

ASSOCIATION OF MISSOURI GEOLOGISTS



66th Annual Meeting and Field Trip,
October 11 – 12, 2019

Eldon, Missouri

Roadside Geology along US Highway 54 around the Lake of the Ozarks

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Introduction

The goal of the field trip is an exploration of the geology and geomorphology along a frequently traveled stretch of highway in mid Missouri: US Highway 54 around the Lake of the Ozarks (Figure 1).

The area of these field stops is located along the northern edge of the Salem Plateau – on of three physiographic provinces comprising the Ozark region. The Ozark Plateau is a fluvio-karst landscape -- deeply incised meanders of a well-connected fluvial system (the Osage River and its tributaries in the area of this field guide) interact with well-developed karst groundwater systems. Upper tributaries of the Osage River may be captured by the karstic systems, with the springs re-emerging at the base level of trunk streams.

The venue for the meeting, Stark Caverns, is an example of this geomorphic/geologic heritage. Formed in the Lower Ordovician Gasconade Formation, it has a storied history up through the Anthropocene, including a brief period as a speakeasy (Figure 2).

General Stratigraphy

The general stratigraphy of the area spans the Cambrian through Ordovician (Figure 2)

Aside from localized outcrops of Middle Cambrian strata related to the Decaturville impact structure (which will be discussed and visited), the oldest outcropping unit in the Lake of the Ozarks region is the Late Cambrian Eminence Formation. The Eminence Dolomite is made up predominantly of dolomitic carbonates with some chert and sandy layers in all but the uppermost part of the formation. In the Ha Ha Tonka area, Schmitz (1984) distinguished a lower and upper member of the Eminence Formation. The lower Eminence Member consists of massive gray dolomite. The upper Proctor Member consists of repeated cycles of massive/thickly bedded dolomite and layered dolomite.

The Gasconade Formation unconformably overlies the Eminence Formation, with a thickness around 330 feet (100 meters) in south-central Missouri (Palmer et al., 2012). The lowermost member of the Gasconade Formation is the Gunter Sandstone, a cross-bedded, quartz sandstone 25 – 33 feet (8 – 10 meters) thick. Above the Gunter Sandstone, the Gasconade Formation is coarsely crystalline dolomite with up to 50% chert by volume – this was labeled the “Van Buren” Member by Schmitz in the Ha Ha Tonka area. The upper Gasconade is predominantly medium-crystalline dolomite along with small amounts of gray chert.

The Roubidoux Formation disconformably lies above the Gasconade Formation. The Roubidoux Formation consists of cyclically bedded dolomite, cherty dolomite, sandy dolomite, dolomitic

sandstone, and sandstone (Overstreet et al., 2003). Compared to the Gasconade Formation, the Roubidoux is much sandier, which Unklesbay & Vineyard (1992) attributed to a source area in the rising Wisconsin Dome. The total thickness of the Roubidoux Formation ranges from 108 – 272 feet (33 – 83 meters). As reported by Thompson (1995), some sandstone units of the Roubidoux Formation are quarried for building stone in central Missouri. The Roubidoux Formation is sparsely fossiliferous in much of its thickness, although locally gastropod mollusks are found.

Jefferson City Dolomite generally does not outcrop until farther east on US Highway 54, just past Eldon, MO. The exception to this are the outcrops around the Decaturville impact structure. The Jefferson City Dolomite is primarily cyclic, light-brown to brown, medium- to fine-grained dolomite. A characteristic lithology found in the lower part of the Jefferson City is a thick- to massive-bedded medium-crystalline dolomite that weathers to a coarse, pitted surface known as “Quarry Ledge”.

Collectively, the Eminence through Jefferson City Formations comprise much of the upper cycle of the Sauk megasequence (Palmer et al., 2012). During the Cambrian and early Ordovician, the region was part of the Great American Carbonate Bank (Derby et al., 2012) (Figure

Tectonic History and Other Deformation

Although minor, punctuated deformation may have occurred in the Ordovician and Devonian, most of the regional deformation in the Paleozoic rocks in the Ozark Plateau is attributed to be co-eval with the Appalachian/Ouachita orogeny in the Late Paleozoic (e.g., Viele, 1989). The Ozark Plateau is located in the foreland of the Paleozoic orogenic belt aligned with a large step in the deformation front. The Ozark Plateau corresponds with one of a series of basement highs that follow the craton margin in the foreland basins of the Appalachian/Ouachita orogeny (Cox, 2009).

A dominant structural trend in the Ozark Plateau is a NW-SE oriented fabric reflected in faults and broad, arch-like folds. In the area of this field trip, the primary structure is the broad Proctor Arch with its hinge passing through the Lake of the Ozarks. Bedrock faults, which involved a combination of normal slip and strike-slip motion, include the Red Arrow, Hurricane Deck, Highway 54, and Highway A faults, among others. Based on cross-cutting relationships of mesoscopic faults around the Ozark Plateau, Cox (2009) inferred 4 episodes of deformation during the Late Paleozoic, which were attributed to the tectonic evolution of the Ouachita orogenic belt.

The present topography of the Ozark dome may also reflect one or more pulses of uplift during the Cenozoic. In particular, McKeown et al. (1988) assessed longitudinal profiles of rivers within

the Ozark region to identify likely indications late Cenozoic uplift based on major knick points and other anomalies from graded river profiles. The authors inferred that in the Salem Plateau, a relatively recent pulse of uplift had occurred for the Ozark dome with possible long-term rates of epeirogenic uplift between 130 and 580 mm per thousand years.

Localized deformation also occurs in the Decaturville structure. As discussed during the field stop, this is generally regarded as a result of an extraterrestrial impact during the Paleozoic.

Final Words

Although distributed among two partial days for this meeting, the field trips could also be combined into a single, full day, as they follow the same general routes of travel.

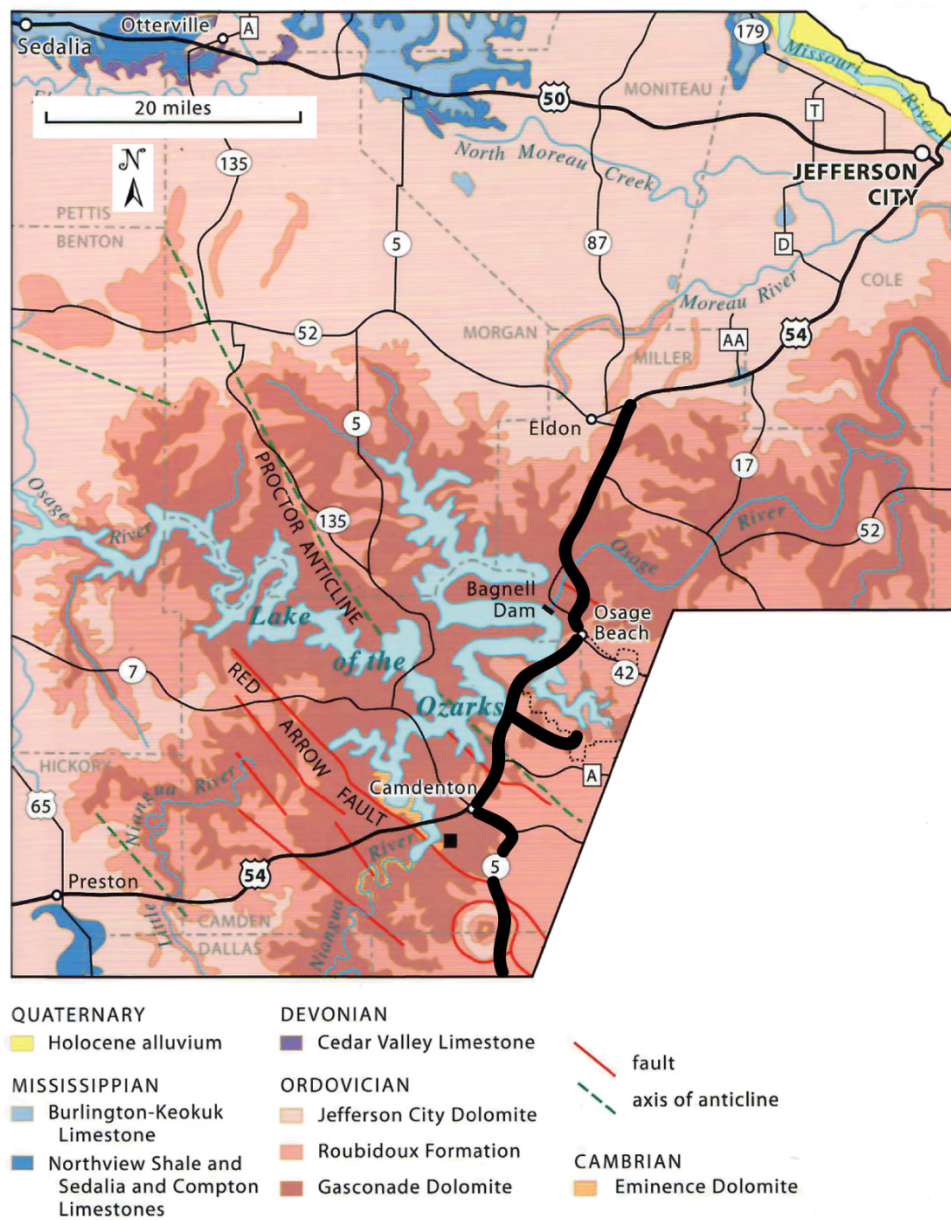


Figure 1. Generalized geology of the field trip area with the general route denoted by the heavy black line. (Modified from Spencer, 2011)

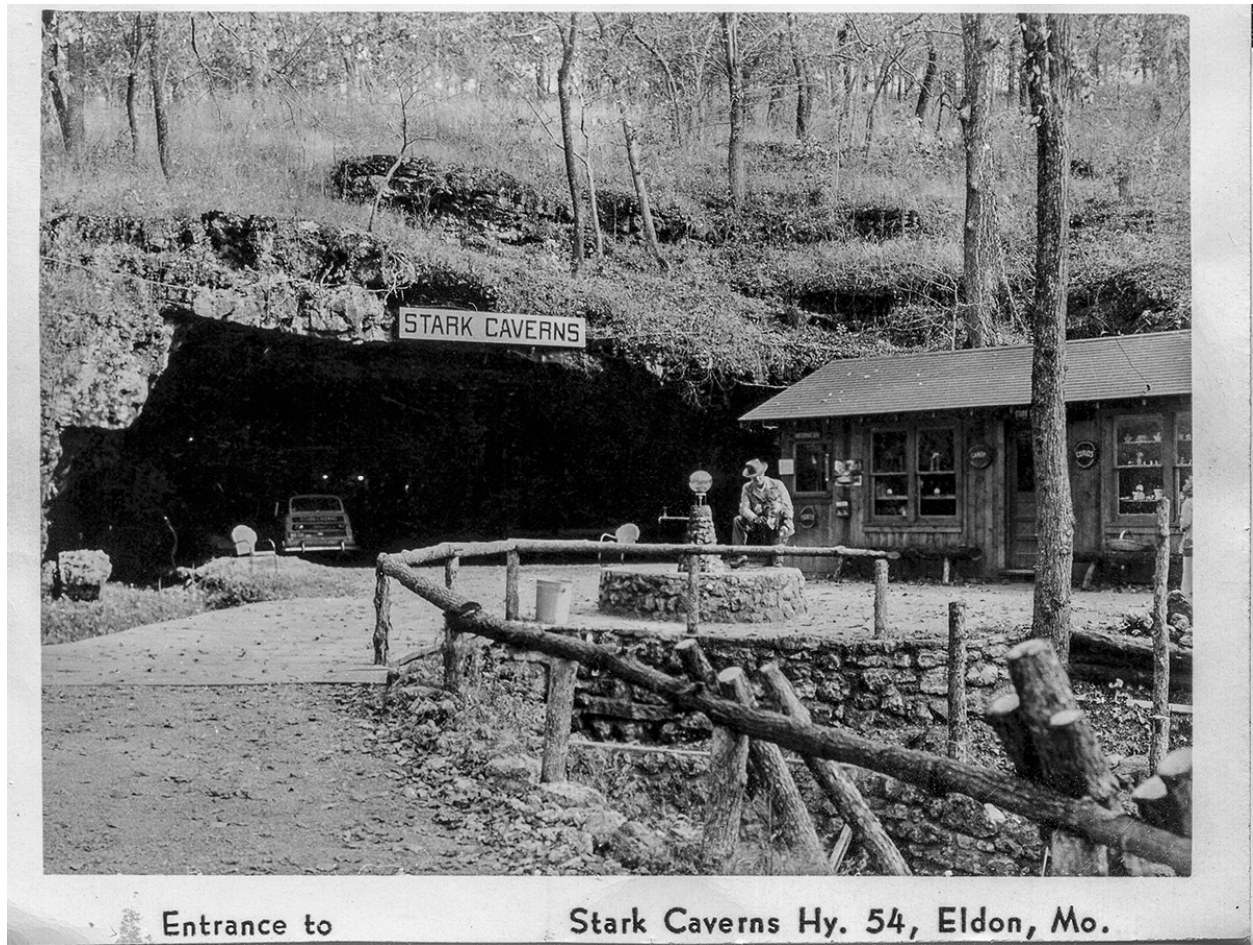


Figure 2. Stark Caverns (courtesy of <https://starkcaverns.com>).

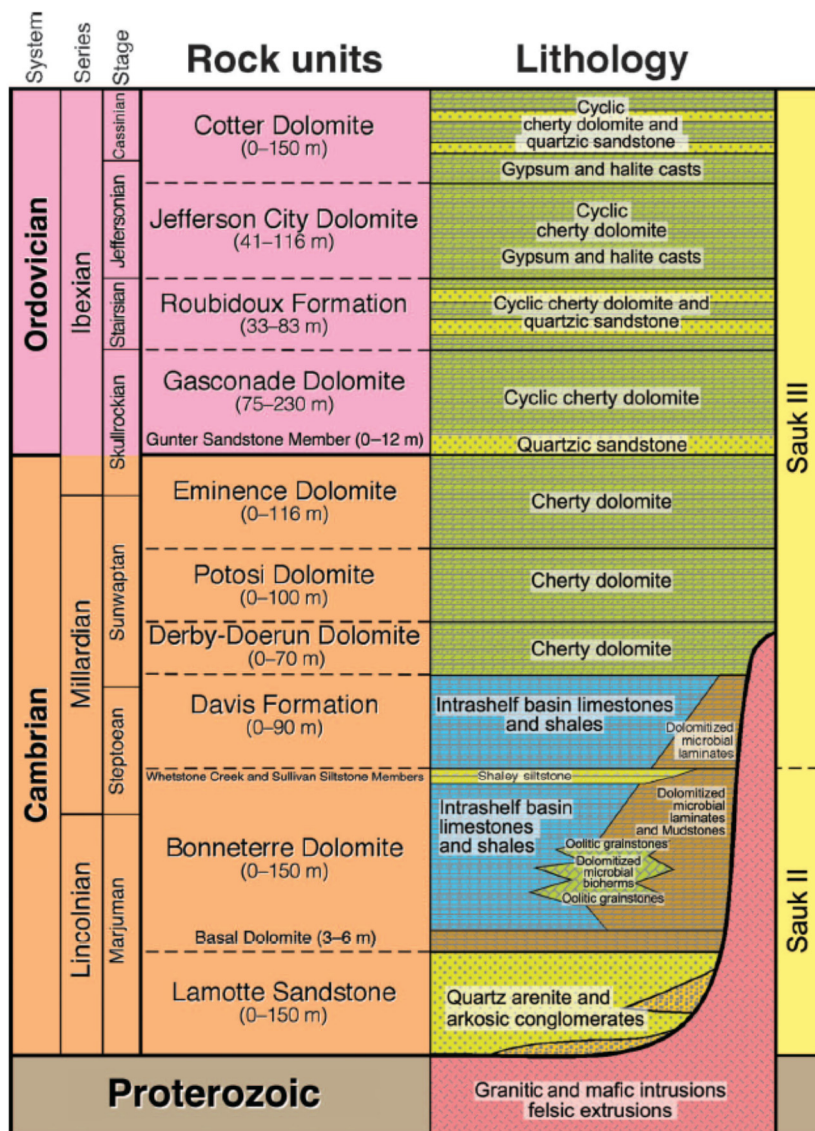


Figure 3. Generalized Cambrian and Ordovician stratigraphy in central and southern Missouri (adapted from Palmer et al., 2012)

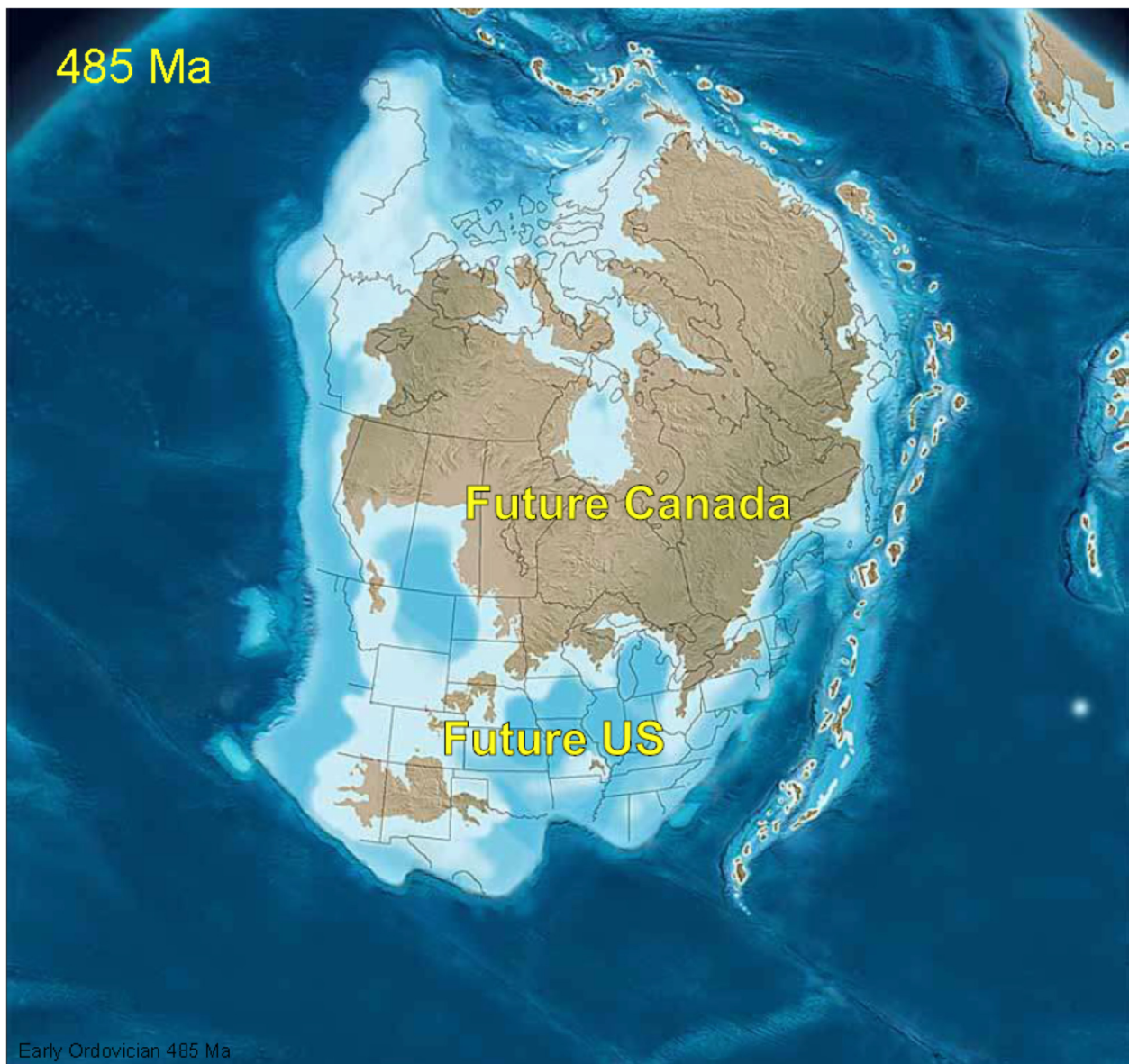


Figure 4. Paleogeographic reconstruction of North American during the Early Ordovician (used with permission from R. Blakey).

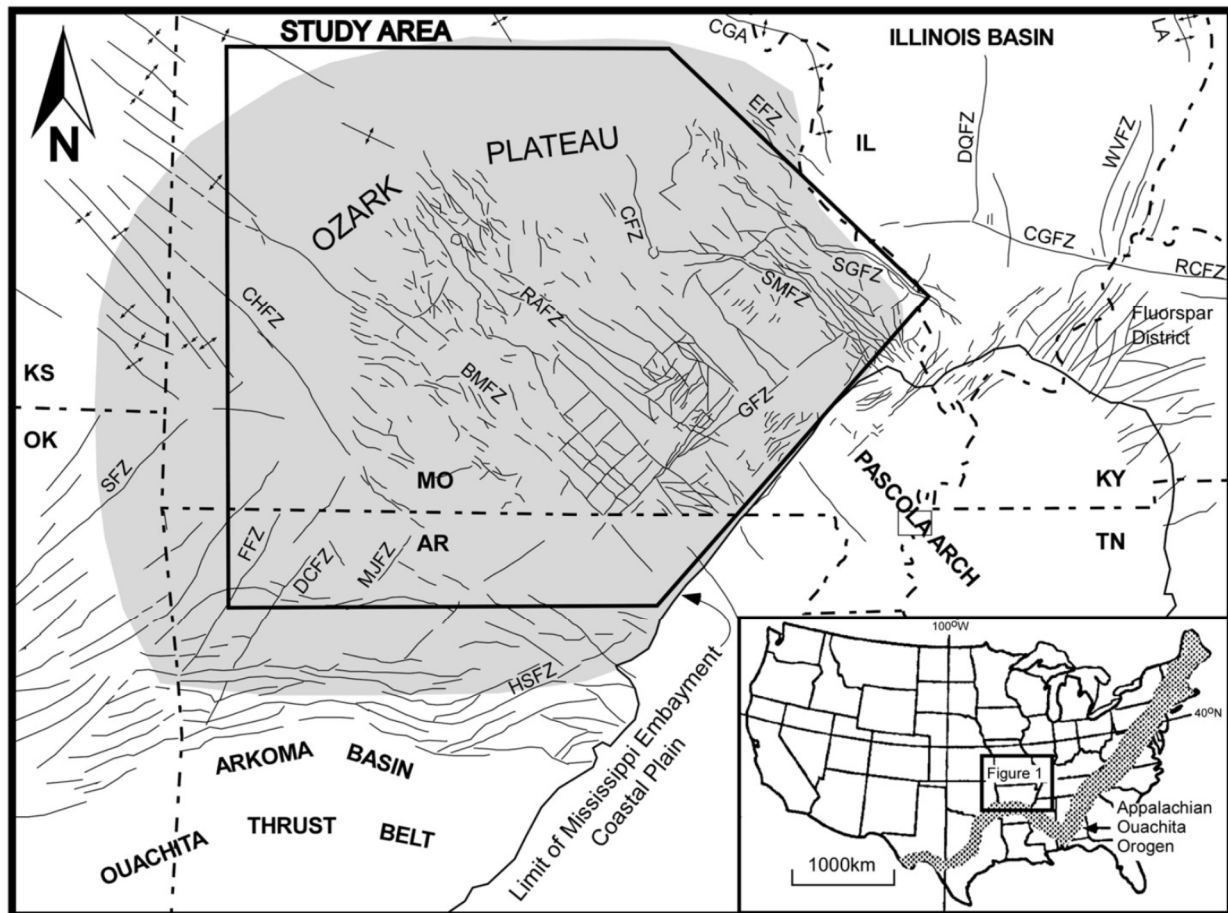


Figure 5. Generalized structural features in the Ozark region and the location relative to the Appalachian/Ouachita orogenic belt (from Cox, 2009).

Field Trip: Day 1

The first day of the field trip will be focusing on deformation of the Paleozoic rocks and the modern heritage of it in terms of the Lake of the Ozarks. The route is shown in Figure 1-1.

Start at the lodging venue: Super 8 Lake of the Ozarks (38.30485N, 92.57528W) at the junction of US Highway 54 and Route 52. (Reset tripmeter.) From the junction, head south on US Highway 54.

Immediately upon entering the highway, across to the east side (next to the overpass), you will see an outcrop of Roubidoux Formation. US Highway 54 will be oscillating about the contact between the Gasconade and Roubidoux Formations as we drive south.

Other geologic features along the route include:

At **4.0 miles**, large road cuts of thick-bedded Gasconade Formation will appear on both sides of the highway. Although deformation within the outcrop is not visible as we pass by, numerous micro faults are present and were some of the data collected by Cox (2009) in his fault kinematic study.

At **7.1 miles**, in the Gasconade Formation, there is a filled sink structure on the east side of the road. (Figure 1-2)

At **12.2 miles**, a large road cut near Osage Beach contains the contact between more massive Gasconade Formation and the disconformably overlying Roubidoux Formation. (Figure 1-3)

At **22.6 miles**, on the west side of the highway, moderately dipping beds of the Gasconade Formation are visible. Compared to most deformation, these are relatively steep. The location is very near the trace of the Hurricane Deck Fault, as well as the core of the Proctor Anticline.

At **24.2 miles**, on the west side of Highway 54, a broad, open fold in the Gasconade Formation is visible. This low amplitude fold is more typical of the minor deformation within the Proctor Anticline.

At **25.9 miles**, **exit US Highway 54** to head south on Highway 5

At **34.4 miles** (8.5 miles from Highway 54), **turn left** (heading east) on Mt. Horeb Rd. toward Decaturville.

Drive 500 ft, and turn right on Old South 5 (the old Highway 5) -- head south.

At **36.2 miles** (1.7 miles from Decaturville), the road ends (a hard right turn puts you back on MO Highway 5). Stop here ... out of the way.

Stop 1: Decaturville Structure: Road cut (37.88237N, 92.70251W)

At this stop, we will examine locally intense deformation associated with the Decaturville structure, a circular structure with an uplifted center and synclinal annulus. *Exercise caution at the road cut, as the outcrop is quite fractured and weak.*

The Decaturville structure is a 5.5 km diameter feature. Although initially thought to be a crypto-volcanic feature, it is now generally regarded to be an impact structure. Evidence for impact origin includes planar deformation features in quartz and shatter cones. Severe deformation, brecciation, and other features provide additional support for the impact origin. The feature was extensively studied in the 1970s (Offield & Pohn, 1979) using a combination of field mapping and drilling. More recent studies have assessed structural relations and timing (e.g., Evans et al., 2009).

On the east side of MO Hwy 5, there is a lengthy (~300 meter) road cut exposing Middle Ordovician Jefferson City Dolomite that has been intensely folded and faulted. This outcrop is located within the outer, synclinal trough that encircles the uplifted core. At the north end of the road cut, coherent, but steeply dipping beds are observed. Toward the south end of the road cut, a massive, polymict breccia may be observed that contains clasts of Cambrian and Ordovician strata (e.g., Elmore & Dulin, 2007).

The Decaturville structure occurs in Paleozoic sedimentary rocks (Figure 1-4), and blocks of Middle Ordovician strata have been reported in its core, placing a minimum age on the timing (Offield & Pohn, 1979). Additionally, crystalline Precambrian basement is observed at the core of the impact feature that correspond in age and composition with similar igneous rocks found in St. Francis Mountains. A cross section is shown in Figure 1-5.

A more recent constraint on the timing of the Decaturville structure was provided by paleomagnetic work (Elmore and Dulin, 2007). The polymict breccia at this stop was analyzed by Elmore & Dulin (2007) using paleomagnetic methods in an effort to constrain the timing of its formation (see below). The paleomagnetic data show that the breccia at Decaturville contains a post brecciation chemical remnant magnetization that is consistent with a mid-

Permian age. This provides an upper constraint on the timing. A maximum age constraint of early Pennsylvanian was determined by crosscutting relations. (Paleomagnetic analysis by the same authors of the Weaubleau structure constrained that event to be no younger than the late Mississippian.)

Offield and Pohn (1979) determined that the strata are displaced upward by at least 300 m in the core and depressed approximately 100 meters in the outer syncline.

There are a number of factors relating the size of the astrobleme to the resulting crater, but an estimate of the size can be inferred using empirical relationships (e.g., Hughes, 2003). Considering the crater is approximately 5 km in diameter, the probably size of the impactor is likely in the range of 300 – 600 meters.

Head north on Highway 5, back toward Decaturville (but do not exit for Decaturville).

After 38.4 miles (2.2 miles from the last stop) on the east side of Highway 5 ...

Stop 1-1a (37.91361N, 92.70516W) (or at least drive slowly)

At this location, a massive polymict breccia is observed in the road cut (Figure 1-6). Class within the breccia are derived from the Davis formation, the Potosi dolomite, and the Roubidoux and Gasconade formations. This was an outcrop sampled by Elmore and Dulin (2007).

Continue on Highway 5 back to Camdenton

At 46.1 miles (7.7 miles from Stop 1-1a), exit Highway 5 onto US Highway 54 East/North.

At 48.2 miles (2.1 miles from the Highway 5 – US 54 junction), turn right onto Rte 54-68 (Business Park Road) toward US Post Office.

At 48.4 miles (after 0.2 mile), continuing past “Lower Business Park Rd.”, turn right (head east) on “Business Park Road”.

At 49.5 miles (1.1 miles from the turn), turn left and climb the road to the Capital Quarries parking lot & office.

Stop 1-2: Capital Quarries / Hurricane Deck fault (38.03224N, 92.68692W)

At this stop, we will examine locally faulting in the Lower Ordovician Gasconade Formation. This is an outcrop of the Hurricane Deck Fault (Figure 1-7), one of many NW-SE striking faults that trace through the area. These are associated with the Proctor Anticline, a NW-SE trending fold that runs through the Lake of the Ozarks region. This is also a good exposure of the lower Gasconade Formation, which is dominated by thickly bedded dolomite. (We will see more of the stratigraphy tomorrow.)

The exposure is found in a non-operational Quarry, currently owned by Capital Materials. If you visit this area outside of this field trip, please make sure to check in at the front office – they are very helpful and accommodating to geology classes! The upper Gasconade Formation is mostly chert-free, massive to thickly-bedded, gray dolomite with a vuggy and coarse crystalline texture. The rock is quarried here primarily for asphalt. This is one of 9 plants operated by Capital Materials in central Missouri. The active quarry and asphalt plant is located down the hill to the south of this non-operational quarry.

The Hurricane fault, which is located very near the hinge of the Proctor Anticline, is characteristic of the other large faults in the area. Faults within the proctor anticline typically trend oblique to the fold hinge. This geometry is typical of wrench faulting, and slip surfaces observed within this outcrop show oblique slip with a dominant component of slip in the horizontal direction.

Using brittle structures (fault surfaces and joints), Cox (2009) identified two phases of deformation documented in structures around the Lake of the Ozarks (Figure 1-8). The earlier event involved a vertical maximum principal deviatoric stress (σ_1); these likely corresponded with the initial warping of the Proctor anticline and brittle bending-moment faults. The second episode involved an E-W principal deviatoric stress (σ_1) with more of a strike-slip tectonic regime. This may reflect a later reactivation of the original faults as wrench-faulting matured.

Return from the parking lot to Rte 54-68, turn right (head west).

At 50.7 miles (1.2 miles from the quarry), turn right (north) on US Highway 54.

At 54.8 miles (4.1 miles from the last turn), turn right and enter parking lot for “Crown Dental”.

Stop 1-2a: Highway A fault outcrop (38.05432N, 92.69868W)

This brief stop allows a view of another exposure of a fault within the core of the Proctor Anticline – this is the Highway A fault (Figure 1-9). The outcrop is the uppermost part of the Gasconade Formation – Roubidoux Formation is mapped on the hill tops nearby. This outcrop is also on private property owned by Crown Dental. They are very accommodating for geologists, as well.

The faults here are expressed as eroded, gullies containing brecciated clasts in a red clay-rich matrix. From the beds, one can see modest amounts of throw (decimeters). Kinematic indicators are not clear in this outcrop without, perhaps, some excavation. As with the Hurricane Deck Fault, this likely has a significant component of strike-slip associated with it.

Return to US Highway 54; turn right (head north/east), driving through Osage Beach.

At 67.5 miles (12.7 miles from the last stop) turn left on “River Rd.”.

At 68.5 miles (1.0 miles along River Road), we arrive at the “Bagnell Dam Historic Site” at the base of the dam. Time permitting, we can make a quick stop to appreciate the height of the dam.

Turn around, and head up “Union Electric Rd.” – i.e., veer left and DO NOT follow River Rd. back to US Highway 54.

At 69.4 miles (0.9 miles from the base), turn into the “Bagnell Dam Overlook” parking lot.

Stop 1-3: Lake of the Ozarks / Bagnell Dam Overlook (38.20614N, 92.62100W)

The Bagnell Dam (also occasionally referred to as the “Osage Dam”) was constructed in 1931 across the Osage River for hydroelectric power (Figure 1-10). The height of the dam is 45 meters, impounding an area of 220 km² to create the Lake of the Ozarks. The power plant has eight generators and a maximum capacity of 215 megawatts. The Bagnell Dam is a concrete arch structure that required more than 500,000 cubic yards of concrete. Construction, part of the Civilian Conservation Corps effort, was completed in less than 2 years. The dam is 775 meters long, including a 160 meter long spillway and a 156 meter long power station.

The Lake of the Ozarks fills the incised meanders of the Osage River into the northern edge of the Salem Plateau. In addition to the main trunk river, the valleys of three major tributaries were also filled, to create the Niangua, Grand Glaize, and Gravois arms of the lake.

In general, construction of dams disrupts the pre-existing hydrologic balance in terms of channel morphology, sediment load, and flow regime. The post-construction adjustments of tributaries downstream from the Bagnell Dam was studied by Germanoski & Ritter (1988). In the case of the Bagnell Dam, discharge pre- and post-dam has remained relatively constant (Figure 1-11). However, the dam sequesters more than 90% of the sediment load, thus releasing a sediment-starved water downstream. The response of the streams is typically a widening of the main trunk channel that results in a lowering of base level reflected in the trunk stream (the Osage River) – the cross sectional area stays the same, but the width increases, so the depth must decrease. Adjustments of tributaries in alluvial materials can be rapid.

Germanoski & Ritter (1988) examined knickpoints in tributaries within 17 km of the dam. The timing of incision was constrained by dendrochronology for trees with roots now exposed laterally across the channel – the idea being that the roots grew when they were below the surface.

This work can be expanded upon using newly released LiDAR data for Camden County (Figure 1-12). For the selected tributary, the lowest knickpoint is observed 180 – 200 meters upstream from the mouth (Figure 1-13). This is comparable to the incision reported by Germanoski & Ritter (1988) for similarly sized catchments of other nearby tributaries. The upper knickpoint in the figure may reflect a base level change associated with longer-term meandering of the Osage River.

Return to Union Electric Rd. from the overlook parking area, turn left (head north).

At 69.8 (0.4 miles from the overlook) turn right onto Bagnell Dam Blvd (heading north). (Note: Heading left takes you across the dam ... but no time for that, today.)

At 70.1 (another 0.3 miles) turn left (north/east) on US Highway 54. Turn left (head north) on US Highway 54.

Around 77.6 miles (another 7.5 miles from the last intersection), **Return** to Super 8 Lake of the Ozarks (38.30485N, 92.57528W) at the junction of Highway 54 and Route 52.

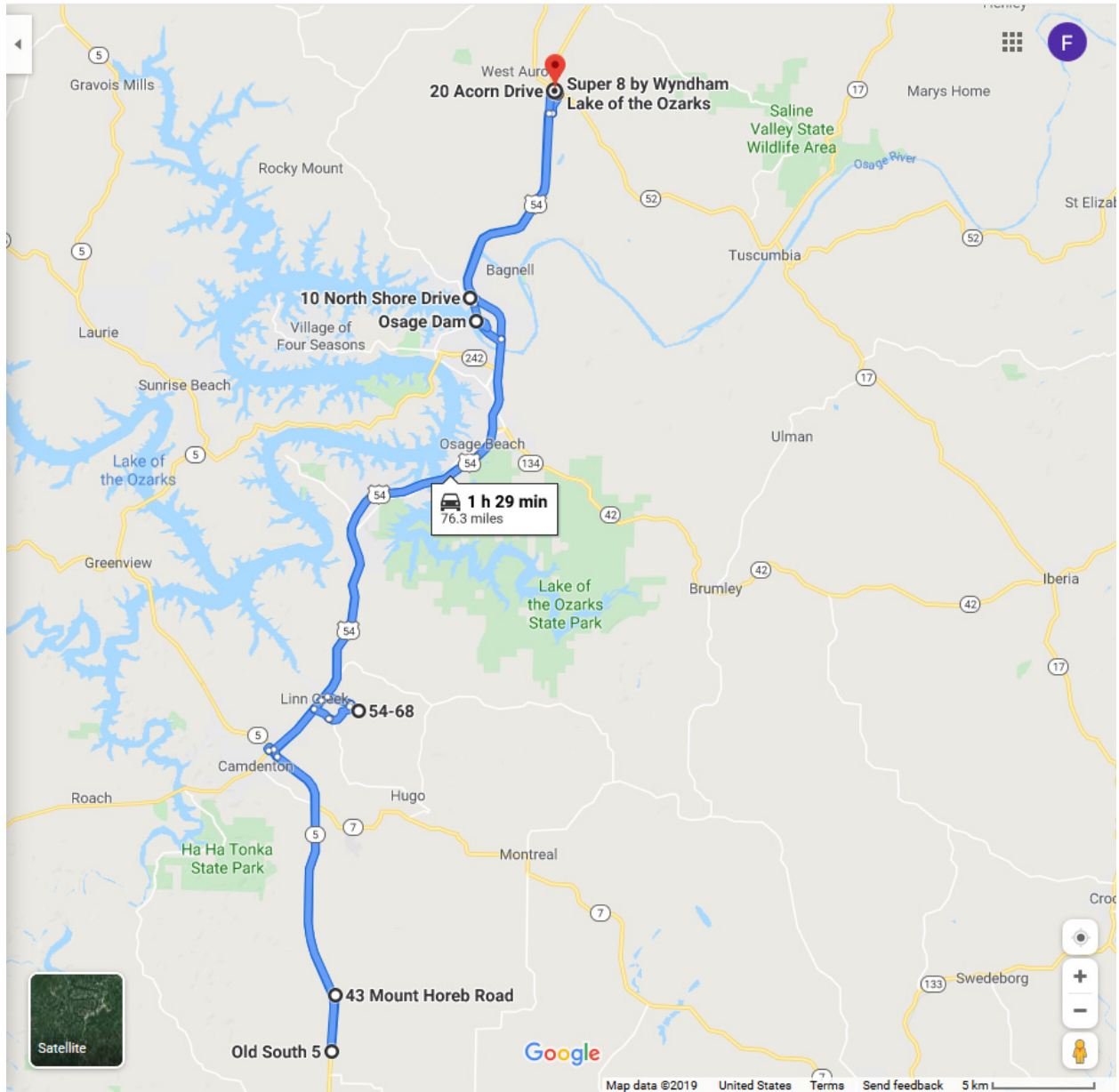


Figure 1-1. The route for Day 1.



Figure 1-2. A filled sink along Highway 54 (Facing East).



Figure 1-3. Roadcut with the Gasconade (G) and Roubidoux (R) Formations (Facing East).

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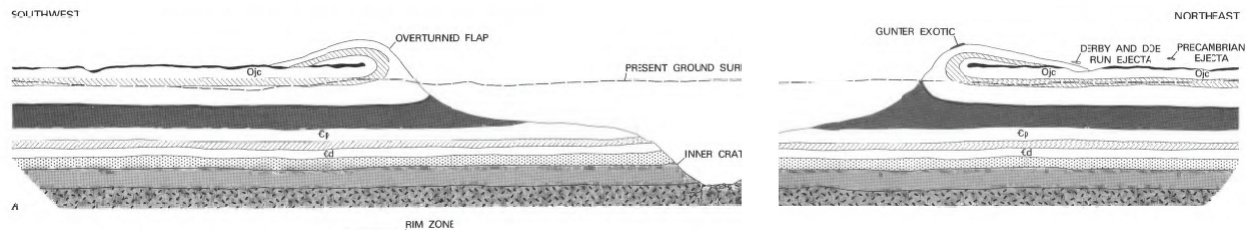


Figure 1-5. Cross section across of the Decaturville structure (Offield & Pohn, 1979).



Figure 1-6. Photo of polymict breccia along Highway 5 (Facing east).



Figure 1-7. Photo of the Hurricane Deck fault (two splays) exposed in a quarry near Linn Creek. (Facing NW) (F = fault)

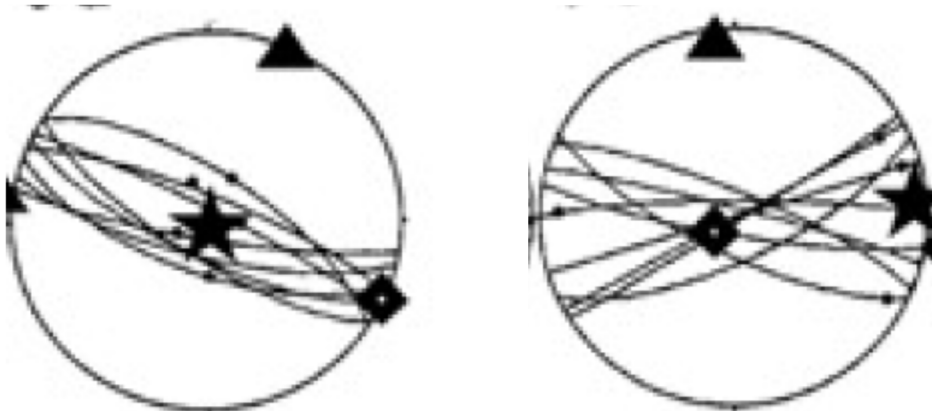


Figure 1-8. Stereonets illustrating fault kinematic results from Cox (2009) for the Lake of the Ozarks region. Star = Sigma-1. Left is the earlier event involving normal faulting. Right is the later stage involving strike-slip reactivation.



Figure 1-9. Photo of the Highway A fault (F) corresponding with a clay gouge zone.

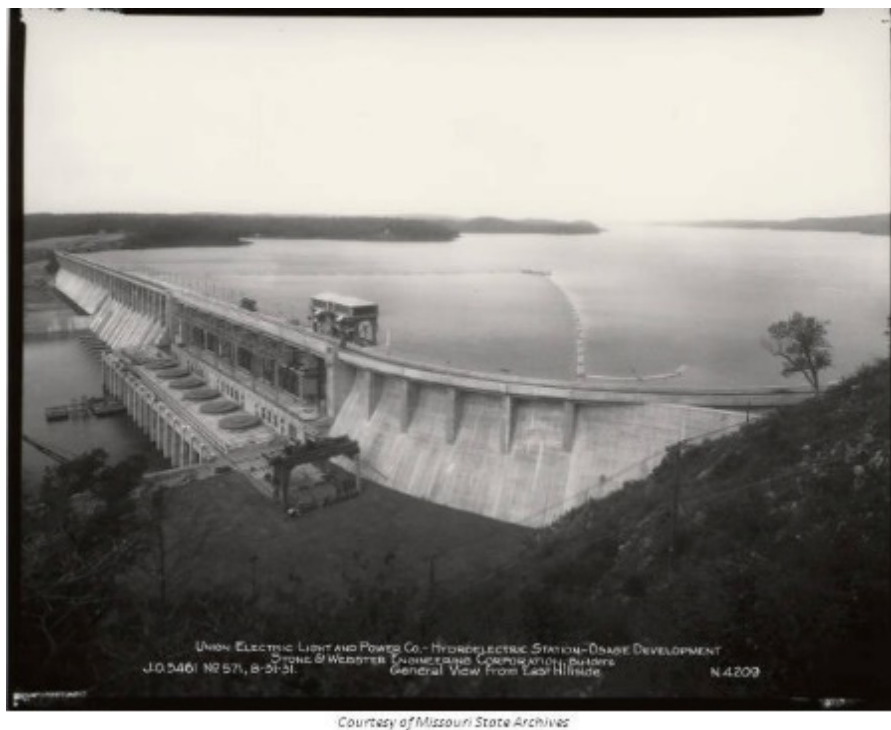


Figure 1-10. Photo of the Bagnell Dam during construction.

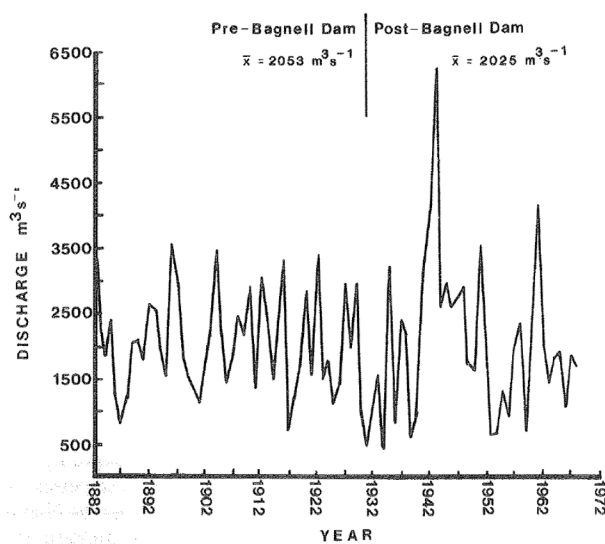


Figure 1-10. Discharge of the Osage River at Bagnell before and after construction of the Bagnell Dam (from Germanoski & Ritter, 1988).

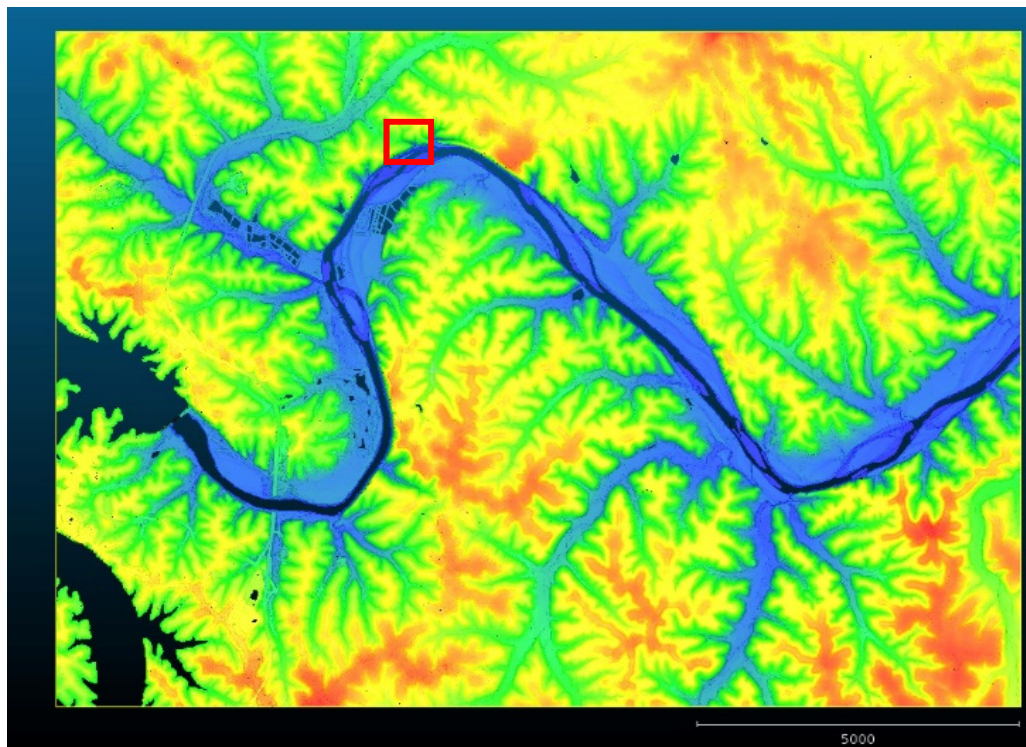


Figure 1-11. Bare-earth LiDAR image (color represents elevation) for the area downstream of the Bagnell Dam. The scale bar is 5000 meters. Red box encompasses the stream profile in Figure 1-12. North is at the top.

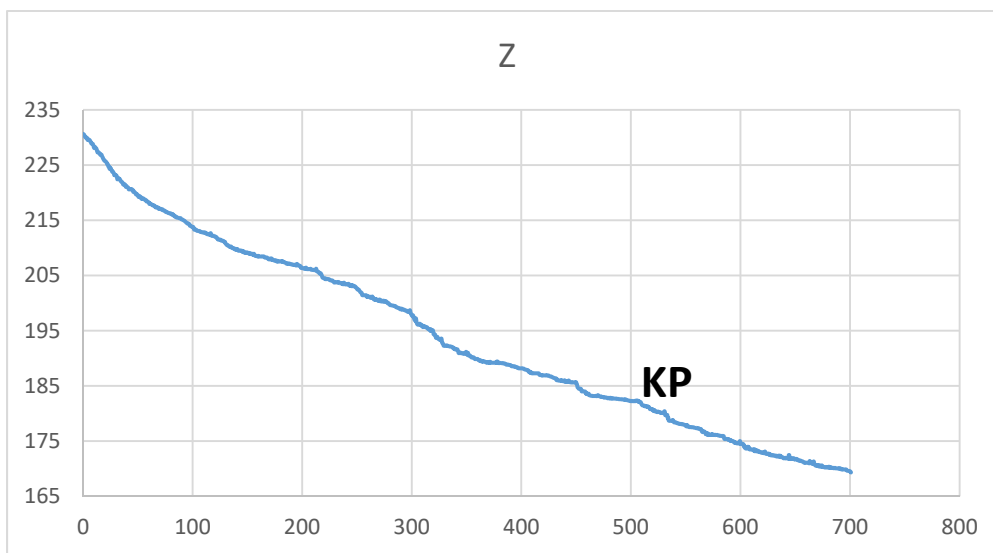


Figure 1-12. Longitudinal profile for small tributary shown in Figure 1-11. The lower knickpoint (KP) likely corresponds with post-construction knickpoints in other tributaries. Units on axes are in meters distance (x-axis) and elevation (y-axis).

Field Trip: Day 2

The second day of the field trip will focus on aspects of the Paleozoic stratigraphy, its implications for paleogeography, and influence on the modern karst hydrogeology. The route map is shown in Figure 2-1.

Start at the lodging venue: Super 8 Lake of the Ozarks (38.30485N, 92.57528W) at the junction of Highway 54 and Route 52.

At the junction, head north on US Highway 54. (Reset tripmeter.)

At 2.2 miles (just past the sign indicating the next exit)

Stop 1: Road cut north of Eldon (38.3344N, 92.5647W)

This stop is along US Highway 54. *Please exercise caution when stopping on the side of the highway.*

At this stop, we will have a close look at an outcrop (Figure 2-2) from the Roubidoux formation that demonstrates meter-scale, stacked patterns of shallowing-upward characteristic of the Lower Ordovician strata southern and central Missouri. Overstreet et al (2003) report that the Lower Ordovician strata (Ibexian Series) in southern Missouri include 60 – 120 meters of such cycles of short-period fluctuations in sea-level.

The Roubidoux Formation consists of sandstones, sandy dolomite, dolomite, and chert. Well-developed sandstone beds are present within the formation, but occur at different levels in various parts of the state (Thompson, 1991). Dolomite is fine to medium crystalline with a light gray to brown color, and banded oolitic layers are frequently observed. As described by Warusavitharana & Parcell (2013), the Roubidoux Formation has abundant stromatolites. The total thickness of the Roubidoux Formation varies from 30 to 90 meters (100 to 300 feet). It is distinguished from the underlying Gasconade Formation by its considerably higher sand content (Unkelsbay & Vineyard, 1992).

The stromatolites in this outcrop can be classified as closely-spaced, laterally linked hemispheroids (LLH-C) – these are typically associated with intertidal environments (Warusavitharana & Parcell, 2013). The stromatolitic mounds develop above a finely bedded, shale layer followed by an oolitic layer. The stromatolites are approximately a meter in width, and covered by a brecciated layer, possibly indicative of inundation. These cycles are, thus, interpreted to represent shallowing and subsequent inundation of the intertidal environment (Overstreet et al., 2003; Warusavitharana & Parcell, 2013).

Continue north on US Highway 54 1.3 miles.

At 3.5 miles, Exit, turn left on Highway 87, and turn left to head south on US Highway 54.

When passing the Overpass for US 54 / Route 52 (i.e., the location of the Super 8 Lake of the Ozarks), reset the tripmeter. The same roadside features we passed yesterday will be visible again:

At 4.0 miles, large road cuts of thick-bedded Gasconade Formation will appear on both sides of the highway. Although deformation within the outcrop is not visible as we pass by, numerous micro faults are present and were some of the data collected by Cox (2009) in his fault kinematic study.

At 7.1 miles, in the Gasconade Formation, there is a filled sink structure on the east side of the road.

At 12.2 miles, a large road cut near Osage Beach contains the contact between more massive Gasconade Formation and the disconformably overlying Roubidoux Formation.

At 22.6 miles, on the west side of the highway, moderately dipping beds of the Gasconade Formation are visible. Compared to most deformation, these are relatively steep. The location is very near the trace of the Hurricane Deck Fault, as well as the core of the Proctor Anticline.

At 24.2 miles, on the west side of Highway 54, a broad, open fold in the Gasconade Formation is visible. This low amplitude fold is more typical of the minor deformation within the Proctor Anticline.

At 28.8 miles, turn left onto Missouri Rte D and head south into Ha Ha Tonka State Park

At 30.3 miles (1.5 miles from US Highway 54), turn in to the Ha Ha Tonka State Park Visitor Center (Figure 2-3).

Stop 2: Visitor Center

This initial stop is primarily to get oriented, use the restrooms (**NOTE:** at the time of this field trip, the restrooms may be undergoing repair – no water, so closed). The Visitors Center may be open, and you can also stop in there.

Ha Ha Tonka State Park was established in 1978. Although the name was said to mean “laughing spring”, or something similar, it appears it may be made-up (The State Historical Society of Missouri). Name aside, Ha Ha Tonka State Park is regarded as one of the best collections of inter-related karst landforms in Missouri. Numerous sinkholes, caves, and springs are found here, and they all appear to be related to a single, large cave system (Bretz, 1956). Although the caves are generally not open to the public, there are numerous, well-maintained trails that permit exploration of the other karst features around the park.

The most recent, comprehensive geological study of the state park and adjacent area was performed by Schmitz (1984). The slightly more recent entry in the Decade of North American Geology Field Guide (Hebrank, 1988) is based primarily on Schmitz’s thesis.

Continue along Missouri Rte D.

At 30.7 miles (0.4 miles from the Visitor Center), turn right onto Natural Bridge Rd.

At 30.9 miles (0.2 miles from the turn), stop in the parking area for Ha Ha Tonka Castle.

Exit the bus at the parking lot – for those with physical limitations, we’ll meet up at the “Castle” in some minutes ... there is limited parking / drop-off (non-buss) up the road.

NOTE: Much of the time here will be spent on a walking geology tour (weather permitting). The total hike is about 2 miles. The last part of the hike will be a descent down to the Ha Ha Tonka Spring at lake-level. We will meet the bus and other vehicles at the Ha Ha Tonka Lake Shelter (they will drive another 1.8 miles without us).

Walk up trail toward the “Castle” (“Castle Trail, yellow marker)

At junction with the “Quarry Trail” (green marker) turn right, walk ~600 ft.

Stop 3: Ha Ha Tonka Castle Quarry (walking)

Exposure of the Gunter Sandstone – lower member of the Gasconade formation (Figure 2-4). The best local building stone is the Gunter Sandstone in the Gasconade Formation. Stream-incised outcrops, such as this, provided the most accessible quarries for the construction of the stone mansion (a.k.a., the “Castle”). The bedrock knickpoint right at the trail creates a nice waterfall when the stream flows, but this is an artificial cut – you can infer the channel surface prior to quarrying from the banks.

The Gunter Sandstone is a well-sorted, quartz sandstone with bimodal current indicators – both in the form of cross beds, as well as ripple marks (such as those in the stream channel below).

Backtrack on the “Quarry Trail”. At “Castle Trail”, turn right and head uphill.

Walk to the “Castle” (Figure 2-5).

Stop 4: The Castle

The story behind the “Castle” (from MO State Parks): Robert Snyder was a wealthy businessman in Kansas City in the late 19th and early 20th centuries. In 1903, Snyder visited the area and began purchase the land around us (more than 8 square miles, in total) – the aim was to construct a private retreat for his family that was styled after a European castle, including 60 rooms and a center atrium rising to 3 ½ stories. The plan also included greenhouses, a carriage house / stables, and a water tower. The materials for construction would all be found locally – we have already visited one quarry for the Gunter Sandstone – and a sawmill was built to cut timber. A local railroad was made in order to transport materials. Construction began in 1905, but stopped abruptly in 1906 when Robert Snyder died in an automobile accident (the first automobile fatality in Missouri). Eventually, construction resumed under the supervision of Snyder’s sons, and it was completed in 1922. The Snyder family was unsuccessful in trying to stop the construction of the Bagnell Dam in the late 1920s; the result was that the lake divided the property as it filled the gorge below. The Snyder family also befell misfortune with the stock market crash of 1929. By the late 1930s the Castle was being operated as a hotel, taking advantage of the growing tourist industry around the Lake of the Ozarks. However, a fire in 1942 destroyed the Castle and the carriage house. The water tower burned in the mid 1970s. The state park was created in 1978.

The bedrock underfoot (and the foundation for the structures) is the Gasconade Formation – in general, Roubidoux Formation does not found except on the outermost (and highest) hilltops in the state park.

Walking to the Castle proper, building stone (primarily Gunter Sandstone) can be examined.

From vantage points adjacent to the Castle, there are nice overlooks of the Ha Ha Tonka Chasm to the south. This gorge is 75 meters (~250 feet) deep and 240 meters (~800 feet) in length. The chasm formed from the collapse of a large cave system. At the eastern end (below and to the left from the overlooks) is the Ha Ha Tonka Spring, which we will be visiting, shortly.

There is also a rail cart displayed here that was used to haul building stone from the quarries during the construction of the mansion (Figure 2-6). These were pulled by mules.

Descend down “Quarry Trail” ~ 600 feet to other quarry.

Stop 5: Another quarry

Once again, Gunter Sandstone Member of Gasconade Formation ... this is another, slightly larger quarry than the one we previously visited. This quarry is larger and shows considerable excavation beyond the banks of the gully.

Let’s continue to the Natural Bridge by following the “Dell Rim Trail” (orange).

We will pass by the ruins of the Water Tower (which burned in the mid 1970s) (Figure 2-7).

Continuing along, the trail passes by Whispering Dell sinkhole. This is a 48 meter deep sink hole that exposes Lower Gasconade Formation (Gasconade Dolomite and Gunter Sandstone) down into the Eminence Formation in which the cave formed. Like most sinks in this area, this one formed by collapse of a cave system below, as indicated by the shear walls around the sink.

At junction with “Colosseum Trail” (yellow), turn left. Note some of the outcrops of the Middle Gasconade as we walk along the trail. Continue to Natural Bridge parking area / trailhead.

(Alternative: If driving, 0.3 miles on Natural Bridge Rd. to parking area)

Walk down steps to Natural Bridge

Stop 4: Natural Bridge & Colosseum

Approaching the Natural Bridge, the resistant Gunter Sandstone is observed at the top. The Gunter Sandstone (the lowest member of the Gasconade Formation) is 8 – 10 meters (25 – 30 feet) in thickness, and its full thickness can be appreciated in the Natural Bridge. At this location, cross beds are well expressed in the sandstone (Figure 2-8).

Note the irregular surface of the unconformity between the Gunter Sandstone and the underlying Eminence Formation. In particular, when initially descending toward the Natural Bridge, a felled channel can be observed at the upper right. Schmitz (1984) reported that he did not observe a basal conglomerate, which is often reported at the base of the Gunter Sandstone in other areas of south central Missouri.

Below the Gunter Sandstone is the Eminence Formation. As described by Schmitz, in the Ha Ha Tonka area, the Eminence Formation primarily consists of extensively dolomitized carbonates, with discrete thin sand layers. The upper part of the Eminence Formation (the Proctor Member) is characterized by low quantities of insoluble residues and consists of three types of dolomite layers that occur in repeated sequence: (1) Massively bedded dolostone at the base, (2) jointed dolostone, and (3) thinly bedded dolostone. The lower Eminence Formation (the Eminence Member) consists of massively bedded gray-tan or pink dolostone. Rock weathering produces dark gray to light gray mottled surfaces on the dolomite and very craggy exposures on the hillsides. Brecciated chert, chalcedony, and euhedral quartz are common in the Eminence Member, along with much more insoluble residues.

Like the Colosseum (and the Whispering Dell), most karst features in Ha Ha Tonka occur within the Eminence Formation (predominantly dolomite). The present water table is approximately 30 meters (100 feet) below the top of this formation. The Eminence Dolomite is extensively jointed, thus enhancing the potential for solution.

(Those who are not hiking, return to parking area and drive to Lake Shelter.)

Continue on Colosseum trail – outcrops of upper Eminence (vuggy) can be observed (Figure 2-9). Climbing further we are back in the Gasconade Formation.

At the junction with the “Spring Trail” (blue), descend (300+ steps) to spring.

Note stratigraphy as we descend. We will cross from the upper part of the Eminence Formation (the Proctor Member) into the lower Eminence Member of the formation, as described by Schmitz (1984). Schmitz interpreted the Eminence formation to represent a regressive sequence of coexistent facies. The massively bedded and bioturbated Eminence Member (the lower part) is the offshore unit, whereas the repetition of the dolomite layers in the Proctor Member (the upper part) represents the tidal range of the nearshore to subaerial facies. The bioturbated dolostone is subtidal, the sandy cross beds indicate tidal channels, and the thin dolostone corresponds with beds periodically exposed subaerially. Complete regression

occurred at the top of the Proctor Member as evidenced by paleokarst features filled in with the overlying Gunter Sandstone (and other irregular surfaces in the unconformity).

Stop 5: Ha Ha Tonka Spring

The Ha Ha Tonka Spring (Figure 2-10) is Missouri's 12th largest, based on average daily discharge (Vineyard & Feder, 1982). It emerges from the Eminence Formation.

Here in the chasm, evidence for collapse is provided by the linear, shear-walled morphology of the gorge, right up until the spring. The present-day knickpoint lacks a sufficient watershed upstream to create this by typical headward erosion. Additionally, there are many large, fallen blocks of bedrock, particularly the Eminence and Gasconade Formations scattered about the gorge (rather than simply confined to the margins adjacent to the side walls). Furthermore, blocks of Roubidoux Formation have been reported, although it is generally lacking from nearby hilltops. This implies that the collapse of the Ha Ha Tonka Chasm occurred prior to the denudation of the Roubidoux from the uppermost surfaces here. Finally, weather blocks of travertine are found in the bottom of the chasm which, in general, suggests a prior cave system.

Following the trail west (along the boardwalk), a residual outcrop of Eminence Formation exists as the "Island". Note the concrete dam adjacent to the trail. Following the construction of the Bagnell Dam, the narrow channels on either side of the Island were impounded to power a grist mill. One of the old millstones is present.

Continue along the trail to Lake Shelter. Look across the gorge to the north for a complete view of the Upper Cambrian and Lower Ordovician strata. The Gunter Sandstone is a prominent layer exposed in the cliff below the castle (and this corresponds with the elevation of the quarries visited earlier on the walking tour).

(Alternatively, drive to Lake Shelter and walk from that parking lot)

LUNCH STOP (#6): Lake Shelter (or return to VC, if unavailable and bad weather)

After lunch (we should be at 32.7 miles on the tripmeter), we will depart.

At 32.9 miles (after 0.2 miles on Tonka Spring Rd.) turn left onto Missouri Rte D.

At 36.0 miles (3.1 miles from the last turn) take US Highway 54 north/east.

At 42.3 miles (6.3 miles from Missouri Rte D) turn right (east) onto Missouri Rte A.

At 49.1 miles (6.8 miles from the last turn) turn left (head north) on Rte A33.

At 49.8 miles (after 0.7 miles) turn right (head east) on Ozark Caverns Rd. Hopefully, the gate is unlocked.

At 50.6 miles (after 0.8 miles) arrive at the Ozark Caverns Visitors Center

Stop 7: Ozark Caverns

Ozark Caverns, originally named Coakley Cave, was first explored in the late 1880s. Commercial development and tours began in the 1930s when the Lake of the Ozarks was created by construction of the Bagnell Dam. In 1979, Ozark Caverns was purchased by the state of Missouri and incorporated into the state park system.

Ozark Caverns have developed in the Gasconade Formation. The cavern is well known for speleothems, particularly the “Angel Showers”. In addition to modern cave fauna (bats, salamanders, and cave invertebrates), traces of Pleistocene mammals (footprints & claw marks) have also been reported (MO State Parks). The cave has also been the subject of paleoclimate studies using stable isotope analysis of speleothems (e.g., Denniston et al., 2000).

We’ll follow a guided tour of the cave (Figure 2-12). Following Bretz (1956) there are three distinct sections: A wide smooth-ceilinged stretch, a narrow, rough-walled and twisting passage, and a uniformly proportioned and slightly crooked chamber to the end of the visitor’s route.

Departing, backtrack to US Highway 54:

At 51.4 miles (after 0.8 miles on Ozark Caverns Rd) turn left (head south) on Rte A33.

At 52.1 miles (after 0.7 miles), turn right (head west) on Missouri Rte A.

At 58.9 miles (after 6.8 miles) turn right (head north/east) on US Highway 54

At 81.4 miles (after 22.5 miles from Missouri Rte A), exit on Rte 52, turn right (head east) and park at the Super 8 Lake of the Ozarks.

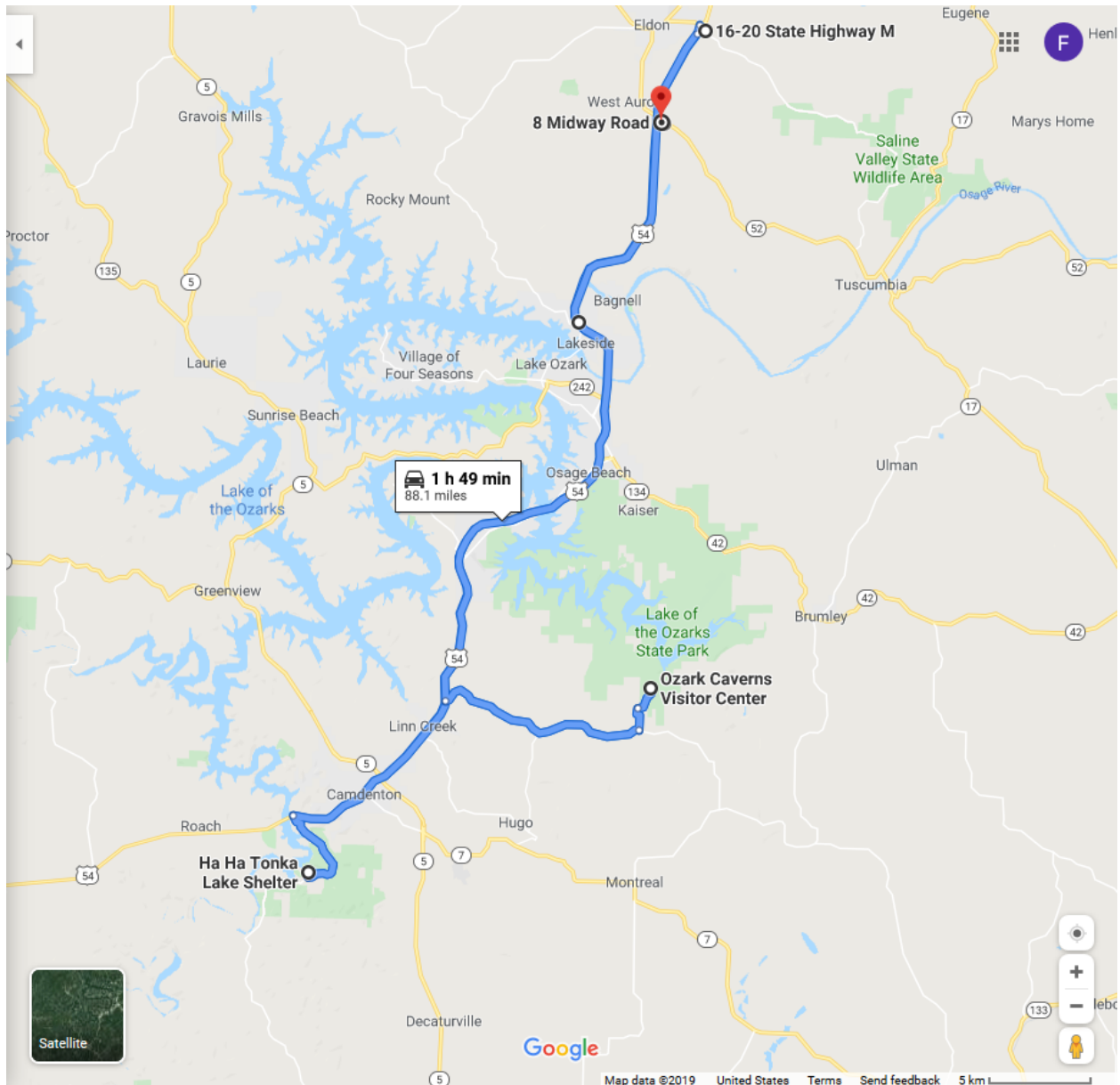


Figure 2-1. The route for Day 2.



Figure 2-2. Stromatolitic mounds (S) in the Roubidoux Formation (Facing East).

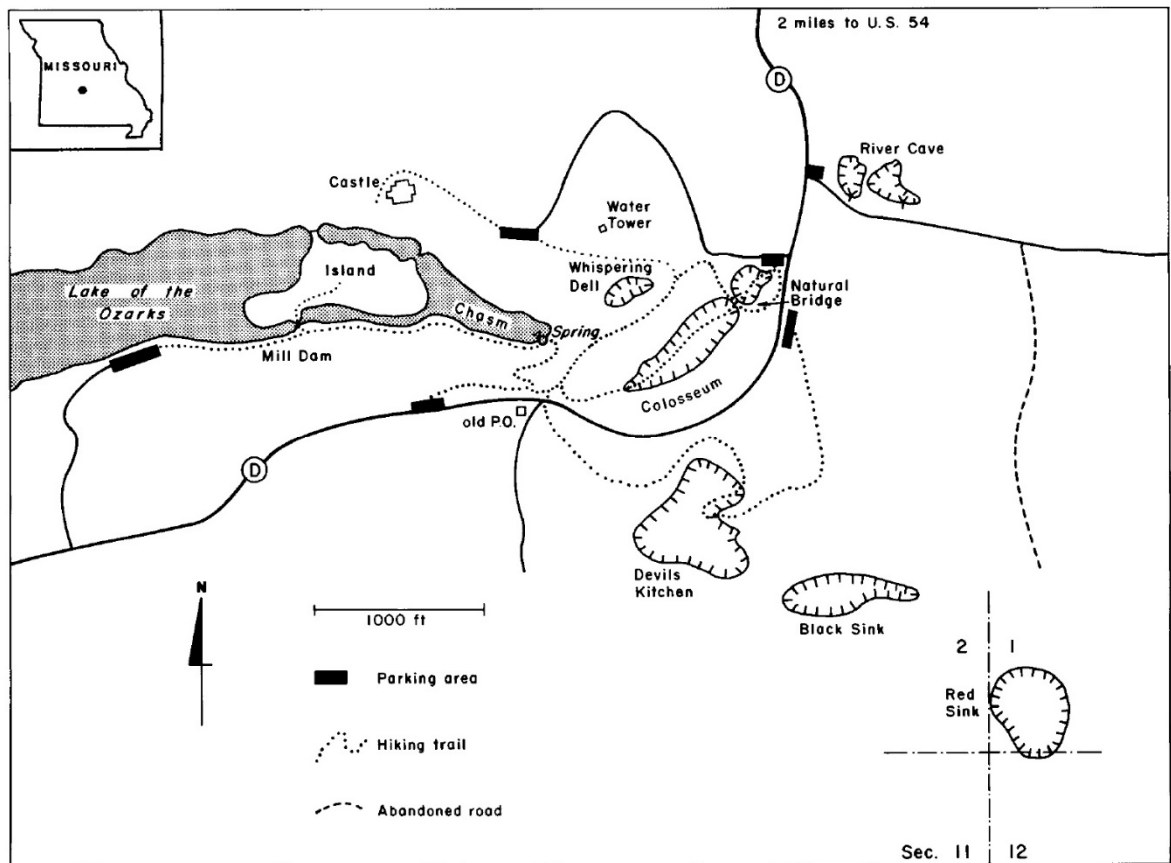


Figure 2-3. Map of trails and karst features in Ha Ha Tonka State Park (modified from Hebrank, 1988).



Figure 2-3. Quarried outcrop of Gunter Sandstone near Ha Ha Tonka Castle. Ripple marks (R) can be observed in the channel below the man-made waterfall.



Figure 2-4. Ha Ha Tonka Mansion (a.k.a., the “Castle”) constructed from Gunter Sandstone.



Figure 2-5. A rail cart used in transporprting quarried Gunter Sandstone during construction of the Castle.



Figure 2-6. The stone water tower.

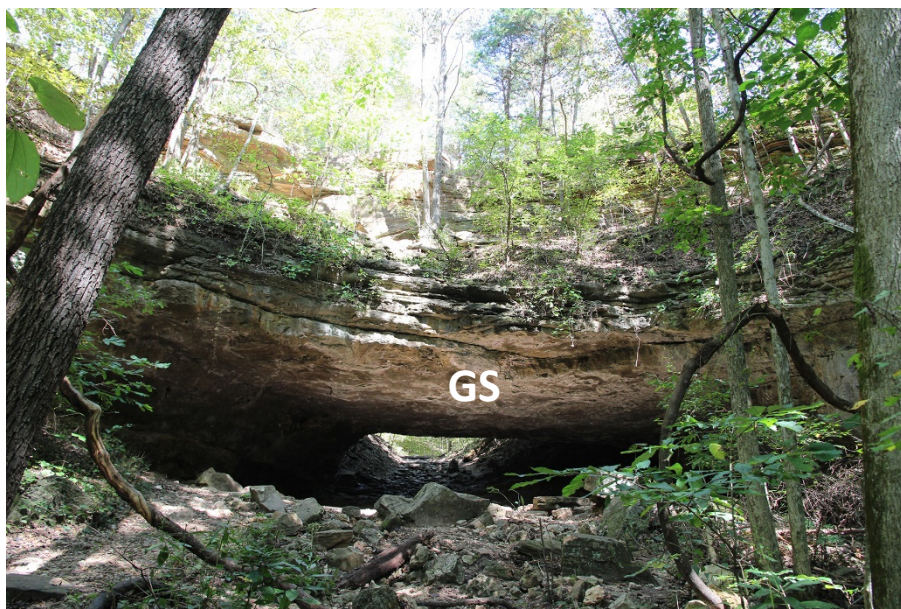


Figure 2-7. The Natural Arch is formed by a resistant bed of Gunter Sandstone (GS). Below is the Eminence Formation. Photo facing north.

Figure 2-8. An outcrop of Eminence Formation.





Figure 2-9. Ha Ha Tonka Spring (Facing West to NE).



Figure 2-11. Upper Cambrian (Eminence) to Lower Ordovician (Gasconade) strata below the Castle. G = Gunter Sandstone at the base of the Gasconade Formation.

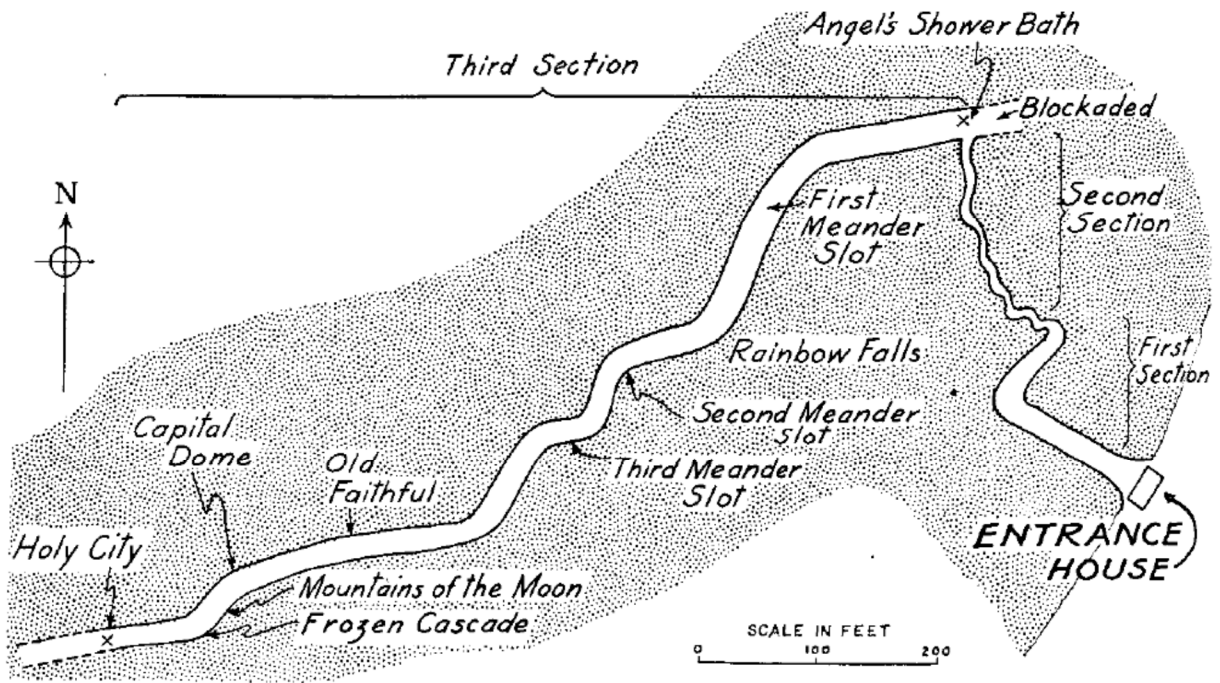


Figure 2-12. Map of Ozark Caverns (from Bretz, 1956).

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