

# **Extension of the Mid-Continent Rift System into the Southern Mid-Continent Region: Possible Implications for Exploration and Natural Hazards\***

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Search and Discovery Article #30450 (2016)\*\*

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## **Abstract**

The Mid-Continent rift system is a prominent, 1.1 Ga age feature that extends to both the SE and SW from the Great Lakes region. The southwestern arm is often thought of as extending only to Kansas. However, there are gravity, magnetic, seismic, and drilling results that suggest this feature may extend across Oklahoma and even into West Texas. In Oklahoma and southern Kansas, simple residual gravity maps reveal a clear NNE trend of gravity highs that generally correlate with the Nemaha uplift. These anomalies are too large to be due to just the modest basement relief across this structure. Thus, deeper linear features that are dense are required to explain these anomalies. One simple explanation is that the Mid-Continent rift system extends across central Oklahoma and is cut by the younger Arbuckle-Wichita uplift. The magnetic anomalies across the region are very complex, but there are linear trends in places that correlate with the linear gravity anomalies. There is also a general correlation the geophysical anomalies with earthquake activity in central Oklahoma. Thus, we suggest that the Mid-Continent rift system extends across Oklahoma and widens much like the East African rift extends through Kenya and widens in Tanzania. These features could have been reactivated in the Pennsylvanian to produce the Nemaha uplift, and some may be reactivated today.

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# The Mid-Continent Rift System

## *It's a Whopper!*

***G. Randy Keller***

***Jonathon Buening***

***Miguel Merino***

***Seth and Carol Stein***

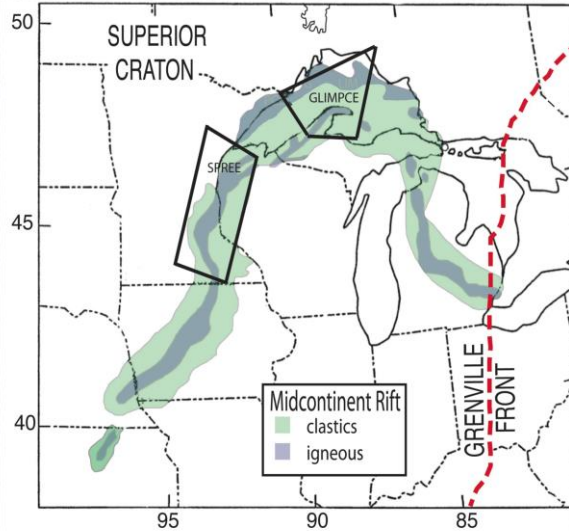
***(Austin Holland, Ken Luza)***



**Oklahoma Geological Survey**



# Mid-Continent Rift System (MCRS)



Stein et al., 2011

- ~1.1 Ga failed continental rift, approximately 2000 km in length, similar to EARS
- Two major arms of the rift are in the Lake Superior region
- Except in the Lake Superior region, the MCRS is buried under Phanerozoic sediment; thus, its extent and geologic character has often been derived from gravity and magnetic anomalies
- The MCRS produced huge volumes of primarily mafic volcanics and intrusives along the axis that are flanked by sedimentary basins

## Why care about the Mid-Continent rift?

- Rift-scale normal faults can act as deep-seated zones of weakness and are often reactivated during subsequent tectonic events (e.g. Nemaha structures, effects on Mississippi Lime?)
- Reactivation of basement structures or even simple basement topography can affect the overlying sedimentary column and can produce traps (e.g., Osage County, OK)
- Proterozoic sediments in the Mid-Continent are viable source rocks (e.g., Nonesuch Shale)

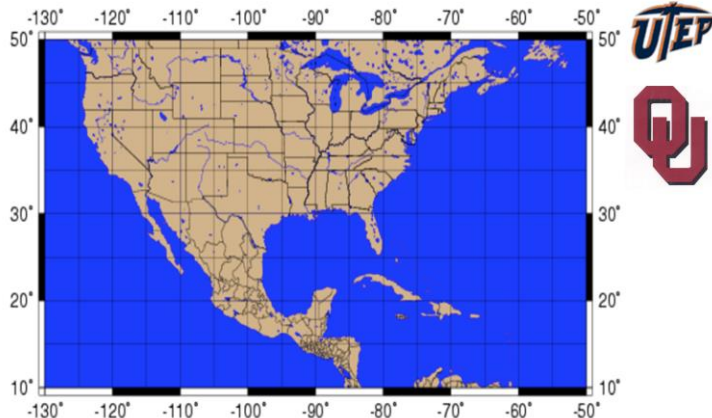
# Our Integrated Approach

- Gather all of the geological and drilling data we can
- Look for seismic reflection and refraction data
- Compile other geophysical data (gravity, magnetic, electrical, remote sensing, etc.)
- Collect data in key areas to the extent possible
- Construct integrated 2-D models across key areas using gravity and magnetic modeling as the integrative platform
- Follow up with as much 3-D analysis as possible



## Gravity and Magnetic Dataset Repository

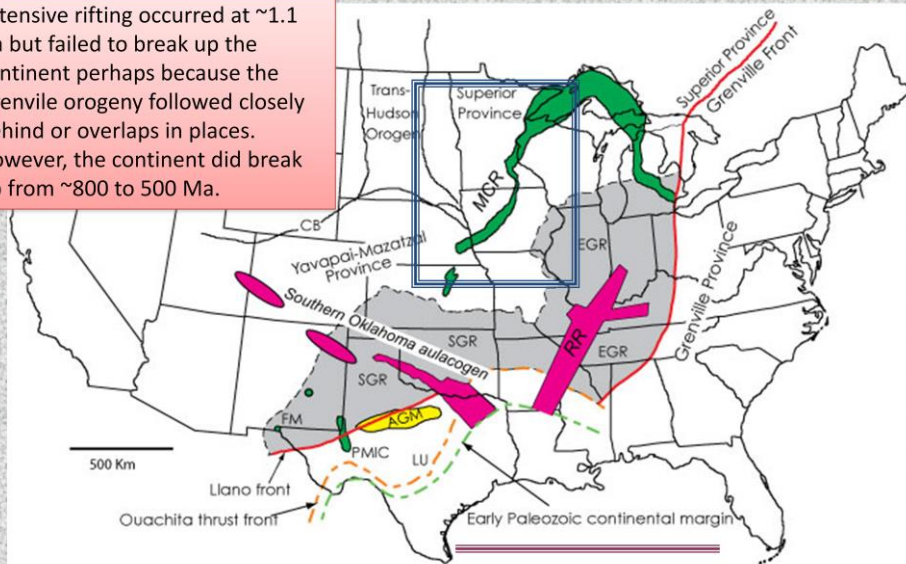
[Pan American Center for Earth and Environmental Sciences \(PACES\)](#)



Use the form below to search the gravity or magnetic datasets by Lat/Lon coordinates in decimal degrees.  
**Note:** In order to ensure quality of service, there is a 500,000 dataset size limit imposed on each search.  
Please breakdown your queries into smaller search areas to accommodate larger datasets.

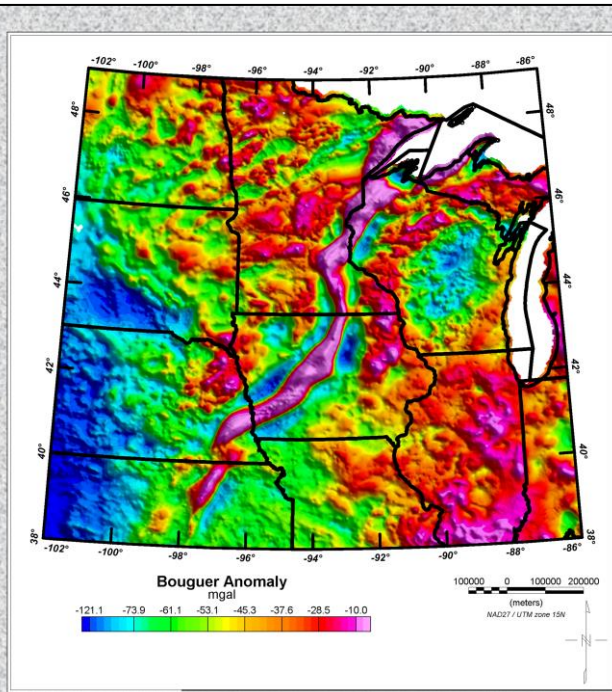
## Late Precambrian/Cambrian Structural Framework

Extensive rifting occurred at ~1.1 Ga but failed to break up the continent perhaps because the Grenville orogeny followed closely behind or overlaps in places. However, the continent did break up from ~800 to 500 Ma.



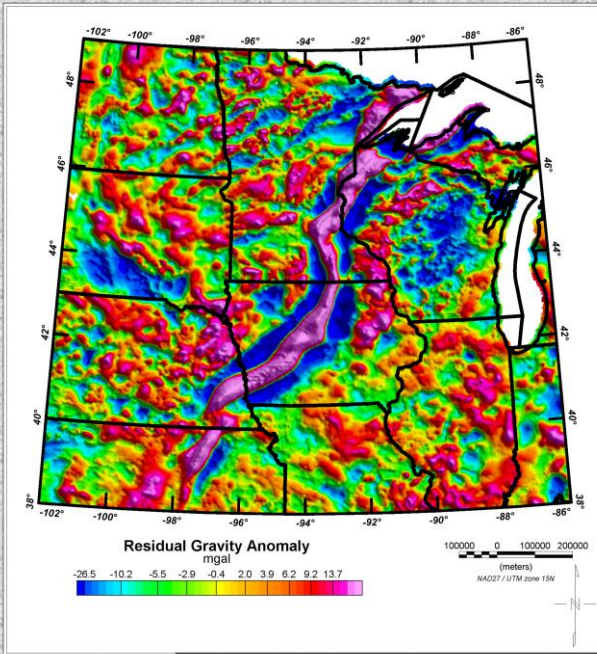
(modified from Barnes and others, 1999, originally modified from Van Schmus and others, 1996).



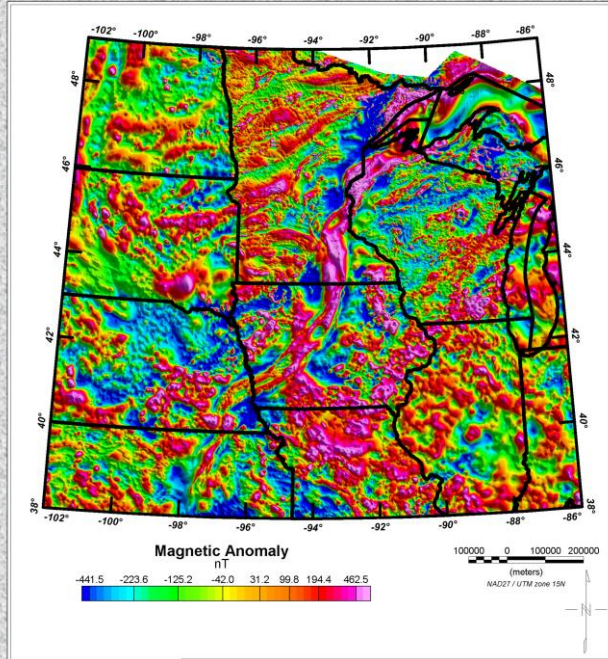


Complete Bouguer  
Anomaly Map of the  
Northern Mid-  
Continent Region.

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



Subtraction of the Upward-Continued grid from the original Bouguer Anomaly grid yields a Residual Anomaly grid. This has the effect of a physics-based high-pass filter. The residual is used to enhance upper-crustal anomalies.

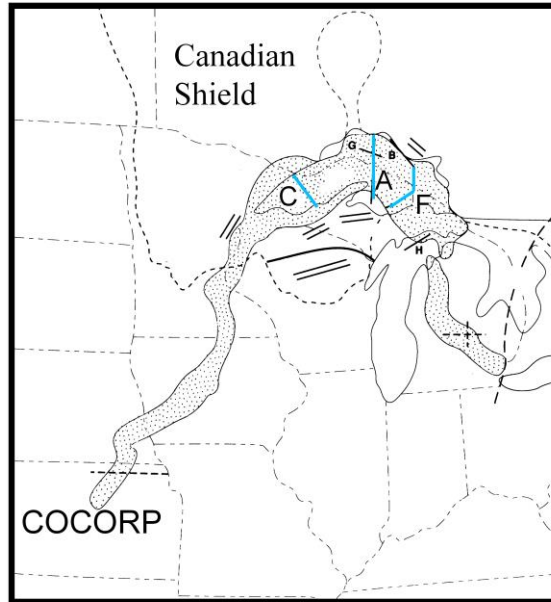


This magnetic anomaly map has been reduced to the magnetic pole in order to remove the effect of the inclination of the induced field.

Some large negative anomalies coincident with the Mid-Continent Rift flanking basins are due to reversely-magnetized volcanics.

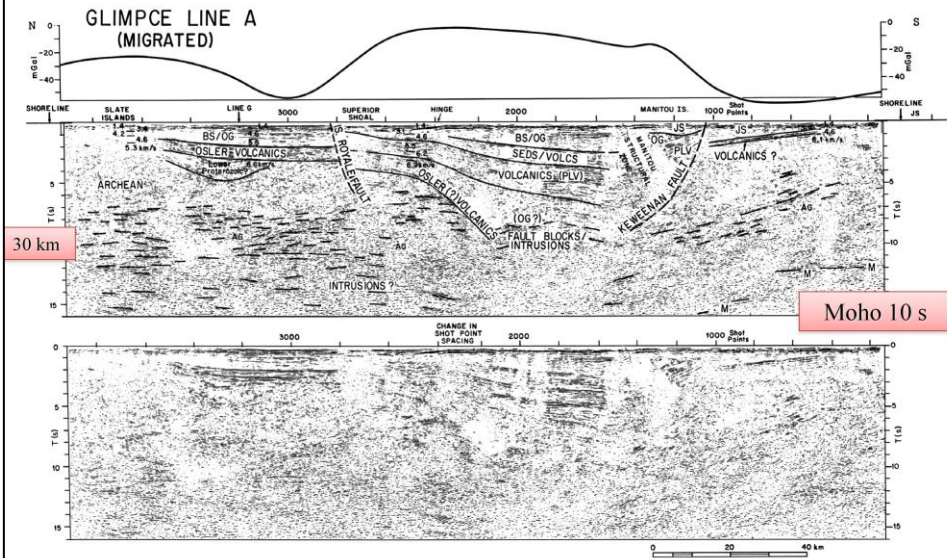
## GLIMPSE experiment - Index map

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

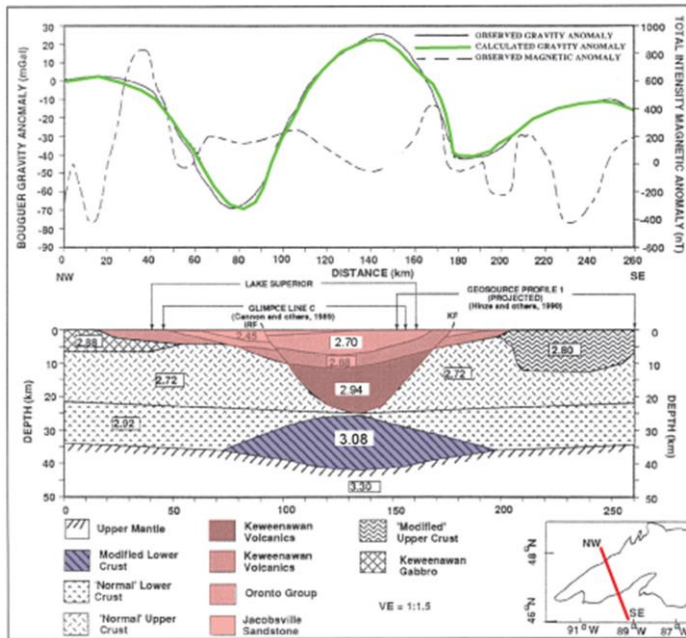




# GLIMPSE - Line A



Provided by Bill Cannon (USGS)

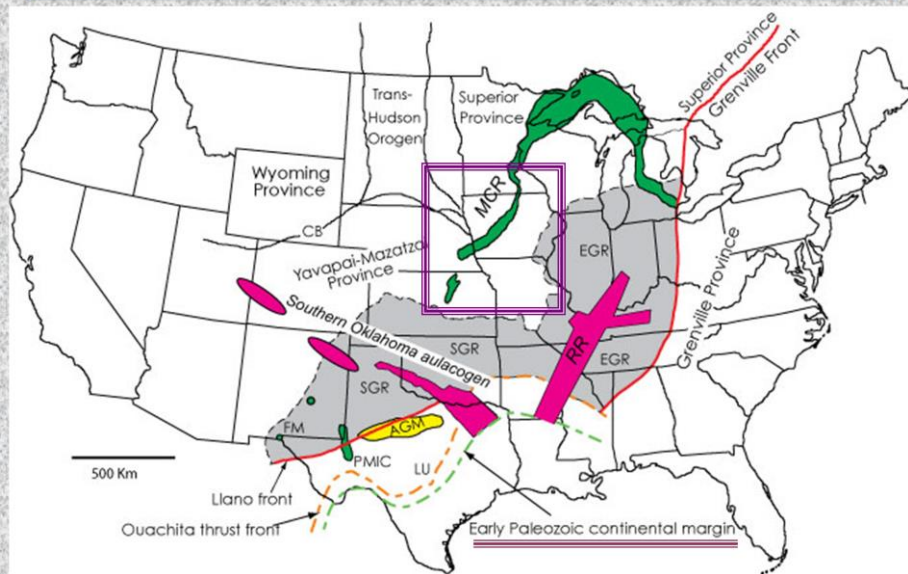


Integrated  
geophysical  
model across  
Lake  
Superior

Hinze et al. (1997)



## Late Precambrian/Cambrian Structural Framework



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

# THE AMOCO M.G. EISCHEID #1 DEEP PETROLEUM TEST CARROLL COUNTY, IOWA

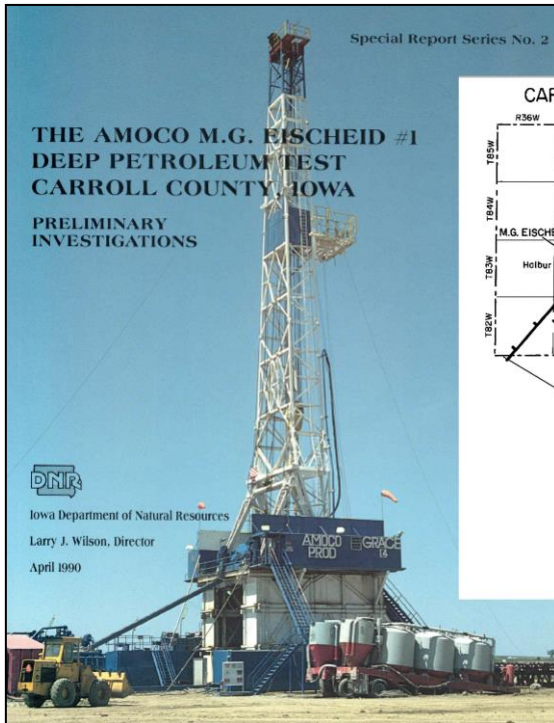
PRELIMINARY  
INVESTIGATIONS



Iowa Department of Natural Resources

Larry J. Wilson, Director

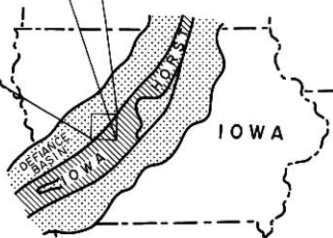
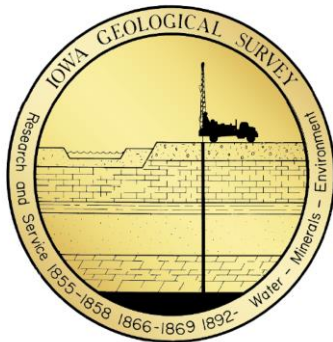
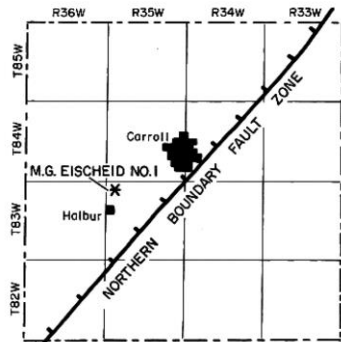
April 1990



## CARROLL COUNTY



# CARROLL COUNTY



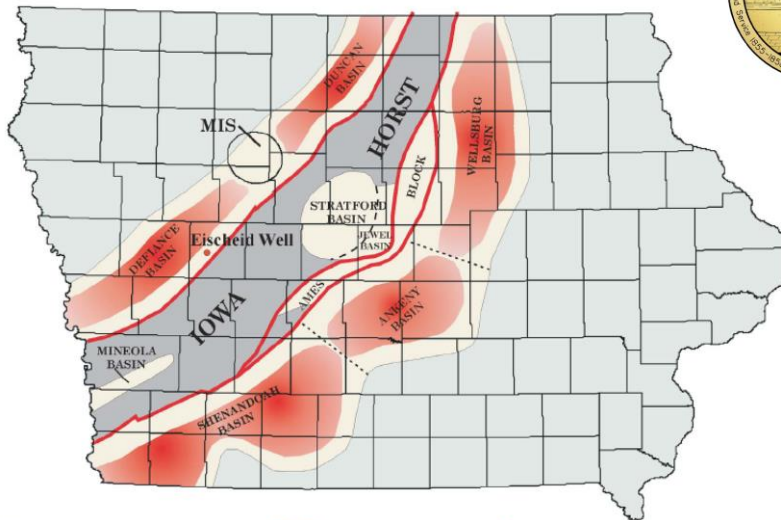
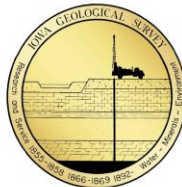
### MSR Stratigraphy

MRS clastic sedimentary rocks in the subsurface of Iowa and southern Minnesota, along with minimal exposures in Minnesota, are correlated with more extensive exposures in northern Wisconsin and Upper Peninsula Michigan.

WISCONSIN		UPPER MICHIGAN		EISCHEID WELL IOWA		MINNESOTA	
Bayfield Group	Chequamegon Sandstone		Upper Red Clastics Series	Unit H			
	Devils Island Sandstone			Unit G	Hinkley Sandstone		
	Orienta Sandstone			Unit F	Fond du Lac Formation		
		Unit E					
Oronto Group	Freda Formation		Lower Red Clastics Series	Unit D	Solar Church Formation		
	Nonesuch Formation			Unit C			
	Copper Harbor Conglomerate			Unit B			



# Primary MRS Petroleum Exploration Areas in Iowa



MRS Clastic Rocks  
Volcanic Rocks of the Iowa Horst

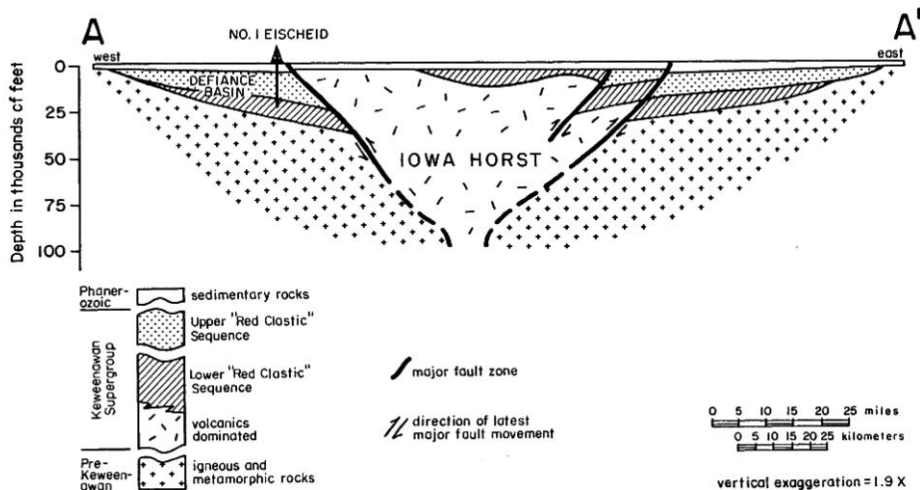
Greatest  
Petroleum  
Potential

Major  
Fault  
Zones

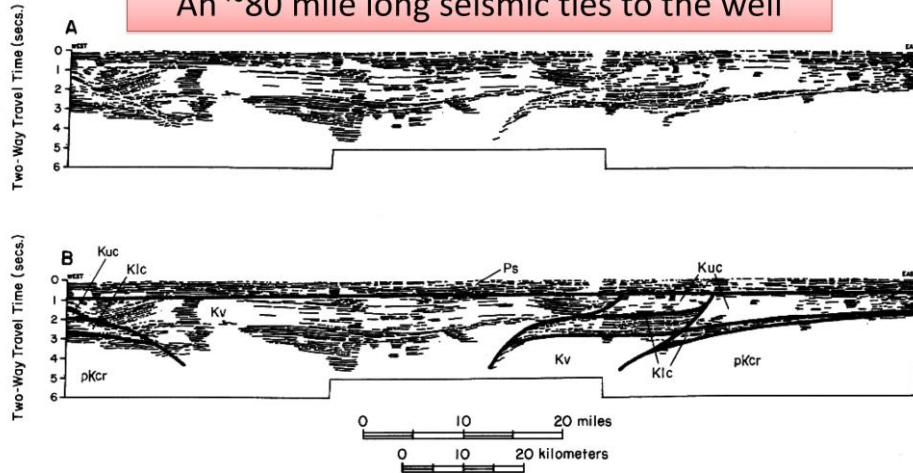
0 60 kms  
scale



As in the Great Lakes area, structural inversion followed on the heels of the rifting



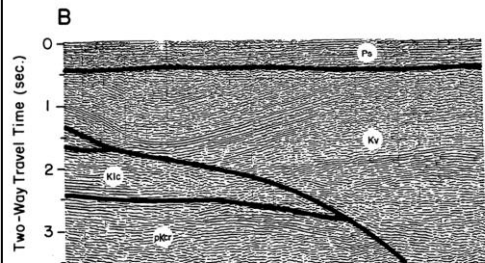
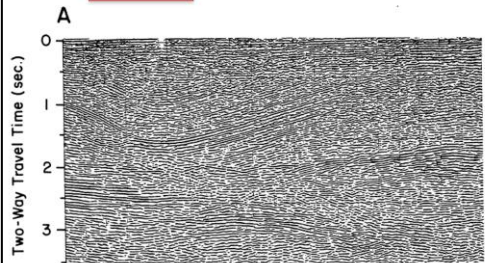
## An ~80 mile long seismic ties to the well



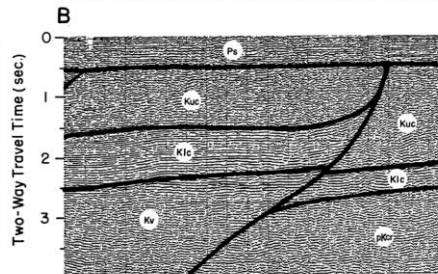
Uninterpreted (A) and interpreted (B) line drawings of the seismic reflection Profile 11. This line is courtesy of Halliburton Geophysical Services.

Pz-Paleozoic sediments; Kv-Keweenawan volcanics; Kuc-Keweenawan Upper "Red Clastic" Sequence; Klc-Keweenawan Lower "Red Clastic" Sequence; pKcr-pre-Keweenawan crystalline rocks.

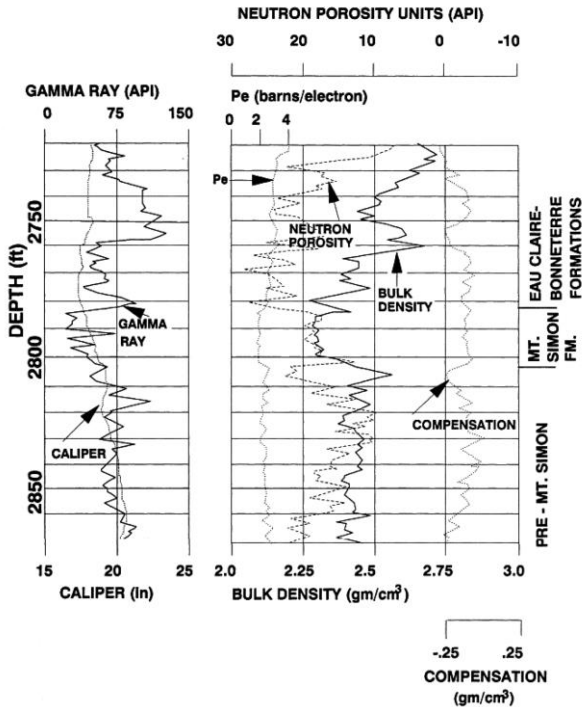
West



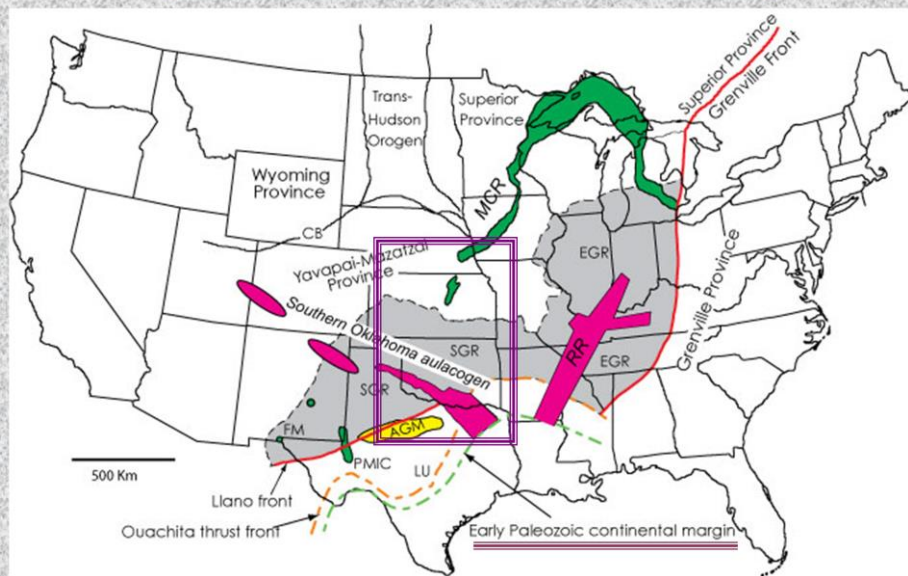
East



Density log of  
the upper part  
of the  
Precambrian  
section  
( $\sim 2.4 \text{ gm/cc}$ )



## Now lets look further south

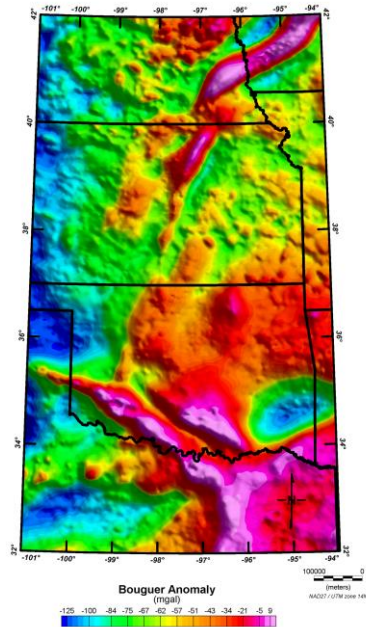


(modified from Barnes and others, 1999, originally modified from Van Schmus and others, 1996).

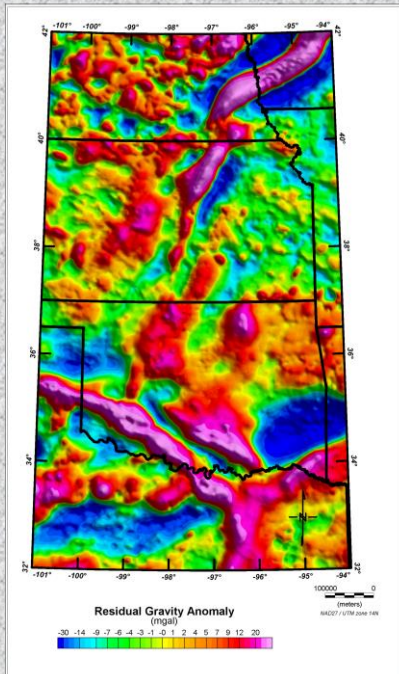


## ***Bouguer Anomaly map of Southwestern Mid-Continent Region***

The Mid-Continent Rift appears to extend into Oklahoma. The Southern Oklahoma Aulacogen and the Arkoma Basin are other major features.







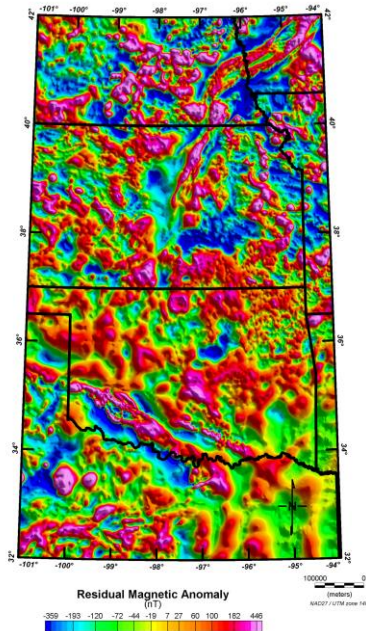
## ***Residual Gravity Map***

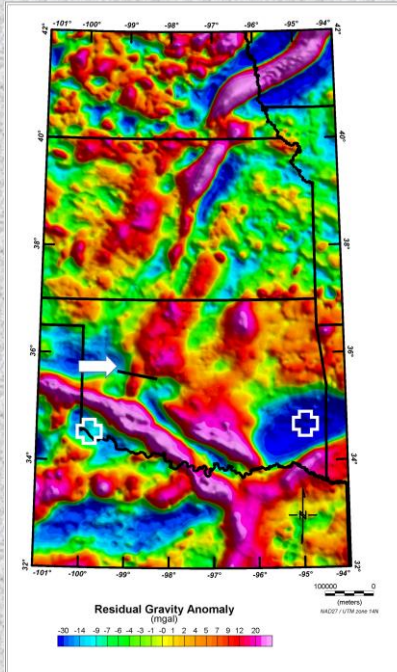
This map clearly suggests that the Mid-Continent rift system extends across southern Kansas and northern Oklahoma. However, the magmatic products do not seem to subcrop.

The possibility is that the resulting faulting effected the formation of the basement structures in central Oklahoma and south-central Kansas.

## ***Residual Magnetic Anomaly Map***

The Southern Oklahoma Aulacogen and the Mid-Continent Rift are evident, but the overall anomalies are much more complex than in the gravity map. This is at least in part due to the 1.4 Ga granite-rhyolite province that forms the uppermost portion of the Precambrian basement.



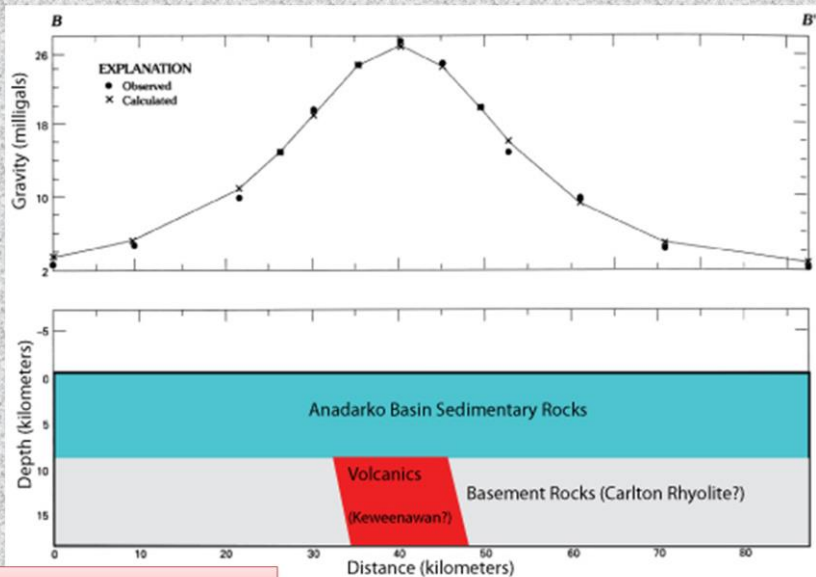


## Residual Gravity Map

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

*Note that the Hardeman and Arkoma basins form large gravity lows, but the Anadarko basin does not.*

## Southern Extension of the MCR?



Robbins and Keller (1992)

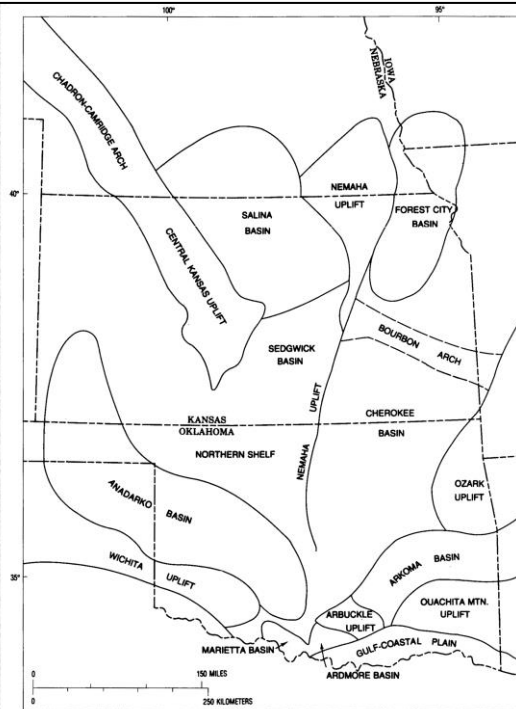


Oklahoma  
Geological  
Survey  
1985

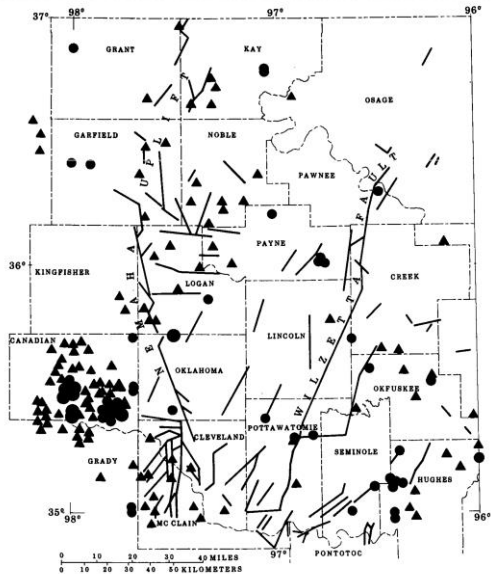
Special Publication 85-2

Seismicity and Tectonic Relationships  
of the Nemaha Uplift  
and Midcontinent Geophysical Anomaly  
(Final Project Summary)

R. R. Burchett, K. V. Luza, O. J. Van Eck, F. W. Wilson







#### EXPLANATION

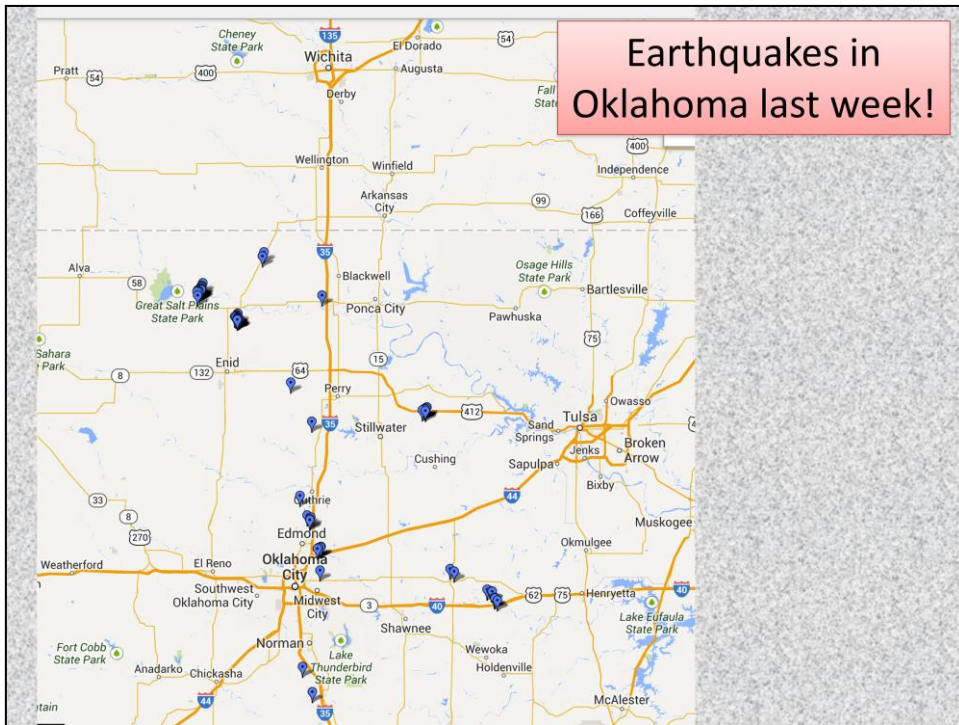
1900 - 1976 EARTHQUAKE EPICENTERS

- MM-INTENSITY IV OR LESS
- MM-INTENSITY V - VI
- MM-INTENSITY VII

1977 - 1981 EARTHQUAKE EPICENTERS

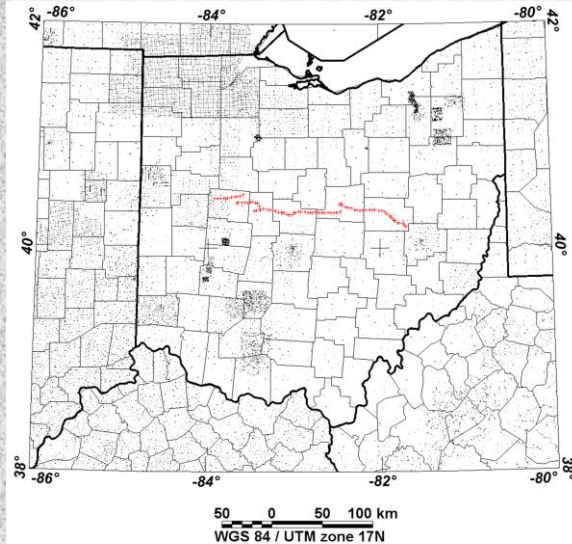
- ▲ MM-INTENSITY IV OR LESS
- ▲ MM-INTENSITY V

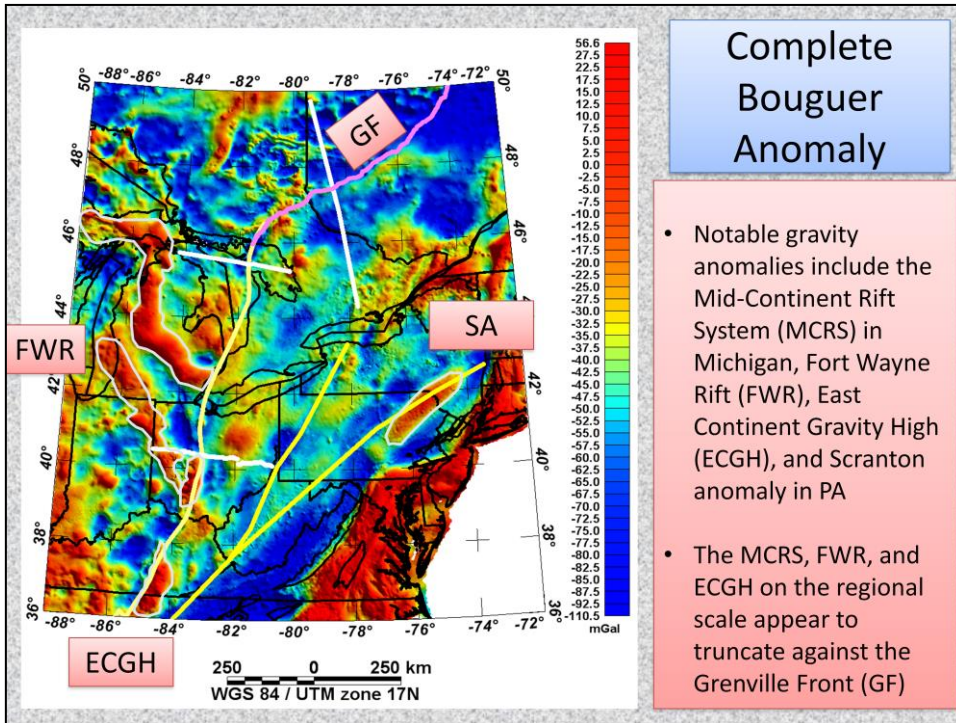
## Earthquakes in Oklahoma last week!



# Data Acquisition and Processing

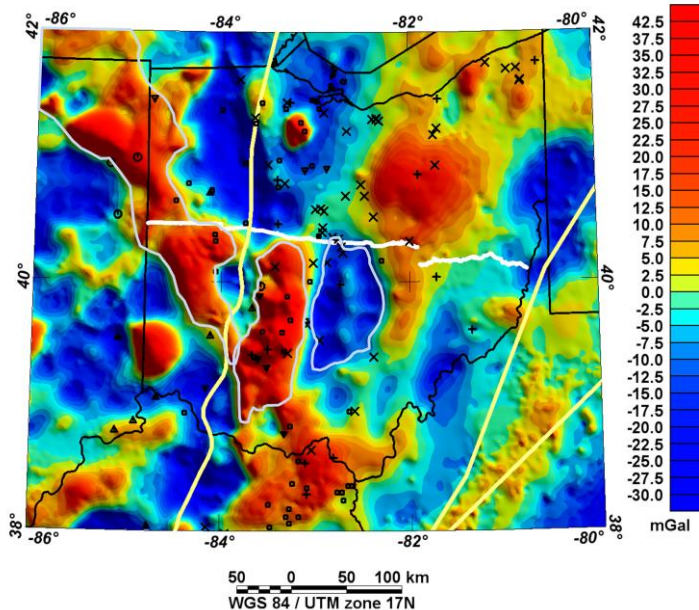
- PACES database and COCORP seismic line were analyzed.
- 118 gravity points were collected with ~3 km spacing in central Ohio to fill in data





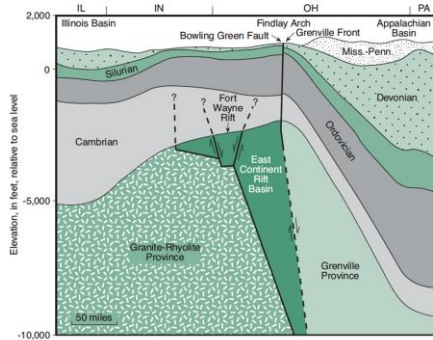
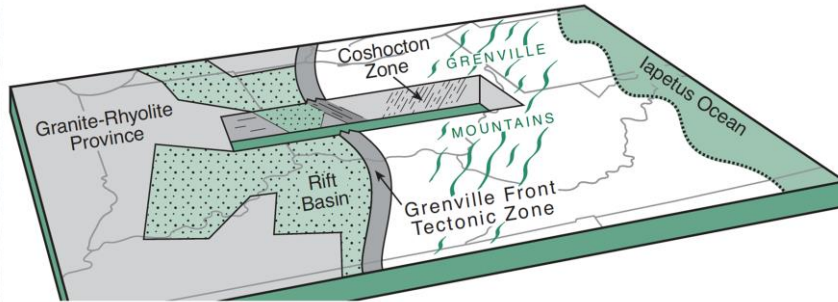


# Residual Gravity Anomaly Map



- Created by removing 40 km upward continued CBA grid
- Reveals gravity lows that correlate with known Proterzoic basins containing the Middle Run Fm.

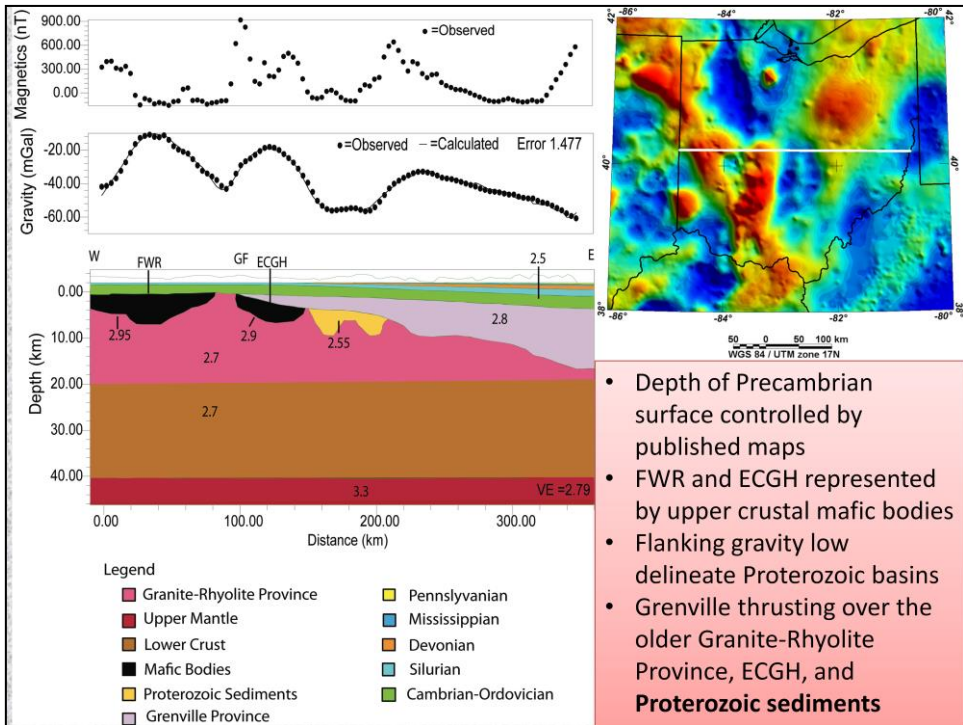




East-west cross section depicting Precambrian rocks and structures and overlying Paleozoic rocks from the Illinois Basin to the Appalachian Basin. Vertical exaggeration 165X. Modified from a diagram by Dr. E. Scott Bair, The Ohio State University.

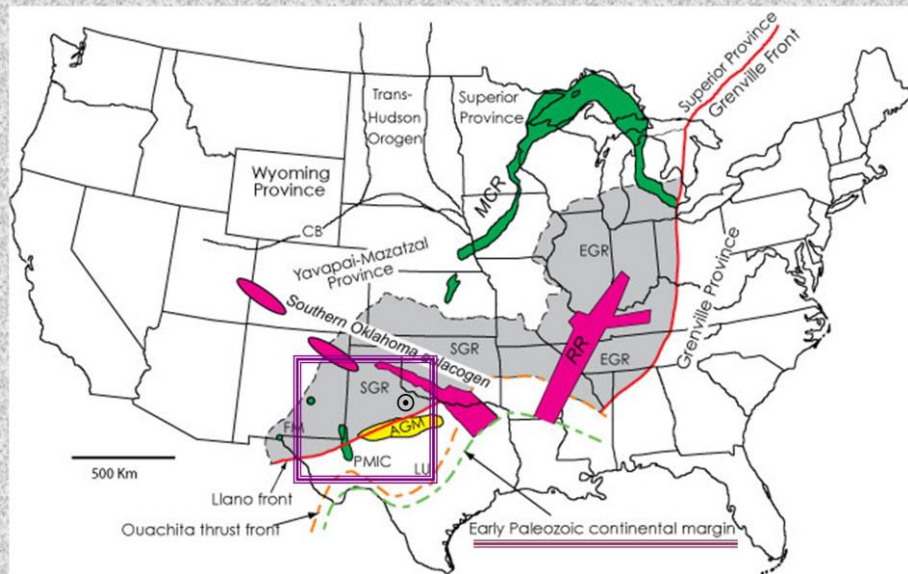
Ohio and adjacent areas depicting paleogeography and principal structural features in Late Precambrian time. Cross-sectional slice depicts reflectors imaged by the COCORP profile.

Precambrian sediments have been interpreted to extend across much of Ohio, Indiana, and Kentucky



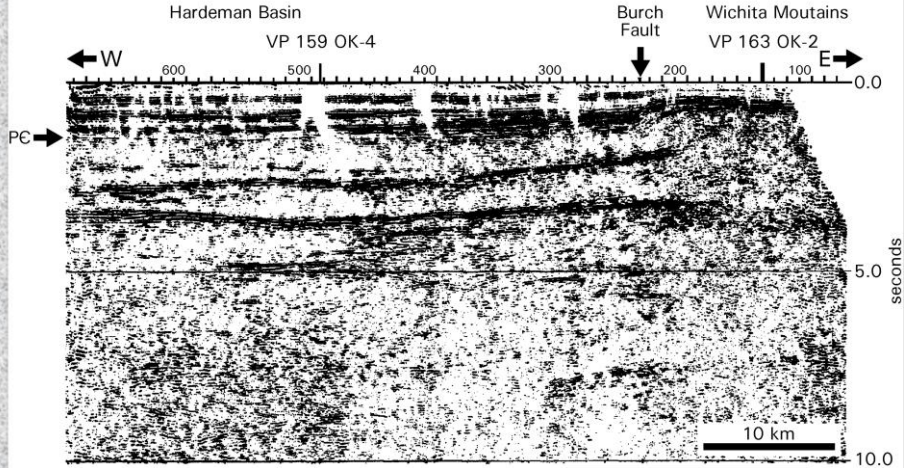
- Depth of Precambrian surface controlled by published maps
- FWR and ECGH represented by upper crustal mafic bodies
- Flanking gravity low delineate Proterozoic basins
- Grenville thrusting over the older Granite-Rhyolite Province, ECGH, and **Proterozoic sediments**

## Now for a quick look at the Permian basin



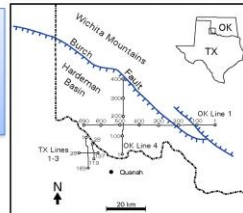
(modified from Barnes and others, 1999, originally modified from Van Schmus and others, 1996).

# COCORP Oklahoma Line 1

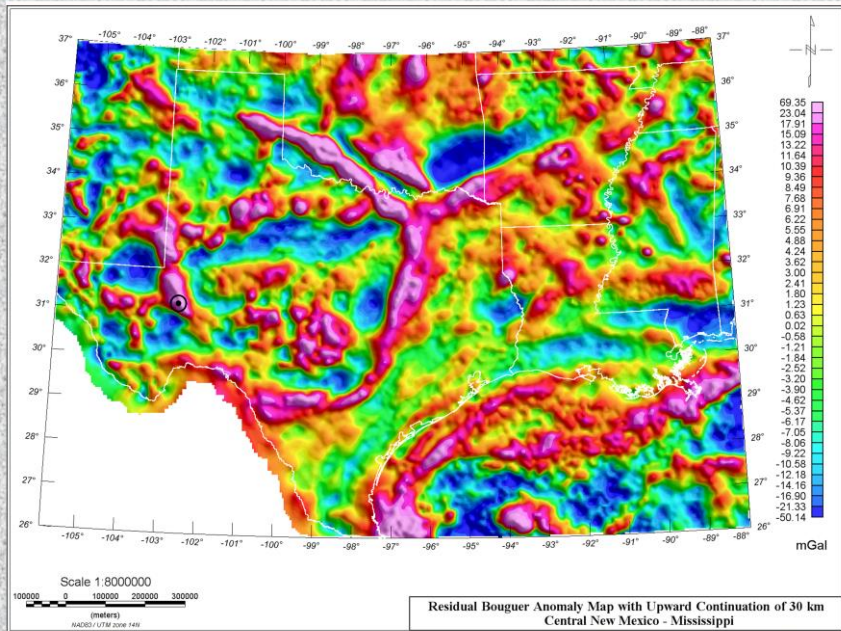


There are a lot of sediments under the Hardeman basin. Are they all metamorphosed?

Pratt et. al. (1992)



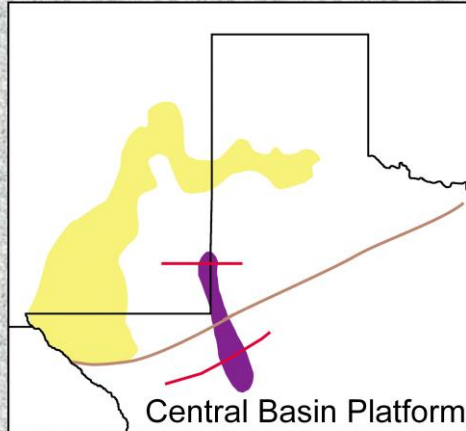
## Residual Bouguer Anomaly (UPCON to 30 km)

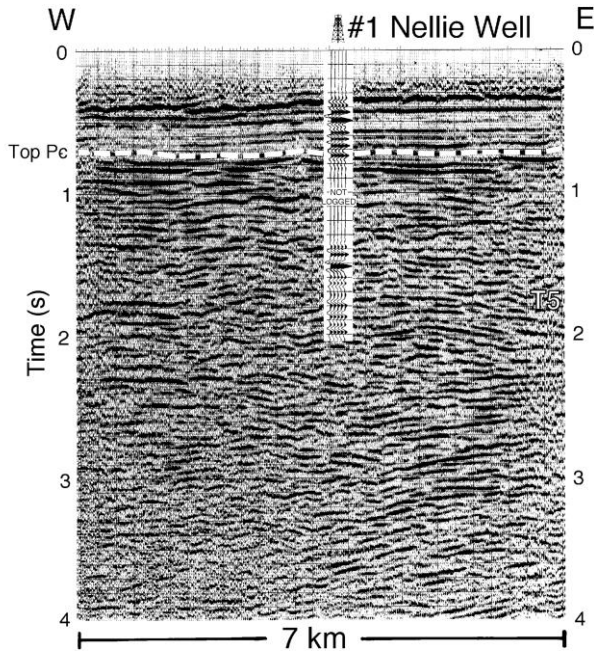




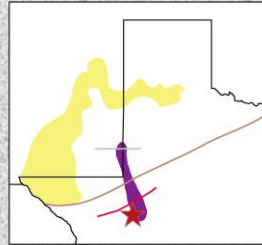
## Pecos Mafic Intrusive Complex (the core of the Central Basin Platform)

- 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

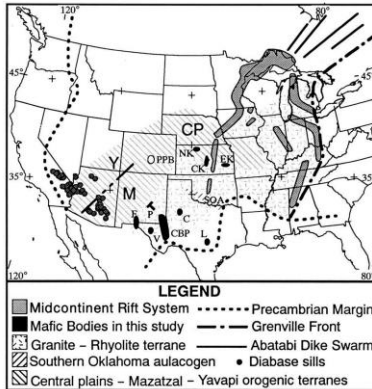


A cautionary tail;  
all layered  
sequences are  
not sedimentary

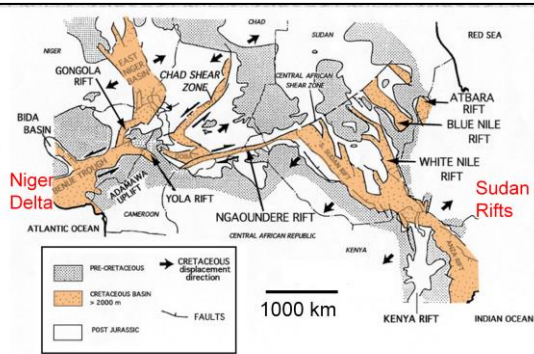
Adams and Miller,  
1995

# Mid-Continent and West and Central Africa Rift Systems

The MCR really is a **whopper!**



Adams and Keller (1994)



Fairhead and Green (1989)

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

# Conclusions

- The Proterozoic assembly of cratonal North America formed the basement and should have produced structures with NE trends; Where are they in the Mid-continent?
- Late Proterozoic rifting was extensive as it spread southward from the Lake Superior region and nearly broke the continent apart.
- There are a lot of Late Proterozoic sediments around.
- Cambrian rifting did break the continent apart, and the structures that formed then radiated into the continental interior produced a complex suite of structures.
- Gravity and magnetic data when coupled with geologic and other geophysical data provide a cost effective way to better understand basement structures.

Thank you!