ENERGIZING THE FUTURE

Innovative Energy Production and Environmental Stewardship in Texas

A field trip as part of the 2025 Annual Meeting of the Geological Society of America

Leaders:

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Date: Saturday, October 18, 2025

Departure Location: Convention Center, San Antonio, Texas, USA

Field Trip Stops: North San Antonio; New Braunfels area; Palmetto State Park; industry sites near Gonzales, Texas

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Field Trip Description:

This field trip for 5th to 12th grade teachers and university students explores subsurface energy technology and innovation. Participants will visit San Antonio field sites to learn about energy resource engineering and geology, and explore energy sector careers. Organized by UT Austin's Choose Energy K-12 Outreach Program and the Railroad Commission of Texas, the trip includes 8 CPE hours for teachers, lunch, and transportation.

IMPORTANT: Attendees are visiting active work sites; therefore, everyone must be appropriately dressed. Attendees must wear long pants, made of thick, durable fabric (jeans, khakis), durable shoes (boots, hiking boots, athletic shoes that completely cover the foot), and a short sleeve shirt (T-shirts are ok). All necessary personal protection equipment (PPE) will be provided and must be worn at work sites.

Prohibited clothing includes – *running tights, yoga pants, athletic pants, tank tops, sleeveless shirts, camisoles, flip flops, sandals, ballet flats or similar style flats. Industry operators have very strict safety rules. Dress codes are for your safety.*

Itinerary - Saturday, October 18, 2025

7:00 a.m. - 7:30 a.m. Check in - Meet at Henry B. González Convention Center San Antonio, Texas

7:30 a.m. Depart Conference Center, Gonzalez Convention Center, 900 E Market Street

8:00 a.m. Arrive Target parking lot, 11311 Bandera Rd., San Antonio

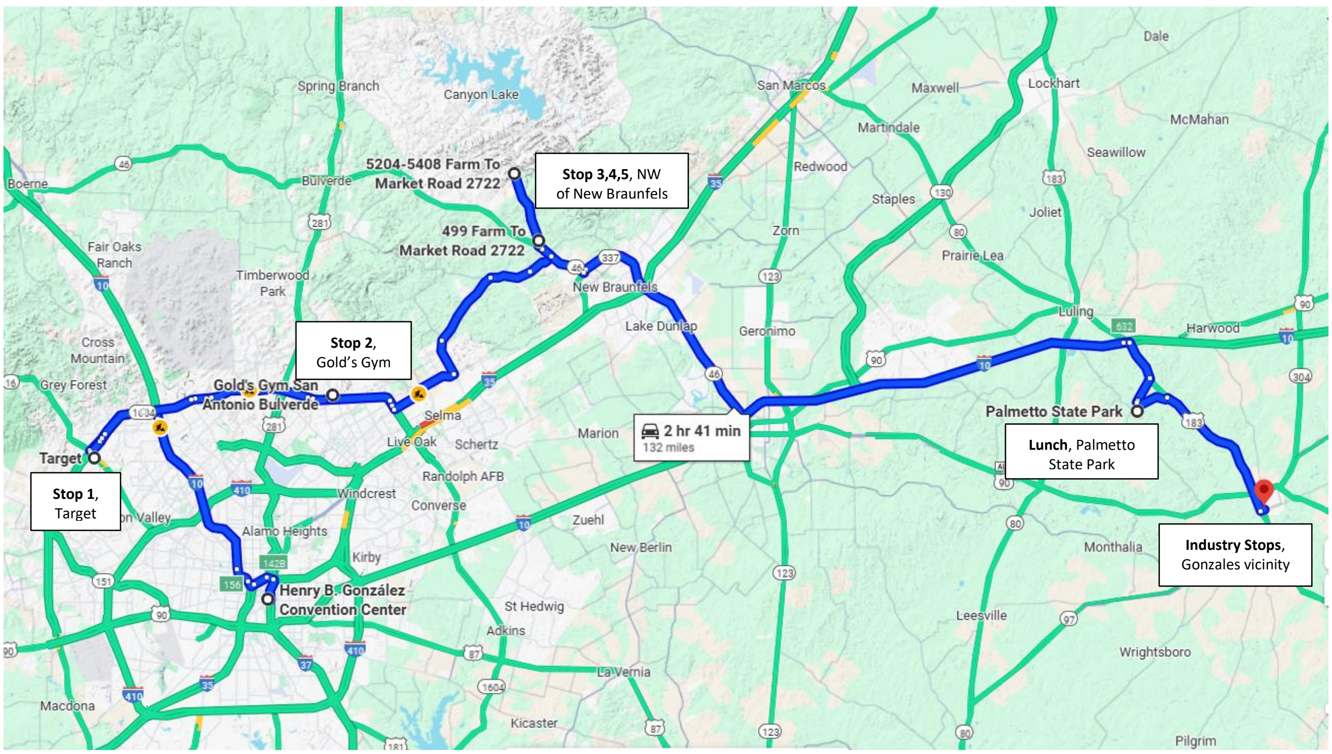
8:30 a.m. Depart for Gold's gym parking lot

9:00 a.m. Stop 2, South of Gold's Gym San Antonio, 17934 Bulverde Rd., San Antonio

9:30 a.m. Depart South of Gold's Gym for New Braunfels

10:15 a.m. New Braunfels geology stops (in vicinity of Hwy 46 and FM 2722)

11:15 a.m.	Depart for Palmetto State Park
12:30 p.m.	Lunch at Palmetto State Park
1:30 p.m.	Depart for Gonzalez, TX vicinity for various oil and gas industry sites (actual stops and order of visits may vary due to industry site work schedules and availability)
2:00 p.m.	Oil and gas plugging operations, hosted by the Railroad Commission of Texas
3:00 p.m.	Depart for EVX saltwater disposal well near Waelder
3:30 p.m.	EVX saltwater disposal well near Waelder and Wilcox core viewing
4:15 p.m.	Depart for San Antonio
6:00 p.m.	Arrive back at Henry B. González Convention Center, San Antonio, TX

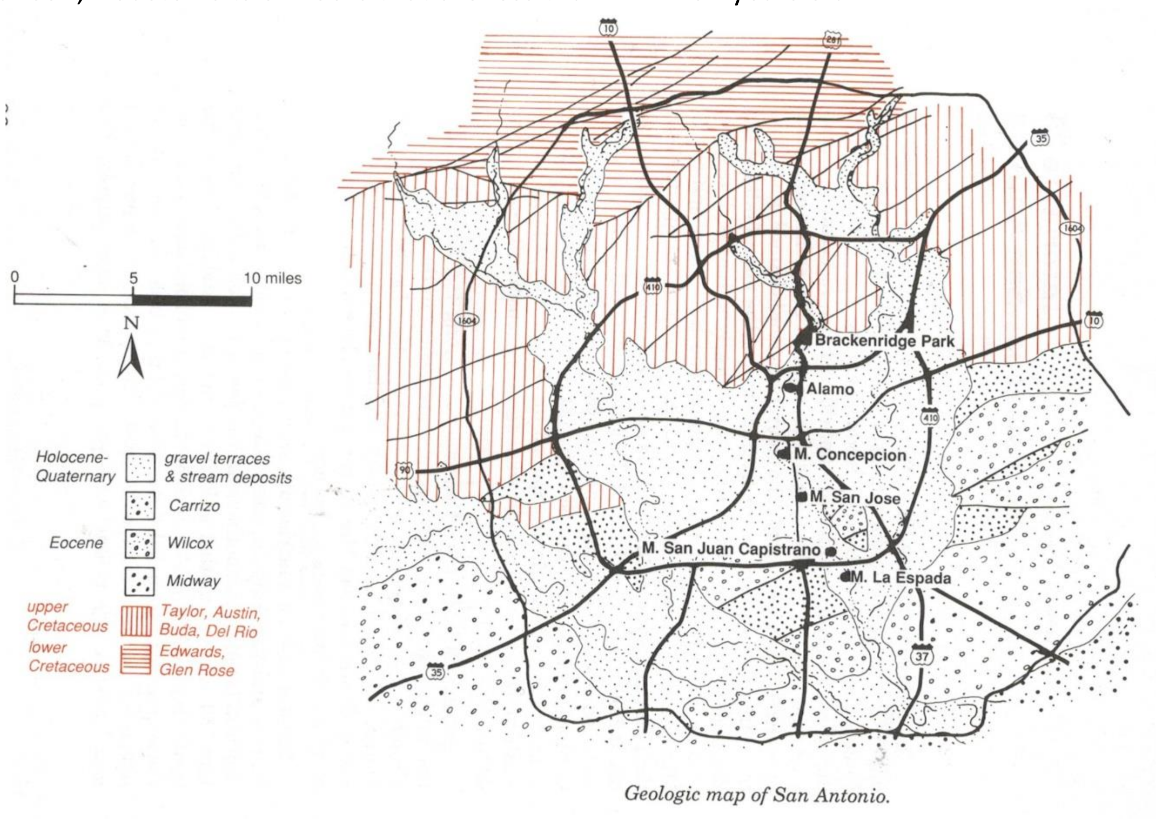


Introduction: Topography and the Balcones Fault Zone

The change in topography and landforms you experience driving from Houston to Austin reflects the difference in the nature of the rocks along your route. San Antonio, Austin and Dallas all lie along trend of the Balcones Fault zone, which separates the Gulf of Mexico Coastal Plain from the Central Texas uplifts and plateaus. The fault zone causes a noticeable break in topography called the Balcones Escarpment, with hills and more rugged topography to the west and lowlands to the east down to the shores of the Gulf. The Spanish word "balcones" means balconies, and was coined as a result of the stair-stepping of the land due to the fault zone (Spearing, 1991). In general, the land to the west of this trend has been uplifted relative to the land to the east. The amount of offset on this fault zone is about 1200 ft (Spearing, 1991). The increase in elevation of the upthrown block accelerates erosion because the base level of the streams have effectively been lowered, giving rise to the canyons and cliffs of the "hill country".

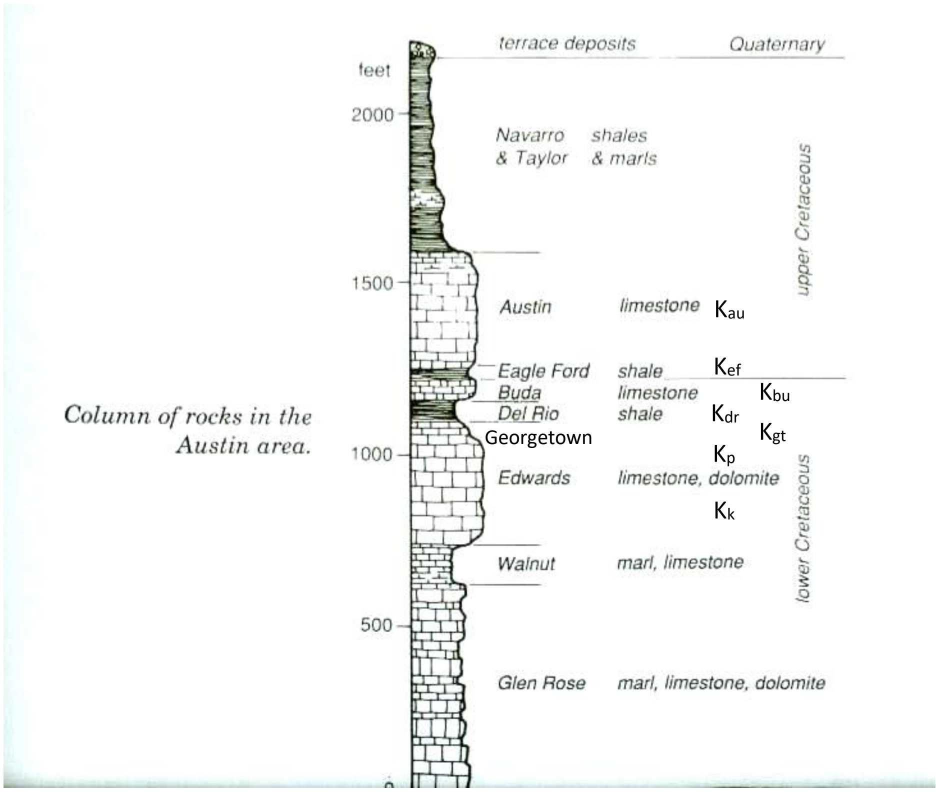
The Age of Rocks in Central Texas

There is also a demarcation in the age of rocks along the Balcones Fault. Rocks to the east of I-35 are 65 million years old and younger, and they all dip toward the Gulf of Mexico. Most of the rocks of the Central Texas Edwards Plateau are Cretaceous in age (about 65 to 144 million years old). If you venture to the Llano (or Central Texas) Uplift, you can actually see some of the oldest rocks in the world – Precambrian granites and metamorphic rocks that are 1 to 2 BILLION years old! In comparison, Houston sits on rocks that are less than 2 Million years old.



Geologic sketch map of San Antonio area from Spearing (1991: page 62).

Most of the rocks that outcrop in this area are Cretaceous, and that time in Texas was dominated by broad, shallow seas where calcite-secreting organism lived, and calcite also may have precipitated directly from the water. A representative stratigraphic column is included below (Figure 2), and the map symbols for the different formations are also included (e.g., Austin chalk's symbol is Kau, where "K" is the letter geologists use to represent the Cretacous and "au" denotes the Austin chalk formation).



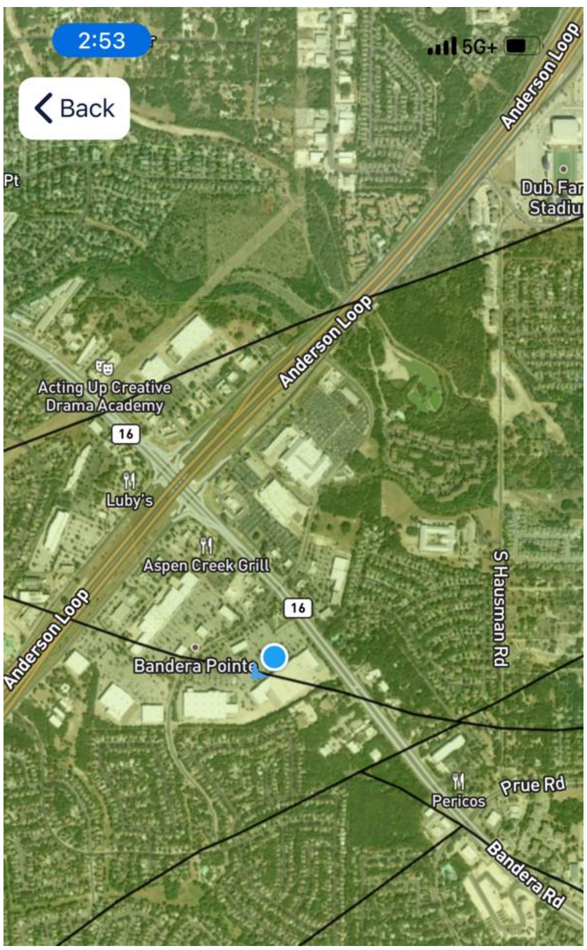
The geologic rock column for the Austin area (from Spearing, 1990: page 63).

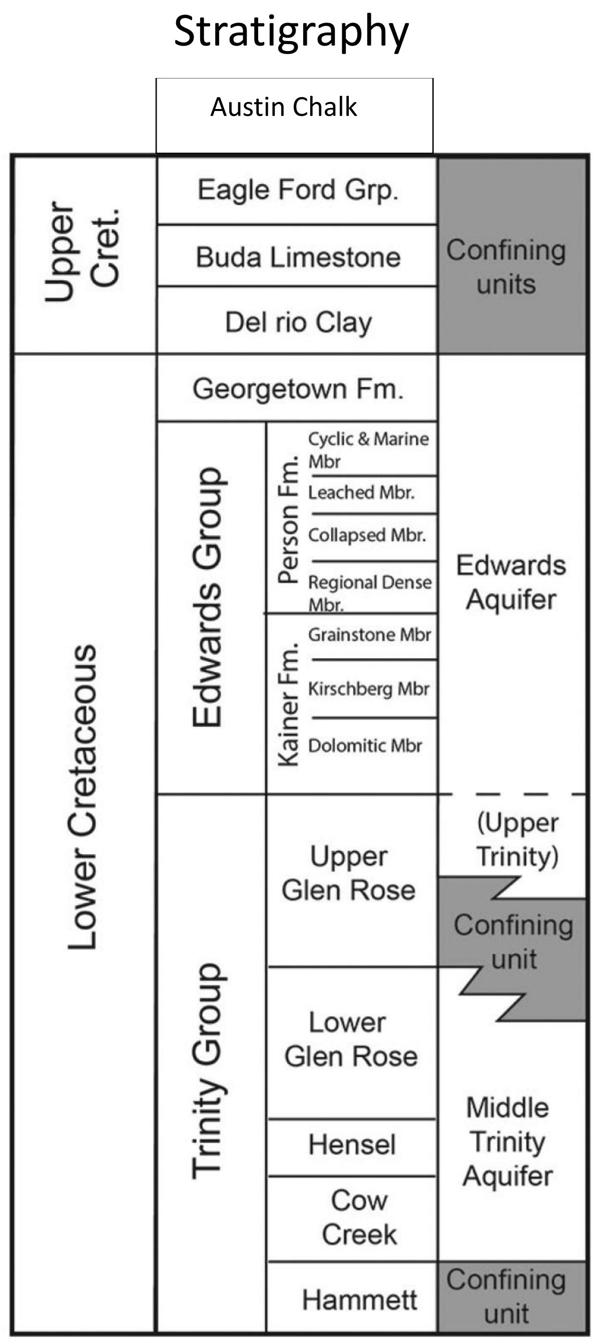
STOP #1
Target Store, rear parking lot south of building
(11311 Bandera Rd, SE of the intersection of Loop 1640 and Bandera Rd/Texas 16))

This stop illustrates some of the Cretaceous geology of the San Antonio area as well as the nature of normal faults in the Balcones Fault Zone. We can also see a section that acts as a confining unit to the Edwards Aquifer.

Geologic Units at Stop #1:

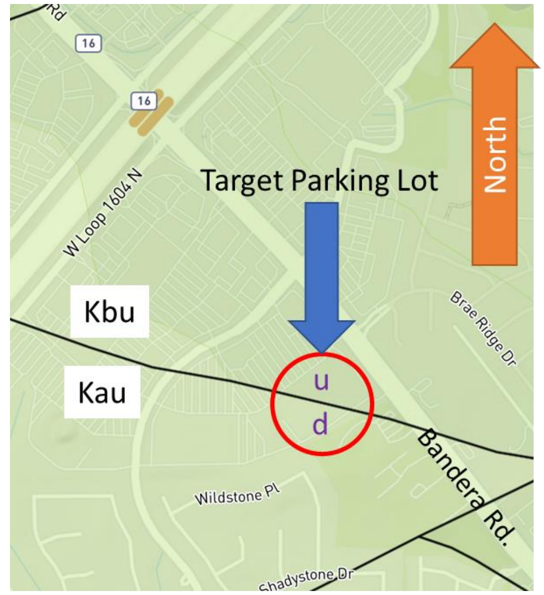
- Buda Limestone (Upper Cretaceous, 40-50 ft thick, porcelaneous limestone)
- Eagle Ford Grp. (Upper Cretaceous shale)
- Austin Chalk (Upper Cretaceous, 130-160 ft thick, white chalky limestone)



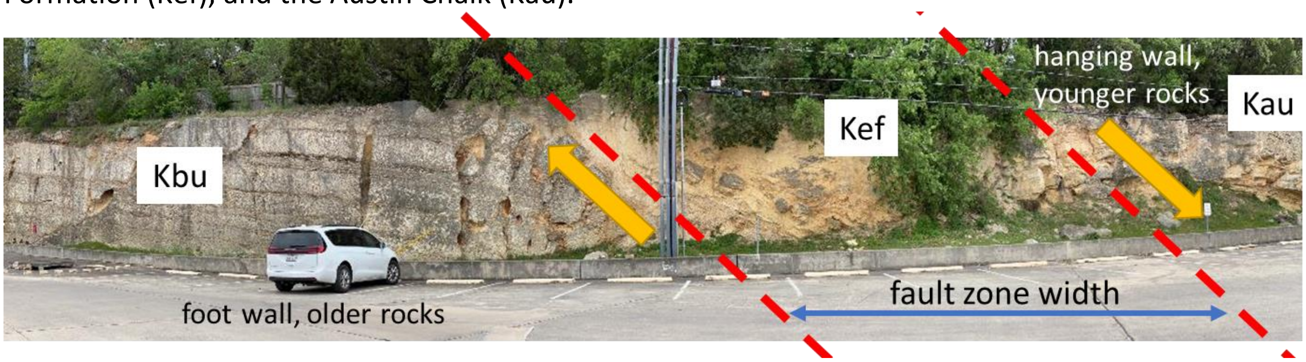


The satellite photo shows additional details about the location of this outcrop. The blue dot is the parking lot in front of Target (to the north), and the outcrop is behind the store (to the south). The black lines on the image are mapped faults, showing one running right through this location.

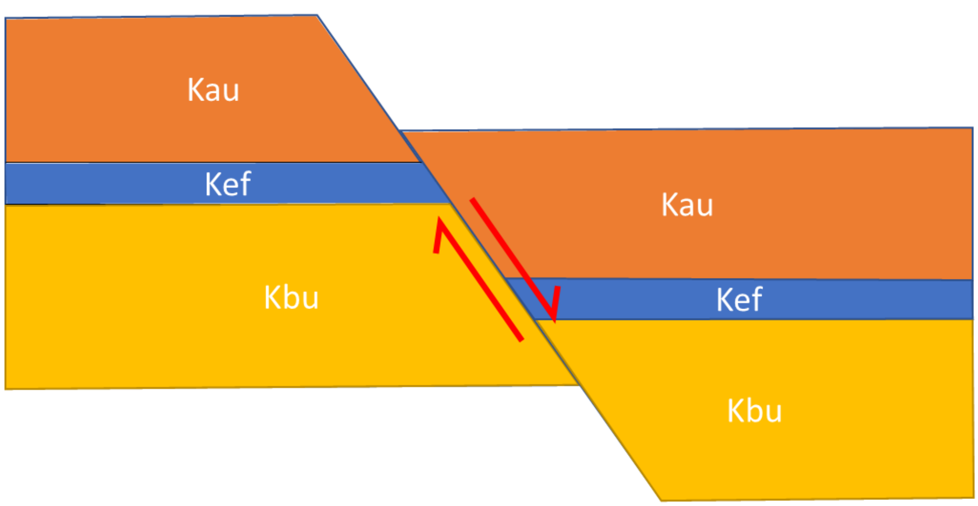
Our outcrop is the location of an exposed normal fault that drops the younger Austin Chalk (Kau) down to the level of the older Buda Limestone (Kbu). The Eagle Ford formation (Kef), which is a fairly thick oil and gas producing unit to the SE, is very thin at this location (only 10 ft), stretched out in the damage zone of the fault. The location map to the right indicates the up and down sides of the mappable fault that cuts through our outcrop and the rock units on either side (the other faults are not annotated). The actual fault planes for small displacement faults are visible here, as is the complicated damage zone of the larger fault.



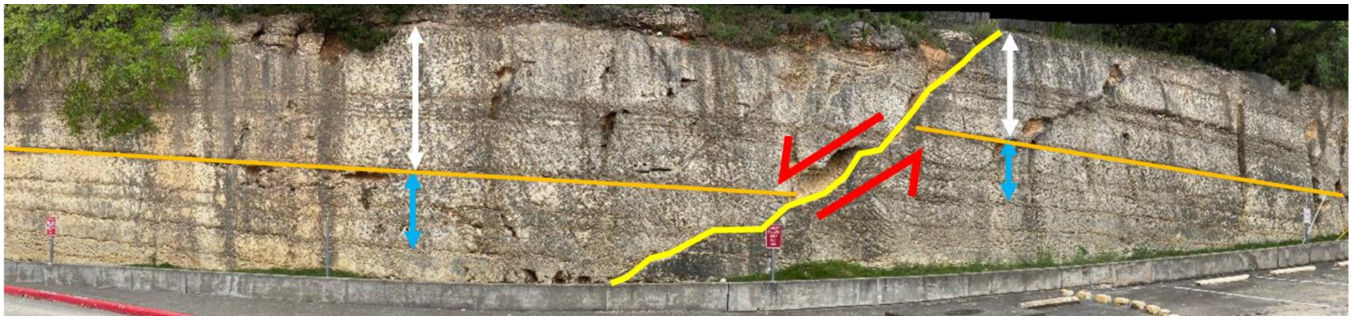
The interpreted photo below depicts the mapped fault in the Target parking lot. There are three formations involved in this deformation, the Buda Limestone (Kbu), the Eagle Ford Formation (Kef), and the Austin Chalk (Kau).



The block diagram below gives a schematic view of the stratigraphy and the deformation represented here. In addition to the structural deformation caused by the fault, which likely has tens of meters of shear offset, there is also evidence of mineral dissolution caused by the flow of water through the rocks, primarily along fractures and faults. These geologic dissolution features are part of a process called karsting and are common throughout the Balcones Fault Zone.



In the foot wall of the major fault at this location, there are smaller-scale fractures and faults. Below is an interpreted photo of a small-scale normal fault (yellow line). The white and blue vertical arrows represent the thicknesses of identifiable bedding sequences on either side of the fault. The boundary between these sequences (orange line) has been shear offset by approximately 2 meters as indicated by the red arrows. Notice also the large voids (called vugs) throughout the outcrop, which are caused by calcite dissolution from freshwater flowing through the outcrop, especially along the fractures.



The photo below shows a close-up of karsting in the outcrop. This dissolution creates conduits that can focus flow for pumping water from wells in an aquifer or for producing oil and gas from hydrocarbon reservoirs. Many of the most productive oil reservoirs in the Middle East are in carbonate rocks that have these large flow conduits created by karsting.

STOP #2
South of Golds Gym, 17934 Bulverde Rd north of Loop 1604
North side of San Antonio, just east of US 281

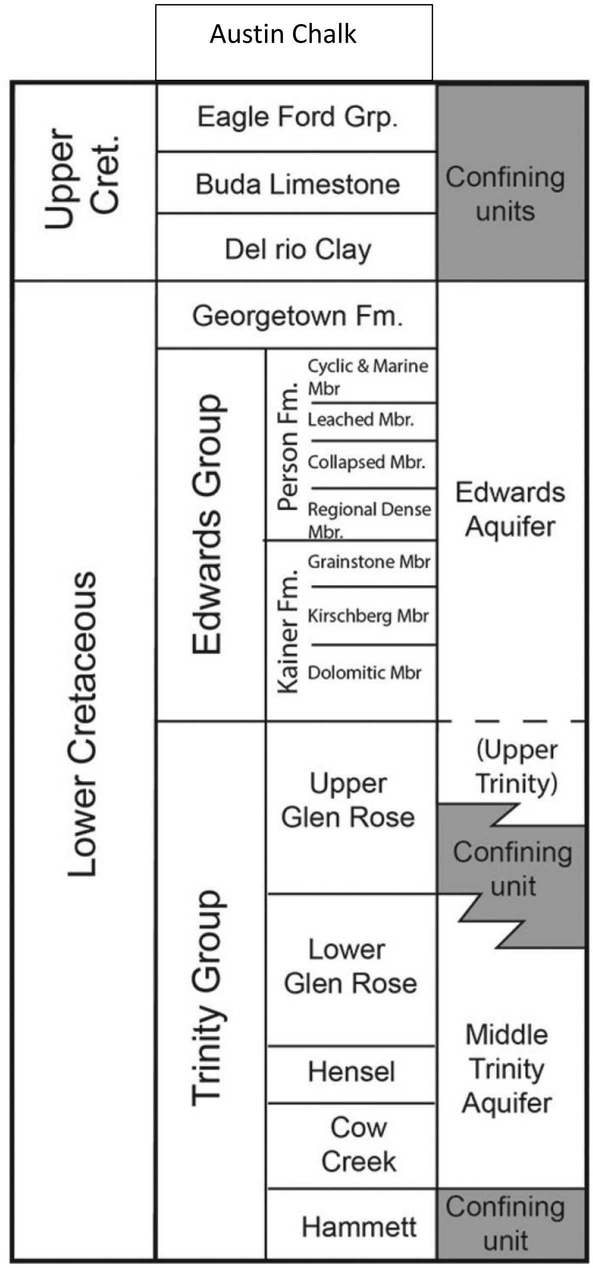
Geologic Unit at Stop:
- Edwards Group: Person Fm. (Lower Cretaceous)

The Edwards Group is divided into the Kainer Fm. and the overlying Person Fm. During our field trip today, we will see multiple examples of the Person Fm.

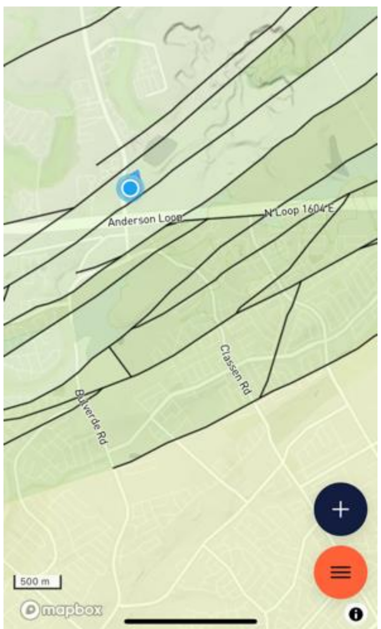
Members of the Person Formation include:
1. Regional Dense Member: The basal, persistent, dense, argillaceous deep-water limestone that acts as a confining bed.
2. Leached and Collapsed Members: Overlying the regional dense member, this unit consists of tidal and supratidal limestone and dolomite packstone with significant honeycomb porosity and collapse breccia due to karst dissolution and erosion.
3. **<u>Cyclic and Marine Members:</u>** The topmost unit, characterized by reefal limestone, dolomitic grainstone, evaporite beds, and argillaceous limestone, with considerable porosity and thickness variations.

At this stop, the Person Formation is the cyclic and marine member, made up of thin graded cycles, some massive beds, and some cross-bedding. It is 80-90 ft thick.

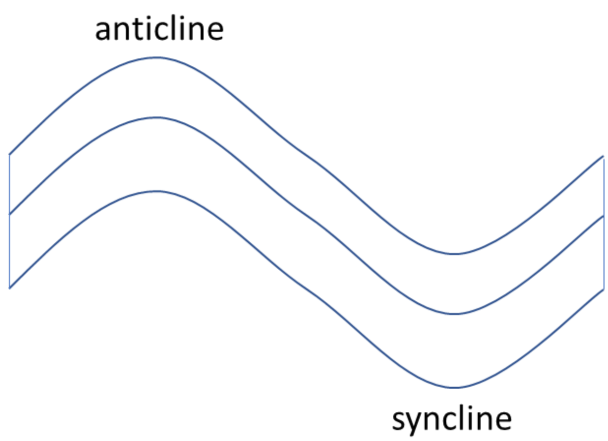
Stratigraphy



Our discussion at this stop will focus on rock folding as illustrated in the photo above (taken looking south in the Gold's Gym parking lot), as well as the extensive karsting evidence found at this location. The scaled map below shows this outcrop location is also in an area of faulting within the Balcones Fault Zone.



The folding of geologic layers can create anticlines and synclines, which often occur together as originally horizontal layers buckle when shortened. The wall at the south end of the parking lot provides an excellent example of anticlinal and synclinal folding. The syncline also appears to have experienced secondary fracturing, presumably to accommodate the crowding of material in the center of the syncline as seen in the photo below.



The outcrops at this location offer more than just a two-dimensional (2d) cross-section view of the deformation. There are planar, 2d rock walls in perpendicular directions here, which together give a three-dimensional perspective. If you view the anticline in the corner of the parking lot where the exposed rock walls are perpendicular, you can see the folding is similar to a dome. You can imagine how such a structure could trap rising low-density fluids in the rock column, such as oil and gas, if there were a sealing layer (like a shale) above the porous and permeable limestone we see in front of us. A photo of this domal view of the folding is included below.

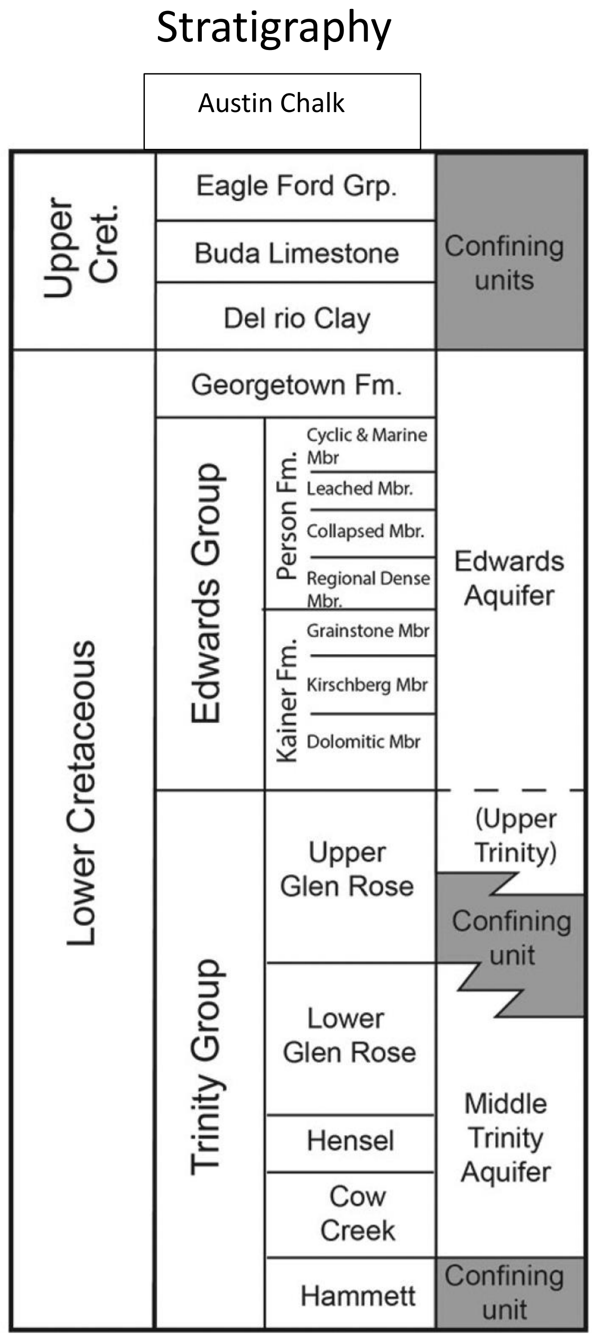
The karsting at this location is more extensive than at the Target outcrops. You can imagine the beginnings of cave-like openings, as well as see evidence of collapse of the roof rock into the open space created by dissolution.

This photo along Bulverde Rd., across from several fast-food restaurants, shows a nice fold in the Edwards.

STOPS #3 and 4
Along FM 2722, northwest of New Braunfels
Stop 3: located .2 miles north of intersection of Hwy 46 and FM 2722, on the east side of FM 2722
Stop 4: located .4 miles north of intersection of Hwy 46 and FM 2722, on the east side of FM 2722

Geologic Unit at these stops:

- Edwards Group: Person Fm. (Lower Cretaceous)

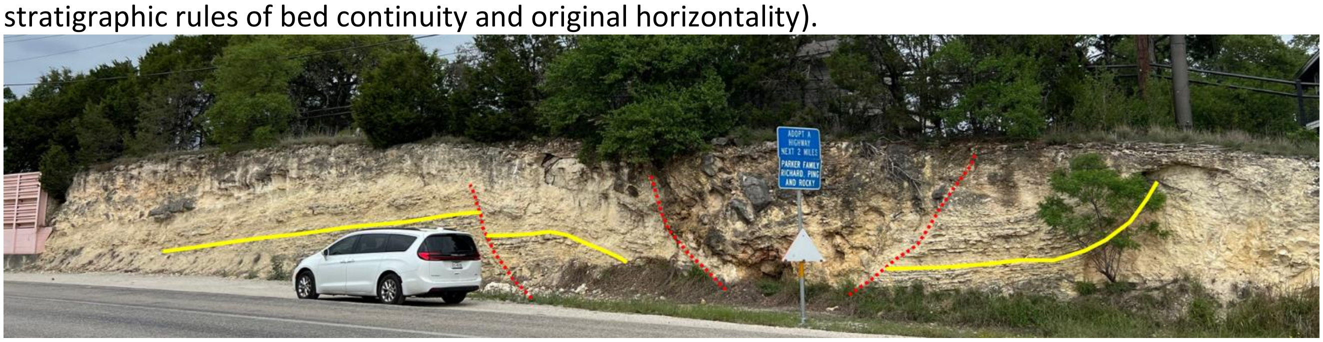


The Edwards Group is divided into the Kainer Fm. and the overlying Person Fm. During our field trip today, we will see examples of the Person Fm along Hwy 46.

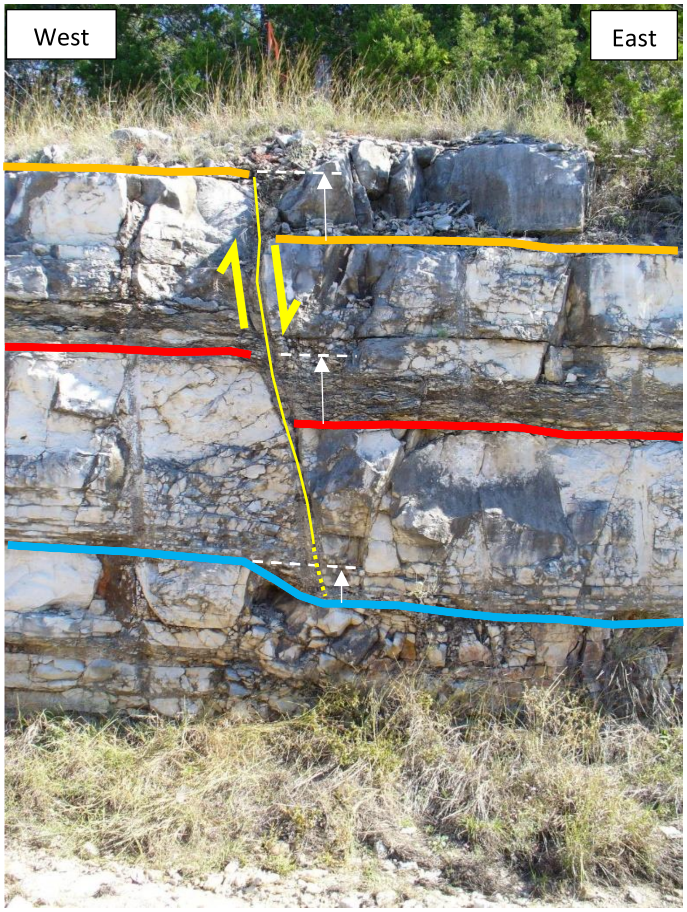
Members of the Person Formation include:

1. Regional Dense Member: The basal, persistent, dense, argillaceous deep-water limestone that acts as a confining bed.
2. **<u>Leached and Collapsed Members:</u>** Overlying the regional dense member, this unit consists of tidal and supratidal limestone and dolomite packstone with significant honeycomb porosity and collapse breccia due to karst dissolution and erosion.
3. Cyclic and Marine Members: The topmost unit, characterized by reefal limestone, dolomitic grainstone, evaporite beds, and argillaceous limestone, with considerable porosity and thickness variations.

Stop 3 – Cretaceous Person Fm. showing a thin-bedded, argillaceous unit overlain by a more massive, thickly bedded limestone. Behind the blue sign is evidence of a karsted zone, which was possibly a small cave, where the roof collapsed. The reason for possible karsting at this spot is the presence of several small displacement faults. Faulting is evident through identification of the actual fault planes themselves as well as offset of previously adjacent beds and folding of originally horizontal beds (this interpretation employs the stratigraphic rules of bed continuity and original horizontality).

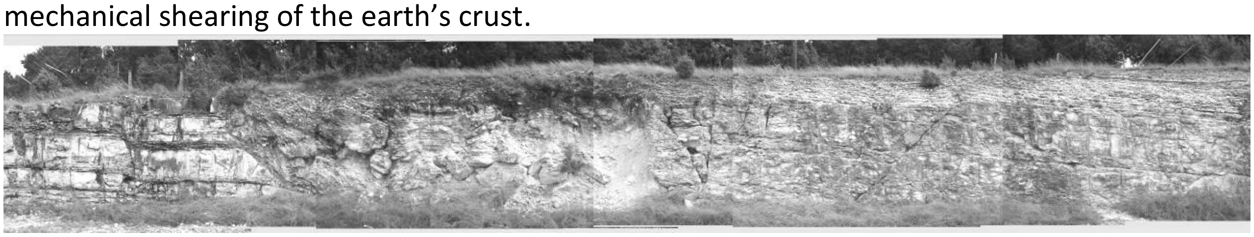


Stop 4 – This is still the Person Fm., but has a very different bedding character than at stop #3. Here there are with thin shaly beds alternating with cleaner, porous limestones, which make for good markers for fault offset.



This fault near the west edge of stop 4 is an exceptional observational opportunity for those interested in structural geology. The yellow line is a normal fault whose shear offset is dying out toward the bottom of the outcrop. At the fault tip, there is still some shear offset of the beds on the left and right side (right side down), but that offset is accommodated by folding and not breakage of the layer or slip along a fracture. This outcrop demonstrates that faults don't have constant slip along their surfaces, and that you can expect folding near the fault tip as offset dies out. This fault shows a maximum of about 6 inches of shear offset at the top of the outcrop that tapers to nothing over a vertical distance of about 3 ft, but even after the fault dies, the layers are shifted a couple inches moving from left to right, accomplished by folding.

There are other small scale faults with inches to feet of shear offset along this outcrop, but taking a broader view it becomes clear there is also a much bigger fault that must have 10's of feet of shear offset, as the geological layering to the western end of the outcrop is totally different than that toward the east (the stratigraphic layering doesn't have a match from one side of the outcrop to the other). The fault zone itself shows intense fracturing of the layers into large blocks (called brecciation), possibly due to more karsting focused along the fault plain, but also due to the mechanical shearing of the earth's crust.



STOP #5

Along FM 2722, northwest of New Braunfels

Located 5 miles north of intersection of Hwy 46 and FM 2722, on the east and west side of FM 2722

Geologic Unit at Stop:

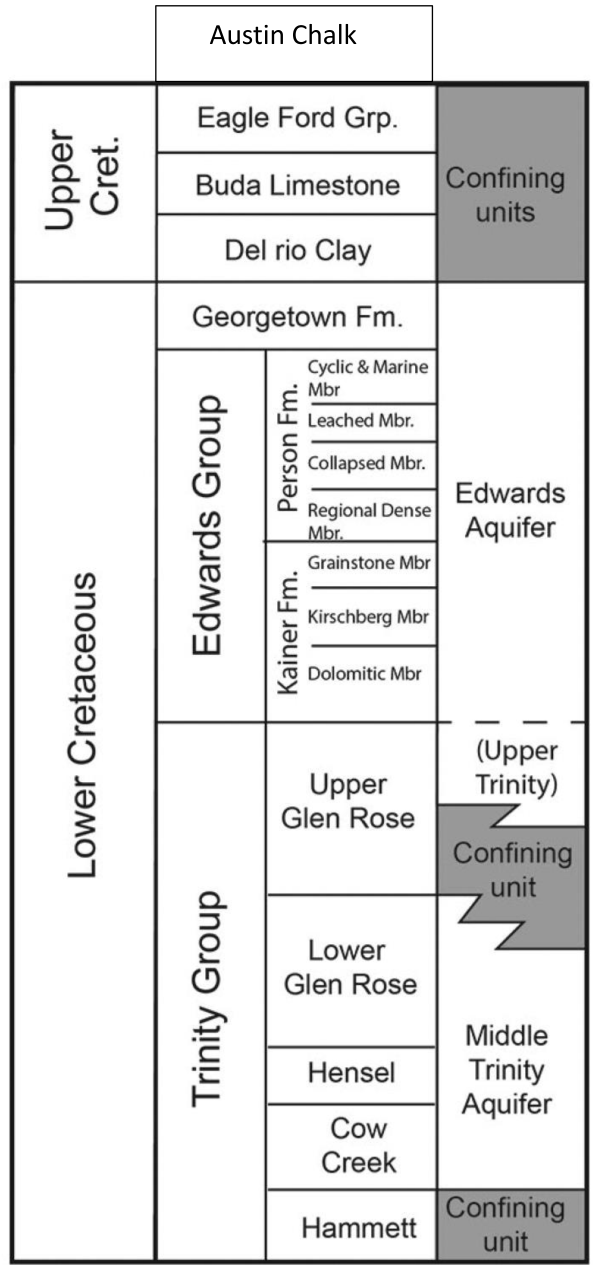
- Glen Rose Limestone (Lower Cretaceous)

The Glen Rose Limestone is the lower confining unit for the Edwards Aquifer.

The Glen Rose Formation is a shallow marine to shoreline geological formation from the lower Cretaceous period exposed over a large area from South Central to North Central Texas. The formation is most widely known for the dinosaur footprints and trackways found in the Dinosaur Valley State Park near the town of Glen Rose, Texas, southwest of Fort Worth and at other localities in Central Texas.

The formation consists mostly of hard limestone strata alternating with marl or marly limestone. Typical fossils include gastropods, sea urchins, bivalves and formaminifers (single-celled marine organisms).

Stratigraphy



Just 5 miles north of this spot, spectacular exposures of the Glen Rose Limestone are visible at Canyon Lake Gorge - a 64-acre geological preserve, created by a massive flood in 2002 that carved a gorge into the landscape, exposing the Glen Rose Limestone. You can visit the gorge for hiking. Details: https://canyongorgetours.com/

This Glen Rose Fm. stop highlights sedimentation that can be caused by faulting. For a normal fault, which is the dominant type of fault found in this area, the hanging wall is the upthrown block relative to the footwall, and this offset creates topographic relief traversing from one side of the fault to the other. Topographic relief drives erosion, breaking pieces of rock from the higher elevation areas and transporting them to lower elevation due to weathering and gravity. The rock pieces are largest near the source of the topographic relief (the fault scarp, which is the fault plane exposed at the earth's surface), and they get smaller as they are transported further. This collection of sediments and rubble is called an alluvial fan when it occurs on dry land, and it would be called a submarine fan if it were created under water in a lake or ocean (fault scarp diagram from Gray et al., 2022, in Earth Surface Dynamics).

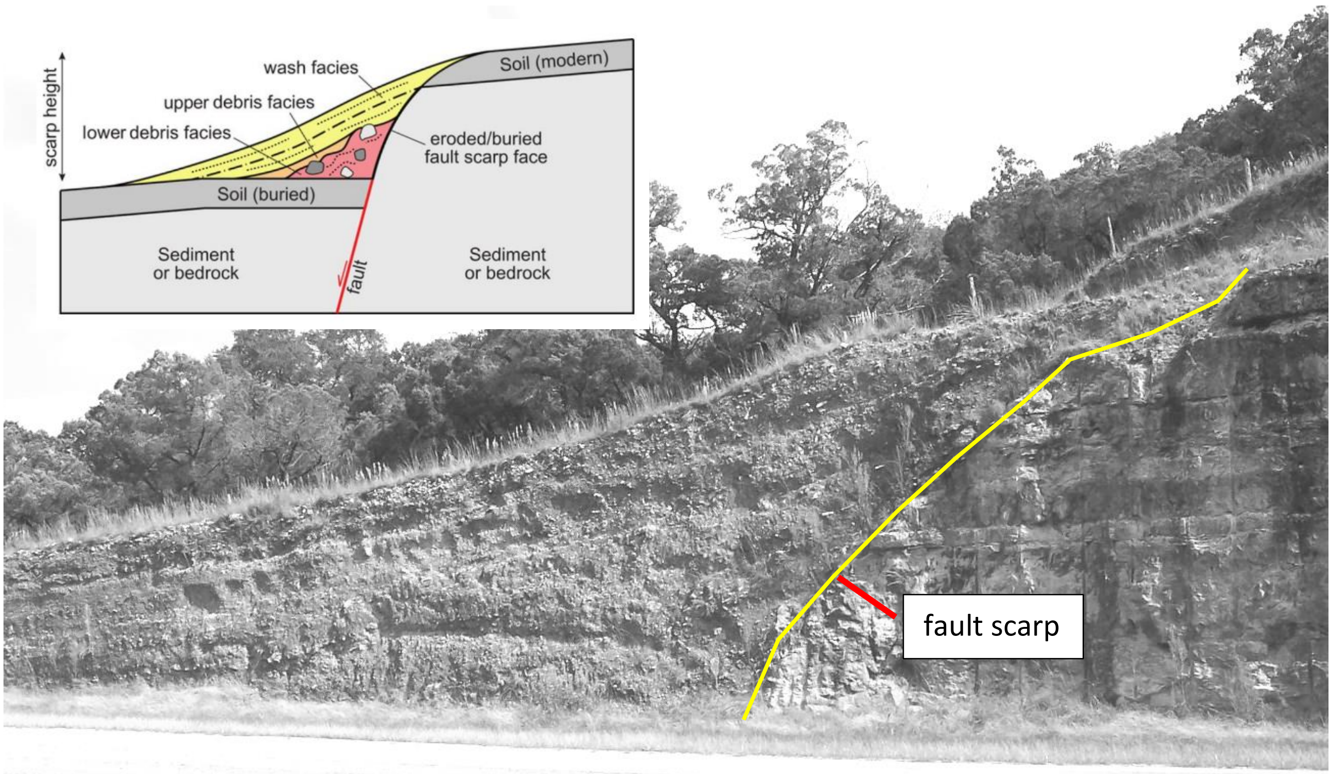


photo by Jon Olson

LUNCH STOP

Ottine, Texas (pronounced "Ah-teen") and Palmetto State Park

Ottine, Texas is a small town about 60 miles east of San Antonio and 15 miles north of Gonzales. Ottine is home to Palmetto State Park, known for its unique landscape and sightings of the mysterious "Thing", a creature that can outrun dogs and man! In addition, a long history of rehabilitation treatment characterizes the area as naturally heated, mineral-rich waters are found here. The land for Palmetto State Park was acquired by deeds from private owners and the City of Gonzales in 1934–1936 and was opened in 1936. The park is named for the dwarf palmetto *(Sabal minor)*, which grows abundantly in the park. Below are some notes on some of the features you can see at our lunchstop.

As you enter Palmetto State Park at the park headquarters, you will see Ottine Mineral Springs across the street and beyond.

Warm Springs Rehabilitation System and Ottine Mineral Springs

Decades after the last patient checked out of Warm Springs Rehabilitation Hospital, the public can now soak in the naturally heated, mineral-rich waters of Ottine Mineral Springs.

Everything at Ottine Mineral Springs centers around the hot water that burbles up on the 60-acre grounds. There are seven outdoor soaking pools and lots of lounge chairs, plus spa treatment rooms and a café that serves wood-fired pizzas, salads, and margaritas. Longer term plans call for hotel rooms in one of the historic buildings; saltwater soaking pools; a steam room, a type of Turkish steam bath called a Hamman; and a "snow room."

The history here runs as deep as the water, which a crew of wildcatters from Houston hit at 1,550 feet while drilling for oil back in 1909. The 105-degree water has been gushing up ever since, at the rate of about 200,000 gallons a day. The property wasn't developed until 30 years later, during the polio epidemic of the 1930s, when eight businessmen from Gonzales surmised that the mineral-rich waters could benefit people who contracted the disease. The Gonzales Warm Springs Foundation for Crippled Children took in its first patients in 1941.

The facility expanded several times. By 1947 the staff was caring for more than 400 patients a year in Spanish-style structures near the San Marcos River, just down the road from Palmetto State Park. It was the only polio treatment center at the time that wasn't segregated, and no patient was turned away based on race, religion, or ability to pay.

With the development of the Salk vaccine in 1952, the hospital's mission shifted away from polio and toward treating people with neuromuscular disabilities caused by injury or disease. The hospital closed its Ottine location in 2002 and moved to Luling, where it still operates. The site went up for sale and sat there until 2017, when it was purchased by the Scott family, owners of Ojo Caliente hot springs resort in New Mexico. To gauge interest in a wellness center, the new owners built two outdoor tubs and opened a private, members-only soaking club. It was a hit.

On June 1, 2025, five new soaking pools, including a large one surrounded by lounge chairs and pool umbrellas, and a cold plunge opened to the public. Besides relaxing in the pools and spa, guests can sign up for yoga, meditation, or forest bathing experiences.

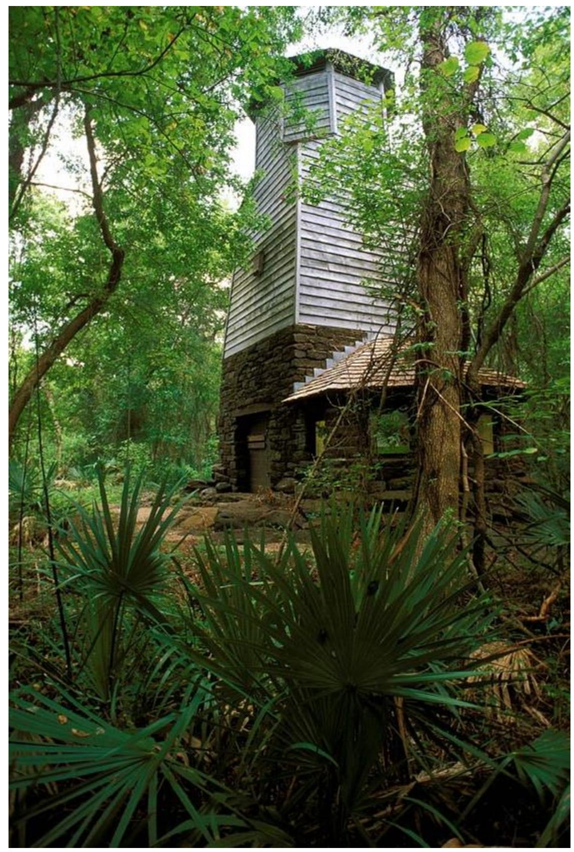
[https://texashighways.com/travel/inside-the-revitalized-historic-ottine-mineral-springs/ August 11, 2025]

We will be stopping at the Refectory for lunch. Please be sure you listen for the time to be ready to depart from the park – the time may vary from what is published in the agenda.

Refectory

No visit to a Texas state park of this era (Palmetto opened in 1936) is complete without taking a moment to appreciate the handiwork of the Civilian Conservation Corps, who labored between 1934 and 1937 on the usual firepits and picnic tables but also buildings like the refectory (lower left), a solid structure whose lichen-festooned sandstone (the Reklaw Formation, local reddish-brown – think hematite - sandstone) makes it look as if it has always been there, deposited long ago by a rampaging river (in 1998 a flood covered all but the very top of the roof). Along the interpretive trail is the CCC-built water tower (lower right).

[https://www.texasmonthly.com/travel/creatures-abound-palmetto-state-park/ April, 2019]



During lunch, you may wish to take a short hike.

Hiking Palmetto Interpretive Trail

A good option for a hike, starting at the Refectory (4 on the map) is to take the Ottine Swamp Trail (beware the “Thing” – see below) from the parking lot to Park Rd. 11. At the road, turn left until you get to the Palmetto Interpretive Trail. Follow that train toward the Water Tower (6 on the map) and complete the trail circuit back to Park Rd. 11, where you will turn right and walk back to the Refectory along the road. You should plan about 20 minutes for your walk (you could walk fast and do it in about 10 minutes). The Palmetto Interpretive Trail is one of the highlights of the park, winding its way through a landscape of dwarf palmettos that look like something out of the movie “Jurassic Park” rather than Central Texas.

Palmetto State Park, TX

The Swamp Thing of Ottine: Your Friendly Neighborhood Bigfoot

Bogs. Dense patches of trees. Extinct mud boils. Murky lagoons. You can probably guess where this is going, especially when you throw in heavy skies and chill winds and sporadic drizzle. [https://www.texasmonthly.com/travel/creatures-abound-palmetto-state-park/ April, 2019]

Parts of Ottine and Palmetto State Park more often resemble a primordial rainforest, boasting flora and fauna that more likely would be found in the Florida Everglades or the Louisiana gator country. It is here that locals and travelers alike claim to have encountered “Bigfoot” or some type of ape-like creature. Cryptozoologists claim that the habitat matches that of areas with other “Bigfoot” sightings.

Those who claim to have seen the Swamp Thing state that the creature is 4-8 feet tall and covered in fur that is some combination of brown, black, and grey. All reported sightings have suggested that the creature walks upright on two legs like a human. Some locals claim there are multiple “Swamp Things” and they can be heard calling or signaling to each other during the night.
[https://texashillcountry.com/swamp-thing-ottine-bigfoot/ August 2018]

Why are There Swamps, Bogs and Palmettos at the Park? The Geology.
The park's swampy conditions allow for a lush, tropical environment to thrive, giving rise to its namesake, the dwarf palmetto. Bogs exist where organic matter accumulates in the wetland area faster than it can decay – the result is a wetland that is highly acidic with low oxygen levels. While the palmettos and swamps above ground are what this park is known for, it's actually what's going on beneath the surface that makes their existence here possible at all.

Rain and the occasional flood along the San Marcos River provide moisture for the plants in this area, keeping the soil nice and damp. The floods also deposit rich soil in the floodplain. The combination of fertile river soil and abundant water makes this an ideal place for plant life to thrive. Water collects in the soil and in low-lying areas, forming the swamps and bogs you can see around the park.

Beneath the soil lies the dense clay of the Reklaw Formation. This layer is so impermeable that it doesn't absorb water easily, which means rain and flood waters remain trapped in the soil above. Because of this, the soil stays very damp and water often collects in low-lying areas, creating swamps and bogs.

Source: Palmetto State Park, trail sign (photo by Hilary Olson)

Underground faults and fractures allow water that has accumulated deeper in the earth, beneath the Reklaw Formation, to rise to the surface. The water bubbles up in the form of artesian springs, creating additional bodies of water that feed the plants and animals here.

The Need for Water, the Guadalupe-Blanco River Authority and Aquifer Storage and Recovery (ASR)
In 2019, the 86th Texas Legislature passed House Bill 721, which mandated that the Texas Water Development Board work with interested parties to conduct studies of Aquifer Storage and Recovery (ASR) for some regions in Texas and to report the results of such studies to regional water planning groups and interested parties. Palmetto State Park is right in the middle of the activity (see below)!

The first study selected to fulfill this legislative mandate was an aquifer characterization of the Carrizo-Wilcox Aquifer to support the Guadalupe-Blanco River Authority (GBRA) in its implementation of the ASR component of the Mid-Basin Water Supply Project. The GBRA plans were to inject treated surface water from the Guadalupe River into the Carrizo-Wilcox Aquifer when availability from the river exceeds customer demand and there is available capacity at the new water treatment facility.

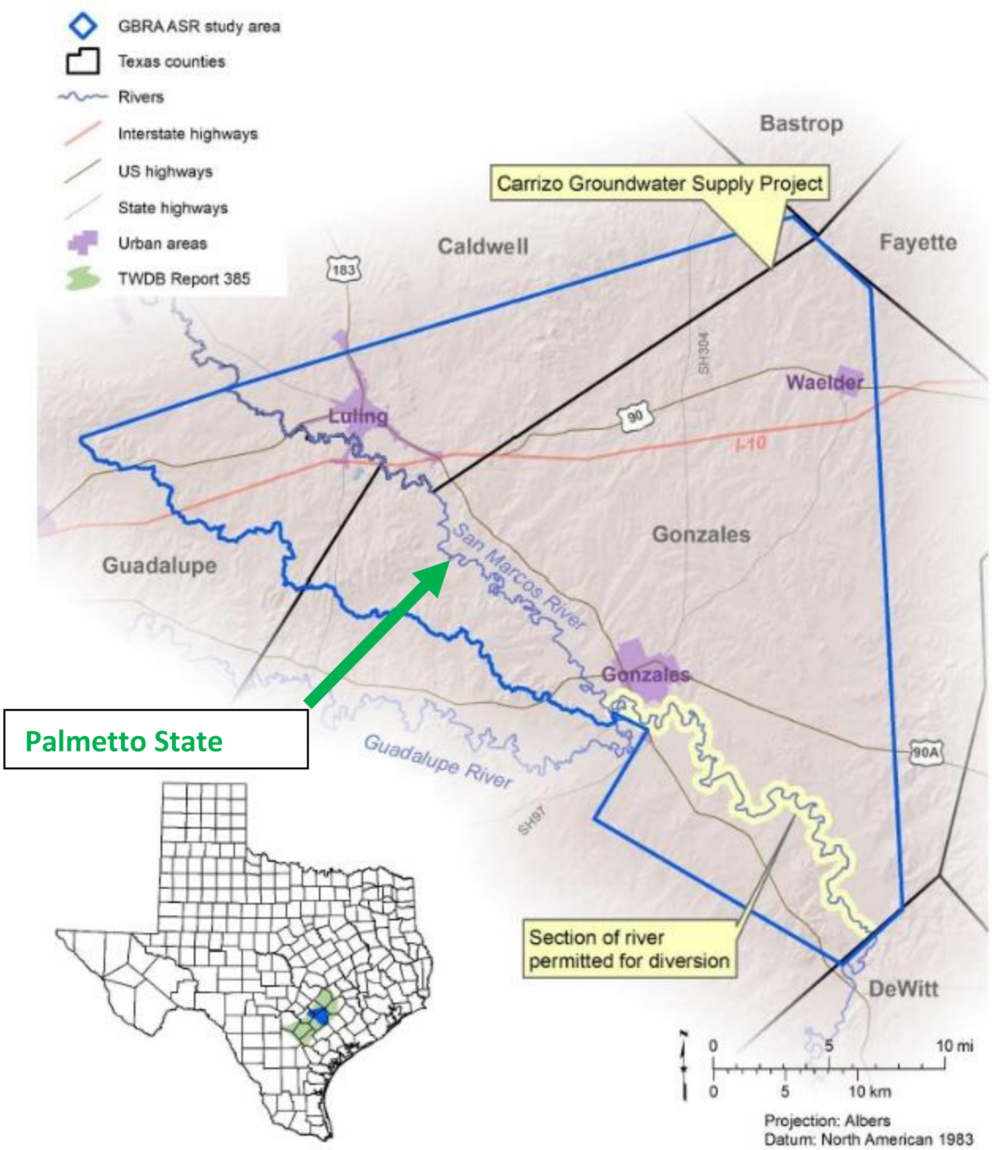


Figure 3-1. **Aquifer characterization study area location map.**

Croskrey, A., Golab, J. & D. Collazo. (2022).

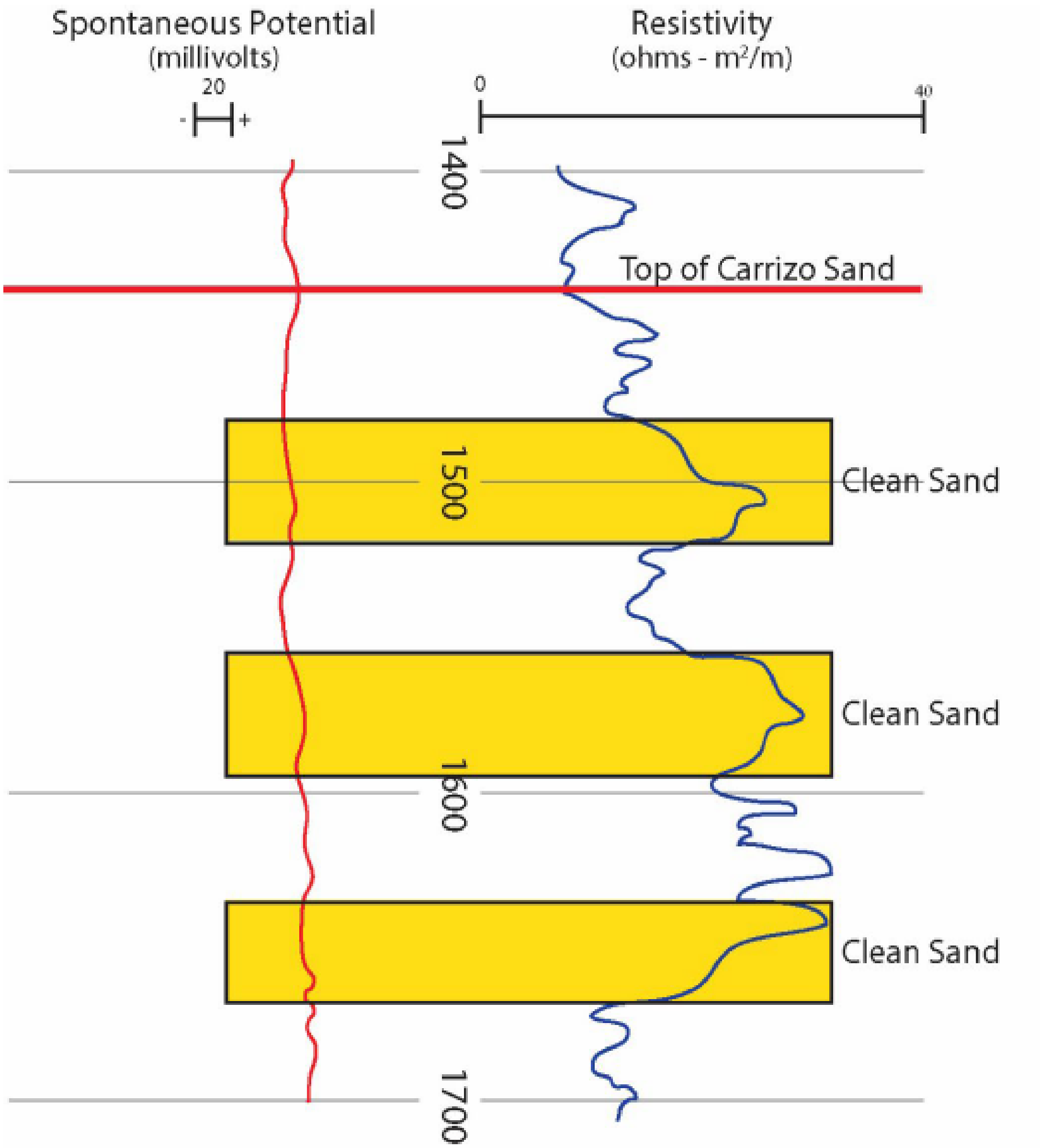
Carrizo Sands and Wilcox Group – Stratigraphic Considerations for Aquifer Storage & Recovery

The aquifer of interest in the study area was mapped as two separate units: the Wilcox Group and the Carrizo Sand. Blue arrows and bars highlight the Carrizo Sand and Wilcox Group that comprise the Carrizo-Wilcox Aquifer. Red arrows and bars highlight the confining units to the aquifer, the Reklaw Formation (upper confining unit) and the Midway Group (lower confining unit).

Epoch	Group	Formation	USGS aquifer name	Texas aquifer name	Aquifer system
Eocene	Jackson	Caddell	Vicksburg-Jackson confining unit	Yegua-Jackson Aquifer	Upper Coastal Plains
		Moodys Branch			
		Hiatus			
	Claiborne	Yegua	Upper Claiborne Aquifer		
		Cook Mountain	Middle Claiborne confining unit	Confining unit	
		Hiatus			
		Sparta Sand	Middle Claiborne Aquifer	Sparta Aquifer	
		Weches		Confining unit	
		Hiatus			
		Queen City Sand		Queen City Aquifer	
		Reklaw	Lower Claiborne confining unit	Confining unit	
		Hiatus			
		Carrizo Sand	Lower Claiborne – upper Wilcox Aquifer	Carrizo-Wilcox Aquifer	
	Wilcox Group	Hiatus			
		Sabinetown			
Paleocene		Rockdale	Middle Wilcox Aquifer		
		Seguin			
	Midway	Wills Point	Midway confining unit	Confining unit	

Croskrey, A., Golab, J. & D. Collazo. (2022). Aquifer Storage and Recovery Report: Carrizo-Wilcox Aquifer Characterization for Eastern Gonzales and Parts of Caldwell and Guadalupe Counties, Texas.

Carrizo Sands and Wilcox Group – Lithologic Considerations for Aquifer Storage & Recovery
There are approximately 362 square miles of Wilcox Group strata less than 2,000 feet deep (maximum economical drilling depth) within the study area. **Wilcox Group** net sands in this area range from zero to 920 feet of accumulated sands. These **sand units are often less than 100 feet thick** and vertically isolated between shale layers. The Carrizo Sand is above the Wilcox Group with approximately 324 square miles of Carrizo Sand strata that are less than 2,000 feet below the surface in the study area. Net sands in this portion of the **Carrizo Sand** range from zero to 623 feet of accumulated sands. These porous sand units **can be over 500 feet thick and highly productive**.



Lithology of the sandstone units in the Carrizo Sand interpreted from a geophysical well log in Gonzalez County, Texas (BRACS ID 15379). Spontaneous potential and deep resistivity values shown. Typical high-resistivity massive sandstone units are highlighted. (Croskrey, A., Golab, J. & D. Collazo, 2022)

Carrizo Sands and Wilcox Group – Groundwater Considerations for Aquifer Storage & Recovery

The **Wilcox Group groundwater** in the study area ranges from fresh to very saline. Salinity tends to increase with depth. The stacked and isolated nature of the sand units within the Wilcox Group means that it is common for a single well to have more than one salinity class interval as the well depth increases. Because of these stacked intervals, **there were no completely fresh zones in the Wilcox Group** mapped in the study area. **Carrizo Sand** groundwater ranges from fresh to moderately saline in the study area. The **area of fresh water in the Carrizo Sand is much more pervasive** than in the Wilcox Group due to its **higher porosity**. The Carrizo Sand also has fewer stacked salinity intervals in a single well, likely due to having **higher vertical connectivity than the Wilcox Group**. Salinities within both geologic formations appear to be influenced by geologic features such as faults and depositional centers.

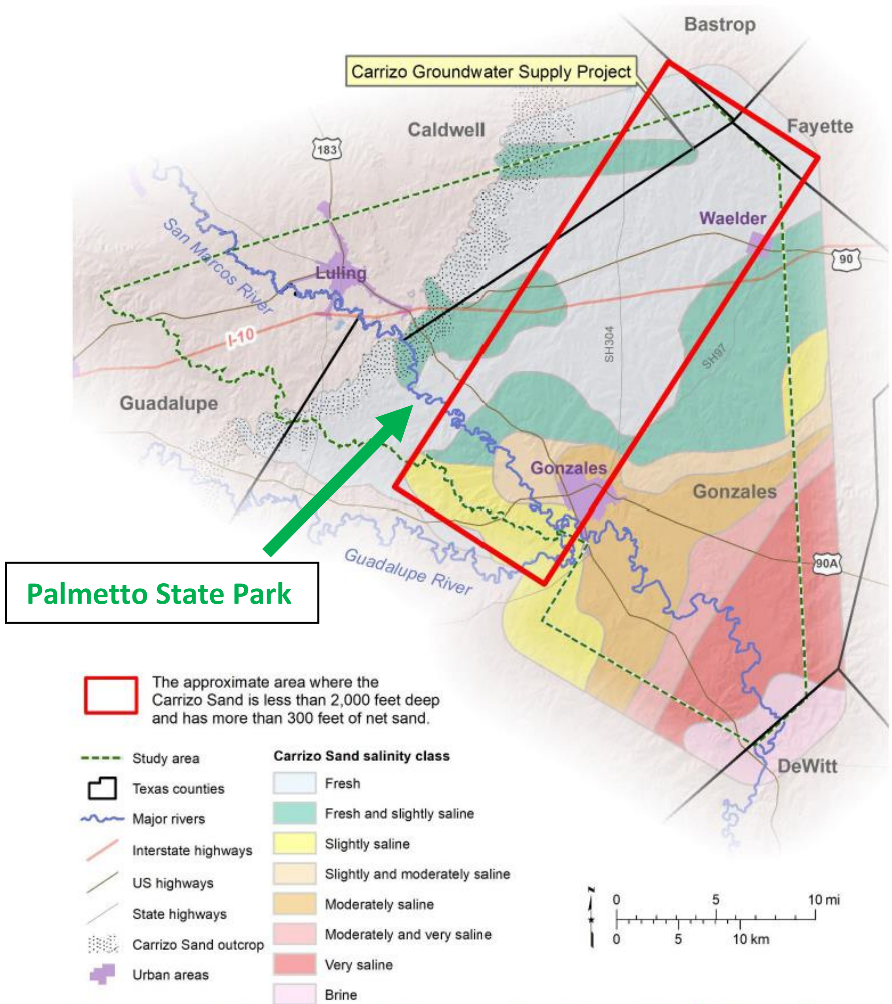


Figure 6-6. Study area location map with Carrizo Aquifer production well field highlighted. Red rectangle indicates the approximate area of the confined portion of the Carrizo Sand that contains at least 300 feet of net sands within 2,000 feet of the surface.

When studies considered the occurrence, quantity, quality, and availability of the Carrizo-Wilcox Aquifer for potential ASR storage in the study area, reporting identified a 9-mile-wide and 25-mile-long swath (~200-square-mile area) of the **Carrizo Sand with the most favorable hydrogeological characteristics**. In this area the Carrizo Sand is shallower than 2,000 feet, has vertical confinement, and has at least 300 feet of accumulated sands. Vertical confinement of the Carrizo Sand is provided by the overlying Reklaw Formation and a regional clay layer in the underlying Wilcox Group and helps control the movement of injected water in an ASR project (Croskrey, A., Golab, J. & D. Collazo, 2022).

Texas has launched its $6 billion WaterSecure Project for Aquifer Storage & Recovery, and Initiative of the Guadalupe-Blanco River Authority

TEXAS UNVEILS $6 BILLION WATERSECURE PROJECT: A BLUEPRINT FOR FUTURE WATER SECURITY

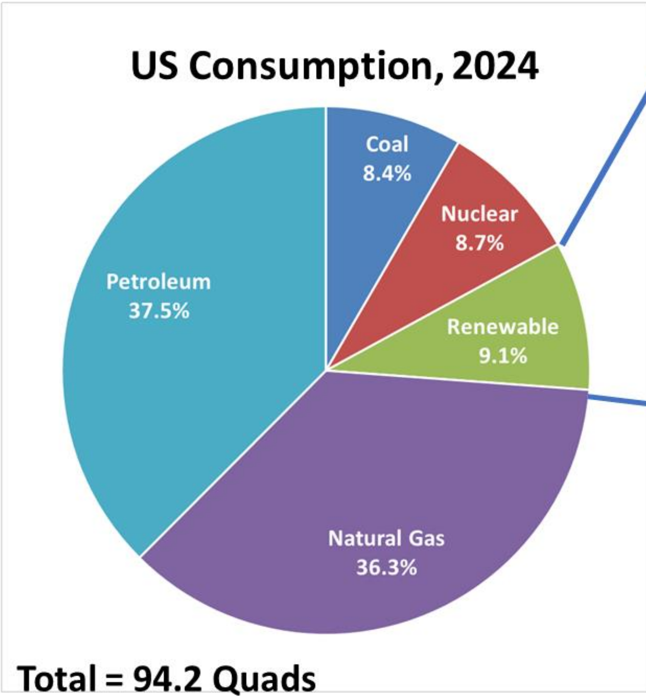
Announced in May of 2025, Texas has launched its $6 billion WaterSecure Project, led by the Guadalupe-Blanco River Authority (GBRA), aiming to ensure long-term water security for millions of residents across Central and South Texas.
Here's what the project includes:

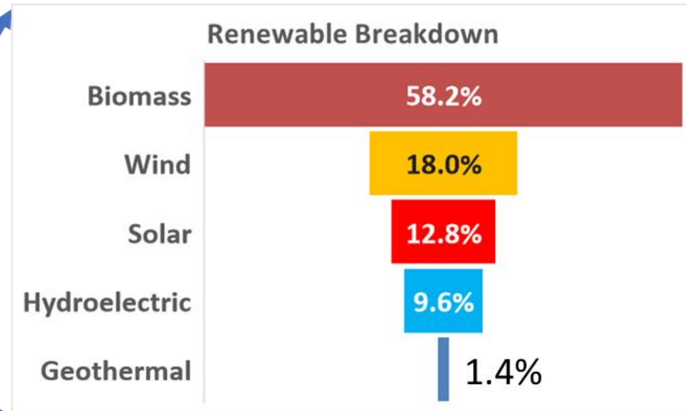
- Construction of a brand-new reservoir on the Lower Guadalupe River
- Over 250 miles of pipeline to transport water across multiple counties
- A cutting-edge water treatment facility that meets future capacity needs
- Desalination plants to treat brackish water sources and reduce dependency on freshwater
- Underground storage solutions to help manage drought conditions more effectively
- Initial delivery capacity of 100,000 acre-feet of water annually by 2033, with
- Expansion plans through the 2040s

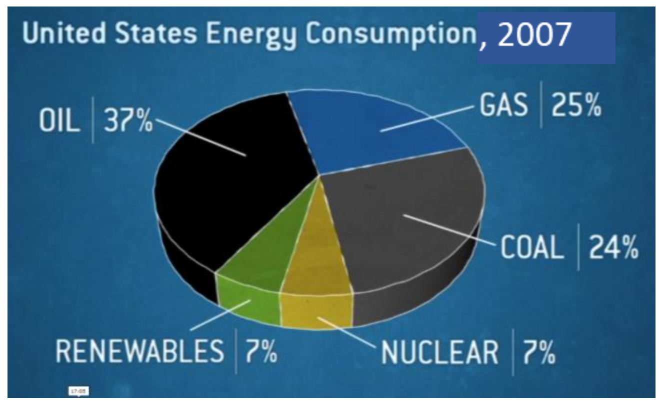
[https://genviss.in/texas-watersecure-project/]

APPENDIX – Resource Materials

General Energy Information

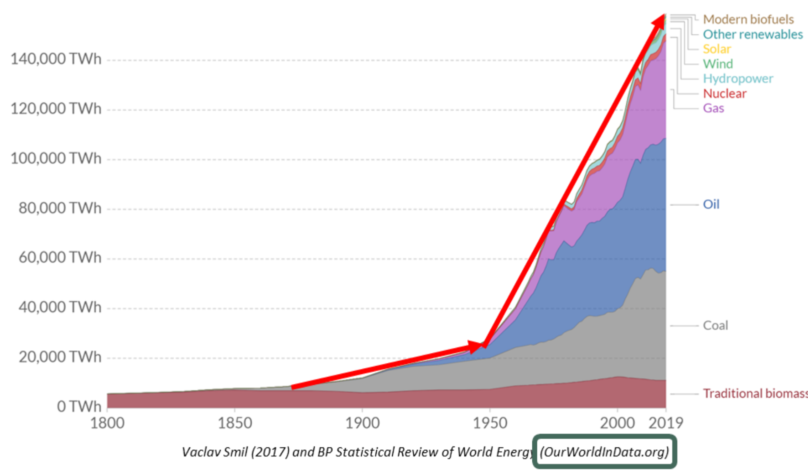






Increasing population, increasing technology, increasing demand

Year	Population	Energy
1870	1.3 B	8.5 Twh
1950	2.5 B (2x)	28.5 Twh (3x)
2019	7.7 B (3x)	173 Twh (6x)



terra (SI unit) = 10^{12} (trillion)
1 TWh = 1 Terrawatt-hour
1 TWh = 3.6×10^{15} J

watt = (energy/time) = unit of power
watt·hour = (energy/time) * time = energy

The University of Texas at Austin
Hildebrand Department of Petroleum and Geosystems Engineering
Cockrell School of Engineering

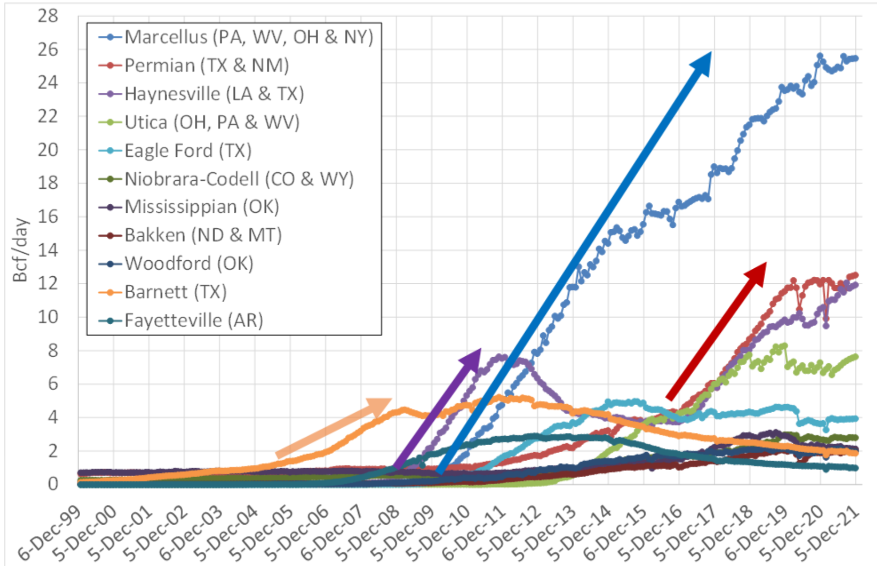
Be an Energy Leader. Be a Longhorn. choose energy The University of Texas at Austin

LEADING TEXAS ENERGY OIL & GAS ★ COAL ★ PIPELINES

US Dry Shale Gas Production

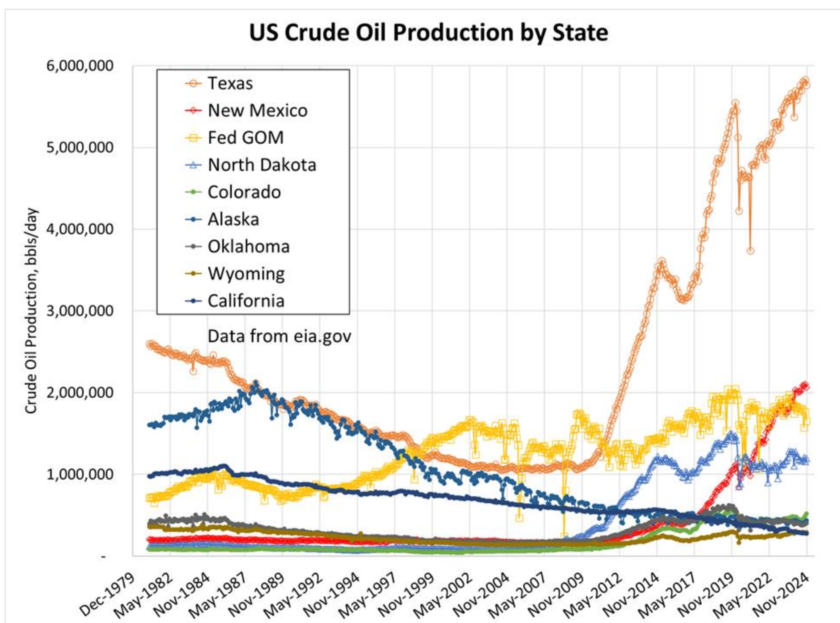
- Barnett started everything (Forth Worth Basin and Mitchell Energy)
- Haynesville second (LA)
- Marcellus the biggest (PA)

Marcellus = *(26 x 10^9 scf/day)*
x (1037 BTU/scf)
x (1 BOE/5.8x10^6 BTU)
*= **4,649,000 BOE/day***



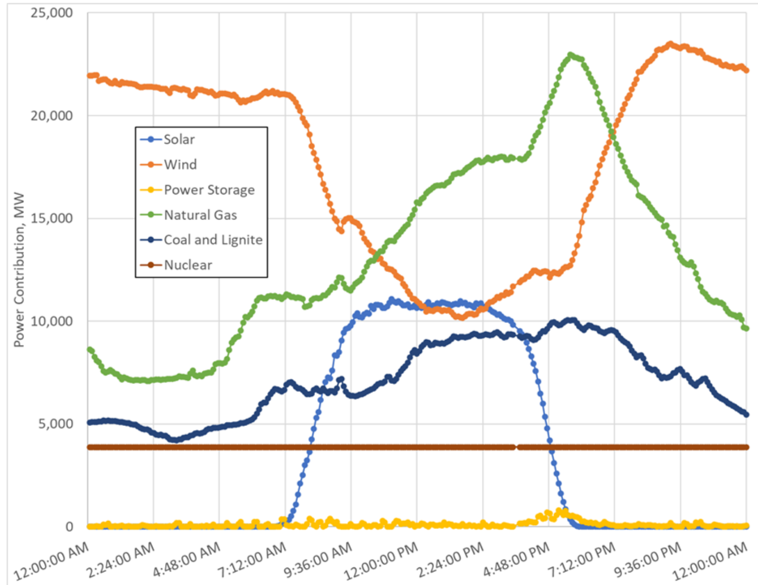
US Crude Oil Production by State

- shale impact – Texas, ND, NM, OK
- Federal GOM has been climbing slowly since 2012, unrelated to shale
- Alaska and California decline because no shale



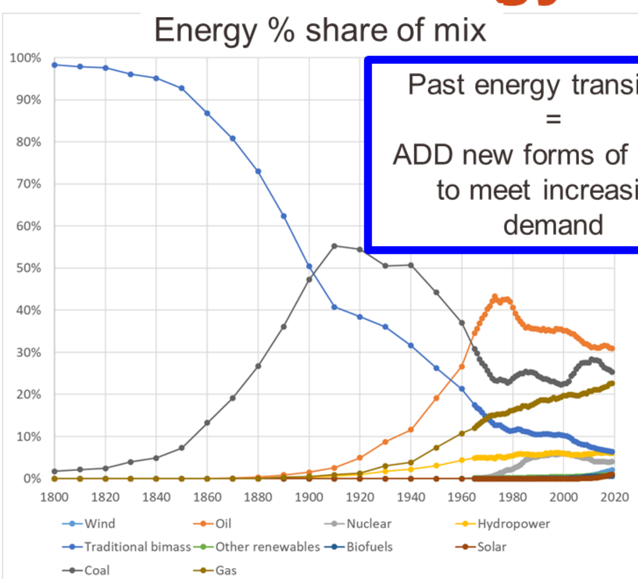
ERCOT Energy Mix, Nov 6, 2023

- wind strong at night
- solar consistent during day, matches wind minima
- late afternoon gap in renewables (solar goes down before wind comes up)
- natural gas fills gap mostly
- storage contribution minimal (TX has 2nd largest capacity in US)

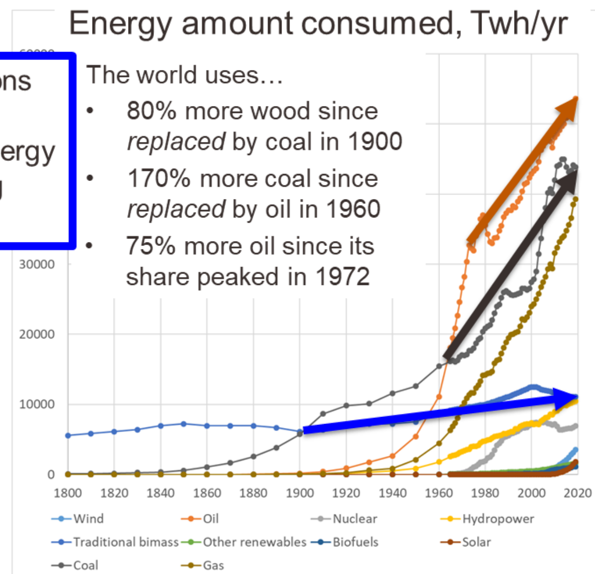


Energy Transition?

Vaclav Smil (2017) and BP Statistical Review of World Energy (OurWorldInData.org)



Past energy transitions
=
ADD new forms of energy to meet increasing demand

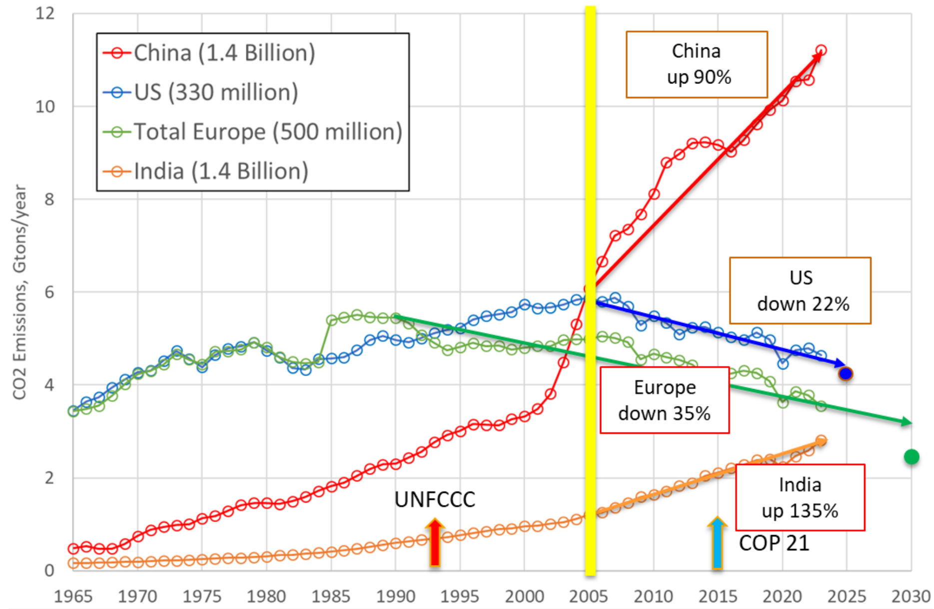


The world uses…
- 80% more wood since *replaced* by coal in 1900
- 170% more coal since *replaced* by oil in 1960
- 75% more oil since its share peaked in 1972

World CO_2 Emissions

- 35 Gigatons annual world CO_2 emissions
- top 4 countries / regions
- emissions impacted by
  - population
  - technology
  - environment

data from EI Statistical Review of World Energy

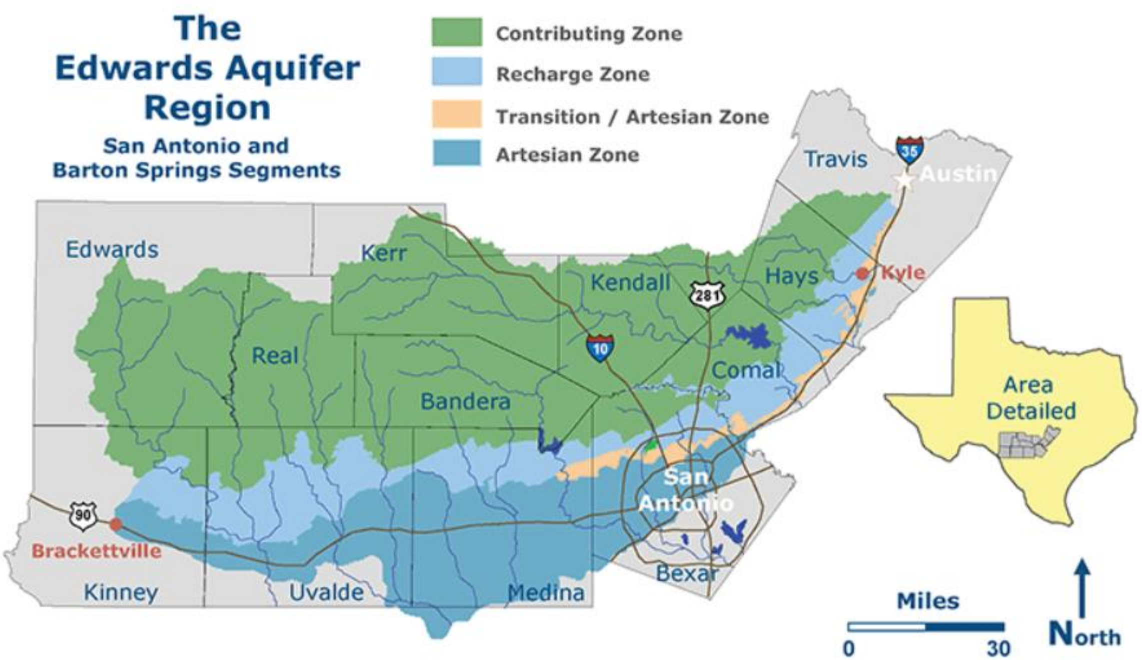


Edwards Aquifer

The Edwards Aquifer is a unique groundwater system and one of the most prolific artesian aquifers in the world. It is one of the greatest natural resources on Earth, serving the diverse agricultural, industrial, recreational, and domestic needs of more than two million users in south central Texas.

Within this region and poised on the edge of the vast Chihuahuan desert lies San Antonio, America's 7th largest city. Water from the Edwards is the reason that 18th century Spanish missionaries were able to establish footholds like the Alamo here on the New World frontier. For over two centuries, San Antonio and many other cities in the surrounding region were able to grow and prosper without developing surface water or other water resources because of the Edwards Aquifer.

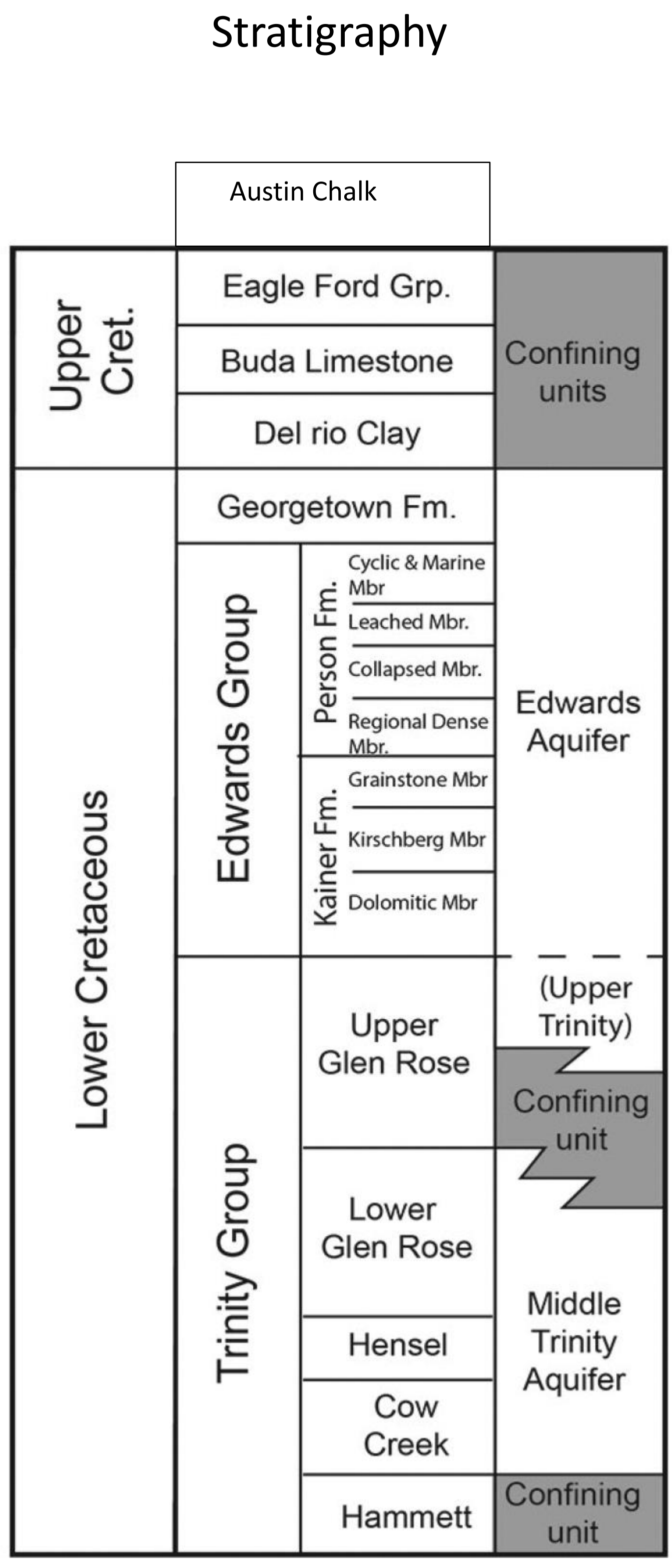
In recent decades, demand for water in the region increased well beyond the Aquifer's capacity to provide for a growing population. Increasing concerns about the welfare of endangered species and regional economies that depend on springflows from the Aquifer became defining issues for central Texas. For these reasons, waters users of the region have faced tough and controversial decisions about who owns, controls, and uses Aquifer water. [https://edwardsaquifer.net/index.html]



The Edwards Aquifer is an underground layer of porous, honeycombed, water-bearing rock that is between 300-700 feet thick. It includes the Edwards and some associated limestones. The San Antonio segment of the Aquifer extends in a 160 mile arch-shaped curve from Brackettville in the west to near Kyle in the northeast, and is between five and 40 miles wide at the surface. [https://edwardsaquifer.net/intro.html]

Stratigraphy

The rock formations of the Edwards Group (including the Kainer Fm. and the overlying Person Fm) and the Georgetown Fm. comprise the Edwards Aquifer. The Del Rio Clay and overlying Buda Limestone and Eagle Ford Group comprise the upper confining units to the aquifer. The lower confining unit is the Glen Rose Formation. We will see the aquifer, as well as its overlying confining unit and its underlying confining unit on this field trip.



Stratigraphic section from: Saribudak, M., 2016, Geophysical mapping of Mount Bonnell fault of Balcones fault zone and its implications on Trinity-Edwards Aquifer interconnection, central Texas, USA, The Leading Edge.

Geologic Setting

To understand the formation of the Edwards Aquifer, we must first go back 105 million years – to the Age of Dinosaurs. At that time, the region was covered by a shallow sea. That sea held a vast collection of life. Coral, forams, gastropods and other creatures composed of carbonate matter. Algae and calcium carbonate also precipitated from the warm ocean waters forming thick carbonate sediments. 65.5 million years ago, a mass extinction event occurred and almost all of the dinosaurs disappeared (with the exception of birds) and made way for the Age of Mammals.

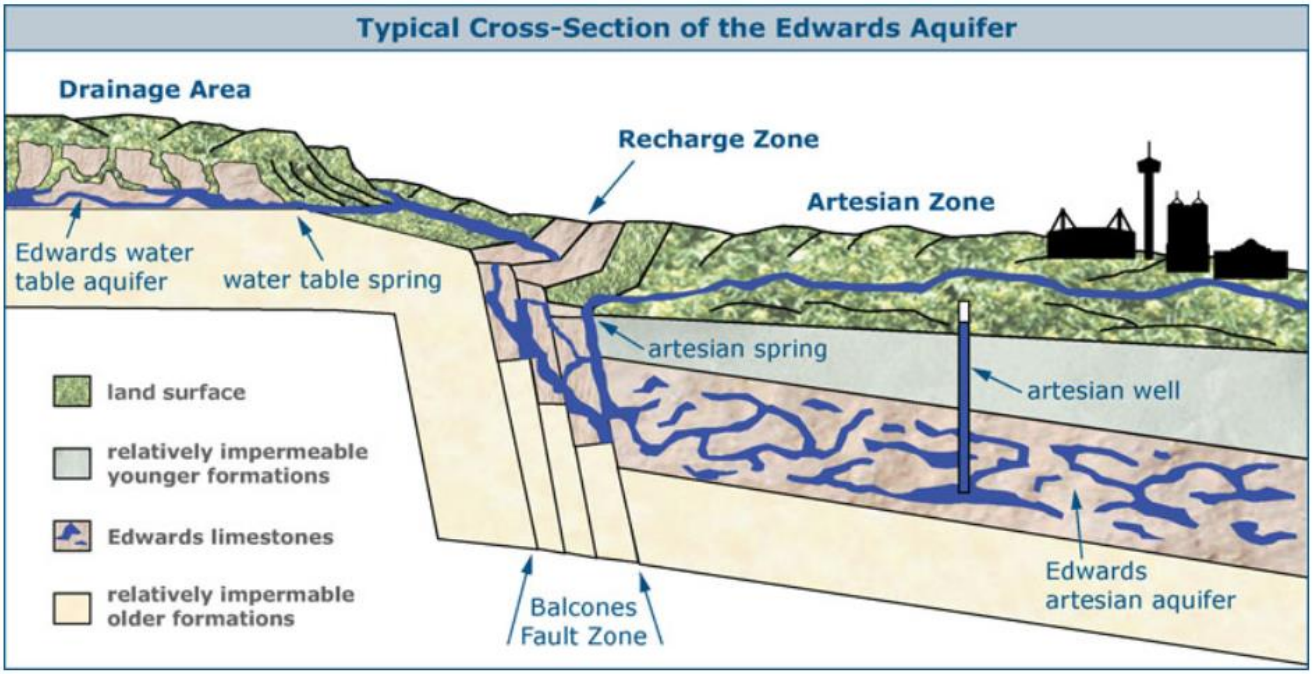
A shallow seaway covered the area of Texas where the Edwards Group was deposited.
[https://www.wittemuseum.org/tracks-spring-2023-texas-treks-through-time/]

Over millions of years, plate tectonics resulted in southcentral Texas being uplifted and the Gulf of Mexico to subside. The resulting heat and pressure caused the soft carbonate muds to turn into the hard limestone that forms the Edwards Plateau. The hinge line between the uplifted Edwards Plateau and the subsiding Gulf of Mexico caused the rocks to fracture and fault, forming the Balcones Fault Zone and the southern edge of the Texas Hill Country. The Edwards Limestone that forms the Edwards Plateau has been dropped down by the faults and forms the recharge zone of the Edwards aquifer.

Rainfall absorbs carbon dioxide from the atmosphere and from decaying organic material in the soil to form carbonic acid – the same gas found in soda drinks. This weak acid, over millions of years, dissolves the limestone. The water flows through the fractures, faults, and pores in the rock, slowly dissolving it to form conduits and caves. A cave is a natural underground space large enough for a person to enter. A conduit is bigger than the diameter of a hose and smaller than a cave. The area where the rock is fully saturated with water, and can yield sufficient useful quantities is called an aquifer. [https://www.edwardsaquifer.org/education/learn-about-the-aquifer/#advgb-tabs-tab1]

The Three Zones of the Edwards Aquifer

The Aquifer is divided into three main zones: the drainage area (a.k.a. catchment area or contributing zone), the recharge zone, and the artesian zone.



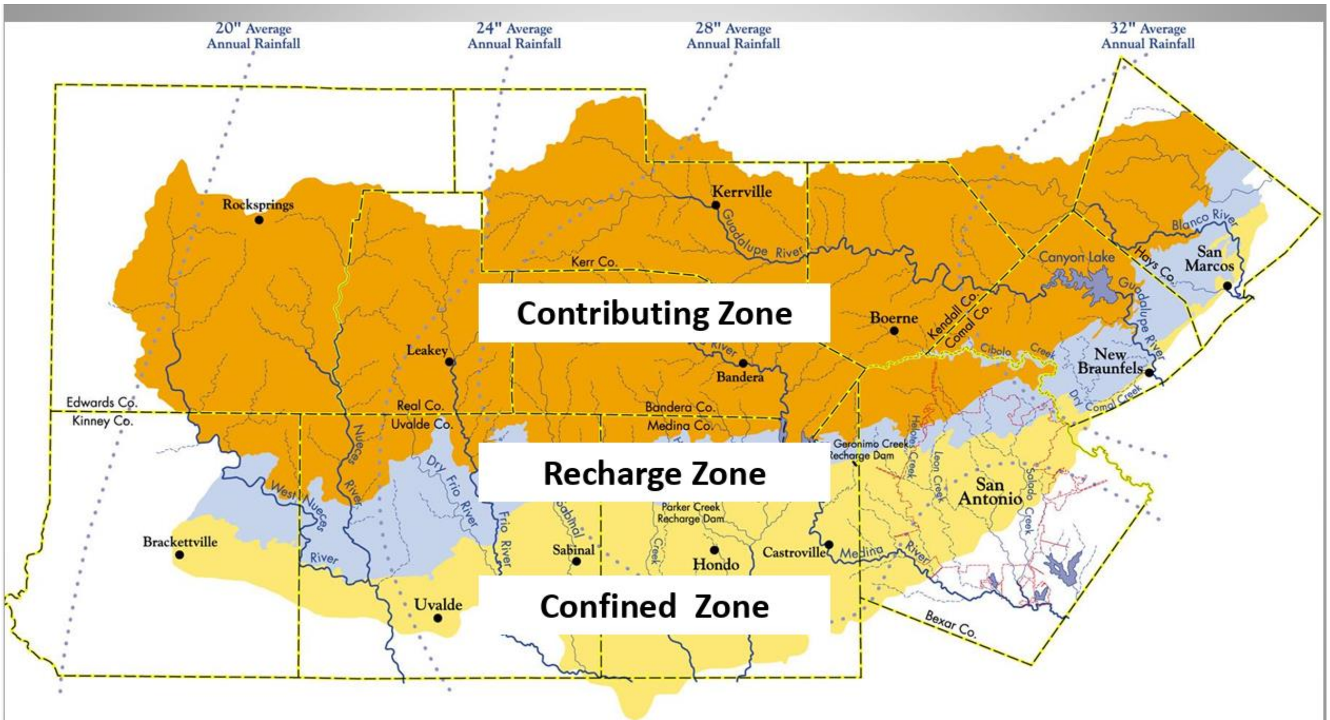
Drainage Area

The drainage area occurs on the Edwards Plateau, also called the Texas Hill Country. It is about 5,400 square miles, and elevations range between 1,000 and 2,300 feet above sea level. The rugged, rolling topography is covered with thick woodlands of oak and cedar.

The land surface "catches" water from rainfall that averages about 30" per year, and water runs off into streams or infiltrates into the water table aquifer of the plateau. Runoff from the land surface and water table springs then both feed streams that flow over relatively impermeable limestones until they reach the recharge zone.

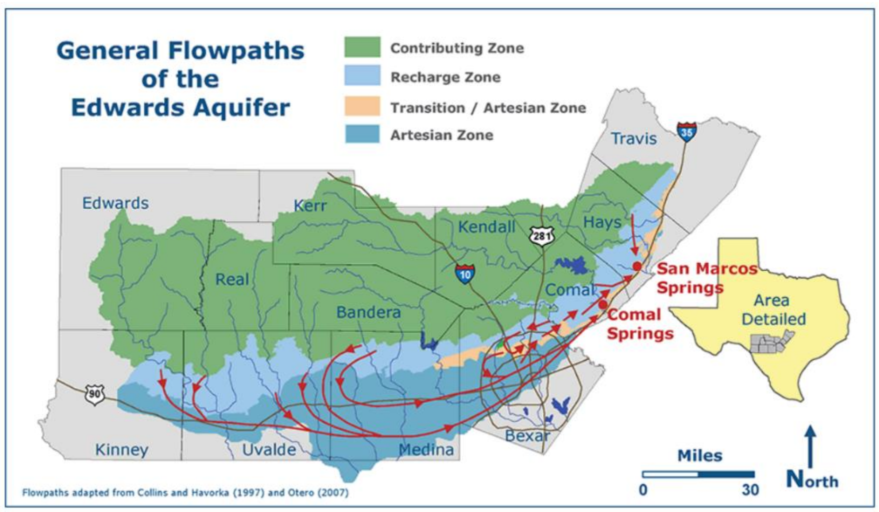
Recharge Zone

The recharge zone is a 1,250 square mile area where highly faulted and fractured Edwards limestones outcrop at the land surface, allowing large quantities of water to flow into the Aquifer. For this reason, the Edwards is often called a fault-zone aquifer. About 75-80% of recharge occurs when streams and rivers cross the permeable formation and go underground through sinkholes, fractures or faults. This is called *allogenic recharge*. Most of the remaining percentage of recharge occurs when precipitation falls directly on the outcrop. This is called *autogenic recharge*. In the recharge zone there are no other rock formations overlying the Edwards - it is exposed at the surface. So the Aquifer here is "unconfined" and has a water table that rises and falls in response to rainfall.



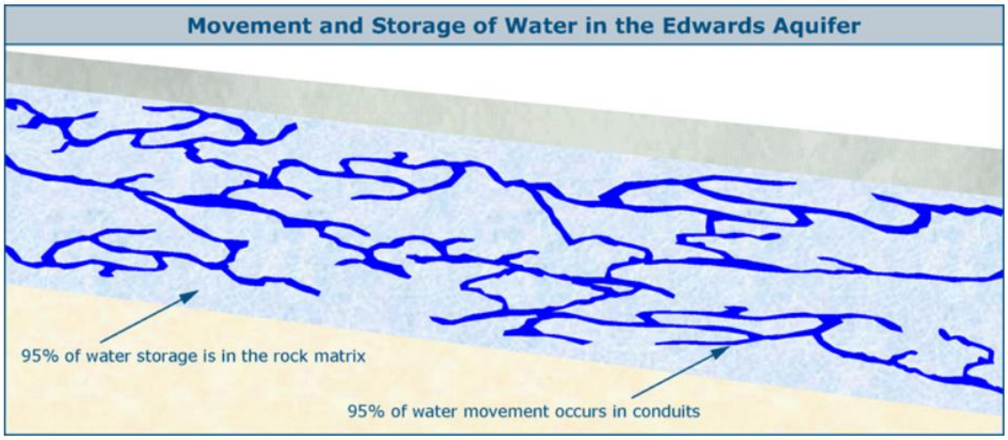
Source: Edwards Aquifer Authority 2008

Artesian Zone



Once recharge water works its way by gravity down into the artesian zone, there are other rock formations lying over the Edwards, and water is trapped inside. The artesian zone of the Edwards is confined between two relatively impermeable formations - the Glen Rose formation below and the Del Rio clay on top. The sheer weight of new water entering the Aquifer in the recharge zone puts tremendous pressure on water that is already deeper down in the formation. Flowing artesian wells and springs exist where hydraulic pressure is sufficient to force water up through wells and faults to the surface. Major natural discharge occurs at San Marcos Springs and Comal Springs in the northeast. Water moves generally from areas of higher elevation in the southwest toward major discharge areas in the northeast, and there are a number of barrier faults that make it difficult for waters in the various units of the Aquifer to mix together. These faults, along with varying porosities and permeabilities of the limestone, control the movement of water in the Aquifer. The J-17 index well is used to monitor the amount of pressure that water in the artesian zone is under. Changing pressure is reflected in rising or falling well levels.

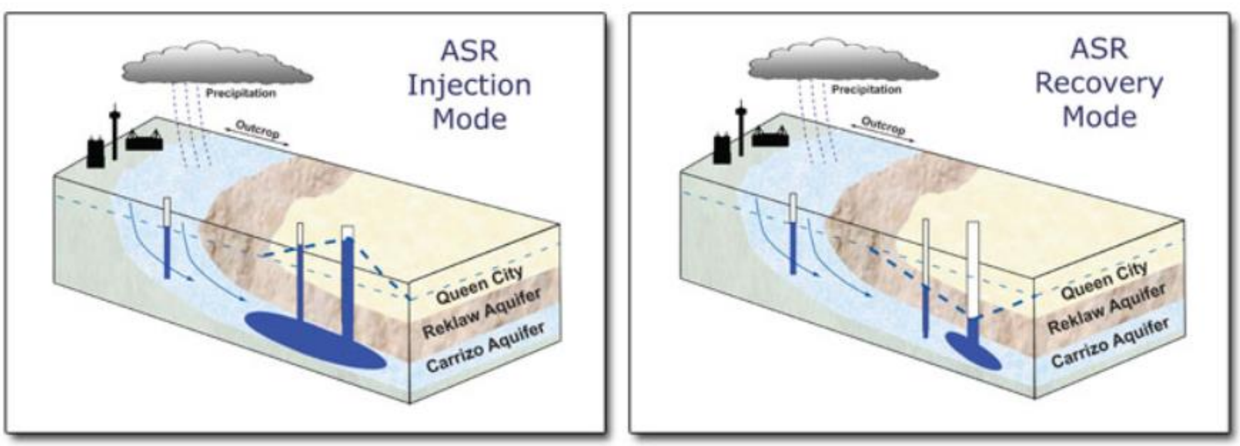
A karst aquifer



There are many sinkholes in the Edwards region, and for this reason it is often referred to as a karst aquifer. However, having sinkholes is not the defining characteristic of karst, rather; conduit porosity is the true defining characteristic of karst (Ewers, 2010), and the Edwards has plenty of that. For the Edwards, 95% of water storage is in the matrix, and 95% of water movement occurs in conduits.

San Antonio Water System's Aquifer Storage and Recovery

In 2020, aquifers supplied 55% of water used in Texas (Texas Water Development Board, n.d.-e). The heavy reliance on aquifers brought about a new era of water challenges when aquifers' pumping rates began to surpass the rate of recharge. One solution, aquifer storage and recovery (ASR), is the process of capturing water in times of water excess to then store within an aquifer to later be recovered when needed (Texas Water Code, Section 27.151). San Antonio Water System's (SAWS) H2Oaks ASR facility is the largest ASR operation in Texas. ASRs are likely to be used in areas that already are experiencing a heavy reliance on groundwater and increasing population. [French, L. and Formont, A., 2025, The Future of Water in Texas.]



When source water is available, it is injected into the Carrizo sand aquifer. The same wells are later used to extract the water and distribute it to users. The water retrieved is the exact same water that was injected, and there is no evaporation. The land overlying the wellfield can also continue to be used for other purposes such as agriculture or grazing.

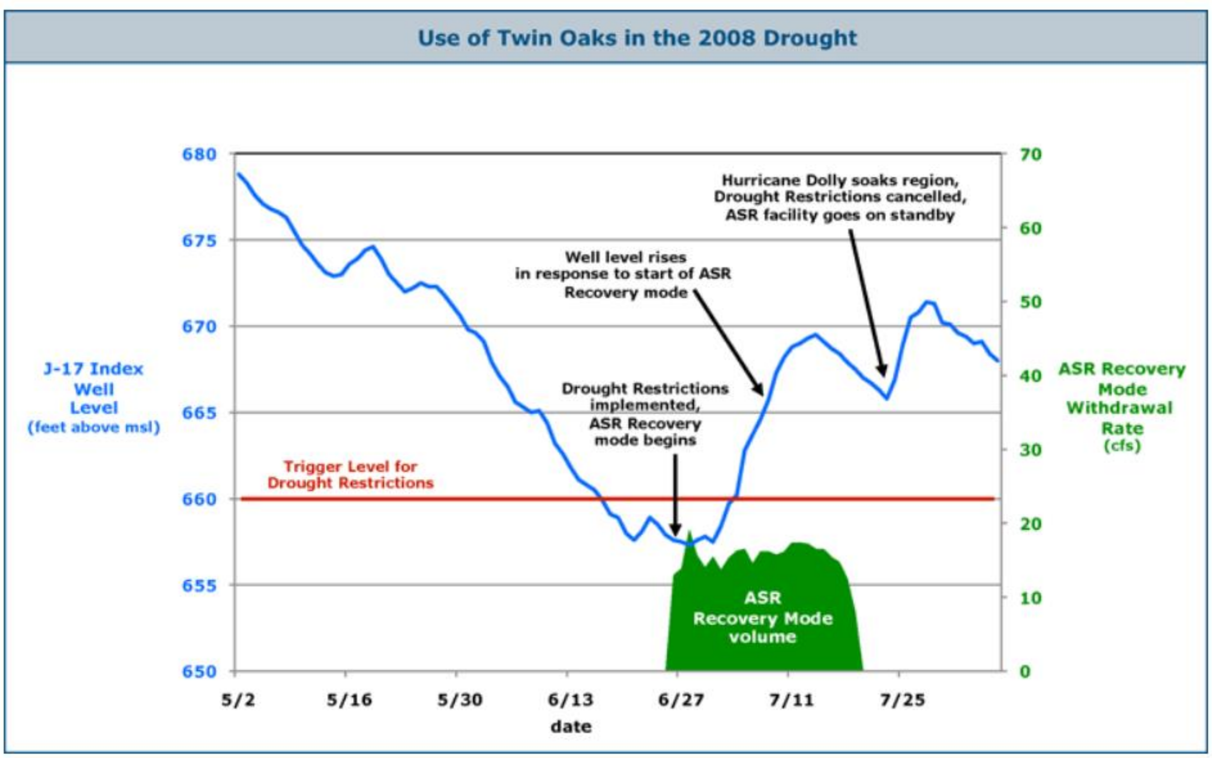
In September 1996 the San Antonio Water System and Bexar Metropolitan Water District were awarded a $200,000 grant to study the possibility of storing water in the Carrizo-Wilcox and Glen Rose aquifers, the saline zone of the Edwards Aquifer, and the Austin Chalk and Anacacho limestone formations. The study included looking at availability of water for storage, whether the source waters were compatible with water in the destination aquifers, and the quality and movement of water in each aquifer. The Carrizo-Wilcox Aquifer was identified as having the characteristics necessary for Aquifer Storage and Recovery. [https://edwardsaquifer.net/asr.html]

The three ASRs in Texas in 2024 include:

1. The City of San Antonio, which injects 60 million gallons per day from the Edwards Aquifer into wells 400 to 600 ft deep into the Carrizo Aquifer.
2. The City of El Paso, which injects 10 mgd of treated wastewater into aquifers 300 to 835 ft below the ground.
3. The City of Kerrville, which injects 25 mgd of water from the Guadalupe River into wells 500-600 ft deep.

An ASR will carefully extract water, usually from one aquifer and often during wet seasons, and inject excess water into a separate aquifer. The biggest advantage to ASRs is that underground storage of water can protect stored water from contamination and evaporation. From an environmental perspective, ASRs also offer a massive reservoir without condemning any land or property at the surface.
[French, L. and Formont, A., 2025, The Future of Water in Texas.]

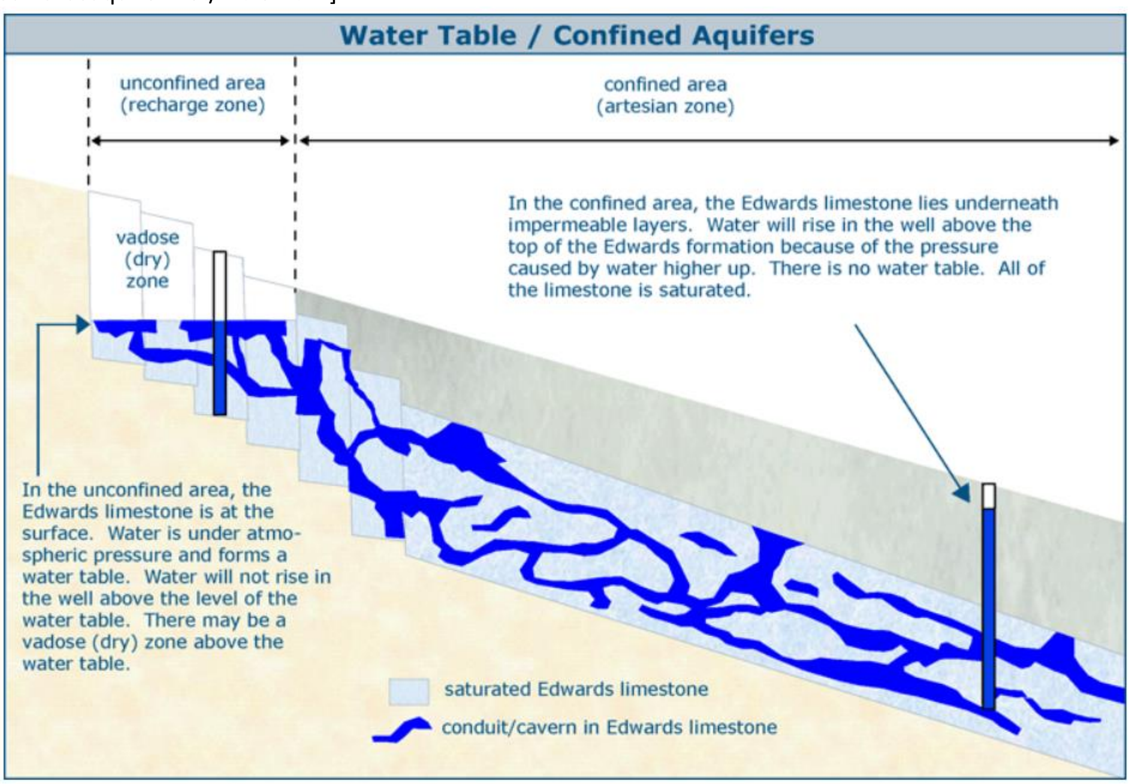
In 2008, the SAWS H2Oaks ASR recovery mode played an important role during the drought by recovering stored Edwards water from the Carrizo Aquifer. [https://edwardsaquifer.net/asr.html]



Water Table (Recharge) and Artesian (Confined) Zones

A water-table aquifer is one in which the water is under atmospheric pressure. Water will not rise above the level of the "table", and the table rises and falls in response to rainfall and recharge. Only a small portion of the Edwards is a water-table aquifer. The water-table portion of the Edwards is the recharge zone, where the Edwards limestone is exposed at the land surface. Here, because there are no confining rock layers on top of the Edwards, the water is under atmospheric pressure. Water will not rise in a well above the level of the water table. There may be an upper zone of unsaturated rock.

Most of the Edwards is an artesian aquifer, in which water is under pressure. In the confined or artesian zone, layers of impermeable rock overlie the Edwards limestone, trapping water inside with no easy way out. Just as diving to the deep end of a pool causes you to notice the pressure in your ears, the sheer weight of new water entering the Aquifer in the recharge zone causes water deeper down to be under great pressure. If water can escape through a well or through a spring opening, it will do so, rising above the top of the limestone formation. If there is sufficient pressure, water will rise all the way to the land surface and gush out in a huge volume. In this zone, all of the limestone is saturated at all times, and there is no rising and falling water table, only rising and falling pressure. New water entering in the recharge zone instantaneously exerts pressure on the entire system, so rainfall can cause rapid rises in well levels far distant from the rainfall itself. A good monitoring well is one that is very responsive to rainfall and pumpage, in a location where there is never enough pressure such that water will rise all the way up and flow out on the land surface (so there is always a well level to measure). The J-17 is one such well, and it is used to monitor Edwards pressure in the San Antonio pool. The well is on a major flowpath and quickly reflects rising and falling pressure. J-17 levels and springflows rates are used to trigger drought restrictions and pumpage cutbacks during dry times.
[https://edwardsaquifer.net/intro.html]



NEARBY TOWN OF LULING, TEXAS

Lovin' Life in Lulin' best describes the laid-back, fun-loving lifestyle of the 6,000 folks who call Luling, TX home, and who welcome visitors with a smile and a choice of relaxing activities and festivals. Where else would you find a festival called a "Thump" with an internationally-known watermelon Seed Spitting contest, or a water tower painted like a giant melon? And oil well pump jacks decorated with cartoon characters and animals? [https://travelinglongdogs.blogspot.com/2017/10/pumped-about-pumpjack-tour.html]

Photos by Hilary Olson

Luling's famous bar-b-q has been called 'the best in the universe', was named Reader's Digest 'best in Texas' and consistently makes the top five lists in just about any story about great brisket, ribs and sausage. If you want to really dive into some BBQ, a Saturday or Sunday road trip to Luling is a worthwhile endeavor. However, Luling does not live by brisket alone. Numerous other restaurants serve up specialties from burgers to enchiladas to desserts.

Located in the gently rolling hills just east of San Antonio and south of Austin, Luling is a microcosm of what made Texas great - oil, cattle, farming, railroad and river.

General Resources

DUNHAM'S CARBONATE ROCK TEXTURE CLASSIFICATION
Relationship to the Edwards Aquifer

Dunham (1962) produced a classification of carbonate rocks that is based on depositional texture. He noted that there are several textural features that are especially useful in classifying carbonate rocks:

(1) presence or absence of carbonate mud (particles less than 20 microns),
(2) abundance of carbonate grains (particles larger than 20 microns),
(3) whether the grains are mud supported or grain supported, and
(4) evidence of organic binding during deposition.

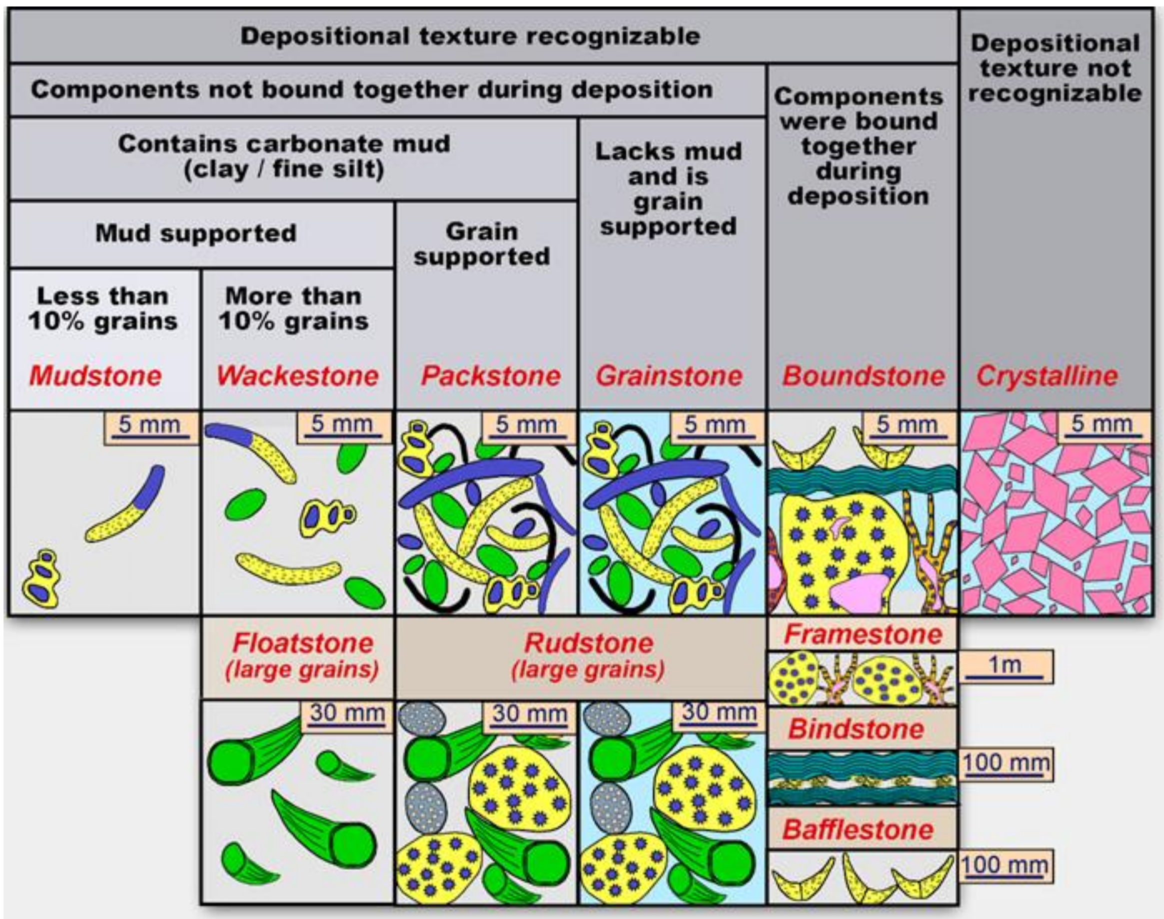
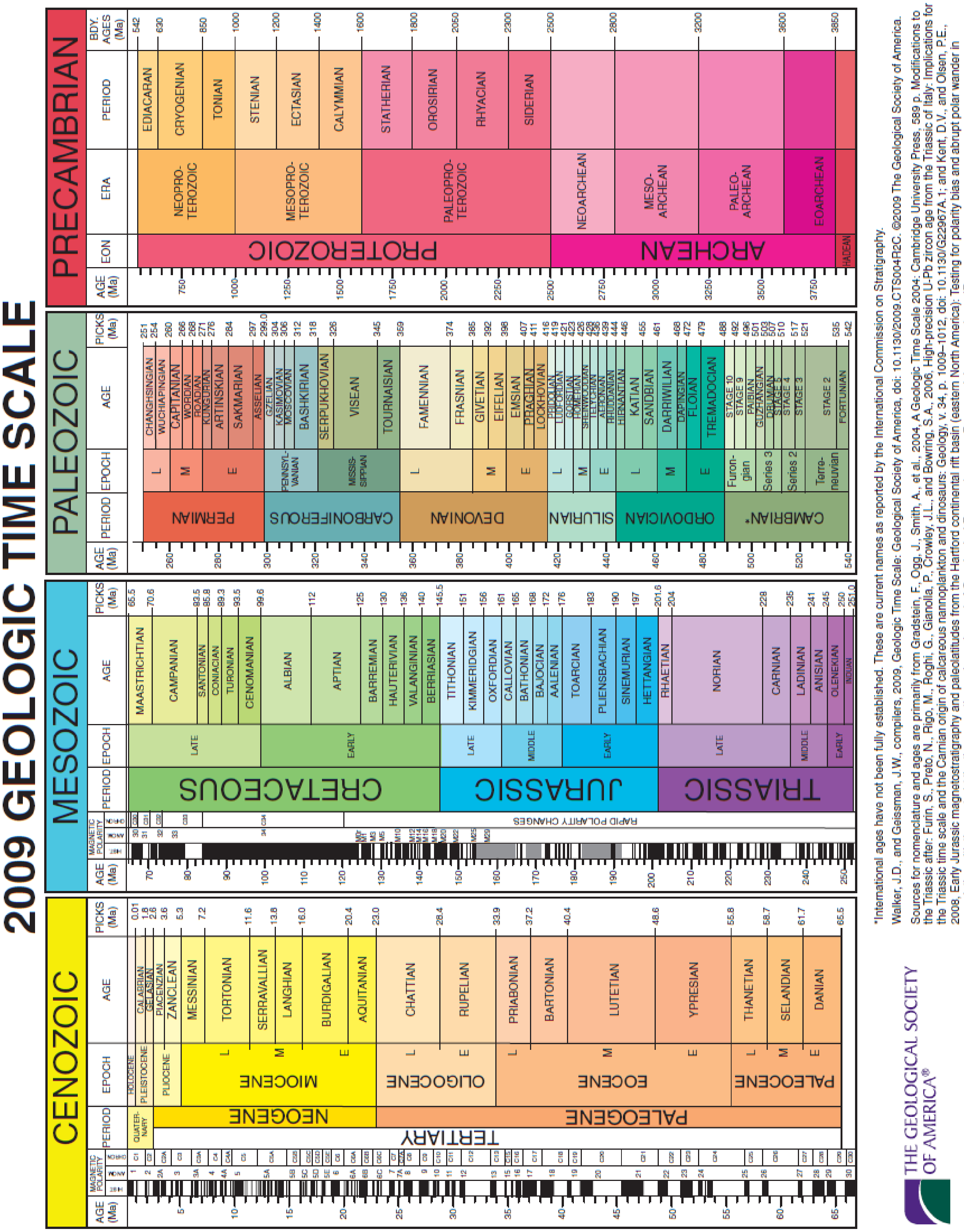


Image: http://www.beg.utexas.edu/lmod/_IOL-CM01/cm01-step03.htm#

The original depositional texture is a primary factor in determining a carbonate rock's initial porosity. High-energy grainstones would have had greater initial porosity than low-energy mudstones. The Edwards Aquifer's high permeability, however, is not primarily due to this initial porosity. Instead, it is the result of significant secondary porosity from processes like faulting, fracturing, and extensive dissolution (karstification) that occurred after deposition. Groundwater movement along faults and fractures has selectively dissolved certain sedimentary features, particularly in permeable strata like collapse breccias and burrowed wackestones, to create larger interconnected voids.


2009 GEOLOGIC TIME SCALE
CENOZOIC
MESOZOIC
PALEOZOIC
PRECAMBRIAN
QUATERNARY
NEOGENE
PALEOGENE
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN*
PROTEROZOIC
ARCHEAN
HADEAN
*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.
Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C. ©2009 The Geological Society of America.
THE GEOLOGICAL SOCIETY OF AMERICA®

OIL AND GAS MAP OF TEXAS

2018

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TEXAS
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Jackson School of Geosciences
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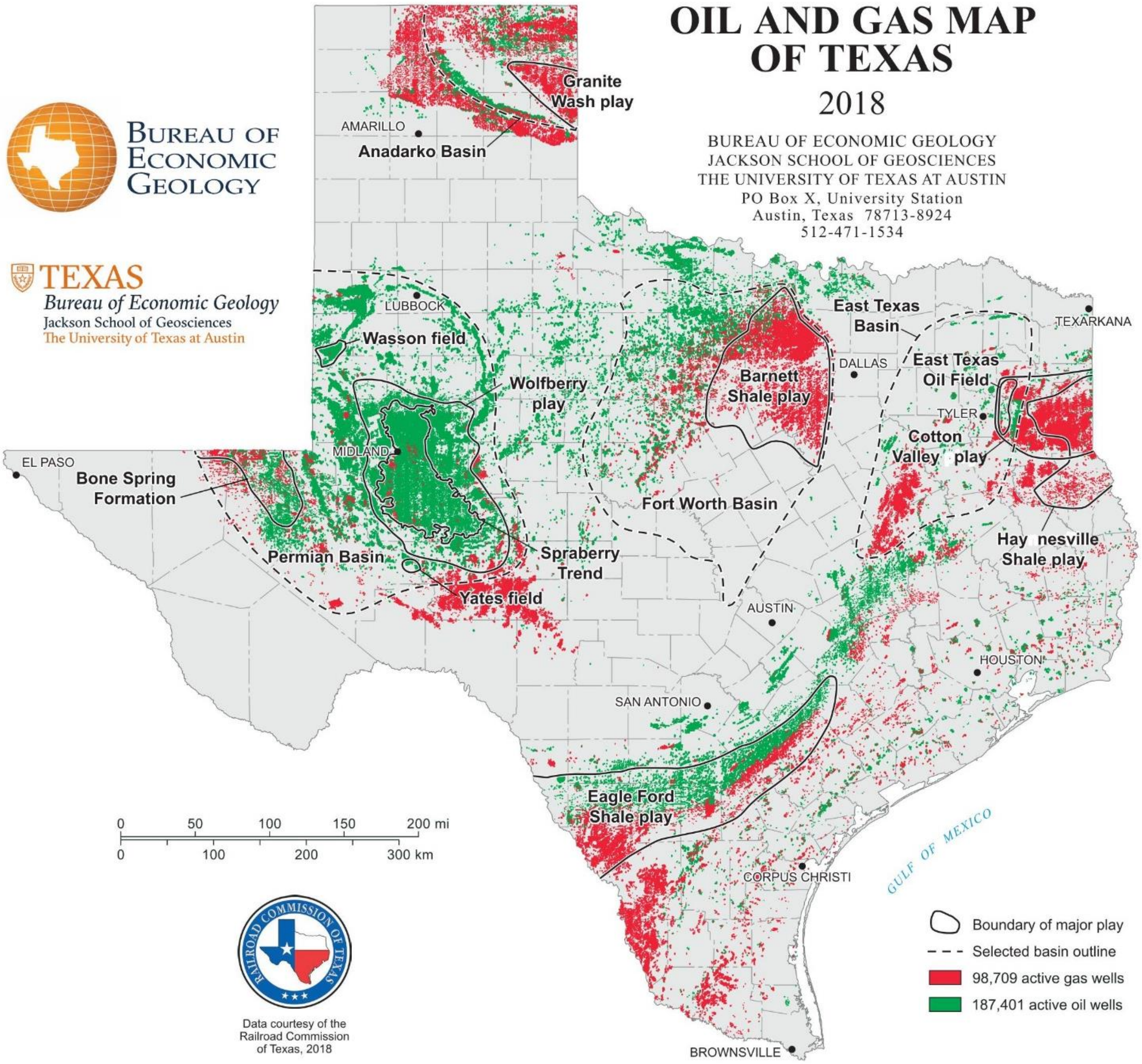
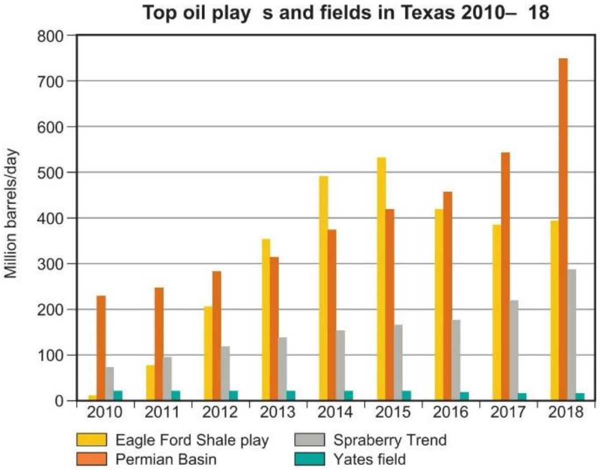
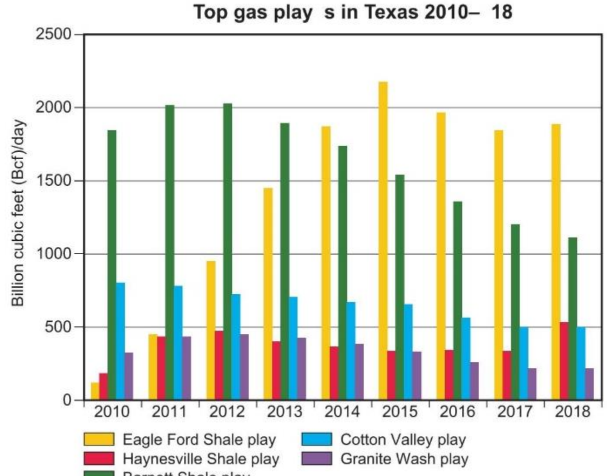


Data courtesy of the Railroad Commission of Texas, 2018

Top oil plays and fields in Texas 2010–18



Top gas plays in Texas 2010–18



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Oil and Gas Production in Texas

Texas has produced more oil and natural gas than any other state and remains the largest daily producer, with ~4 million barrels per day (MMbbl/d) of oil and more than 20 billion cubic feet per day (Bcf/d) of gas in 2019. No other state or region worldwide has been as heavily explored or drilled for oil and natural gas as Texas. Currently (as of December 2018), 187,401 active oil wells and 98,709 active gas wells produce oil and natural gas in the state, according to the Railroad Commission of Texas.

Historic Oil and Gas Production and Recent Significant Developments

Oil drilling in Texas first occurred at Oil Springs, near Nacogdoches in East Texas, in 1866, less than a decade after Colonel Edwin Drake's 1859 well in Titusville, Pennsylvania. In 1894, the Texas age of oil began with the first major discovery, Corsicana field, in East Texas. The first boom came in 1901 with Spindletop field in the Gulf Coast Basin. Thousands of other discoveries have followed. East Texas Oil Field, the largest oil field in Texas or in any of the U.S. Lower 48 states as measured by cumulative production, was discovered in 1930. Texas oil production peaked in 1972 at 3.5 MMbbl/d, and thereafter production declined to 1.1 MMbbl/d by 2009. Successes in Enhanced Oil Recovery (EOR) projects from the 1990's to the present in mature fields in West Texas were insufficient to offset the overall statewide decline trend in oil production. Since 2009, oil production has increased dramatically, reaching ~4 MMbbl/d in 2019. Nearly all of this increase is from unconventional reservoirs. Unlike conventional reservoirs where hydrocarbons flow readily into the wellbore, unconventional reservoirs (including shales) require hydraulic fracturing, which creates cracks in the reservoir and enables oil and gas to flow into the well.

In the past 10 years, the combination of horizontal wells and multistage hydraulic fracturing technologies has revitalized both oil and natural gas production in Texas and in the United States. Historically, natural gas in Texas was produced as a byproduct of oil. This form of natural gas, which is in contact with crude oil in the reservoir, is termed *associated gas,* and in earlier years it was wastefully flared and vented off without being captured and utilized. With increased oil exploration and production in Texas, and the growth of *nonassociated gas* production, annual natural gas production steadily rose and peaked in 1972 at 9.6 trillion cubic feet (Tcf). However, unlike oil production, Texas gas production remained fairly flat from 1984 to 2005, mainly as a result of hydraulic fracturing technology in tight-gas sand reservoirs in the Gulf Coast, Permian, and East Texas Basins. Since 2005, gas production has increased more than 40% to 8.5 Tcf in 2018, with most of the increase coming from the Wolfberry, Barnett, Eagle Ford, and Haynesville Shale plays.

Major Texas Oil and Gas Fields

The top oil plays in Texas in 2019 include the Eagle Ford Shale in South Texas, the Wolfberry (combined Spraberry and Wolfcamp Formations), and the Wasson and Yates fields in the Permian Basin, which currently account for 15% of U.S. oil production. Unconventional oil production from shales and other tight reservoirs in the Permian Basin is expected to grow dramatically because of the recent sharp increase in successful horizontal drilling and hydraulic fracturing activity there. Mature conventional fields (Wasson, Yates) with access to carbon dioxide for EOR operations continue to be major producers. Major natural gas fields in Texas, measured by current production rate, include the Newark East field (Barnett Shale) in North Texas, the Eagle Ford Shale, and two tight gas sands—Granite Wash (northern Panhandle) and Cotton Valley (East Texas). These large gas fields in Texas are all products of application of advanced technologies, mainly hydraulic fracturing and horizontal drilling, that have enabled economically viable gas production from very impermeable (tight) reservoir rocks. The Gulf Coast also continues to produce significant volumes of gas from Tertiary-age conventional sandstone reservoirs.

U.S. and World Ranking

The application of advanced technologies continues to make Texas the leading state in oil production. Texas produced 1,275 MMbbl of oil, or ~35% of the U.S. total, in 2018, and 8.5 Tcf of gas, or ~25% of the U.S. total, in 2017. If Texas were a nation, it would rank as one of the top 10 producers in the world. In terms of proven oil and natural gas reserves, Texas has 33% (11.1 billion bbl), and 29% (93.5 Tcf), respectively, of the U.S. total (source: Energy Information Administration [EIA]). Proven reserves are the estimated quantities that analysis of geologic and engineering data demonstrate with reasonable certainty will be recoverable in future years from known reservoirs, under existing economic and operating conditions.

Economic Impact

The major resurgence of oil and natural gas production in Texas makes these commodities an important source of economic benefit in terms of value, jobs created, and tax revenue. According to the Texas Comptroller's input–output model of Texas' economy, the total economic value of oil and gas is 2.91 times the value of production. Additionally, 19.1 jobs are created per million dollars of oil and gas production. Assuming oil and natural gas prices of $100/bbl and $3.5/Mcf, and year 2018 annual production of 1,275 MMbbl and 8.5 Tcf, the wellhead value was $127.5 billion for oil and $29.8 billion for gas. Severance, *ad valorem,* and indirect taxes provide additional economic benefits of more than $4.5 billion to Texas. The leasing of mineral rights to State- and University-owned lands statewide, moreover, provides royalty and leasing revenue that replenishes the Permanent University and School Funds, important sources of revenue for public education in Texas.

Railroad Commission of Texas

The Railroad Commission of Texas, established in 1891, is the oldest regulatory agency in the state and one of the oldest of its kind in the nation. The Railroad Commission has regulatory divisions that oversee Texas' oil and natural gas industry, gas utilities, pipeline safety, safety in the liquefied petroleum gas industry, and surface mining of coal and uranium. As the regulatory agency for the oil and gas industry, it provides extensive drilling and production statistics. The Railroad Commission continues to serve Texas in its stewardship of natural resources and the environment, its concern for the individual and communal safety of citizens, and its support of enhancing development and economic vitality for the betterment of Texas as a whole.

The authors thank the staff of the RRC for their assistance in providing statistical data.

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and Mark Shuster

Bureau of Economic Geology

The **Bureau of Economic Geology,** established in 1909, is the oldest research unit at The University of Texas at Austin. The Bureau is the State Geological Survey of Texas, and Director Scott W. Tinker is the State Geologist. The Bureau conducts basic and applied research programs in energy resources and economics, coastal and environmental studies, land resources and use, geologic and mineral mapping, hydrogeology, geochemistry, and subsurface nanotechnology.

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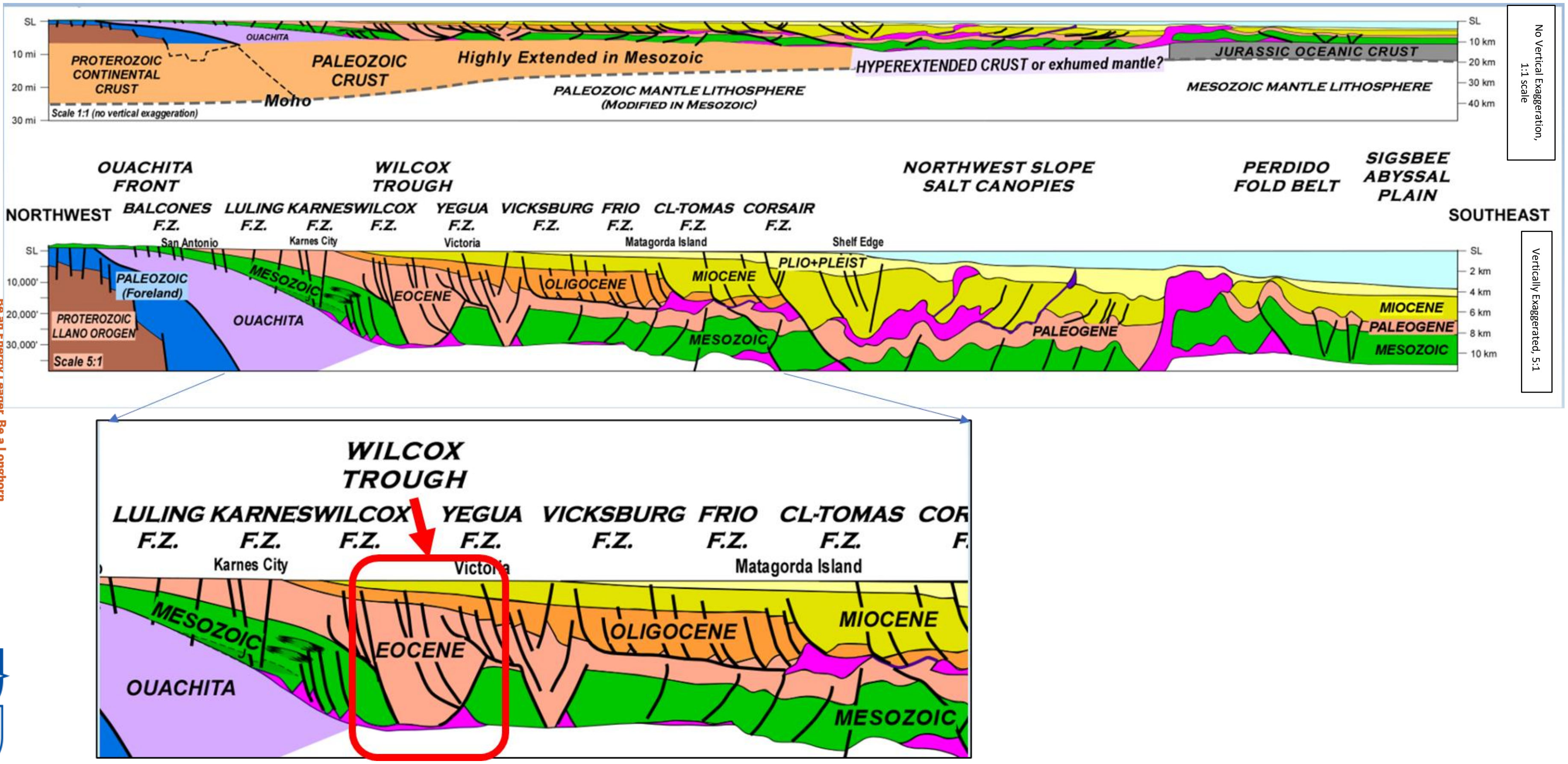
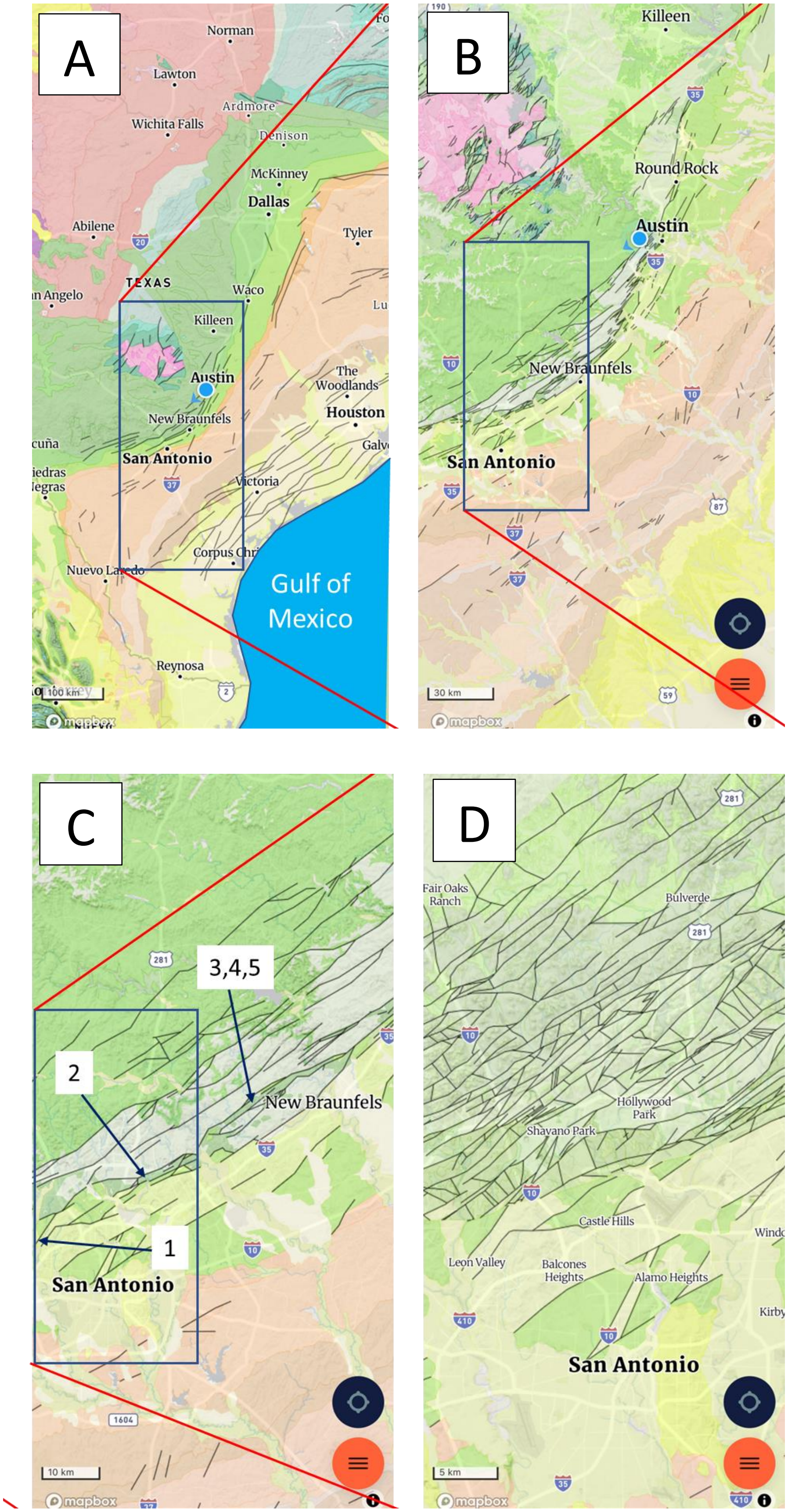
Generalized Geologic Cross-section, Ewing (2019)

https://www.searchanddiscovery.com/documents/2019/11217ewing/ndx_ewing.pdf)





Geologic Reference Maps

The maps above are screenshots from the geologic app Rockd available for smartphones. A geologic map depicts the age and type of rocks that can be seen on the surface (but are sometimes coverd with vegetation). Each map has a scale bar in lower left corner, ranging from 100 km in map A to 5 km in map D. **A)** This widest view runs from Texas-Mexico border to Oklahoma. The pink area about 100 km WNW of Austin depicts the Llano Uplift basement rock exposure, which represent the oldest rocks in Texas (of Precambrian age, as old as 1.4 billion years). Rocks in Texas get successively younger radially outward from the Llano Uplift. Most prominently the pink Precambrian area is surrounded by green, which is the standard map color used for the Cretaceous Period (ages from to 146.5 to 65.5 ma). The Balcones Fault zone is highlighted by the black lines running from SW of San Antonio all the way to Dallas, along the boundary between the green and the brown/tan band of rocks, which are from the Paleogene period (65.5 to 23 ma). Moving further toward the Gulf of Mexico, colors change to shades of yellow, representing the Neogene (23 to 2.6 ma) and the Quaternary (2.6 to 0 ma). **B)** A closer view of the Balcones Fault Zone geometry which also includes the location of the city of Gonzalez, the vicinity where our well site stops are located. **C)** Our geologic field trip stops are annotated on this map. **D)** This map is included to illustrate the intensity of faulting in the Balcones Fault Zone in the north areas of San Antonio, with fault spacings as small as 1 km over a 30 to 40 km wide zone oriented SW-NE.

FIELD TRIP LEADERS

Sabrina Ewald

Program Manager for Education Outreach and Training, The University of Texas at Austin
M.S. Education, Louisiana Tech University

Sabrina Ewald is the Program Manager for K-12 Outreach for the Center for Subsurface Energy and the Environment (CSEE). She brings 23 years of secondary science teaching experience to CSEE, with the last 18 years spent in Frisco ISD teaching AP Environmental Science (APES), Earth and Space Science, Environmental Systems, and other science electives. She also served as a district curriculum writer for Earth and Space Science, Environmental Systems, and Astronomy.

Sabrina is an AP Reader, a teacher workshop facilitator for Texas Mining and Reclamation Association, and previously worked for Duke University as an instructor for the Duke Talent Identification Program (TIP) summer residential program. She brings a wealth of experience and knowledge working as a secondary science educator and curriculum developer. She uses her expertise to help develop classroom resources and content for Energy Excursions and teacher professional development opportunities. Her focus is creating an engaging and dynamic learning environment while exposing students to real-world connections and career opportunities.

Sabrina is currently the president of the South Central Section of the National Association of Geoscience Teachers (NAGT), a member of the NAGT K-12 Ad Hoc Committee, a member of the SPE Energy4Me Advisory Council, and a member of the K-12 outreach committee for the Southwest Section of AAPG.

Sabrina manages the teacher community for UT Austin's Hildebrand Department of Petroleum & Geosystems Engineering Choose Energy Program on the EnergyExcursions.com website.

Hilary Clement Olson

Associate Professor of Instruction, The University of Texas at Austin
Ph.D., Geology, Stanford University

Dr. Olson is the director of the Energy Excursions project at The University of Texas at Austin. Her education, training, and outreach programs address the areas of unconventional resources and carbon storage, with audiences ranging from state and federal regulators to the public. Her K-12 teacher professional development activities are focused on energy and earth science education, and have received support from the National Science Foundation and the Department of Energy.

Hilary's technical research integrates biostratigraphic and paleoenvironmental data with core, well-log, and seismic data to examine the Earth's stratigraphic record, including studies in the offshore and onshore Gulf of Mexico, Faeroe Basin, California, and New Jersey Margin. Before joining the University of Texas at Austin Dr. Olson worked as a research geologist for Mobil Research and Development Corporation. She is a member of the American Association of Petroleum Geologists and recipient of their Public Service Award, a member of the Society of Petroleum Engineers and recipient of their Regional Distinguished Achievement Award for Petroleum Engineering Faculty, past president of the North American Micropaleontology Section (SEPM), past Distinguished Lecturer of the Ocean Drilling Program, and recipient of the Dallas Geological Society Public Service Award.

Jon Olson

Professor, The University of Texas at Austin
Ph.D., Stanford University

Jon Olson specializes in geomechanics, production optimization and environmental impact issues related to unconventional oil and gas development. His research includes hydraulic fracture design and modeling, induced seismicity, wellbore stability and reservoir compaction and subsidence.

Dr. Olson participates in public outreach focused on secondary school science teachers with regard to energy supply and utilization, the place of fossil fuels in the energy mix for the USA, and the use of geologic carbon storage to mitigate greenhouse gas accumulation in the atmosphere.

Before joining the University of Texas at Austin, Jon worked as a research engineer for Mobil Research and Development Corporation. Dr. Olson has served as a Distinguished Lecturer for both the Society of Petroleum Engineers and the American Association of Petroleum Geologists. Jon served as Chair of the Hildebrand Department of Petroleum & Geosystems Engineering at UT Austin from 2015 to 2023. He is a Registered Professional Engineer in the state of Texas.

Tiffany Cotledge

Tiffany Cotledge serves as the Public Engagement Coordinator for the Railroad Commission of Texas. In her role within the Office of Public Engagement, she aims to enhance public understanding of energy regulation in Texas and coordinate speaking engagements that address region-specific oil and gas questions while highlighting the vital role of Texas' energy industry. Prior to joining the Railroad Commission, Tiffany gained valuable experience in the automotive and transportation sectors. She holds a Bachelor of Business Administration in Marketing from the University of Texas at Austin.

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James Harcourt, P.G., P.M.P., M.B.A.

James is Manager of the Geologic Advisory Unit (GAU) in the Technical Permitting Department, Oil & Gas Division of the Railroad Commission of Texas (RRC). The GAU is responsible for geologic investigations, the protection of groundwater resources, the prevention of pollution and waste of natural resources, and certifications for tight gas severance tax exemptions. Formerly, James worked in The State Funded Plugging Program at RRC.

Prior Experience and Education

James is a licensed Professional Geologist in Texas, Pennsylvania, and Florida. Prior to joining the Railroad Commission, James worked as a Professional Geologist for more than 35 years across five states, focusing on oil and gas exploration and production, groundwater protection, underground injection control, solid and hazardous waste disposal, and environmental protection.

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CAREER PROFILES

Brooke Franklin

Academic Background

- B.S. Petroleum Engineering, The University of Texas at Austin, 2023

Brooke Franklin is a recent graduate from the Hildebrand Department of Petroleum and Geosystems Engineering. She is currently a full-time production engineer at bpx energy, a subsidiary company of British Petroleum, where she "aims to make the work done in the field easier to complete for the crew and those overseeing operations".

Brooke served as the president of Women in Petroleum & Geosystems Engineering during her junior year and was also active in the Society of Petroleum Engineers and American Association of Drilling Engineers. Brooke always knew she would be an engineer because, from an early age, she loved efficiency and optimization. The energy industry fascinates her, as it is dynamic, cutting-edge, and constantly striving to make our world better. It is also the cornerstone of many facets of life, and one of the main reasons Brooke chose to be a petroleum engineer – she wanted to be right in the middle of it!

Keivan Khaleghi

Academic Background

- **BS, Chemical Engineering, Sharif University, 2007**
- **MS, Chemical Engineering, University of Alberta, 2011**
- **PhD candidate, Petroleum Engineering, The University of Texas at Austin**

Keivan Khaleghi is pursuing his degree in petroleum engineering at The University of Texas at Austin with Dr. Hugh Daigle as his PhD advisor. His research is focused on the direct use of geothermal heat in industrial applications and for heating and cooling living spaces.

Keivan spent the summer of 2023 as a Geothermal Production Analytics Intern for Calpine at Geysers, the largest geothermal field in the world in Northern California. He is looking forward to incorporating this experience in his research and contributing to a budding geothermal industry in Texas. Keivan is passionate about geothermal energy as a renewable resource that has a lot of untapped growth potential. He is excited about the prospect of Texas high school students learning about this tremendous power and helped design this online mini-course on geothermal.

Sam Klarin

Academic Background
B.S. Petroleum Engineering, The University of Texas at Austin
M.S. Energy and Earth Resources The University of Texas at Austin

Sam Klarin is a recent graduate and has worked at Eden in Geothermal Business Development and at Sage Geosystems in reservoir evaluation. His M.S. research looked at the resource availability of geothermal energy along Texas' Gulf Coast region and East Texas. He integrated energy technologies from various areas within the energy sector, such as carbon capture and storage, CO2-plume geothermal, oil & gas, and hydrogen production, into his analysis to demonstrate geothermal's crossover with many other industries. Sam specifically researched the Brazos protraction area (an offshore area in the Gulf of Mexico) and produced an economic analysis of its geothermal potential. Sam received his Bachelor of Science degree from UT Austin where he studied Petroleum & Geosystems engineering. His oil and gas drilling background prepared Sam to study similar geologic sites to research geothermal.

ENERGIZING THE FUTURE
Innovative Energy Production and Environmental Stewardship in Texas

Standards Correlation

This document highlights TEKS and NGSS standards that connect directly to the field trip's content and activities.

Organized by grade and course, these standards help teachers create meaningful, hands-on lessons that build both content knowledge and essential skills—like those outlined in TEKS 1–5 for science.

Elementary Science TEKS (K-5th)

3rd Grade	11.A	Explore and explain how humans use natural resources such as in construction, in agriculture, in transportation, and to make products
	11.B	Explain why the conservation of natural resources is important
4th Grade	10.A	Describe and illustrate the continuous movement of water above and on the surface of Earth through the water cycle and explain the role of the Sun as a major source of energy in this process
	11.A	Identify and explain advantages and disadvantages of using Earth's renewable and nonrenewable natural resources such as wind, water, sunlight, plants, animals, coal, oil, and natural gas
	11.B	Explain the critical role of energy resources to modern life and how conservation, disposal, and recycling of natural resources impact the environment
	11.C	Determine the physical properties of rocks that allow Earth's natural resources to be stored there
5th Grade	10.B	Model and describe the processes that led to the formation of sedimentary rocks and fossil fuels
	11	The student understands how natural resources are important and can be managed. The student is expected to design and explain solutions such as conservation, recycling, or proper disposal to minimize environmental impact of the use of natural resources.
	12.C	Describe a healthy ecosystem and how human activities can be beneficial or harmful to an ecosystem

Middle School Science TEKS (6th – 8th)

6th Grade	10.A	Differentiate between the biosphere, hydrosphere, atmosphere, and geosphere and identify components of each system
	10.C	Describe how metamorphic, igneous, and sedimentary rocks form and change through geologic processes in the rock cycle
	11.A	Research and describe why resource management is important in reducing global energy, poverty, malnutrition, and air and water pollution
	11.B	Explain how conservation, increased efficiency, and technology can help manage air, water, soil, and energy resources
7th Grade	6.C	Distinguish between physical and chemical changes in matter
	6.E	Investigate and model how temperature, surface area, and agitation affect the rate of dissolution of solid solutes in aqueous solutions
	10.A	Describe the evidence that supports that Earth has changed over time, including fossil evidence, plate tectonics, and superposition
	11.A	Analyze the beneficial and harmful influences of human activity on groundwater and surface water in a watershed
8th Grade	10.A	Describe how energy from the Sun, hydrosphere, and atmosphere interact and influence weather and climate

High School Science TEKS (9^{th} – 12^{th})

Aquatic Science	6.A	Identify key features and characteristics of atmospheric, geological, hydrological, and biological systems as they relate to aquatic environments
	6.B	Describe the interrelatedness of atmospheric, geological, hydrological, and biological systems in aquatic ecosystems, including positive and negative feedback loops
	10.A	Identify sources of water in a watershed, including rainfall, groundwater, and surface water
	10.B	Identify factors that contribute to how water flows through a watershed
	10.D	Describe human uses of fresh water and how human freshwater use competes with that of other organisms
AP Environmental Science	Unit 1 – The Living World: Ecosystems	1.1 – Introduction to Ecosystems 1.7 – Water Cycle
	Unit 4 – Earth's systems and Resources	4.1 – Plate Tectonics 4.3 – Soil Composition and Properties 4.6 – Watersheds
	Unit 5 – Land and Water Use	5.1 – Tragedy of the Commons 5.9 – Impacts of Mining 5.11 – Ecological Footprints
	Unit 6 – Energy Resources & Consumption	6.1 – Renewable vs Nonrenewable Energy Resources 6.3 – Fuel Types and Uses 6.4 – Distribution of Natural Energy Resources 6.5 – Fossil Fuels
	Unit 8 – Aquatic and Terrestrial Pollution	8.1 – Sources of Pollution 8.2 – Humans Impacts on Ecosystems 8.9 – Solid Waste Disposal 8.10 – Waste Reduction Methods

Environmental Systems

5.B	Explain the cycling of water, phosphorus, carbon, silicon, and nitrogen through ecosystems, including sinks, and the human interactions that alter these cycles using tools such as models
5.C	Evaluate the effects of fluctuations in abiotic factors on local ecosystems and local biomes
6.A	Compare and contrast land use and management methods and how they affect land attributes such as fertility, productivity, economic value, and ecological stability
6.B	Relate how water sources, management, and conservation affect water uses and quality
6.C	Document the use and conservation of both renewable and non-renewable resources as they pertain to sustainability
6.E	Analyze and evaluate the economic significance and interdependence of resources within the local environmental system
7.A	Describe the interactions between the components of the geosphere, hydrosphere, cryosphere, atmosphere, and biosphere
7.B	Relate biogeochemical cycles to the flow of energy in ecosystems, including energy sinks such as oil, natural gas, and coal deposits
8.B	Identify factors that may alter carrying capacity such as disease; natural disaster; available food, water, and livable space; habitat fragmentation; and periodic changes in weather
12.A	Evaluate cost-benefit trade-offs of commercial activities such as municipal development, food production, deforestation, over-harvesting, mining, and use of renewable and non-renewable energy sources
12.B	Evaluate the economic impacts of individual actions on the environment such as overbuilding, habitat destruction, poaching, and improper waste disposal
12.C	Analyze how ethical beliefs influence environmental scientific and engineering practices such as methods for food production, water distribution, energy production, and the extraction of minerals
12.D	Discuss the impact of research and technology on social ethics and legal practices in situations such as the design of new buildings, recycling, or emission standards
12.E	Argue from evidence whether or not a healthy economy and a healthy environment are mutually exclusive

Earth Systems Science (ESS)	8.E	Explain how plate tectonics accounts for geologic processes, including sea floor spreading and subduction, and features, including ocean ridges, rift valleys, earthquakes, volcanoes, mountain ranges, hot spots, and hydrothermal vents
	9.B	Investigate and model how surface water and groundwater change the lithosphere through chemical and physical weathering and how they serve as valuable natural resources
	9.C	Model the processes of mass wasting, erosion, and deposition by water, wind, ice, glaciation, gravity, and volcanism in constantly reshaping Earth's surface
	9.D	Evaluate how weather and human activity affect the location, quality, and supply of available freshwater resources.
	12.E	Predict how human use of Texas's naturally occurring resources such as fossil fuels, minerals, soil, solar energy, and wind energy directly and indirectly changes the cycling of matter and energy through Earth's systems
	13.A	Analyze the policies related to resources from discovery to disposal, including economics, health, technological advances, resource type, concentration and location, waste disposal and recycling, mitigation efforts, and environmental impacts
	13.B	Explore global and Texas-based careers that involve the exploration, extraction, production, use, disposal, regulation, and protection of Earth's resources
Integrated Physics & Chemistry (IPC)	6.G	Evaluate evidence from multiple sources to critique the advantages and disadvantages of various renewable and nonrenewable energy sources and their impact on society and the environment
	8.D	Construct and communicate an evidence-based explanation of the environmental impact of the end-products of chemical reactions such as those that may result in degradation of water, soil, air quality, and global climate change

NGSS Standards		
NGSS Elem. (3rd – 5th)	4-ESS-1-1	Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.
	4-ESS2-2	Analyze and interpret data from maps to describe patterns of Earth's features.
	4-ESS3-1	Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.
	5-ESS2-1	Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact
	5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
	5-PS1-3	Makes observations and measurements to identify materials based on their properties.
NGSS M.S. (6th – 8th)	MS-ESS1-4	Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's-4.6 billion-year-old history.
	MS-ESS2-1	Develop a model to describe the cycling of Earth's materials and flow of energy that drives this process.
	MS-ESS2-2	Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.
	MS-ESS2-4	Develop a model to describe the cycling of water through Earth's systems drive by energy from the sun and the force of gravity.
	MS-ESS3-1	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.
	MS-ESS3-2	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
	MS-ESS3-4	Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.
	MS-PS1-3	Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
NGSS H.S. (9th – 12th)	HS-ESS2-1	Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
	HS-ESS2-2	Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
	HS-ESS2-5	Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
	HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
	HS-ESS3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
	HS-ESS3-3	Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
	HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
	HS-ESS3-6	Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.