Central Texas Geology Trip Suggested Station Guide

Prepared for the GeoFORCE/ STEMFORCE INSTRUCTIONAL TEAM

12th Grade Academy Summer 2018

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**NOTE: The instructional team determines how best to organize stations.**

**Mount Bonnell**

**Station 1.** Mount Bonnell Summit. Orientation/ Map Reading

* + Locate Mount Bonnell on the geologic map.
	+ Have students determine location and orient themselves in space by using hand-held GPS units, Silva Ranger compasses and cells phones.
	+ What is GPS and how does it work?
	+ What is the Geographical Coordinate System? Some measurements may be in in degrees, seconds and minutes (DMS) or in decimal degrees. Be sure that the students understand both DMS and decimal degrees.
	+ What is the difference between true north and magnetic north? Discuss Earth's magnetic field and magnetic declination. Be sure to adjust the Silva compasses for the magnetic declination at Mount Bonnell (3.83 degrees East).

Magnetic Declination Estimated Value, NOAA National Centers for Environmental Information, at https://www.ngdc.noaa.gov/geomag-web/#declination

**Station 2.** Summit. Mount Bonnell Fault and Faulting (Discussion)

Mount Bonnell is situated above Lake Austin. The Mount Bonnell Fault runs along the base of the hill, passes beneath Lake Austin, and continues to the skyline. The Tom Miller Dam (see in the distance) was built across the Colorado River, separating Lake Austin and Lady Bird Lake. It marks the location where the Mount Bonnell Fault passes beneath Lake Austin. This point is at a divide. Upstream of the Colorado is the Hill Country, which is the higher, or uplifted, section from the Balcones. Downstream, you will also notice that the land soon flattens out. The rock layers all along Mount Bonnell and vicinity are horizontal.

* + What is a fault? Why does faulting occur?
	+ What are the main types of fault? Describe the stresses and displacement associated with the different types of faults.
	+ What is the difference between a fault and a joint?
	+ What is the connection between earthquakes and faulting?

**Station 3.** Mount Bonnell Summit. Balcones Escarpment (Discussion)

The Balcones Escarpment marks the boundary between the American South (downfaulted, on the left/south) and the American West (upfaulted, on the right/north). At Mount Bonnell the fault displacement is about 670 feet (200 meters). Note the change in the tree cover and the species of trees. You are standing in the Hill Country and it is full of cedar, youpon, and flowering bushes. Look now at the flatlands and you will see fewer trees, almost none of which are cedar. This point is only a little over 750 feet above sea level, but the soil and the climate are sufficiently different from the flats to make a difference in rainfall and in the types of vegetation (Long).

* How does the Balcones Escarpment influence climate, weather, and the distribution of vegetation?
* Geology has also influenced human activities, settlement patterns, agricultural practice, and commerce from prehistoric times to the present. How did the Balcones Escarpment influence the economic and cultural development of Texas during the period of early settlement? It marks the boundary between the cotton economy of the Old South and the cattle economy of the Old West. People settled along the Balcones Escarpment in order to draw on both economies--cotton and cattle. In time many major towns and cities were established along the Balcones Escarpment, drawn by the dependable water supplies provided by the great springs that issue forth along the fault zone. Examples where industry and commerce flourished are Del Rio, San Antonio, Austin, Temple, Waco, Dallas/Fort Worth and Sherman/Denison. Transportation routes were established parallel to the escarpment. In the 20th Century, Interstate 35 (I-35) was developed and follows the Balcones Escarpment along a large part of its route.
* How does the Balcones Escarpment influence the development of Austin Today? Examples are: Patterns of population growth, new transportation corridors and recreation.
* Note: Balcones is the Spanish word for "balconies".

**Station 4.** Summit. Edwards Plateau (Discussion and chemical reactions)

From our vantage point, we look out across Lake Austin to the Edwards Plateau, also known as the "Hill Country".

* What does the widespread deposition of carbonate material in the Cretaceous tell us about Earth's climate and the paleolatitude of central Texas at that time? The climate was warm and tropical and Austin was closer to the equator.
* Geoscientists estimate that atmospheric CO2 levels exceeded 2000 ppm at some times during the Cretaceous. How does this compare with modern levels of atmospheric CO2? Modern atmospheric CO2 levels are ~400 ppm.
* How did the climate impact sea level? The warm Cretaceous climate made sea level higher because no H2O was stored in ice sheets as is the case today. Additionally, warm water is less dense than cold water and has a greater volume.
* Students should create an annotated sketch of the area from this location.

**Station 5.** Base of stairs and immediately below the gazebo at the top of Mt. Bonnell. Glen Rose Limestone. (Rock and mineral ID)

The Cretaceous Glen Rose Limestone outcrops at Mount Bonnell. It consists of alternating layers of harder and softer limestone or marl. These shallow-water marine formations were deposited through a number of marine regressions and transgressions. The stair "risers" are held up by hard strata and the recessive "treads" are where soft material has eroded back. A variety of fossils are found in the Glen Rose, including gastropods, clams and echinoids.

Have students use their hand lenses, scratch kits and dilute HCl (0.1 M hydrochloric acid) to identify the type of rock at this station. They should also use their Silva compasses or phones to measure the strike and dip of the layers of the Glen Rose Limestone.

* + What is the lithology of the rock present? Instructors should refer back to the chemical reaction of carbonate dissolution to explain the CO2 gas bubbles that form upon reaction with HCl.
	+ Can you see any fossils?
	+ In what type of environment were these rock layers deposited? The Glen Rose represents a shallow subtidal to supratidal environments; in the Austin area the much of the rock formation was formed under supratidal conditions. The source of the carbonate sediment was from subtidal organic accumulations of carbonates, which were in turn reworked into supratidal environments by storms, winds, and waves.
	+ Explain the staircase profile on hill as you ascend and descend Mount Bonnell. The harder beds are more cemented than the softer beds and more resistant to erosion than the softer, crumbly layers. Because of the differing strengths of the layers, the limestone weathers to form a staircase profile on hills.

**Station 6.** Impact of Balcones Fault Zone on Hydrogeology (Discussion)

The Edwards Aquifer is an important karst aquifer. The aquifer feeds several well-known springs. Springs such as [San Pedro Springs](https://en.wikipedia.org/wiki/San_Pedro_Springs), [Comal Springs](https://en.wikipedia.org/wiki/Comal_Springs_%28Texas%29), [San Marcos Springs](https://en.wikipedia.org/wiki/San_Marcos_Springs), [Barton Springs](https://en.wikipedia.org/wiki/Barton_Springs) and [Salado Springs](https://en.wikipedia.org/wiki/Salado_Springs) are found in the Balcones Fault Zone and provide a source of fresh water and a place for human settlement.

What is an aquifer? An aquifer is a body of saturated rock through which water can easily move. It is estimated that more than 95% of the fresh water available to humans is stored as groundwater is aquifers around the world.

**Barton Springs**

**Station 1 and Station 2.** Entrance to Barton Springs (the same information is covered at both stations)

* Deliver an overview of Barton Springs.
* What is an aquifer? Recharge Zone? Contributing Zone?
* A unit of rock that has the ability to store and transmit water of usable quality and quantity is called an aquifer.
* Have you noticed around Austin signs that say, "Aquifer Recharge Zone"? Or, "You are entering a sensitive recharge area for the Edwards Aquifer". What does this mean?
* What is the recreational value of Barton Springs to the residents of Austin?
* Ask students to consider the value of the springs and to name threats that development poses.
* What are the threats to the Edwards Aquifer and its great springs, such as Barton Springs? Rapid urbanization of Central Texas poses three primary threats to the aquifer: over pumping of the water, contamination, and the reduction of impervious cover (roads, parking lots, etc.)
* Filling in sinkholes, fractures and other recharge features by constructing buildings, roads, and parking lots may reduce the amount of water entering the aquifer. Increased impervious cover also leads to increased flooding and erosion of stream banks, which results in higher levels of sediments entering the aquifer and emerging at the Springs.
* Runoff containing hazardous materials from urban pollution or chemicals applied to farmland and yards in neighborhoods may find its way into the aquifer, reducing the water quality and potentially endangering the health of users. Animal waste (ranches, farms and, dare we admit, our canine companions) can also contaminate the aquifer.

**Stations 3 & 4.** SPLASH Exhibit. Students enter into a simulated limestone cave to experience Barton Springs and the Edwards Aquifer [https://austintexas.gov/sites/default/files/files/Parks/ANSC/BSEC\_Splah\_Exhibit\_website\_2018.pdf/'SPLASH'](https://austintexas.gov/sites/default/files/files/Parks/ANSC/BSEC_Splah_Exhibit_website_2018.pdf/%27SPLASH%27)

<https://austintexas.gov/sites/default/files/files/Parks/ANSC/BSEC_Splash__Exhibit_website_2018.pdf>)

Instructors should take two groups into the SPLASH Exhibit at a time. One group can concentrate on the video, Strata Cave, and Watershed Model (Station 3). The other group can focus on the Aquaria, Pollution Tubes and Water Science Room (Station 4).

* Theater. On the touchscreen menu, choose the heading "Science" and the video "Carved in Stone." This 4- minute movie illustrates the geologic processes that formed the aquifer and Barton Springs. Discuss the large span in geologic time and how Austin used to look.
* Strata Cave. This passageway shows the rock layers of the aquifer that exist below us in Central Texas.
	+ Touch and describe the differences between each layer.
	+ How does the physical make-up of each rock layer impact the movement of water through the aquifer?
* Watershed Model
* How does water enter the aquifer?
	+ Each button and corresponding animation show the journey water must take to enter the Edwards Aquifer.
* Aquaria. Each of the 4 aquaria represents a different part of the local watershed; upper Barton Creek, Barton Springs Pool, lower Barton Creek and the Colorado River.
	+ What are the differences between each aquarium.
* Pollution Tubes. These tubes represent the different kinds of impacts human actions can have upon waterways.
	+ What are the causes and effects of each type of pollution, especially in regard to the aquatic critters that live in Austin's creeks?
* Water Science Room. Take 5-10 minutes to explore the interactive games and models. Students
	+ who live in Austin, can enter the name of their school to find their school's watershed,
	+ test Barton Creek's water with light to measure for nitrates,
	+ use a dichotomous key to identify an aquatic insect and
	+ determine if storm water flows faster over pavement or parkland.

**INSIDE POOL AREA**

**Station 5.** Inside Barton Springs Pool (west end of pool)

* Sketching activity. Identify the rocks that outcrop on the on south side of the pool
* Measure the orientation and dip of the beds
* Note the vegetation.
* In the deeper part of the Barton Springs Pool, measure the temperature, pH, and phosphate concentration if possible.

**Station 6.** Swimming in Barton Springs Pool.

* Encourage students to reflect on the springs as a source of inspiration for art, poetry, music and dance, spiritual replenishment, and enjoyment. Students may be inspired to write a poem or draw a picture or create a dance.

**ENCHANTED ROCK**

**NOTE: The instructional team determines how best to organize stations.** There are six stations at Enchanted Rock along the Summit Trail. A trip to the summit is optional, weather permitting. Ideally groups should rotate between stations, but this may be challenging given that the stops are on the summit trail.

**Station 1: Gazebo**

The gazebo is good spot from which to visually survey Enchanted Rock, review how it formed, discuss its dome shape, and establish where we are in geologic time and in space.

* + Locate Enchanted Rock on the geologic map and where the station is on the Enchanted Rock Trail Map.
	+ Have students determine location and orient themselves in space by using hand-held GPS units, Silva Ranger compasses and cells phones.
	+ What is GPS and how does it work?
	+ What is the Geographical Coordinate System? Some measurements may be in in degrees, seconds and minutes (DMS) or in decimal degrees. Be sure that the students understand both DMS and decimal degrees.
	+ What is the difference between true north and magnetic north? Discuss Earth's magnetic field and magnetic declination. Be sure to adjust the Silva compasses for the magnetic declination at Enchanted Rock (4.40 degrees East).
	+ When and how was the Enchanted Rock batholith exposed?

Magnetic Declination Estimated Value, NOAA National Centers for Environmental Information, at https://www.ngdc.noaa.gov/geomag-web/#declination

**Station 2. This station is at the base of the steps leading down from the gazebo. It is a creek (dry or with intermittent flow)**

GPS: 30.499, -98.817

* + Notice the fractures. These formed during tectonic activity (uplift).
	+ What role do fractures and water play in the development of Enchanted Rock?
	+ Point out how erosion and weathering along faults have segmented the Enchanted Rock batholith into the other nearby domes such as Little Rock and granite hills such as Turkey Peak. Point out valleys, such as Echo Valley, and discuss how fractured bedrock erodes into valleys.
	+ Notice the pink gravel known as grus. What is it composed of?
	+ How have chemical and mechanical weathering contributed to the disintegration of the granite?

**Station 3. Rock Pedestals or Mushroom Rocks**

Elevation: 451 meters GPS: 30.512, -98.818

After climbing up the Summit Trail through a jumble of boulders, you'll reach the smoother surface of Enchanted Rock. To the left of the trail is a collection of rock pedestals and to the right a shady spot under a live oak where it is possible to take cover and drink some water. This is a good spot to have students use a hand lens to identify the minerals in the granite and grain size chart to determine the size of the grains. It is also a good spot to review how differential weathering helps to sculpt Enchanted Rock. The granite at Enchanted Rock is coarse-grained granite composed of quartz, microcline feldspar, plagioclase feldspar, albite feldspar, biotite mica, and hornblende. The blocky pinkish to orange microcline feldspar stands out, giving Enchanted Rock its characteristic color.

* + What minerals are visible in the granite?
	+ Have you seen this granite anywhere else? Granite quarried from the Enchanted Rock batholith was used in the construction of the original Austin Dam (replaced by Tom Miller Dam). It is also found at the Texas State Capitol.
	+ In many places the microcline feldspar have a parallel arrangement known as magmatic foliation, which is more or less parallel to the margin of the batholith. Look for examples of magmatic foliation.
	+ How do we know the age of Enchanted Rock?
	+ How did the rock pedestals form? Differential weathering.
	+ What explains the grain size?
	+ Notice that plants, including fairy ferns and live oak trees, grow in the fractures. How can plants live in the harsh environment of the fractures at Enchanted Rock?

**Station 4. Sign Post Above Mushroom Rocks**

Elevation: 475 meters GPS: 30.502, -98.818

Above the rock pedestals, the trail gives way to the steeper, smooth surface of Enchanted Rock. This is a good place to look around at the many exfoliation features that are visible on the flanks of Enchanted Rock and Little Rock, and observe dikes and weathering pits (gnammas). Exfoliation occurs along curved fractures that formed parallel to the surface at Enchanted Rock when the overlying rocks were eroded reducing the pressure on the batholith during uplift (also known as exhumation). Sheets or slabs of curved granite peel away like the layers of an onion. Notice the depressions called weathering pits or gnammas. In some depressions, water collects and the granite erodes faster than the surrounding surface. Pits that hold water for several weeks are called vernal pools. Over time, soil develops in these pools, evolve into microhabitats that support a unique assemblage of plants and animals. These are among the most ecologically significant habitats found in Texas.

* + How has weathering contributed to the distinctive dome shape of Enchanted Rock?
	+ What are the depressions in the granite and how did they form? In many case, they follow a linear alignment. Measure the strike of this alignment.
	+ How tall are sides of depression pits and/or vernal pools? Does the height vary around the edges? Any
	+ How are the depressions and vernal pools similar and different from the pot potholes at Pedernales Falls?
	+ How did Enchanted Rock get its name?

**Enchanted Rock Summit (optional).**

Some students may get to the summit of Enchanted Rock. Be sure that those who continue on have plenty of water. From this vantage point, it is possible to see a series of granite domes and hills trending to the northeast and the southwest. These are mark the boundary of the Enchanted Rock batholith. To the east are the Riley Mountains, a fault-bounded area of Paleozoic sedimentary rocks. The Precambrian Enchanted Rock batholith and the Paleozoic sedimentary rocks comprise the Llano Uplift. To the south, the flat landscape is the Edwards Plateau, which is composed on Cretaceous limestone deposited on top of the Precambrian and Paleozoic rocks of the Llano Uplift.

* + Why are the younger limestone rocks lower that the older granite rock of the Enchanted Rock?
	+ Encourage those students who hike to the top to take images that they can share with team members.

From the summit, descend down the Summit Trail to the base of Enchanted Rock.

**Station 5. This station is at the base of the steps just below the gazebo. It is a creek (dry or with intermittent flow).**

GPS: 30.499, -98.817

It is the same location as Station 2. Observe the fault gouge. Fault gouge is the crushed and ground up rock that produced by friction between two sides of a fault when a fault moves. The faulting occurred during tectonic activity (in this case uplift). Therefore fault gouge is a tectonite. Geologists can use the amount of fault gouge to estimate how much movement occurred along a fault. This is a good spot to collect drone imagery, making certain to fly the drone away from any hikers on the trail.

* + Describe the rock. Is it the same or different from the granite of Enchanted Rock?
	+ How did it form?
	+ Is there active faulting at Enchanted Rock today?
	+ Measure the strike of the fault gouge.
	+ Collect imagery with drone (if permissible).

**Station 6. Gazebo (Sketching Activity and Wrap-Up)**

The gazebo is a shady spot where students can create one or more annotated sketches of Enchanted Rock. Instructors can ask questions to monitor student learning, answer questions and clarify misconceptions.

**Drone Flyover (designated area for which project has approval).** Students should collect aerial photos and video imagery of the field site, using the camera that comes with the drone. Back in the classroom, they will download photos and video to the laptops computers. Students should do either activity 1 or Activity 2. The truly ambitious students could attempt Activity 3, but note that it requires additional software.

INSTRUCTORS: PLEASE BE SURE YOU HAVE ASSEMBLED THE MATERIALS NEEDED FOR THESE ACTIVITIES PRIOR TO IMPLEMENTATION.

* + Activity 1: [How High is My Drone Flying?](https://scied.ucar.edu/activity/uav-test-altitude/), UCAR Center for Science Education [UCAR Center for Science Education\_How High?.pdf](https://serc.carleton.edu/admin/private_download.php?file_id=160155) (Acrobat (PDF) 542kB May24 18)

**INKS LAKE DEVIL’S WATERHOLE**

**Station 1. This station is located where you leave the gravel trail and ascend the outcrop over solid rock.**

GPS: 30.748; -98.359

* Describe the appearance of the rock unit that we are standing on (color, gain size, hardness, etc.). Identify the lithology and type of rock? Note any diagnostic characteristics to support the identification. Texture - some finer crystals along with larger crystals. Foliations. Veins.
* What minerals can you identify?
* Does the rock look similar to anything you've seen before? Town Mountain Granite. How is it similar? How is it different?
* Use the geologic and trail maps to help you determine where you are in geologic time and space.
* Proceed along the trail, noticing migmatites and dikes.

**Station 2. Outcrops covered in lichen.**

* Look for and note examples of some of the special flora and fauna found in Inks Lake State Park.
* What role does biology play in weathering?

**Station 3. Open clearing with sand-filled depressions.**

GPS 30.748; - 98.323

* Why is the sand reddish in color? Where did it come from?
* How did it get into the depressions?
* Look out at the landscape. Make a quick sketch "What a Geologists Sees"

**Station 4. Valley Spring Creek**

GPS: 30.748; -98.357

* At this station, ask student to try to point out and describe the many features that are indicative of deformation and the high temperatures that are indicative of metamorphism. These include foliation, migmatites, veins, dikes, and boudinage. Numerous joints and faults are present. BRING A JUG OF WATER TO SPLASH ON THE GNEISS TO HIGHLIGHT THESE FEATURES.
* If there is water in the creek, notice how it follows the joint patterns. How does this impact erosion?
* Use phone apps or Silva Compasses to record to the strike of the many features.

**Station 5. Sketching**

GPS: 30.748; -98.357

Students should find a comfortable spot to make an annotated sketch of the outcrop with the a number of cross-cutting dikes. They should order the features chronologically, using their knowledge of the Principle of Cross-Cutting Relationships.

**Station 6. Drone Flyover.**

GPS: 30.748; -98.357

At this station students should collect aerial photos and video imagery of the field site, using the camera that comes with the drone. Back in the classroom, they will download photos and video to the laptops computers. Students should do either activity 1 or Activity 2. The truly ambitious students could attempt Activity 3, but note that it requires additional software.

INSTRUCTORS: PLEASE BE SURE YOU HAVE ASSEMBLED THE MATERIALS NEEDED FOR THESE ACTIVITIES PRIOR TO IMPLEMENTATION.

* + Activity 1: [How High is My Drone Flying?](https://scied.ucar.edu/activity/uav-test-altitude/), UCAR Center for Science Education [UCAR Center for Science Education\_How High?.pdf](https://serc.carleton.edu/admin/private_download.php?file_id=160155) (Acrobat (PDF) 542kB May24 18)

**LCRA Red Bud Isle Wilkerson Center**

**NOTE: The instructional team determines how best to organize stations. The order here doesn't really matter.**

**Station 1.** The The Highland Lakes and dams are the heart of the lower Colorado River management system. The Wilkerson Center's outdoor installation is a physical model that depicts the Highland Lakes and the dams that separate one from another.

* Students should trace the flow of the Colorado through the Highland Lakes System from Lake Buchanan to Lady Bird Lake. Students can turn spigots to simulate the flow through the system.
* Students should make an annotated sketch of the Highland Lakes System.

**Station 2.** Gridded walkway out to Tom Miller Dam viewing area. The walkway is a timeline of key events in the history of the Highland Lakes System. The record of the 2000's is wearing away (erosion) as people walk over the area. Ask students to rewrite this section of the history for the LCRA. From this point, there is a view of a Hydromet station to the left as you look out toward Lady Bird Lake.

**Station 3.** At the end of the walkway is a lookout for viewing the [Tom Miller Dam](https://www.lcra.org/water/dams-and-lakes/Pages/miller-dam.aspx/). The main Balcones Fault (Mount Bonnell Fault) crosses the Colorado River obliquely just north of Tom Miller Dam. Lead a discussion of the history of dam construction at this location on the Colorado River in Austin. Bruce Hunt's article, [The Rise and Fall of the Austin Dam](https://notevenpast.org/rise-and-fall-austin-dam/), tells the story of the old Austin Dam that was the precursor to the Tom Miller Dam, which separates Lake Austin from Lady Bird Lake downstream on the Colorado River.

* The current Tom Miller Dam is the third to be constructed across the river at this location. What a factors did the engineers fail to recognize when the constructed the earlier dams that contributed to dam failure?
* How was Red Bud Isle formed? Parts of the old Austin Dam, including the massive granite blocks, were washed downstream away when the dam failed. The debris served as a nucleus around which trapped sediment accumulated,creating the island.

**Station 4.** LCRA Hydromet Station. [https://hydromet.lcra.org/ 'LCRA's Hydromet'](https://hydromet.lcra.org/%20%27LCRA%27s%20Hydromet%27) is a system of more than 275 automated river and weather gauges throughout the lower Colorado River basin in Texas. In addition, the website displays gauges maintained by the City of Austin and USGS. The Hydromet provides near-real-time data\* on streamflow, river stage, rainfall totals, temperature and humidity.

**Station 5**. Water Retention System (Gather under the shady spot at the garden trellis at far end of the largest retentions pond).

LCRA actively manages stormwater runoff around the Highland Lakes and the lower Colorado River to contain the pollution found in stormwater runoff, such as pesticides, soil, nutrients and other contaminants from everyday life. Travis County, the Highland Lakes Watershed Ordinance (HLWO), Edwards Aquifer Protection Program, and City of Austin standards all require permanent controls to treat storm water runoff. At this station, students see how bioretention is used by LCRA to manage storm water runoff.

* Students make an annotated sketch of the water retention system employed at this site.
* Students write a paragraph to explain how the system works.

Terms: Spillway, detention pond, extended detention pond, vegetated swale, bioretention (an attractive landscaped water quality basin that functions as a soil and plant-based infiltration device).

**Station 6.** Amphitheater. Discussion.

This spot in the shade is a good place to review the geology of the site. The Wilkerson Center sits on a series of gravel layers deposited in the past on the river's floodplain. These older sediments are of Pleistocene to Holocene in age. They are referred to as river terraces since they occur at a higher elevation than the Colorado River's modern floodplain. The river terraces overlie the older units of the Cretaceous-aged Edwards Limestone.

* What can you infer about discharge (amount of water flowing) the Colorado in the recent past in comparison to modern times?
* The tectonic activity responsible for the Mount Bonnell Fault created a scarp. What impact did this have on the gradient of the Colorado River? How did this influence sediment deposition and erosion?

**PEDERNALES FALLS**

**Station 1**. Pedernales Falls Trail Scenic Overlook (north end of park at the top of the rock stairs)

The shaded scenic overlook is good spot from which to review the geology of the park, visually survey Pedernales Falls, discuss unconformities, and flash flooding. The Pedernales River drops about 50 feet in elevation over a distance of 3,000 feet as it flows through the falls. Water cascades over tilted, layered stair steps of limestone. The scenic overlook is also a good place to observe that the limestone beds in the falls are dipping to the east and to point out the features that underscore the power of water (in this case the river) to carve, scour and sculpt the terrain. The falls are usually gentle, but flash flooding is a particular geologic hazard at Pedernales Falls.

* Locate Pedernales Falls on the geologic map and where the station is on the trail map.
* Have students determine location and orient themselves in space by using hand-held GPS units, Silva Ranger compasses and cells phones.
* What is GPS and how does it work?
* What is the Geographical Coordinate System? Some measurements may be in in degrees, seconds and minutes (DMS) or in decimal degrees. Be sure that the students understand both DMS and decimal degrees.
* What is the difference between true north and magnetic north? Discuss Earth's magnetic field and magnetic declination. Be sure to adjust the Silva compasses for the magnetic declination at Pedernales Falls (4.09° E ± 0.33° degrees East).

Magnetic Declination Estimated Value, NOAA National Centers for Environmental Information, at <https://www.ngdc.noaa.gov/geomag-web/#declination>

**Station 2**. Falls. Marble Falls Limestone (beyond the base of the steps).

* Students walk out onto the limestone and establish where they are in geologic time and in space.
* What is the elevation?
* What is the GPS location (UTM) where you are standing?
* Describe the appearance of the rock unit that we are standing on (color, gain size, hardness, etc.). Identify the lithology and type of rock? Note any diagnostic characteristics to support the identification. Limestone fizzes in the presence of dilute HCl. Contains fossils. Formed from a fine-grained mud (offshore, deep water).
* Discuss transgression and regression.

**Station 3.** Beds, Fractures and Angular Unconformity.

* What is the GPS location (UTM) where you are standing?
* Measure the strike and dip of the beds. The beds are tilted to the east. The tilting is the result of the collision of South America with North America during the Ouachita tectonic event.
* After the rocks were tilted, they were eroded away. The result was more or less a horizontal surface. Younger limestones were deposited on top of the older tilted beds. Have students look across the falls to the other side of the river where they should be able to see the contact between the older Marble Falls Limestone and younger Cretaceous limestone rocks (above). The change in vegetation marks this boundary.
* What is this type of boundary called?
* How much time is missing in the interval represented at the contact between the older Marble Falls Limestone and younger Cretaceous limestone rocks (above)? About 180 - 200 million years.
* Note the fractures in the Marble Falls Limestone. Are they randomly distributed or do they follow particular directions?
* What are the major orientations of the fractures? Measure and record the strike. The fractures running across the river are joints. Note that the fractures parallel to the river are veins. They are filled with calcite.

**Station 4**. Crinoids and Chert

* What fossils are present in the Marble Falls Limestones? Crinoids, marine animals also known as sea lilies, are abundant.
* What do the fossils tell you about the environment of deposition? Marine or terrestrial? High or low energy?
* Note the crusty orange irregularly patterned surface. Use your hardness kit tools to determine if the crust, rust-colored surface is harder or softer than the grey limestone rock. It is chert (flint, SiO2). Pedernales is the Spanish word for flints.
* Describe the pattern? More or less polygonal and wavy, tubelike.
* What can you infer from the color and the pattern? The crusty surface formed on an ancient subaerially exposed mud flat. The chert (silica) formed as a result of diagenesis in desiccation cracks, the polygonal fractures that typically from when mud dries out, and in tubes created by burrowing creatures. The chert acts like a cement that fills in fractures and pore spaces, as well as replaces some carbonate grains and fragments. The red color is indicative of oxidation (need O2 from the atmosphere).
* The word "pedernales" is Spanish and refers to the flint (chert) that is found in many places in the Marble Falls Limestone.

**Station 5**. Potholes, Sands and Gravel

* What is the GPS location (UTM) where you are standing?
* Note the depressions that are present in the slabs of rock. These are known as potholes. How did they form? Potholes form where eddies drive rocks in a swirl that erodes the limestone (and traps the rocks). There are alsosmall shallow pits and widened fissures that are the result of chemical erosion or dissolving of the limestone.
* Is there a difference between the upstream and downstream ends of the potholes?
* Look for other sedimentary features in the limestone rock.
* Note the accumulations of sand and gravel at the falls. Explain the occurrence, What is the age of these sedimentary deposits?

**Station 6**. Drone Flyover.

* What is the GPS location (UTM) where you are standing?

At this station students should collect aerial photos and video imagery of the field site, using the camera that comes with the drone. Back in the classroom, they will download photos and video to the laptops computers. Students should do either activity 1 or Activity 2. The truly ambitious students could attempt Activity 3, but note that it requires additional software.

INSTRUCTORS: PLEASE BE SURE YOU HAVE ASSEMBLED THE MATERIALS NEEDED FOR THESE ACTIVITIES PRIOR TO IMPLEMENTATION.

* Activity 1: [How High is My Drone Flying?](https://scied.ucar.edu/activity/uav-test-altitude/), UCAR Center for Science Education [UCAR Center for Science Education\_How High?.pdf](https://serc.carleton.edu/admin/private_download.php?file_id=160155) (Acrobat (PDF) 542kB May24 18)

**Station 6**. Scenic Overlook.

Climb back up the stone steps to the scenic overlook. Have the students make an annotated sketch of falls and the rock outcrops across the river. Encourage them to note the angular unconformity.

**BUS RIDE TO WACO MAMMOTH NATIONAL MONUMENT**

**Questions/Topics**

On the bus ride to Waco, have each team generate 3 questions to ask the tour guide. Examples of topics and questions related to the site and to the discussion on the bus include:

* How can we date the flood event that caused the death of the mammoths?
* Were there early humans or other hominids living in the area 67,000 years ago?
* What environmental hazards does the area and its geology hold for human settlement? The construction of transportation routes (e.g., railway lines)?
* Is flooding still a problem in the Waco area? On the Bosque River?
* How has the city of Waco mitigated flood events? *Lake Waco and the Waco Wetlands.*
* How can we use plants and fossils AND chemistry (of teeth?) to describe past environments?
* See grain size (indicates flood event?)
* Climate change (fossilized plants look like arctic plants?)
* Reconstruction of climate
	+ Climate curve
	+ Glacial/interglacial graph
	+ Key to show which plants grow in low temps
* Tie together Waco + Vertebrate paleontology lab + "Death and Burial" board game (if played).