Uplift History of the St Francois Mountains and
Exploitation of Sinkhole Iron Deposits on Their Northwestern Flank

Dr. Russell Myers
26 April 2022
Ozark Regional Library, Ironton, Missouri
Two Talks

1. How old are the St Francois Mountains anyway?
2. Sinkhole Iron Deposits of the Ozark Uplift
   a) Distribution and Origin
   b) Maramec Iron Works (1826 -1878)
   c) Sligo Furnace Company (1880 – 1923)
How old are the St Francois Mountains anyway?

Commonly heard:

1. St Francois Mountains are the oldest mountains in the world!
   • Let’s talk about that....
2. Taum Sauk Mountain has never been under the ocean!
   • This is not true!

St. Francois Mountains
• Highest Elevation
• Deepest Erosion
• Oldest Rocks Exposed

- Cambrian
  500 M.Y.
- Precambrian
  1500 M.Y.
Burial of SEMO Precambrian Rocks

<table>
<thead>
<tr>
<th>Dated Event</th>
<th>Age (Ma)</th>
<th>Sediment Thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambrian Sedimentation</td>
<td>485</td>
<td>2,000</td>
</tr>
<tr>
<td>Early Ordovician Sedimentation</td>
<td>470</td>
<td>1,150</td>
</tr>
<tr>
<td>Middle and Late Ordovician Sedimentation</td>
<td>443</td>
<td>2,650</td>
</tr>
<tr>
<td>Silurian Sedimentation</td>
<td>419</td>
<td>200</td>
</tr>
<tr>
<td>Devonian Sedimentation</td>
<td>359</td>
<td>50</td>
</tr>
<tr>
<td>Mississippian Sedimentation</td>
<td>323</td>
<td>330</td>
</tr>
<tr>
<td>Pennsylvanian Sedimentation</td>
<td>298</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Total sediment thickness</strong></td>
<td></td>
<td><strong>8,380</strong></td>
</tr>
<tr>
<td>Hawn SP Precambrian Elevation</td>
<td></td>
<td><strong>800</strong></td>
</tr>
<tr>
<td><strong>Total Uplift and Erosion</strong></td>
<td></td>
<td><strong>9,180</strong></td>
</tr>
</tbody>
</table>

- Precambrian rocks buried by mostly marine sediments (at or below sea level)
- Now at surface so must have been uplifted enough to remove all sediment.
- This data does not tell us why or when this uplift and erosion took place.

Need More Data!
Thermochronology

Heat  Time  Study

Using minerals to determine temperature and time

Key Concept: Geothermal Gradient

Temperature increases with depth below the surface

Normal Geothermal Gradient: 25°C/Kilometer (23°F/1000 feet)

If:

We know temperatures at different times

Then:

Burial history can be determined
Key Thermochronometers

Zircon – zirconium silicate: ZrSiO$_4$
Apatite – calcium phosphate: Ca$_5$[PO$_4$]$_3$(OH,F,Cl)

Useful because:
1. contain traces of radioactive Uranium and Thorium
2. common in most igneous rocks
3. very durable and persist in sedimentary and metamorphic rocks.

Mid-1990’s technology advances results in previously unimaginable precision and accuracy.
Zircon & Apatite Thermochronometers

Uranium and Thorium alpha particle decay

\[ ^{238}\text{U} \rightarrow ^{234}\text{Th} + \text{He}_{(\text{gas})} \]
\[ ^{235}\text{U} \rightarrow ^{231}\text{Th} + \text{He}_{(\text{gas})} \]
\[ ^{232}\text{Th} \rightarrow ^{228}\text{Ra} + \text{He}_{(\text{gas})} \]

Mineral Closure Temperature

Hotter than Closure T  \rightarrow  Helium Gas Escapes
Colder than Closure T  \rightarrow  Helium Gas Trapped

Zircon closure = 180-130°C
Apatite closure = 70-40°C

When did mineral close?
Measure U&Th isotopes and He

At normal Geothermal Gradient 23°F/1000 feet
Zircon closes between 21,000-14,000 feet
Apatite closes between 6,500-2,600 feet

SEMO sediment thicknesses
Fission Track Thermochronometry

Key Idea: Annealing Temperature
- Tracks anneal and disappear at temperatures above 120°C
- Tracks partially anneal between 70-120°C
- Track count related to uranium content and time <120°C

Apatite Fission Track + Apatite (U-Th)/Helium provide two temperature points to measure uplift

Fission of $\text{U}^{238}$ sends out charged particle which destroys crystal lattice leaving visible track
Missouri Precambrian Thermochronology Measurements

**Apatite Helium 70-40°C**
- **Granite – Knob Lick**
- **Gneiss – Hawn State Park**

**Apatite Fission Track 120-70°C**
- Apatite Fission Track Age Range

200 Million Years is not “Old”!

DeLucia et al. (2018) Geology v. 46; no. 2; p. 167-170
Thermal History of the Ozarks Precambrian

Numerical modeling of Ozarks thermal history

\[ A\text{He} = \text{Apatite (U-Th)/He} \ [n=6] \]
\[ \text{AFT} = \text{Apatite Fission Track and Mean Track Length data} \]

1. Uplift and Erosion 650-500Ma
2. Greatest Burial after 300Ma
3. Dramatic Uplift after 200Ma

Current Ozark Uplift is not “Old”

McDannell et al. (2021) Proceedings of the National Academy of Sciences https://doi.org/10.1073/pnas.2118682119
Elevation of Precambrian to Cambrian Contact

Regional base of Cambrian defines sea level surface

Current regional elevation approximately 400 feet below sea level.

Current Taum Sauk elevation 1771 feet above sea level

Cambrian elevation of Taum Sauk Mtn at least: 400’+1771’ = 2171’ amsl
Regional Setting

South American Collision
Ouachita Mountains
Climax - 318-271 Ma

South America Departs
Gulf of Mexico Rift
200 Ma initiation
160-130 Ma Gulf Forms

Reelfoot Rift
Old tear in continent - 565 Ma
Reactivated 100-60 Ma

Mississippi Embayment
Gulf of Mexico from
100 - 4 Million Years

● Alkaline Igneous Intrusions
  From >100 mile depth
  106 - 88 Ma
  Crater of Diamonds
Ouachita Causes Ozark Uplift

Over 3000 feet of sediment eroded from Ozarks exposing Early Ordovician sediments which were later buried by Pennsylvanian sediments.

300 Million Years Ago

North American Precambrian Crust

Foreland Bulge (Ozarks)

Foreland Basin (Arkoma)

South American Mountains

Ouachita Mountains

Ouachita Suture
New Madrid Seismic Zone is located at the north-east end of the rift. Isostatic uplift on east and west sides of rift.

1811-1812 – New Madrid Earthquakes
New Madrid Seismic Zone is located at the north-east end of the rift.
<table>
<thead>
<tr>
<th>Dated Event</th>
<th>Age (Ma)</th>
<th>Sediment Thickness (ft)</th>
<th>Taum Sauk Elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambrian Sea Transgression</td>
<td>500</td>
<td>0</td>
<td>2170</td>
</tr>
<tr>
<td>Cambrian Sedimentation</td>
<td>485</td>
<td>2000</td>
<td>170</td>
</tr>
<tr>
<td>Early Ordovician Sedimentation</td>
<td>470</td>
<td>1150</td>
<td>-980</td>
</tr>
<tr>
<td>Middle and Late Ordovician Sedimentation</td>
<td>443</td>
<td>2650</td>
<td>-3630</td>
</tr>
<tr>
<td>Silurian Sedimentation</td>
<td>419</td>
<td>200</td>
<td>-3830</td>
</tr>
<tr>
<td>Devonian Sedimentation</td>
<td>359</td>
<td>50</td>
<td>-3880</td>
</tr>
<tr>
<td>Mississippian Sedimentation</td>
<td>323</td>
<td>330</td>
<td>-4210</td>
</tr>
<tr>
<td><strong>Ouachita Mt Bulge Erosion (Early Penn)</strong></td>
<td>315</td>
<td>-3230</td>
<td>-980</td>
</tr>
<tr>
<td>Minimum Ouachita Foreland Sedimentation (Pennsylvanian on Ozarks flank)</td>
<td>298</td>
<td>2000</td>
<td>-2980</td>
</tr>
<tr>
<td>Maximum Pennsylvanian Sediment implied by Hawn SP Apatite Fission Track (&gt;70°C)</td>
<td>250</td>
<td>4610</td>
<td>-5590</td>
</tr>
<tr>
<td><strong>Gulf Rift Uplift (Apatite (U-Th)He 40°C 30°C decrease = 3900 foot uplift)</strong></td>
<td>150</td>
<td>-3900</td>
<td>-1690</td>
</tr>
<tr>
<td>Reelfoot Rift (Middle Ordovician on coast)</td>
<td>100</td>
<td>-710</td>
<td>-980</td>
</tr>
<tr>
<td>Present</td>
<td>0</td>
<td>0</td>
<td>1771</td>
</tr>
</tbody>
</table>

Cambrian elevation of Taum Sauk Mtn at least: 400’+1770’ = 2170’ amsl
So...
How old are the St Francois Mountains anyway?

<100Ma Reelfoot Rift Uplift means elevation is young

But...

young erosion re-exposed a 500 Million year old landscape
So...

Next time you are out, allow yourself to time-travel back to the St Francois Islands as you enjoy the ancient topography exposed by the young uplift of the Ozark Highlands.
On to Iron Mining……

300 Million Years Ago

Ouachita Mountains

Pennsylvanian Uplift and Erosion

South American Mountains

Ouachita Suture

Arkoma Basin

North American Precambrian Crust

Ozark Foreland Bulge
Filled Sinkhole Deposits

300Ma Ouachita Collision: uplift and erosion in the Ozarks

Carbonate rocks dissolved creating caves and hundreds of sink holes

Some later filled with sediments including coal and clay

Others became chemical traps that filled with pyrite ($\text{FeS}_2$).
Caves/Sinkholes and Pyrite

A Low oxygen content of groundwater reduces Fe$^{+3}$ in solid iron oxide minerals to soluble Fe$^{+2}$ which goes into solution.

B Burial heating results in formation of soluble Hydrogen Sulfide (H$_2$S) which rises toward the surface.

C Mixing of soluble sulfur and iron cause pyrite to precipitate

\[ \text{Fe}^{+2} (\text{aq}) + 2\text{HS}^- (\text{aq}) \underset{\text{C}}{\leftrightarrow} \text{FeS}_2(\text{s}) + \text{H}_2(\text{g}) \]
Erosion after 100Ma Ozark uplift exposes pyrite to weathering, converting it to hematite and sulfuric acid.

$$2 \text{FeS}_2 + 4 \text{H}_2\text{O} + 7.5 \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3(s) + 4 \text{H}_2\text{SO}_4(aq)$$

70% Iron
The Iron Ores of Missouri by G.W. Crane (1912)

How important were filled sink iron deposits?

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>Iron Production 1824-1912 (Tons)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PreCambrian Ores</td>
<td>5,627,799</td>
<td>63</td>
</tr>
<tr>
<td>Pilot Knob, Iron Mtn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filled Sink Hematite</td>
<td>3,072,637</td>
<td>34</td>
</tr>
<tr>
<td>Limonite Ore</td>
<td>291,656</td>
<td>3</td>
</tr>
</tbody>
</table>

Perspective:
2020 West Australia Production = 2.2 million tons/day
88 years = 4 days
Size and Distribution of Mined Sink Iron Deposits

Sink Iron Mine Production (tons)

- **100,000 – 440,000** (7)
- **50,000 – 100,000** (1)
- **1,000 – 50,000** (41)
- **100 – 1,000** (13)
- **0 – 100** (39)

From Crane (1912)
Important Historic Sink Iron Smelting Operations

1. Maramec Iron Works
   1826 - 1878

2. Sligo Furnace Company
   1880 - 1923

Smaller operations are poorly documented.
Maramec Iron Works – First Major Development

Thomas James learns of red hematite used by Shawnee for face paint
1825 – (ten years after iron smelting began in Ironton)
Evaluation by Samuel Massey found:
- High grade iron ore
- Large volume spring for water power
- Forest for charcoal

- Manufactured consumer goods
- Pig iron shipped to other markets

1938 – Lucy Wortham James, great granddaughter of Thomas James, put the site into a trust managed by the James Foundation for public enjoyment.
Maramec Technology

Iron Ore:
- 68% Iron (Fe\(^{3+}\)), 2% Silica (SiO\(_2\)), 0.04% Phosphorous

Limestone (CaCO\(_3\)):
- Releases calcium binding with silica to form slag

Charcoal (C\(^0\)):
- Burn temperature 2600-3000\(^\circ\)F

Furnace Charge: (Charged 100 times/day)
- 640 lbs. Ore, 18 bushels (360 lbs.) of charcoal, 1 bushel of charred wood, 100 lbs. of Limestone

Products:
- Iron metal (Fe\(^0\)) + Slag + vast quantities of CO\(_2\)

http://www.virginiaplaces.org/ggs380/11wood.html
Charcoal: The key to it all!

Twice the heat content of wood – able to make 2500°F required for smelting 150-200 bushels of charcoal/ton of pig iron (pre-1900)
At 20lbs/bushel this is almost 1 ton of charcoal for every ton of iron!

Maramec Iron Mine Charcoal Needs:

375,000 tons of ore x 65% Iron x 65% recovery = 158,000 tons of pig iron
@175 bushels/ton = ~28,000,000 bushels of charcoal
30-40 bushels/cord of wood; 30-50 cords/acre
800,000 cords of wood required = 20,000 acres

Completely denuded 31 square miles!

- Cleared land for agriculture
- Created off-season work for farmers
Charcoal: wood burned in low oxygen environment

Maramec Charcoal

- produced in “pits” built where the wood was cut
- transported to the smelter by wagon.
Transportation – Bane of Maramec Iron Works

1826-1860 (34 years)
- Bulk iron transported to Gasconade River or Gray Summit Railhead
- Consumer goods taken to Rolla, Lebanon and Springfield
- **Limited growth**

1860-1873 (13 years)
- Rail arrived in St James
- Civil war and post war growth fed demand
- **Iron ore mostly depleted**

“Panic of 1873”: 1873-1877 global depression and Maramec bankruptcy in 1876
New Beginnings:
St. Louis, Salem and Little Rock Railroad Company

Built “by Lee Family from St Louis” to Exploit Iron Deposits in Dent County
1871 – Incorporation
1873 - Construction complete – 40 miles
1873-1877 “Panic of 1873” Depression
History lost

Sink Iron Mine
Production (tons)

- 100,000 – 440,000 (7)
- 50,000 – 100,000 (1)
- 1,000 – 50,000 (41)
- 100 – 1,000 (13)
- 0 – 100 (39)
Chapter 2: Sligo Furnace Company

Incorporated in 1880 to exploit Iron Deposits along St Louis, Salem and Little Rock Railroad.

Site selected for water and timber access.

1880: Rail access constructed to furnace site.

Original Furnace Charge:
3300 lbs. Ore, 80 bushels charcoal, 330 lbs. Limestone

Sink Iron Mine
Production (tons)

- 100,000 – 440,000 (7)
- 50,000 – 100,000 (1)
- 1,000 – 50,000 (41)
- 100 – 1,000 (13)
- 0 – 100 (39)
Stockpile of 90,000 tons of pig iron bars accumulated between 1893 and 1897.

Operations recovered wood alcohol and other distillates from kiln gases.
Lidar Mapping: Sligo Smelter Site

Abandoned Sligo Furnace Site – Microsoft Bing Aerial Photography

Abandoned Sligo Furnace Site – USGS 1 meter Digital Elevation Model
Lidar Mapping: Benton Creek Mine - 1873-1887

Abandoned Benton Creek Mine Site – Microsoft Bing Aerial Photography

Abandoned Benton Creek Mine Site – USGS 1 meter Digital Elevation Model
Sligo Furnace Co. Expansion 1880-1912

Sligo iron was high quality and in demand to mix with lower quality iron from other sources.

1891 Furnace Rebuild
- Production 100 tons of iron/day
- Capacity 25,000 tons per year

72 Charcoal Kilns
- 45-55 cords each
- 2,160,000 bushels per year

Railroad Expansion
- New iron mines
- New supplies of wood

Cutting ~1300 acres/year of forest
Death of the Sink Iron Era

Competition

Billion-ton iron deposits discovered in Michigan (1844) and Minnesota (1890)
Use of Coal and Coke in Blast Furnaces allowed larger charges
Charcoal was not strong and limited size of charges
Greater heat content of both coke and coal – hotter and cleaner
Economies of Scale decreased costs and consequently iron prices

Great Lakes Transportation System brought together Iron Ore and Coal

- Chicago
- Detroit
- Gary
- Cleveland
- Buffalo

New 19th Century Steel Cites
Sligo Furnace Company Demise

- Post WWI economics were poor
- 1923 Furnace “Blow out” too expensive to repair
- Operations dismantled by 1923
- Sligo and Eastern Railroad continued to operate until 1930
- Rest of railroad closed shortly thereafter.
Sligo Furnace Company
43 Years of Operation
2 generations of employment
(1880 life expectancy = 39 years)

Impacts
- Reliable employment for hundreds of people employed directing in mining and smelting operations
- Purchase of iron ore from other companies
- Purchase iron ore from individuals
- Purchase of timber for charcoal
- Purchase of charcoal

Communities
- Communities developed at rail stations
- People gone but names remain
Wrap Up

How old are the St Francois Mountains?
• Both young and old!
  • Current Ozark Highlands elevation rise <100Ma in response to Reelfoot Rift
  • 500Ma St Francois Island landscape exhumed during current erosion

Sink-iron Deposits of Phelps, Crawford and Dent Counties
• Geology
  • 300Ma – Pyrite sinkholes
  • <100Ma – re-emergence and oxidation
• 1826-1878 Maramec Iron Works
• 1880-1923 Sligo Furnace Company
• 100 years of Multi-generational employment and income impacting rural communities in at least 4 counties