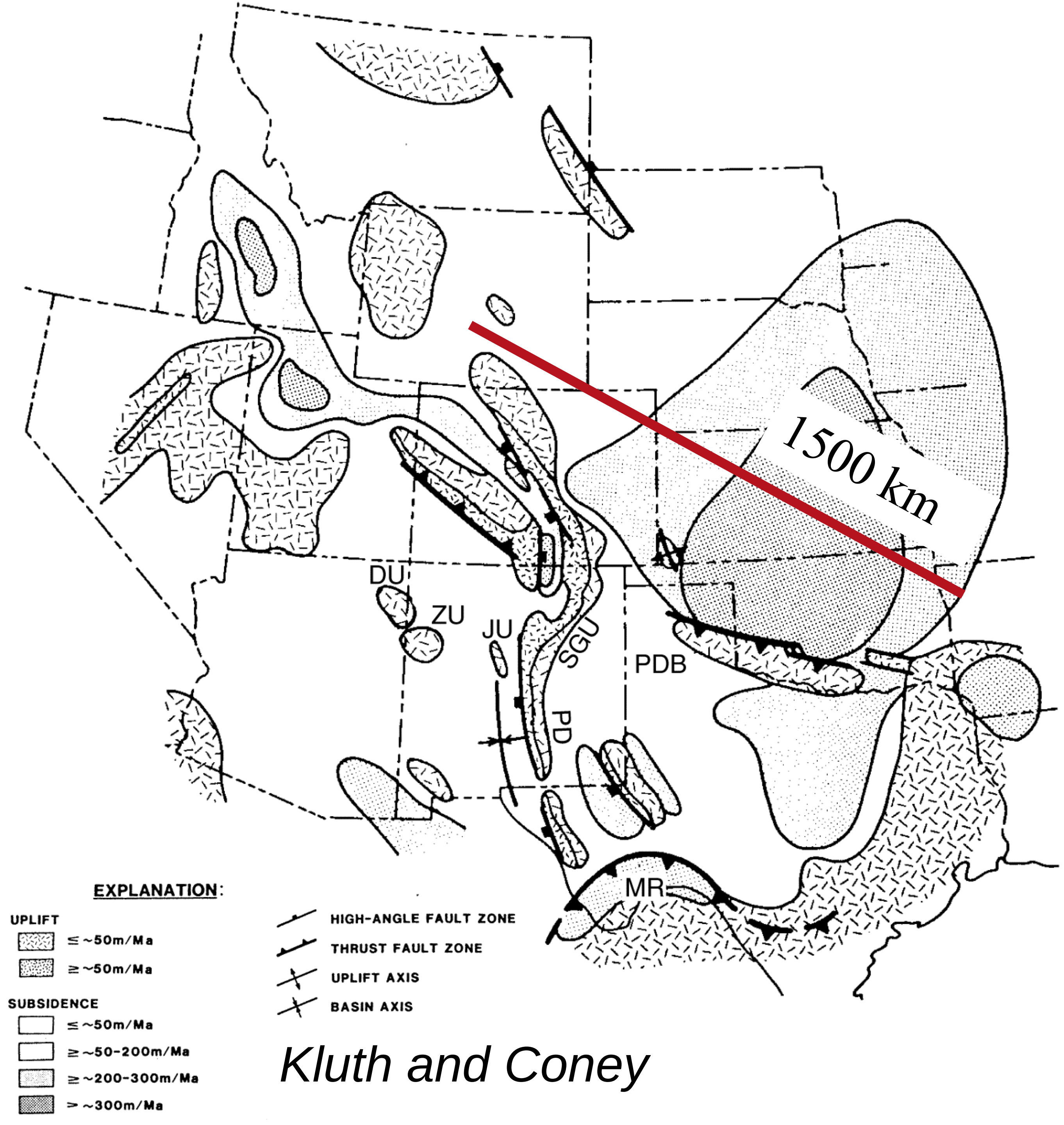


WICHITA FRONTAL FAULT ZONE
CENTRAL OKLAHOMA FAULT ZONE
CYRIL BASIN
WICHITA UPLIFT
HOLLIS BASIN
PAULS VALLEY-HUNTON HORST
ARBUCKLE UPLIFT
ARDMORE BASIN
ARBUCKLE MOUNTAINS
MARIETTA BASIN
CRINER UPLIFT
WAURIKA-MUENSTER UPLIFT
BECKHAM
WASHITA
CADDO
GRADY
MCCLAIN
CLEVELAND
POTTAWATOMIE
GREER
KIOWA
HARMON
JACKSON
COMANCHE
GARVIN
STEPHENS
MURRAY
TILLMAN
COTTON
CARTER
JEFFERSON
LOVE

The Ancestral Rockies

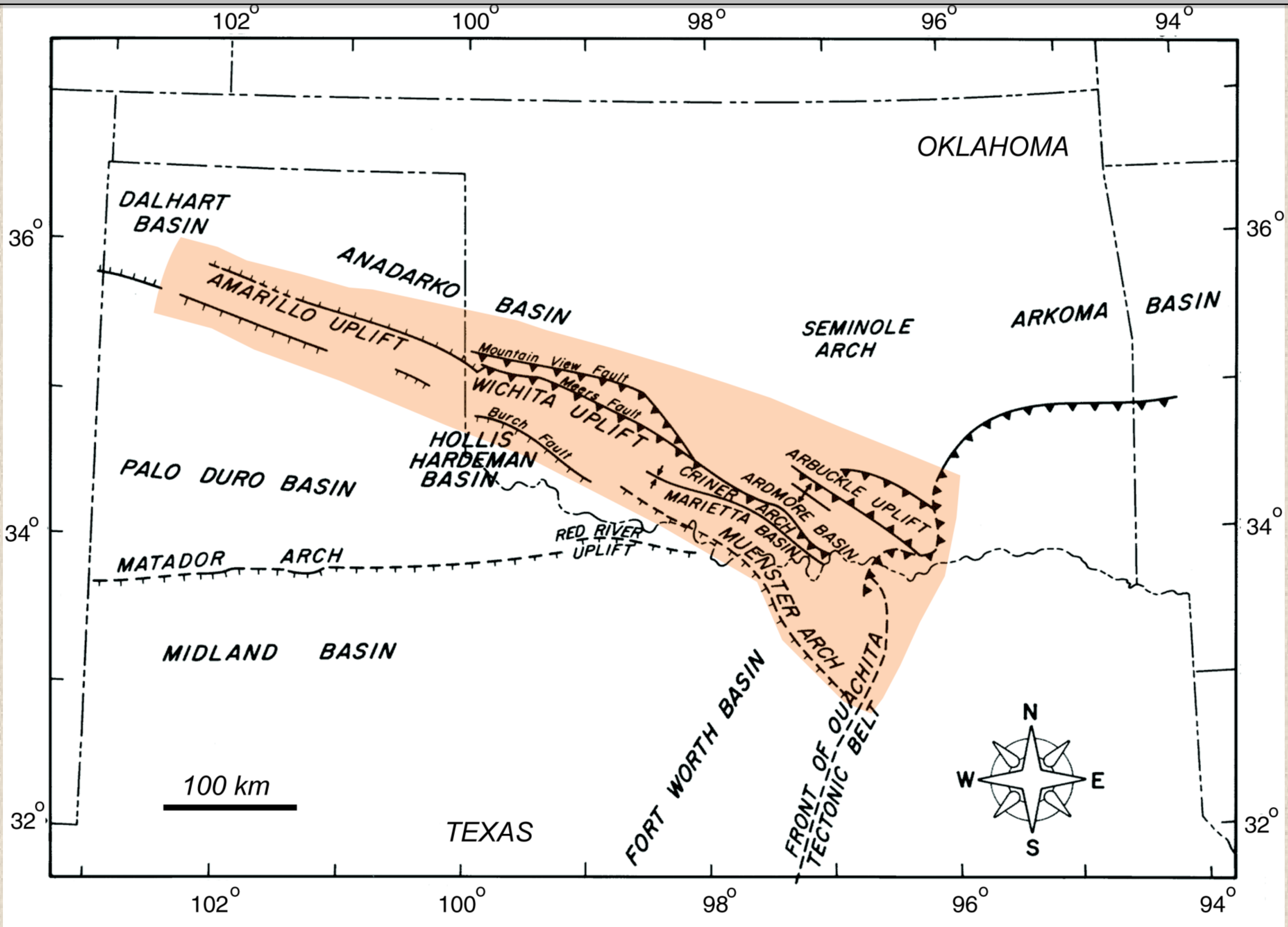
This massive Late Paleozoic intraplate deformation generally cut across Precambrian tectonic trends

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.

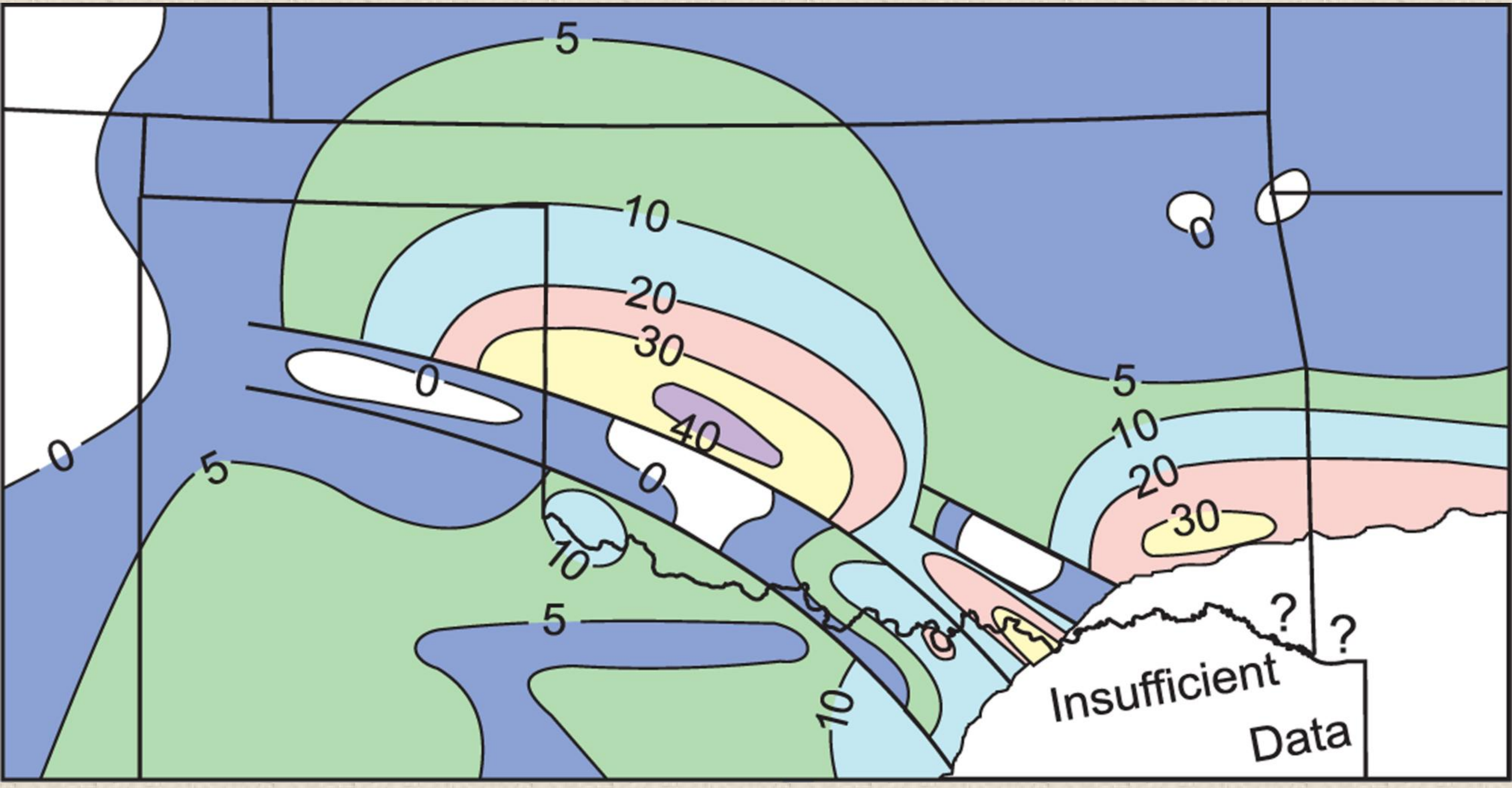


Kluth and Coney

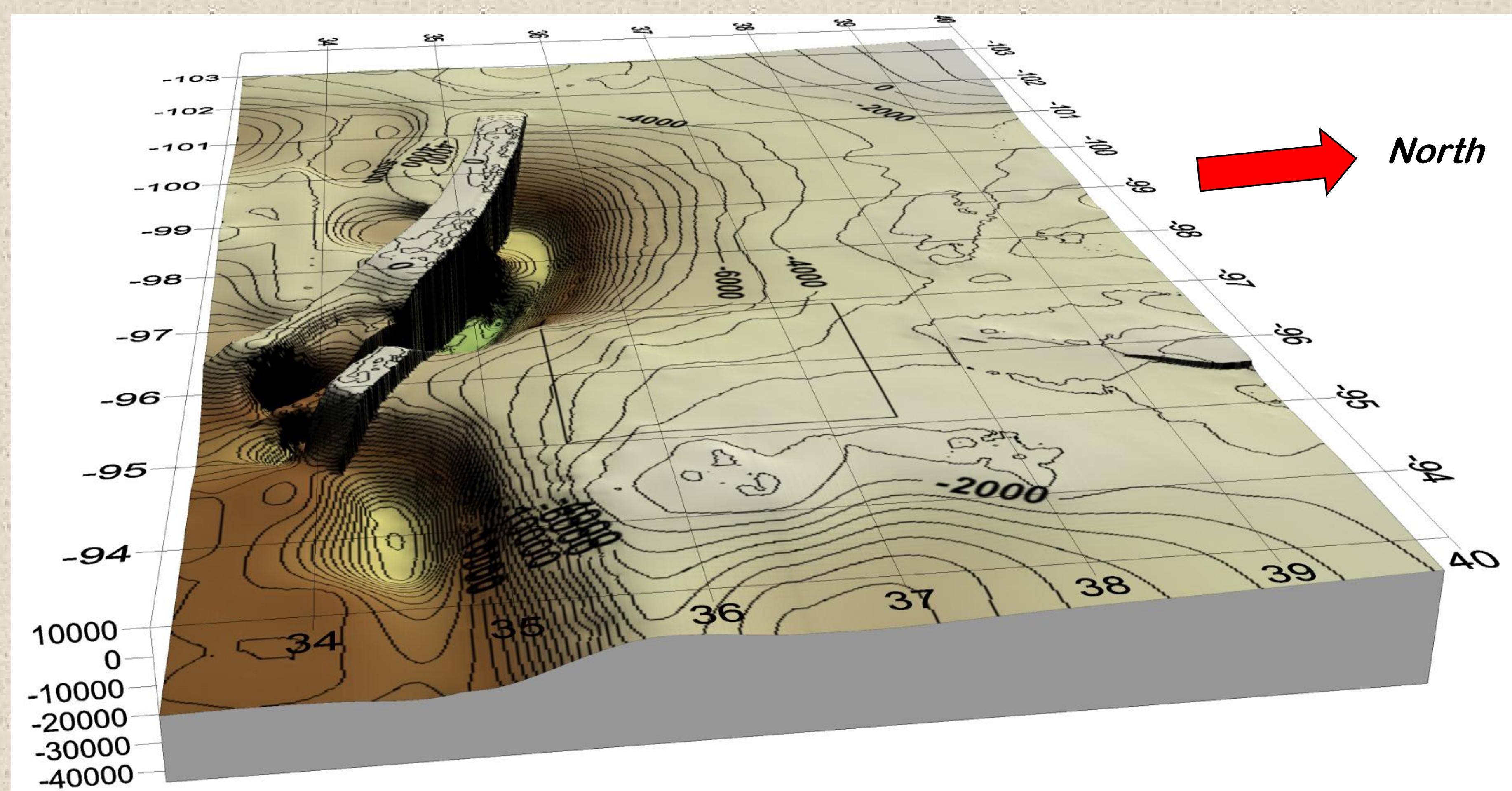
The Southern Oklahoma Aulacogen (SOA) is a classic example of a failed rift and is an ARM structure.



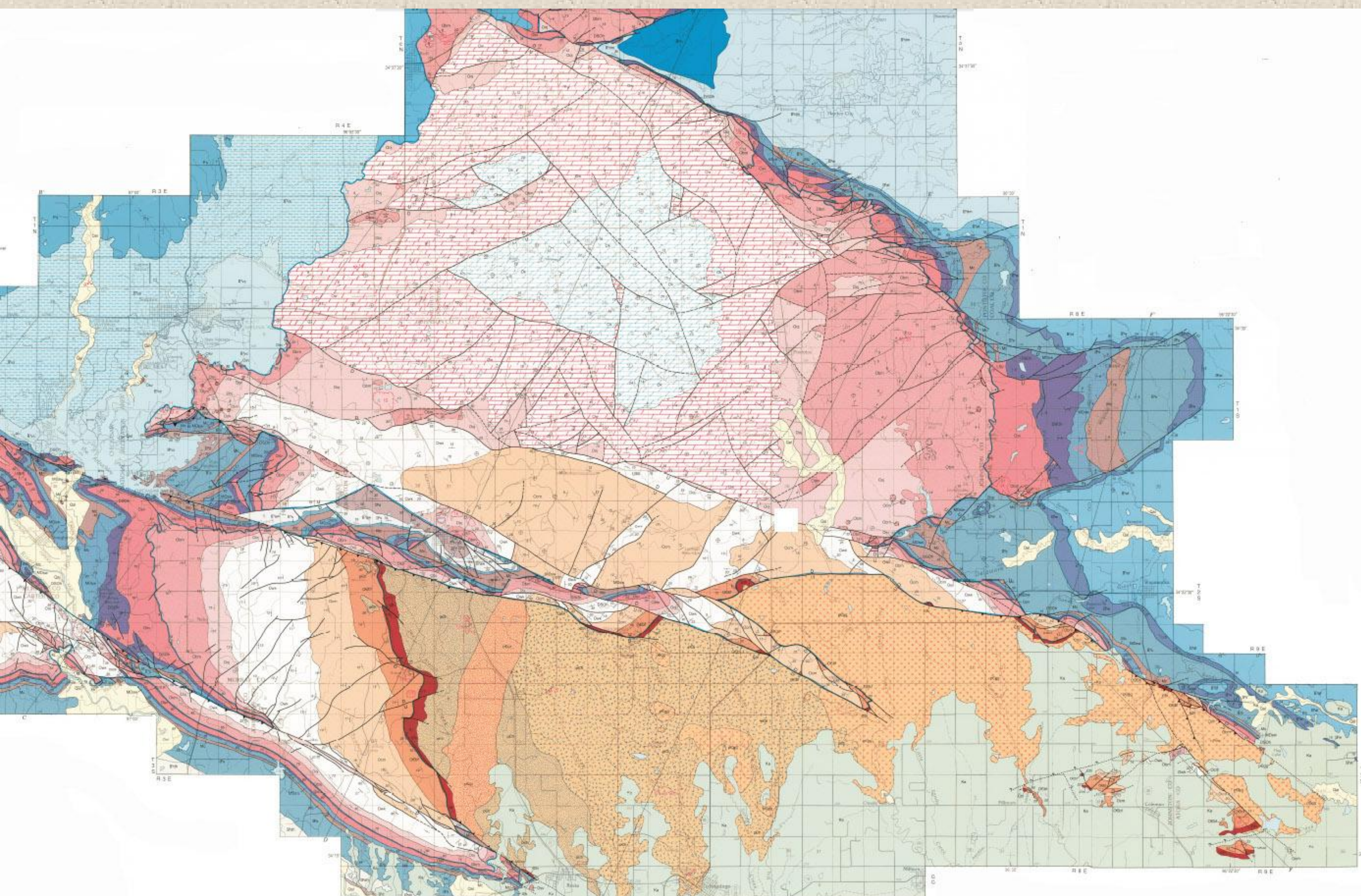
Anadarko and Arkoma basement depths (feet) relative to sea level



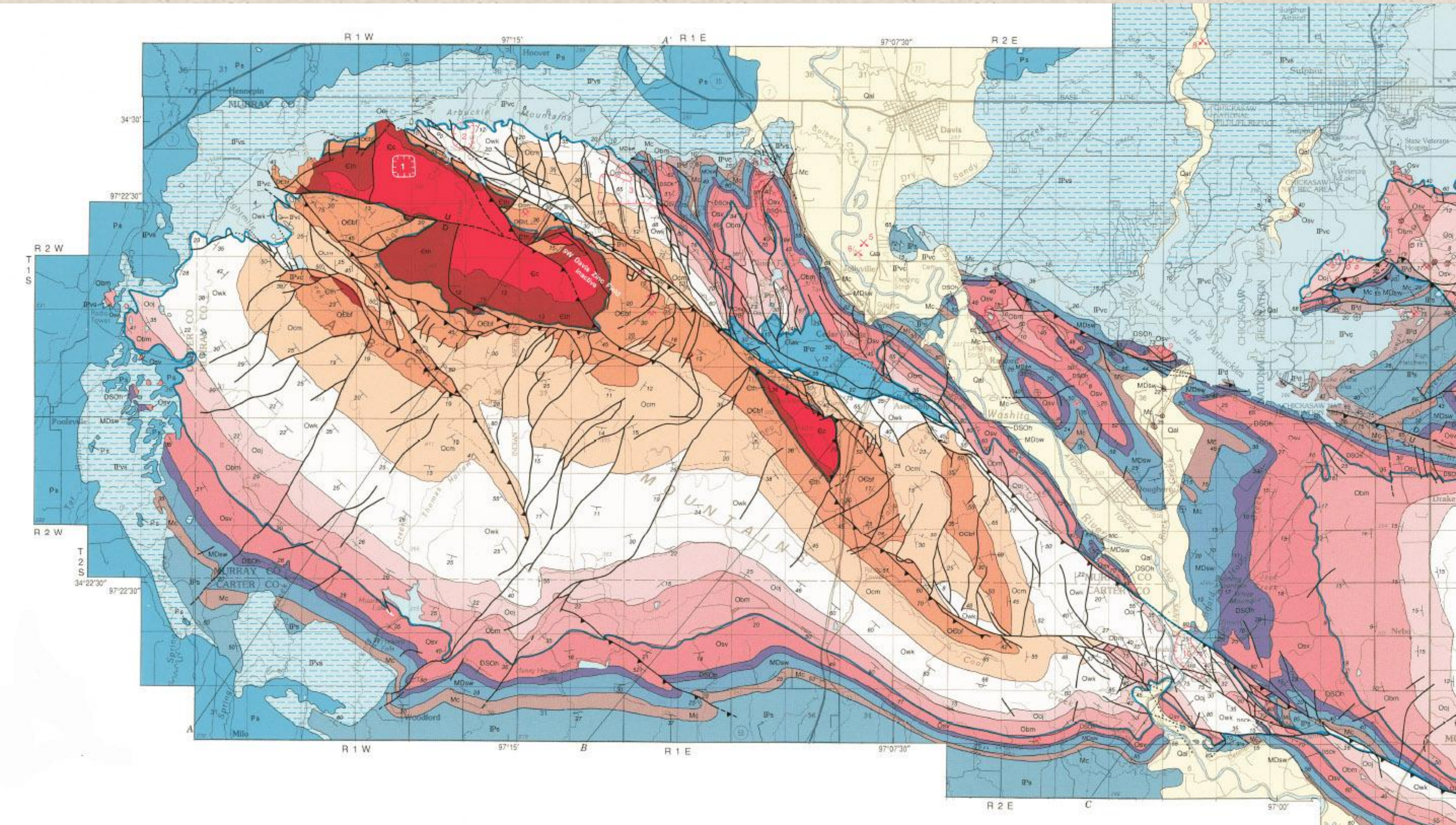
3-D perspective view of the Wichita-Arbuckle uplifts and Anadarko- Arkoma basins



Kevin Crain



William E. Ham and Myron E. McKinley and others, 1954
Revised by Kenneth S. Johnson, 1990



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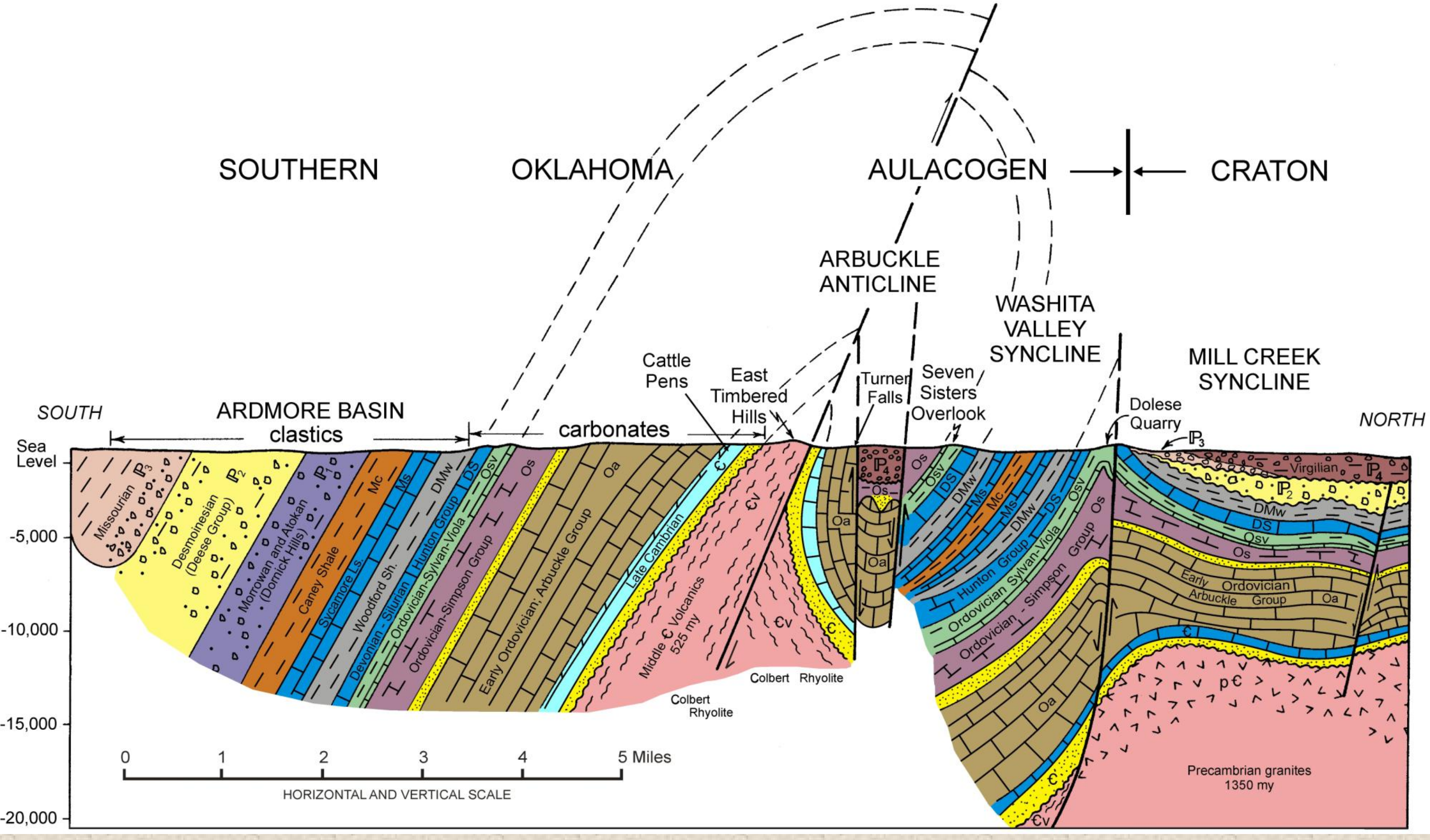
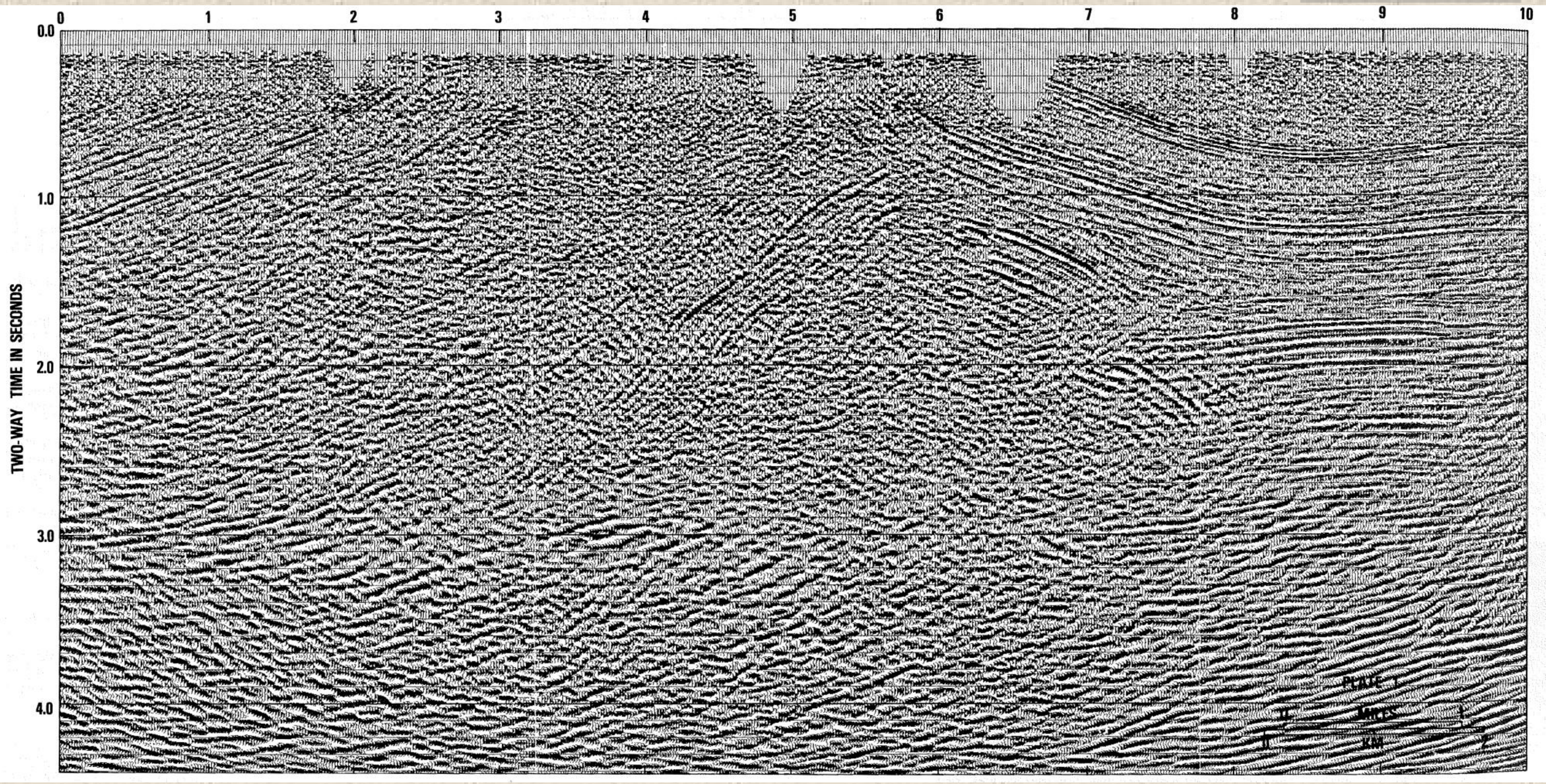


Johnson et al., 1984

Ardmore Basin seismic line

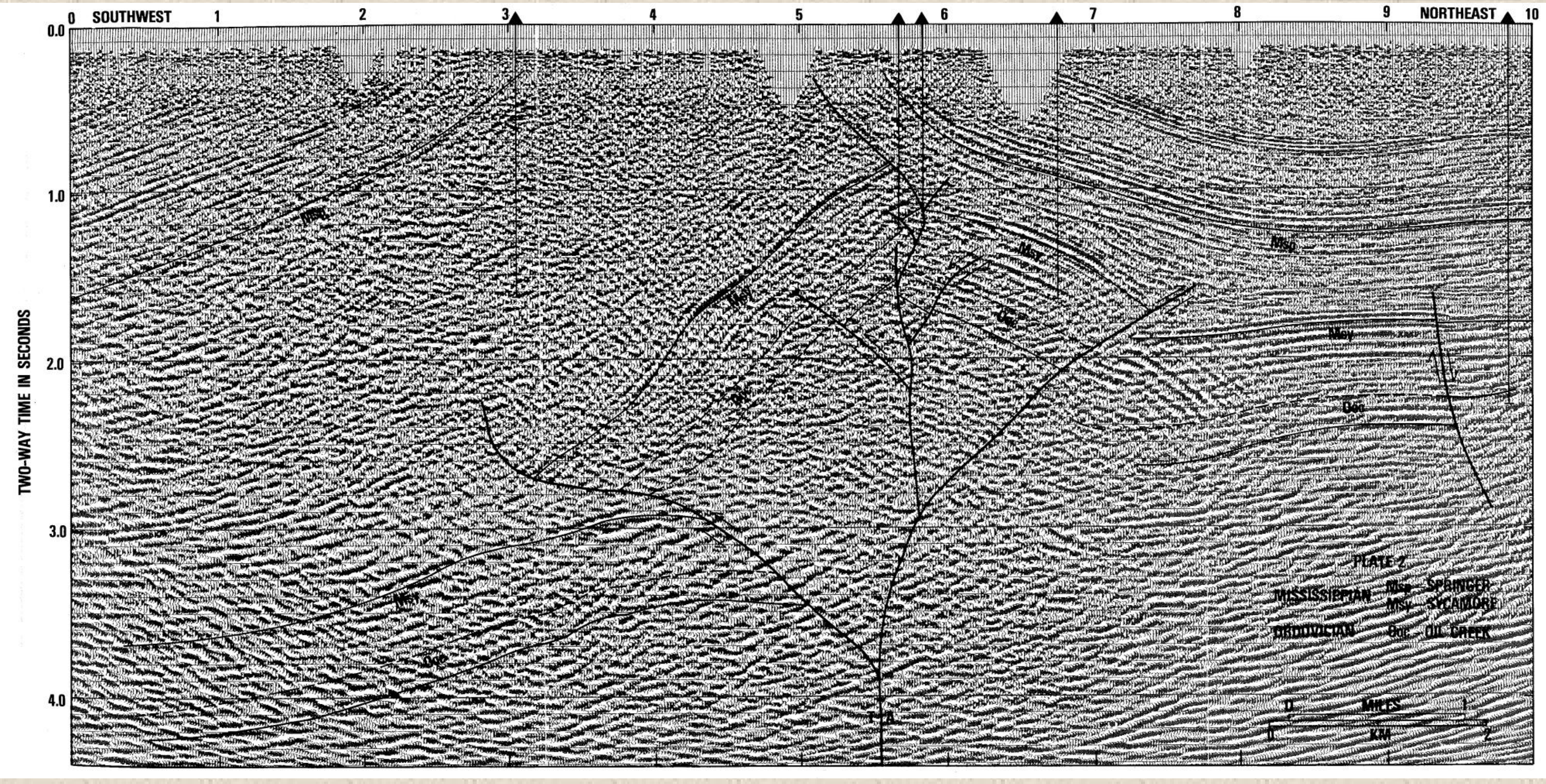
Northeast



Harding et al. (1983)

Harding et al. (1983)

Northeast



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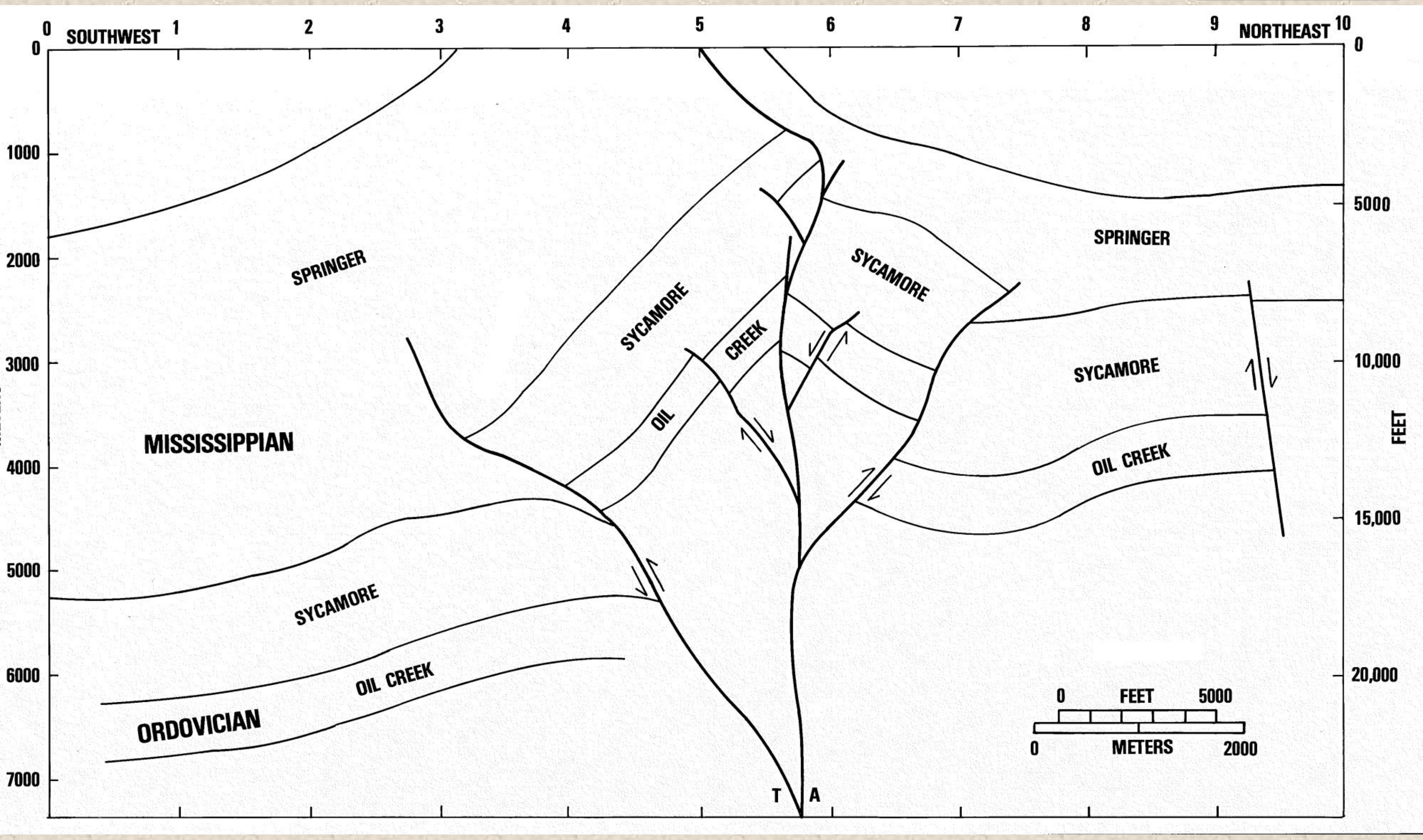
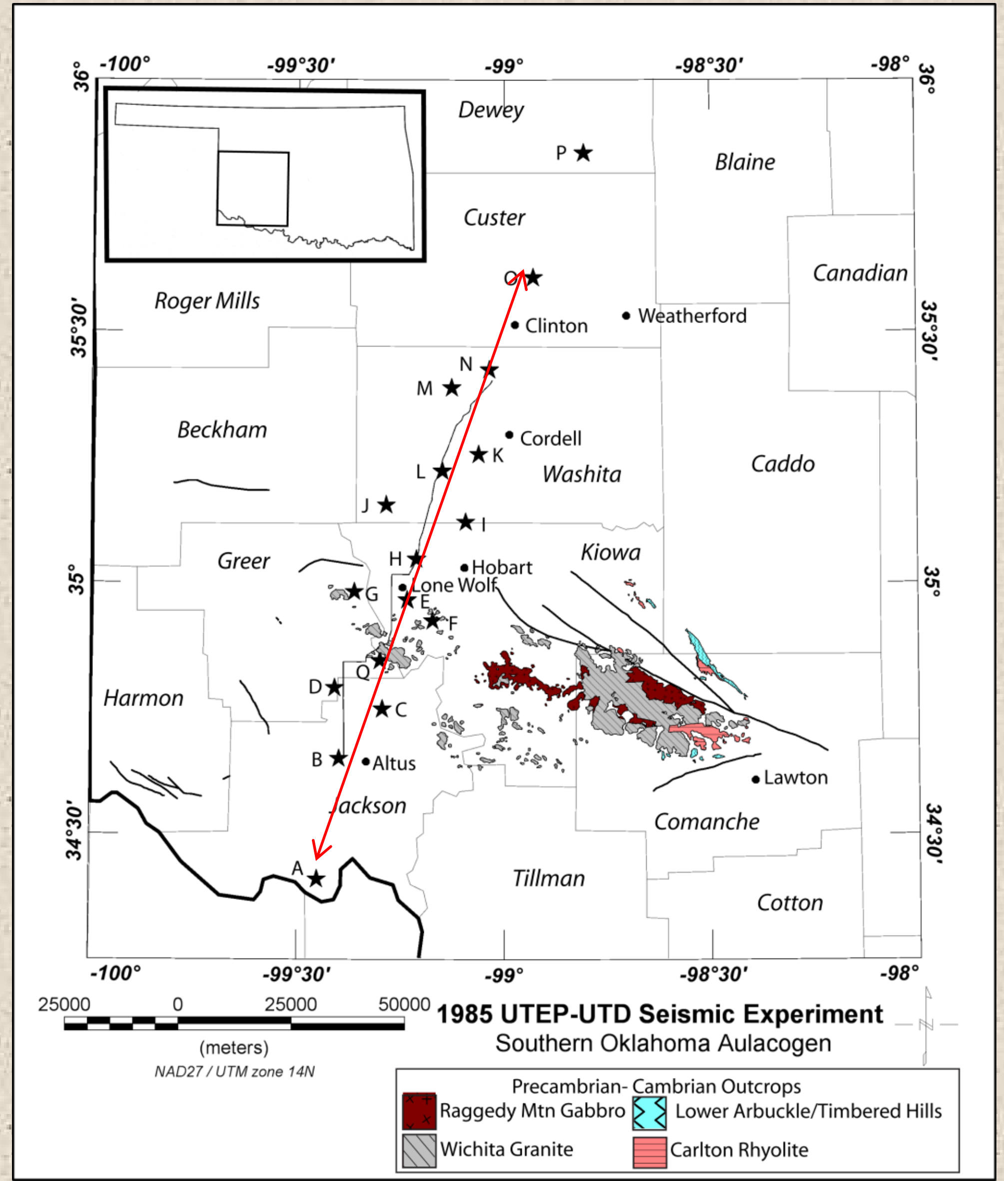
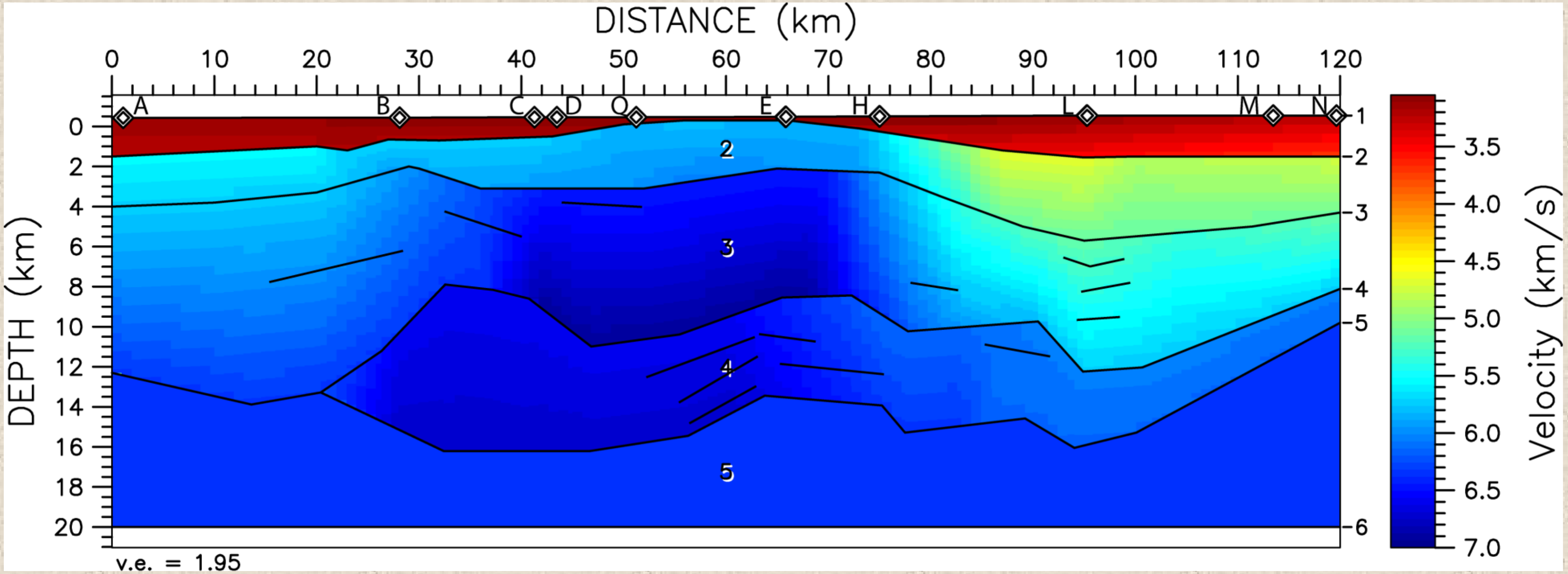


Wichita Uplift
Refraction/Wide-Angle Reflection Experiment

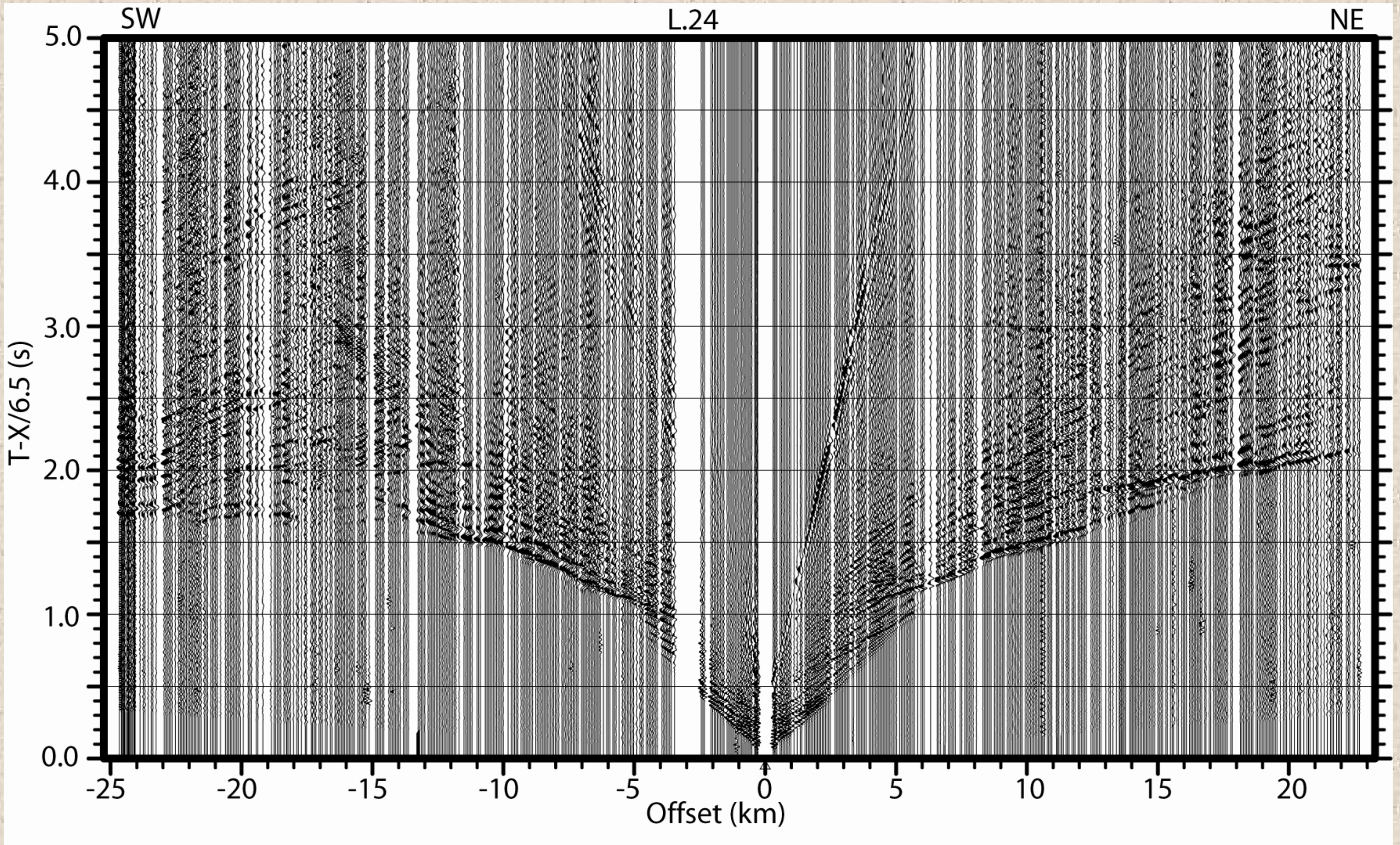


New Analysis by Amanda Rondot Buckey

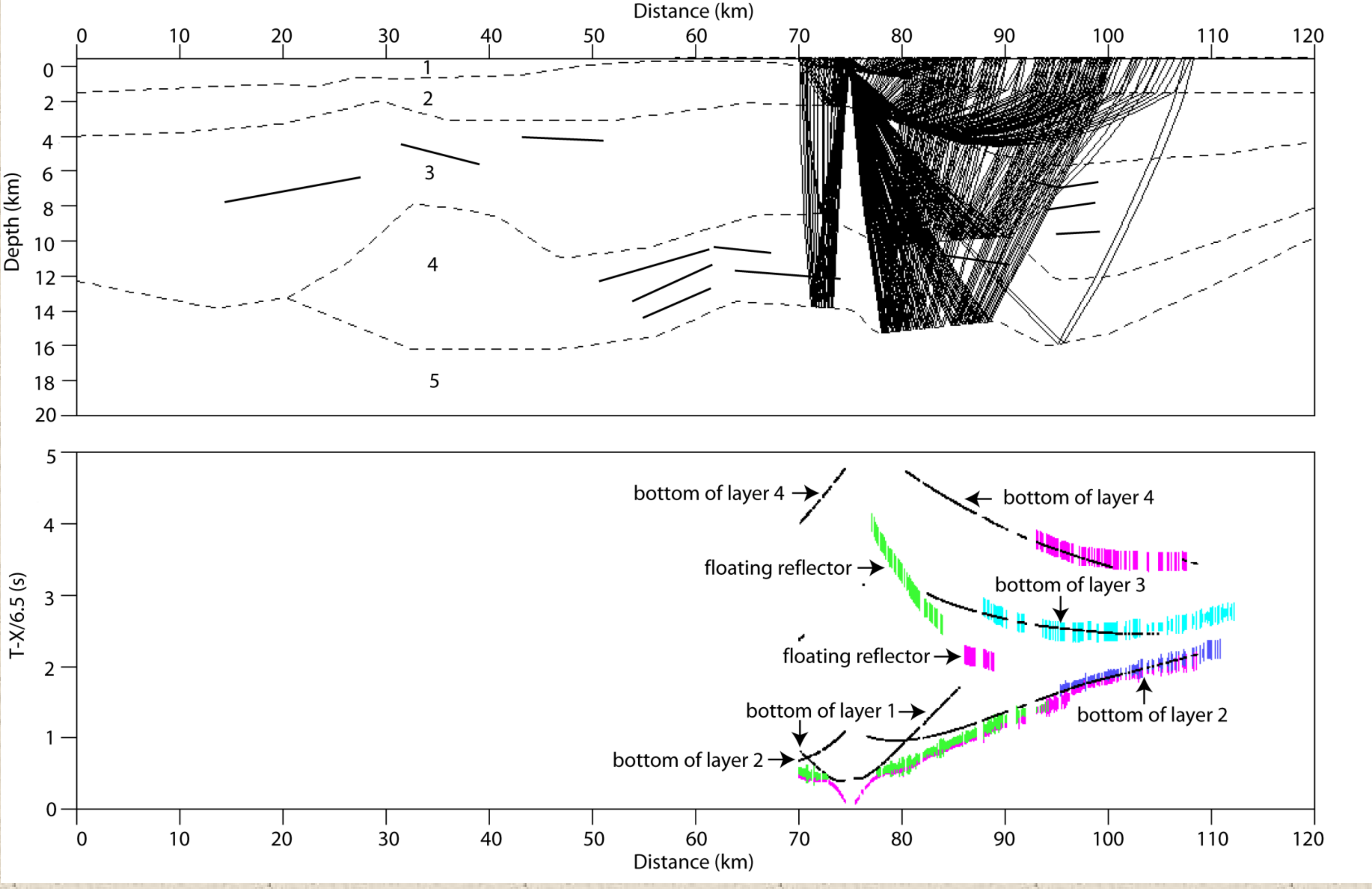
Seismic Velocity Model



Shot L.24



Shot H.22 – Reflection Ray Tracing

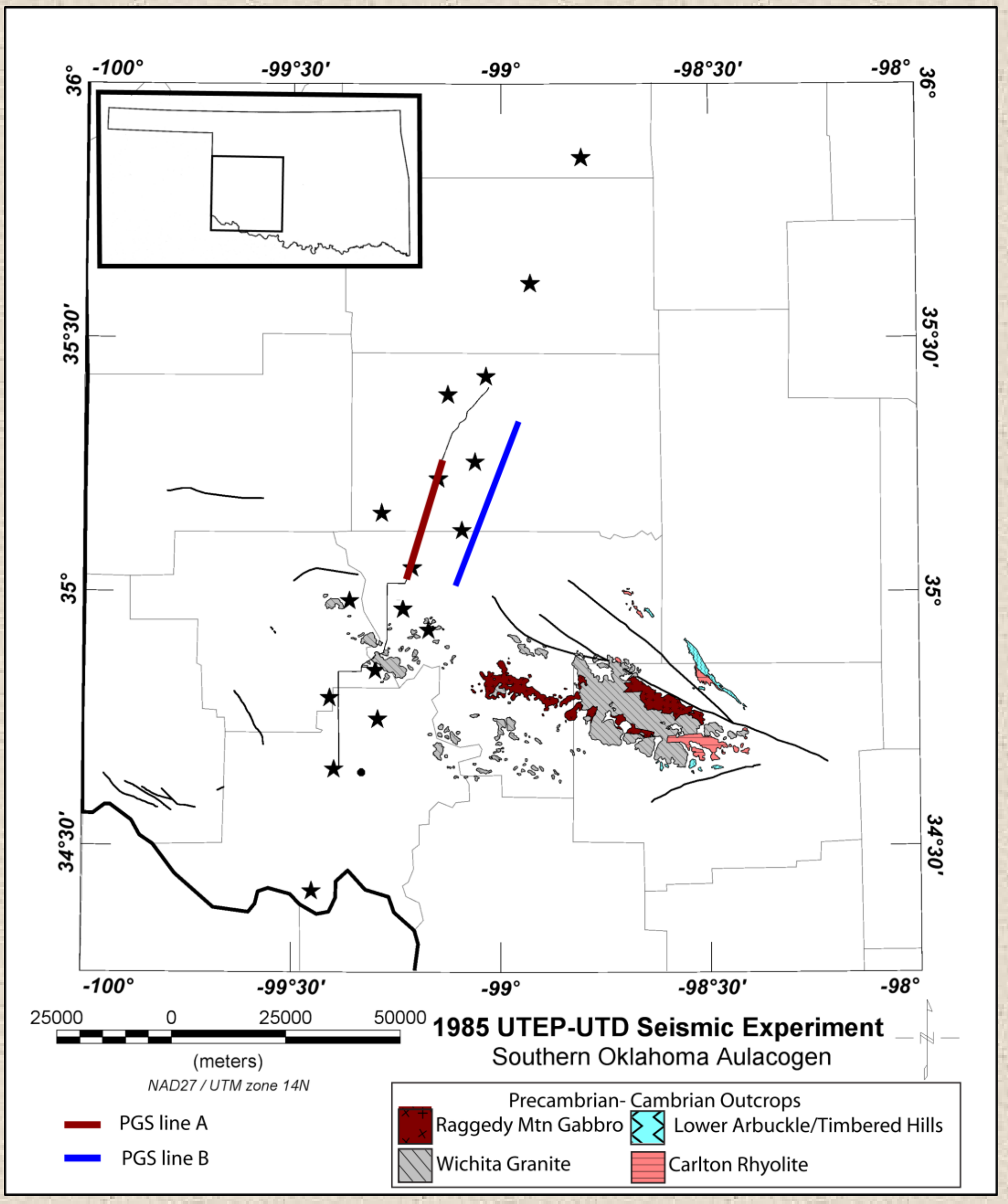


Geokinetics 3-D seismic reflection data

- Merged 3D Wichita Mountain Front Surveys
- High resolution (> 23,000 trace/mile)
- >18,000 ft offset
- Time migrated

Geokinetics KNOWLEDGE REVEALED.

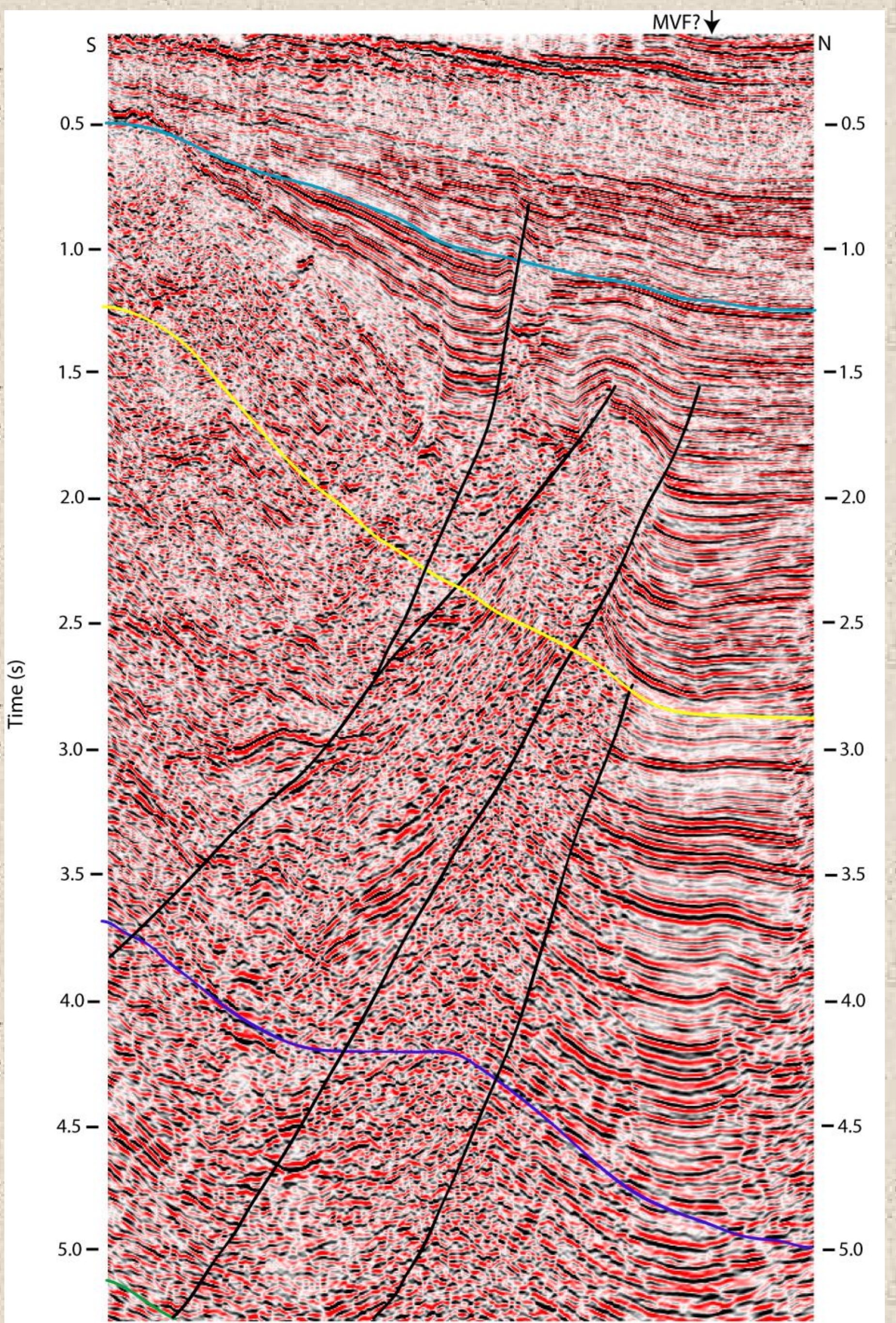
Locations of Vertical Slices Through the 3-D Data Volume

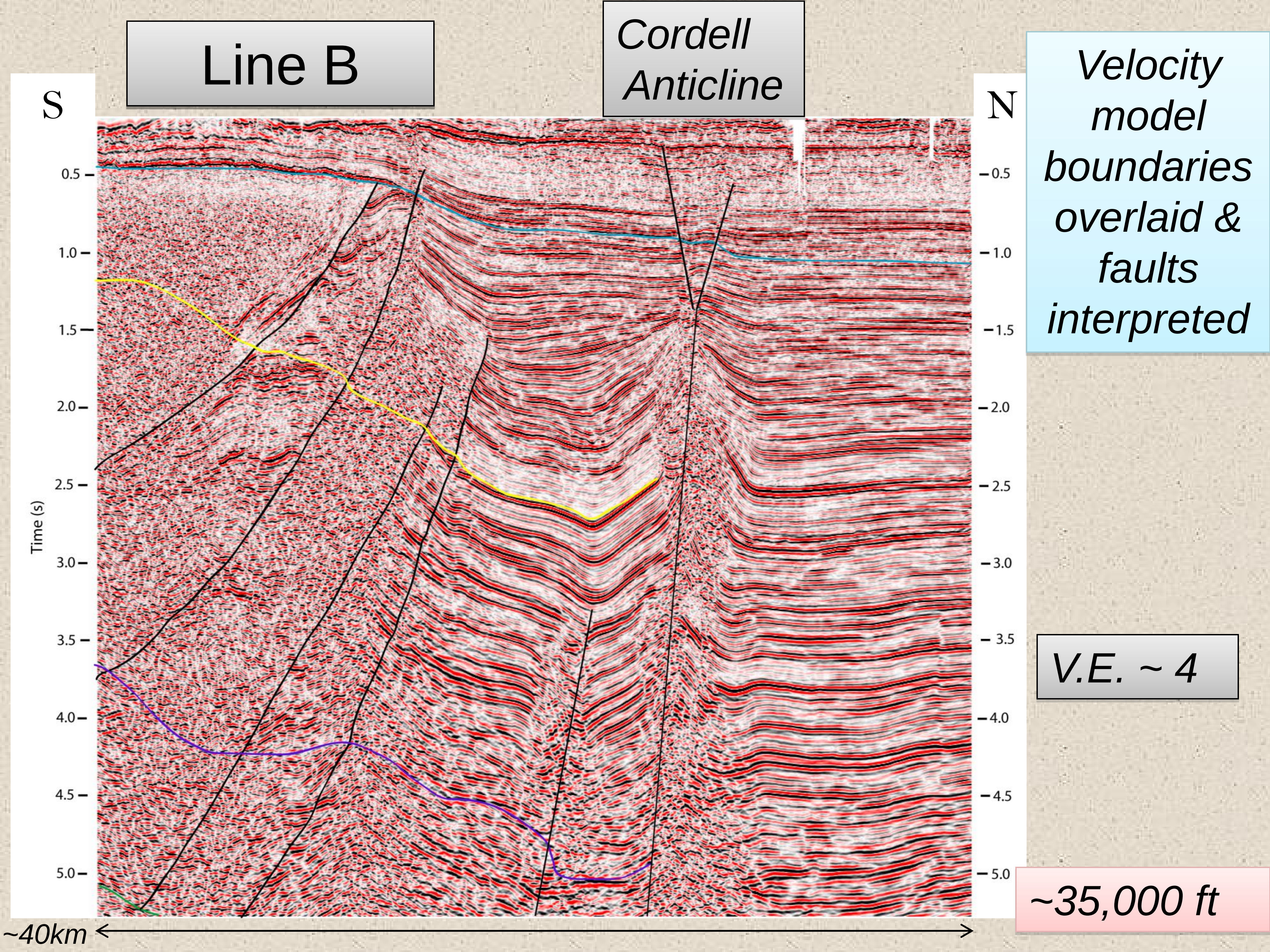


Geokinetics™ KNOWLEDGE REVEALED.

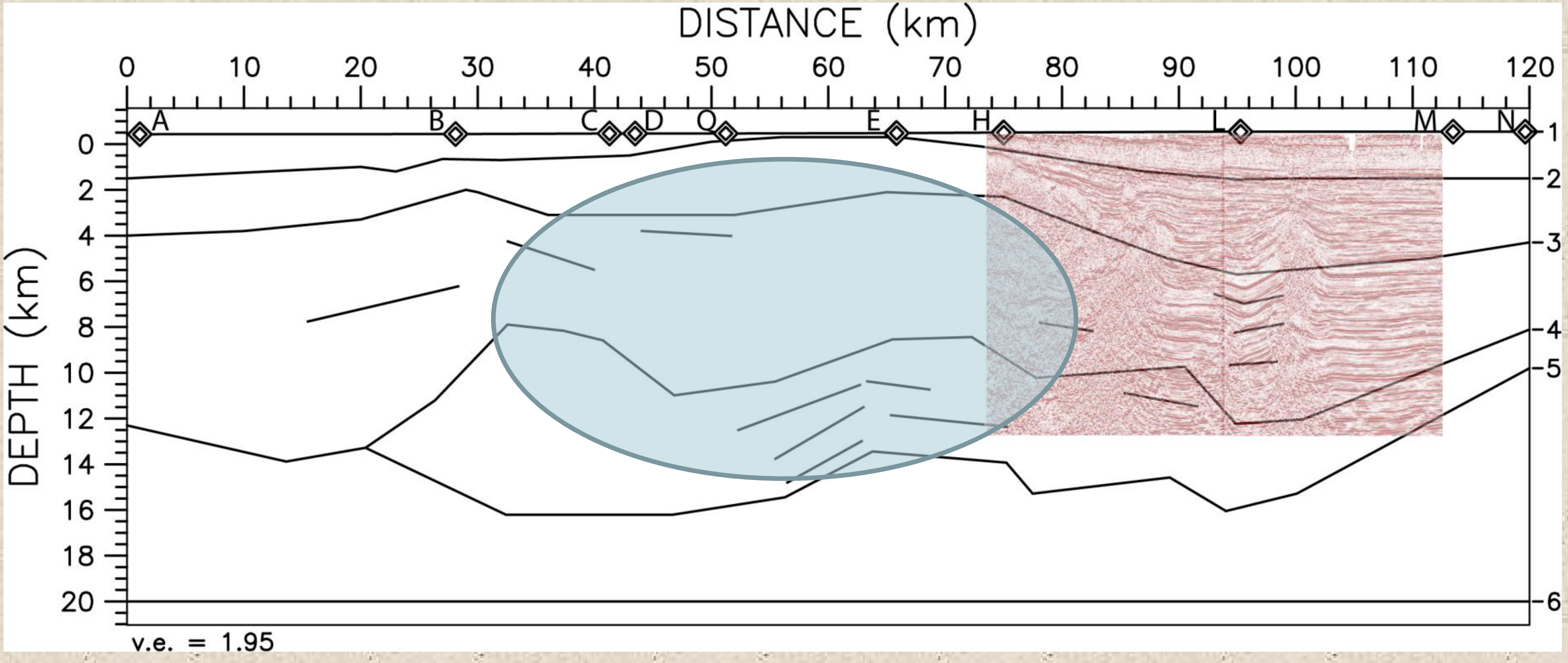
Line A

Model boundaries overlaid & faults interpreted

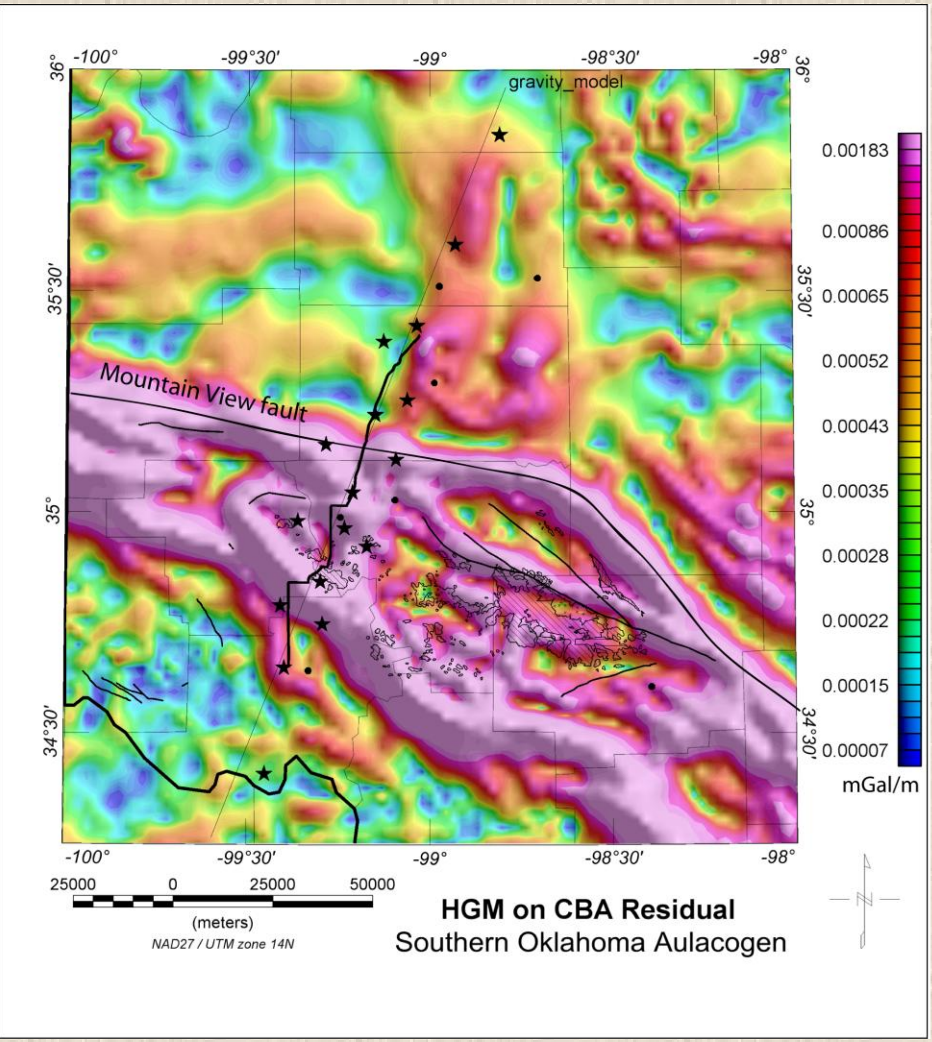



Line B
Cordell Anticline
Velocity model boundaries overlaid & faults interpreted
S
N
Time (s)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
V.E. ~ 4
~35,000 ft
~40km

Velocity Model Reflection Image Overlay

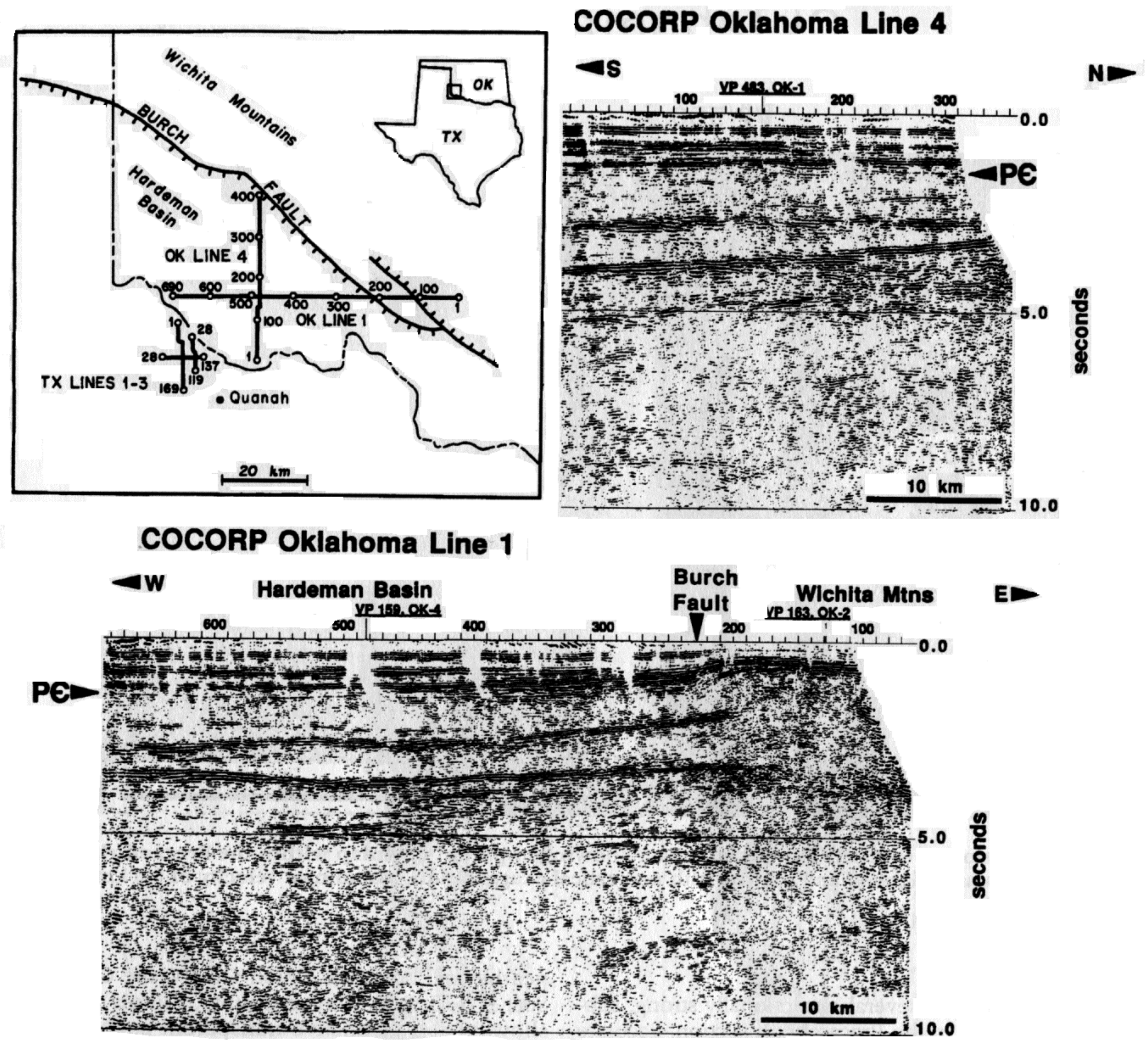


Gravity Edge Detectors and the Meers Fault

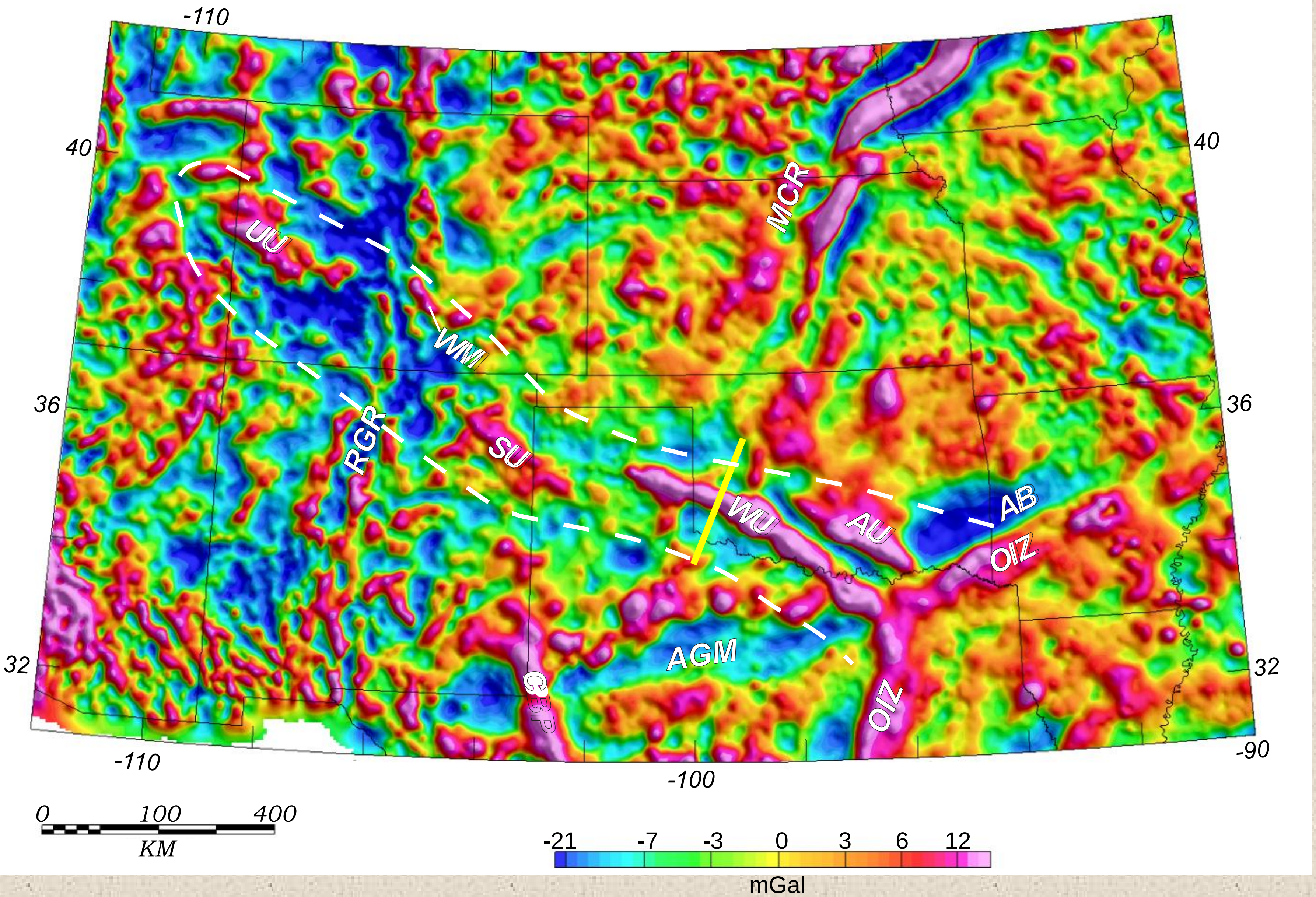


COCORP results

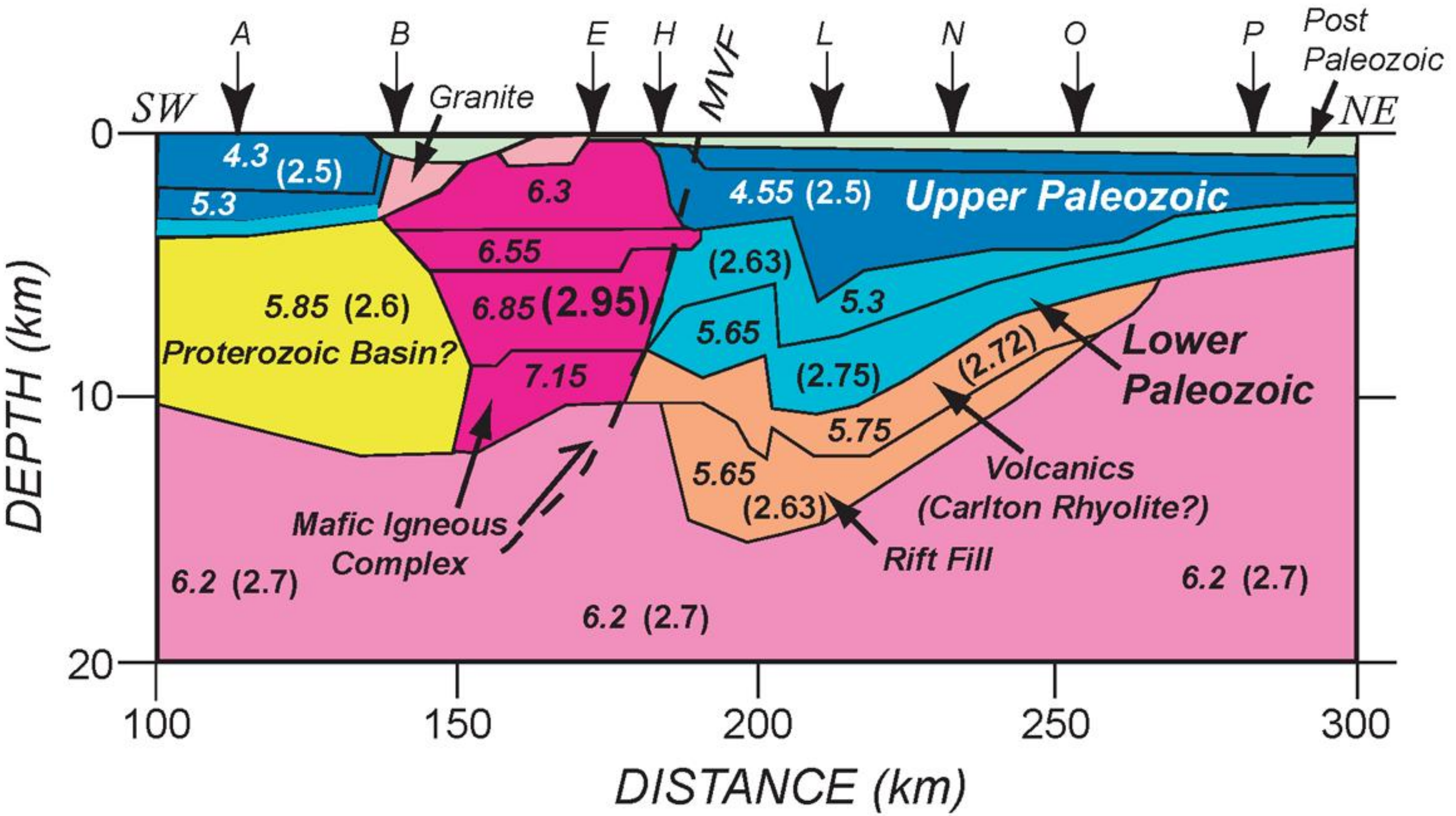
Extensive layered sequences lie beneath the top of the "basement"

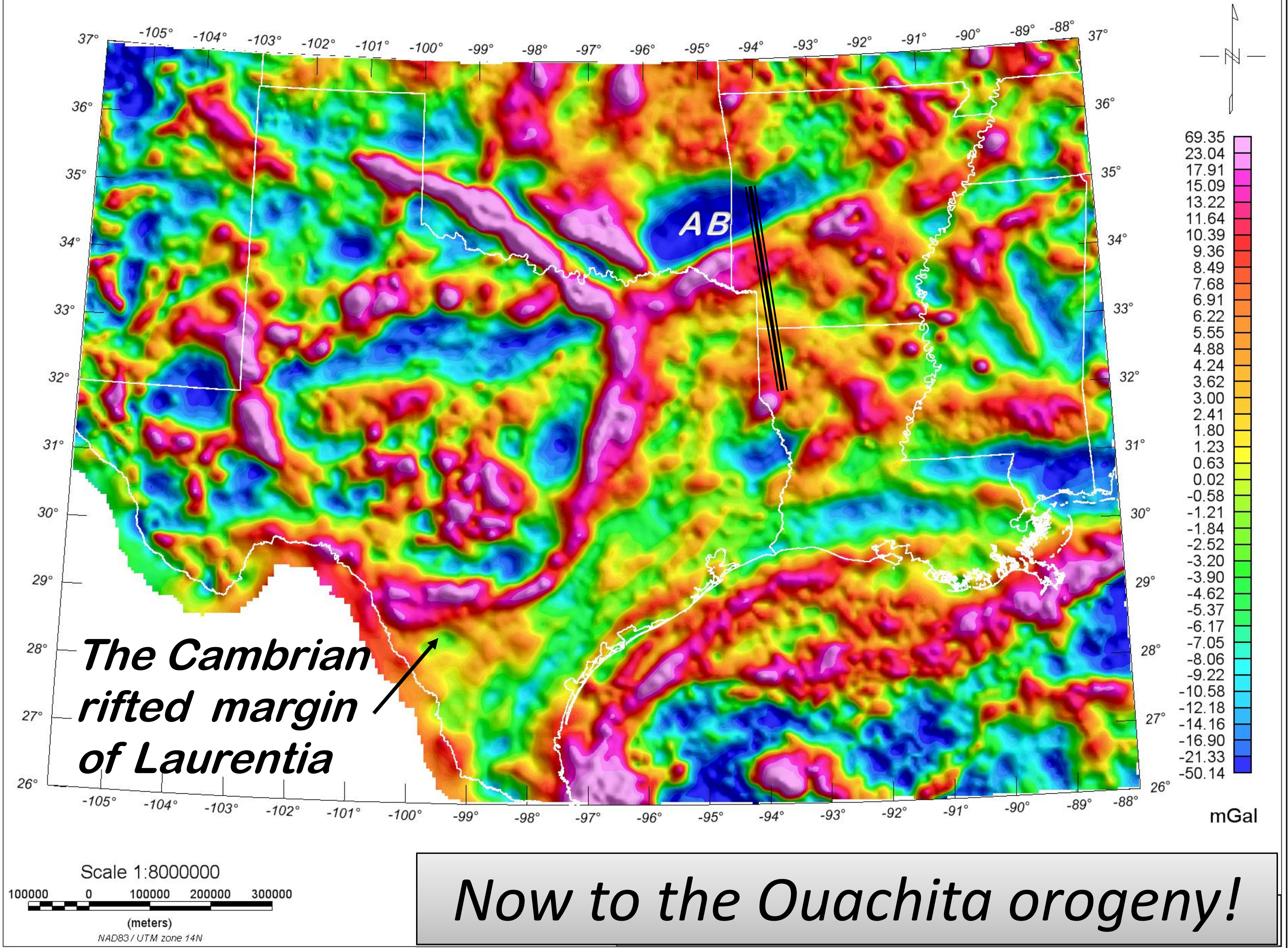


Residual Bouguer Gravity Anomaly Map

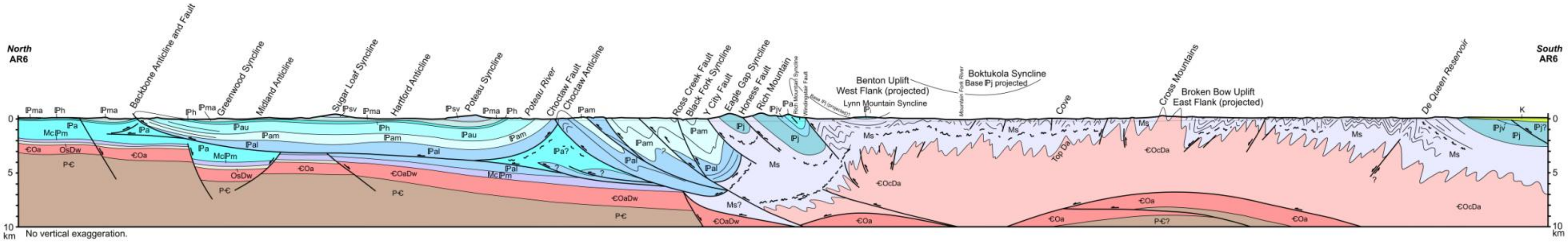


Integrated Velocity/Density Model of the Upper Crust

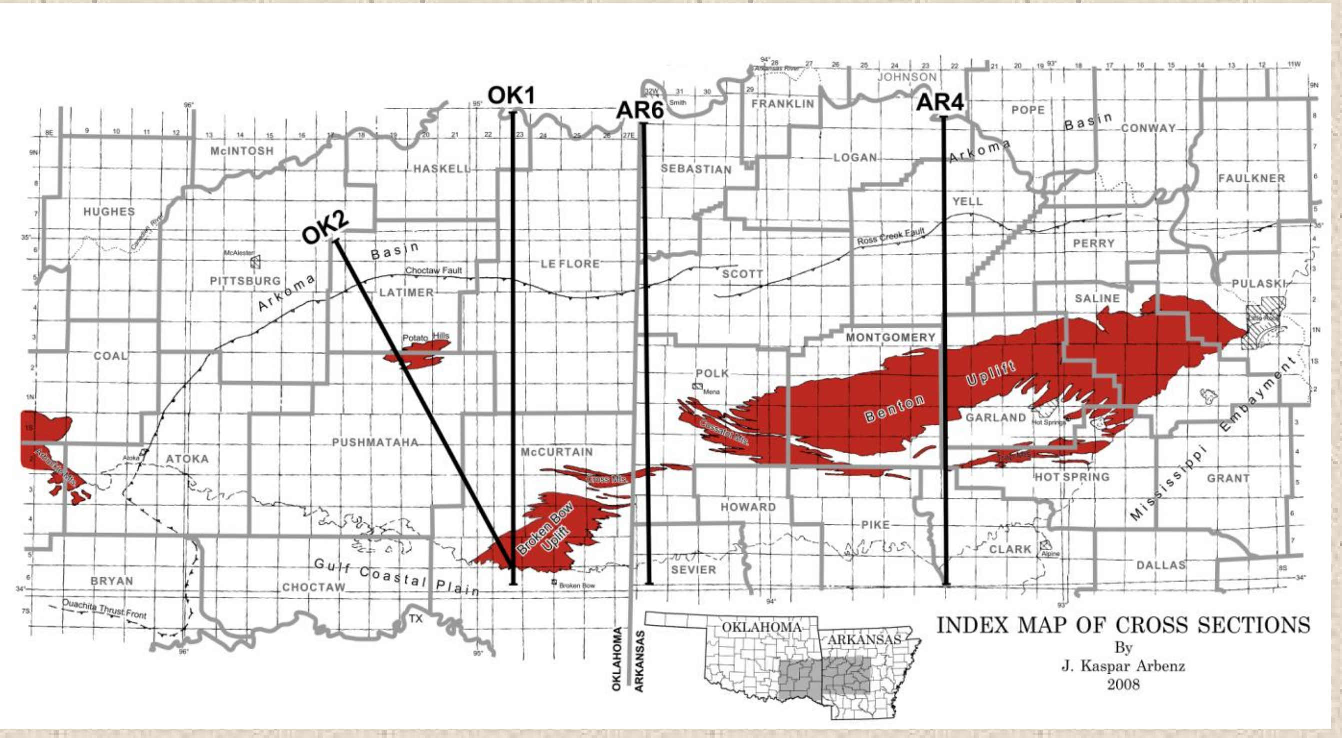




Now to the Ouachita orogeny!

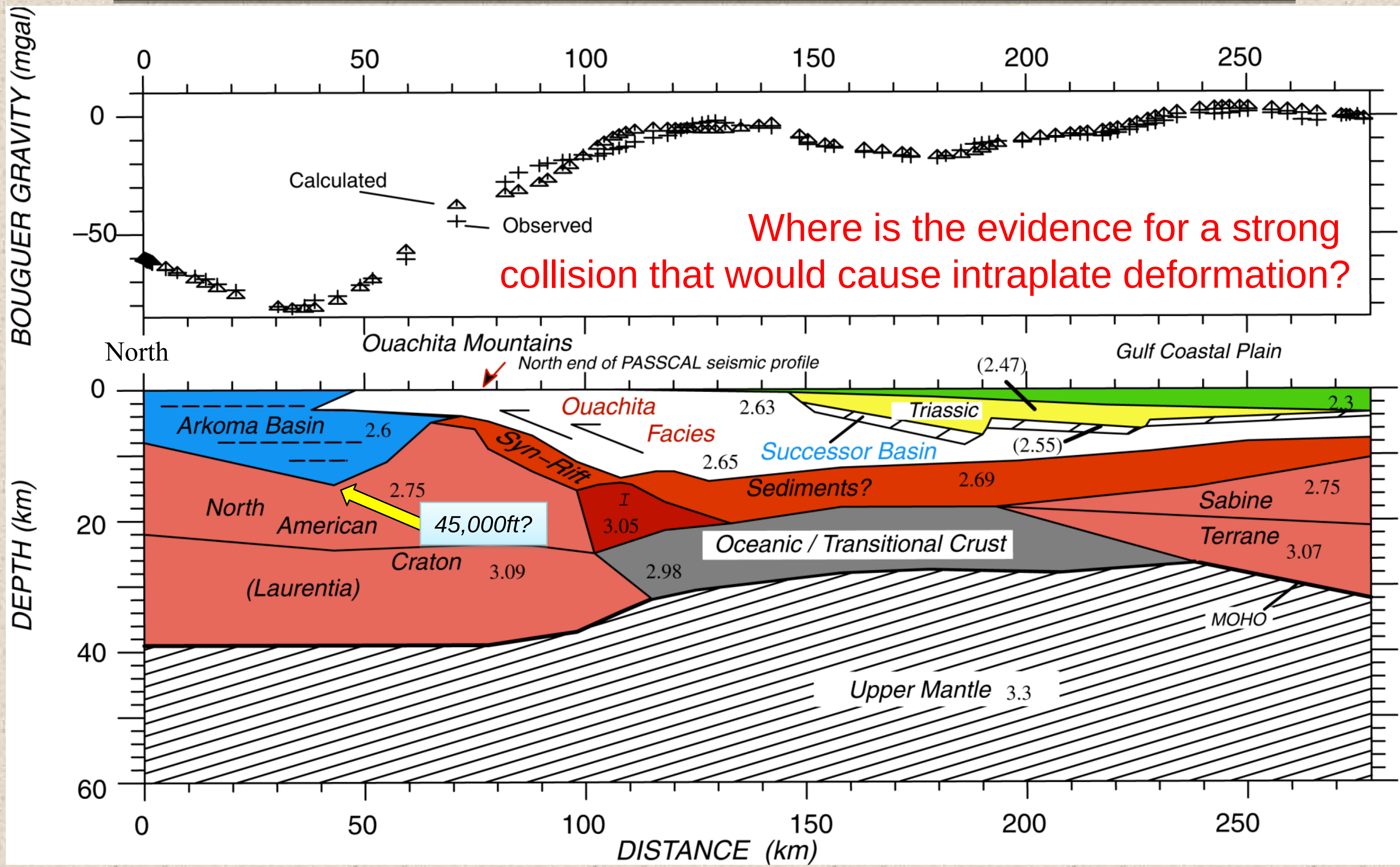


STRUCTURAL CROSS SECTION AR6 ACROSS THE ARKANSAS OUACHITA MOUNTAINS
By
J. Kaspar Arbenz
2008

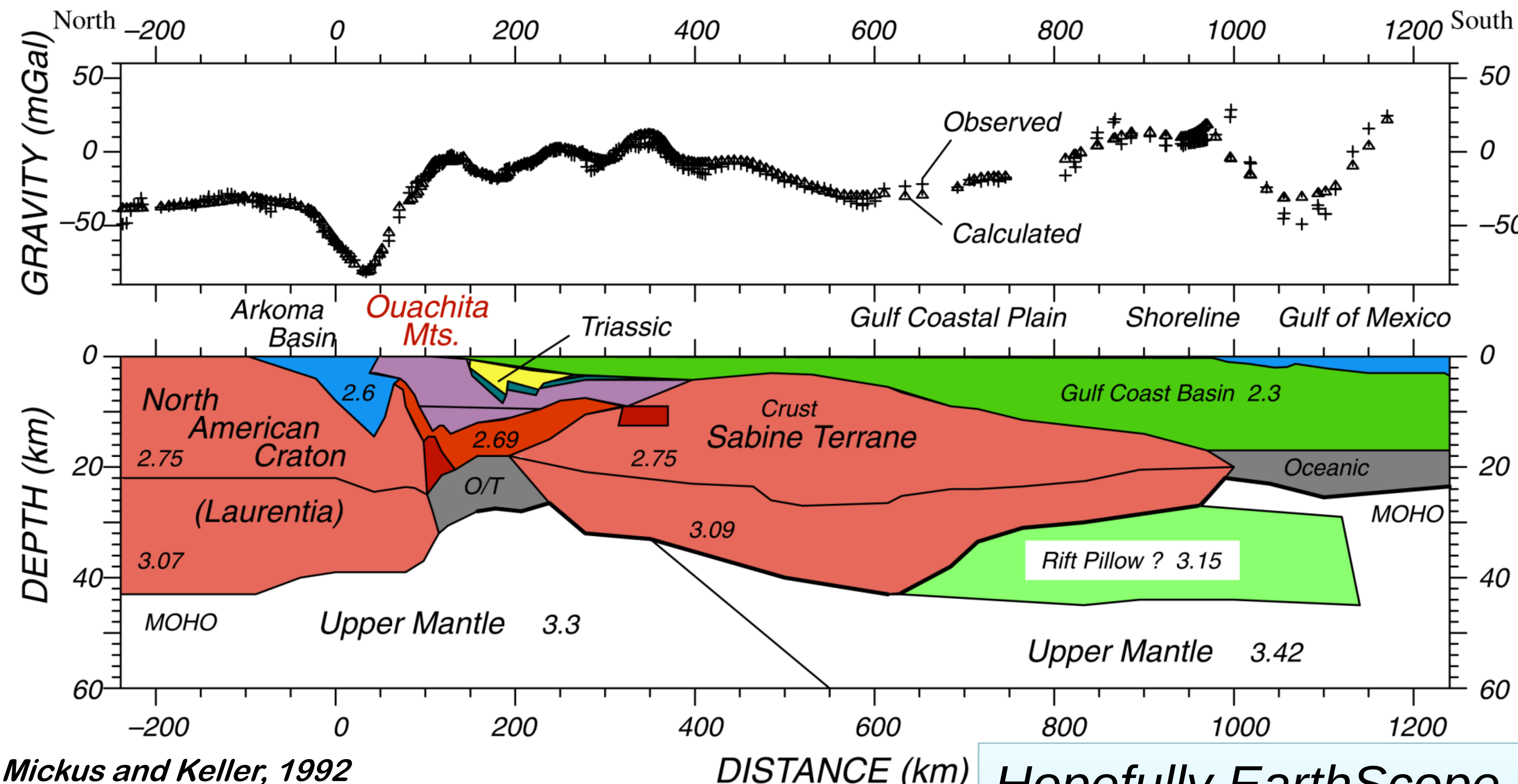


INDEX MAP OF CROSS SECTIONS
By
J. Kaspar Arbenz
2008

PASSCAL Seismic Experiment Integrated Model



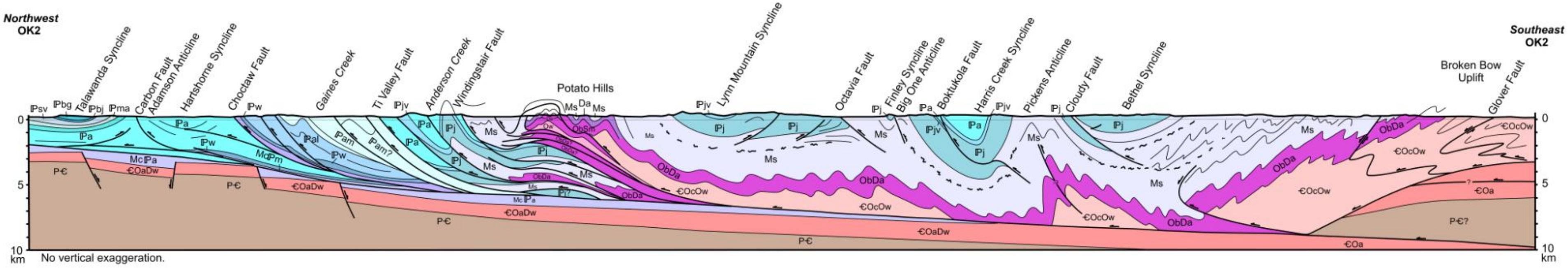
Craton to Gulf of Mexico Lithospheric Transect Model



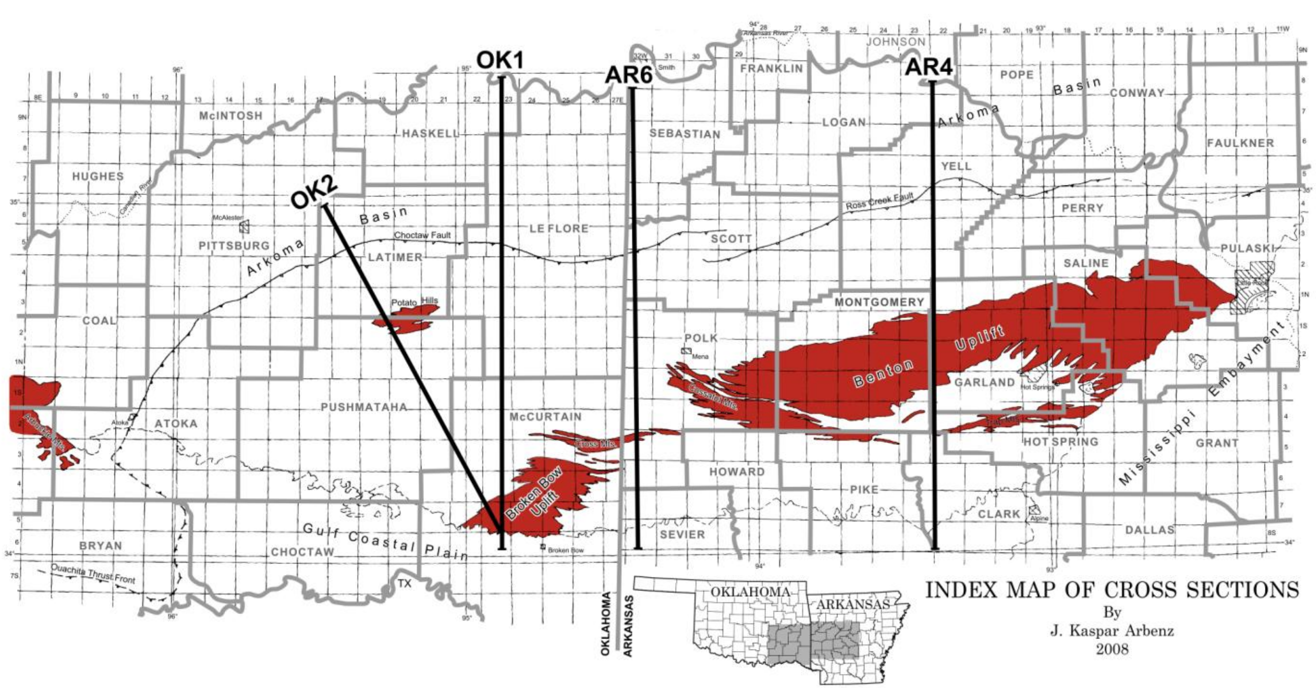
Mickus and Keller, 1992

This looks like the soft docking of an outboard terrane

Hopefully EarthScope will provide new data to test this model



STRUCTURAL CROSS SECTION OK2 ACROSS THE OKLAHOMA OUACHITA MOUNTAINS
By
J. Kaspar Arbenz
2008



INDEX MAP OF CROSS SECTIONS
By
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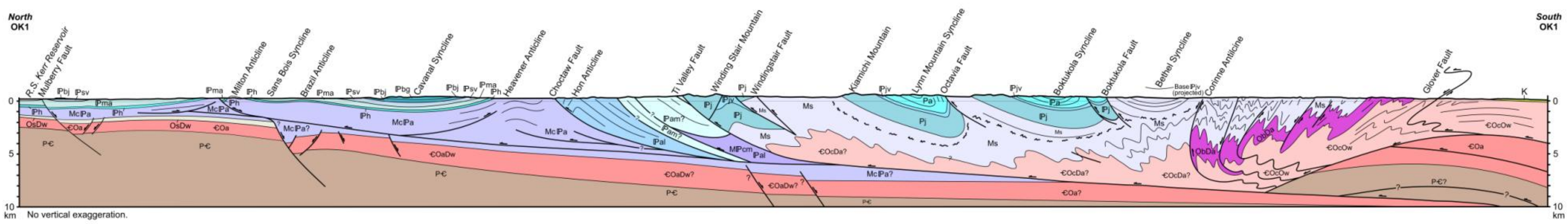
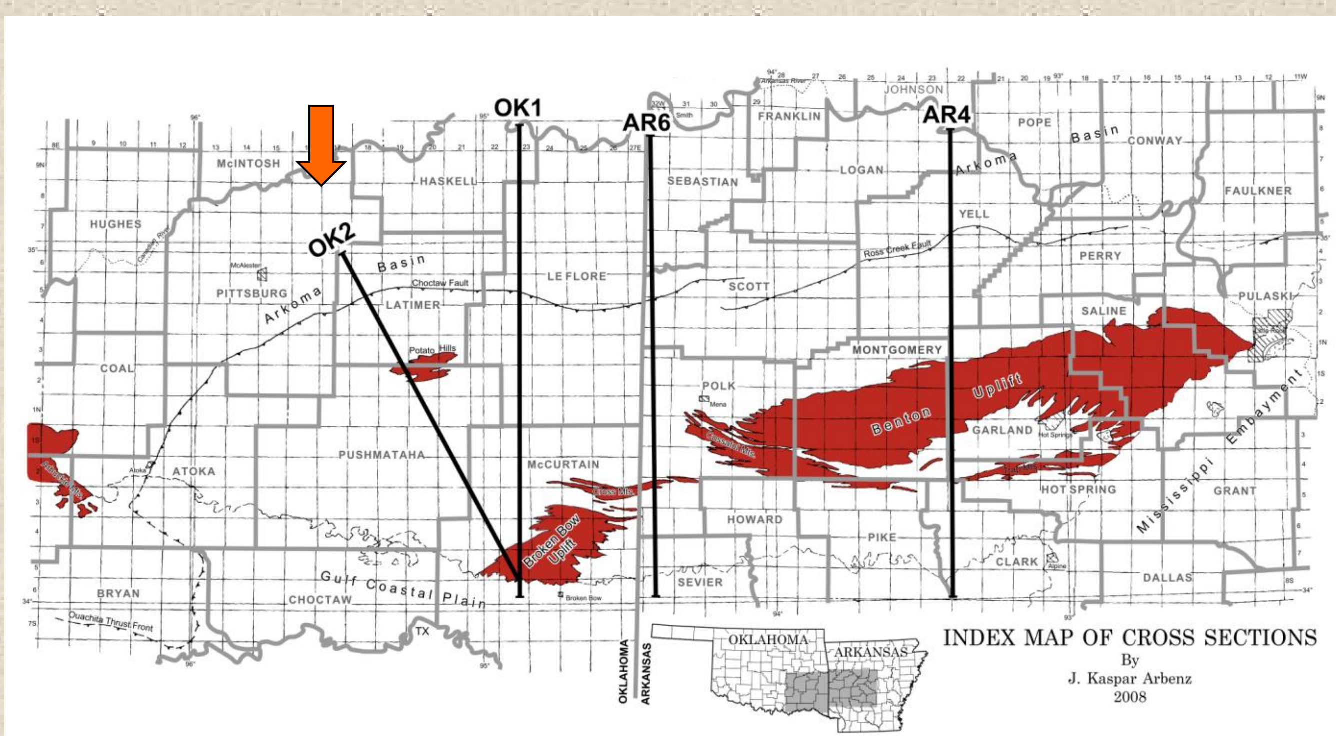
2008

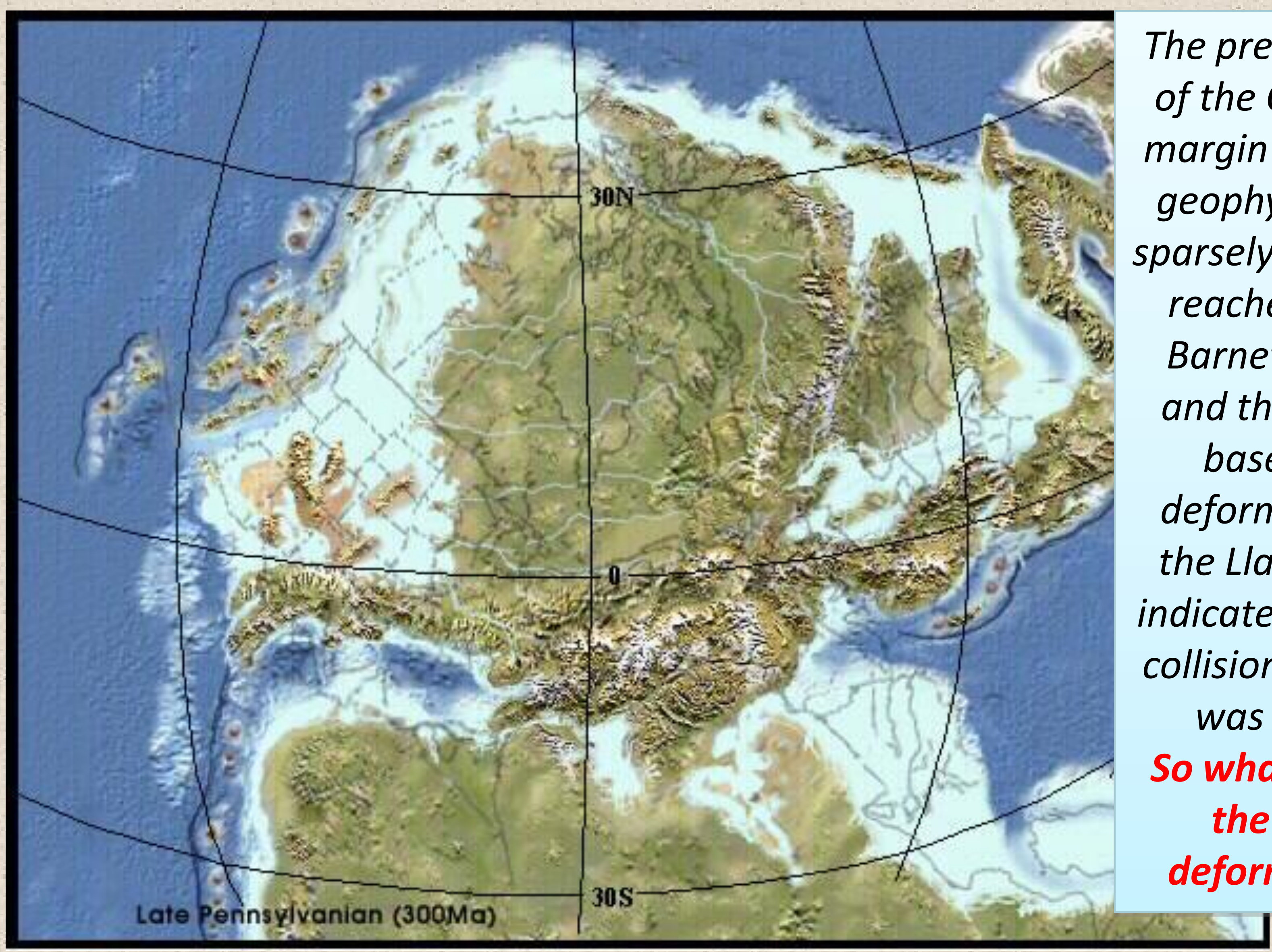


STRUCTURAL CROSS SECTION OK1 ACROSS THE OKLAHOMA OUACHITA MOUNTAINS
By
J. Kaspar Arbenz
2008



INDEX MAP OF CROSS SECTIONS
By
J. Kaspar Arbenz
2008

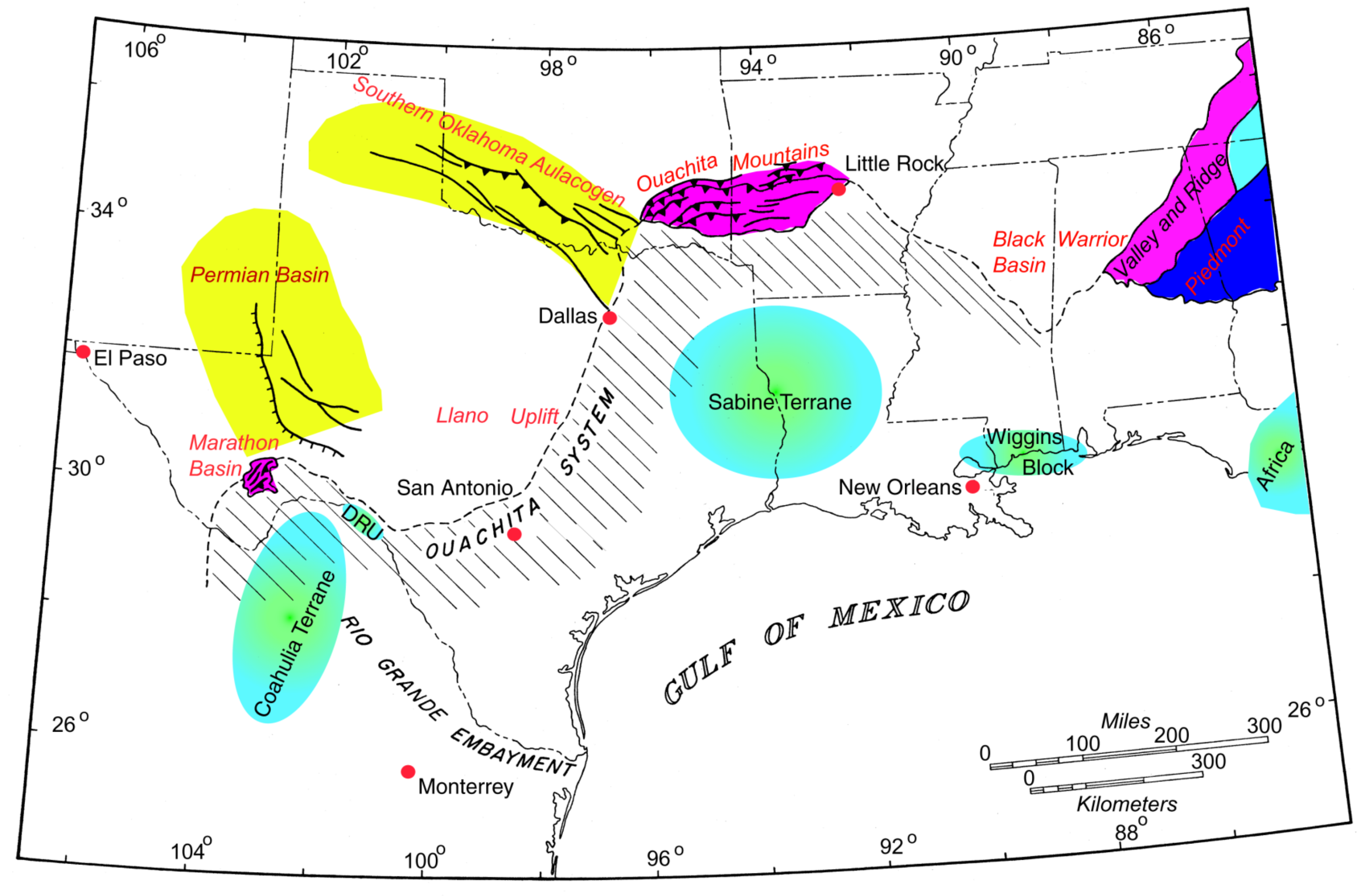
Appalachian, Ouachita - ARM Orogeny



The preservation of the Ouachita margin based on geophysics, the sparsely fractured reaches in the Barnett Shale, and the lack of basement deformation in the Llano uplift indicates that the collision involved was "soft".

So what caused the ARM deformation?

Ron Blakey NAU



It is amazing how little we really know about the deep structure outboard of the Ouachita orogen!

Conclusions

1. *Southern Laurentia has been a tectonically active region for **over a billion years***
2. *The Mid-continent rift system is **one of the largest on Earth***
3. *The Southern Oklahoma Aulacogen is **the** classic example of a failed and structurally inverted rift*
4. *The Ouachita orogenic belt is a major feature that formed as Pangea was assembled, and the Arkoma basin may be the **deepest foreland basin** formed during this event*
5. *The Ancestral Rocky Mountains formed in the late Paleozoic and are a **globally significant example** of intraplate deformation. The processes that formed them are the subject of considerable debate and a major tectonic paradox*
6. *The opening of the Gulf of Mexico was framed at least to some extent by the trace of the Ouachita orogenic belt, but **we have a lot to learn** about the areas adjacent to this orogen*

Earthquakes and faulting in Oklahoma

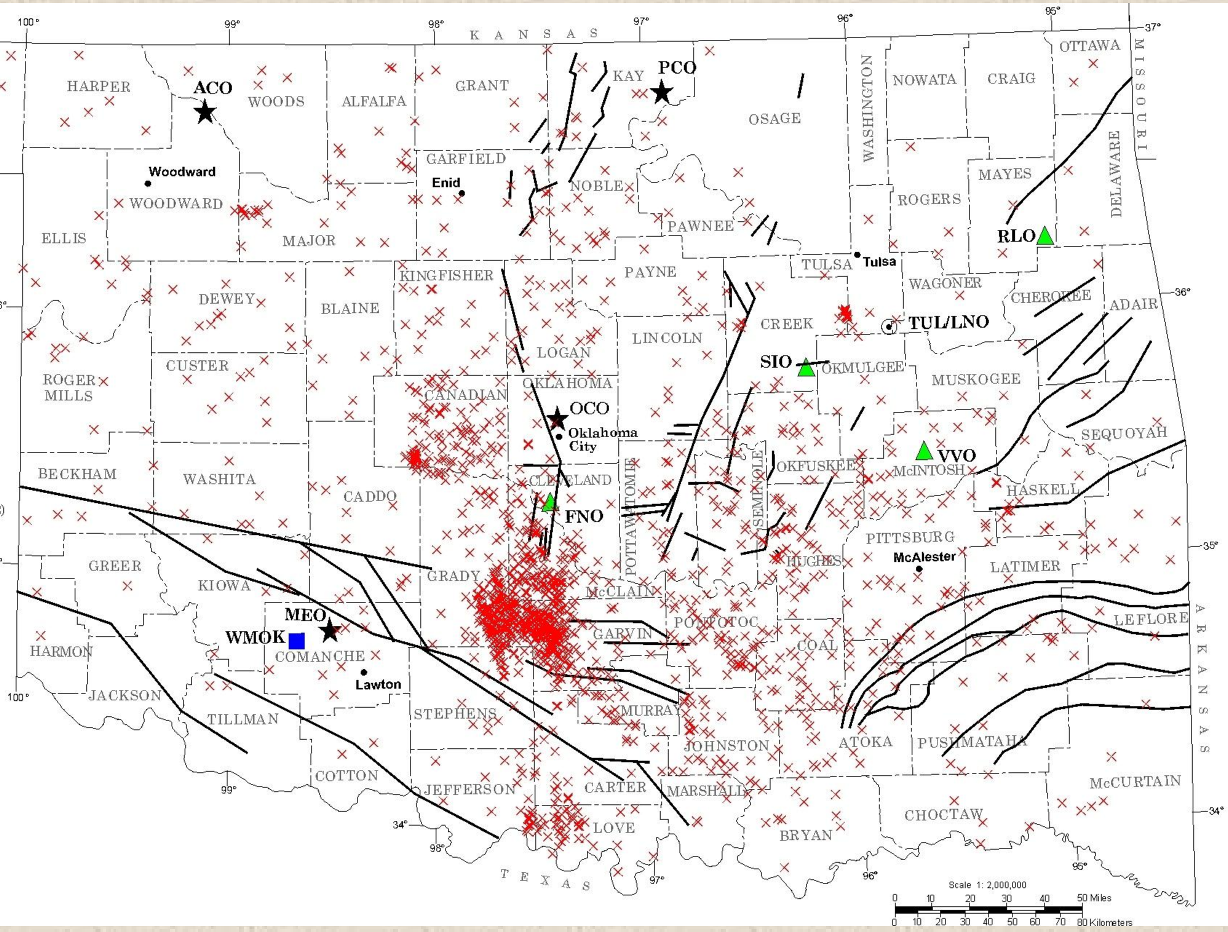


Table 2. Abridged Modified Mercalli (MM) Earthquake-Intensity Scale (modified from Wood and Neumann, 1931)

- I Not felt except by a very few under especially favorable circumstances.
- II Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
- III Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.
- IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.
- V Felt by nearly everyone, many awakened. Some dishes, windows, etc. broken; unstable objects overturned. Pendulum clocks may stop.
- VI Felt by all; many frightened and run outdoors.
- VII Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving automobiles.
- VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.
- IX Damage considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Building shifted off foundations. Ground cracked conspicuously.
- X Some well-built wooden structures destroyed; ground badly cracked, rails bent. Landslides and shifting of sand and mud.
- XI Few if any (masonry) structures remain standing. Broad fissures in ground.
- XII Damage total. Waves seen on ground surfaces.

TABLE 3. — OKLAHOMA EARTHQUAKES WITH MAGNITUDES ≥4.0

Date	Origin time (UTC)[a]	County	Nearest town	Intensity MM[b]	Magnitudes[c] 3Hz	bLg	DUR	Lat. °N	Long. °W
1952 Apr 09	1629 15	Canadian	El Reno	7		5.0[d]		35.4	97.8
1939 Jun 01	0730	Hughes	Spalding	4		4.4		35.0	96.4
1997 Sep 06	2338 01.99	Coal	Stonewall	7		4.4	3.7	34.676	96.499
1926 Jun 20	1420	Sequoyah	W Marble City	5		4.3		35.6	94.9
1959 Jun 17	1027 07	Comanche	NE Faxon	–6		4.2		34.5	98.5
1995 Jan 18	1551 39.90	Garvin	Antioch	6	4.1	4.2		34.712	97.542
1998 Apr 28	1413 01.27	Comanche	NW Richards Spur	6		4.2		34.809	98.402
1956 Oct 30	1036 21	Rogers	Catoosa	7		4.1		36.2	95.8
1961 Apr 27	0730	Latimer	Wilburton	5		4.1		34.9	95.3
1929 Dec 28	0030	Canadian	El Reno	6		4.0		35.5	98.0
1959 Jun 15	1245	Pontotoc	Ada	5		4.0		34.8	96.7
1990 Nov 15	1144 41.63	Garvin	Lindsay	6	4.0	3.9	3.0	34.761	97.550

[a]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To convert to local Central Standard Time, subtract 6 hours.

[b]Modified Mercall (MM) earthquake-intensity scale.

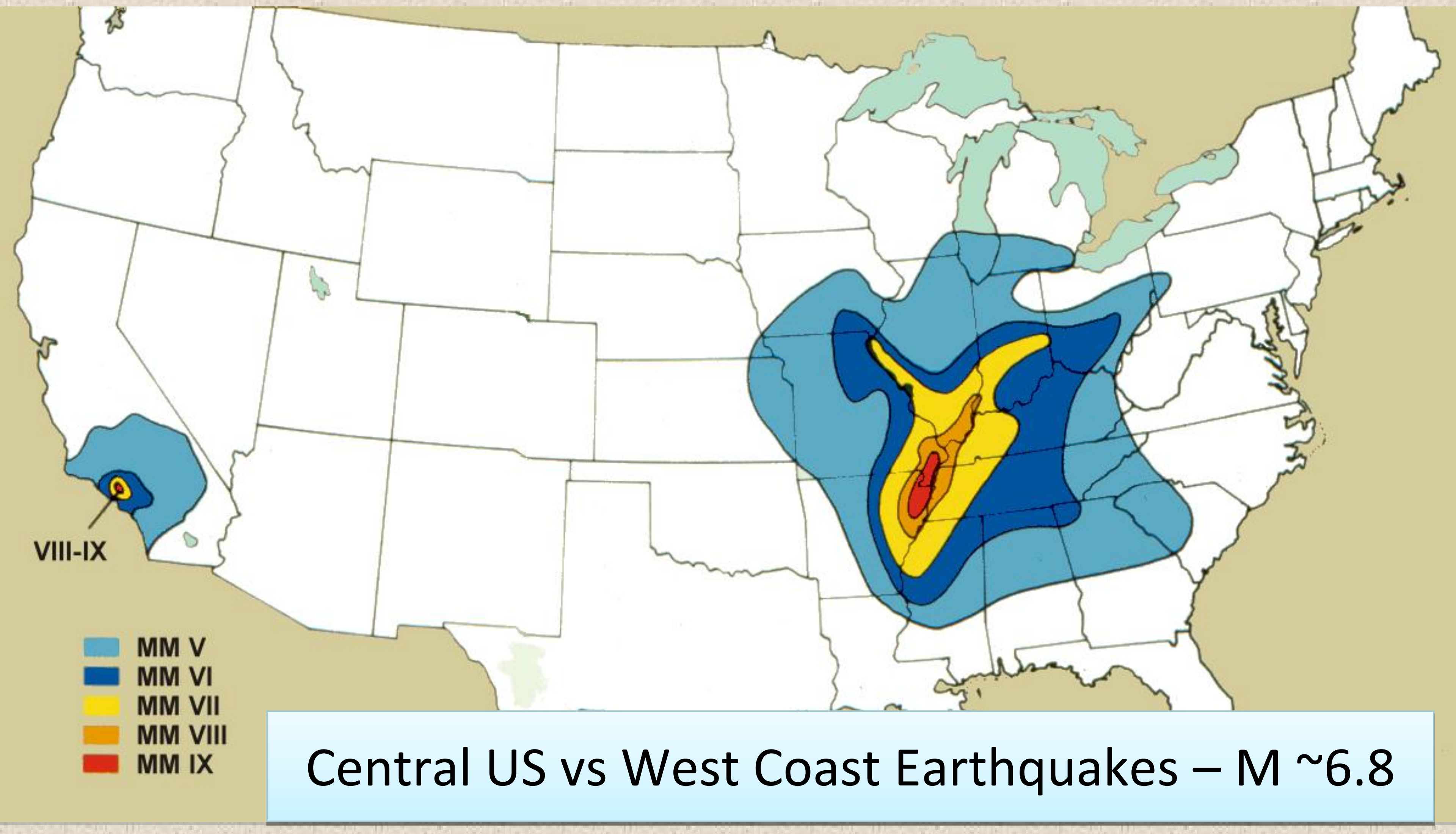
[c]Magnitude is a measure of earthquake size, determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicenter. Three magnitude types—mbLg (similar to Richter magnitude), m3Hz, and mDUR—are used by the OGS to determine the size of Oklahoma earthquakes (Lawson and Luza, 1995).

[d]The El Reno earthquake had a Gutenberg-Richter magnitude (mb) of 5.5.

Earthquake epicenters from 1897 to 2002

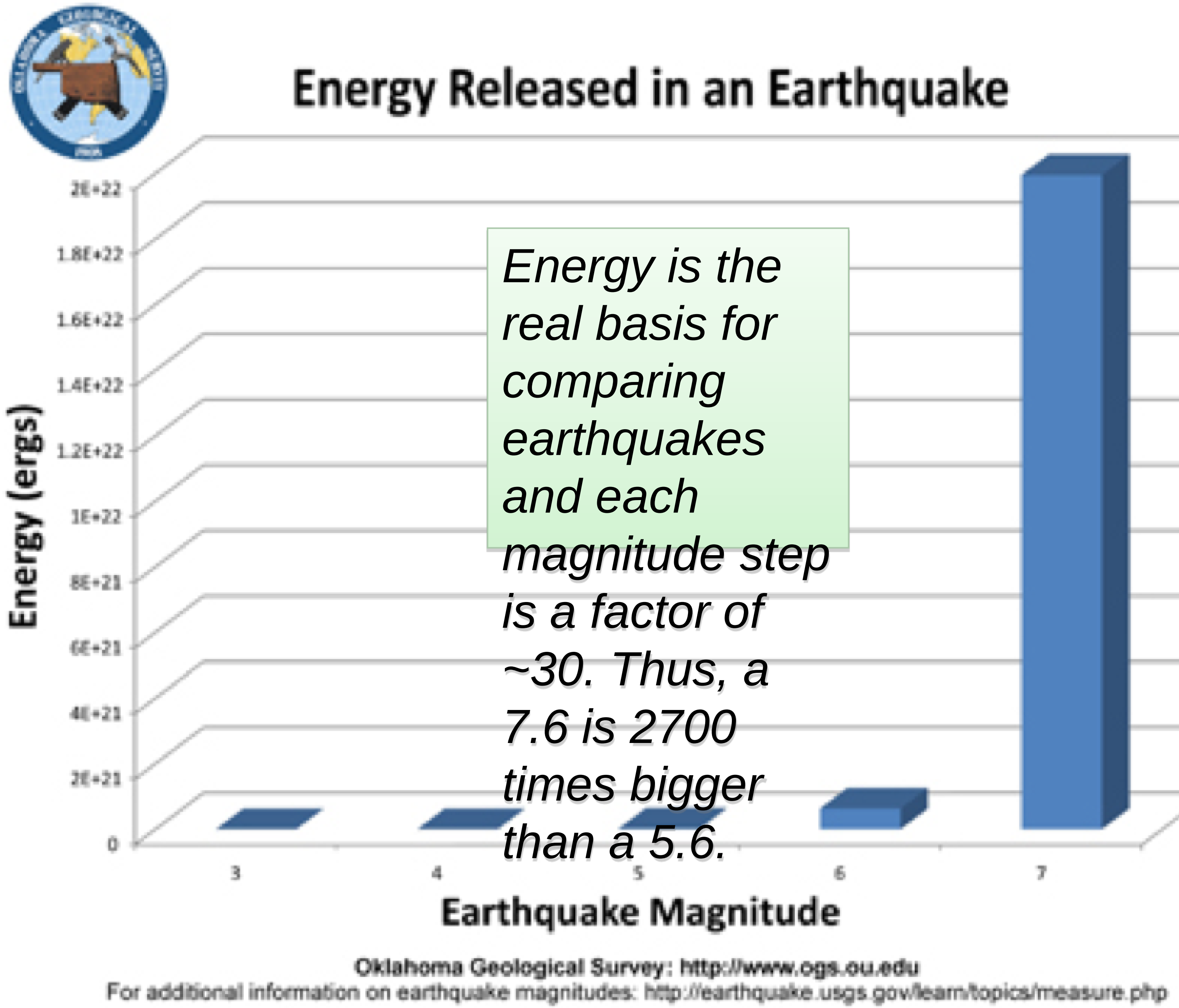
The Meers Fault (>30km lateral offset in the Quaternary, ~3m of movement ~1300 years ago)

Why do we feel little earthquakes so often?



Central US vs West Coast Earthquakes – M ~6.8

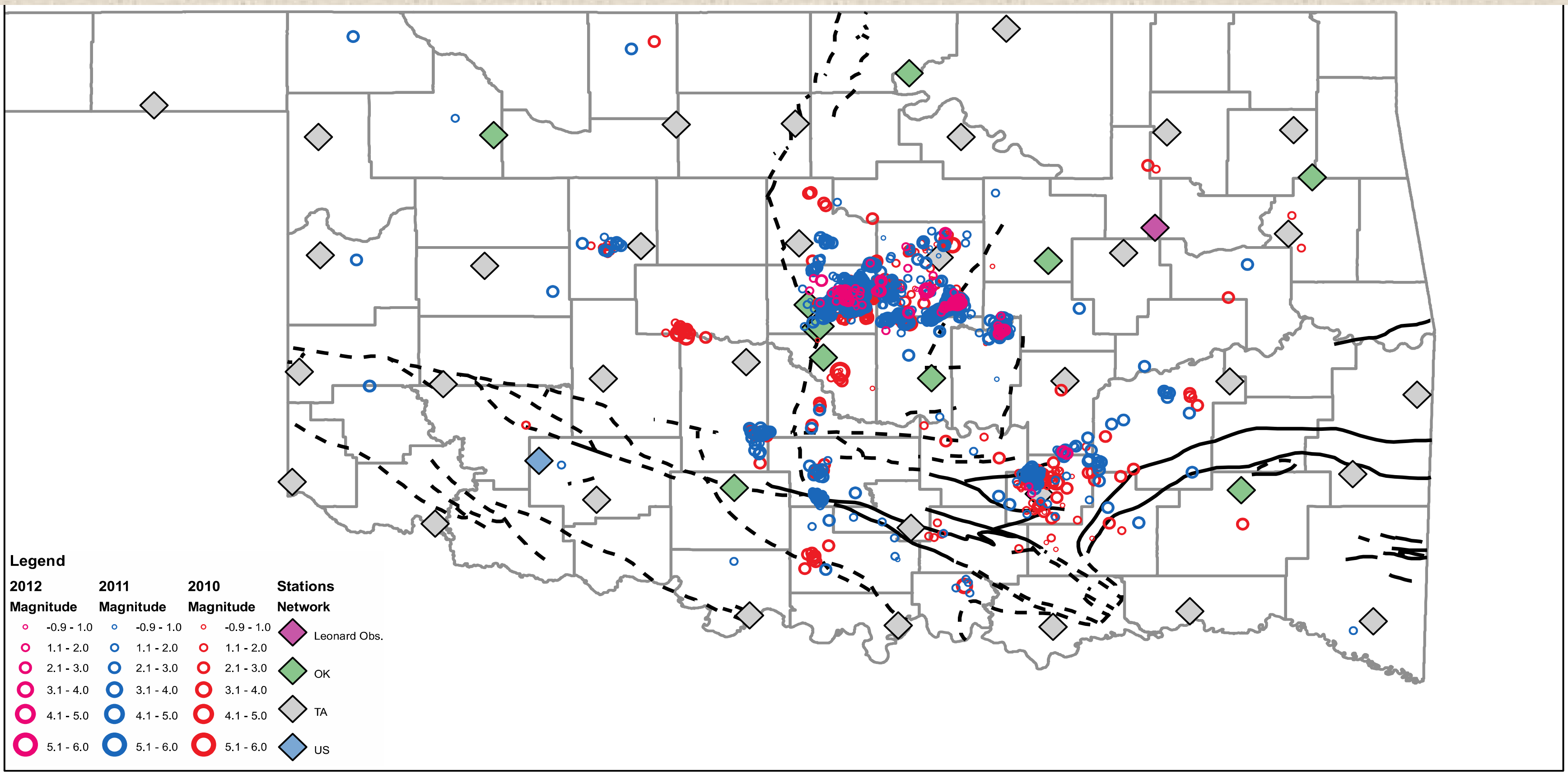
(Missouri Department of Natural Resources)



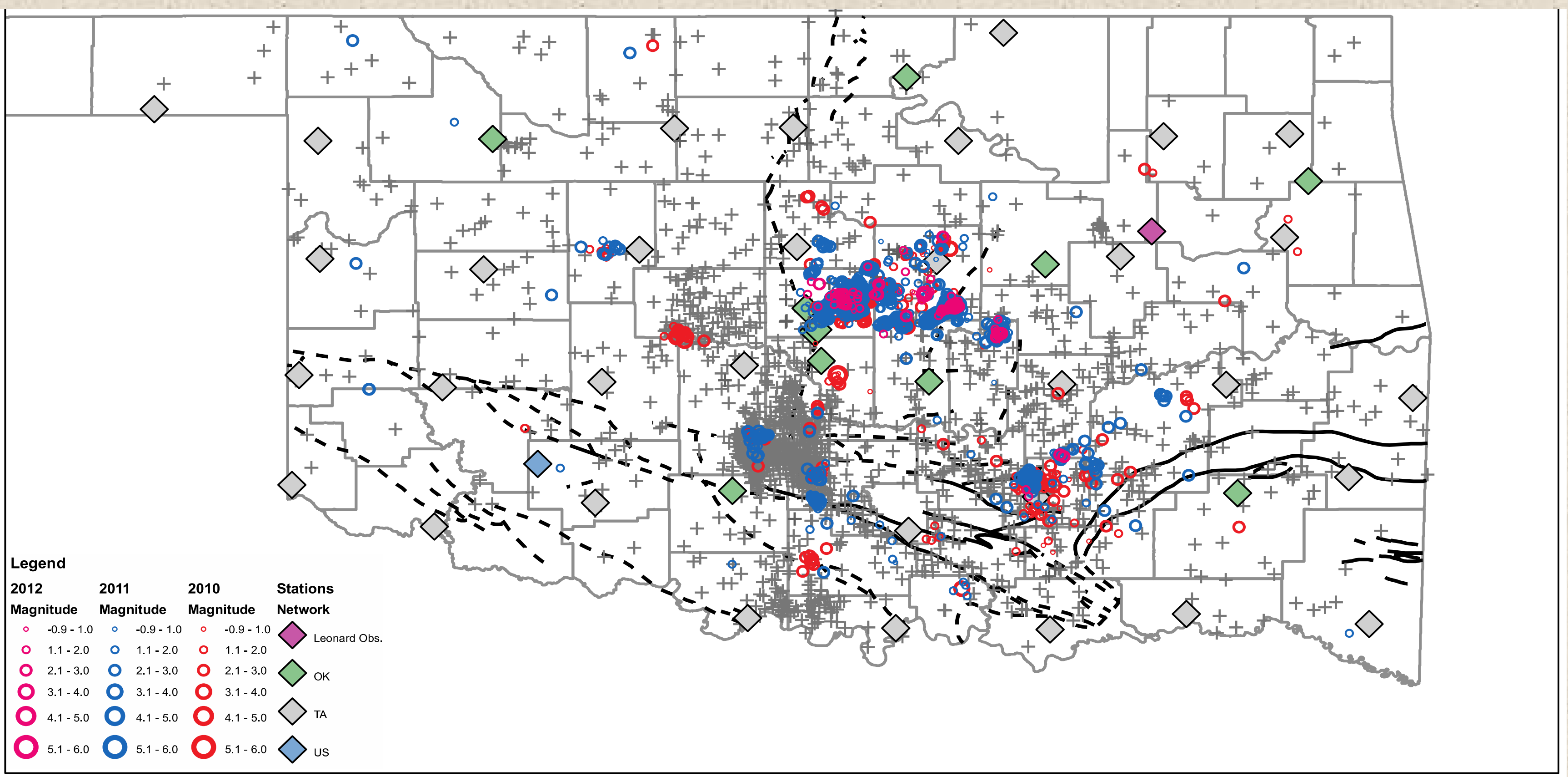
Energy is the real basis for comparing earthquakes and each magnitude step is a factor of ~30. Thus, a 7.6 is 2700 times bigger than a 5.6.

NSF Earthscope

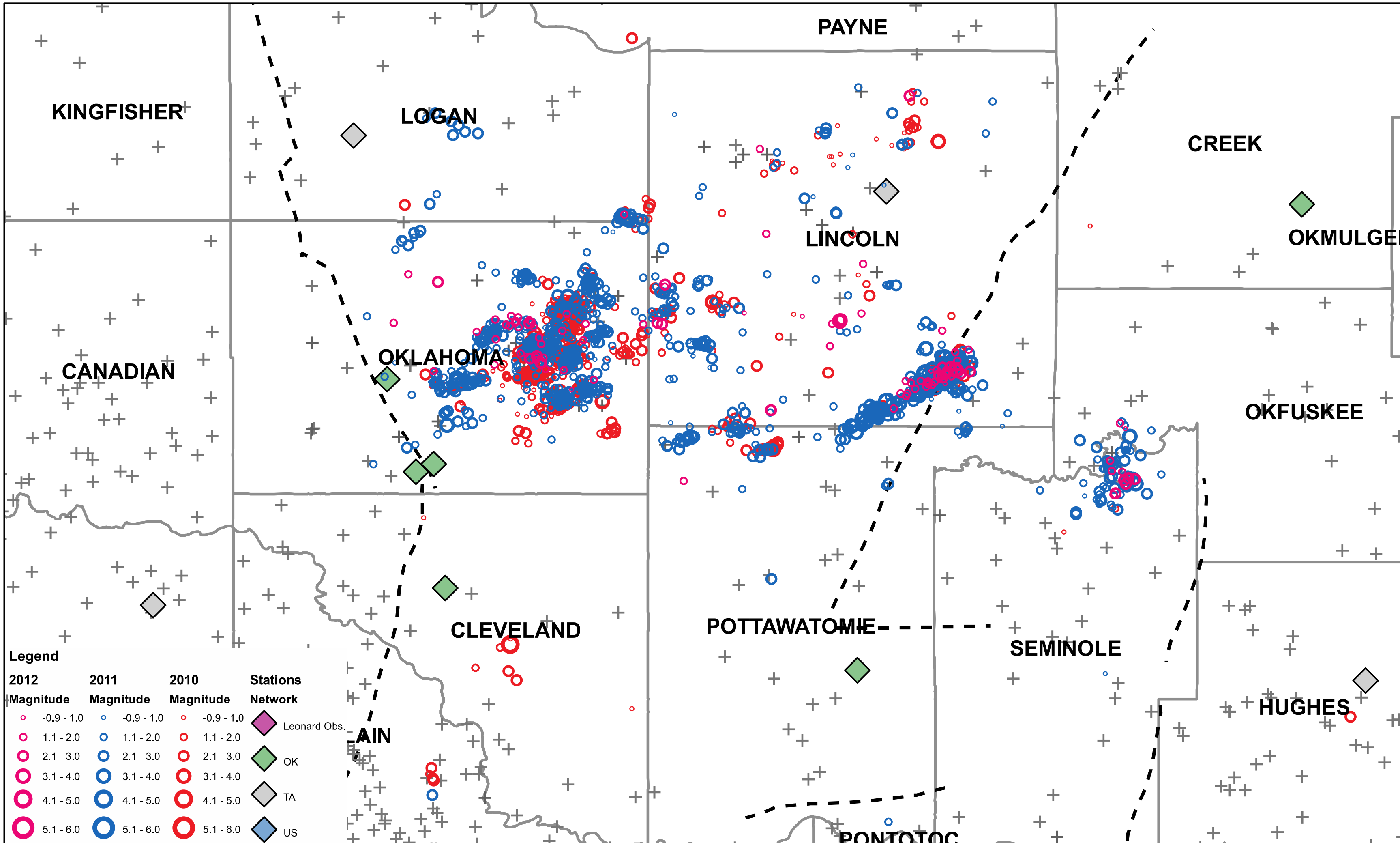
OGS Earthquake Catalog 2010-2012



OGS Earthquake Catalog 1897-2012

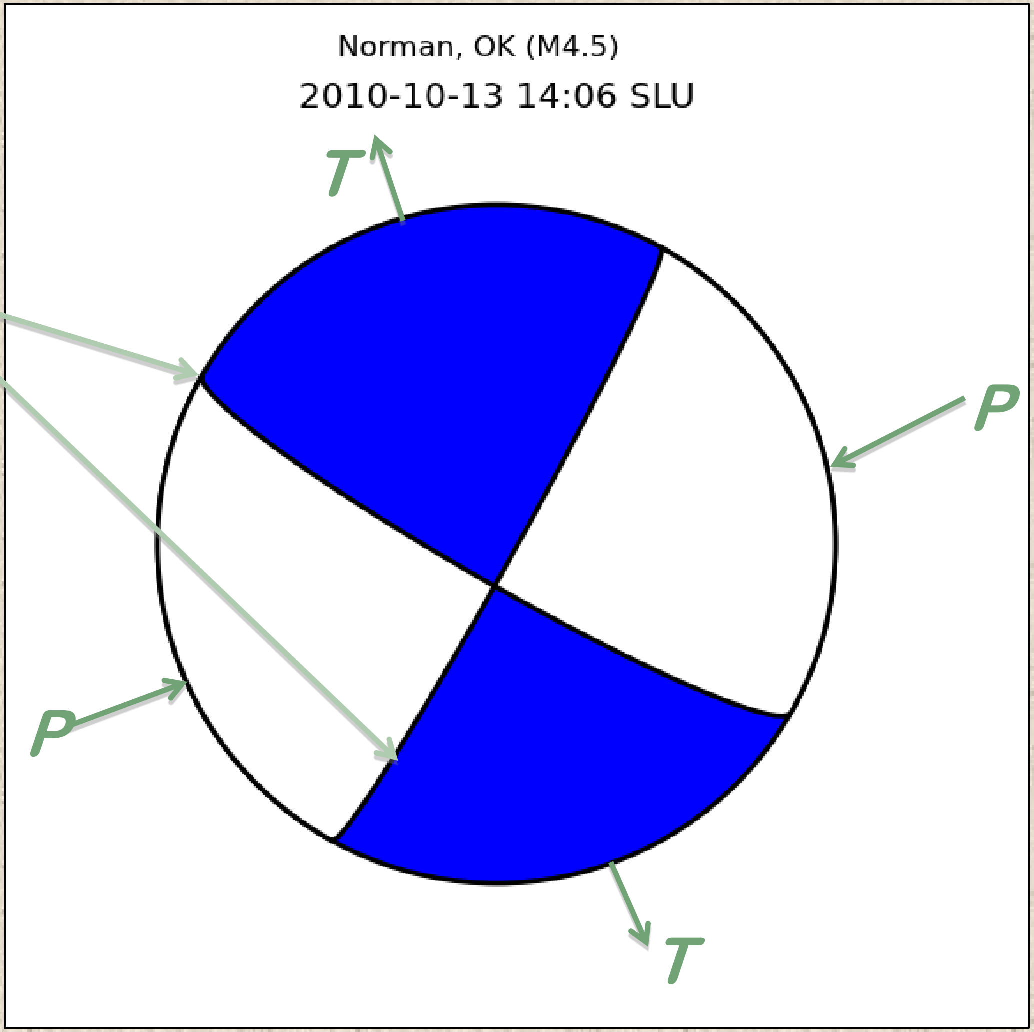


OGS Earthquake Catalog 2010-2012

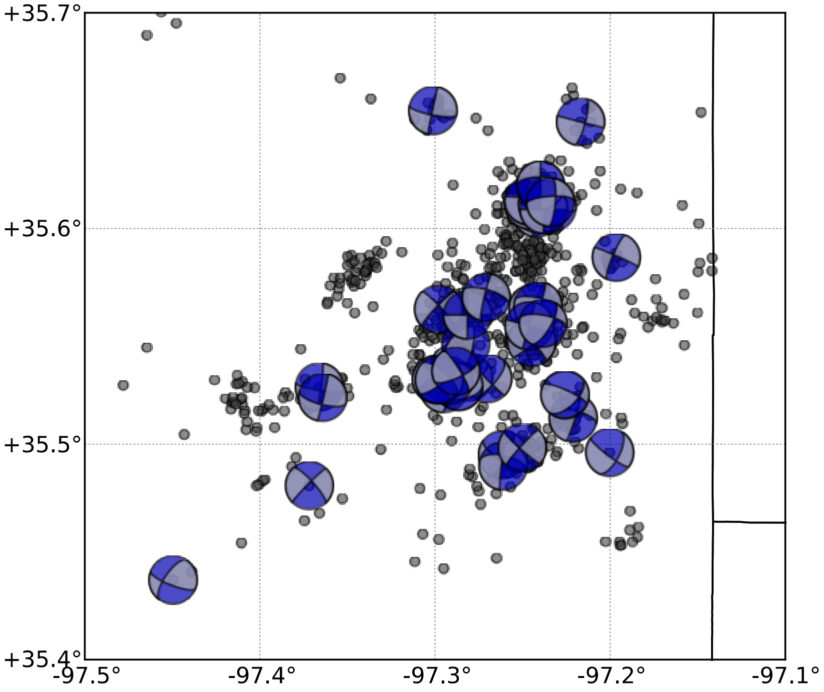


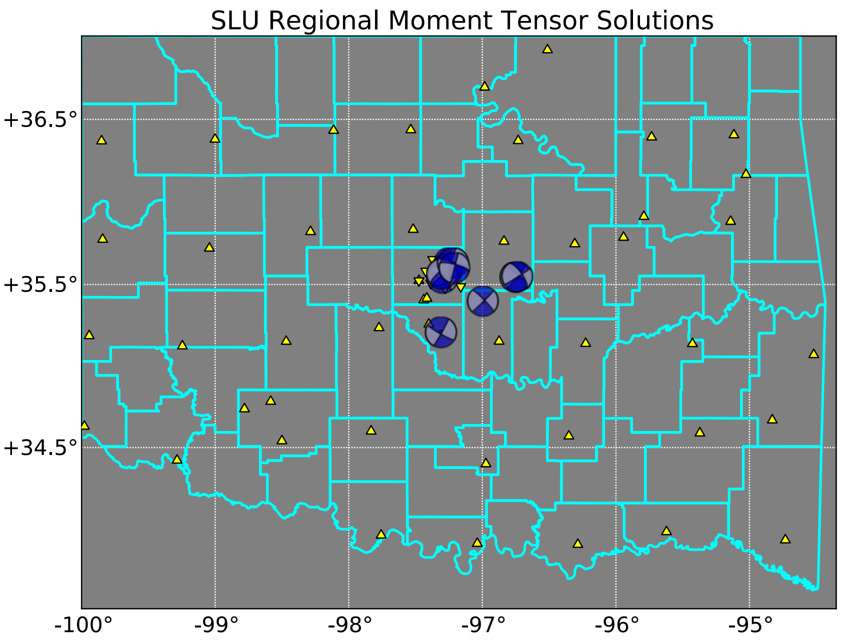
Focal Mechanisms

- Lower hemisphere stereographic projection
- Two planes indicate the two possible fault planes
  - One is the fault
  - The other an auxiliary plane
- The colored region indicates the compressive region (first motions up)
- P and T axis found by bisecting the compressional and dilatational quadrants



Regional Focal Mechanisms

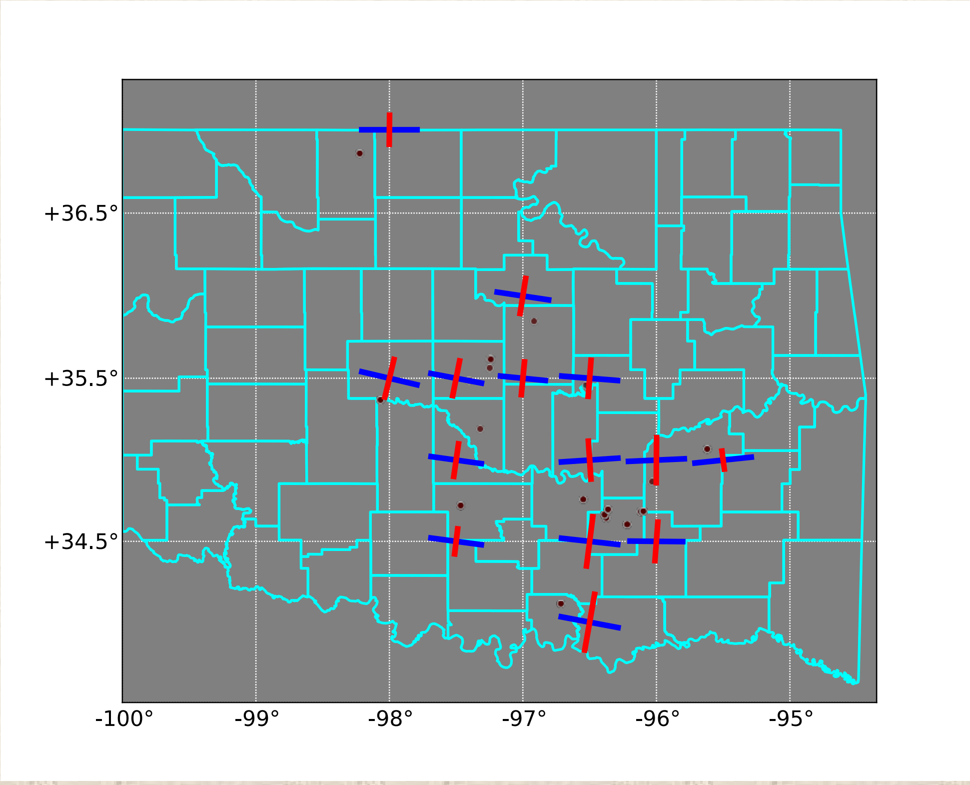


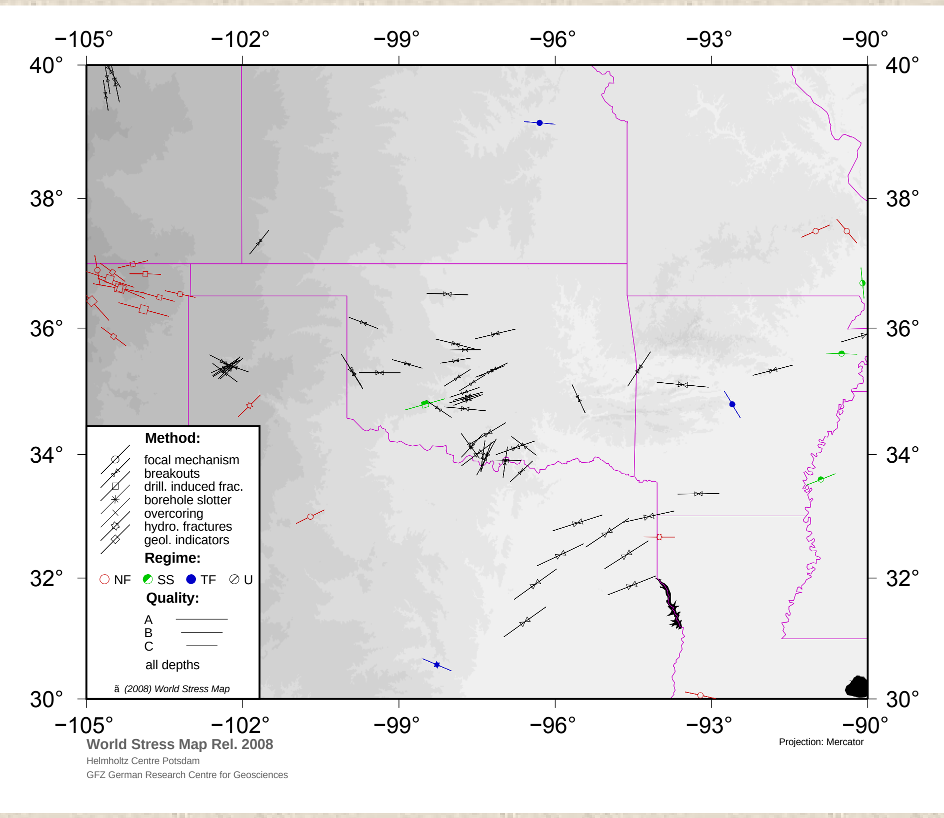


Source: Saint Louis University and USGS

Now more than 300 focal mechanisms calculated by the OGS

Regional Stress Field



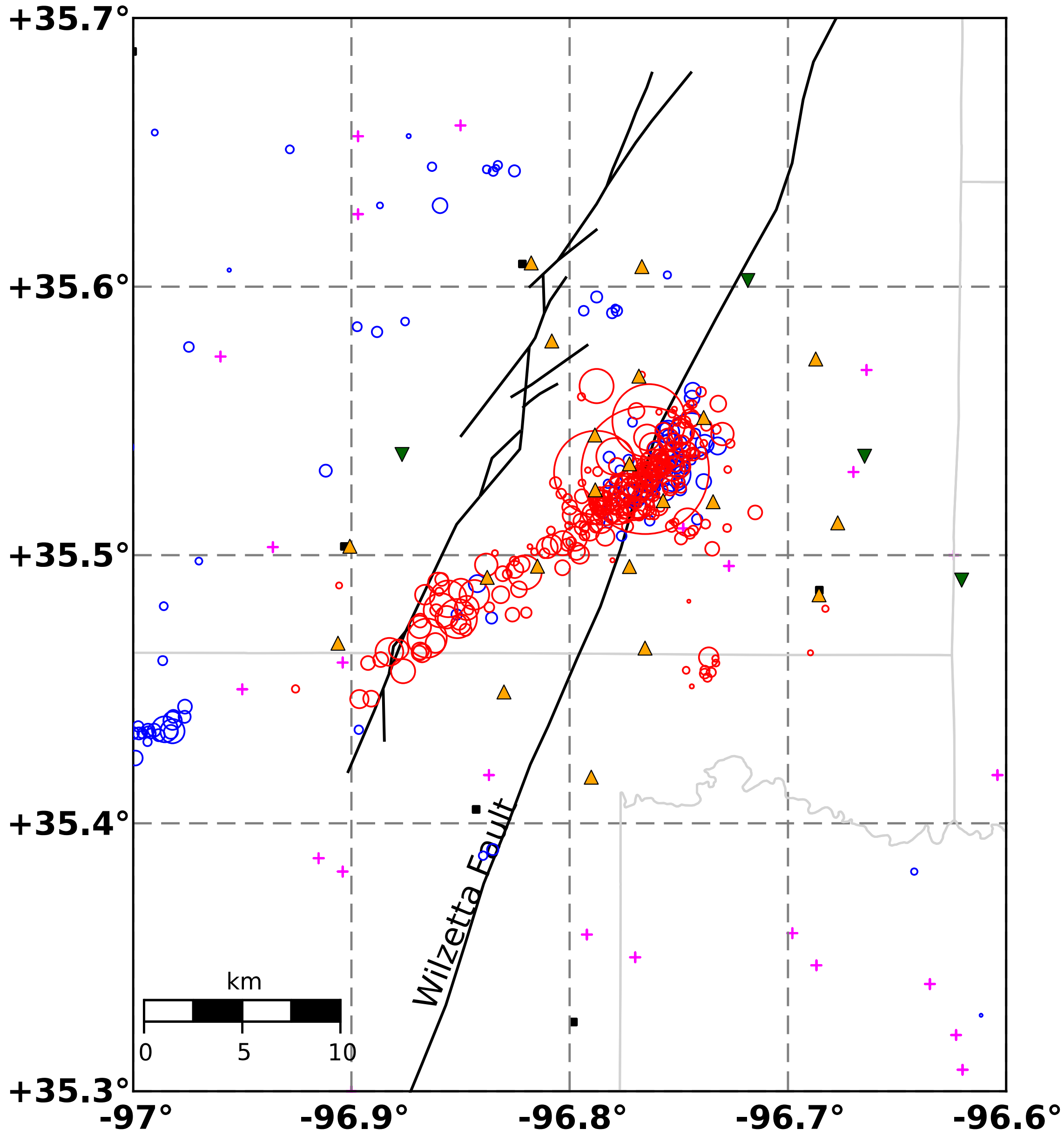


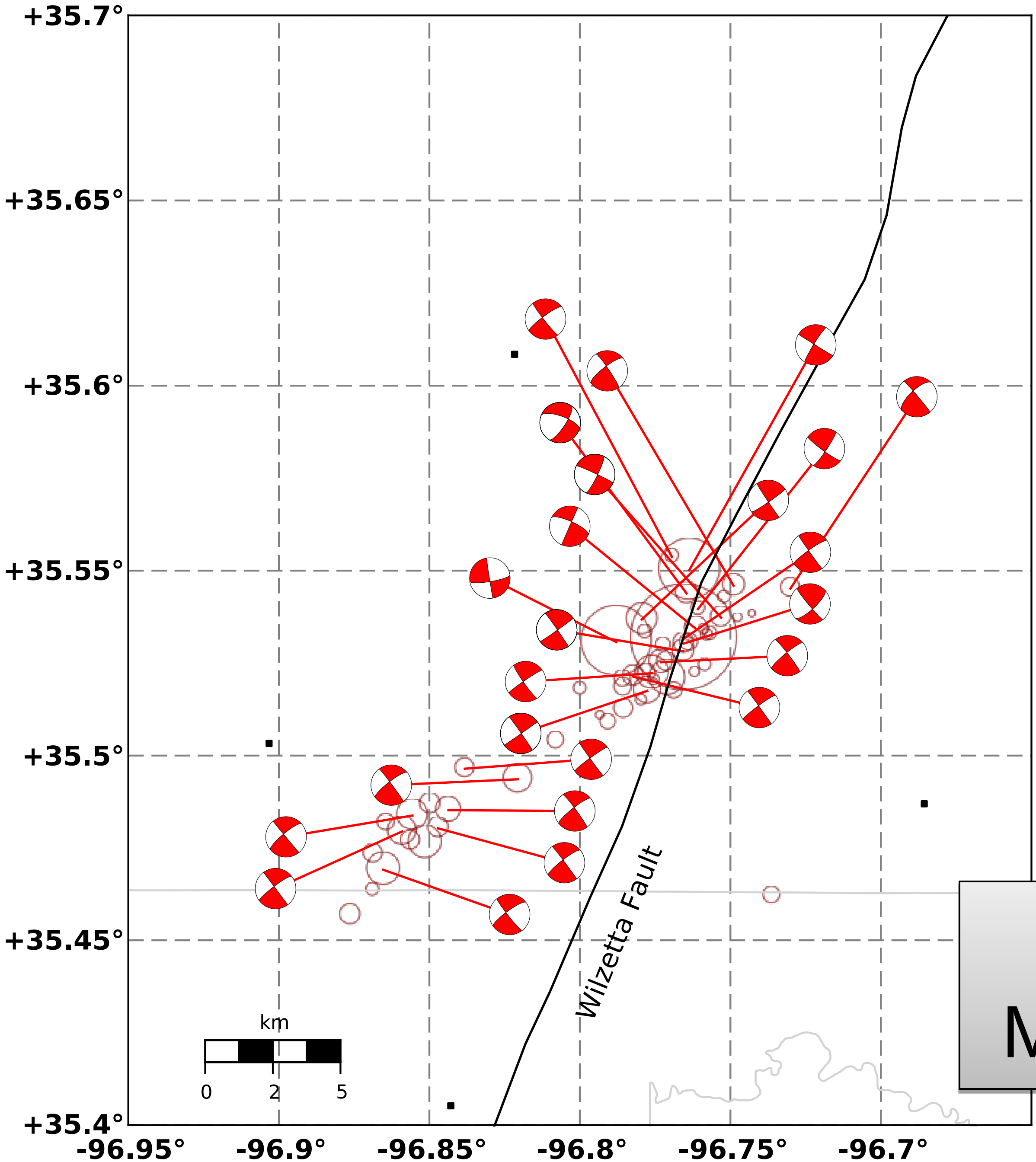
Temporary Stations Response Prague Earthquake

Oklahoma Consortium (orange triangles)

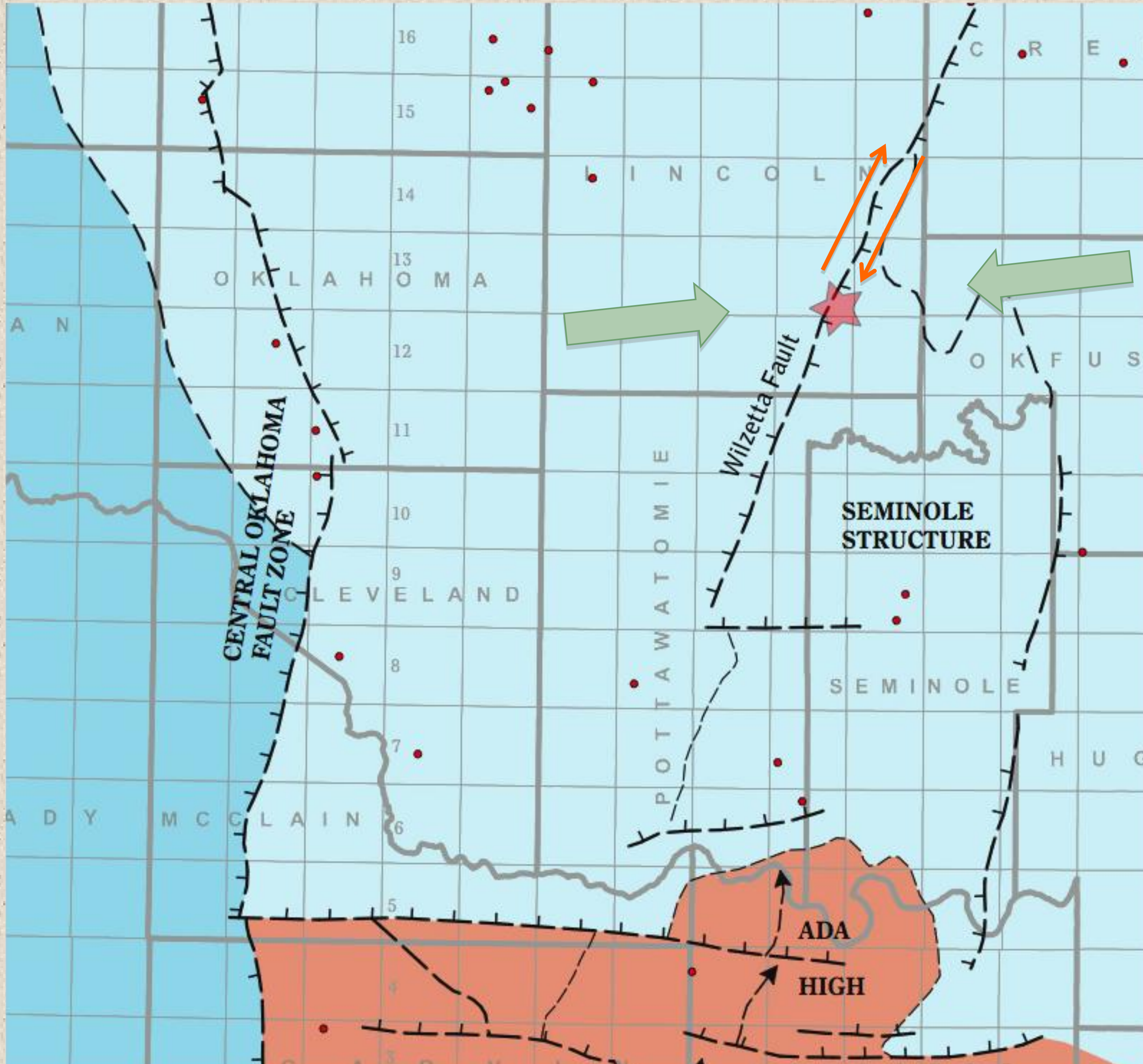
- Dr. Katie Keranen, OU
- Dr. Estella Atekwana, OSU
- Austin Holland, OGS

USGS Temporaries (green triangles)





Focal Mechanisms



16
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C R E E
L I N C O L N
O K L A H O M A
A N
O K F U S
Wilzetta Fault
CENTRAL OKLAHOMA FAULT ZONE
SEMINOLE STRUCTURE
C L E V E L A N D
P O T T A W A T O M I E
S E M I N O L E
H U G
A D Y
M C C L A I N
ADA HIGH