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

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26 April 2022

Ozark Regional Library, Ironton, Missouri

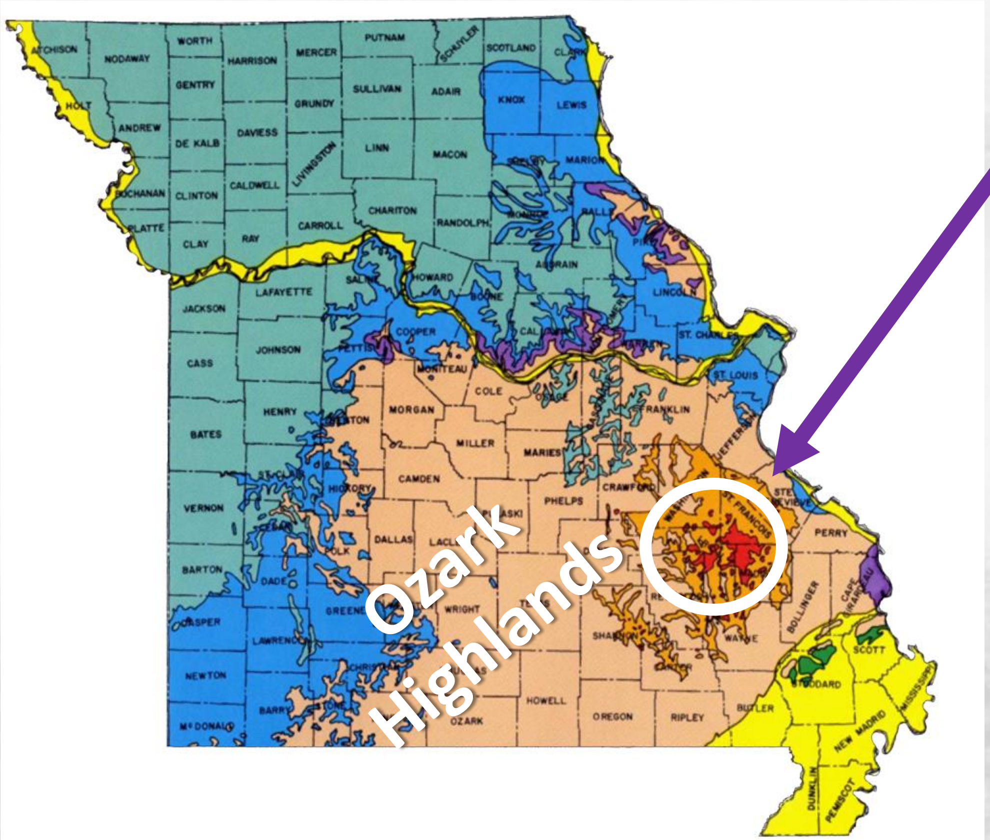
Two Talks

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)

Meramec River
Maramec Spring

Cherry Valley Mine No. 2
Operated 1881-1910 by
Sligo Furnace Company

How old are the St Francois Mountains anyway?



St. Francois Mountains

- **Highest Elevation**
- **Deepest Erosion**
- **Oldest Rocks Exposed**

Cambrian
500 M.Y.

Precambrian
1500 M.Y.

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!**

Burial of SEMO Precambrian Rocks

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

- 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

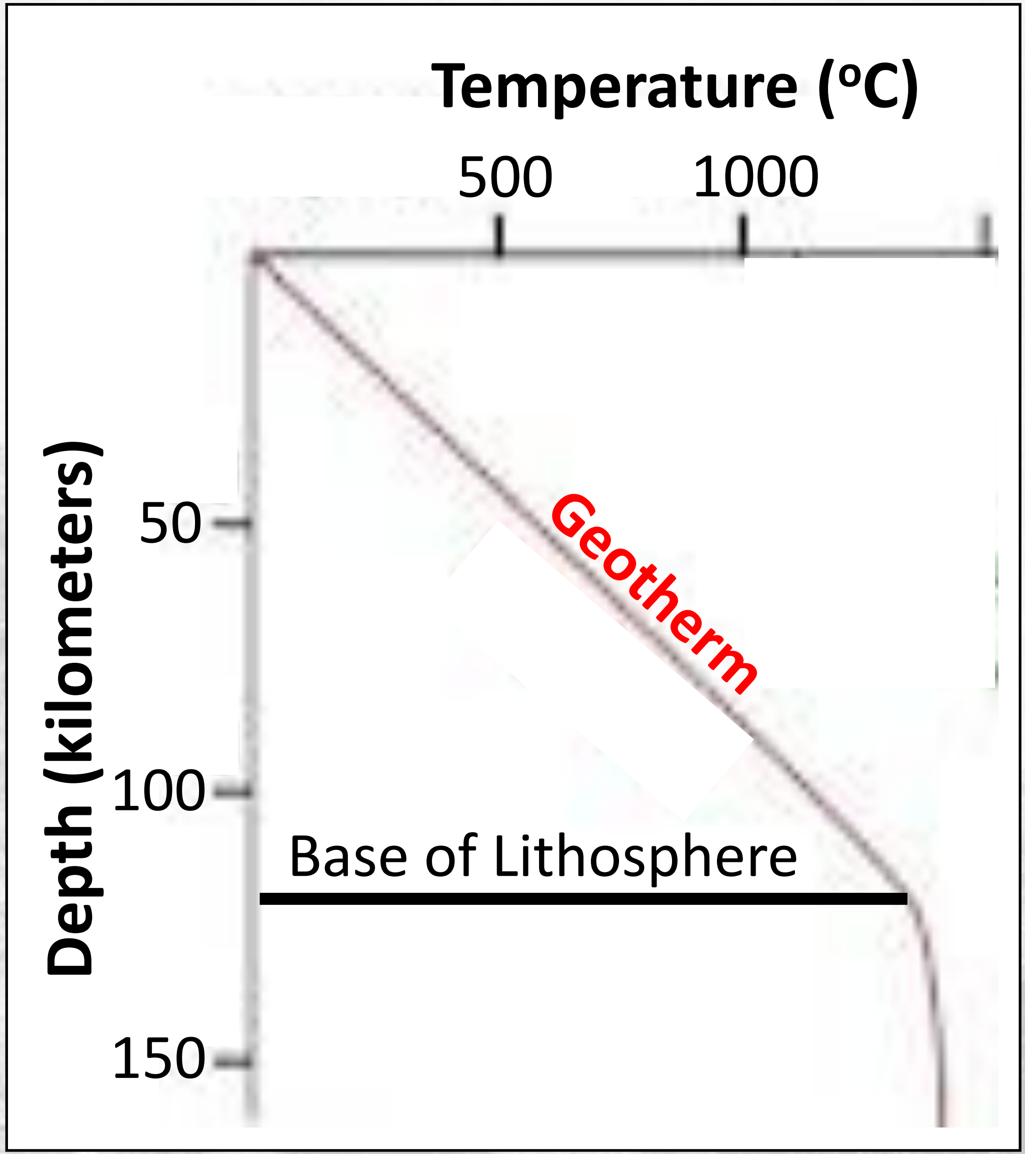
Normal Geothermal Gradient: **25°C/Kilometer (23°F/1000 feet)**

If:

We know temperatures at different times

Then:

Burial history can be determined



Zircon
&
Apatite

Key Thermochronometers

Zircon – zirconium silicate: $ZrSiO_4$

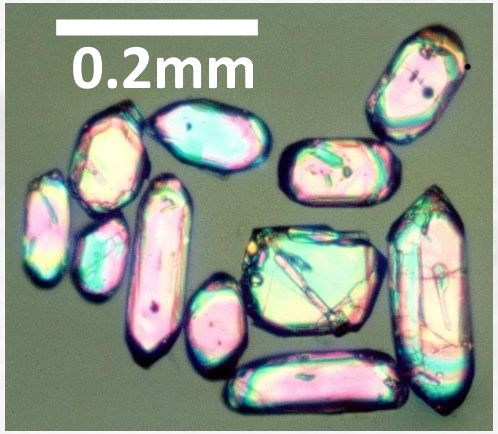
Apatite – calcium phosphate: $Ca_5[PO_4]_3(OH,F,Cl)$

Useful because:

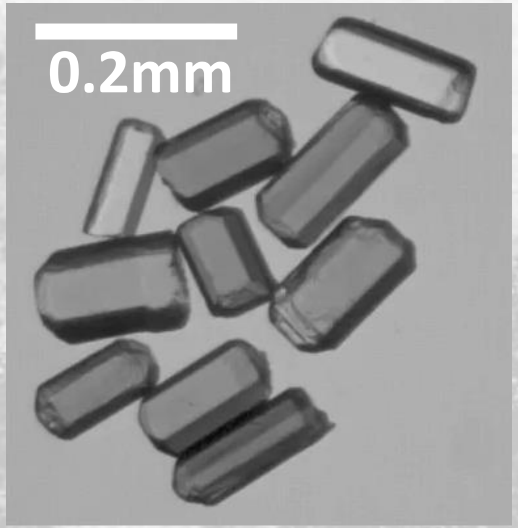
1. **contain traces of radioactive Uranium and Thorium**
2. **common in most igneous rocks**
3. **very durable and persist in sedimentary and metamorphic rocks.**

Mid-1990's technology advances results in previously unimaginable precision and accuracy.

Zircon Grains



Apatite Grains



Zircon & Apatite

(U-Th)/He Thermochronometers

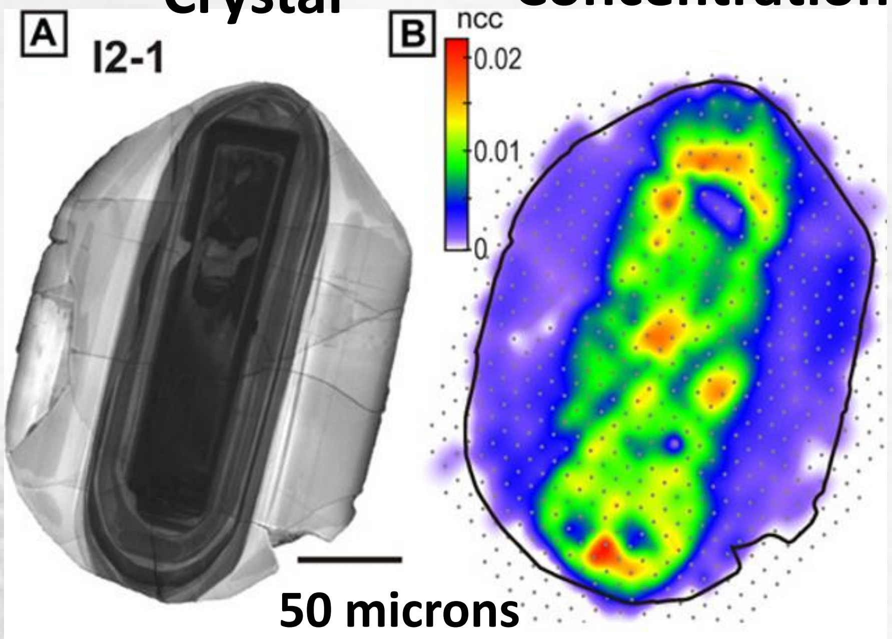
Uranium and Thorium alpha particle decay

$^{238}U \rightarrow {}^{234}Th + He_{(gas)}$

$^{235}U \rightarrow {}^{231}Th + He_{(gas)}$

$^{232}Th \rightarrow {}^{228}Ra + He_{(gas)}$

Zircon Crystal **Helium Concentration**



Mineral Closure Temperature

Hotter than Closure T ➔ Helium Gas Escapes

Colder than Closure T ➔ Helium Gas Trapped

When did mineral close?

Measure U&Th isotopes and He

At normal Geothermal Gradient 23ºF/1000 feet

Zircon closes between 21,000-14,000 feet

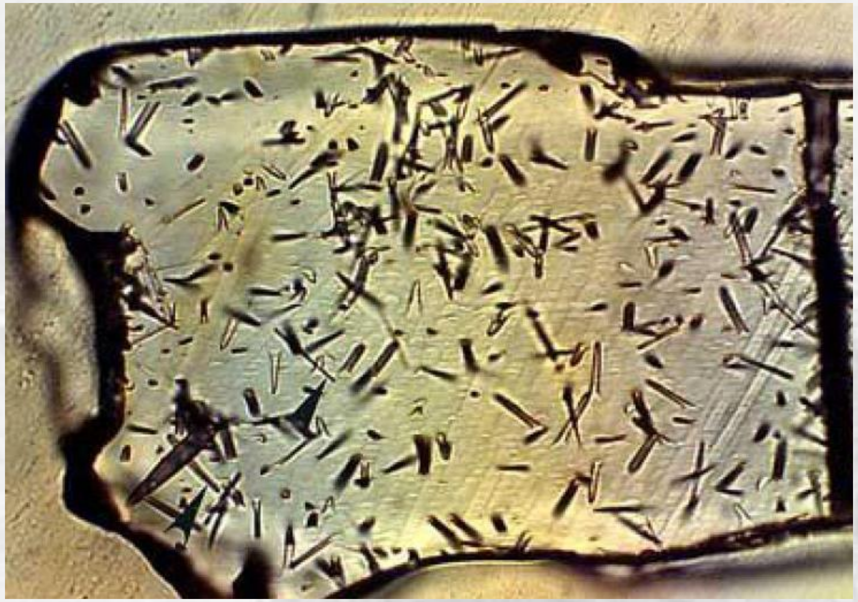
Apatite closes between 6,500-2,600 feet ⇐ **SEMO sediment thicknesses**

Zircon closure = 180-130ºC

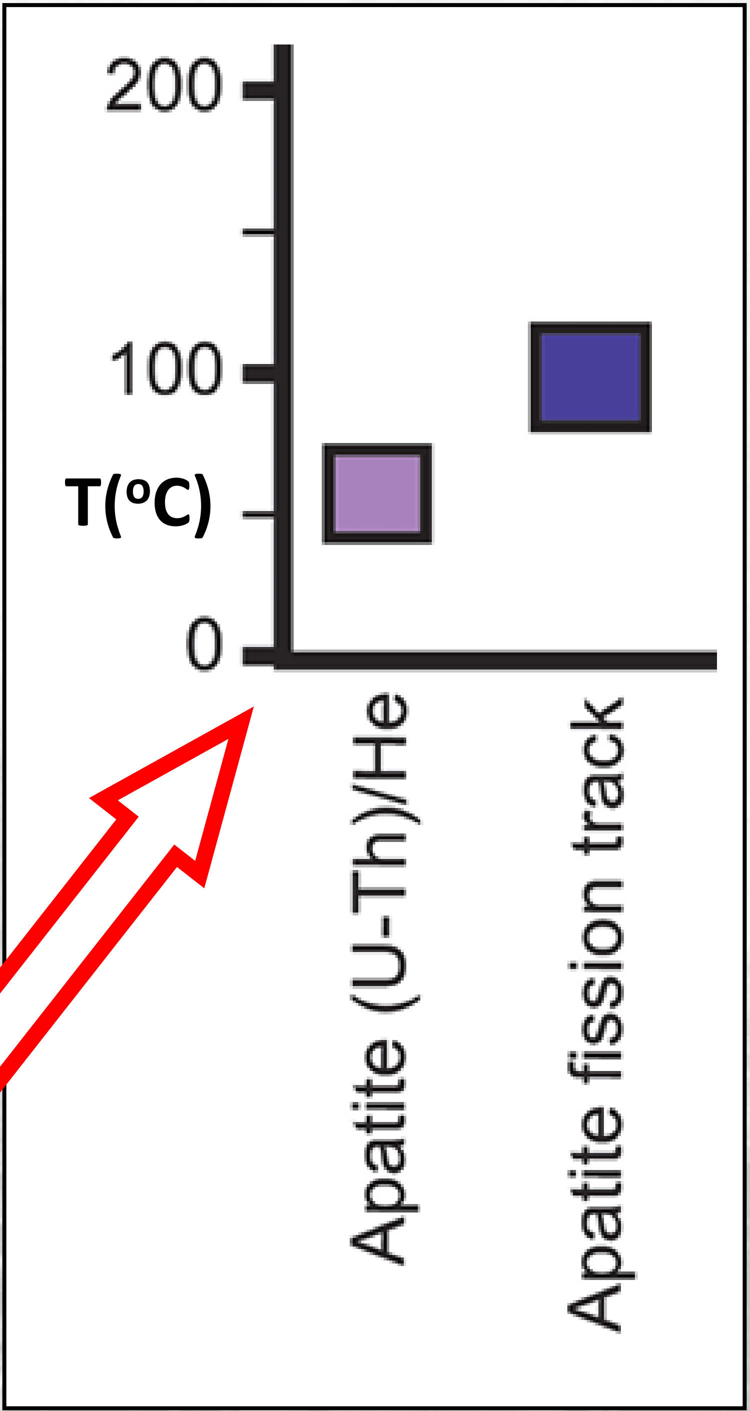
Apatite closure = 70-40ºC

Fission Track Thermochronometry

Apatite Fission Tracks (AFT)



Fission of **U^{238}** sends out charged particle which destroys crystal lattice leaving visible track



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

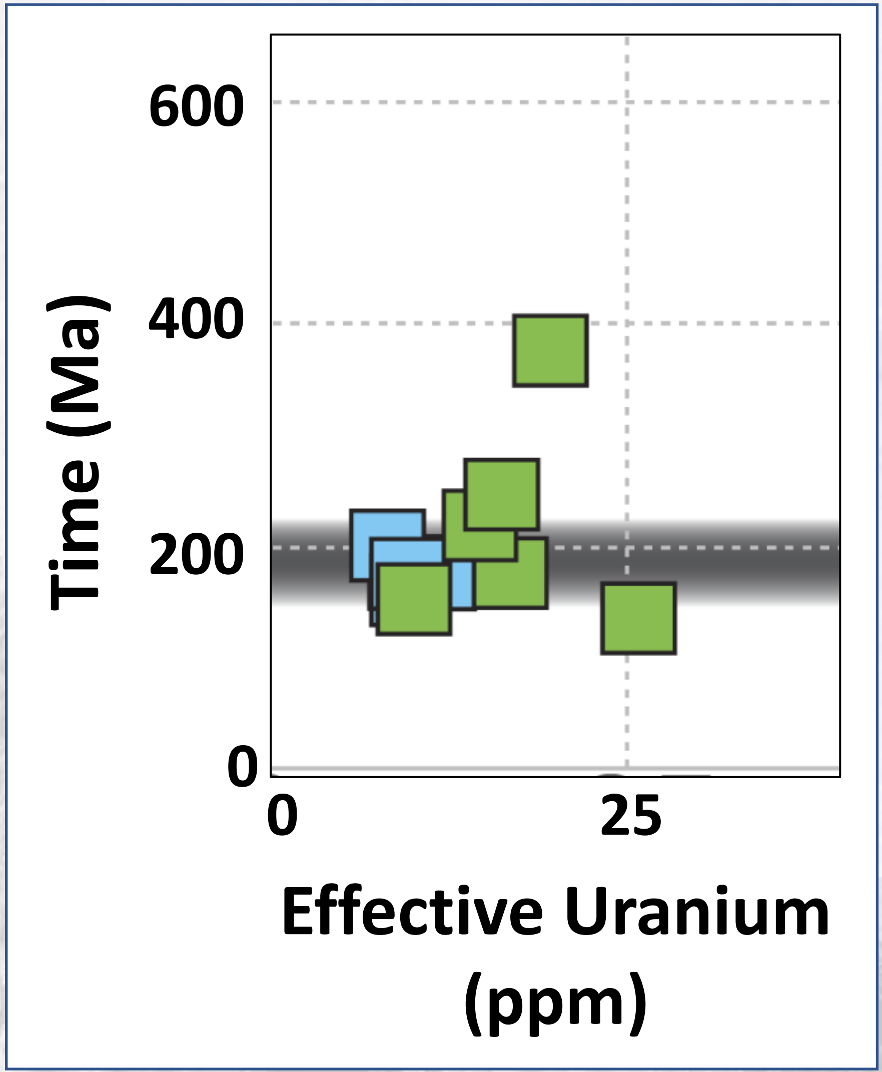
Missouri Precambrian Thermochronology Measurements

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

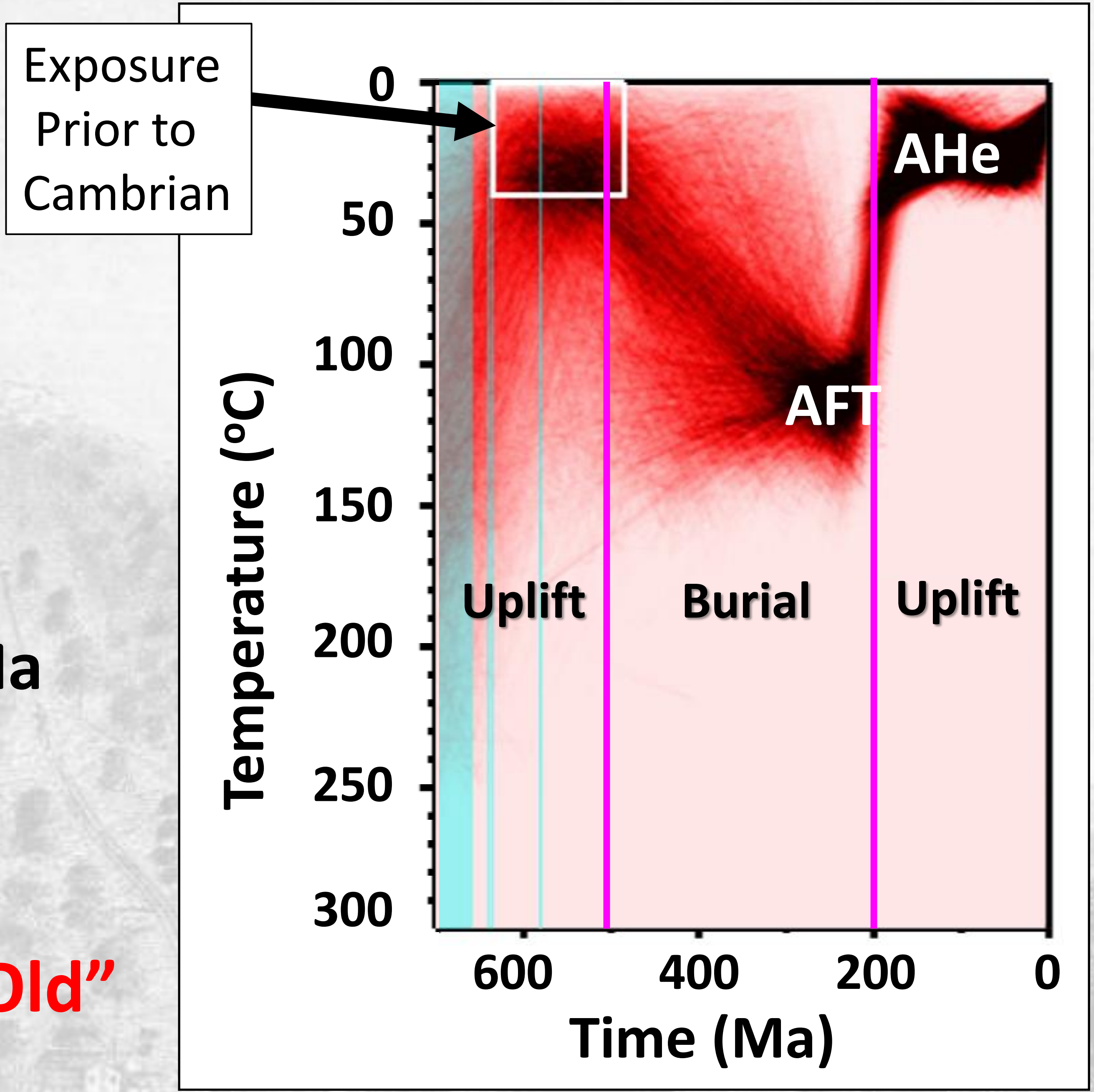
Numerical modeling of Ozarks thermal history

AHe = Apatite (U-Th)/He [n=6]

AFT = 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

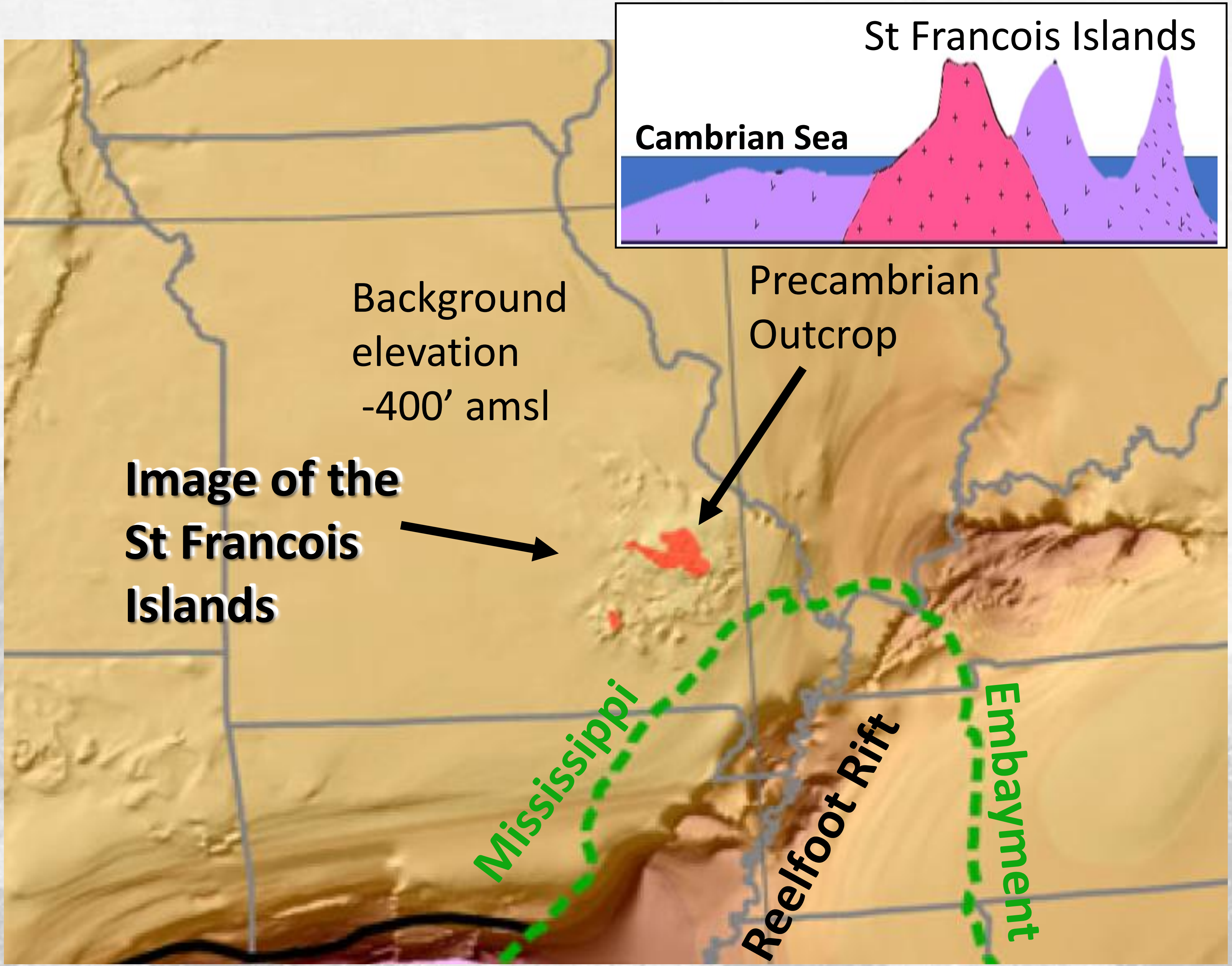
Elevation of Precambrian to Cambrian Contact

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

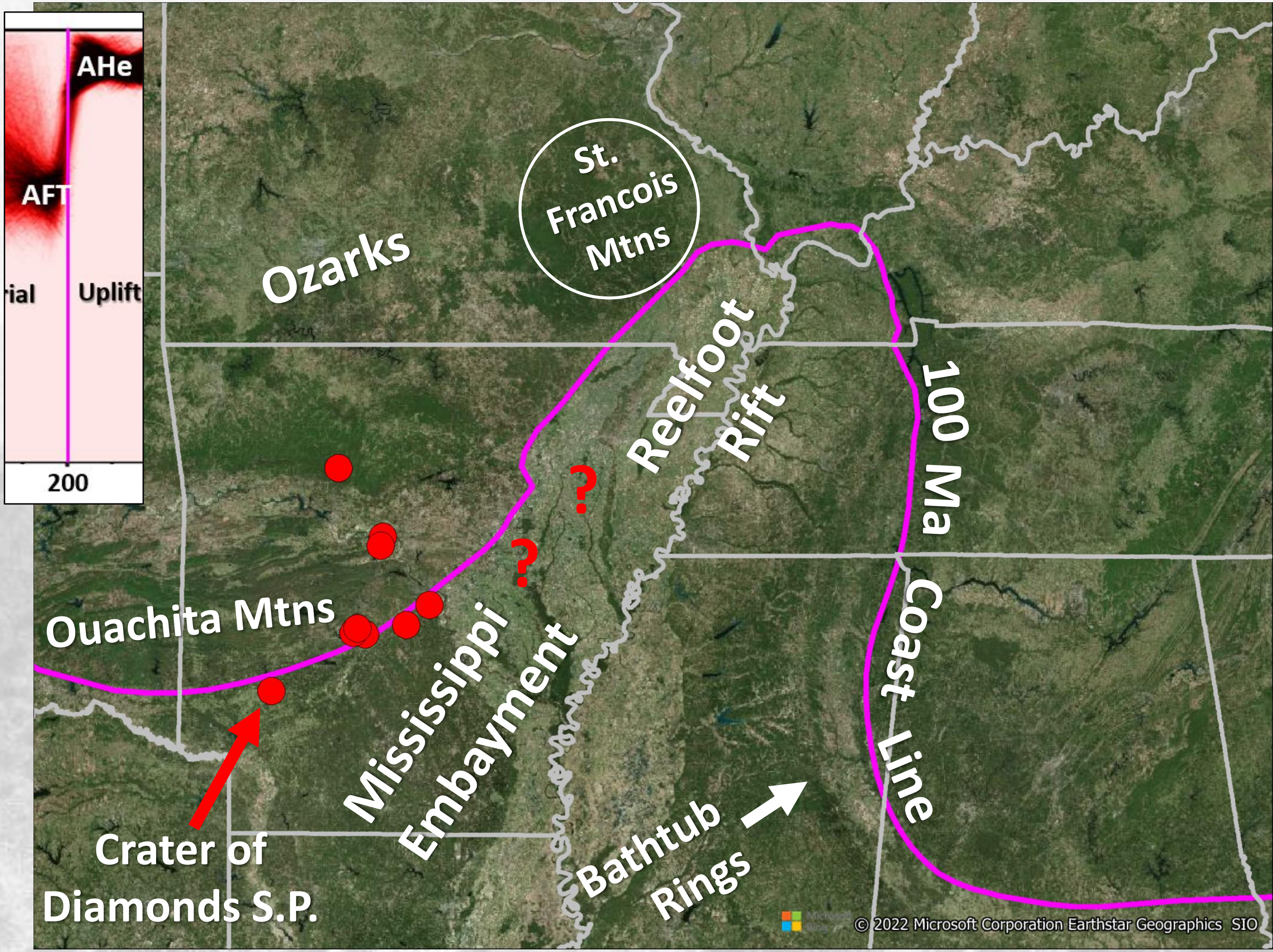
Gulf of Mexico Rift
200 Ma initiation
160-130Ma Gulf Forms

Reelfoot Rift

Old tear in continent – 565 Ma
Reactivated 100-60 Ma

Mississippi Embayment

Gulf of Mexico from
100 – 4 Million Years

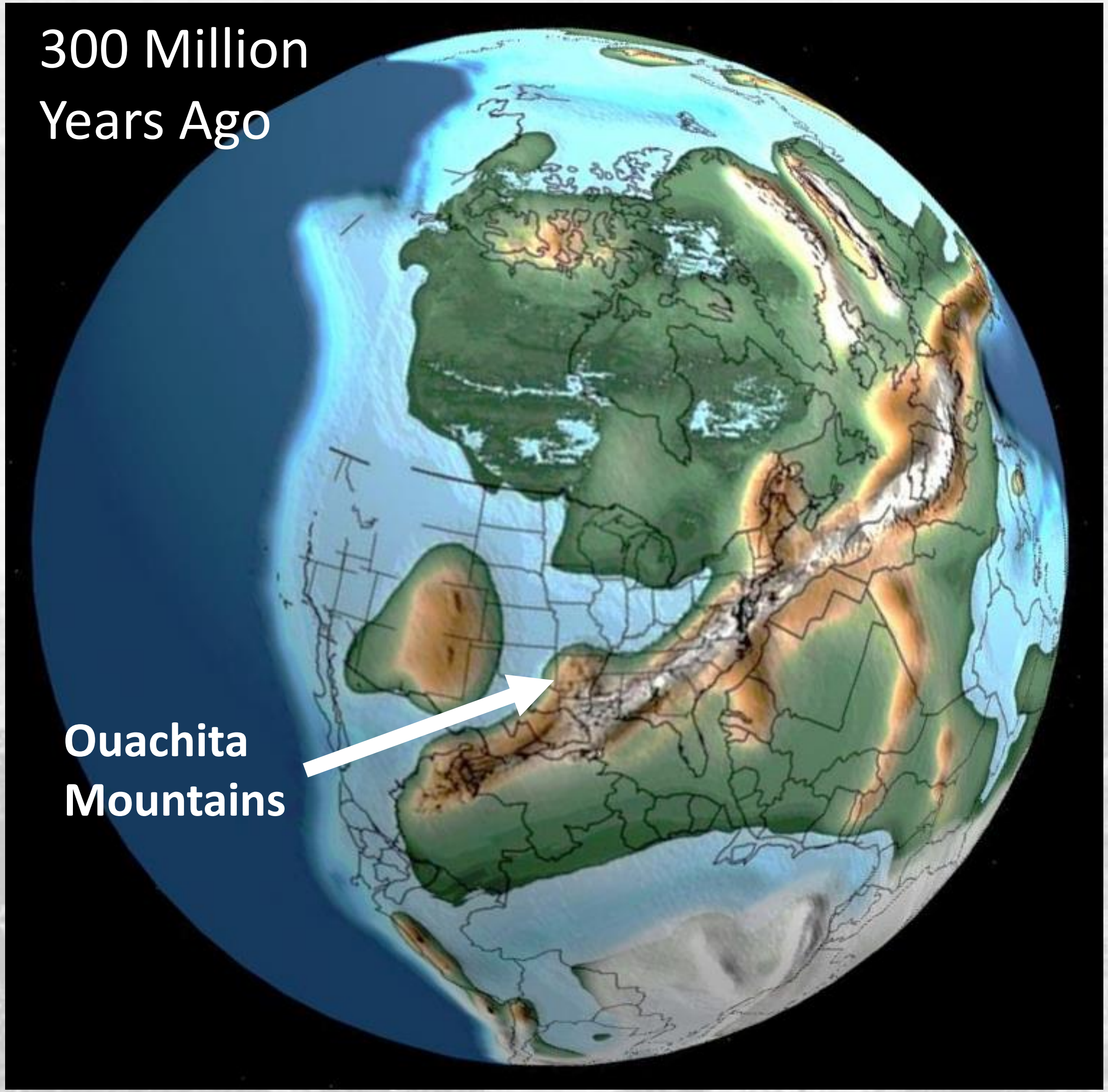


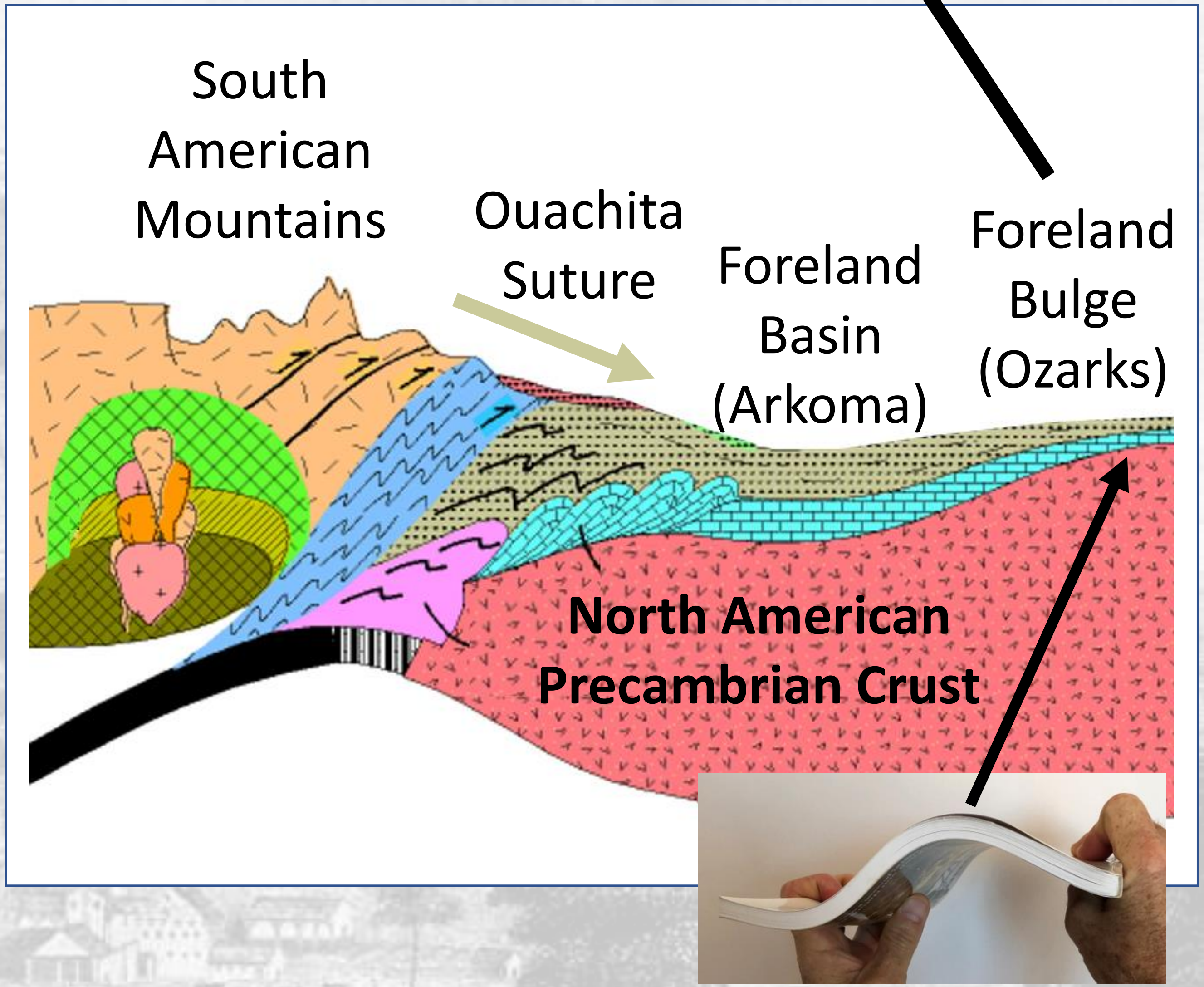
● Alkaline Igneous Intrusions

From >100 mile depth
106 – 88 Ma
Crater of Diamonds

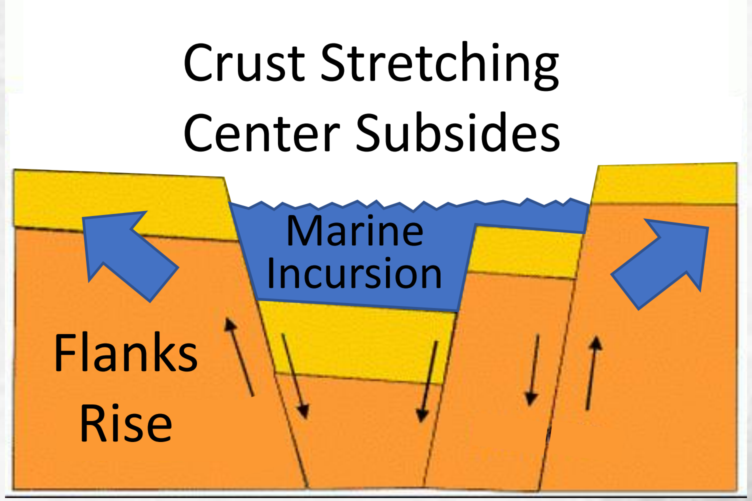
Ouachita Causes Ozark Uplift

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





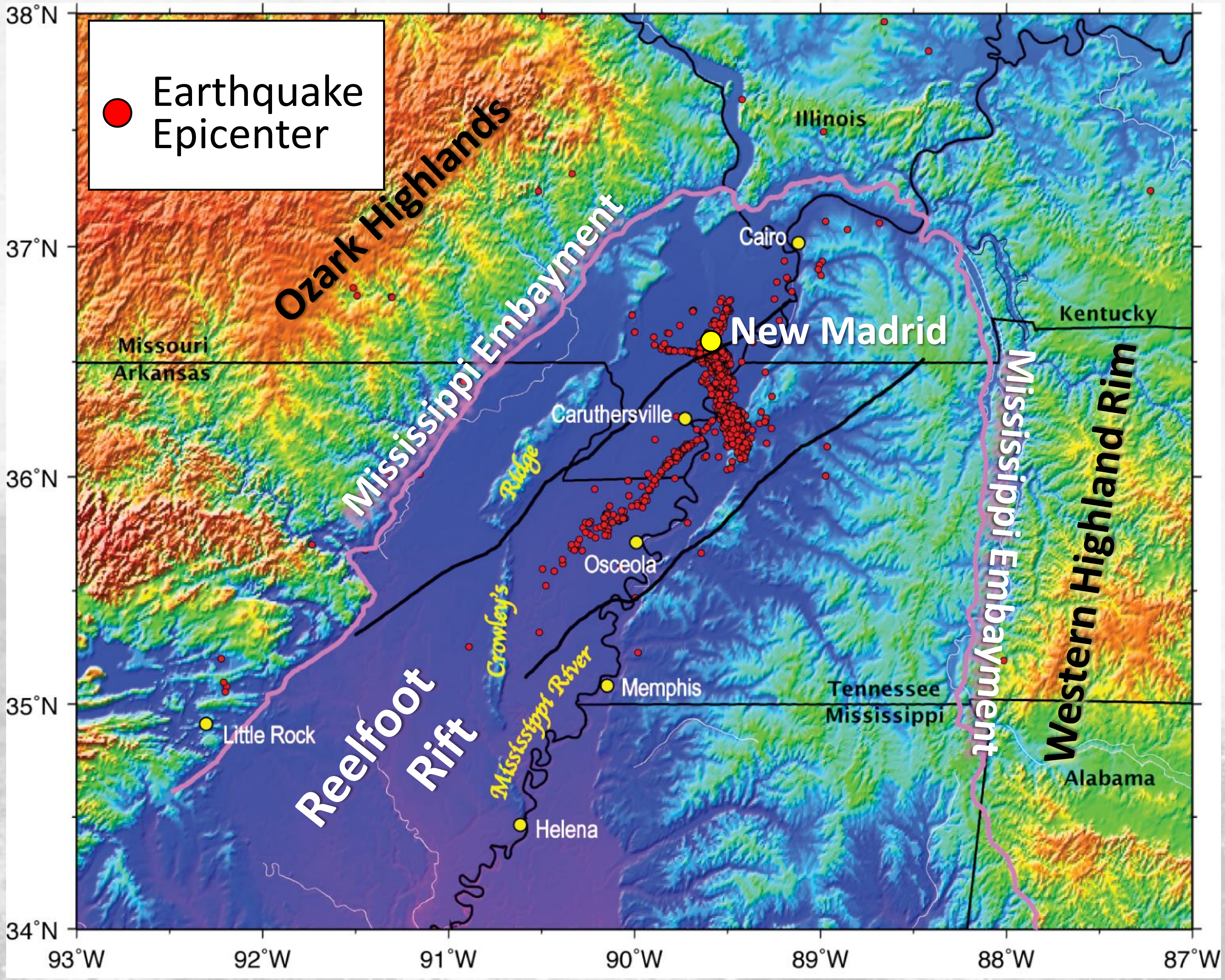
Reelfoot Rift



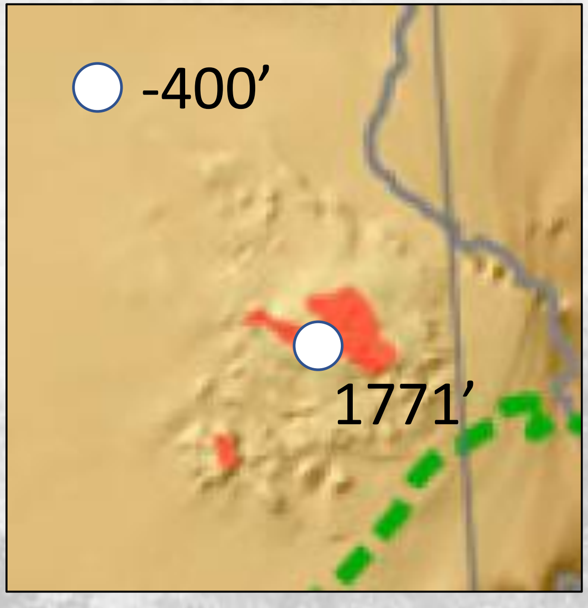
1811-1812 –
New Madrid Earthquakes

New Madrid Seismic Zone is located at the north-east end of the rift.

Isostatic uplift on east and west sides of rift.



Taum Sauk Elevation History



Cambrian elevation of Taum Sauk Mtn at least: 400’+1770’ = 2170’ amsl

Dated Event	Age (Ma)	Sediment Thickness (ft)	Taum Sauk Elevation (ft)
Cambrian Sea Transgression	500	0	**2170**
Cambrian Sedimentation	485	2000	**170**
Early Ordovician Sedimentation	470	1150	-980
Middle and Late Ordovician Sedimentation	443	2650	-3630
Silurian Sedimentation	419	200	-3830
Devonian Sedimentation	359	50	-3880
Mississippian Sedimentation	323	330	-4210
Ouachita Mt Bulge Erosion (Early Penn)	315	**-3230**	-980
Minimum Ouachita Foreland Sedimentation (Pennsylvanian on Ozarks flank)	298	2000	-2980
Maximum Pennsylvanian Sediment implied by Hawn SP Apatite Fission Track (>70°C)	250	4610	-5590
Gulf Rift Uplift (Apatite (U-Th)He 40°C 30°C decrease = 3900 foot uplift	150	**-3900**	-1690
Reelfoot Rift (Middle Ordovician on coast)	100	-710	-980
Present	0		**1771**

Below Sea Level

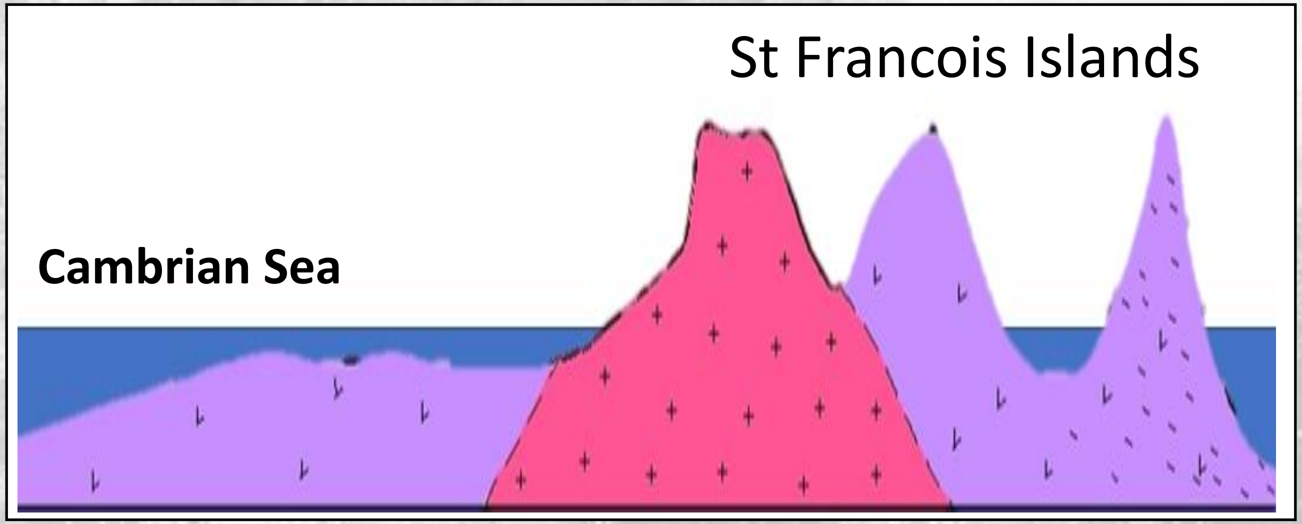
So…

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

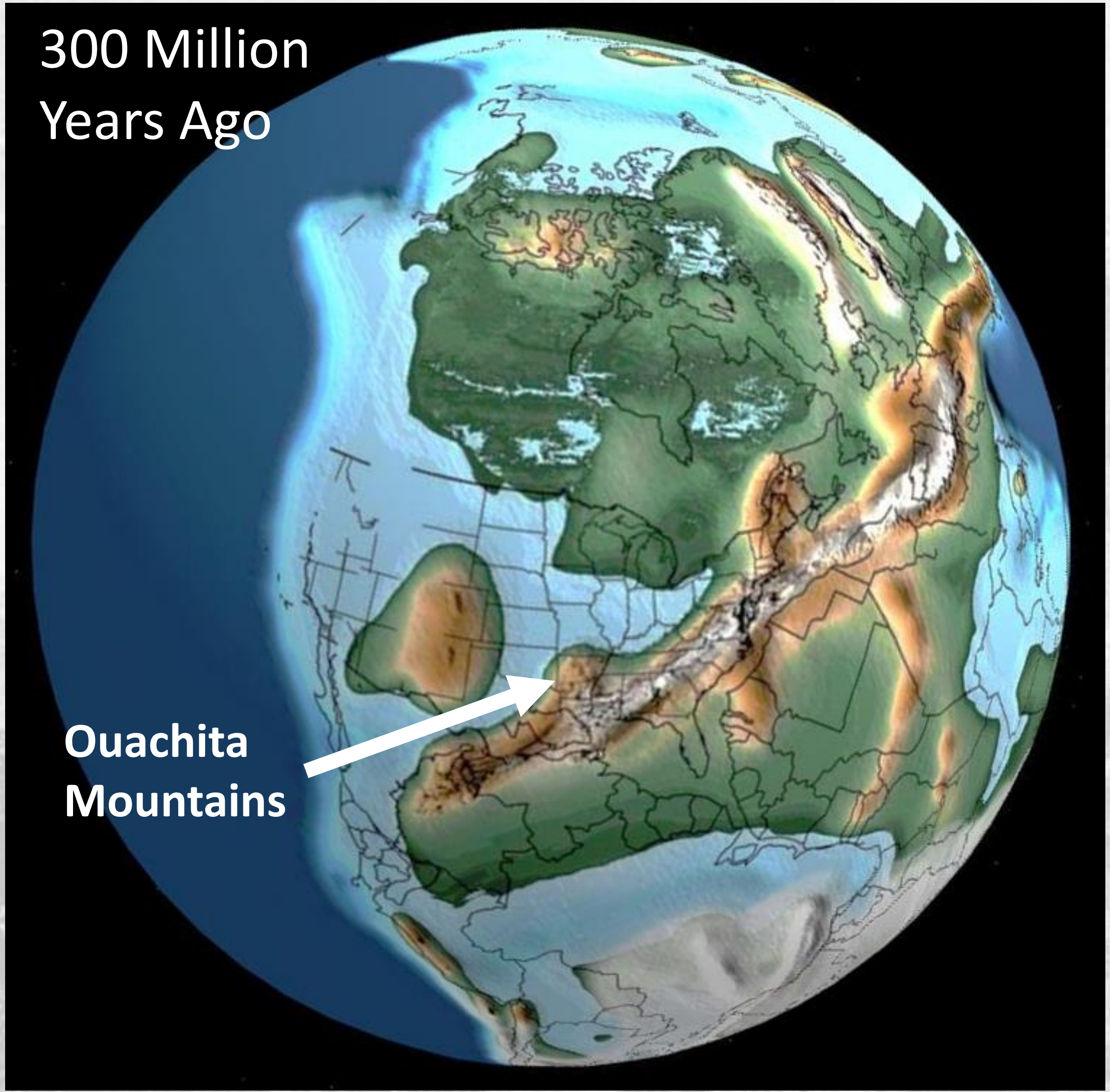


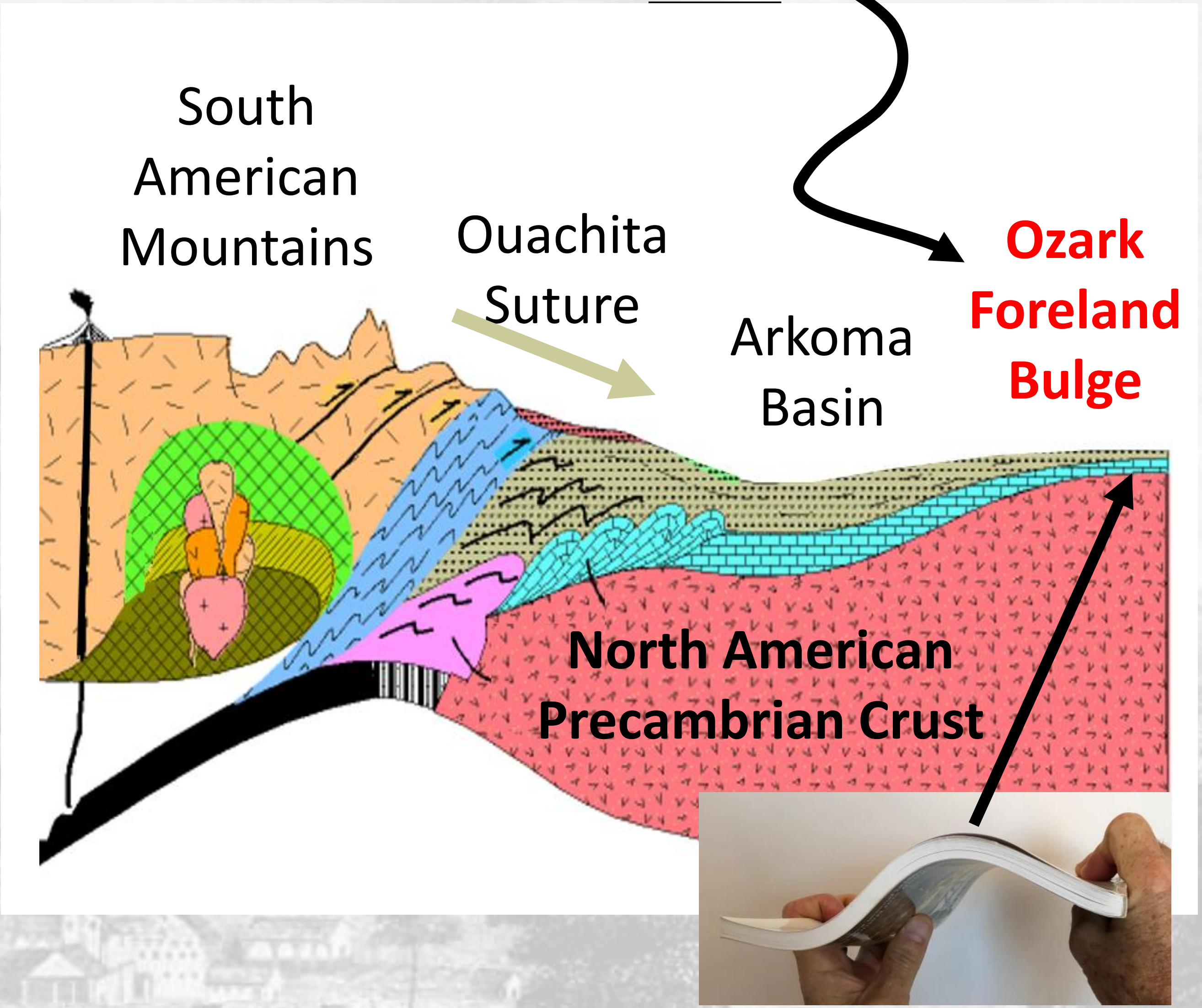
So…

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…….

Pennsylvanian Uplift and Erosion





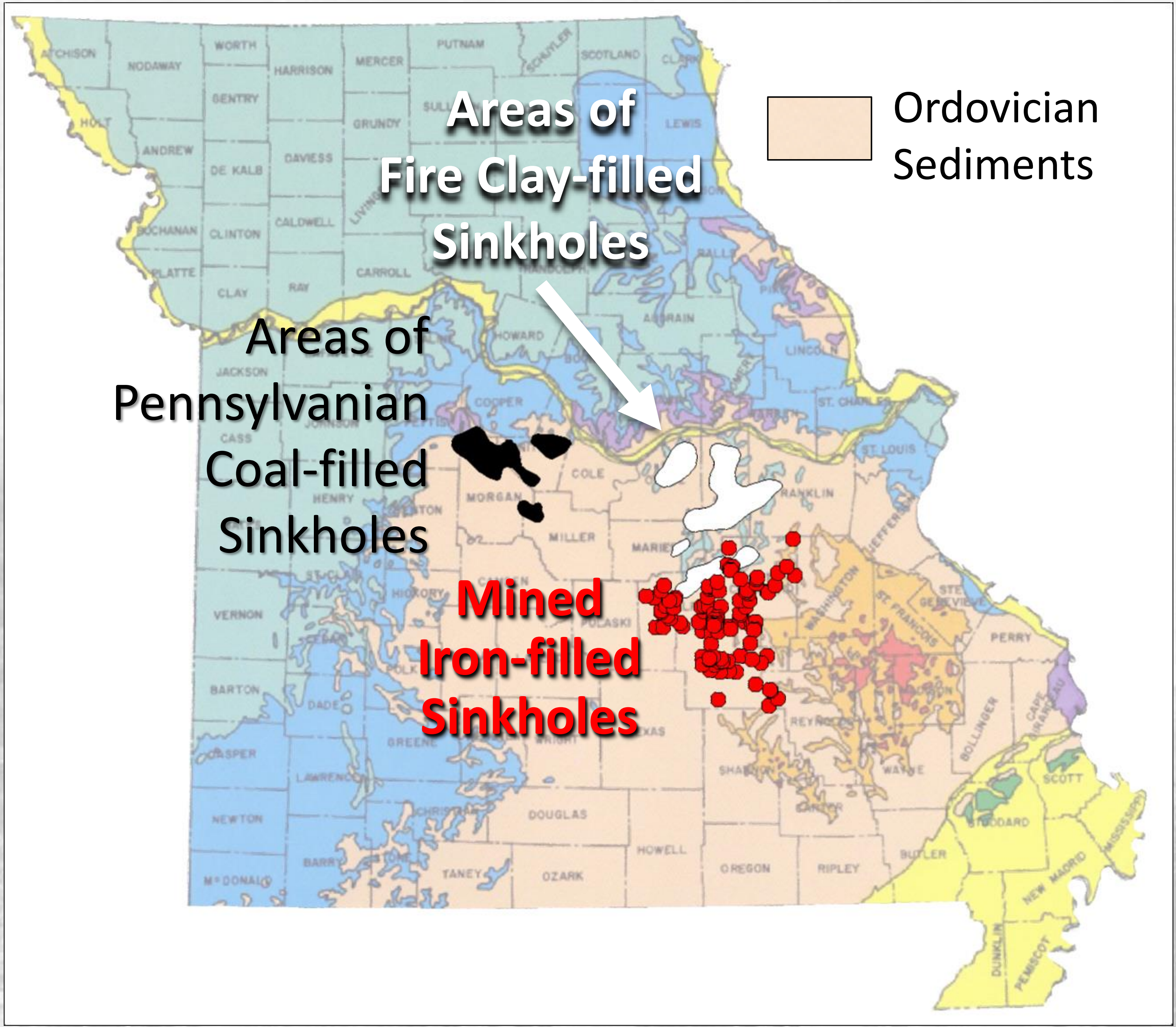
Filled Sinkhole Deposits

300Ma Ouachita Collision: uplift and erosion in the Ozarks

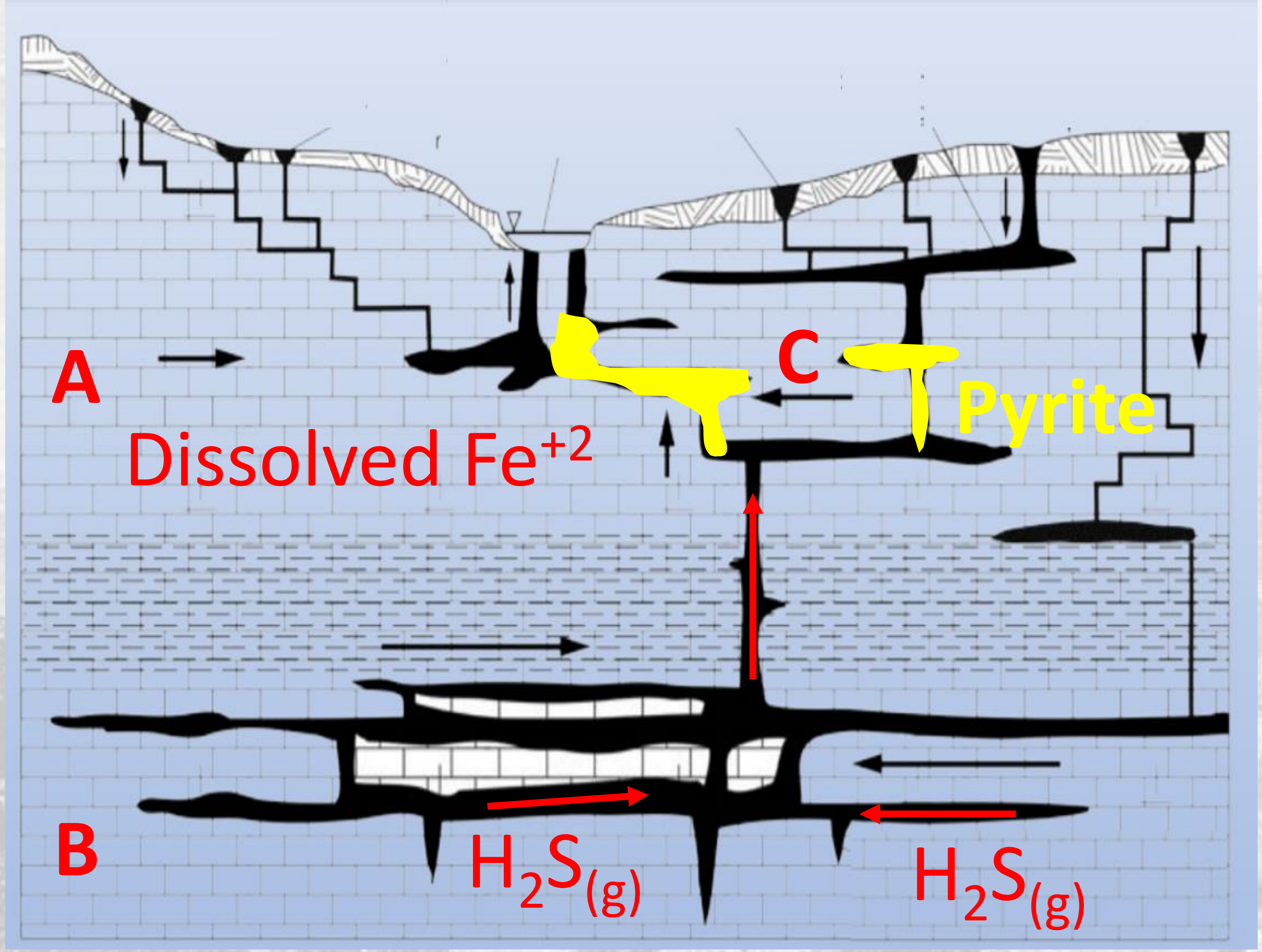
Carbonate rocks dissolved creating caves and hundreds of sink holes

Some later filled with sediments including coal and clay

Others became chemical traps that filled with pyrite (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_2S) which rises toward the surface.

$$H_2S_{(g)} \Leftrightarrow H^+_{(aq)} + HS^-_{(aq)}$$

C Mixing of soluble sulfur and iron cause pyrite to precipitate

$$Fe^{+2}_{(aq)} + 2HS^-_{(aq)} \Leftrightarrow FeS_{2(s)} + H_{2(g)}$$

Filled Sink Iron Deposit

Erosion after 100Ma Ozark Uplift exposes Pyrite to weathering converting it to Hematite and Sulfuric Acid

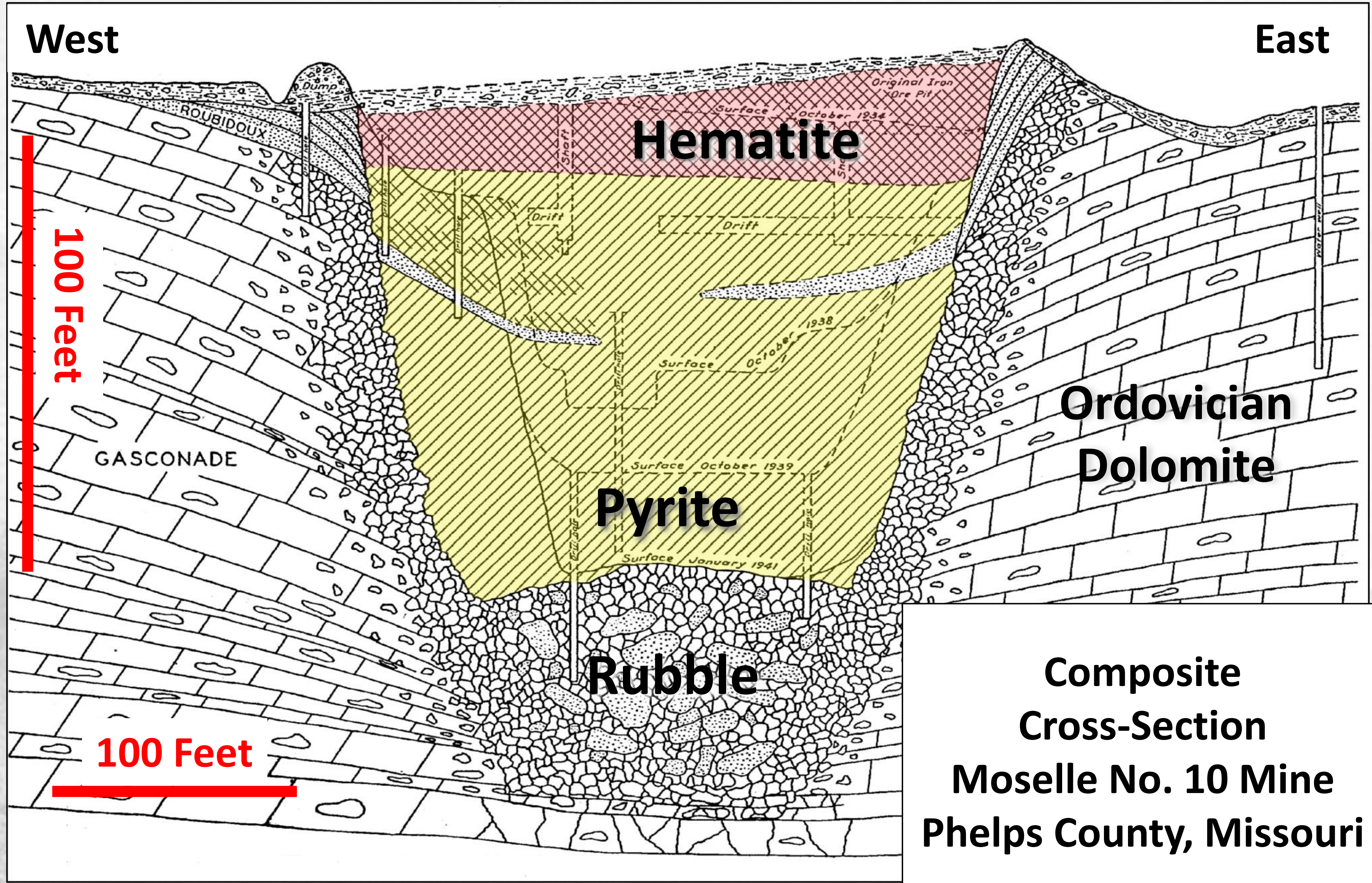
$$2FeS_2 + 4H_20 + 7.5O_2$$

⬇

$$Fe_2O_{3(s)} + 4H_2SO_{4(aq)}$$

⬆

70% Iron



Composite Cross-Section Moselle No. 10 Mine Phelps County, Missouri

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

How important were filled sink iron deposits?

Deposit Type	Iron Production 1824-1912 (Tons)	%
PreCambrian Ores		
Pilot Knob, Iron Mtn	5,627,799	63
Filled Sink Hematite	3,072,637	34
Limonite Ore	291,656	3

Perspective:

2020 West Australia Production = 2.2 million tons/day

88 years = 4 days

MISSOURI BUREAU OF GEOLOGY AND MINES

H. A. BUEHLER, Director.

Vol. X., Second Series

THE IRON ORES

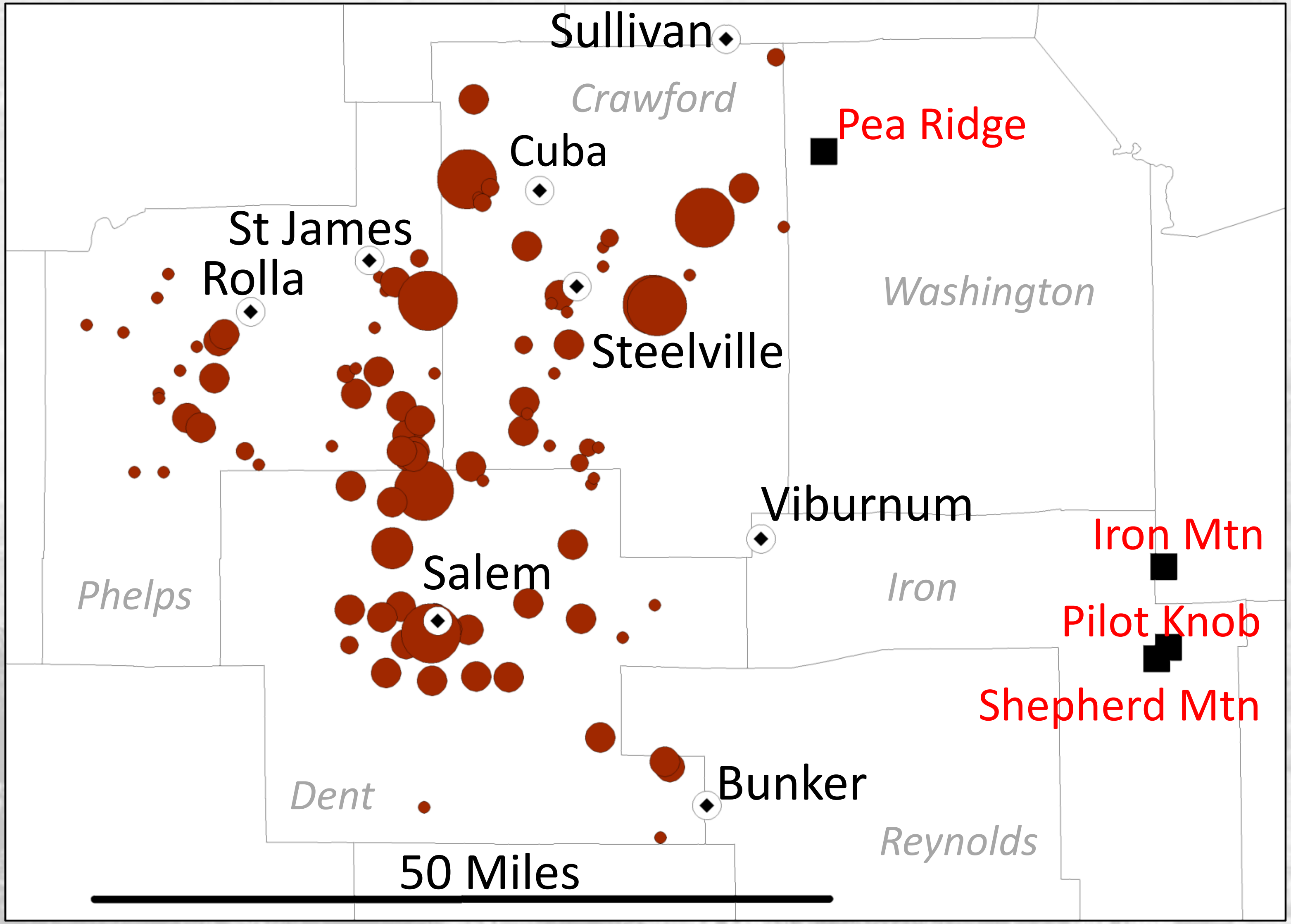
OF

MISSOURI

BY

G. W. CRANE

Size and Distribution of Mined Sink Iron Deposits



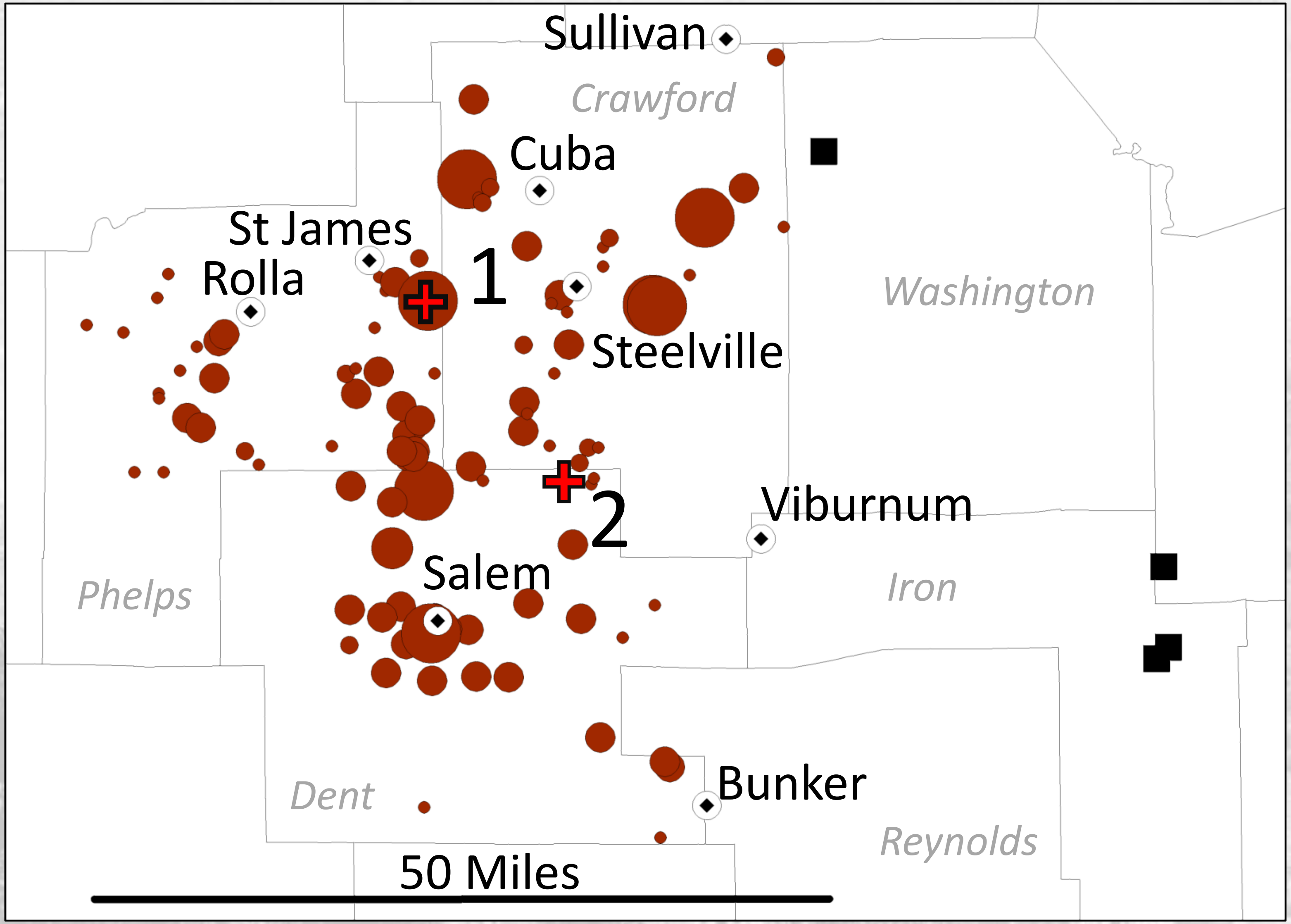
Mines on Precambrian Iron Deposits

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

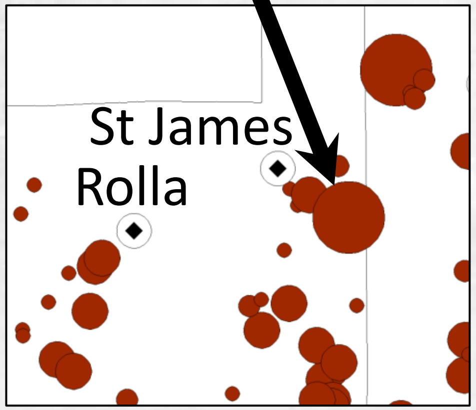


1 Maramec Iron Works
1826 - 1878

2 Sligo Furnace Company
1880 - 1923

Smaller operations are poorly documented

Maramec Iron Works – First Major Development

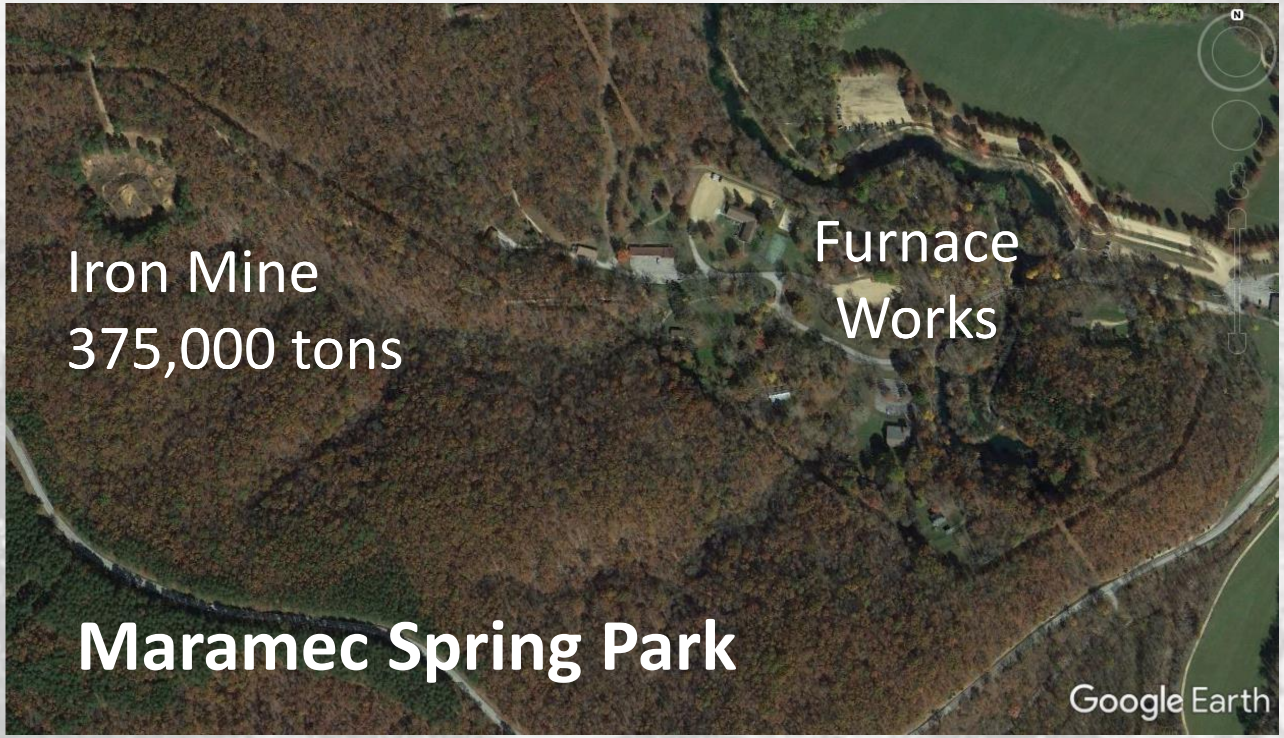


Thomas James learns of red hematite used by Shawnee for face paint

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



1826 – 1829 Thomas James finances construction of Iron Works.

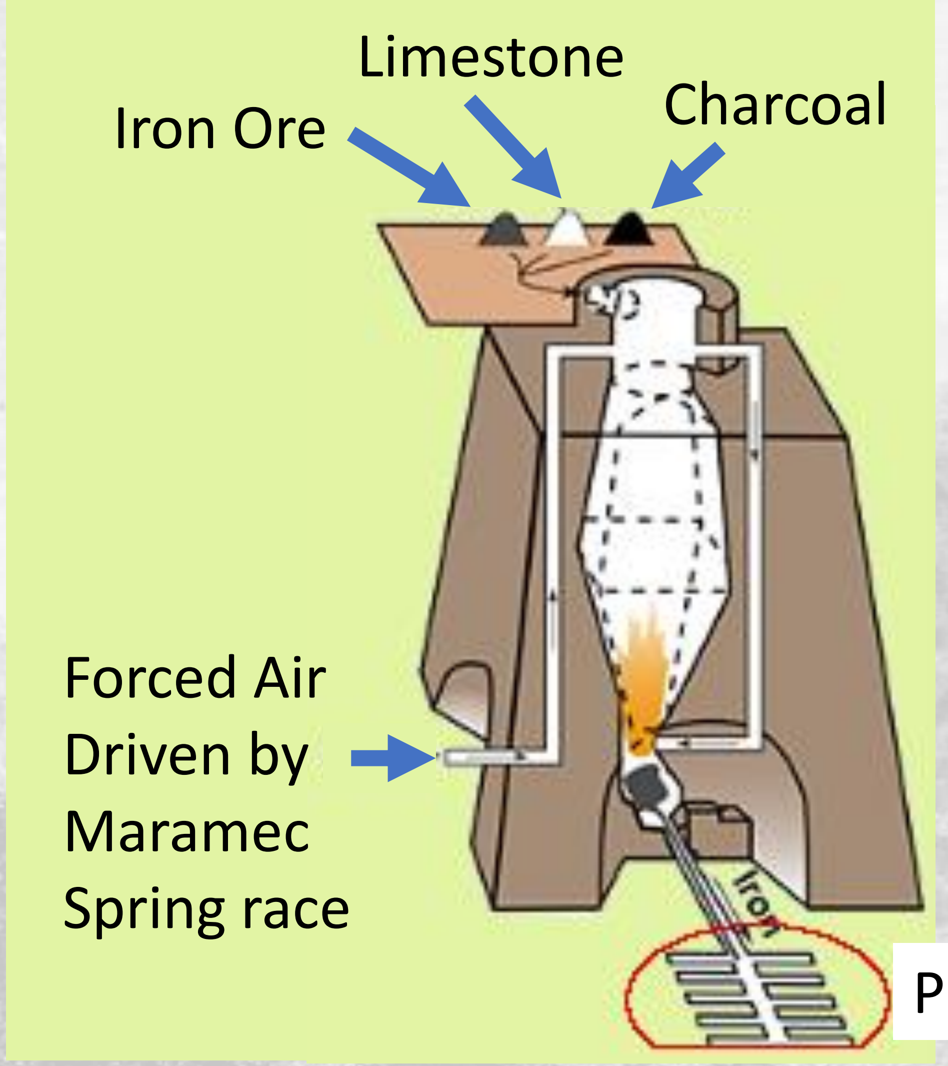
- Manufactured consumer goods
- Pig iron shipped to other markets

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

Products:

Iron metal (Fe^0) + Slag + vast quantities of CO_2



Iron Ore:

68% Iron (Fe^{+3}), 2% Silica (SiO_2), 0.04% Phosphorous

Limestone ($CaCO_3$):

Releases calcium binding with silica to form slag

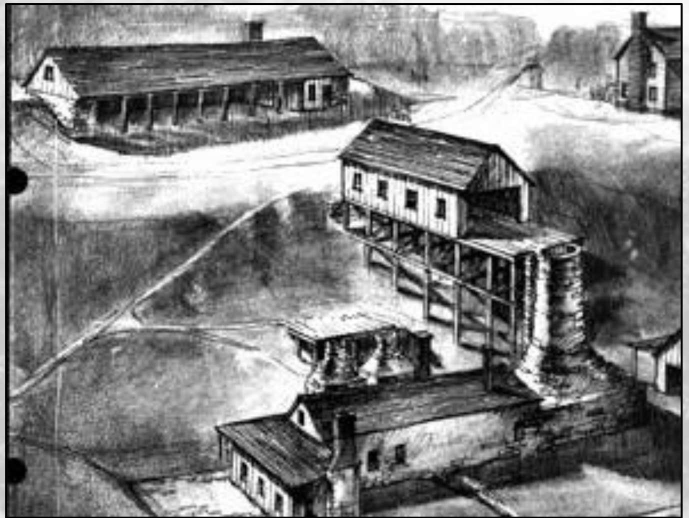
Charcoal (C^0):

Burn temperature 2600-3000°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

Pig Iron



http://www.virginiaplaces.org/ggs380/11wood.html

Charcoal: The key to it all!

Twice the heat content of wood – able to make 2500^{o}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!

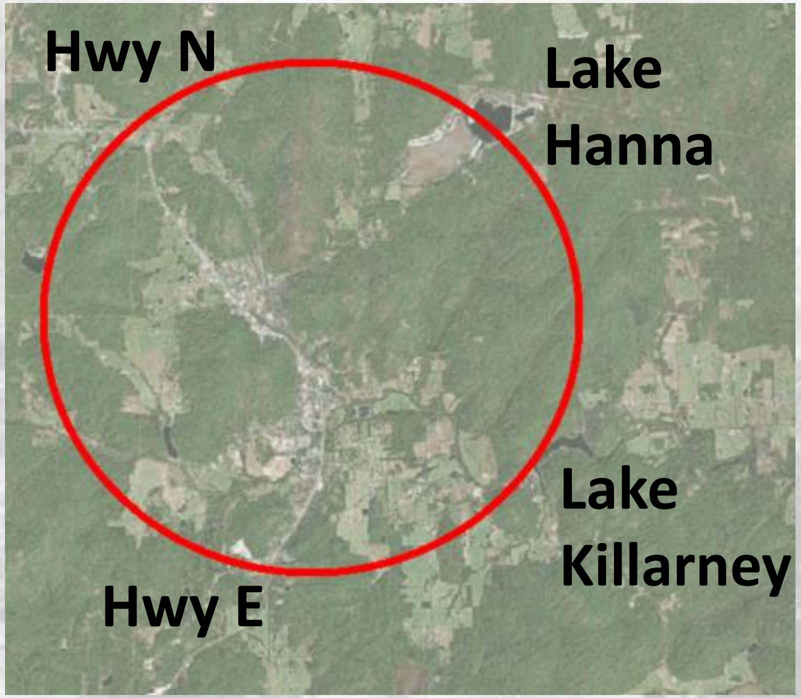
Maramec Iron Mine Charcoal Needs:

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.

Stack with central chimney

Stack being covered with dirt to **cut off air**

Stack ready for ignition

Finished charcoal being removed from pit

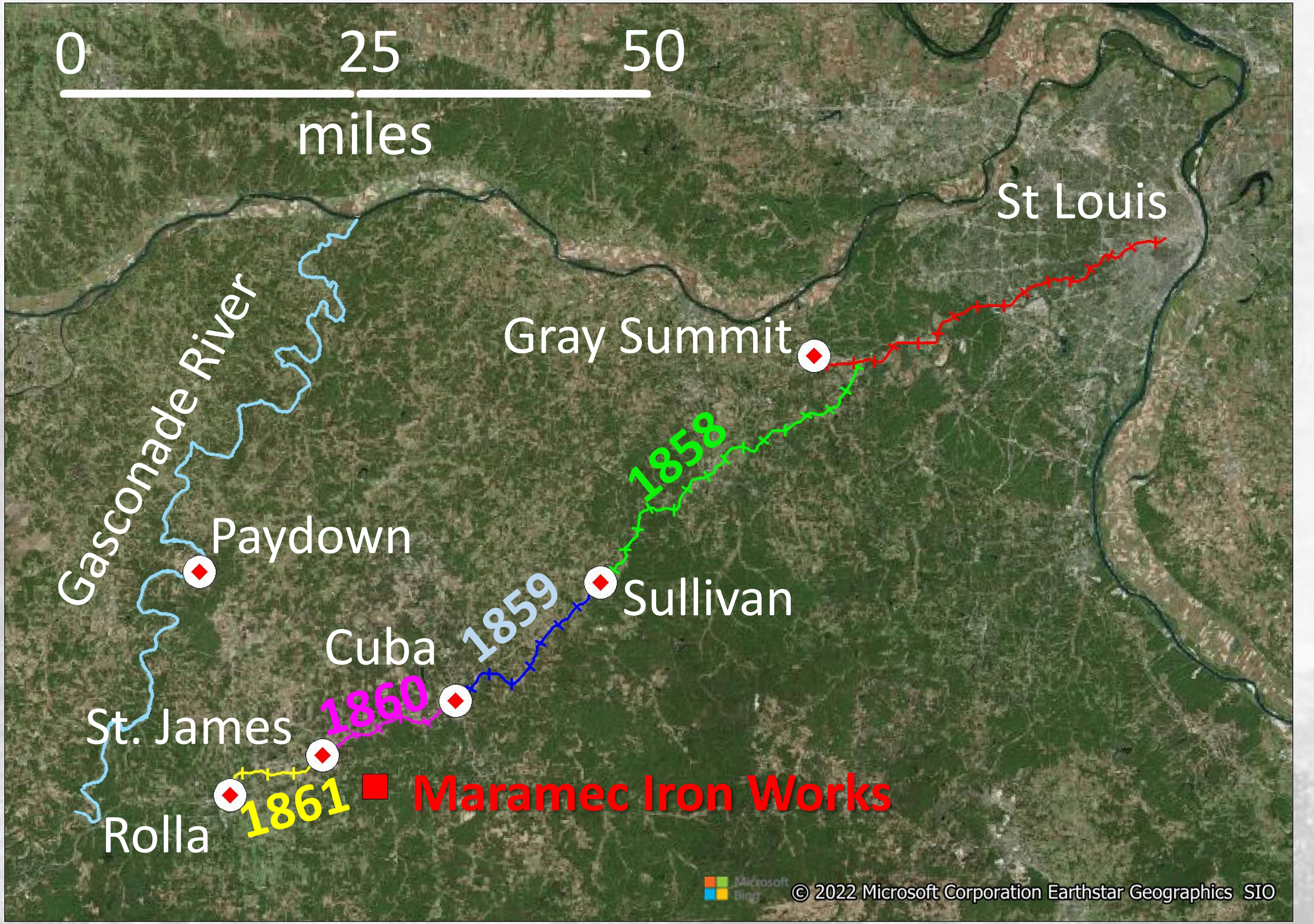
Transportation – Bane of Maramec Iron Works

1826-1860 (34 years)

- Bulk iron transported to Gasconade River or Gray Summit Railhead
- Consumer goods taken to Rolla, Lebanon and Springfield
- **Limited growth**

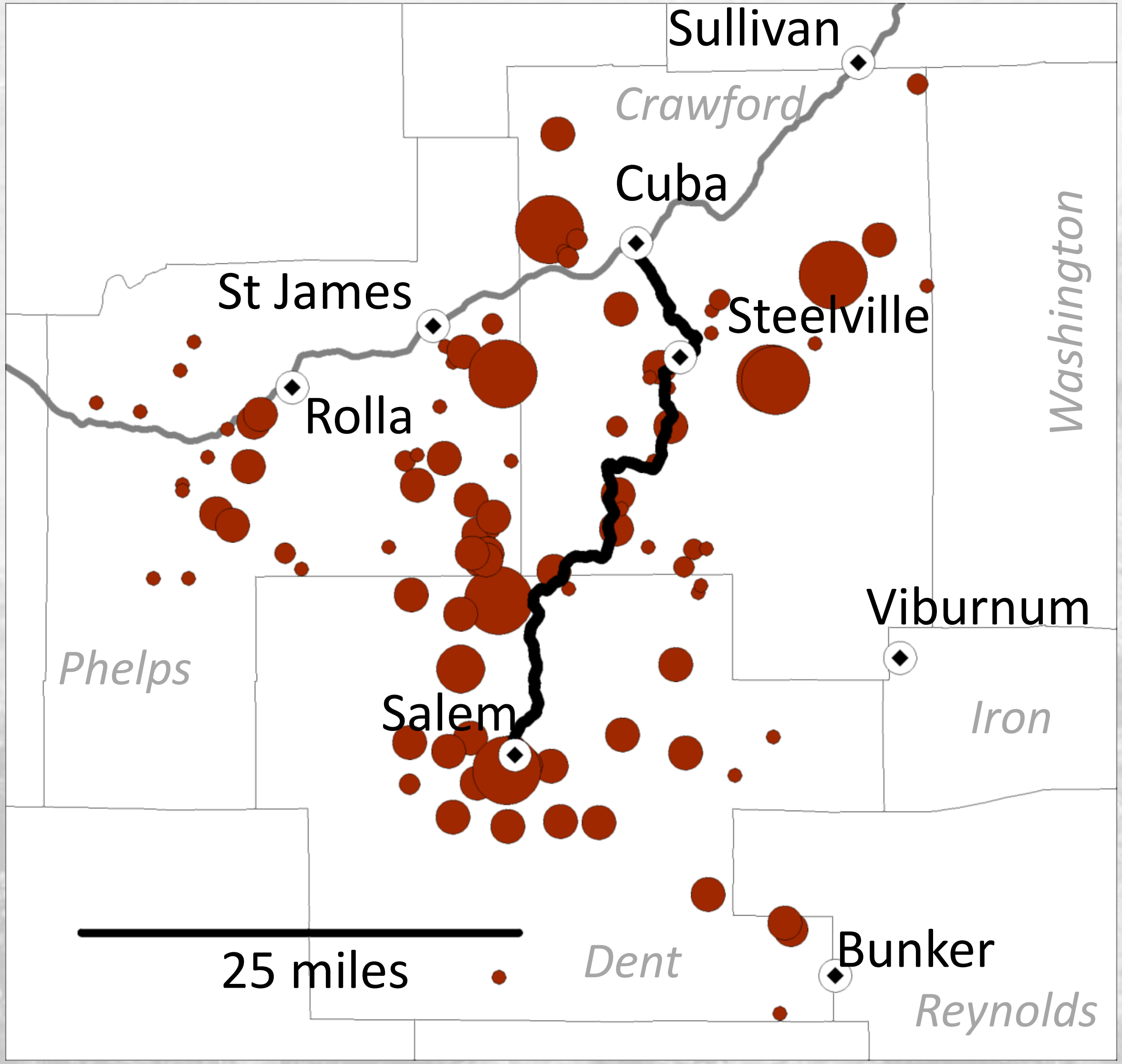
1860-1873 (13 years)

- Rail arrived in St James
- Civil war and post war growth fed demand
- **Iron ore mostly depleted**



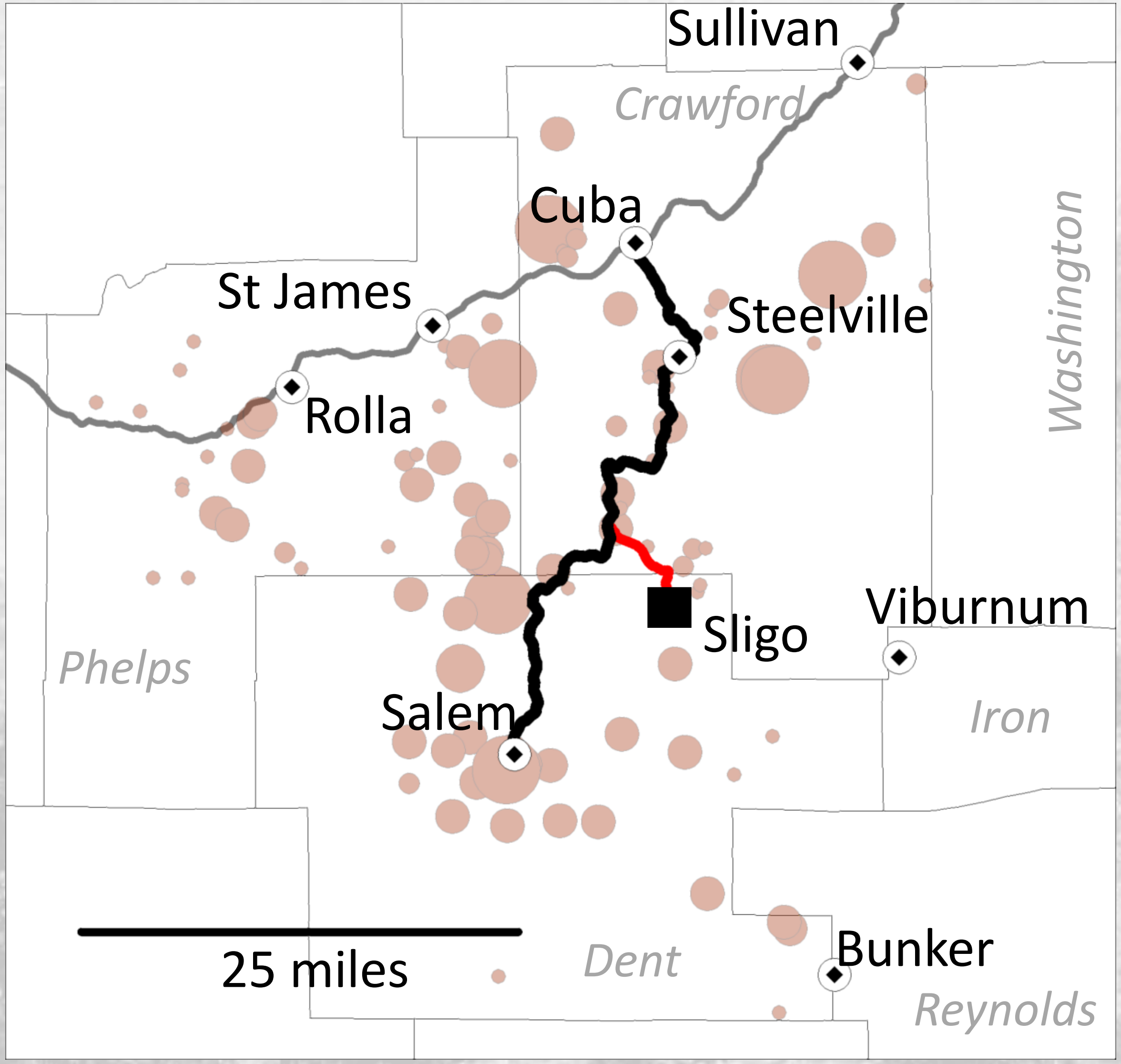
"Panic of 1873": 1873-1877 global depression and Maramec bankruptcy in 1876

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

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

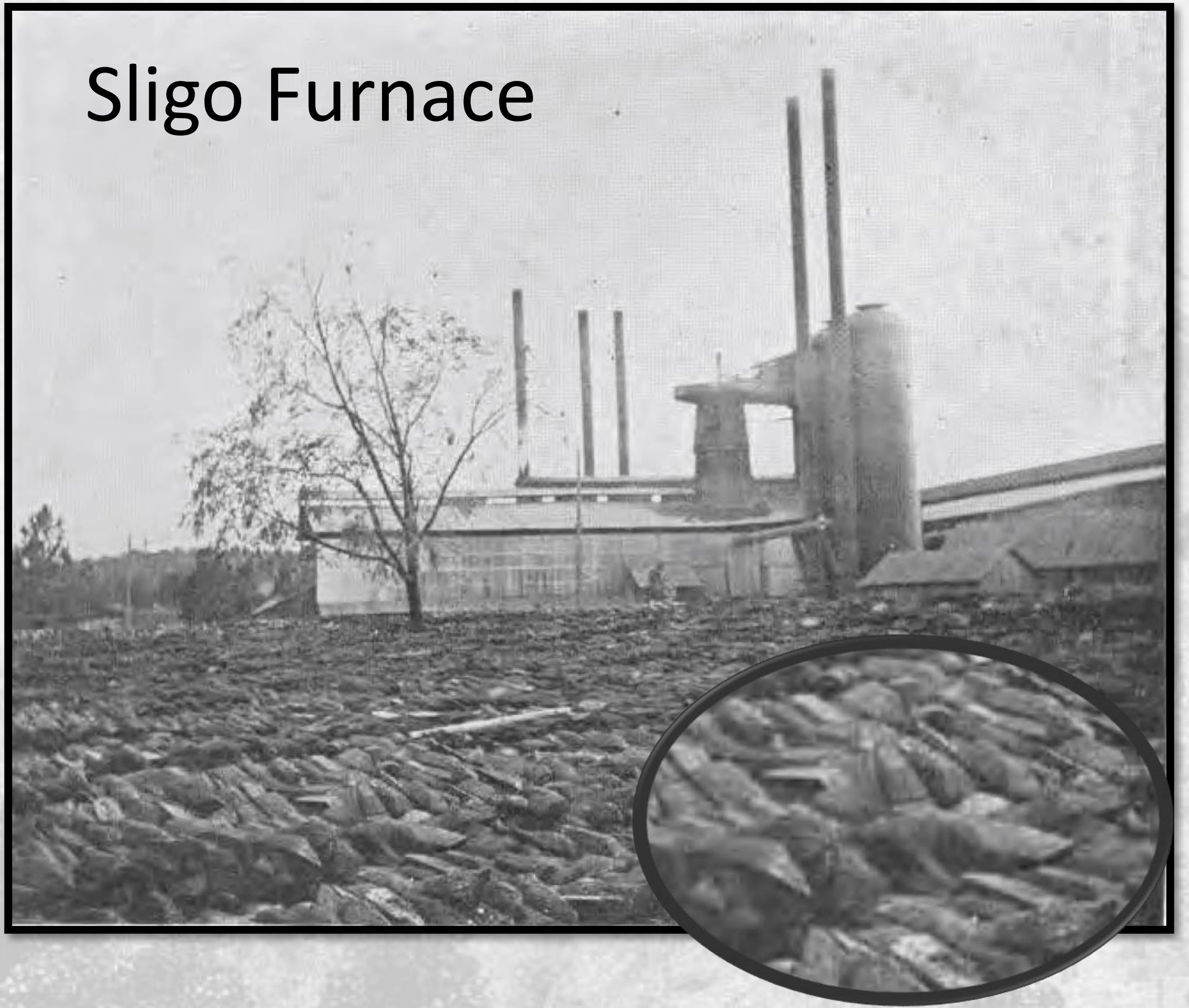
>4x Larger than Maramec

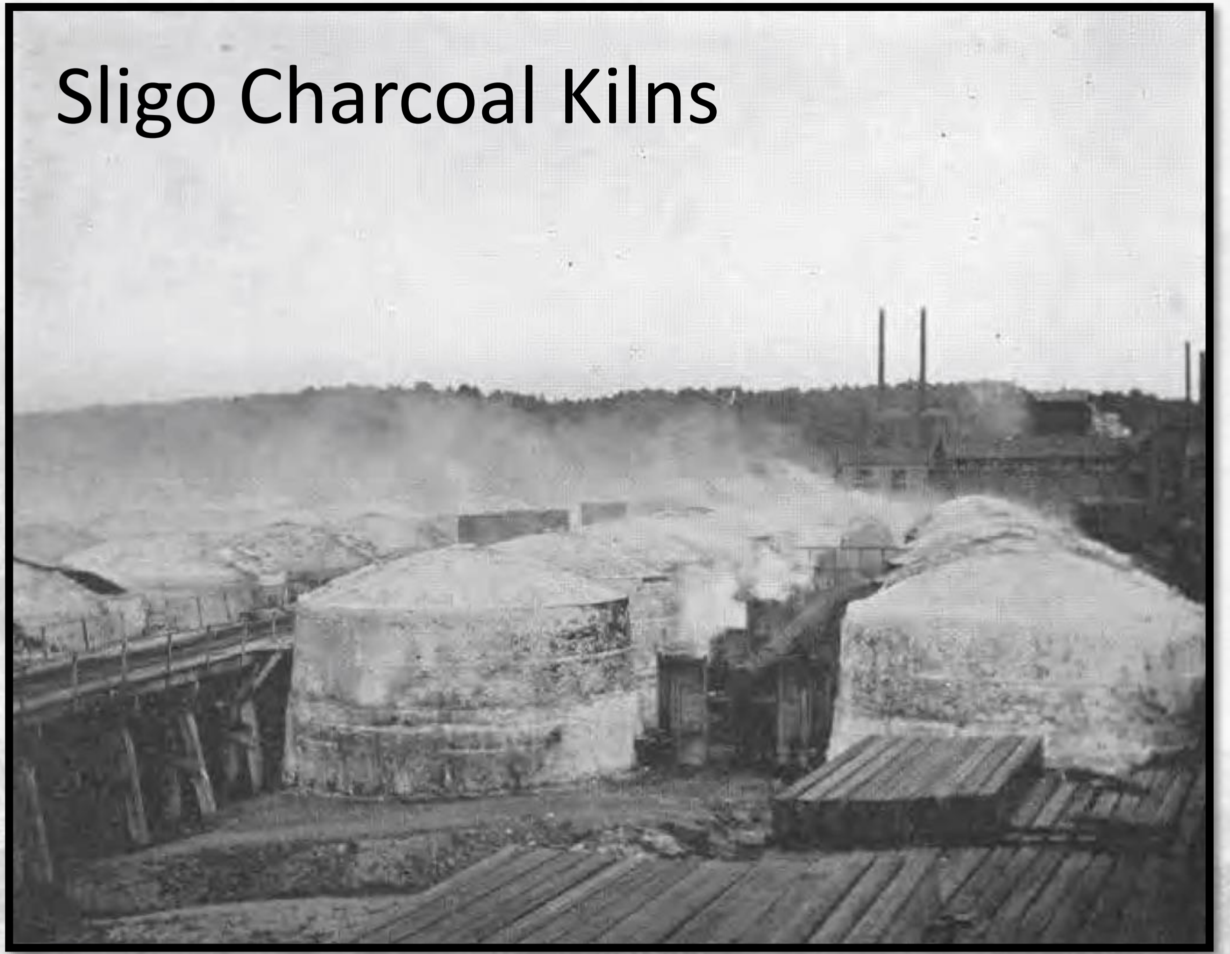
Sink Iron Mine Production (tons)

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

Sligo Furnace Works circa 1897

Not artisanal!



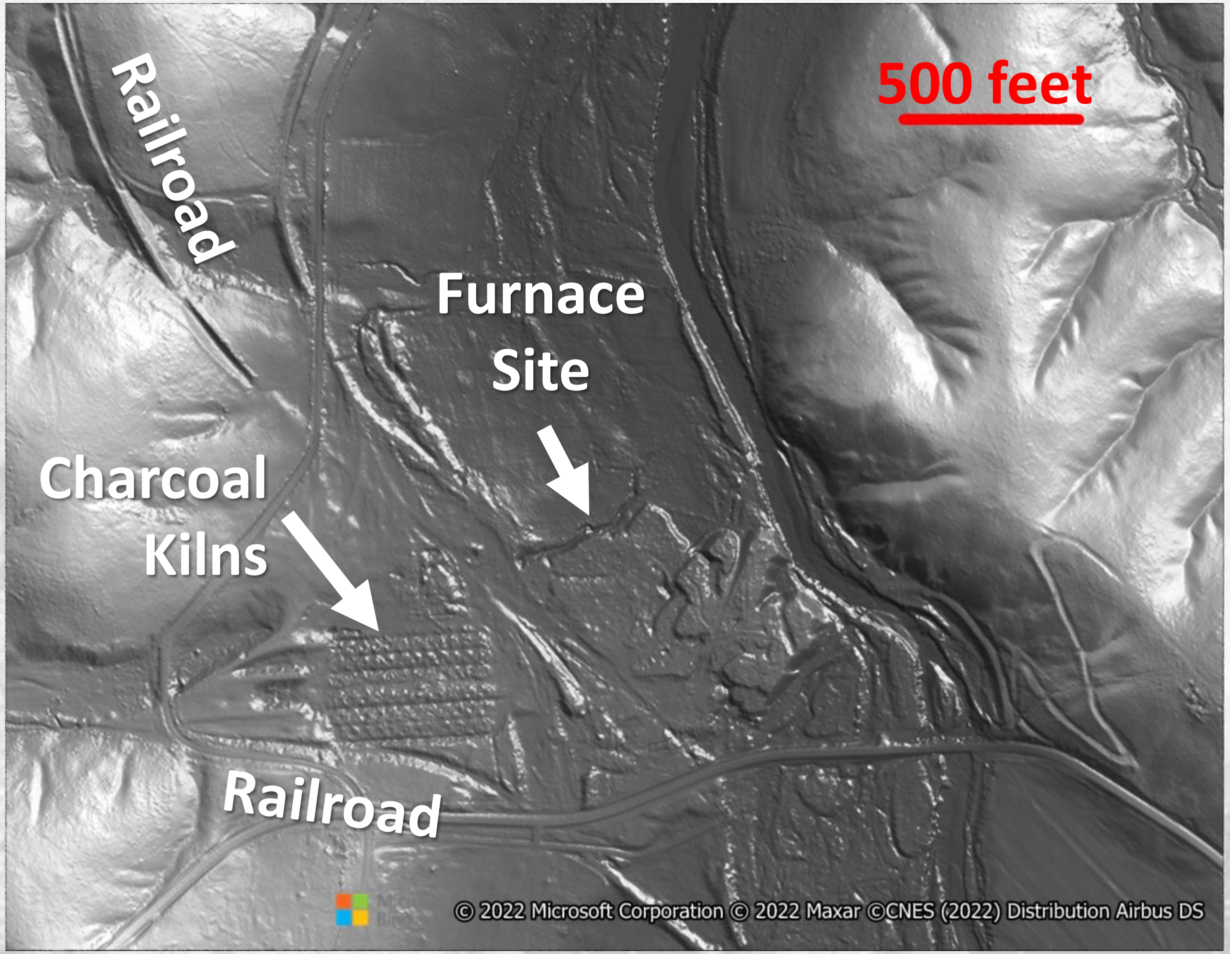


Stockpile of 90,000 tons of pig iron bars accumulated between 1893 and 1897.

Operations recovered wood alcohol and other distillates from kiln gases.

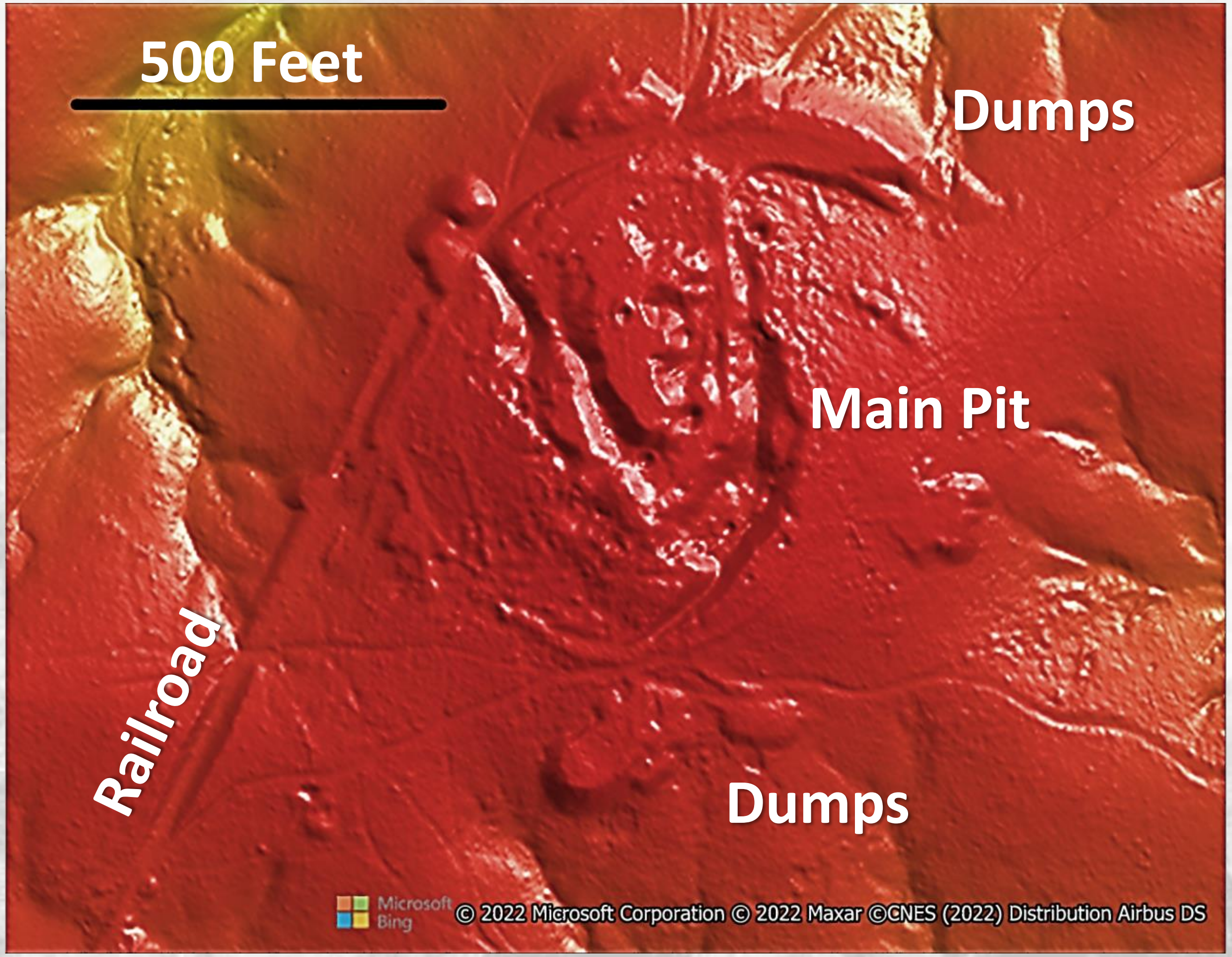
Lidar Mapping: Sligo Smelter Site

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

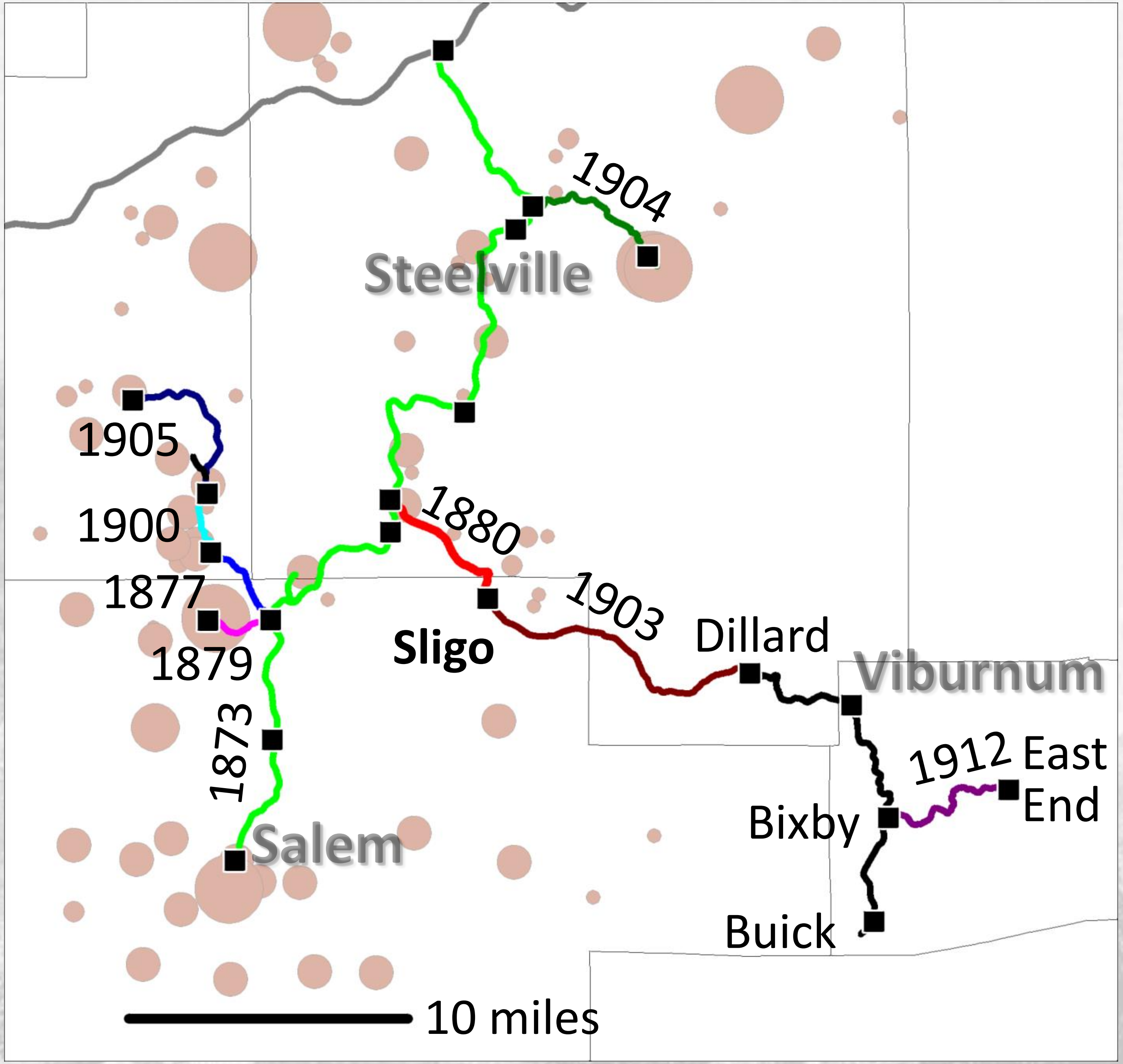
Sligo iron was high quality and in demand to mix with lower quality iron from other sources.

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

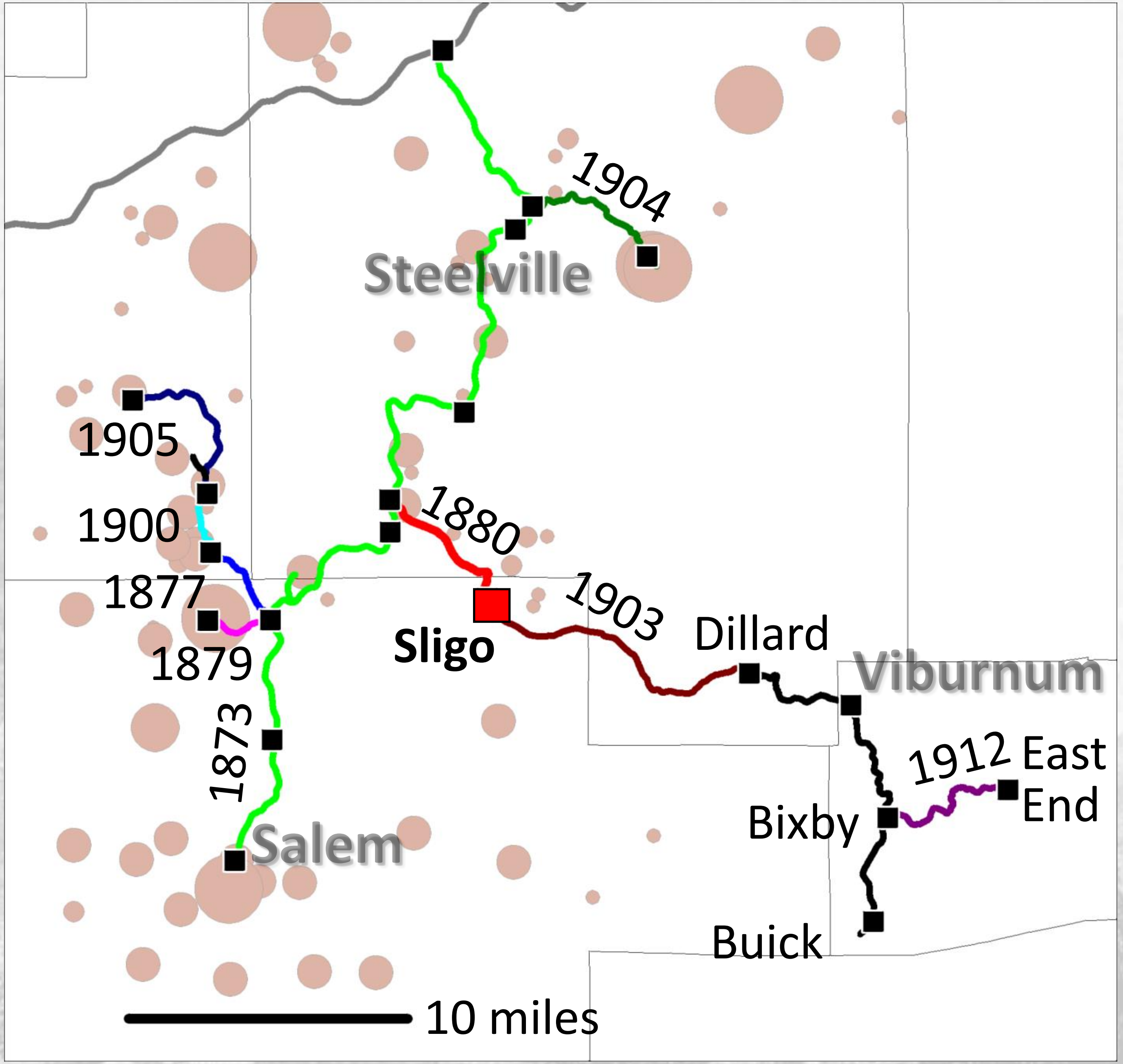
Great Lakes Transportation System brought together Iron Ore and Coal

New 19th Century Steel Cites

- Chicago
- Detroit
- Gary
- Cleveland
- Buffalo

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

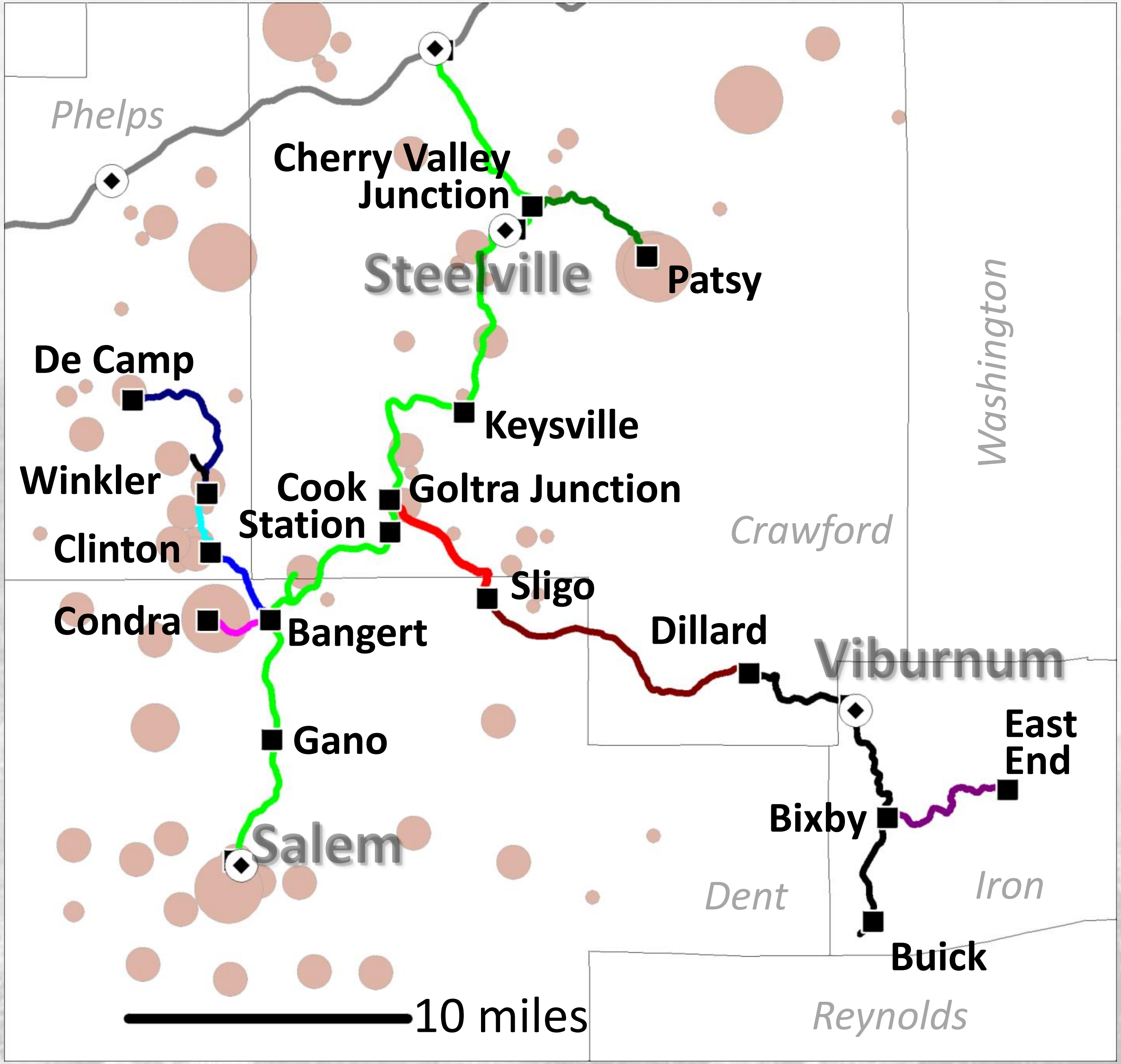
(1880 life expectancy = 39 years)

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