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Geology of the Northern Llano Uplift, Junction to Llano, Texas

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Texas Academy of Science, 2016 Field Trip:

Geology of the Northern Llano Uplift, Junction to Llano, Texas

March 6, 2016

Boudin Structure Llano River Bridge, Llano, Texas

Field Trip Leaders:
R. LaRell Nielson and Chris A. Barker

Department of Geology
Stephen F. Austin State University
Nacogdoches, Texas

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Stromatolitic bioherms at the picnic area where U.S. Highway 377 crosses the San Saba River, Texas. Note the large mound structure that contains a number of smaller elongate build-ups.

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Department of Geology
Stephen F. Austin State University
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Acknowledgements

The writers are grateful to the Geology Department at Stephen F. Austin State University for providing the opportunity to conduct geological research and to lead field trips to the Hill Country for many years. Thanks goes to the Department of Geology for partially funding these field trips and research projects and to our students who have helped us learn more about the area through their questions.

A great deal of thanks and appreciation is given to our spouses (Sylvia and Anne) for their support and encouragement to complete this project.

*Stromatolitic bioherms in San Saba River where it crosses U.S. Highway 377. A number of the larger buildups are present in the river bed and have a northeast-southwest orientation***.**

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Introduction

This year's Texas Academy of Science Geology Field Trip will visit nine interesting locations in two different areas in the Texas Hill Country (Figure 1). In the first area we will look at the Cretaceous stratigraphy around Junction, Texas (Figures 1, 2, 3, and 4). The expedition will then travel to the northern part of the Llano uplift and study Cambrian and Precambrian stratigraphy and structure of the northern Llano Uplift (Figures 4 and 5). Stop 9 will be at Cooper’s BBQ for lunch.

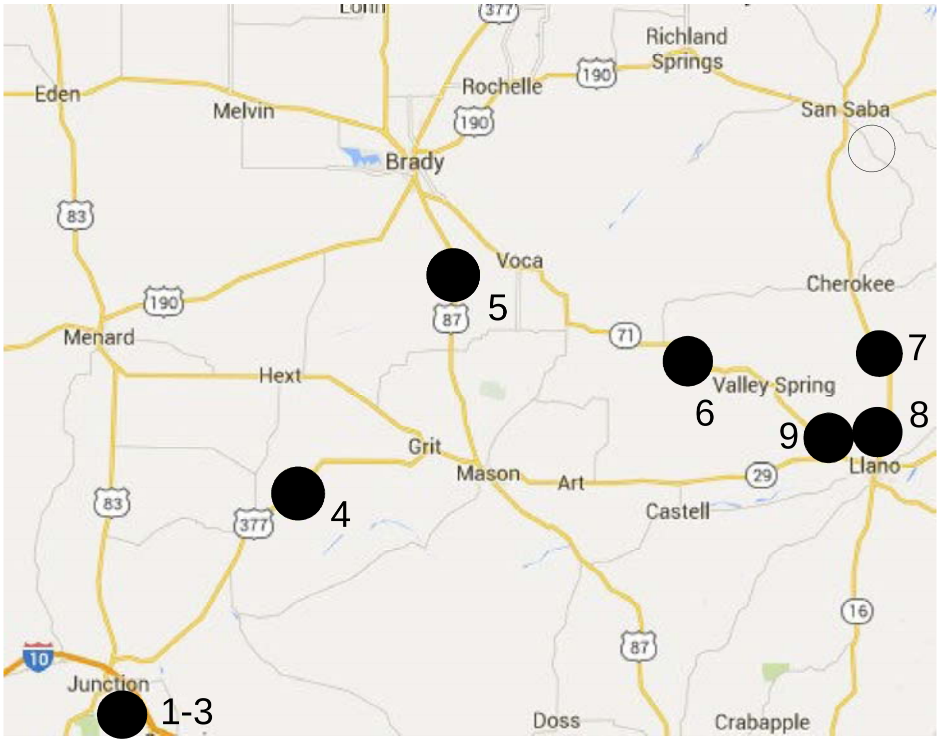


Figure1. Index map to the 2016 Texas Academy of Science field trip stops.

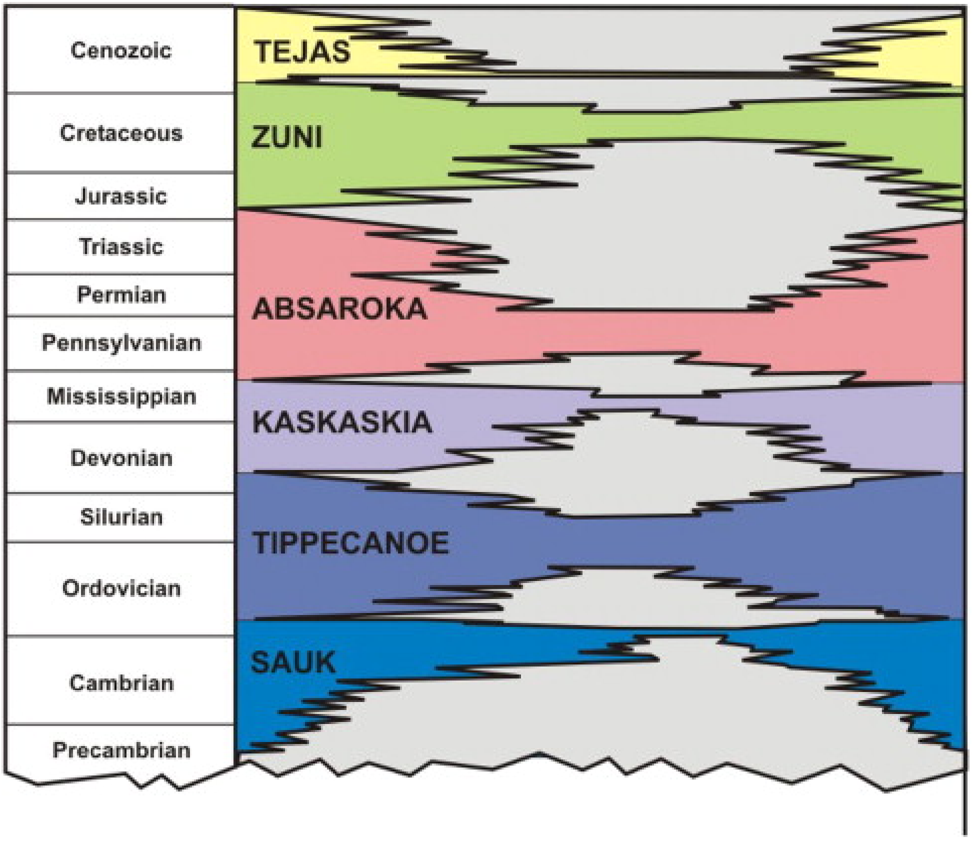


Figure 2. Sloss (1963) cycles - after Donovan (2010 p. 24).

Lithostratigraphic Units				Geologic Time Units
	Buda Limestone			Cretaceous
	Del Rio Clay			
Edwards Group	Segovia Formation			
	Fort Terrett Formation			
Trinity Group	Glen Rose Limestone	Trinity Group Und. white marl pink marl	Hansel Formation	
Undifferentiated Paleozoic's				Paleozoic

Figure 3. Generalized stratigraphic column for the Junction area, Texas.

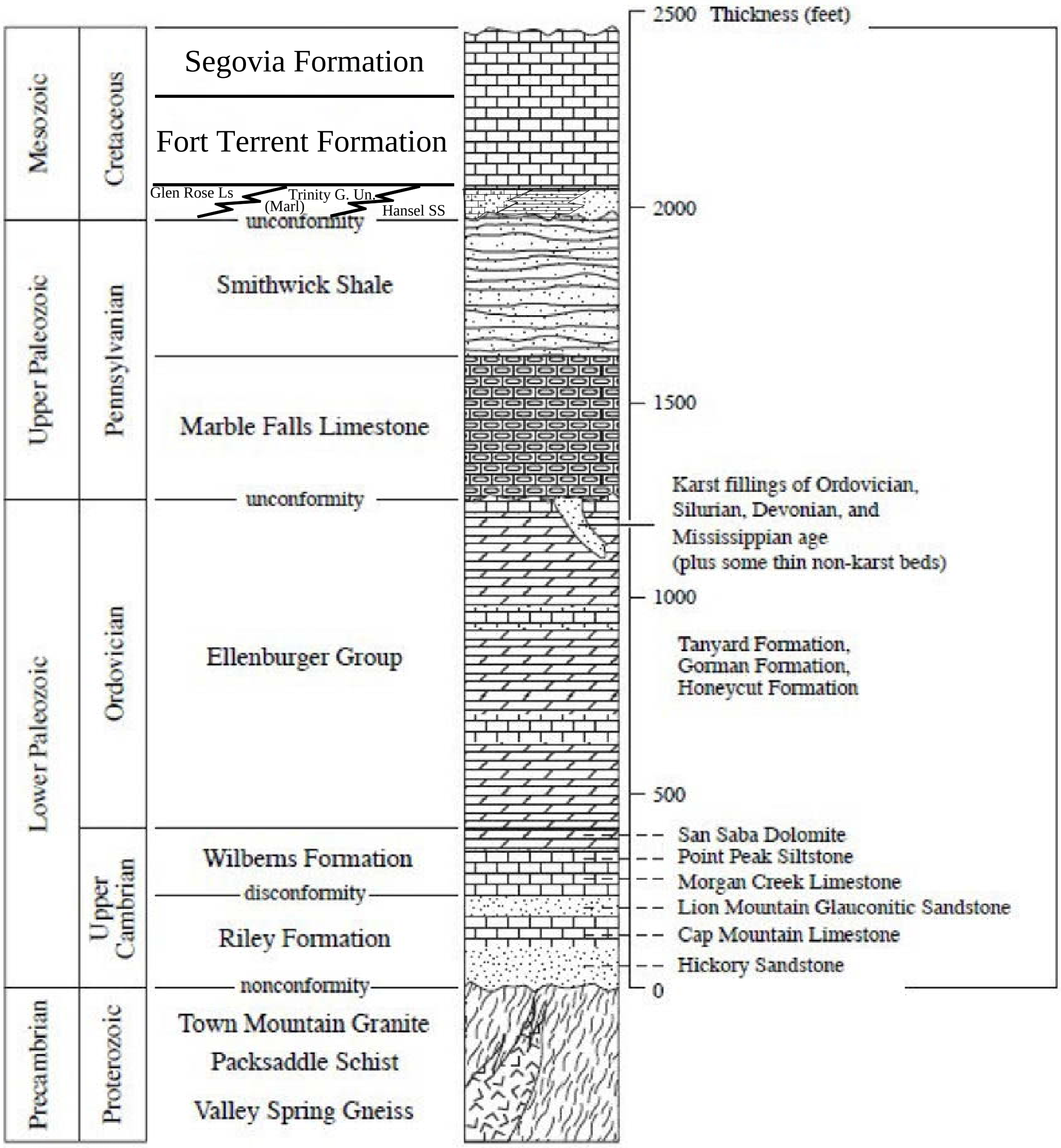


Figure 4. Generalized stratigraphic section showing units present in the western Llano (after L. Long 2010).

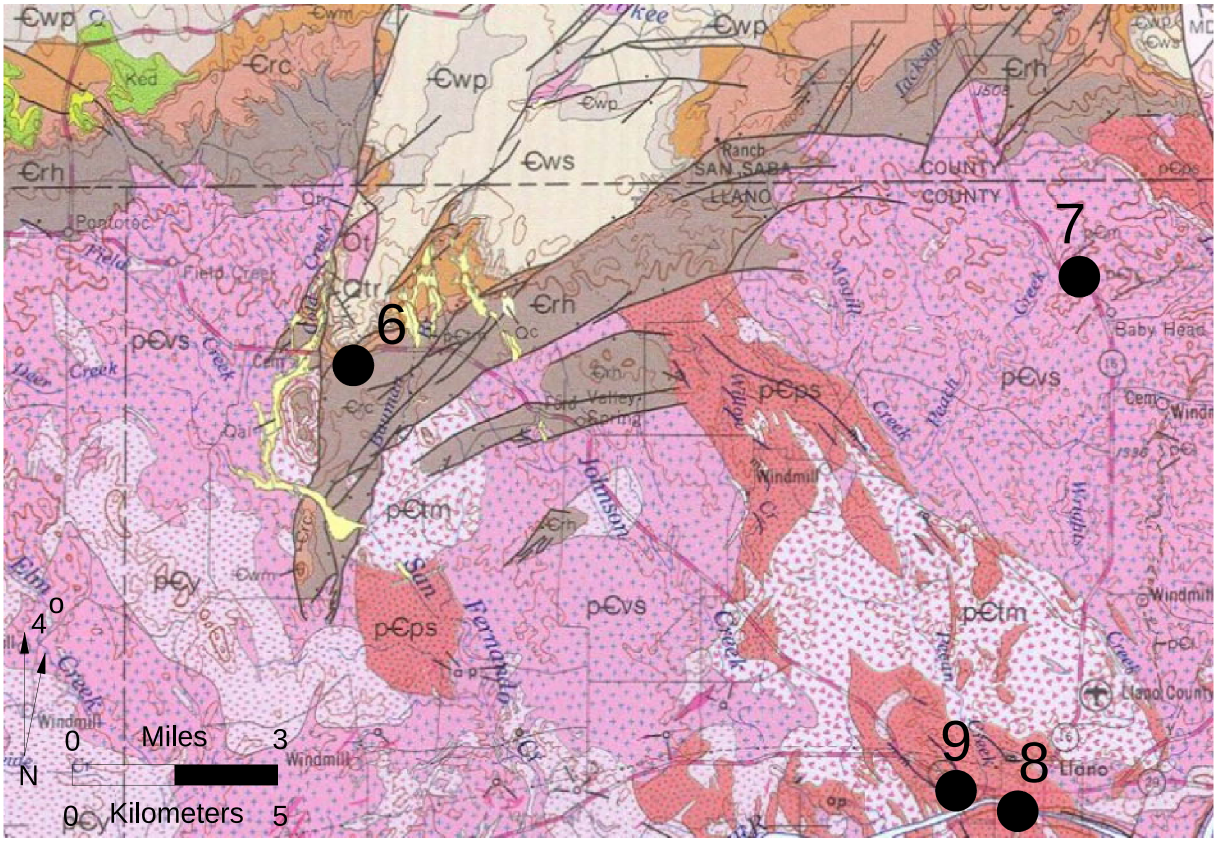


Figure 5. Geologic map of Stops 6, 7, 8 and 9 showing the geology at each stop (Geologic Atlas of Texas, Llano Sheet, Barns, 1986). Map symbols: pCtm – Town Mountain, pCps – Packsaddle Schist, Crh – Riley Formation, Hickory Sandstone, Crc- Riley Formation – Cap Mountain Limestone, Cwp – Point Peak Member, Cws – Wilberns Formation, San Saba Member, Ot – Tanyard Formation, MD –Devonian and Mississippian, IPmf – Marble Falls Limestone, IPsw – Smithwick Formation, Kh – Hensel Sandstone, Kgr – Glen Rose Limestone, Kw – Walnut Formation, Ke- Edwards Group, Kft – Fort Terrett Formation, and Ks-Segovia Formation

Field Trip Stops 1, 2, 3, A and B

Introduction to the Cretaceous, Trinity (undifferentiated) and Edwards (Fort Terrett Formation) groups – Junction, Texas

In the area surrounding Junction, Texas, there are excellent exposures of the Fort Terrett and Segovia formations in the Edwards Group. The white limestone cliffs that surround Junction are Fort Terrett Formation (Figures 3 and 4). Below the Fort Terrett Formation is the Trinity Group that to the south and east contains the Glen Rose Limestone and to the west and north contains the Hansel Formation (Rose, 1972, p. 64 and 65). Jacka (1977 p. 184 and 185) in the section that he measured near Junction, Texas, noted the presence of a disconformity marked by pebbles and cobbles between the Fort Terrett and the Glen Rose Limestone on U. S Highway 84 north of Junction. However, he did not discuss the units below the Glen Rose Limestone. Rose (1972) noted the facies changes that occur between the Glen Rose Limestone and the Hansel Formation but does not describe these changes. Willis et al. (2001, p. 390) described this facies as being a terrigenous, red silty shale that is laterally equivalent to the Glen Rose Limestone and Hansel Formation.

The purpose of Stops 1, 2, 3, A and B, are to provide the opportunity to study these facies changes in the Cretaceous between the Glen Rose Limestone to the south and the Hansel Formation to the north and the overlying Fort Terrett Formation (Figures 6, 7, 8, and 9). The Fort Terrett Formation (Edwards Group) forms the cap of the hills around Junction. Further to the east, the Segovia Formation rests disconformable on the Fort Terrett Formation. This trip will start by looking at the upper part of the Fort Terrett Formation. We will then move down to the lower part of the Fort Terrett Formation and finally examine the terrigenous white and pink marl facies of the Trinity Group. These beds are equivalent to the Glen Rose Formation to the south and east and the Hansel Formations to the north and west (Willis et al, 2001). Stops on this trip will be on Loop 481 on the hill east of Junction.

Two stops (A and B), not visited on this trip, but important to the study of the Cretaceous in this area, are placed in the guidebook for those that want a more complete understanding of the Cretaceous stratigraphy in the area (Figure 9).

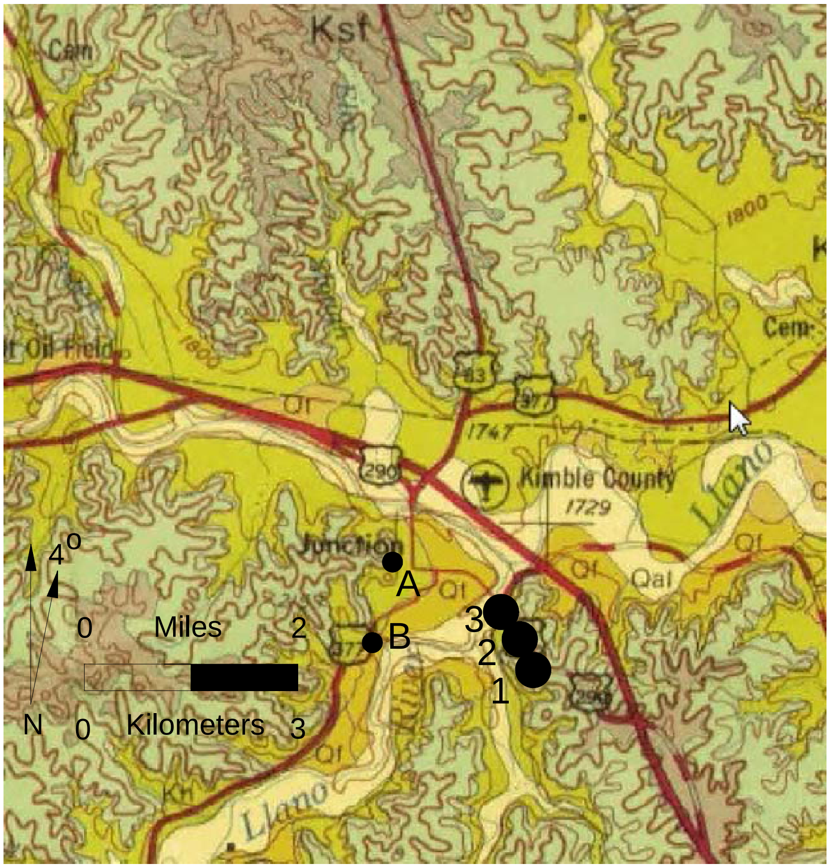
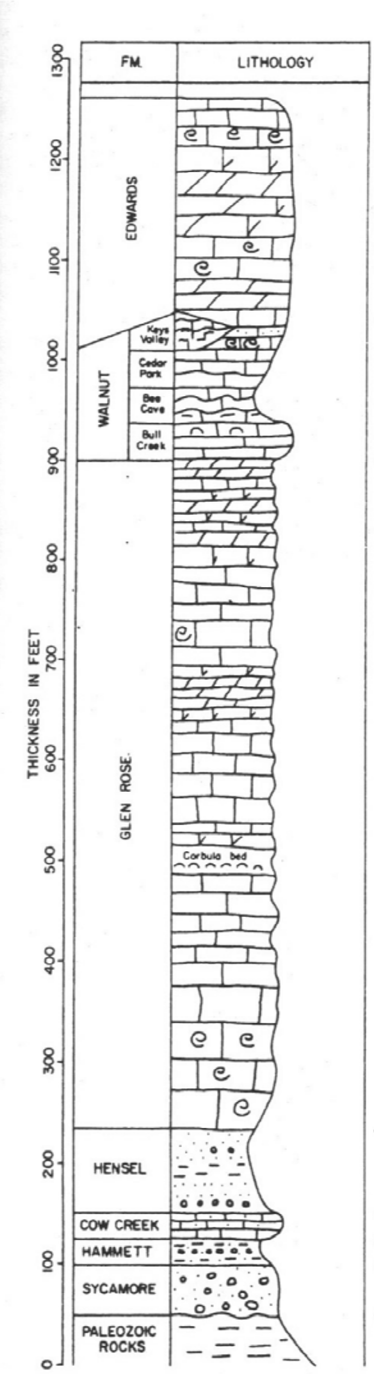


Figure 6. Geologic map of the area around Junction, Texas showing the location of the first three stops (and additional locations A and B). Map symbols: Kh – Hensel Sandstone, Kgr – Glen Rose Limestone, Kw – Walnut Formation, Ke- Edwards Group, Kft – Fort Terrett Formation, and Ks - Segovia Formation



Hard coarse to grained, shelly and rudist Limestone porous dolomite, and evaporites

Nodular marly limestone, marl and granular shell frigment limestone with oysters and ammonites

Interbedded hard and soft limestone, marly limestone, marl, and dolomite

Conglomeratic sand and re-brown clayey silt

Shelly and marly limestone

Conglormatic silty clay

Conglomerate, and Conglomeratic sand

Shale and limestone

Figure 7. Generalized stratigraphic column for the Cretaceous rocks of Llano area.

Junction, Texas Stratigraphic Section

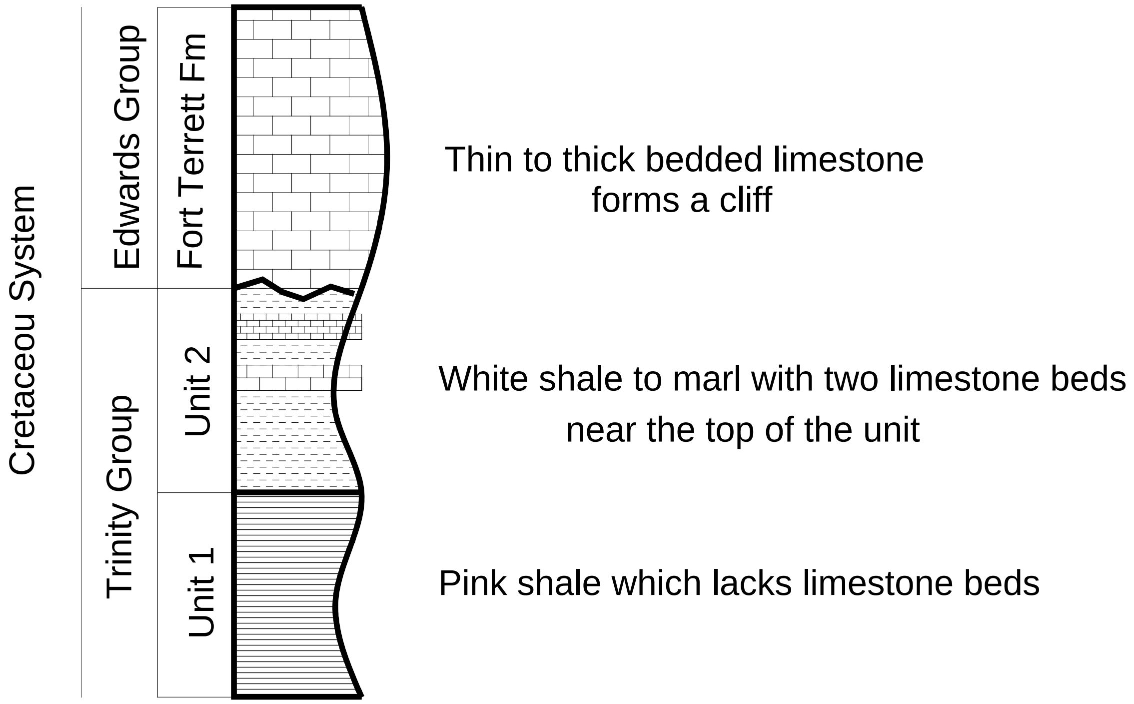


Figure 8. Generalized Cretaceous stratigraphic section for the Junction, Texas area showing Fort Terrett Formation above the white marl and pink marl in the Trinity Group.

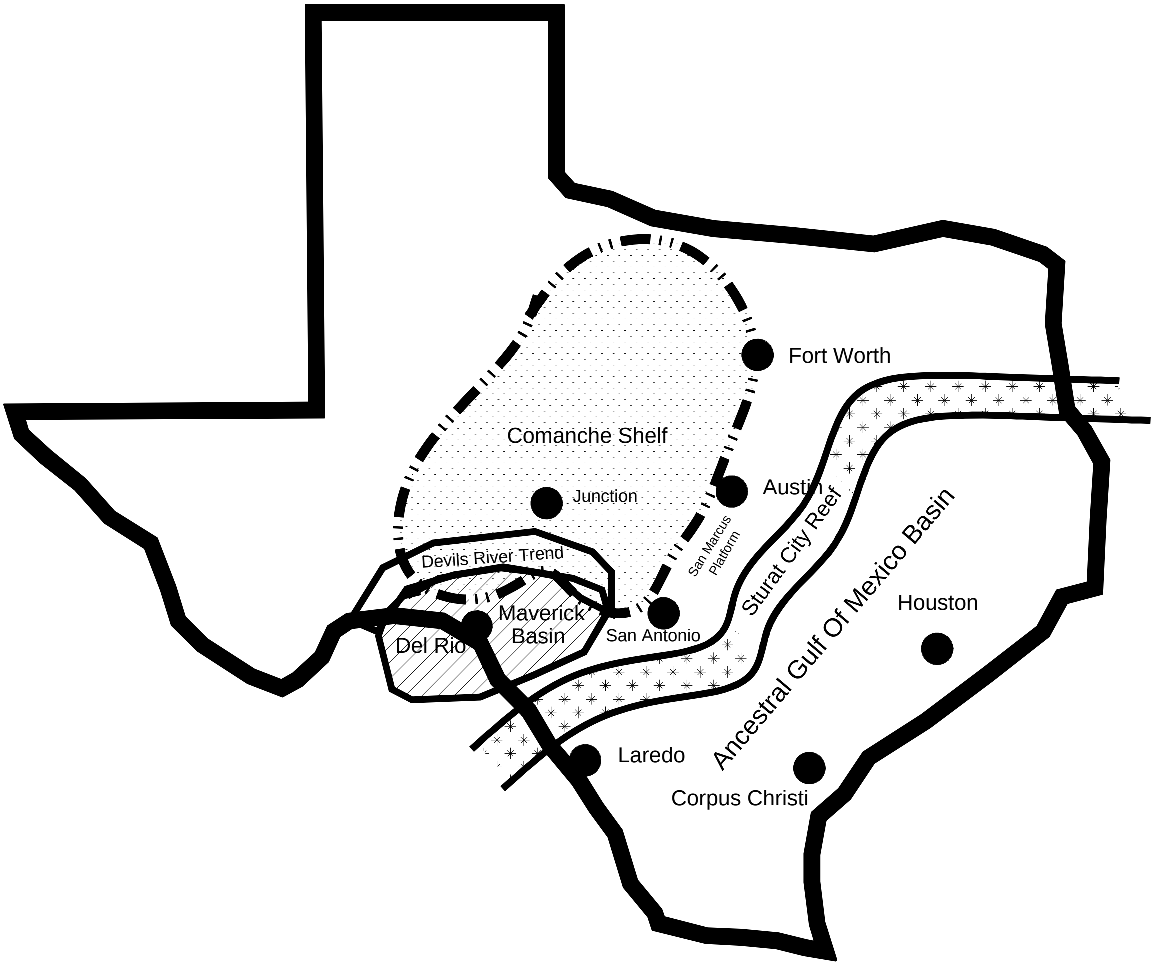
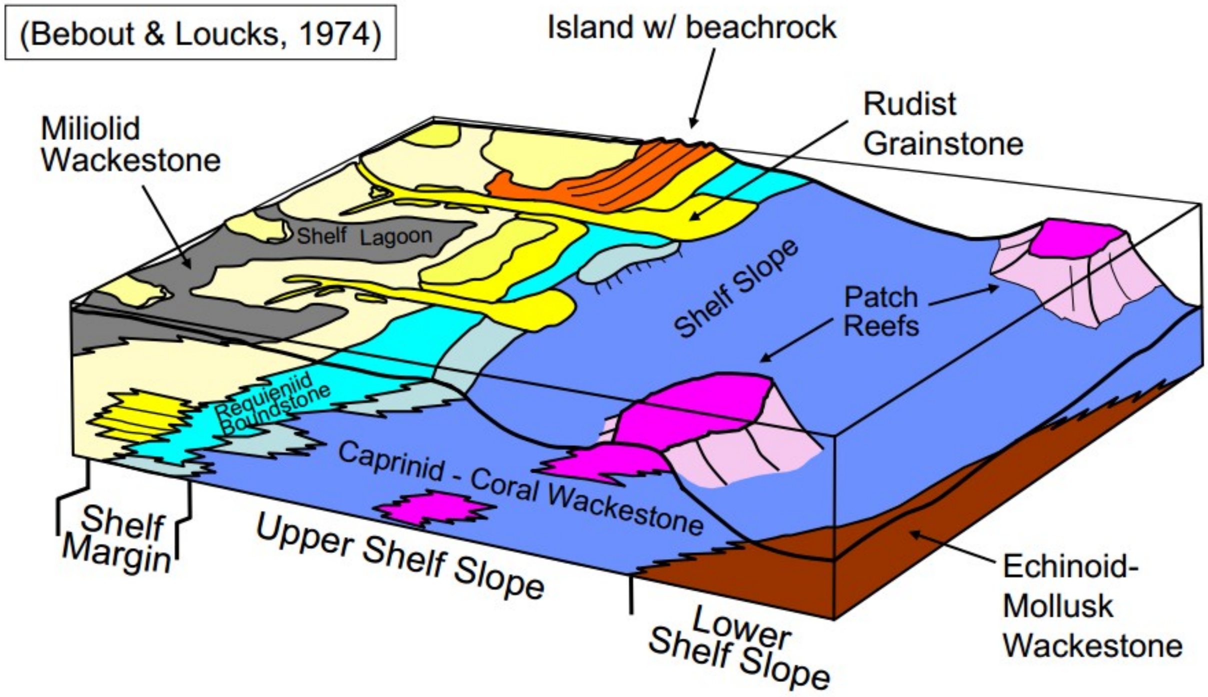


Figure 9. Physiographic features present during the Early Cretaceous Period in Texas.

Figure 10. Generalized map for the Stuart City Reef trend in relation to the Junction, Texas area.



Stop 1.

Fort Terrett Formation – Top of the Hill on Loop 481

Stop 1 is located 1.8 miles east of Junction, on Loop 481 at the top of the hill (N 30.4335, W 99.75095) (Figure 11). Exposures of the upper Fort Terrett Limestone showing horizontal beds of limestone are overlain by breccia deposits and deformed limestone beds. The breccia zones suggest dissolution of gypsum and limestone at the end of Fort Terrett Formation deposition. Folding within the Fort Terrett Limestone is attributed by Willis and Willis (2009) to be the result of calichifraction. These structures have also been interpreted as forming by the dissolution of gypsum beds by Willis, et al. (2001).

Figure 11. Stop 1. Top of the hill east of Junction Texas on Loop 481 as viewed to the northeast. Flat lying limestone beds are overlain by a unit that contains dissolution pits that have been filled with breccia deposits. Dissolution areas are surrounded by tilted limestone beds deformed during dissolution.

Stop 2:

Fort Terrett Formation, Loop 481, Junction, Texas

Lower Fort Terrett Formation, on the 481 loop 1.4 miles east of Junction, Texas (N. 30.477588 W. 99.75652) (Figure 12). The lower Fort Terrett Formation contains flat lying beds of mudstone that have small bioherms. These beds indicate a flat lying carbonate shelf environment. The disconformity found at other locations by Jacka (1977) on U.S. Highway 84 does not appear to be present here (Figure 13).

Figure 12. Stop 2 near the base of the Fort Terrett Limestone. Note that all of the bedding is horizontal and that there is a lack of dissolution breccia. A few small fossil bioherms are present.

Figure 13. One of the bioherms present in the lower part of the Fort Terrett Formation at Stop 2. Note the mound shape and extensive burrows.

Stop 3:

Trinity Group, Loop 481, Junction Texas

Trinity Group (undifferentiated) – Junction, Texas

Stop 3 is 1.1 miles east of Junction, Texas, on the north side of the road (N. 30.47590, W. 99.75645) (Figure 14). Marls and claystones are present below the Fort Terrett Limestone and are placed in the Trinity Group. These marls and claystones are laterally equivalent to the Glen Rose Limestone to the southeast and the Hansel Formation to the northwest. They are placed here in the Trinity Group as undifferentiated units that need additional study. The contact between the Fort Terrett and the Trinity Group is not well exposed at this location. The two principle units seen here are an upper white marl to claystone with limestone beds at the top of the section that weathers to form a cliff and a lower pink claystone to marl with thin white limestone beds. The lower contact of the Trinity Group is not seen here.

Figure 14. Outcrop of the white marl to claystone and the pink marl to claystone present in the Trinity Group at Stop 3. These units represent a lateral facies transition between the Glen Rose Limestone and Hansel Formation.

Stop A:

Contact between Trinity Group and Fort Terrett Formation

Stop A is located west of Junction High School near the city water storage tanks (N. 30.49945, W.90.78301) (Figure 15). The contact between the Fort Terrett Limestone and the Trinity Group is well exposed at this location and is placed at the change in lithology from a thick bedded limestone (mudstone) of the Fort Terrett Formation to the laminated marl to claystone units of the Trinity Group. There does not appear to be a pebbles to cobbles zone at the contact as described by Jacka (1977) on U. S. Highway 84 and along Interstate 10 east of this location. The two limestone beds present below the contact are placed in the Trinity Group. These marl and claystone units are facies equivalent to the Glen Rose Formation to the south and east and the Hansel Formation to the north and west.

Figure 15. Contact between the Fort Terrett Limestone and the Trinity Group. The upper white marl to claystone is seen with several beds of limestone (mudstone) near the top of the section. The lower pink marl can be seen in the foreground. The section is located near Junction High School where the water storage tanks are located on the hill.

Stop B:

Trinity Group on U.S. Highway 377, 2.3 miles south of Junction, Texas

Excellent exposures of the white marl and pink claystone are seen in the Trinity Group 2.3 miles south of Junction, Texas on U.S. Highway 377 (N. 9979420, W. 30.46729). These sediments represent the facies transition between the Glen Rose Limestone and the Hansel Formation and were deposited in a shallow quiet water shelf environment (Figure 16).

Figure 16. Excellent exposures of the two units seen in the Trinity Group 2.3 miles south of Junction, Texas on U.S. Highway 377. The contact between the white and pink marls appears to be conformable. Deposition of both units was on a quiet low energy shelf.

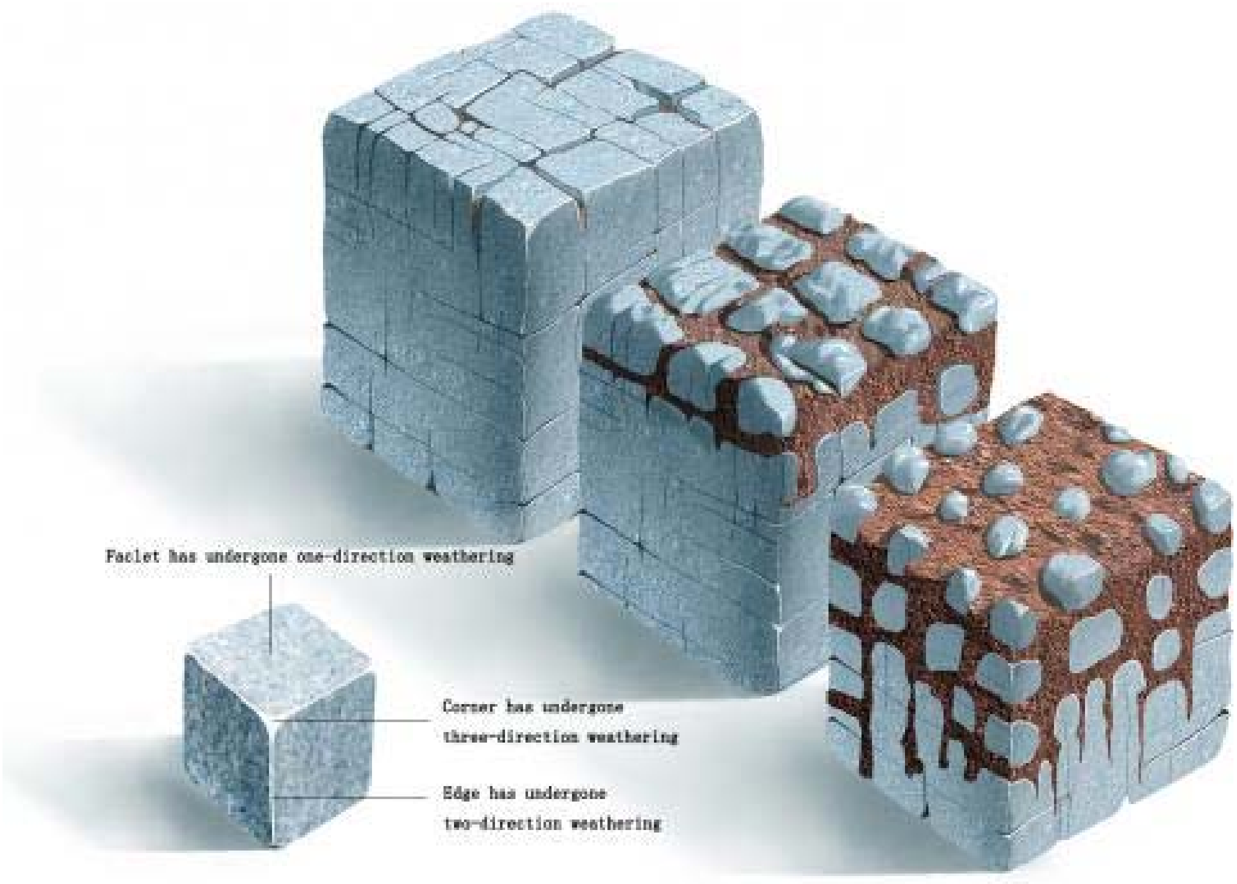
Stop 4:

Spheroidally Weathered Boulders – near Streeter, Texas

This stop is located 35.5 miles northeast of Junction, Texas (N 30. 4777588, W 99.75652) on U.S Highway 377 east of Streeter, Texas (Figure 17). Excellent examples of spheroidal weathered boulders are seen at the contact between the Hickory Sandstone and the Precambrian Town Mountain Granite. The spheroidally weathered boulders were produced by weathering of evenly spaced joints in the Town Mountain Granite (Figures 18 and 19).

Figure 17. Stop 4, 35.5 miles northeast of Junction, Texas (N 30. 4777588, W 99.75652) on U.S Highway 377 east of Streeter Texas. At this stop there are excellent examples of spheroidally weathered boulders produced by weathering along equally spaced joints.

Figure 18. Diagram showing the development of spheroidal boulders (http://southchinaenvir.com/historical-perspectives/historic-fire-effects-on-the-granite-wall-of-st-pauls-church-macau/



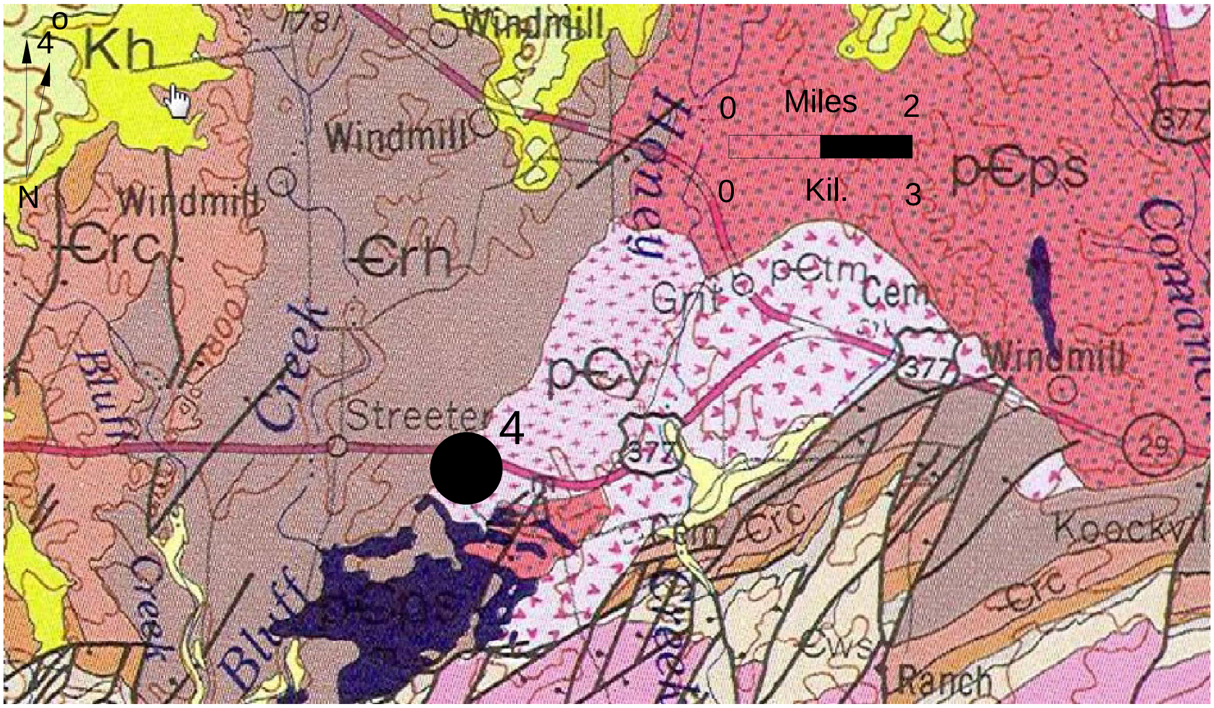


Figure 19. Geologic map of the Streeter area showing Stop 4. located 35.5 miles north of Junction, Texas (N 30. 4777588, W 99.75652) on U.S Highway 377 near Streeter, Texas. Map symbols: pCtm – Town Mountain, pCps – Packsaddle Schist, Crh – Riley Formation, Hickory Sandstone, Crc- Riley Formation – Cap Mountain Limestone, Cwp – Point Peak Member, Cws – Wilberns Formation, San Saba Member, Ot – Tanyard Formation, MD –Devonian and Mississippian, IPmf – Marble Falls Limestone, IPsw – Smithwick Formation, Kh – Hensel Sandstone, Kgr – Glen Rose Limestone, Kw – Walnut Formation, Ke- Edwards Group, Kft – Fort Terrett Formation, and Ks - Segovia Formation

Stop 5:

San Saba River Crossing On US Highway 377

This stop is located at the picnic area on the south side of the San Saba River under the U.S. Highway 377 bridge north of Camp San Saba, Texas (N 31.00392, W 99.26883) (Figures 20 and 21). At river level there are a number of large stromatolitic biohermal mounds. Their geometry shows a steep wave cut side on the northwest and a gentle slope on the lagoon side to southeast. The biohermal mounds are 2 to 4 meters in diameter and contain a number of smaller heads10 to 25 centimeters in size (Figures 22, 23, and 24). These biohermal mounds are considered to be part of a Cambrian wave resistant structure or reef that developed around the Llano Uplift during the Cambrian Period during the deposition of the Point Peak and San Saba members of the Wilberns Formation. The stromatolitic biohermal buildups are also seen at Whites Crossing on the Llano River and on Park Road 4 west of Long Horn Caverns (Figure 24 and 25).

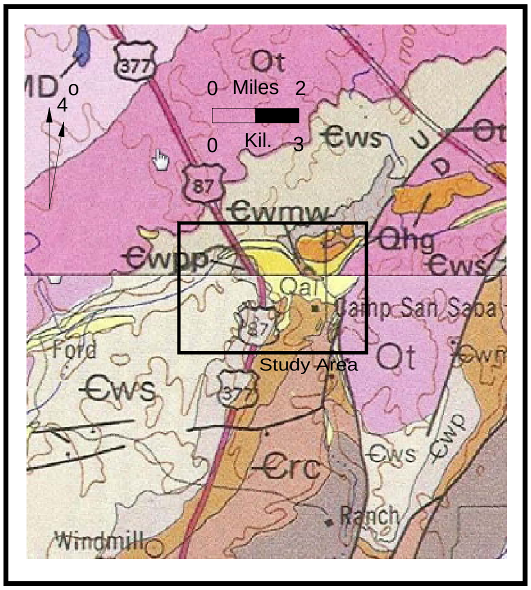
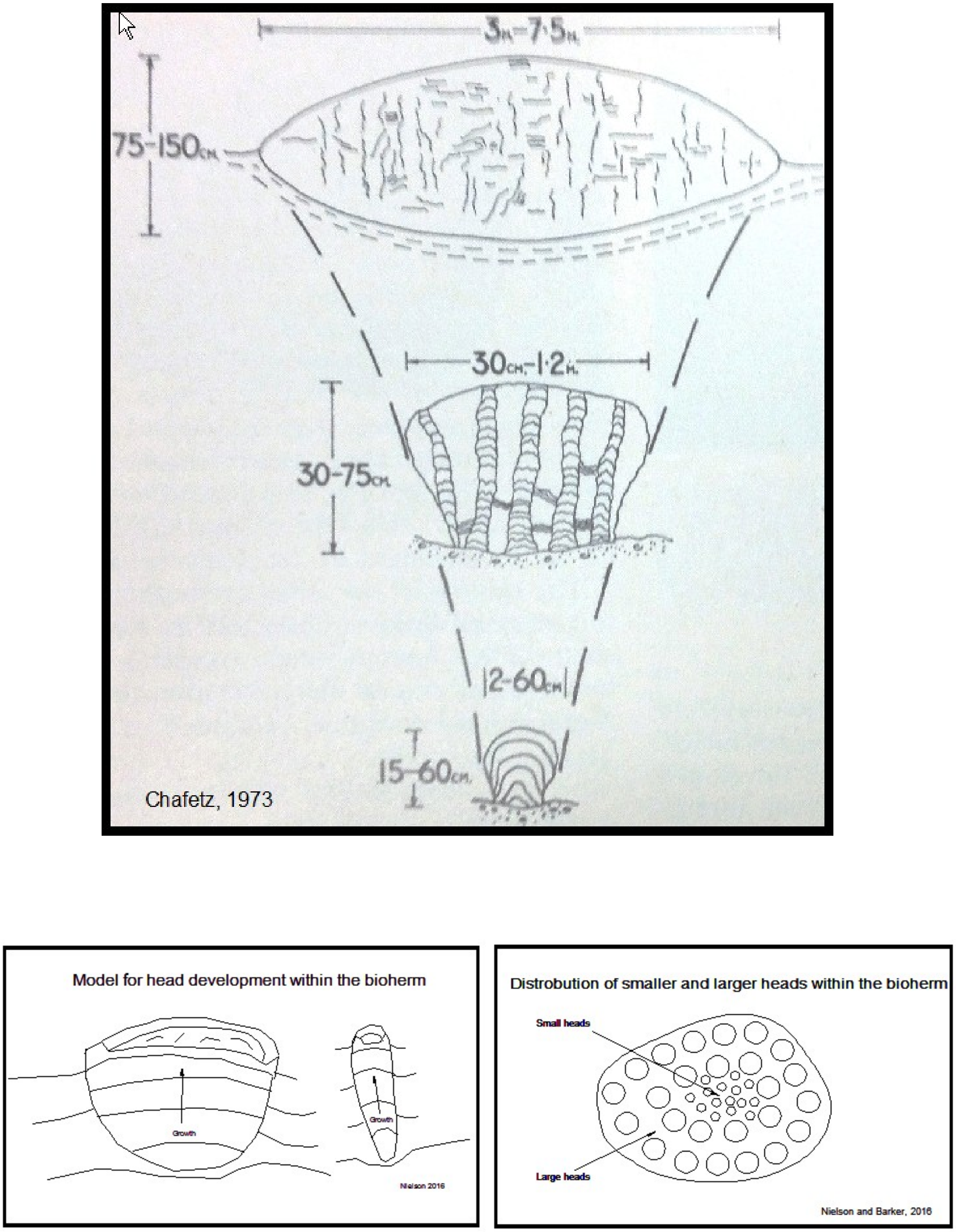


Figure 21. Geologic map of the Camp San Saba area where stromatolitic biohermal build ups are present in the Point Peak and San Saba members of the Wilburns Formation. Map symbols: pCtm – Town Mountain, pCps – Packsaddle Schist, Crh – Riley Formation, Hickory Sandstone, Crc- Riley Formation – Cap Mountain Limestone, Cwp – Point Peak Member, Cws – Wilberns Formation, San Saba Member, Ot – Tanyard Formation, MD –Devonian and Mississippian, IPmf – Marble Falls Limestone, IPsw – Smithwick Formation, Kh – Hensel Sandstone, Kgr – Glen Rose Limestone, Kw – Walnut Formation, Ke- Edwards Group, Kft – Fort Terrett Formation, and Ks - Segovia Formation



Chafetz, 1973

Model for head development within the bioherm

Nielson 2016

Distrobution of smaller and larger heads within the bioherm

Nielson and Barker, 2016

Figure 20. Models for Bioherm development within the San Saba Member of the Wilburns Formation (Chafetz, 1972).

Figure 22. Stromatolitic bioherms in the San Saba River where it crosses U.S. Highway 377 south of Brady, Texas (Stop 5). At this location the mounds have a northeast trend and contain smaller elongated to circular stromatolitic heads.

Figure 23. Internal structure of the stromatolitic bioherms along San Saba River, north of Camp San Saba (Stop 5). Note the columnar structure of the heads.

Figure 24. Internal structure of the stromatolitic bioherms where U.S. Highway 377 crosses over the San Saba River (Stop 5). Note that two smaller heads grew to produce a larger head.

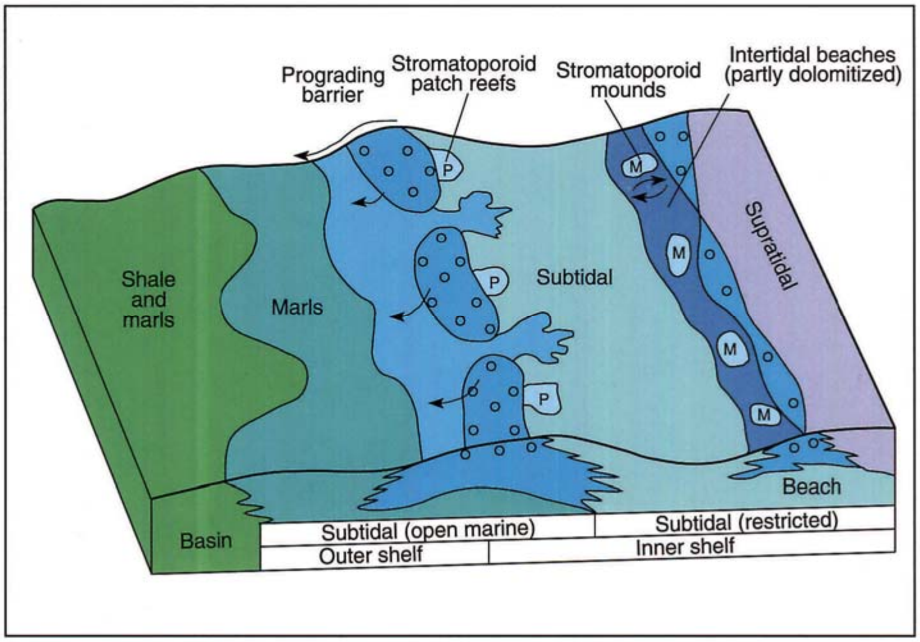


Figure 25. Diagram showing the development of stromatolitic bioherms (mound) structures (Reekmann and Friedman, 1982)

Stop 6:

Hickory Sandstone - East of Pontotoc, Texas

Exposures of the Cambrian, Hickory Sandstone are seen in a road cut, 4 miles east of Pontotoc, Texas on Texas Highway 71 (N. 30.87505, W. 98.87273) (Figures 26 and 27). The Hickory Sandstone, at this location, is cross laminated, thick-bedded and contains rounded, well sorted, quarts grains with hematite cement. It is classified as a quartz arenite. In places it contains specularite hematite cement. Lingula (disarticulate brachiopod) are found throughout the outcrop (Figures 28 and 29). Ripple marks, and planar cross laminations suggest deposition in a beach environment. No festoon or trough cross bedding was noted which suggests that a dune complex did not develop in association with the beach. The lack of dunes could be the result of the lack of land plants, during the Cambrian Period, to stabilize sand. Mud cracks have been found on several bedding planes along with worm trails but are not common. Deposition of the Hickory Sandstone occurred during the Sauk transgression in the Cambrian Period (Figure 2). The Cambrian transgressive sequence in the Northern Llano area consists of sandstone, shale, and limestone and is similar to the sequence seen across North America. The Hickory Sandstone was preserved at this location because it is found in a down dropped graben within the Precambrian, Valley Spring Gneiss (Figure 26). To the south of the road cut is an abandoned quarry in the Hickory Sandstone. The quarry is on the highway right-of-away and may be accessed from the east end of the road cut (Figure 30).

Figure 26. Hickory Sandstone (Cambrian) outcrop (Stop 6) between Ponototoc – Valley Springs, Texas on Texas Highway 71. Note the thin bedded, well rounded, hematite cemented, sandstone (quartz arenite) that forms the cliff.

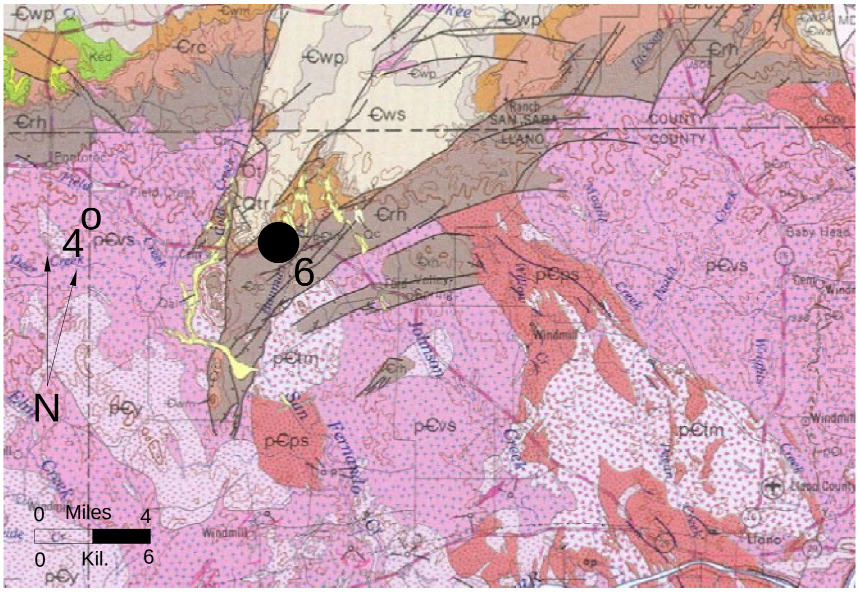


Figure 27. Geologic map of the Ponototoc – Valley Springs, Texas area showing the distribution of the Hickory Sandstone (Cambrian) and the outline of the graben in which it is preserved (Stop 6). Map symbols: pCtm – Town Mountain, pCps – Packsaddle Schist, Crh – Riley Formation, Hickory Sandstone, Crc- Riley Formation – Cap Mountain Limestone, Cwp – Point Peak Member, Cws – Wilberns Formation, San Saba Member, Ot – Tanyard Formation, MD –Devonian and Mississippian, IPmf – Marble Falls Limestone, Ke- Edwards Group.

Figure 28. Lingula brachiopods (inarticulate) exposed on a bedding plane in the Hickory Sandstone (Cambrian) at Stop 6.

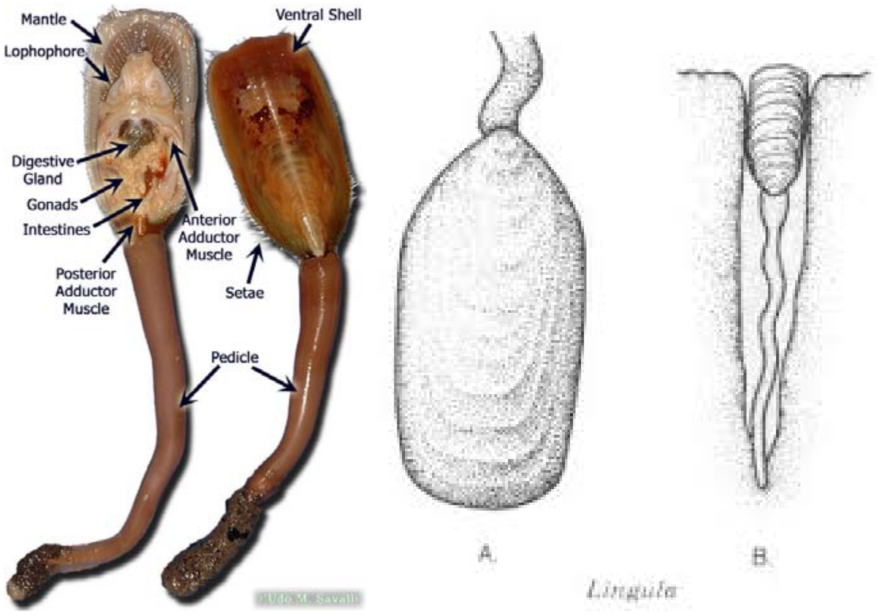


Figure 29 Diagram of the Lingula Brachiopod showing how it lived (https://www.geol.umd.edu/~tholtz/G331/lectures/331lopho.html - Lingula, http://www.geo.arizona.edu/geo3xx/geo308/FoldersOnServer/2003/4brachiopds.htm – Lingula)

Figure 30, South of the road cut in the Hickory Sandstone is a quarry where the iron rich Hickory Sandstone was mined. The quarry can be accessed by walking a road that is present on the east side of the road cut on Texas Highway 71.

Stop 7:

Llanite Dike, Near Baby Head, Texas

The Llanite Dike is one of the most famous dikes in Texas. It is exposed in an outcrop 8.9 miles north of Llano, Texas on Texas Highway 16 (N 30.88991, W 98.89026) (Figures 31 and 32). The dike has a northeast – southwest trend. This hypabyssal rhyolite porphyry contains blue quartz and pink microcline phenocrysts. The quartz gets its blue color from ilmenite inclusions in the quartz phenocrysts and larger, less abundant ribbon-shaped ilmenite inclusions lying on the rhombohedral growth surfaces of the host quartz crystals (Zolensky, M. E., Sylvester, P. J. and Paces, J. B. 1988)(Figure 32 and 33). The blue quartz phenocrysts are euhedral with color zoning from light blue in the center to dark blue on the edges (Figure 33). Quart phenocrysts retain the bata quartz dipyramidal shape and are up to 5 mm in diameter. The blue quartz weathers out as euhedral quartz crystals that can be collected from the grus at the base of the outcrop. It is considered by some igneous petrologists to be a late stage differentiate of the Town Mountain Granite and is one of the youngest Precambrian intrusive bodies in the Llano Uplift.

The Llanite dike cooled in two stages. The first stage of cooling was deep seated and allowed the formation of the microcline and quartz phenocrysts. The magma then moved upward where it cooled rapidly producing the fine grained matrix. It was emplaced into the Valley Spring Gneiss, which at this location has a large amount of muscovite. The age of the dike is about 1093 Ma (U-Pb zircon, Helper and others 1966).

Be very careful when hitting the rock with a hammer to use eye protection and be aware of others around you because it is very hard and often splinters when hit. Llanite rhyolite has a crushing strength of 37,800 lb/in^2 (Barnes 1988). Rhyolite from the dike, has been quarried to the west of the road. The rhyolite porphyry is very beautiful when polished, but if exposed to weathering becomes a dull brown as seen in the road cut (Figure 33).

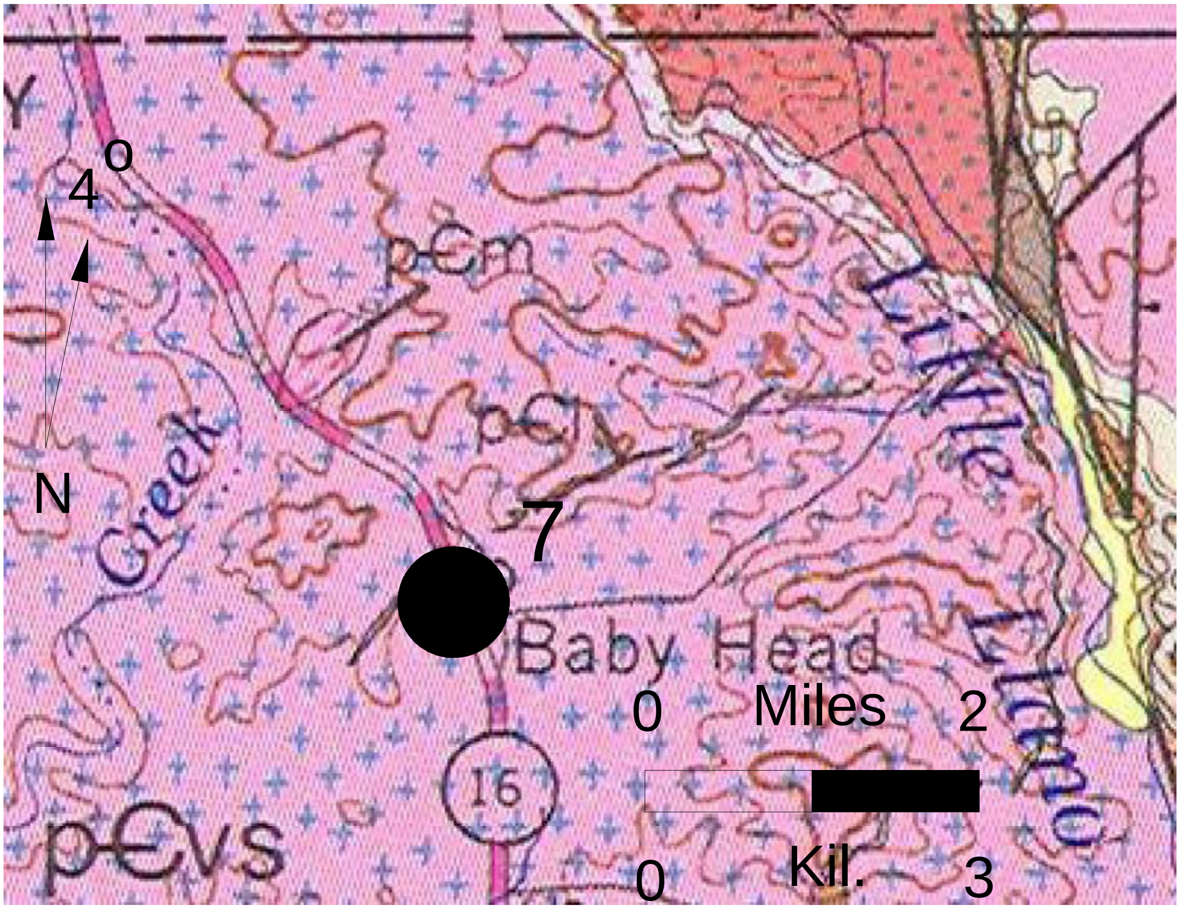


Figure 31.Geologic map of the Baby Head area showing the Llanite Dike. The dike cuts through the Pack Saddle Schist (pCvs). Map symbols: pCtm – Town Mountain, pCps – Packsaddle Schist, Crh – Riley Formation, Hickory Sandstone, Crc- Riley Formation – Cap Mountain Limestone, Cwp – Point Peak Member, Cws – Wilberns Formation, San Saba Member, Ot – Tanyard Formation.

Figure 32. The Llanite collecting location 8.9 miles north of Llano, Texas.

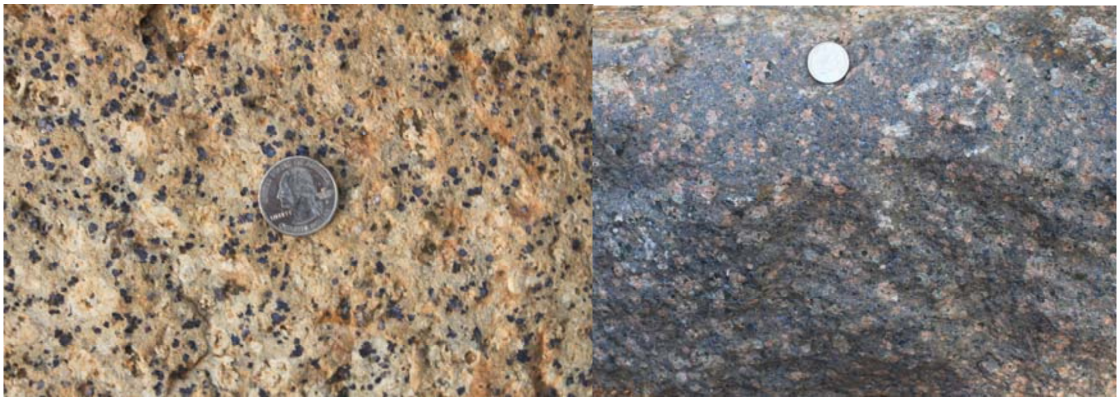


Figure 33. Euhedral grains of blue quarts in the Llanite rhyolite. Also note the large pink euhedral orthoclase phenocrysts and aphanitic ground mass. Grains of the blue quartz can be collected form the grus at the base of the outcrop. The surface on the left is weathered and the surface on the right is fresh.

Stop 8:

Llano River Bridge, Llano, Texas

At this stop beneath the Texas Highway16 bridge over the Llano River in Llano, Texas (N. 30.75467, W. 98.6777) (Figures 34 and 35) you will see boudins and other ductile structures in the Packsaddle Schist, one of the main Precambrian units in the Llano Uplift. Other interesting features include syntectonic dikes and sills with varying degrees of deformation; antiforms and synforms; younger Precambrian granitic intrusive bodies and strike-slip faults.

The features described next are on the north side of the Llano River, just downstream from the dam, in the area between the dam and the bridge.

Figure 34. Llano River bridge in Llano, TX. Boudins, lineations, folds and mylonites in the Precambrian Packsaddle Schist are visible here and indicate that these rocks were subjected to ductile deformation at high temperatures.

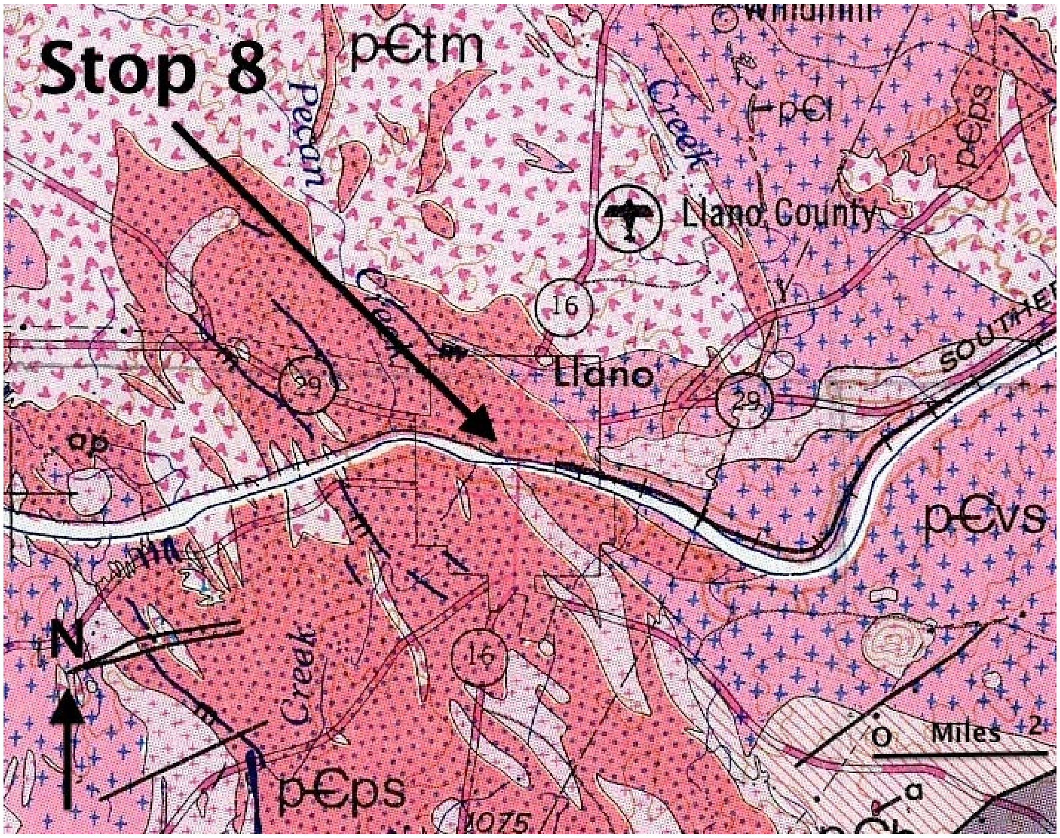


Figure 35. Geologic Map of the Llano River Bridge area in Llano, Texas. Note the location of Stop 8. The main unit at this stop is the Precambrian Packsaddle Schist (pCps). Also present at this stop are "Younger Granitic Intrusive" bodies, shown as an elongate zone of pink with small red plus symbols (near the head of the arrow). To the north of Llano is the Town Mountain granite (pCtm); to the east is Valley Springs gneiss (pCvs).

The Precambrian Packsaddle schist is about 1.25 billion years old (Reese et al., 2000) and in much of the Llano Uplift is the country rock into which younger Proterozoic granites and other igneous rocks were intruded. The Packsaddle Domain is interpreted to have formed as basinal supracrustal sedimentary units deposited adjacent to Laurentia (Mosher, 1998); Laurentia is proto-North America. Those basinal sedimentary rocks were pushed onto the continental margin (and over the 1.27 billion years Valley Springs Gneiss) during the collisional assembly of the Precambrian supercontinent Rodinia (Reese et al., 2000). The rocks were metamorphosed during that orogeny to form the Packsaddle Schist.

The Packsaddle Schist in this area is mostly very dark, strongly foliated, amphibolite-biotite schist with prominent lineations on the foliation planes (Figure 36). The foliated Packsaddle schist, shown in Figure 36, has an average (though variable) strike and dip of about N45E, 25 SE. The plunge and bearing of the lineations is about 25, S33E.

Figure 36. Strongly foliated Packsaddle Schist beneath the Llano River bridge in Llano, Texas. The Llano River is in the background. View to the southeast. Student in shorts is standing on a foliation plane. Note the prominent lineations on the foliation planes. The pink line that trends diagonally across the upper foliation plane (and passes beneath the student's foot) is a narrow felsic dike.

The fabric of the Packsaddle schist indicates that in this location it is a mylonite that formed by dynamic metamorphism in a shear zone below the brittle-ductile transition zone (BDTZ), which is usually at 10 to 15 km depth. Below the BDTZ, rocks are hot enough that they respond to long-term stress by stretching and shearing, rather than fracturing with a discrete fault plane.

The prominent lineations on the foliation planes probably formed when these foliation planes slid over each other during shearing movement deep underground. An analogy would be the movement of playing cards sliding over each other when a deck of cards is pushed across a table.

Other ductile structures at this outcrop support the interpretation that the rock is mylonitic. For example, the amphibolite schist has a number of small felsic porphyroclasts (possibly remnants of the original rock or of an earlier metamorphic phase) with “wings” that indicate primarily sinistral shear when viewed to the northeast (Figures 37 and 38). To determine the sense of shear one should look at porphyroclasts on a joint face that is perpendicular to the foliation and parallel to the lineation (Figures 39 and 40) because structures on that face will show the correct sense of shear that created the wings or other ductile structures.

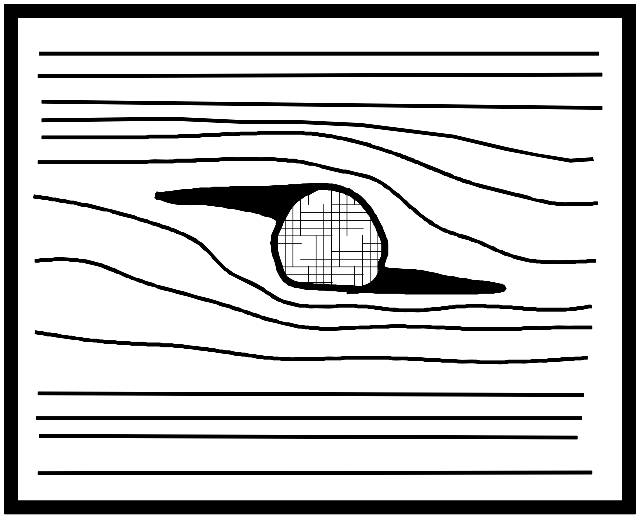


Figure 37. A sigma-winged porphyroclast showing sinistral shear. This indicates that the foliation planes above the porphyroclast moved to the left relative to the planes below it.

Figure 38. Packsaddle Schist at this outcrop with a felsic porphyroclast (the elongate pink area to the left of the end of the wooden handle) with wings indicating sinistral shear.

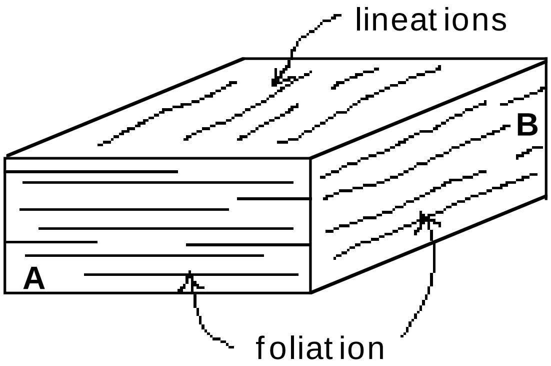


Figure 39. Drawing of a block of foliated and lineated mylonite. Shear sense indicators, such as winged porphyroclasts, should be examined in joint face B, which is perpendicular to the foliation and parallel to the lineation.

Figure 40. The student in the pink shirt is looking at an appropriate joint face for correctly determining sense of shear in this mylonitic Packsaddle Schist. View to the southeast. Photo taken west of the Llano River Bridge, Llano, Texas.

Since the lineations on the foliations planes are plunging to the southeast at this location (which is toward the Llano River), the sinistral shear in the mylonite indicates that the type of fault movement in the shear zone was thrust faulting with the top (the hanging wall) moving to the northwest (assuming the rock is still in its approximately original orientation). This was presumably caused by compression from the southeast. This shear zone faulting probably occurred when the original Packsaddle protolith rocks were thrust upward onto Laurentia during assembly of the supercontinent Rodinia in the Proterozoic. This collisional event was part of the Grenville Orogeny which affected the east and south sides of Laurentia and would have created a mountain range in this area. Since that collision occurred over a billion years ago, the mountains are long since eroded away and we are looking at the exposed deep roots of that former mountain range.

These ancient rocks are exposed because they are part of the Llano Uplift (Figures 41 and 42), an approximately 75-mile wide circular zone in central Texas where extremely old rocks that are normally deeply buried have been pushed upward by tectonic forces. Ongoing studies in the eastern and western Llano Uplift have found that the orientation of shear zones changes across the uplift suggesting that this region was part of a doubly vergent orogeny during Grenville time (Levine and Mosher, 2010).

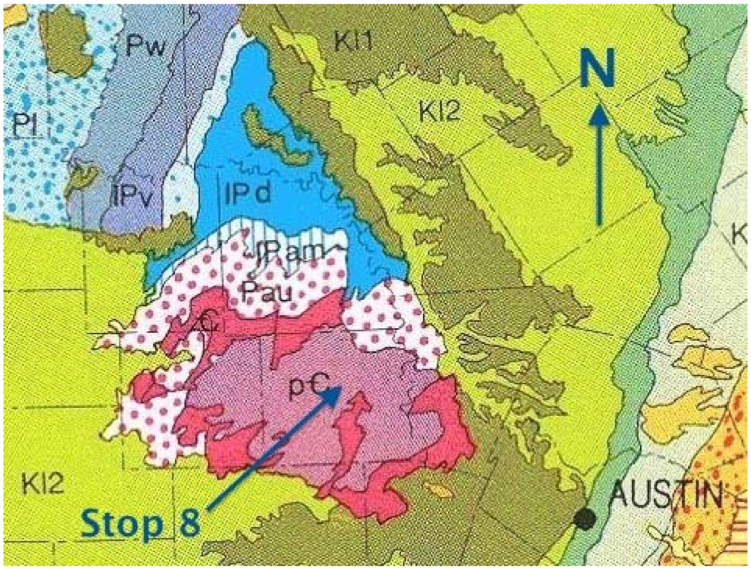


Figure 41. Geologic map of the Llano Uplift in central Texas, northwest of Austin. The Llano Uplift is the circular area of mostly red, pink and polka-dots. Precambrian rocks (pC) in the Uplift are approximately 1.2 to 1.3 billion years old. Rocks marked C, Pau, IPam, IPd and IPv are lower to upper Paleozoic and are around 500 to 300 ***million*** *years old. The rocks in shades of green are Mesozoic, Cretaceous rocks as young as 65 million years old. Cretaceous rocks at one time probably covered most or all of the area, but have been eroded away to expose a window into the ancient rocks. The distance across the map is approximately 120 miles. (Adapted from Texas Bureau of Economic Geology map.)*

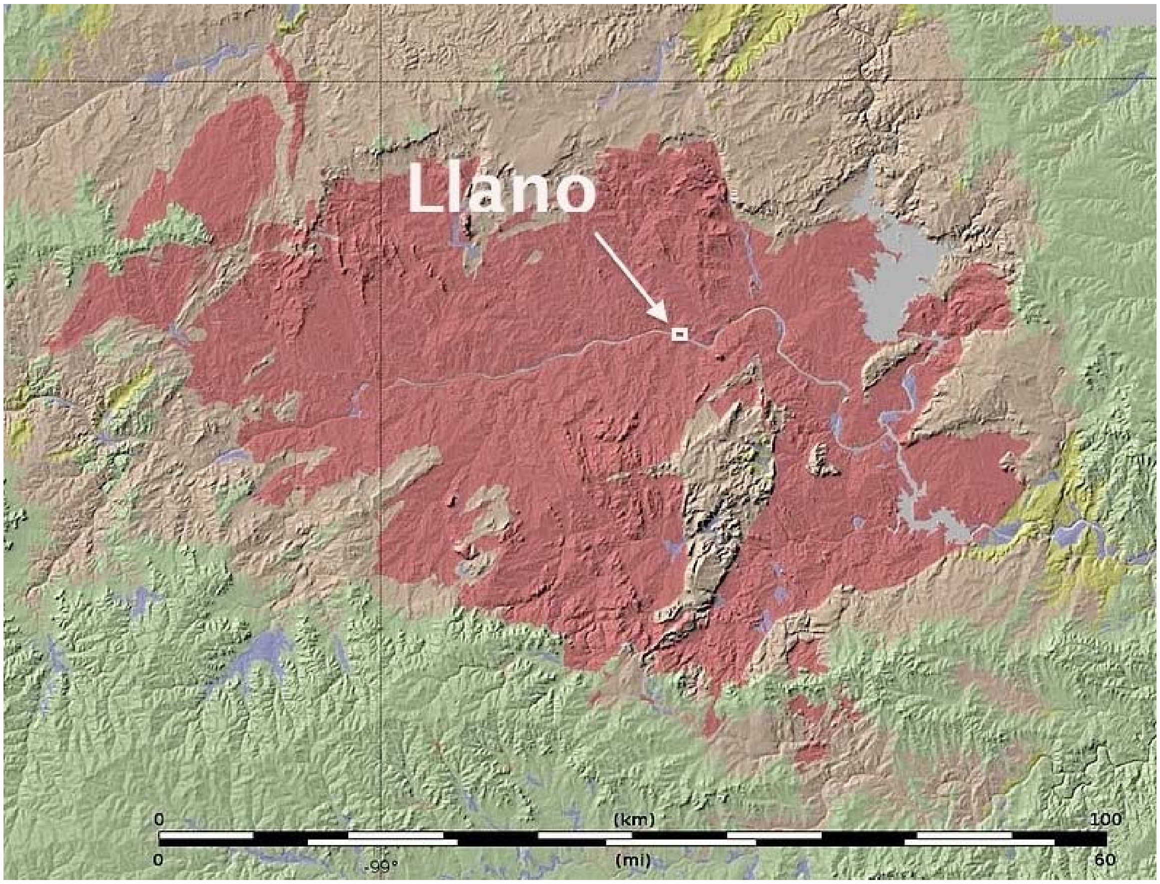


Figure 42. Geologic and topographic map of the Llano Uplift. The town of Llano (and site of Stop 8) is located on the Llano River. Precambrian and Paleozoic rocks are shown in red and tan; Cretaceous in green. North is to the top. (Adapted from Wiki image.)

BOUDINS

One of the most distinctive features of this outcrop are a series of boudins, which are elongate bodies that look like a string of sausages—think of Cajun boudins! Boudins (Figures 43 and 44) usually form in sheared metamorphic rocks when alternating layers of mechanically strong and weak rocks are deformed together. At this outcrop the weak rocks are the amphibolite schists and the strong rocks are granitic sills that were intruded between foliation planes in the schist. The felsic sills are syntectonic; they were intruded while shearing deformation was on-going. During shearing, the amphibolites deformed easily as foliations planes slid over each other. The mechanically stiff granitic sills, however, responded to the same stress by “balling-up” into elongate boudins. Gaps between the boudins became sites of quartz precipitation.

Figure 43. Felsic boudins in amphibolite schist. Granitic magma was intruded between foliation planes in the schist, thus forming a sill. During crystallization, or afterwards, it was deformed into elongate shapes by continued shearing of the surrounding mylonitic schist.

Figure 44. Asymmetric boudins form sigmoidal shapes that can be used to determine sense of shear in the same manner as wings on porphyroclasts. These boudins have a slight asymmetry that suggests sinistral shear. Note the grayish quartz zone between each boudin. View to the northeast.

Shear zones are intriguing but are rarely exposed because they form at great depth. Boudinaged rocks are even more unusual, especially large boudins such as the ones at this outcrop.

In addition to sills, there are many dikes cutting through the Packsaddle Schist, all of which are felsic. The felsic nature of the sheet intrusions suggests that their magma source was the same as or similar to the magmas that produced most of the late Precambrian granites in the central Llano Uplift.

The dikes at this outcrop are variably deformed and have complex cross-cutting relationships which makes them useful for age-dating the intrusive and deformational history of the Uplift.

The Packsaddle schist at this location is folded into broad, open to gentle, low-amplitude, long-wavelength antiforms and synforms (Figure 45). The folds plunge toward the southeast at this location and were caused by compression oriented NE-SW; therefore, the folding of the foliation planes was a later deformational event than the one that created the lineations on the foliation planes (which was caused by compression oriented NW-SE).

Figure 45. Synform in the Packsaddle Schist at Stop 8. The long arrow shows the plunge direction of the fold, which is toward the southeast. Outcrop is just west of the Llano River bridge, Llano, Texas.

The remaining features discussed below are on the upstream side of the dam, close to the parking lot.

Move to an outcrop of granite on the west (upstream) side of the parking lot (Figure 46).

Figure 46. Outcrop of granite just west of the parking lot in the Llano city park near the Llano River bridge at Stop 8.

This granite is part of an elongate (NW-SE) body that is labeled Precambrian “Younger Granitic Intrusive Rocks” on the Bureau of Economic Geology’s geologic maps of Texas (Figure 35). It is a relatively fine-grained, leucocratic granite that is cut by several dikes in this outcrop.

The dikes are mostly coarse-grained pegmatites and many have a fine-grained chill rim along the margin of the dike (Figure 47).

Figure 47. Coarse-grained felsic pegmatite dike in fine-grained granite. Note the darker chill rim on the margins of the dike. Outcrop is in the Llano city park parking lot near the Llano River bridge in Llano, TX

Pegmatite dikes are thought to form in the late stages of magma cooling when the remaining magma fluid has become progressively more silica-rich and watery (because water is not included in most igneous minerals and because early-forming minerals do not use up much silica). When such magma is intruded into a fracture, nucleating minerals grow very rapidly in the watery medium and the resulting crystals in the dike are notably coarse-grained. This is in contrast to most dikes and sills which are typically finer-grained than any plutonic rocks into which they are intruded.

Because late-stage magma is so silica-rich, the main large minerals that crystallize in pegmatite dikes are quartz and potassium feldspar, which can be seen as the large grayish-white and pink crystals, respectively, in Figure 47. Rare and sometimes valuable minerals can also be found in some pegmatites, so they are occasionally mined for such minerals.

The granite and dikes in this outcrop have been cut by faults (Figure 48). The faults appear to be mainly strike-slip faults with sinistral offset. The faults in this part of Stop 8 are brittle faults with discrete fault planes, unlike the shear zone below the dam where the deformation was ductile. Therefore, these faults must have occurred much later than the shearing. They would have formed after enough of the overburden was eroded away that these rocks were colder and more brittle. This represents another, later stage of deformation that effected the Llano Uplift.

Figure 48. Pegmatite dike offset by apparent left-lateral strike-slip fault. View to the south. Outcrop is near the parking lot, west of the Llano River Bridge in Llano, Texas (Stop 8).

Stop 9:

Lunch at Coopers BBQ in Llano, Texas

Lunch will be at Cooper's Barbeque in Llano. It is consistently rated as one of the best barbeque restaurants in Texas by Texas Monthly and other periodicals.

References

Ahr , W., 1967, Origin and Paleoenvironment of some Cambrian Algal reefs, Mason County Area Texas: Unpublished Ph.D. Dissertation, Rice University, Houston Texas, 104 p.

Ahr, W., 1971, Paleoenvironment, Algal Structures and Fossils Algae in the Upper Cambrian of Central Texas, Journal of Sedimentary Petrology, v. 41, p. 205-216.

Barker, D. S. and Reed, R. M., 2010, Proterozoic granites of the Llano Uplift, Texas: A collision–related suite containing rapakivi and topaz granites: GSA Bulletin v. 122, no. 1-2, p. 253-264.

Barnes, V. and Bell, W. C., 1954, Cambrian Field Trip Llano Area 1954, West Texas Geological Society, p.139.

Barnes, V., Bell, W. C., Clabaugh, S. E., Rodda, P. U. and Young K., 1972, Geology of the Llano Region and Austin Area, Field Excursion: Guidebook Number 12, Bureau of Economic Geology, p.75.

Barnes, V., Kaiser, William, Maclay, Robert, and Young, Keith, 1976, Economic Geology of South Central Texas, South Texas Geological Society, San Antonio, TX p. 104.

Barnes, V. and Bell, W. C. 1977, Cambrian Field Trip Llano Area, San Angelo Geological Society, p.139.

Barnes, V., 1986, Geological Atlas of Texas: Llano Sheet, Scale 1:250,000, Texas Bureau of Economic Geology, http://www.twdb.state.tx.us/groundwater/aquifer/GAT/.

Barnes, V. E., 1988, Geological Society of America Centennial Field Guide – South-Central Section, p. 361-368.

Bell, W. C., and Barnes, V. E., 1962, Cambrian History, Llano Region, Geology of the Gulf Coast and Central Texas, and Guidebook of Excursions.

Bridge, J., Barnes, V., and Cloud, P., Jr., 1947, Stratigraphy of the Upper Cambrian, Llano Uplift, Texas, Geological Society of America Bulletin, v. 56., no. 1, p. 109-123.

Bebout, D.G. and R.G. Loucks, 1974, Stuart City trend, Lower Cretaceous, south Texas: University of Texas at Austin, Bureau of Economic Geology, Report of Investigations 78.

Chafetz, H., 1972, Morphologic Evolution of Cambrian Algal Mounds, Texas with Changing Depositiona Environment: AAPG Bulletin v. 56, no. 3, p. 608

Chafez, H., 1973, Morphologic Evolution of Cambrian Algal mounds in response to change in Depositional Environment: Journal of Sedimentary Petrology, v. 43, no. 2, p. 435-446.

Donovan, A., 2010, Application of Modern Stratigraphic Techniques, SEPM Special Publication 95. 134 p.

Frazier, A. S., Gobel, V.W., 1982 Rutile as the cause of blue color of quartz from Llanite, Llano County, Texas: The Geological Society of America, Abstracts With Program, v.14. no. 3, p. 111.

Gobel, V. G., 1986, Geologic Overview for Bear Mountain, Gillespie County, Southern Llano Uplift, Central Texas: GSA Guidebook field Trip 13, San Antonio (1986) p. 42-50.

King, D. T., and Chafetz, Henry S. 1983, Tidal-Flat to Shallow-Shelf Deposits in the Cap Mountain Limestone member of Therieley Formation, Upper Cambrian of Central Texas, Journal of Sedimentary Petrology, v. 53, no. 1, p. 261-273.

Helper, M. A., Gose, W.A., and Roback, R. C., 1976, Virtual geomagnetic pole position from 1.1 Ga intrusive rocks of the Llano uplift, central Texas, Geological Society of America, Abstracts with Programs, v.28, p. 18.

Iddings, J. P., 1904, Quartz-feldspar-porphyry (graphiphyroliparosealaskose) from Llano, Texas, Journal of Geology, 12, p. 225-231.

Jacka, A. D., 1977, Deposition and Diagensis of the Fort Terrett Formation (Edwards Group) in the Vicinity of Junction Texas: Bureau of Economic Geology, Report of investigations no. 89. p. 182-199.

Levine, J. and Mosher, S., 2010, Contrasting Grenville-age tectonic histories across the Llano uplift, Texas, New evidence for deep-seated high temperature deformation in the Western Uplift: Lithosphere, v. 2, no. 6,01.12.2010, p. 399-410.

Long, L., 2010, Town of Burnet: Vanishing Texas River Cruise: http://uts.cc.utexas.edu/~rmr/road-log-VTRC-public.pdf.

Milliken, K. L., and Reed, R. M., 2002, Internal Structure of Deformation Bands as Revealed by Cathodoluminescense images, Hickory Sandstone (Cambrian), Central Texas, Gulf Coast Association of Geological Societies Transactions, v. 52, p. 725-738.

Mosher, S., 19998, Tectonic evolution of the southern Laurentian Grenville, Orogenic Belt: GSA Bulletin, v. 110, no. 11, p. 1357-1375.

Mosher, S., Levin, J. S. F., and Carlson, W. D., 2008, Mesoproterozoic plate tectonics: A collisional model for the Grenville-aged orogenic belt in the Llano Uplift, central Texas: Geology, v. 36, no. 1, p. 55-58.

Reeckmann, A. and Friedman, G.M. 1982. Exploration for carbonate petroleum reservoirs, John Wiley and Sons, New York, 213 p.

Reese, J. F., Mosher, S., Connelly, J. and Roback, R., 2000, Mesoproterozoic chronostratigraphy of the southeastern Llano Uplift, central Texas: GSA Bulletin, v. 112, no. 2, p. 278-291.

Rose, P., 1972, Edwards Group, Surface and Subsurface, Central Texas: Report of Investigations, Bureau of Economic Geology, 197 p.

Rose, P. R. 1972, Edwards Group, Surface and Subsurface, Central Texas: Bureau of Economic Geology, Report of Investigation no. 74, 198 p.

Waite, L. E. 2009, Edwards (Stuart City) Shelf Margin of South Texas: New Data, New Concepts: http://www.searchanddiscovery.com/documents/2009/10177waite/images/waite.pdf

Willis, J. J., Lock, B.E., Cornell, K. C., and Robert, D. A., 2001, An Exposed Evaporate Weld and Related Deformational Structures, Edwards Plateau, 1-10 Corridor, Kerrville-Junction-Sonora Area, Texas, Gulf Coast Association of Geological Societies Transactions: v. LI 2001, p. 389-397.

Willis, J. J., Willis, K. M. 2009, Calichification-Induced Structures in the Edwards Plateau, Texas: Gulf Coast Association of Geological Societies Transactions, v. 59. p.797.

Yu, Andrey, Wood, Z., and Wood, R., 1995, Lower Cambrian Reef algal Cryptic Communities: Paleontology, v. 38 pt. 2, p. 443 -470.

Zhuravlev, Y. Z., and Wood, Rachel, 1995, Lower Cambrian Reefal Cryptic Communities, Paleontology, v. 38, p. 443-470.

Zolensky, M. E., Sylverster, P. J., and Paces, J. B., 1988, Origin and significance of blue coloration in quartz from Llano rhyolite (Llanite), north-central Llano County, Texas, Am. Min. v. 73, p. 313-323.