A Regional Overview of Southern Oklahoma Structures
(and some stuff about recent earthquakes)

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(with the help of many students and colleagues)
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**
Laurentia went through a “growth spurt” from 1.8 Ga to 1.0 Ga (Grenville) via accretion of island arcs and microcontinents.
The Yavapai Province was a Banda Sea-style assembly of arcs.

Proterozoic growth of Laurentia

Juvenile terrane accretion

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

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

Mazatzal granitoids stitch juvenile terranes with older provinces
Granite-Rhyolite granitic plutons stitch much of southern Laurentia together making it a stable craton.

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
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.

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

Proterozoic growth of Laurentia

Continent-continent collisions
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.
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)

3. The break-up of the continent in the Cambrian

4. The Ouachita orogeny and formation of the Ancestral Rocky Mountains
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 was a large international cooperative seismic experiment that featured the acquisition of multi-channel reflection data in the Great Lakes.
Seismic reflection profile showing that the pre-rift crust was almost completely destroyed. However, the rift failed. Why?

Provided by Bill Cannon (USGS)
Hinze et al. (1997)

Integrated geophysical model across Lake Superior

Intraplating and underplating
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.
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
Adams and Miller, 1995

A cautionary tail; all layered sequences are not sedimentary.
An analogy to the Osage Anomaly
Mid-Continent and West and Central Africa Rift Systems

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.

Fairhead and Green (1989)
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.
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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 550 Ma.

What Happens Further South?
Afar vs. SOA Triple Junctions

From the mouth of Afar to Tanzania ~1500 km

The scales are approximately the same

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.
Oklahoma-Texas region basement
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The Ancestral Rockies

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.

This massive Late Paleozoic intraplate deformation generally cut across Precambrian tectonic trends.
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
William E. Ham and Myron E. McKinley and others, 1954
Revised by Kenneth S. Johnson, 1990
Johnson et al., 1984
Ardmore Basin seismic line

Harding et al. (1983)
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
Locations of Vertical Slices Through the 3-D Data Volume
Model boundaries overlaid & faults interpreted
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

- SW to NE: Granite
- Depth (km): 0, 4.3 (2.5), 5.3, 5.85 (2.6), 6.3, 6.85 (2.95), 7.15, 4.55 (2.5)
- Distance (km): 100, 150, 200, 250, 300
- Layers: Upper Paleozoic, Lower Paleozoic, Mafic Igneous Complex, Rift Fill, Volcanics (Carlton Rhyolite?)
- Locations: A, B, E, H, L, N, O, P

Post Paleozoic
Locations of Integrated Models of Crustal Structure

The Cambrian rifted margin of Laurentia

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
Where is the evidence for a strong collision that would cause intraplate deformation?
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
STRUCTURAL CROSS SECTION OK1 ACROSS THE OKLAHOMA OUACHITA MOUNTAINS

By
J. Kaspar Arbenz
2008

INDEX MAP OF CROSS SECTIONS
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2008
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?
It is amazing how little we really know about the deep structure outboard of the Ouachita orogen!
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

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.
OGS Earthquake Catalog 2010-2012
OGS Earthquake Catalog 1897-2012
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
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