Warp and Weft of the Ozarks: Structural Analysis of Top of the Rock Sinkhole, Ridgedale, Missouri

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ABSTRACT. Warp and Weft of the Ozarks: Structural Analysis of Top of the Rock Sinkhole, Ridgedale, Missouri

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On May 22, 2015, a sinkhole collapsed below a 3.1-acre (1.25 ha) lake at Johnny Morris' Top of the Rock Golf Course at Big Cedar Lodge and Ozarks Heritage Preserve. The Sinkhole (36° 32' 29.75" N, 93° 14' 59.41" W) is located on the Ridgedale, Missouri 7.5-minute quadrangle. Since the collapse, crews have continued to excavate the sinkhole to reveal a spectacular cathedral-like topography developed in the walls of this unique karst feature. On March 17, 2023, our team measured and described a stratigraphic section and logged a partial gamma-ray profile in the sinkhole. The sinkhole exposes a continuous succession of the upper approximately 30 ft. (10 m) of lower Ordovician Cotter Dolomite through part of the mid-Mississippian Elsey Formation. Typically, such stratigraphy is observed only in drill core. In contrast, sinkhole walls provide three-dimensional, 100% exposed strata, vertically and laterally.

The sub-Mississippian unconformity is about 30 feet above the sinkhole floor. The Bachelor Formation, marking the base of the Mississippian, is a thin sandstone and shale unit that includes chert pebbles eroded from the Cotter. The Compton Limestone, mostly lime mudstone, overlies the Bachelor; it is 10 ft. (3 m) thick. The Northview Formation is 7 ft. thick with interbedded argillaceous limestone and red and light gray-green shale beds. The brick-red argillaceous lime mudstone of the Baird Mountain Limestone Member of the Northview is at least 2 ft. (0.6 m) thick. The PiersonLimestone, brachiopod-crinoid wackestone to packstone is 76 ft. (23.2 m) thick. Dark cherty limestone of the Reeds Spring Formation, 32 ft. (9.8 m) and at least 16 ft. (4.9 m) of the Elsey, interbedded lime mudstone to crinoid packstone caps the succession.

The sinkhole is 4 miles (6.4 km) southwest of the trace of the Ten O'Clock Run Fault, and 2.5 miles (4 km) northeast of Beardsley Branch fault and monocline. These structures parallel one another, trending roughly 310°. Nearly perpendicular to the structures, fractures cut though the sinkhole area are slightly bowed to the northwest, trending 32°. Another set of fractures trends parallel to the bounding structures. Slight bowing of the fractures is consistent with gentle counterclockwise rotation between the Ten O'clock Run and Lampe fault systems with deep-seated basement fault movements.

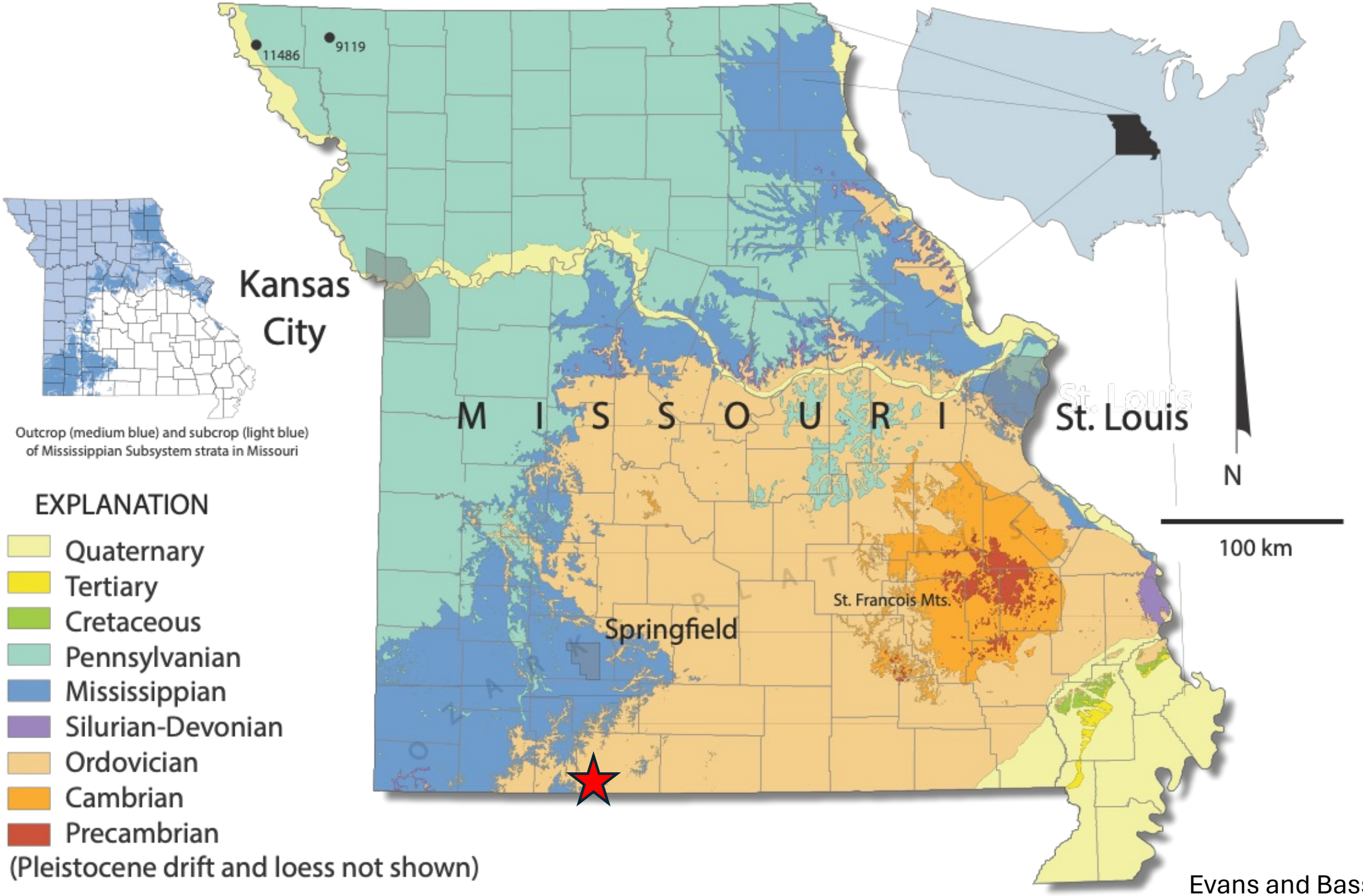
TAKE-AWAY POINTS

- Ozarks mid-to-late Devonian uplift with culmination in Pennsylvanian
- Intersecting fault systems across Ozarks influenced Mississippian sedimentation with intrashelf basins
- Sinkhole developed in Lower Mississippian strata
- Baird Mountain Limestone Member of Northview Formation present…best stratigraphic section of it!
- Thick section of Pierson Limestone, 22.9 m (76 ft.)
- Fractures trend 32° and 310°, and $\delta^1 = 351°$

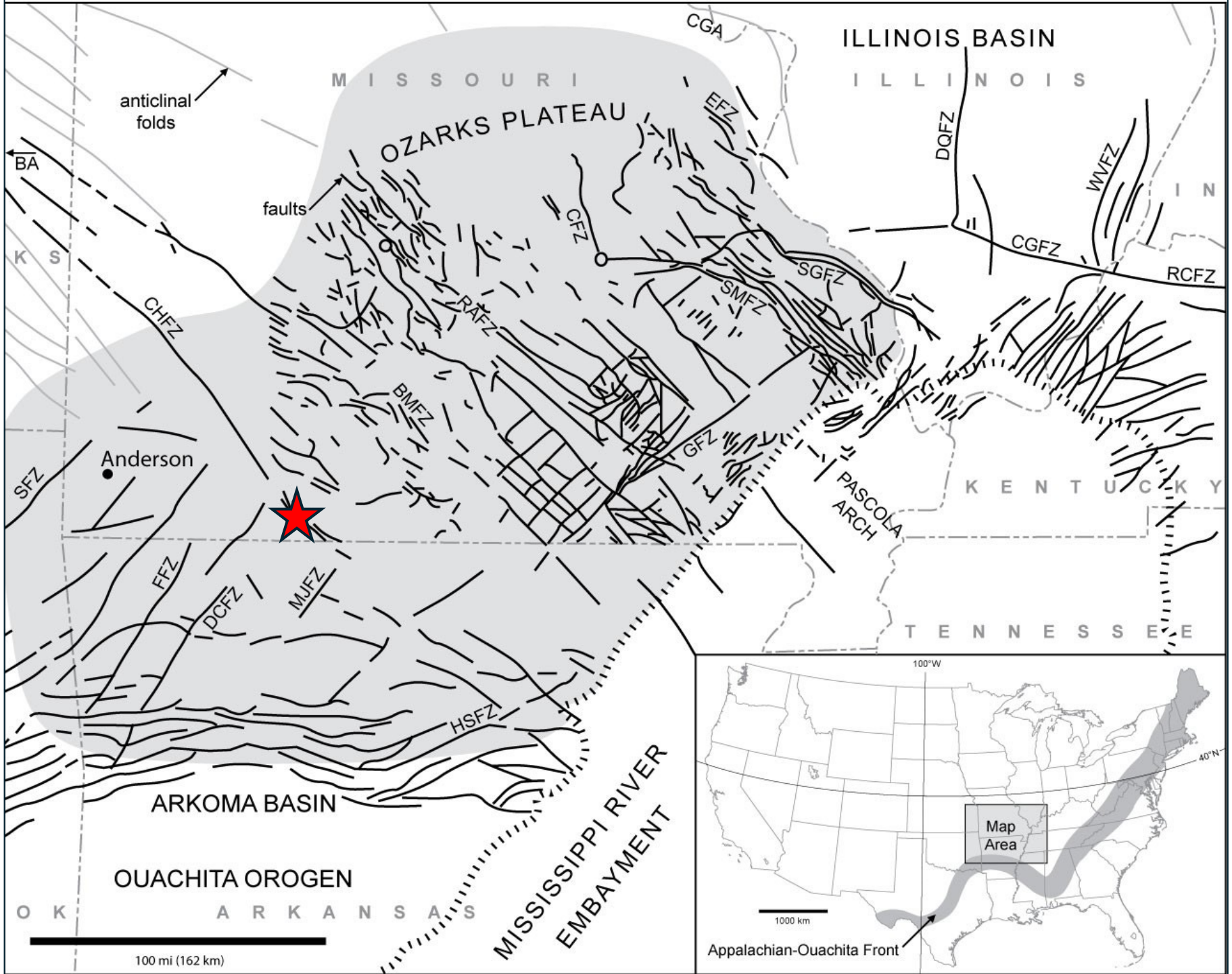
On May 22, 2015, a sinkhole collapsed below a 3.1-acre (1.25 ha) lake at Johnny Morris' Top of the Rock Golf Course at Big Cedar Lodge and Ozarks Heritage Preserve near Ridgedale, Missouri.

Photo credit: Springfield Business Journal

Crews began to excavate the sinkhole in an attempt to link it to a known cave.



Evans and Bassett (2022)


ILLINOIS BASIN
OZARKS PLATEAU
MISSOURI
ILLINOIS
INDIANA
KENTUCKY
TENNESSEE
ARKOMA BASIN
OUACHITA OROGEN
OKLAHOMA
ARKANSAS
MISSISSIPPI RIVER EMBAYMENT
PASCOLA ARCH
anticlinal folds
faults
BA
CGA
EFZ
DQFZ
WVFZ
CFZ
CGFZ
RCFZ
SGFZ
SMFZ
RAFZ
BMFZ
GFZ
CHFZ
SFZ
FFZ
DCFZ
MJFZ
HSFZ
Anderson
100 mi (162 km)
100°W
40°N
Map Area
1000 km
Appalachian-Ouachita Front

Cox (2009)

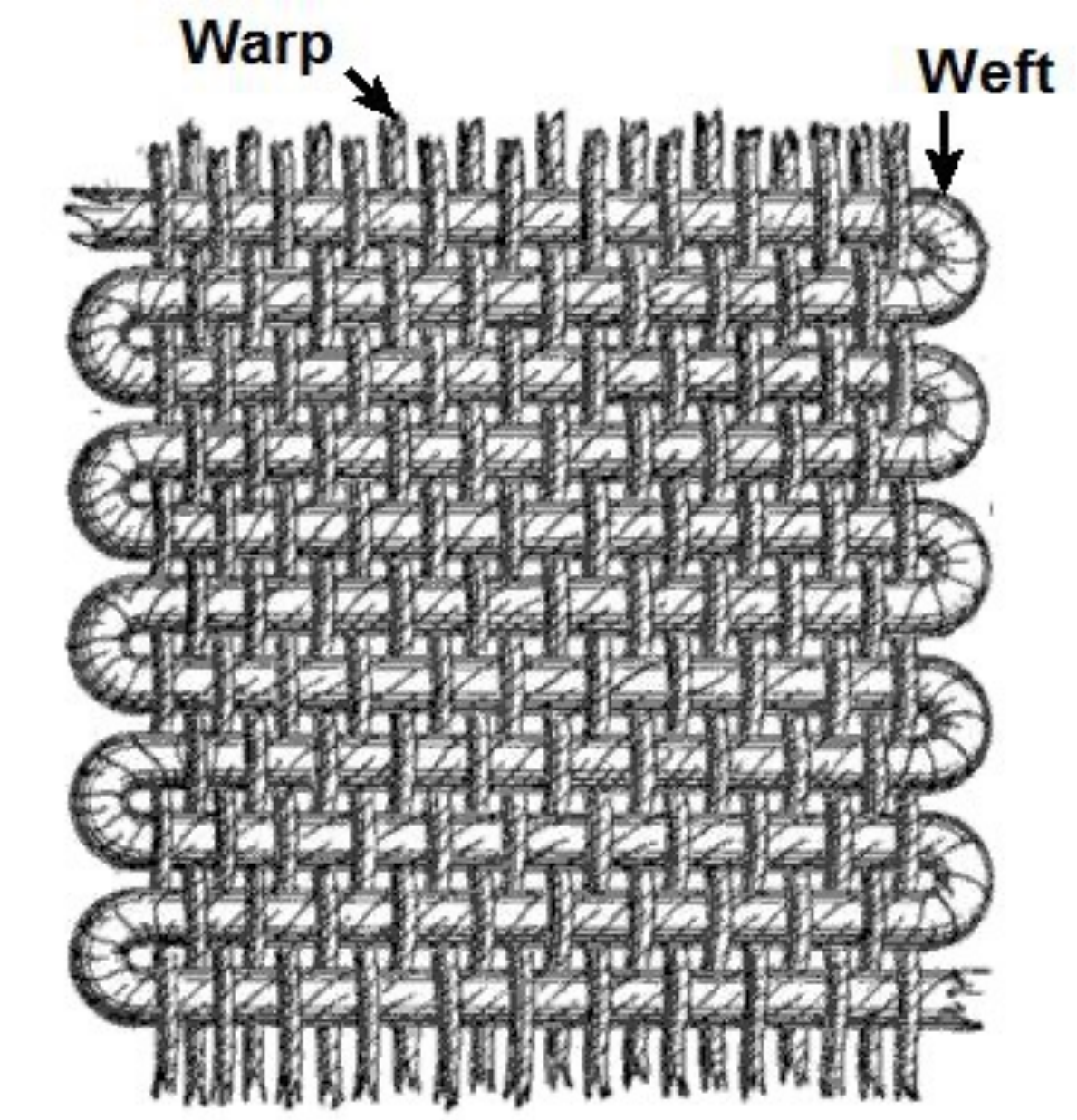
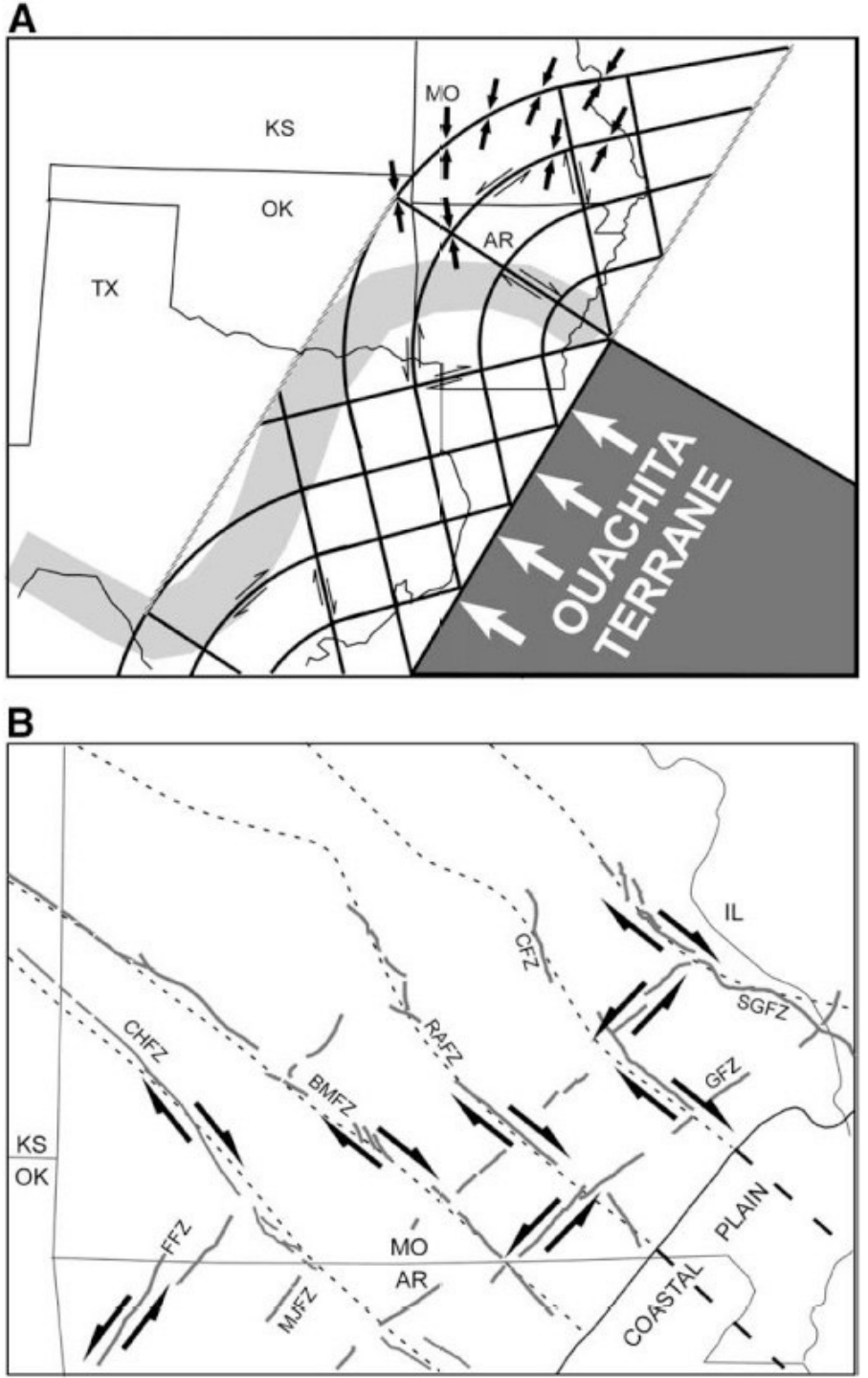
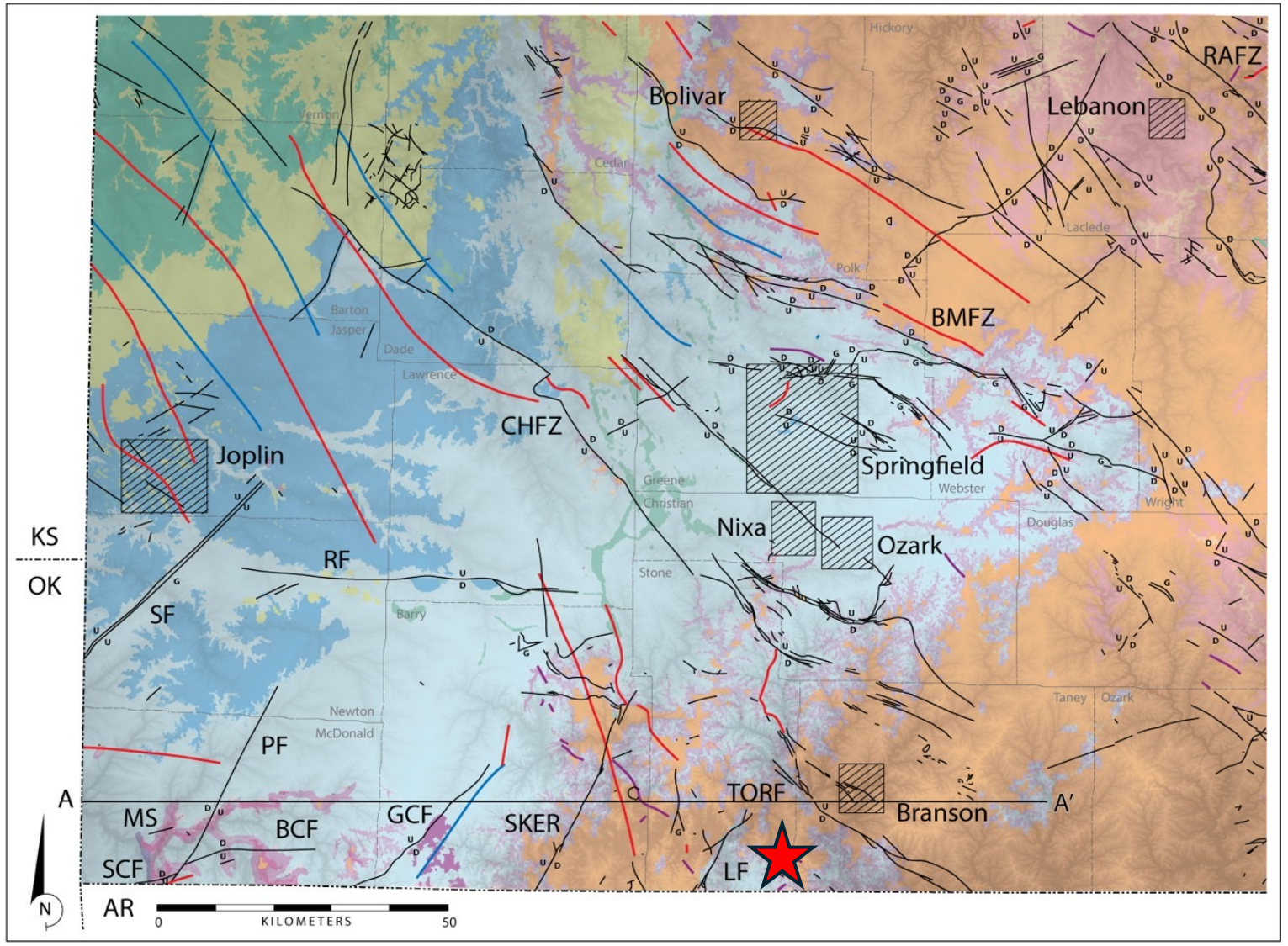


Illustration by Alfred Barlow adapted from *The History and Principles of Weaving by Hand and by Power* (Low, Marston, Searle, and Rivington, Publishers, London



Cox (2009)



EXPLANATION

Pennsylvanian Subsystem
- Marmaton Group
- Cabaniss Group
- Krebs Subgroup and Atokan Stage
- Pennsylvanian channel sandstones

Mississippian Subsystem
- Chesterian Stage
- Meramecian Stage
- Osagean Stage
- Kinderhookian Stage

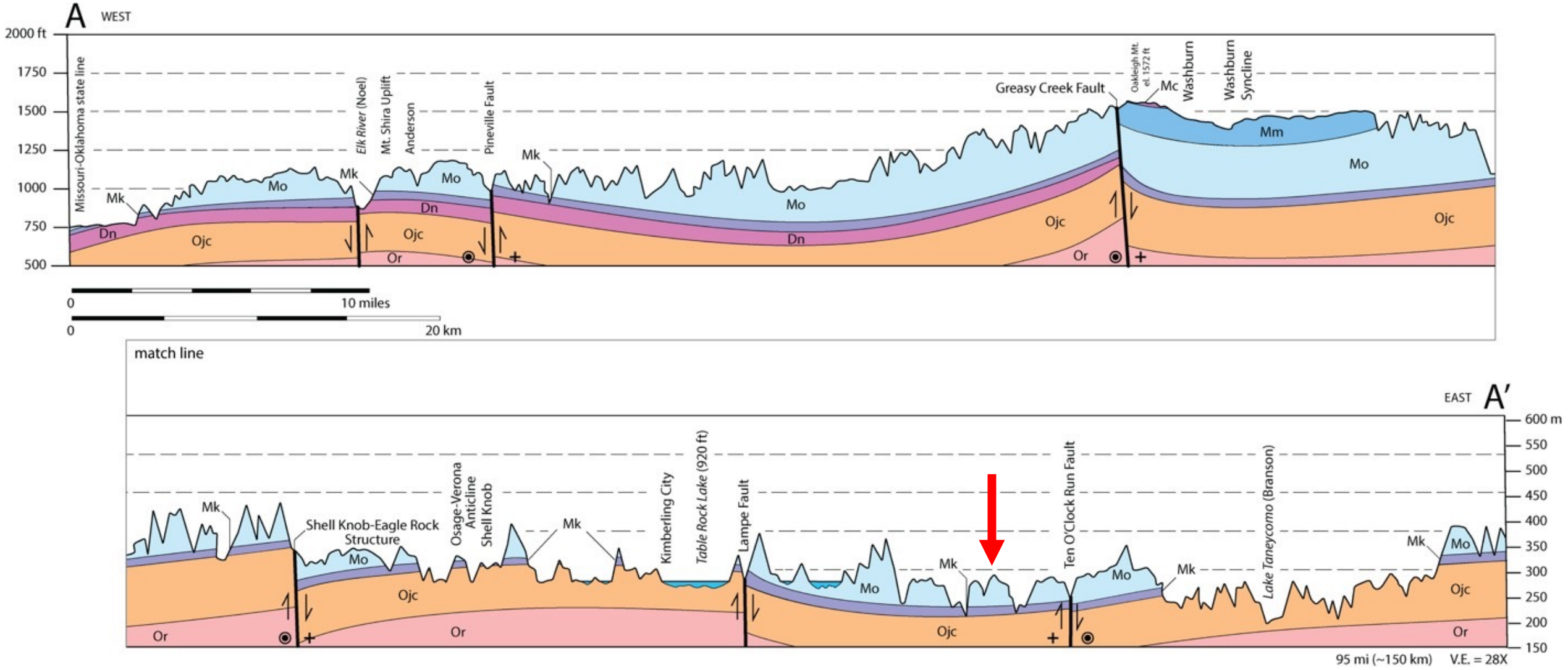
Devonian System
- Noel Shale

Ordovician System
- Jefferson City-Cotter Dol.
- Roubidoux Formation
- Gasconade Dolomite

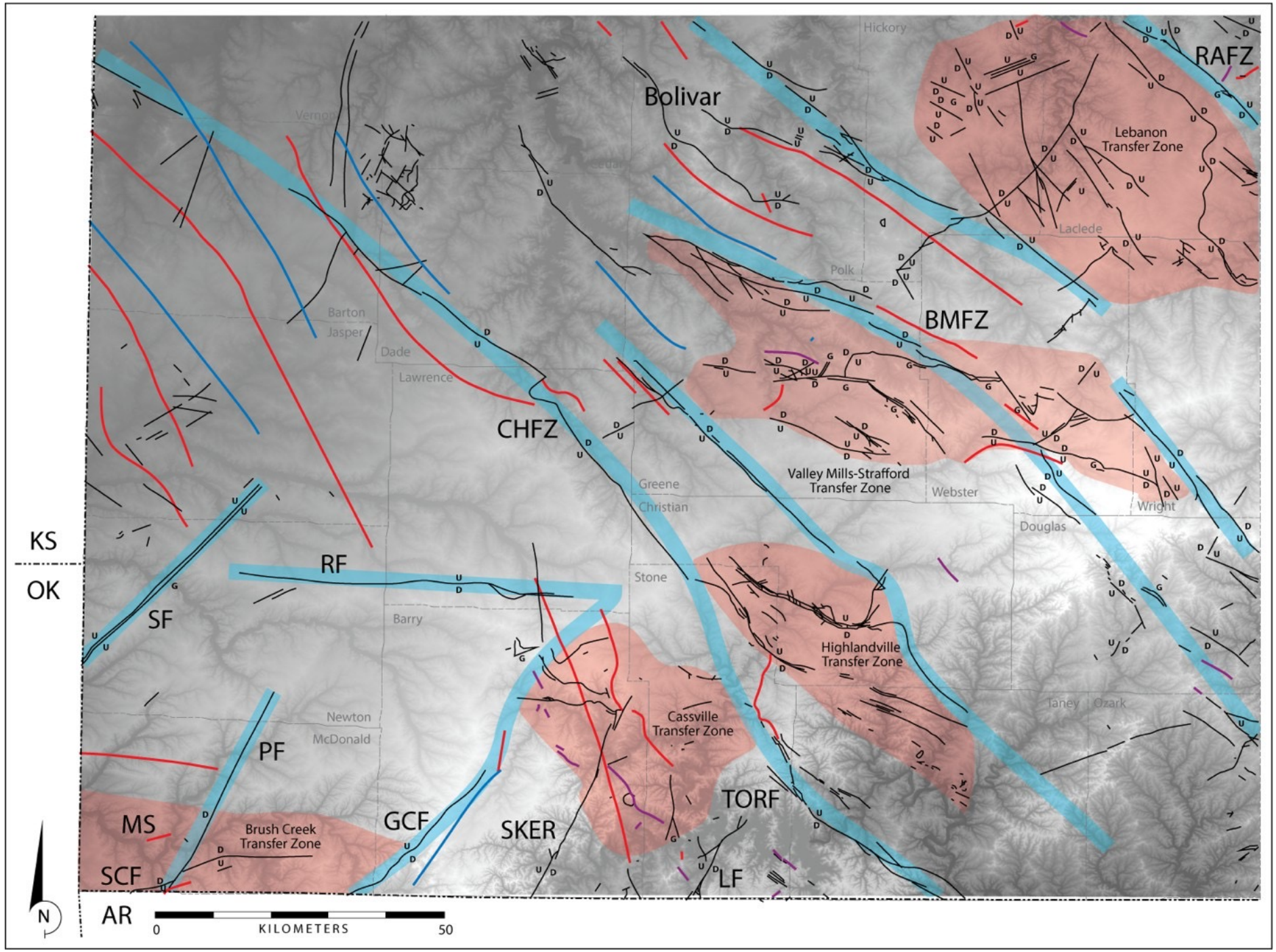
Symbols
- anticline
- syncline
- monocline
- faults; U = up, D = down
- G = graben
- urban areas (pop. > 10,000)

Digital elevation model overlay 25% transparency.

Evans and Bassett (2022)

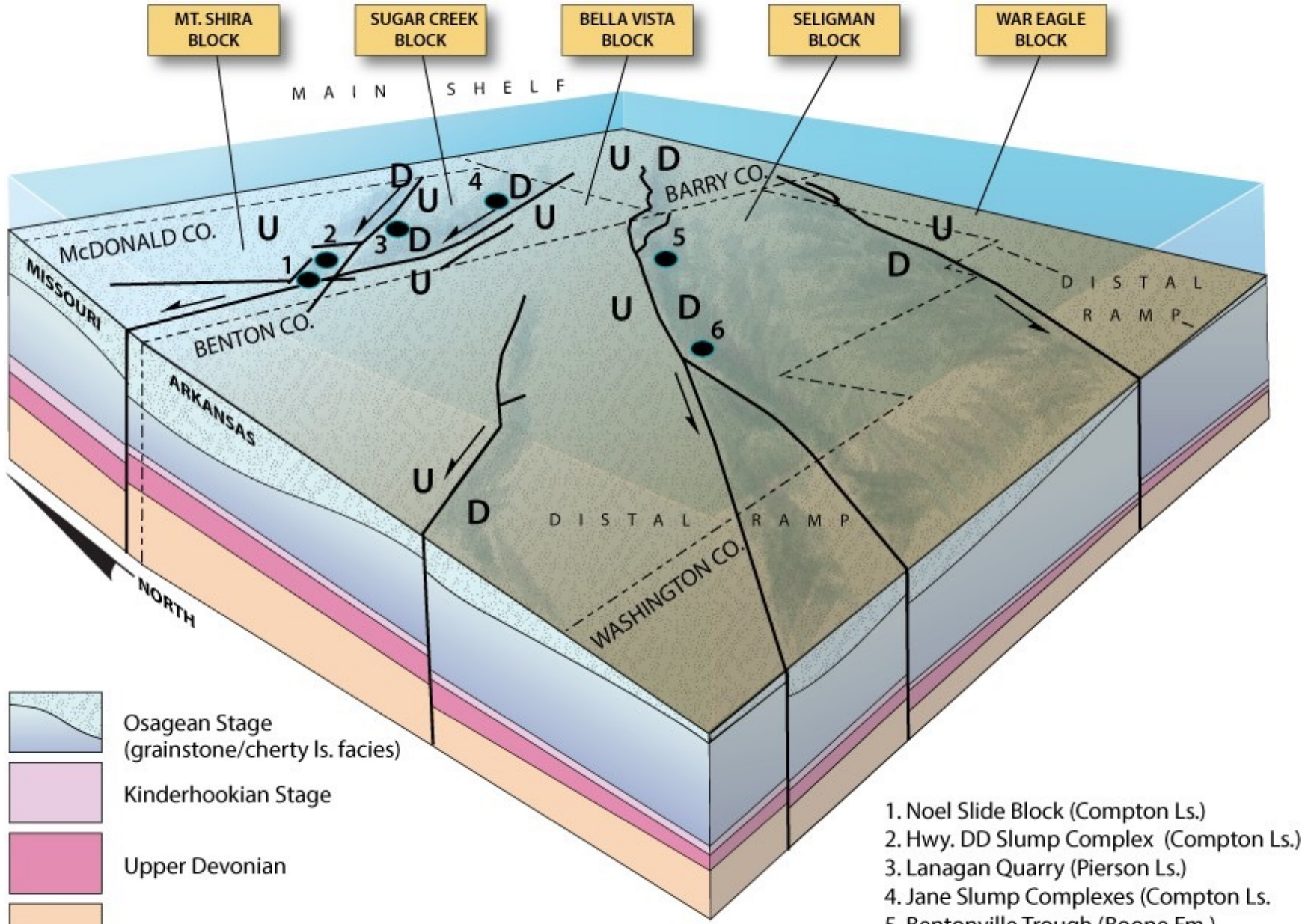


Evans and Bassett (2022)

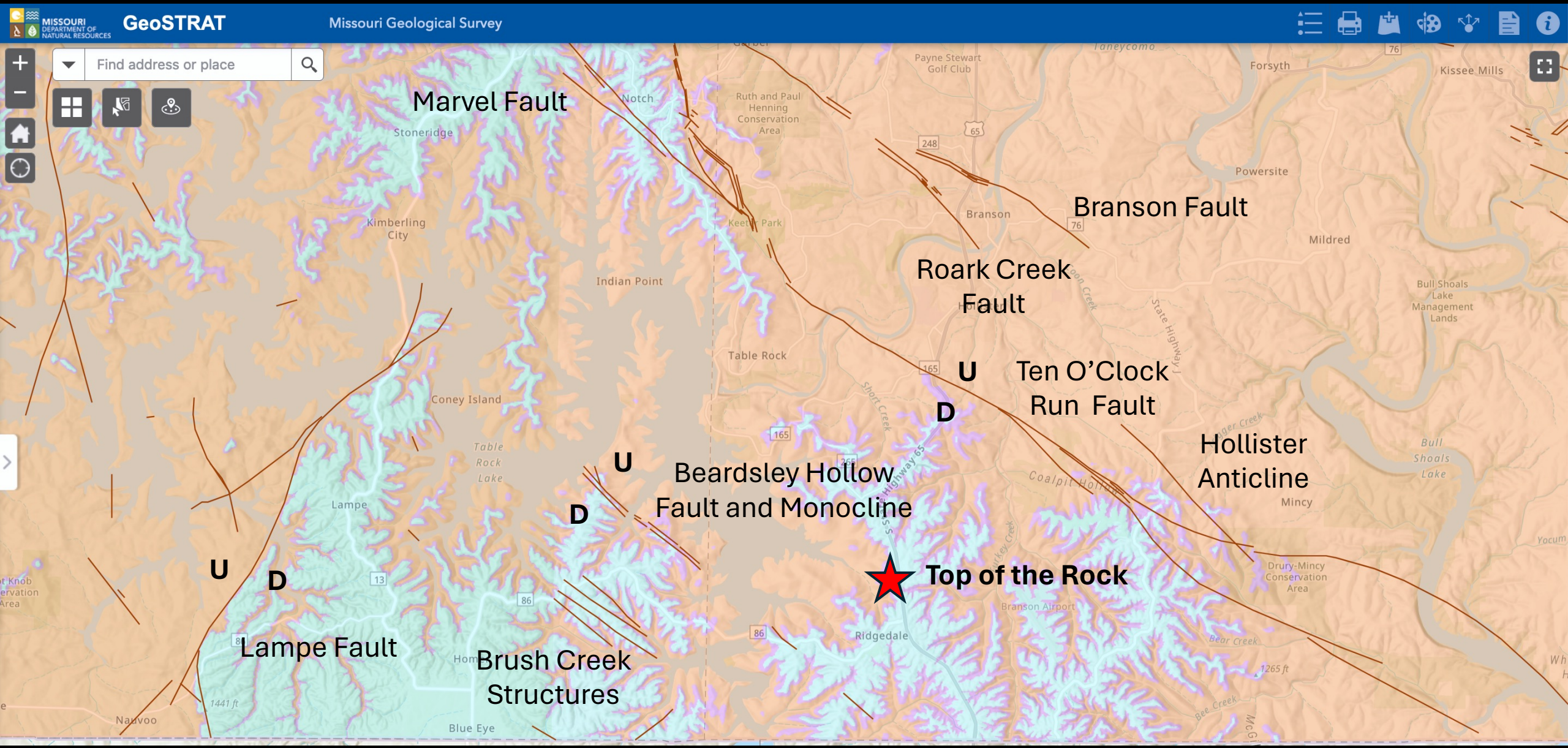


Evans and Bassett (2022)

MISSISSIPPIAN SYNTECTONIC SEDIMENTATION FEATURES



Evans and Bassett (2022)



Wedge (2003) and GeoSTRAT

Plans call for the construction of of a series of greens on the relatively flat surfaces of the bedrock.

ORDOVICIAN SYSTEM

IBEXIAN SERIES

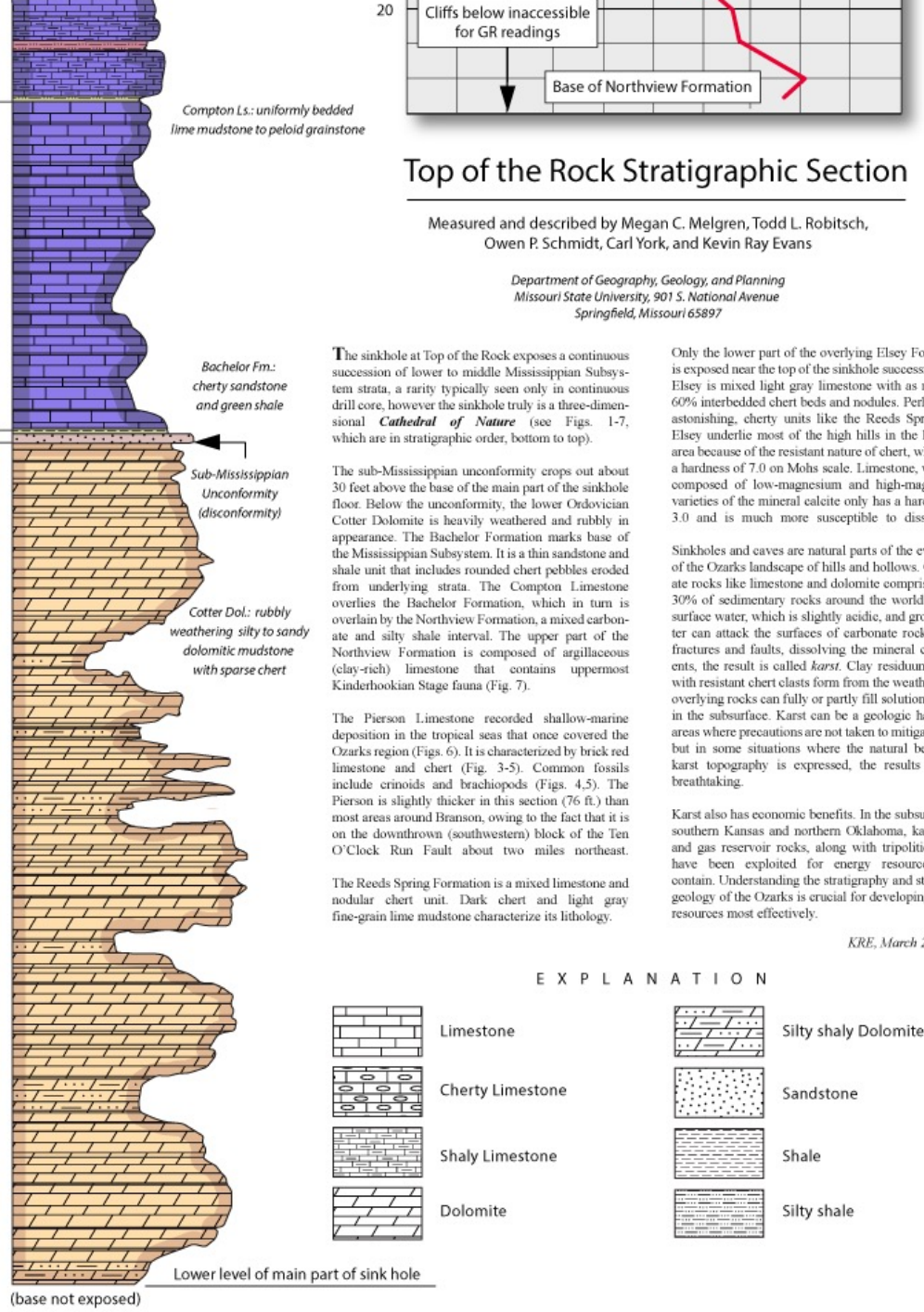
KINDERHOOKIAN STAGE

Cotter Dolomite

Bachelor Formation

Compton Limestone

Northview Formation



Top of the Rock Stratigraphic Section

Measured and described by Megan C. Melgren, Todd L. Robitsch, Owen P. Schmidt, Carl York, and Kevin Ray Evans

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The sinkhole at Top of the Rock exposes a continuous succession of lower to middle Mississippian Subsystem strata, a rarity typically seen only in continuous drill core, however the sinkhole truly is a three-dimensional ***Cathedral of Nature*** (see Figs. 1-7, which are in stratigraphic order, bottom to top).

The sub-Mississippian unconformity crops out about 30 feet above the base of the main part of the sinkhole floor. Below the unconformity, the lower Ordovician Cotter Dolomite is heavily weathered and rubbly in appearance. The Bachelor Formation marks base of the Mississippian Subsystem. It is a thin sandstone and shale unit that includes rounded chert pebbles eroded from underlying strata. The Compton Limestone overlies the Bachelor Formation, which in turn is overlain by the Northview Formation, a mixed carbonate and silty shale interval. The upper part of the Northview Formation is composed of argillaceous (clay-rich) limestone that contains uppermost Kinderhookian Stage fauna (Fig. 7).

The Pierson Limestone recorded shallow-marine deposition in the tropical seas that once covered the Ozarks region (Figs. 6). It is characterized by brick red limestone and chert (Fig. 3-5). Common fossils include crinoids and brachiopods (Figs. 4,5). The Pierson is slightly thicker in this section (76 ft.) than most areas around Branson, owing to the fact that it is on the downthrown (southwestern) block of the Ten O'Clock Run Fault about two miles northeast.

The Reeds Spring Formation is a mixed limestone and nodular chert unit. Dark chert and light gray fine-grain lime mudstone characterize its lithology.

Only the lower part of the overlying Elsey Formation is exposed near the top of the sinkhole succession. The Elsey is mixed light gray limestone with as much as 60% interbedded chert beds and nodules. Perhaps not astonishing, cherty units like the Reeds Spring and Elsey underlie most of the high hills in the Branson area because of the resistant nature of chert, which has a hardness of 7.0 on Mohs scale. Limestone, which is composed of low-magnesium and high-magnesium varieties of the mineral calcite only has a hardness of 3.0 and is much more susceptible to dissolution.

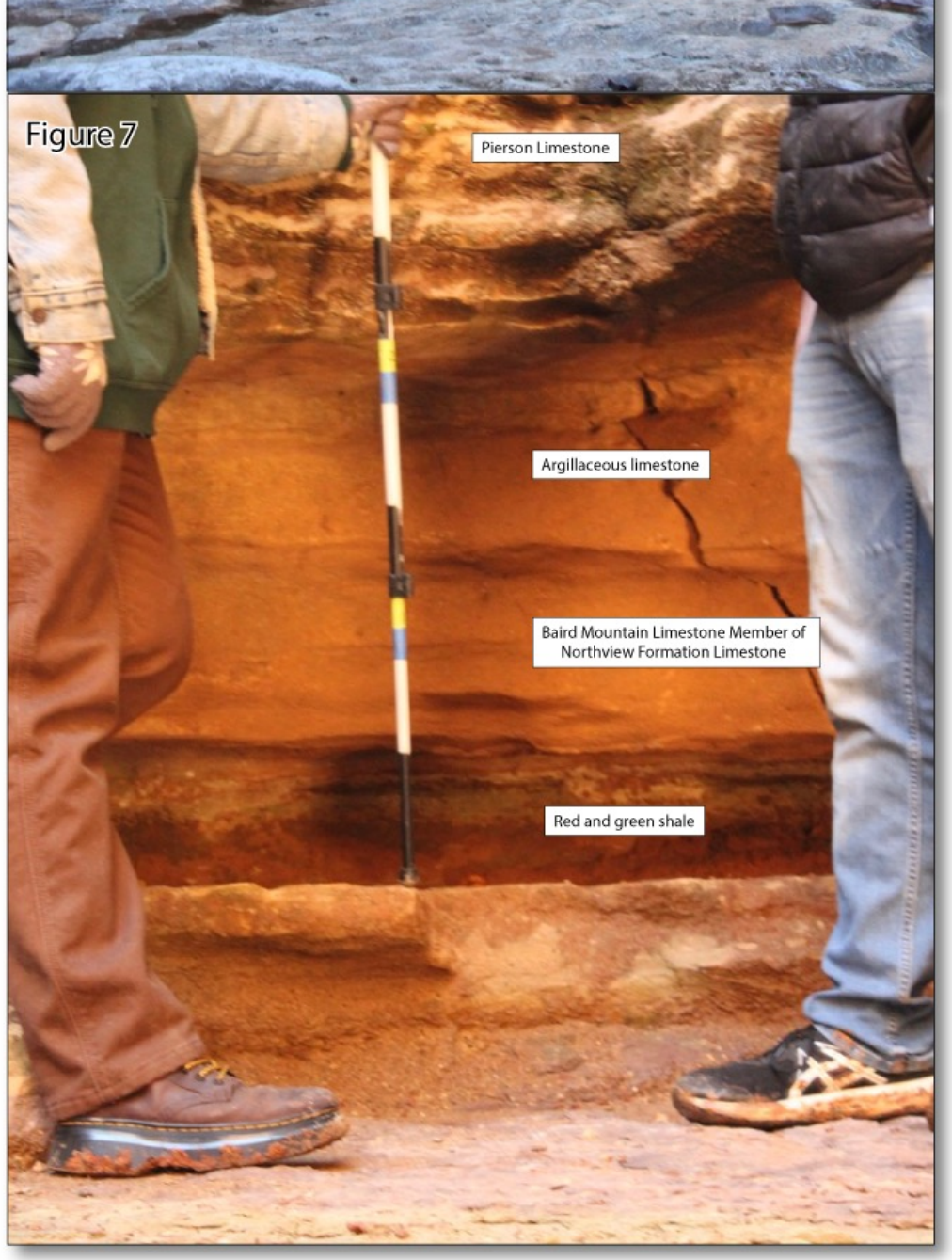
Sinkholes and caves are natural parts of the evolution of the Ozarks landscape of hills and hollows. Carbonate rocks like limestone and dolomite comprise about 30% of sedimentary rocks around the world. Where surface water, which is slightly acidic, and groundwater can attack the surfaces of carbonate rocks along fractures and faults, dissolving the mineral constituents, the result is called *karst*. Clay residuum mixed with resistant chert clasts form from the weathering of overlying rocks can fully or partly fill solutional voids in the subsurface. Karst can be a geologic hazard in areas where precautions are not taken to mitigate risks, but in some situations where the natural beauty of karst topography is expressed, the results can be breathtaking.

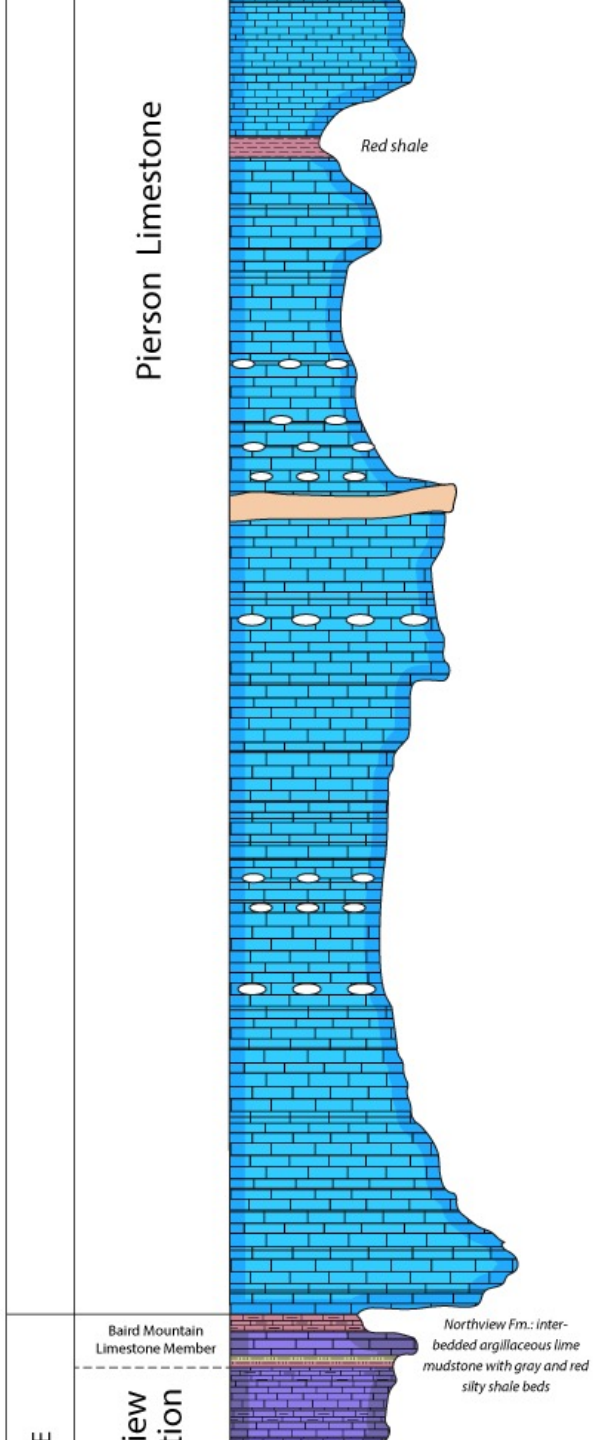
Karst also has economic benefits. In the subsurface of southern Kansas and northern Oklahoma, karstic oil and gas reservoir rocks, along with tripolitic cherts have been exploited for energy resources they contain. Understanding the stratigraphy and structural geology of the Ozarks is crucial for developing those resources most effectively.

KRE, March 21, 2023

EXPLANATION

- Limestone
- Cherty Limestone
- Shaly Limestone
- Dolomite
- Silty shaly Dolomite
- Sandstone
- Shale
- Silty shale




Pierson Limestone
Red shale
Baird Mountain Limestone Member
Northview Fm.: inter-bedded argillaceous lime mudstone with gray and red silty shale beds

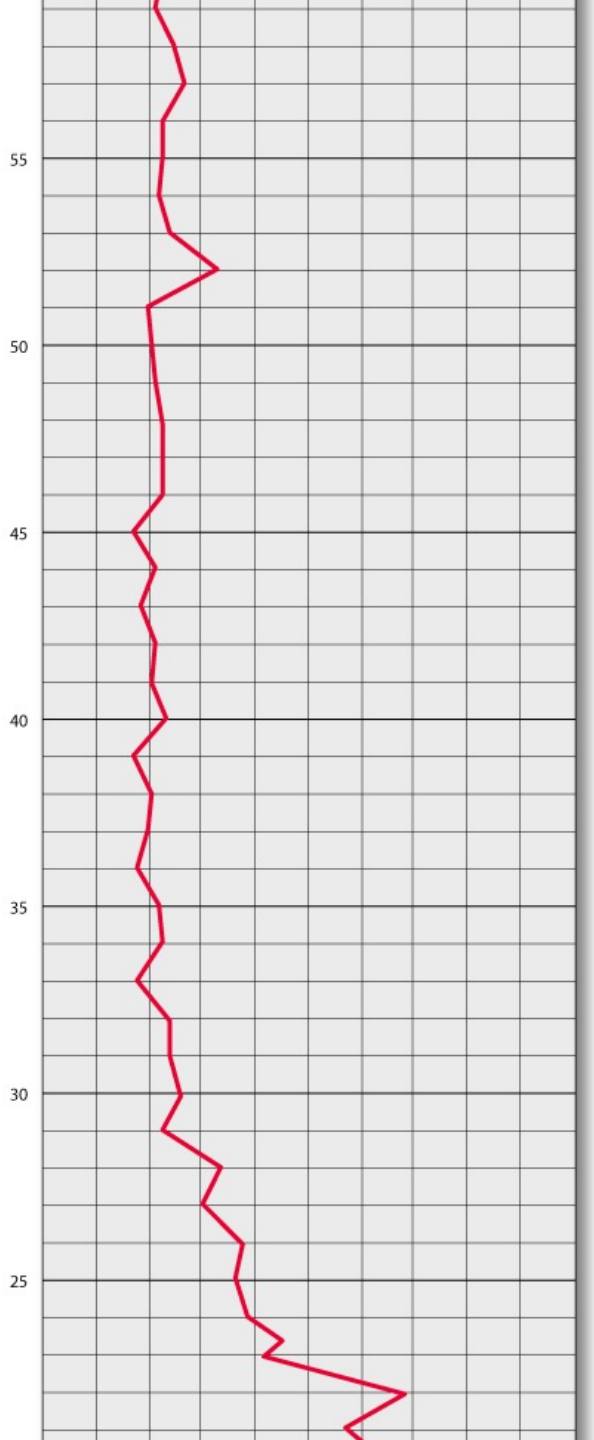

55
50
45
40
35
30
25


Figure 6
Reeds Spring Formation
Pierson Limestone

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SUBSYSTEM

OSAGEAN STAGE

to red and white chert nodules and beds

95

90

85

80

75

70

65

60

Cliffs inaccessible for GR readings

Elsey Formation

Reeds Spring Formation

Reeds Spring Fm.: interbedded lime mudstone with light gray to black chert nodules and beds

140
135
130
125
120
115
110
105

Figure 2

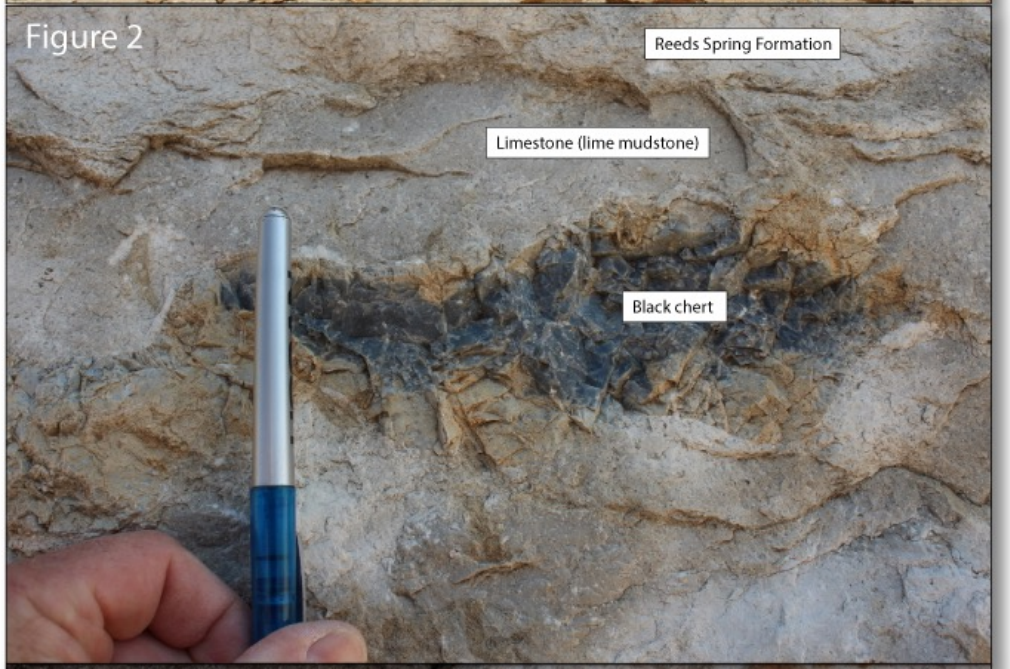
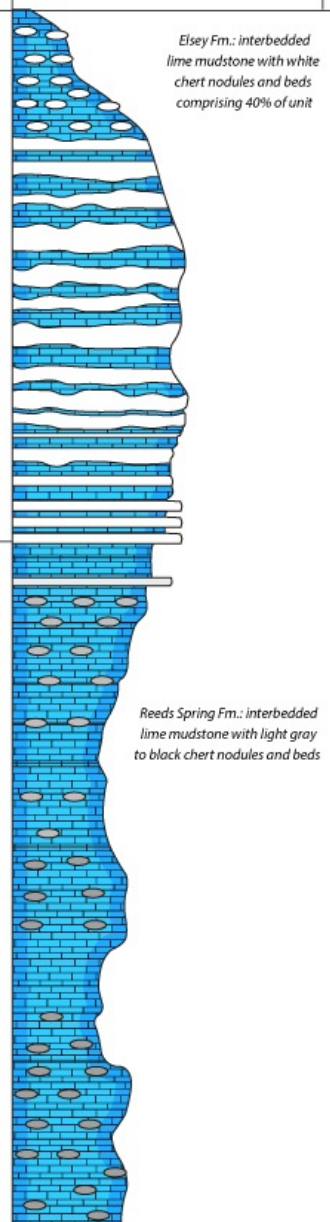
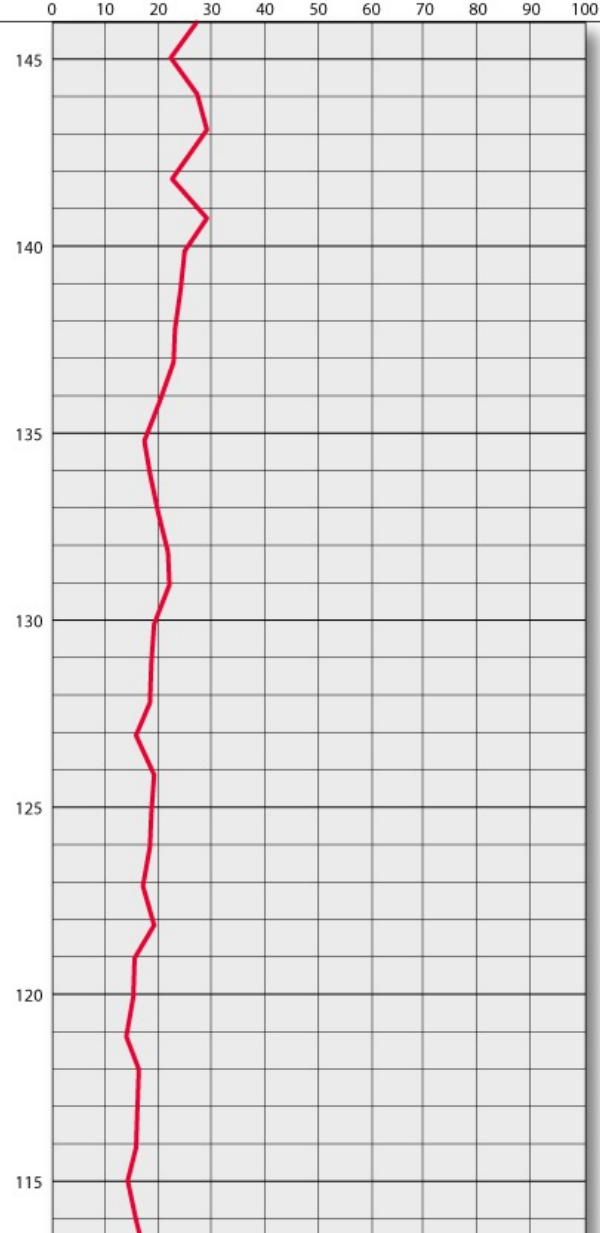


Figure 3

TOP OF THE ROCK

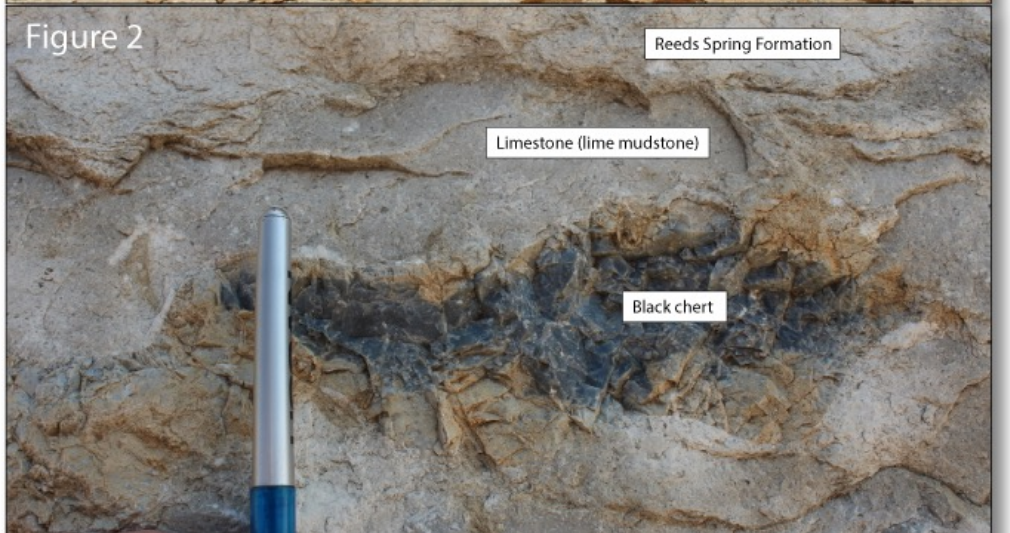
SYSTEM	SUB-SYSTEM	SERIES/ STAGE	FORMATION/ MEMBER	LITHOLOGIC COLUMN	GAMMA-RAY PROFILE (counts/sec.)	IMAGE GALLERY

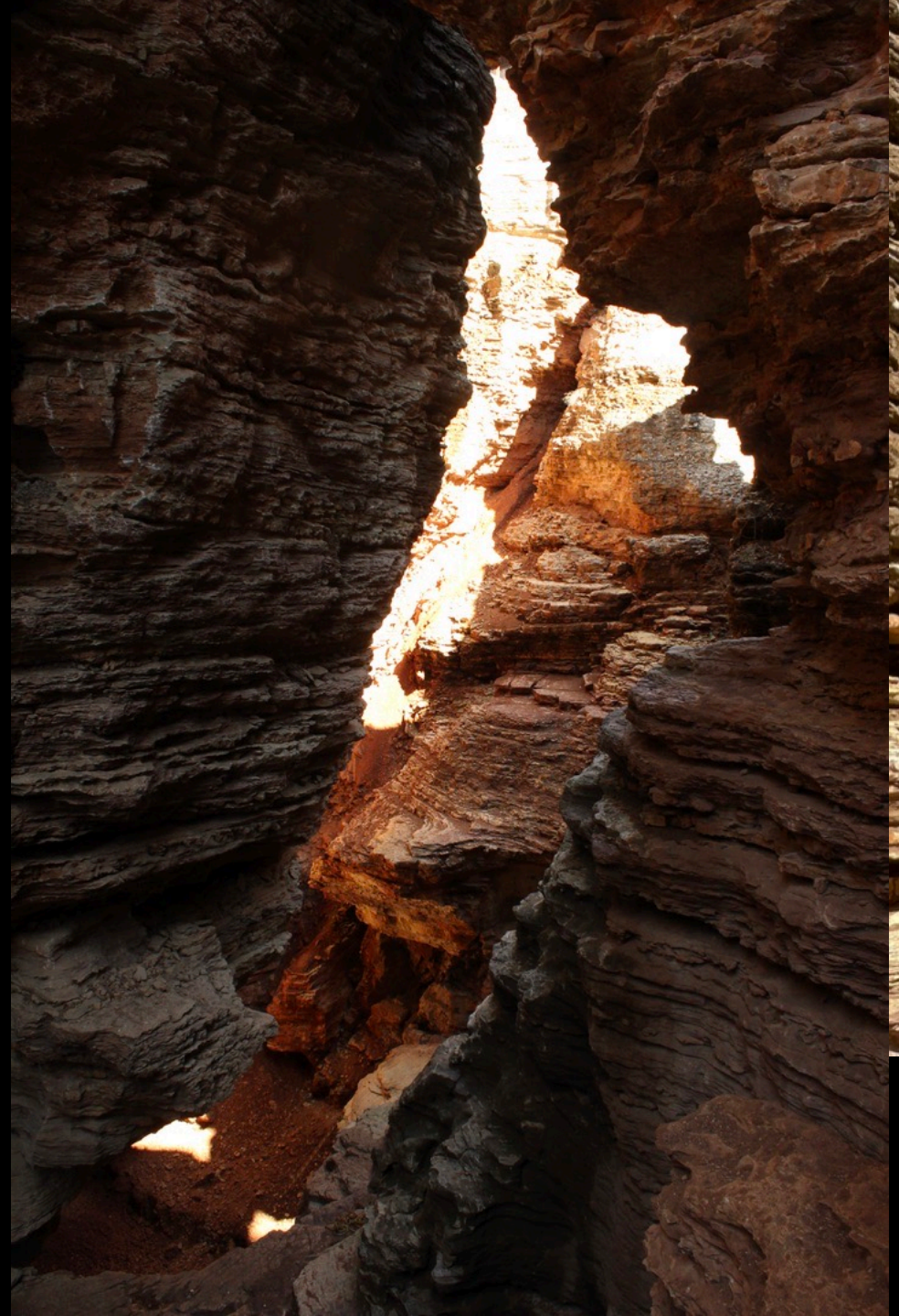




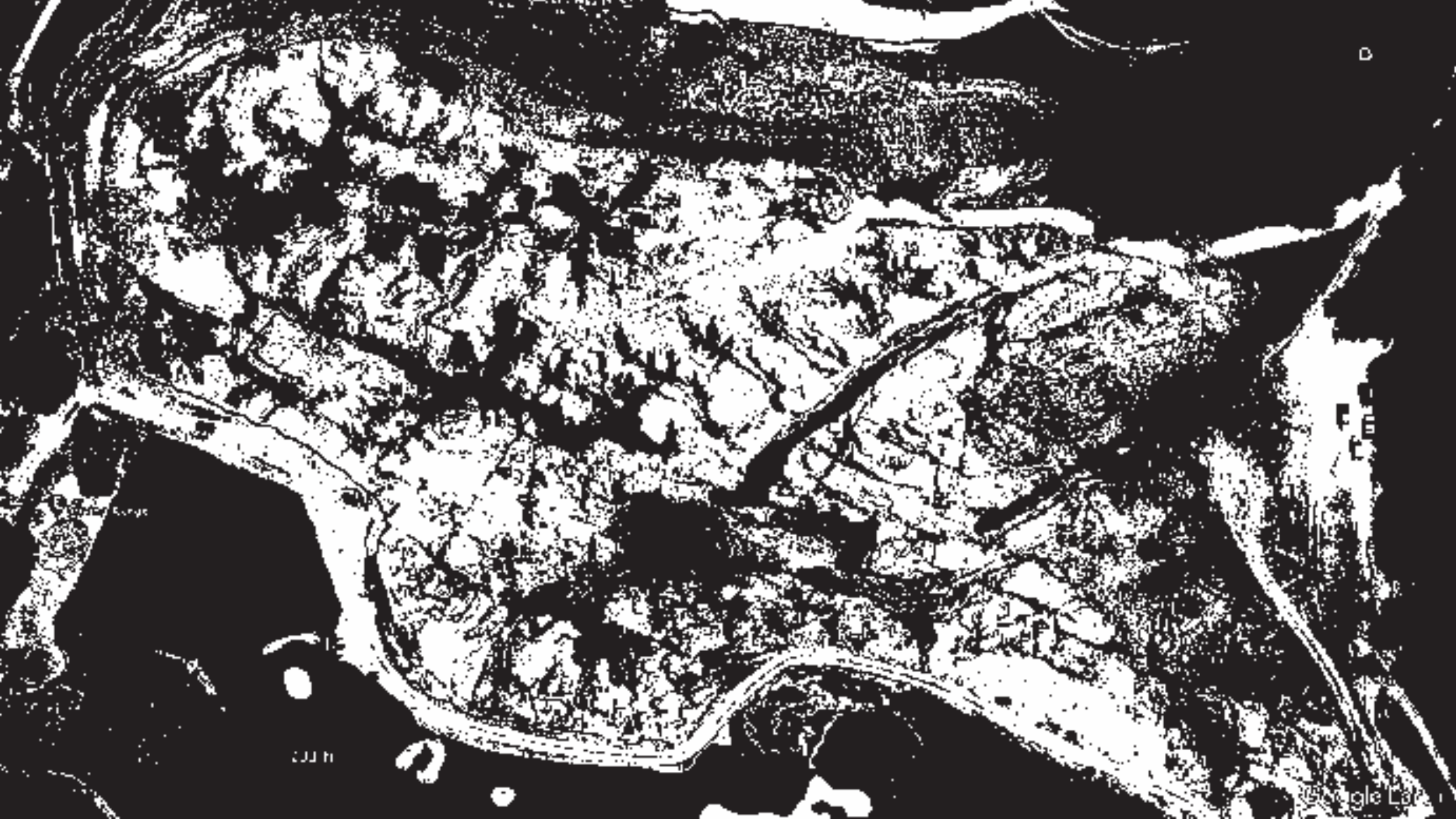
Elsey Formation

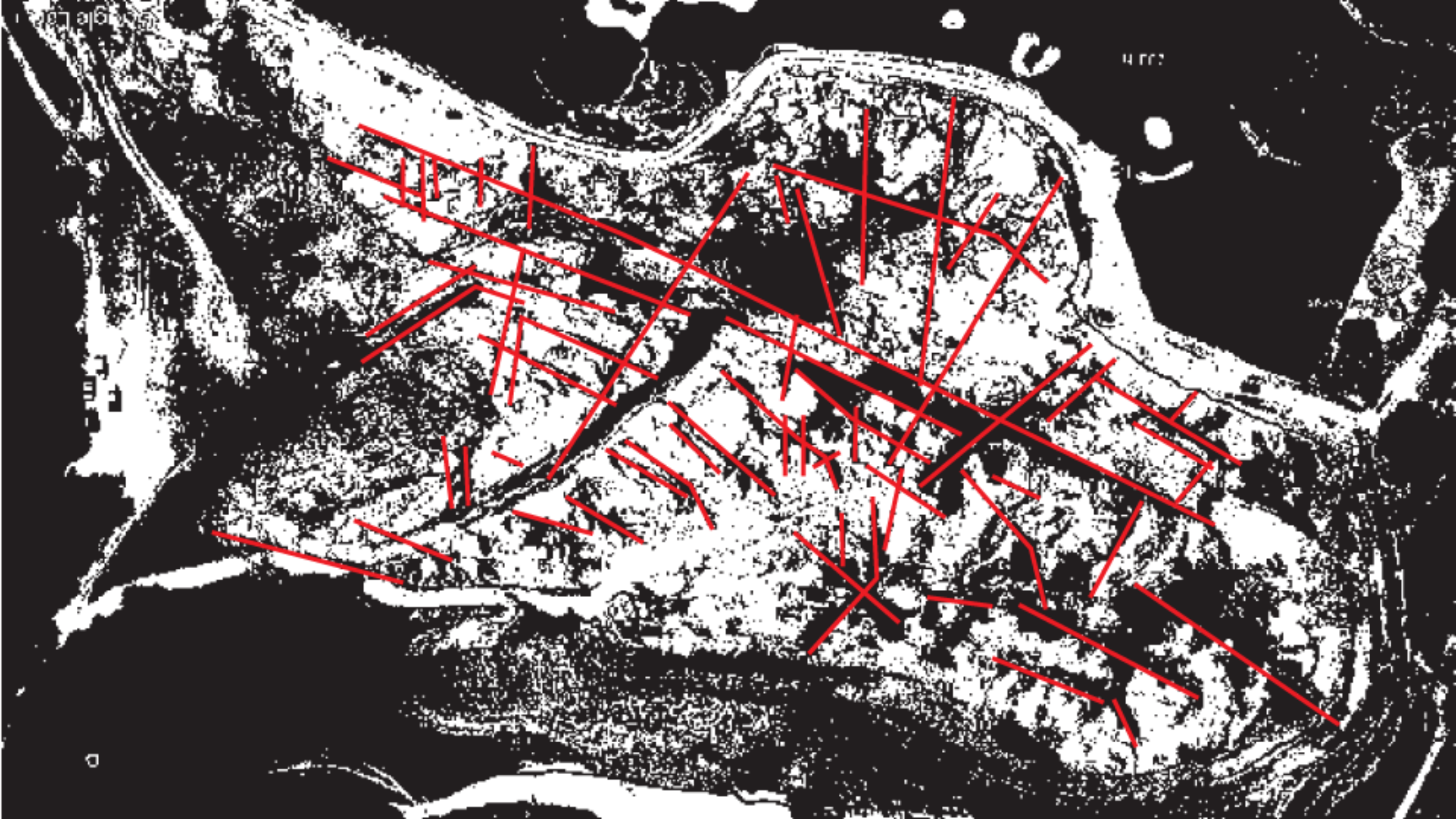
Reeds Spring Formation

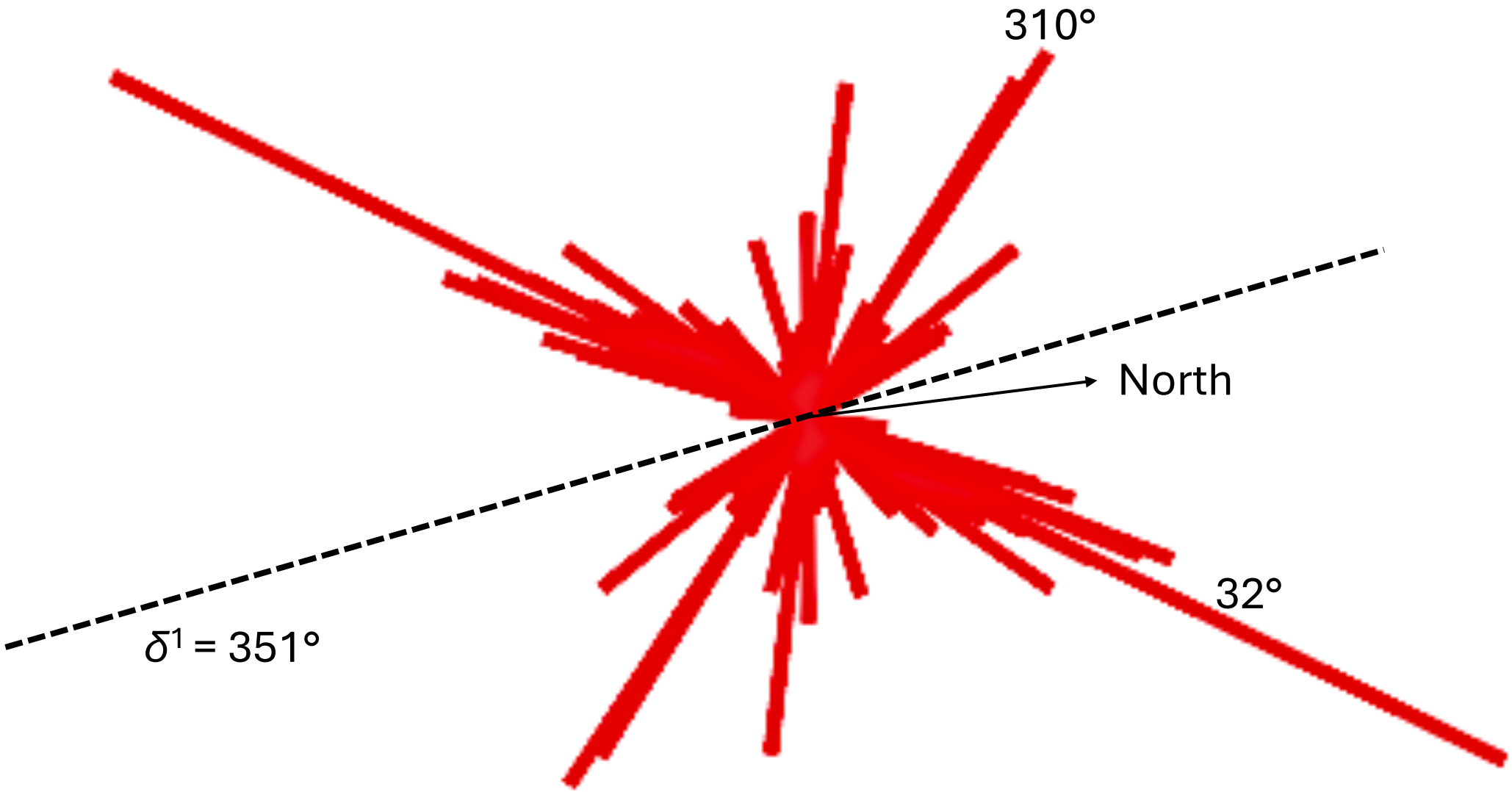





235 ft
Google Earth






310°
North
32°
δ¹ = 351°

SUMMARY

- Ozarks mid-to-late Devonian uplift with culmination in Pennsylvanian
- Intersecting fault systems across Ozarks influenced Mississippian sedimentation with intrashelf basins
- Sinkhole developed in Lower Mississippian strata
- Baird Mountain Limestone Member of Northview Formation present …best stratigraphic section of it!
- Thick section of Pierson Limestone, 22.9 m (76 ft.)
- Fractures trend 32° and 310°, and $\delta^1 = 351°$