Economic Geology Resources of the Llano Uplift Region and the Historical Impacts to the Region's Growth

Guidebook to the Texas Section- American Institute of Professional Geologists Spring Field Trip, Llano Uplift Region, Central Texas: May 14-15, 2016

Rima Petrossian, Ph.D., P.G., C.P.G.: Author and Field-Trip Organizer

Renee Ryan, P.G., C.P.G.: Author and Field-Trip Leader

Chris Caran, P.G.: Author and Field Guide, Los Almagres Mine

Michael Jacobs, P.G., Field Trip Organizer

Michael D. Campbell, P.G., P.H., C.P.G.: Author and Field-Trip Organizer

Martin Meinshausen: Field Guide, Voca Sand Mine

Neyda Maymi: Field Guide, Voca Sand Mine

Version 2.2

Acknowledgements

A big thank you goes to the Stotts Family for allowing us exclusive access to Los Almagres mine site at Packsaddle Mountain. Also, a special thanks to *Premier Silica* for access to the Hickory Sands Mine and for sponsoring lunch.

Field Trip Schedule, May 14-15, 2016

Friday Evening:

Optional Friday happy hour/no-host dinner:

6 PM Evening at *River City Grille*, Marble Falls, Texas.

Saturday Morning:

0730 hrs. **Stop 1**: Meet at Historical Marker Roadside Park, FM1431 westbound about 1.85 miles from Hwy 281 across from Town Mountain Granite Mine on the north side of the road for breakfast tacos (provided).

Distribute for signature and return the AIPG Indemnification Document, and hand out field-trip guide; discuss geology and historical importance of groundwater and granite to Llano Uplift area (Ryan, Wise, Jacobs, etc., 30 minutes)

Depart first stop in caravan east 1.85 miles to Hwy 281 and FM 1431 west intersection, turn south or right.

Continue on to intersection of Highway 281 and 71 and turn onto Hwy 71 West. Go about 11 miles to Sandy Creek and pull off the road on the right. We will hike back to the overlook on Sandy Creek. After return to Hwy 71, then continue on 4.6 miles to historical marker on right ("Packsaddle Indian Fight") turn right on County Road 309 (there will be two mail boxes) head east to second gate on left ~0.6 miles. Follow dirt road to meeting point.

0915 hrs. Stop 2: At Packsaddle Pass for Los Almagres Silver Mine at Packsaddle Mountain, Chris Caran to lead talk (< 60 minutes).

1045 hrs. Depart for *Premier Silica* in Brady for BBQ lunch.

60 miles to Brady

1200 hrs. Lunch stop at *Premier Silica* Office in Brady.

Depart for mine tour.

1300 hrs. or earlier, Stop 3: Travel east on Hwy 71, arrive at Voca Sand Mine, get safety training for being in *Pioneer Natural Resources Hickory Sand Mine* area (30 minutes)

1400 hrs through 1815 hrs. Mine tour with Marvin Meinshausen and Neyda Maymi as tour leaders (Four hours and 30 minutes).

1830 hrs. Dinner Stop: Go to Brady, dinner at *Mi Familia* in Brady, north on 87 into town, one block before you reach the town square turn left (west) on 1st Street, go one block, the parking lot is between Church and High Streets on the north side of 1st Street.

Depart to hotels on your own.

Field Trip Schedule, May 14-15, 2016 (continued)

Sunday Morning:

0730 hrs Meet-up: Breakfast on your own, meet at *Best Western Inn* parking lot, depart for first stop travelling south on Hwy 87.

South 8 miles just past San Saba River Bridge, turn left to picnic area (blue sign).

0745 hrs. Stop 4: Roadside park, outside of Brady, stromatolites in limestone, Wilbern Formation, down along the river.

0800 hrs. Leave for Emerald Ridge Pegmatite/Pegmatite stops:

South on Hwy 87 about 6.5 miles.

0815 hrs. Stop 5: Turn left on FM 1222 toward Katemcy, go 0.4 miles to first creek road cut, park on side of road look for Topaz!

0830 hrs South on 87 to Mason, Dairy Queen about 10 miles, on the right. (Note: pick up lunches at Stripes/Subway just before 9 AM).

0900 hrs. Meet at Dairy Queen (back/side lot all together so we will be recognizable as a group), mine site guide will meet us there.

0910 hrs. Depart *Dairy Queen* escorted to Emerald Ridge.

0930 hrs. Stop 6: Renee Ryan/Henry Wise/Michael Jacobs to lead talk(s), answer questions (20 minutes each).

1200 hrs. Sack lunch onsite or alternatively depart at 12:30 PM for lunch in town.

1400 hrs. Wrap-up discussion of geology (30 minutes) at lunch or continue site observations until 3 PM or so.

End of Field Trip Schedule.

Contents

Background

The center of our universe for this field trip, the Llano Uplift, is spectacularly anchored by Enchanted Rock, primarily composed of pre-Cambrian granite, combined with Cambrian limestones laced with stromatolites, pure silica sands of the Hickory Formation, and granites with local pegmatite exposures flecked with blue topaz.

We are going to explore, the way the conquistadors explored, with the anticipation of all the riches and wealth offered in the Llano Uplift, and in the way students explore, to find the connections and threads from the past to the life that we experience today in the Hill Country.

The Llano Uplift area is a rich crossroads of myths, wealth, fascinating geomorphology, and human history. Ancient peoples recognized the value of the Llano Uplift natural resources in several ways including sustenance, short-term camp sites, and cultural practices. Archeological sites (see Figure 1) revealing hot-rock cooking techniques known as earth ovens show that generations of small bands of early humans used the limestone and granite rocks. Sites such as near Honey Creek (A.D. 1100-1700), where for more than 600 years, natives cooked plants for several days to make them edible and digestible. Plants such as yucca, cactus pads, stool, and wild onions along with many sources of wood and seeds have been identified. At the same site, some spear points are dated to about 8,000 years ago, either being reused by the more recent inhabitants or dating from much earlier encampments.

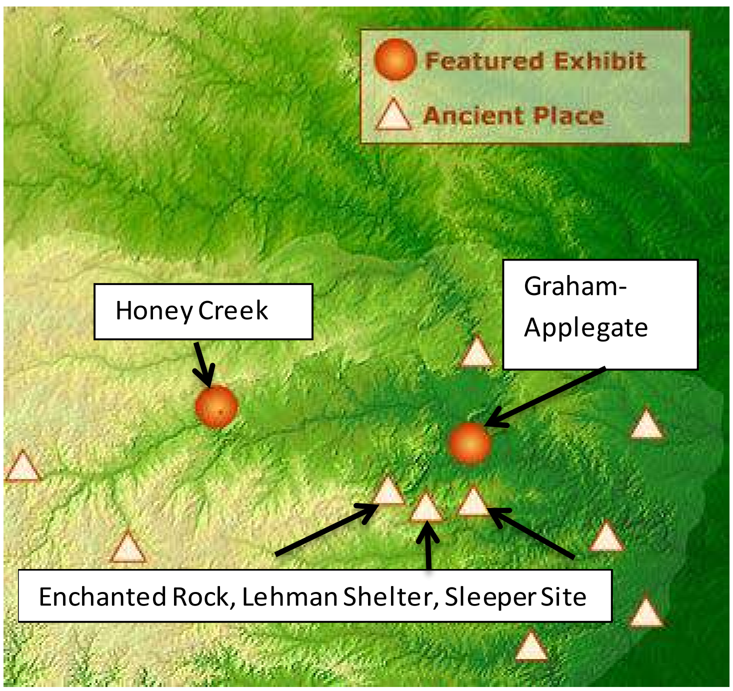
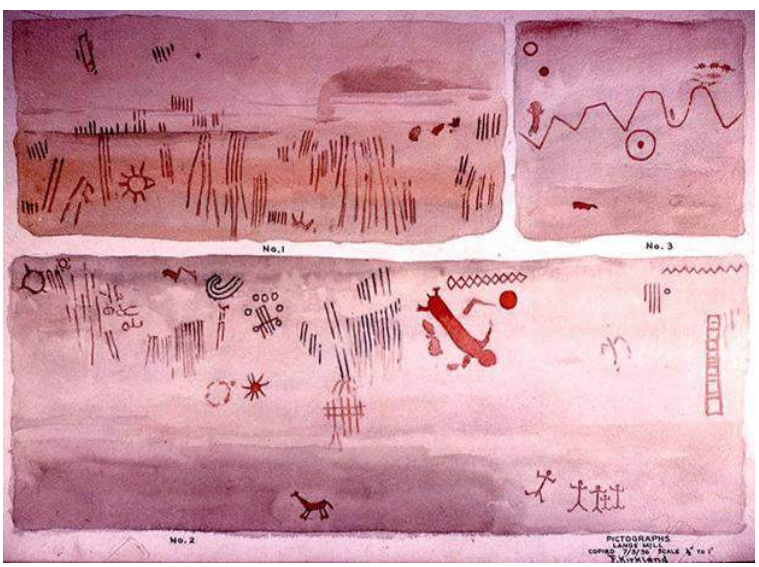


Figure 1. Lay of the Lands

Nearby in Blanco County, at the Sleeper Site (above), and West Walnut Creek, artifacts such as milling stones for processing plants foods and arranged burned rocks called baking heaps date to around 6,000 to 4,000 B.C. Freshwater mussels, snail shells, and lesser amounts of bison and deer bones, along with dart points and blade tools suggest encampments of small bands taking advantage of seasonal occupation for processing food. On Enchanted Rock, bedrock mortars were found in clusters formed by grinding food in shallow, saucer-shaped hollows, about 8 inches in diameter and less than an inch deep. Pestles and manos, stones that fit easily in the hand for pounding, are not found often not only because they are so portable but because collectors have already carried them away. Wood staffs might also have been used for a variety of cooking tasks. Archeologists recognize that wear patterns such as fracture lines or polished crystals or pitting in the granite shows evidence of either pounding or grinding functions of the rock tools.

Near Kingsland, Texas is the Graham-Applegate Rancheria, which sheltered generations of Native Americans for over a thousand years. Centuries before the Spanish explorers arrived, this group abandoned the site or blended into other tribes. Excavations show five large houses interpreted to be permanent winter housing due to presence of large central hearths and large wall supports. Granite cobbles line a central large earth oven for cooking plant materials such as wild onions and smaller granite cobbles with remains of mussel shells indicate cooking activities such as grilling meats. Archeologists have not found evidence supporting an agrarian lifestyle of these people, they were more hunters and gatherers, and chert arrow tips and knives and obsidian obtained from Utah indicates either people were traveling around to different sites or the utensils were obtained by trading. This location is an example of a settlement inhabited by people that are not truly nomadic but were not necessarily part of an established permanent village.

On Onion Creek in northeast Gillespie County, Lehman Shelter is one of the easternmost occurrences in the Edwards Plateau showing pictographs. Pictographs (1936 painting of drawings shown in Figure 2), mostly drawn in red, black, and white, showing humans, animals, and symbols, helped researchers to develop a narrative of prehistoric Texas social practices and living conditions.



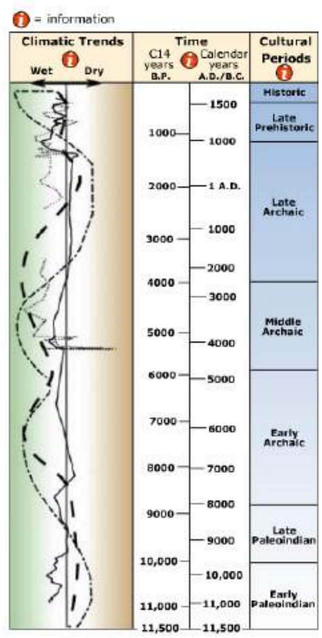


Figure 2. Pictographs Drawn by Prehistoric Inhabitants (http://www.texasbeyondhistory.net/)

Figure 3. Climate Variations showing Four Trends from Different Lines of Reasoning
(http://www.texasbeyondhistory.net/plateaus/prehistory/images/climatic.html)

Climate variations shown in the left-hand column of Figure 3 over the past 11,000 years contributed to the migration and habitation patterns of hunter-gatherers in the Llano Uplift.

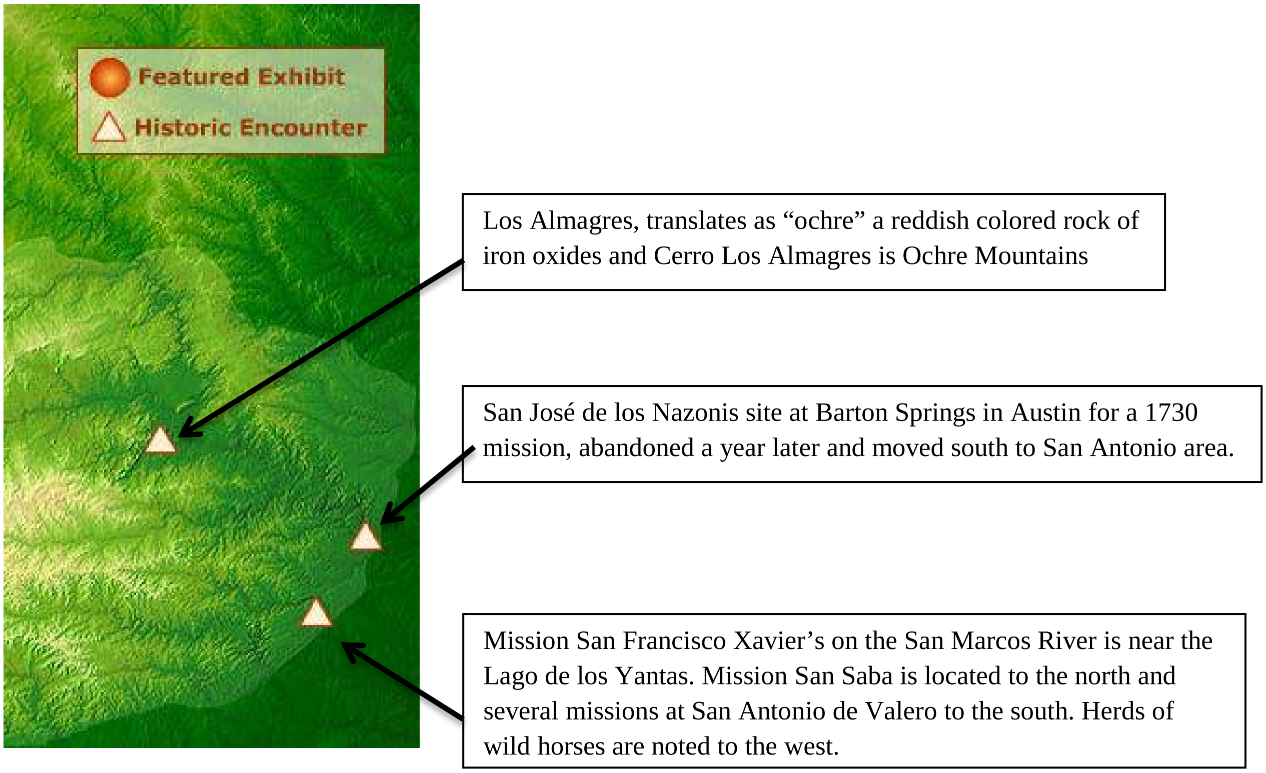


Figure 4. Eastern Llano Uplift

Spanish explorers, such as Bernardo de Miranda y Flores allegedly found believable evidence of silver and gold in the hills in the eastern part of the Llano Uplift (see Figure 4). He wrote about his trip using the enthusiastic statement below to capture and convince the Spanish Viceroy of the riches…

"Silver! Enough for every person to own a silver mine!"

However, for some reason, further exploration was abandoned, and in 1829 Stephen F. Austin published a map showing San Sabá presidio as a location for a silver mine.

Archeology, Biota, and Fauna of the General Area

As an example of the work done in the general area on the archeological findings and on the biota and fauna found in the region, Haefner (2011) produced a Master's Thesis on the Tee Box Six locale near San Marcos and covers the general geological, biological, and faunal features of the area, which relates in many instances to that of the field trip area.

For additional coverage of the history of this area, see the references below (with links).

References:

Black, S.L., 2005. Graham-Applegate Rancheria, http://www.texasbeyondhistory.net/graham/index.html, accessed October 19, 2015.

Black, S.L., 2005. Honey Creek, http://www.texasbeyondhistory.net/honey/index.html, accessed October 19, 2015.

Black, S.L., 2005. Los Almagres, http://www.texasbeyondhistory.net/plateaus/images/he13.html, accessed October 19, 2015.

Black, S.L., 2005. Plateaus and canyonlands, http://www.texasbeyondhistory.net/plateaus/index.html, accessed October 19, 2015.

Black, S.L., 2005. Prehistory, http://www.texasbeyondhistory.net/plateaus/prehistory/index.html, accessed October 19, 2015.

Haefner, J. J., 2011, Subsistence, Technology, and Site Use Through Time at 41HY160, the Tee Box Six Locale, Master's Thesis, Texas State University – San Marcos, Texas, August, 399 p., Accessed March 15, 2016 via: http://i2massociates.com/Downloads/HAEFNER-THESIS2011C.pdf

Johnson, LeRoy, Jr.,1991. Early Archaic Life at the Sleeper Archaeological Site, 41BC65 of the Texas Hill Country Blanco County, Texas. Texas State Department of Highways and Public Transportation Highway Design Division, Publications, accessed March 15, 2016 via: http://www.texasbeyondhistory.net/plateaus/images/ap3.html and textbook: https://books.google.com/books/about/Early_Archaic_Life_at_the_Sleeper_Archae.html?id=S6igGAAACAAJ

Groundwater and Springs

In Texas, early explorers and Native Americans developed roads and pathways based partly on availability of both food and water resources to sustain them along each journey. Water-rich pathways from Mexico and coastal Texas into the Llano uplift mining region extended from Barton Springs in Austin, southward along the Balcones Fault Zone to the San Pedro Springs in San Antonio, Texas. Availability of water resources drives much of the current and expected Hill Country development.

In Gillespie, Llano, Mason, McCulloch, and San Saba counties, encompassing much of the Llano Uplift, most aquifers are local and considered minor. On the western edge of the uplift, throughout Gillespie County, in western Mason County and in about half of McCulloch County, the major Edwards-Trinity (Plateau) Aquifer exists in a thin veneer as outcrop. The Trinity Aquifer outcrops in about half of south and eastern Gillespie County. Three minor aquifers, Marble Falls, Hickory, and Ellenburger-San Saba, radiate out in a target pattern from the dry bullseye of pre-Cambrian granite outcrop, and likely recharge zone, covering much of Llano County.

Ellenburger-San Saba Aquifer (see Figure 5) water quality is fresh, tending toward high total dissolved solids downdip and slightly brackish to about 3,000 feet. Limestone and dolomite comprise the saturated portion, full of fractures and cavities which may yield up to 1,000 gallons per minute. Water uses are primarily municipal, irrigation, and livestock (Texas Water Development Board, 2015). Texas Water Development Board calculated the Total Estimated Recoverable Storage (see Table 1) for planning purposes. Modeled available groundwater, the amount of groundwater that can be pumped to meet the locally-derived policy goal of aquifer conditions in 50 years, is one factor groundwater conservation districts consider when issuing permits (see Table 2).

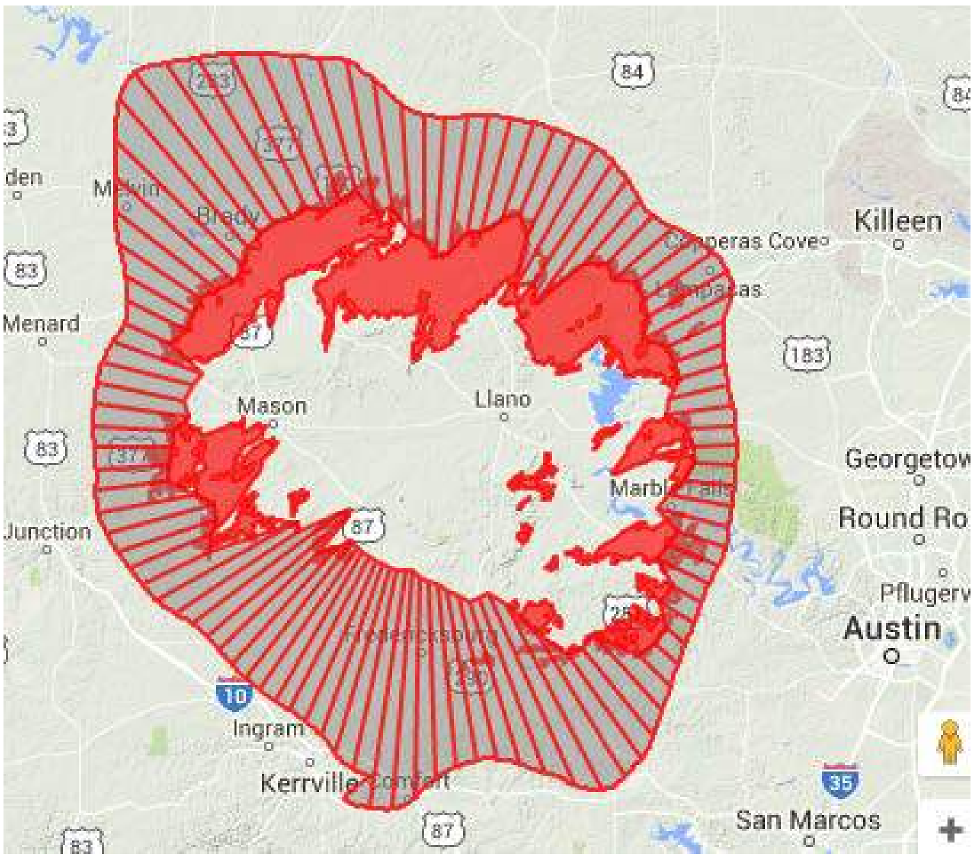


Figure 5. Ellenburger-San Saba Aquifer.

Table 1. Groundwater Total Estimate for Ellenburger-San Saba, in Llano Uplift Area.

TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE ELLENBURGER-SAN SABA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 7. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Coleman	1,400,000	350,000	1,050,000
Concho	62,000	15,500	46,500
Gillespie	6,500,000	1,625,000	4,875,000
Kimble	6,000,000	1,500,000	4,500,000
Llano	350,000	87,500	262,500
Mason	1,900,000	475,000	1,425,000
McCulloch	16,000,000	4,000,000	12,000,000
Menard	1,600,000	400,000	1,200,000
San Saba	20,000,000	5,000,000	15,000,000
Total	53,812,000	13,453,000	40,359,000

Source: Texas Water Development Board, 2013, accessed October 5, 2015,
http://www.twdb.texas.gov/groundwater/docs/GAMruns/Task13-030.pdf

Table 2. Modeled Available Groundwater in Llano Uplift Area.

Groundwater Management Area 7 - Modeled Available Groundwater

Aquifer	County	Regional Water Planning Area	River Basin	Modeled Available Groundwater						TWDB Report
				2,010	2020	2030	2040	2050	2060	
Ellenburger-San Saba	Concho	F	Colorado	0	0	0	0	0	0	AA 10-10 MAG
Ellenburger-San Saba	Gillespie	K	Colorado	6,270	6,270	6,270	6,270	6,270	6,270	AA 10-10 MAG
Ellenburger-San Saba	Gillespie	K	Guadalupe	1	1	1	1	1	1	AA 10-10 MAG
Ellenburger-San Saba	Kimble	F	Colorado	304	304	304	304	304	304	AA 10-10 MAG
Ellenburger-San Saba	Mason	F	Colorado	5,801	5,801	5,801	5,801	5,801	5,801	AA 10-10 MAG
Ellenburger-San Saba	McCulloch	F	Colorado	5,369	5,369	5,369	5,369	5,369	5,369	AA 10-10 MAG
Ellenburger-San Saba	Menard	F	Colorado	791	791	791	791	791	791	AA 10-10 MAG
Ellenburger-San Saba	San Saba	K	Colorado	10,893	10,893	10,893	10,893	10,893	10,893	AA 10-10 MAG
Hickory	Concho	F	Colorado	1	1	1	1	1	1	AA 10-11 MAG
Hickory	Gillespie	K	Colorado	1,659	1,659	1,659	1,659	1,659	1,659	AA 10-11 MAG
Hickory	Gillespie	K	Guadalupe	0	0	0	0	0	0	AA 10-11 MAG
Hickory	Kimble	F	Colorado	6	6	6	6	6	6	AA 10-11 MAG
Hickory	Llano	K	Colorado	2,018	2,018	2,018	2,018	2,018	2,018	AA 10-11 MAG
Hickory	Mason	F	Colorado	12,294	12,294	12,294	12,294	12,294	12,294	AA 10-11 MAG
Hickory	McCulloch	F	Colorado	7,152	7,152	7,152	7,152	7,152	7,152	AA 10-11 MAG
Hickory	Menard	F	Colorado	1,016	1,016	1,016	1,016	1,016	1,016	AA 10-11 MAG
Hickory	San Saba	K	Colorado	1,479	1,479	1,479	1,479	1,479	1,479	AA 10-11 MAG
Marble Falls	San Saba	K	Colorado	11,063	11,063	11,063	11,063	11,063	11,063	AA 10-12 MAG

Source: Texas Water Development Board, 2014, accessed October 8, 2015,
http://www.twdb.texas.gov/groundwater/management_areas/dfc_mag/GMA_7_MAG.pdf

Hickory Aquifer (see Figure 6.) water quality although mostly fresh, contains naturally occuring radiactivity above the state's primary drinking standards and usually must be treated and is the public drinking water supply for Brady, Mason, and Fredrickburg (Texas Water Development Board, 2015). Texas Water Development Board calculated the Total Estimated Recoverable Storage (see Table 3) for planning purposes. Modeled available groundwater, the amount of groundwater that can be pumped to meet the locally-derived policy goal of aquifer conditions in 50 years, is one factor groundwater conservation districts may consider when issuing permits (see Table 2).

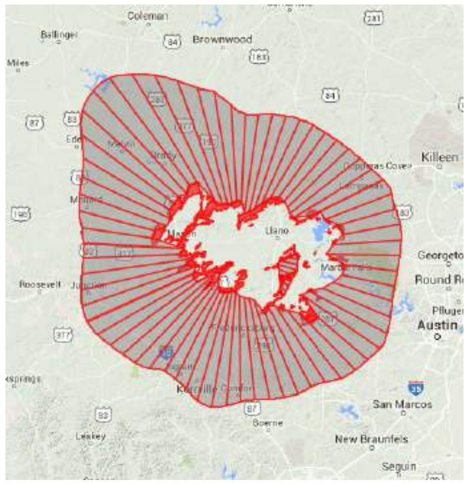


Figure 6. Hickory Aquifer.
(Click to Enlarge)

Table 3. Groundwater Total Estimate for the Hickory Aquifer, Llano Uplift Area.

TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE HICKORY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 7. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	Total Storage (acre-feet)	25 percent of Total Storage (acre-feet)	75 percent of Total Storage (acre-feet)
Coleman	1,500,000	375,000	1,125,000
Concho	2,800,000	700,000	2,100,000
Gillespie	7,200,000	1,800,000	5,400,000
Kimble	5,900,000	1,475,000	4,425,000
Llano	1,000,000	250,000	750,000
Mason	5,400,000	1,350,000	4,050,000
McCulloch	8,500,000	2,125,000	6,375,000
Menard	4,500,000	1,125,000	3,375,000
San Saba	7,500,000	1,875,000	5,625,000
Total	44,300,000	11,075,000	33,225,000

Source: Texas Water Development Board, 2013, accessed October 5, 2015, http://www.twdb.texas.gov/groundwater/docs/GAMruns/Task13-030.pdf

Marble Falls Aquifer (see Figure 7) water quality is fresh and yields high well flow rates in some areas due to solution features in the limestone formation. With a maximum thickness of 60 feet and high permeability in some places, contamination from surface sources may produce high nitrate levels. Water is generally fresh, below 1,000 milligrams per liter, but toward the higher end of fresh (Texas Water Development Board, 2015). Texas Water Development Board calculated the Total Estimated Recoverable Storage (see Table 4) for planning purposes. Modeled available groundwater, the amount of groundwater that can be pumped to meet the locally-derived policy goal of aquifer conditions in 50 years, is one factor groundwater conservation districts may consider when issuing permits (see Table 2).

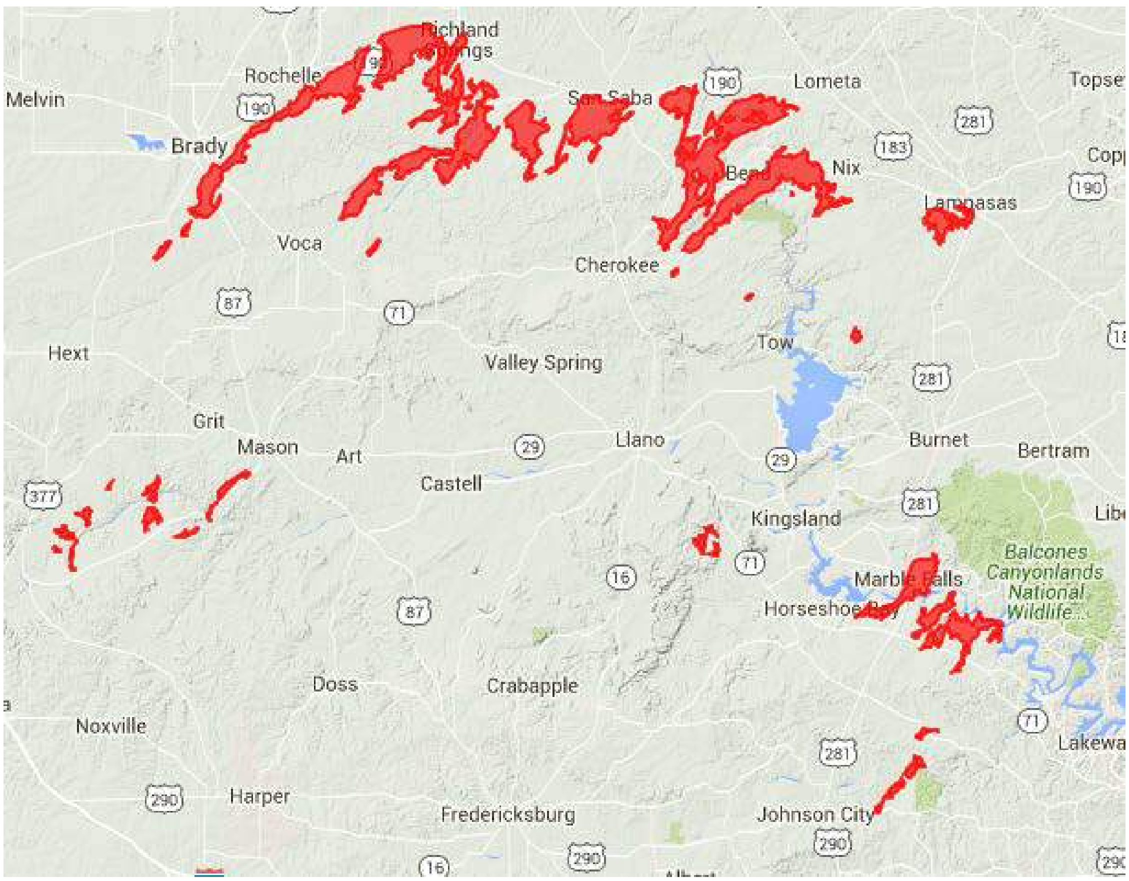


Figure 7. Marble Falls Aquifer

Source: Texas Water Development Board, 2015, accessed October 7, 2015, http://www.twdb.texas.gov/groundwater/aquifer/minors/marble-falls.asp

Table 4. Groundwater Total Estimate for the Marble Falls Aquifer, Llano Uplift.

TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE MARBLE FALLS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 7. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Kimble	2,400	600	1,800
Llano	2,100	525	1,575
Mason	5,300	1,325	3,975
McCulloch	33,000	8,250	24,750
San Saba	144,000	36,000	108,000
Total	186,800	46,693	140,078

Source: Texas Water Development Board, 2013, accessed October 5, 2015, http://www.twdb.texas.gov/groundwater/docs/GAMruns/Task13-030.pdf

Silver and Gold, and Religion

Information about prospector gold exploration (in contrast to professional gold exploration programs) as reported on the Internet is almost as mythical as the Seven Cities of Cibolo. In the past, documentation of the New World in the 1500's supported stories about cities of gold or huge gold deposits, persisting through the Spanish exploration of the southwestern United States. Historians indicate that the Spanish exploration of the New World emerged in the late 1400's due to Spain's successful expansion on the Iberian Peninsula when the monarchs saw opportunities to expand territory through global exploration "blessed by God" to dominate through converting natives, finding gold, and winning distinction and honor charting the unknown.

Although tribes living in North America for thousands of years must have already found gold prior to the 1500's and had stories about gold other than the Spaniards exploration, this is a good place to begin Texas' riches-of-gold stories. Trail maps (Brune, 2002) spanning the 15th through the 19th century show the travel direction and springs accessed by primarily Spanish explorers beginning in 1497 with Amerigo Vespucci hugging the Texas coast.

In 1519, Spanish explorer and surveyor Captain Alonso Alvarez de Pineda is credited as being the first European to map the Texas coast (Weddle, 2010). In 1528, Spanish explorer Alvar Nuñez Cabeza de Vaca, part of the Spanish conquistador Pánfilo de Narváez expedition that sailed from Cuba to Mexico along the Gulf Coast. The ship wrecked on Galveston Island after searching for gold and food in the eastern part of the Gulf Coast and only a few survived, including Cabeza de Vaca. Cabeza De Vaca travelled on an east-west trail (1528-1536) from Galveston Island through Bexar, Kendall, Kerr, and Kimble counties toward a spring in Sutton County. His party dropped down into Mexico at another spring on the Rio Grande near a native settlement. Through a series of complex events, Cabeza de Vaca thoroughly documented his experiences in the southwest through travelling for years across what is now Texas, New Mexico, and Mexico. He changed his focus from finding riches for the crown to higher order pursuits as he embraced a simpler life as a faith healer and trader with local Native Americans.

In 1540, Spain commissioned Francisco Vázquez de Coronado to explore Texas and New Mexico via Mexico. Historians suggest that Native Americans learned that the best way to keep European explorers successfully occupied elsewhere was to suggest vast riches could be found elsewhere. Perhaps not a coincidence but after visiting the Pueblo Indians in New Mexico, Coronado subsequently spent years searching for gold and silver deposits across the High Plains of Texas, Oklahoma and Kansas. Somewhat later a north-south trail (1542-1547) formed from north of Wilbarger County through Concho, Menard, and Kimble County toward a spring in Edwards County. This trail dropped down into Mexico at Francias Crossing at the Rio Grande in southern Maverick County. These two trails crossed in Kimble County, in the western Llano Uplift but apparently did not use the same springs (Brune, 2002).

Missions and presidio's of the 17th century anchored the locations of most of the Spanish trails. Mendoza and Lopez travelled east and circled back (1683-1684) from El Paso to the western edge of the Llano Uplift in Menard County to Mission San Clemente. In the 18th century, the Llano Uplift became heavily travelled with at least six documented trails, most likely due to the lessening threat of attack and increased interest in mining. All mapped trails through the Llano Uplift area originated in San Antonio, now a well-established and civilized outpost, and headed north.

Regarding Los Almagres Silver Mine, located somewhere in southeastern Llano County, Brune (2002) indicated that Koch springs in the lower Glen Rose Formation, Blanco County, is likely to be the "abundant springs" that Bernardo de Miranda y Flores, Lieutenant Governor of Texas (province of Mexico) identified on an exploration trip. In 1756, Miranda set out with a small party to find the rumored mineral deposits Cerro del Almagre and Almagre Grande. After his return to San Antonio, Miranda asked the Spanish Viceroy and gained permission for a silver assay of his findings near Honey Creek and the Llano River, but the assay apparently did not happen.

References:

Gunnar Brune, 2002,"Springs of Texas, Volume 1," Texas A & M Press, College Station, Texas.

Frank Goodwyn, "Miranda Y Flores, Bernardo De" Handbook of Texas Online, accessed October 06, 2015 (http://www.tshaonline.org/handbook/online/articles/fmi49), Uploaded on June 15, 2010. Published by the Texas State Historical Association.

Texas State Mineral Exploration

Almost 100 years later, silver mining was reported in Presidio County in 1860 when a rancher reportedly hauled silver ore to Mexico for smelting at $20.50 a ton. Subsequently, in 1876 Texas State Geologist Samuel Buckley surveyed the general area and identified silver, lead, copper, zinc, mercury, and uranium mineralization. Profitable gold extraction and refining in Texas is limited to two mines in west Texas, and the Heath Mine (now Dixie Graphite Mine) in Llano County.

Significant silver and gold extraction from the Shafter Mining District in Presidio County, silver at 32.6 million ounces and gold at 8,277 fine ounces (valued at about $233,499 in 1942) began in 1883 and ended in 1952. Although published information is inconsistent, apparently commercial gold production ended in 1942 when the Presidio Mine, Chinati Mountains, closed. Smith reported in The Handbook of Texas online that about 92 percent of the silver and 73 percent of the gold in Texas came from Presidio Mine.

Figure 8. Llano Ore Mill.

Photo source: http://www.mindat.org/loc-42306.html.

Note from U.S. Geological Survey Mineral Resources On-Line Spatial Data under Dixie Graphite Mine:
Economic Comments: Old Heath Gold Mill Converted 1916 to Process Graphite.

In Texas, minor deposits of gold were identified mostly in the far west parts of Texas, although for centuries the Llano uplift area served as a Texas bullseye of hidden and lost mines primarily because the outcropping rocks were "unusual", but remain a source of gold mostly based on legends and myths. One exception is the historic Heath Mine (see general location in Figure 9), recorded as a gold mine by U.S. Geological Survey, located 5 miles northeast of Llano and opened in 1896.

Exploration history all over the world shows that where minor gold was reported at the surface in the early days, detailed exploration more recently, especially via drilling, can locate bonifide ore bodies.

The possibility exists that the area has been underexplored by professional geologists experienced in exploration for gold and other metals.

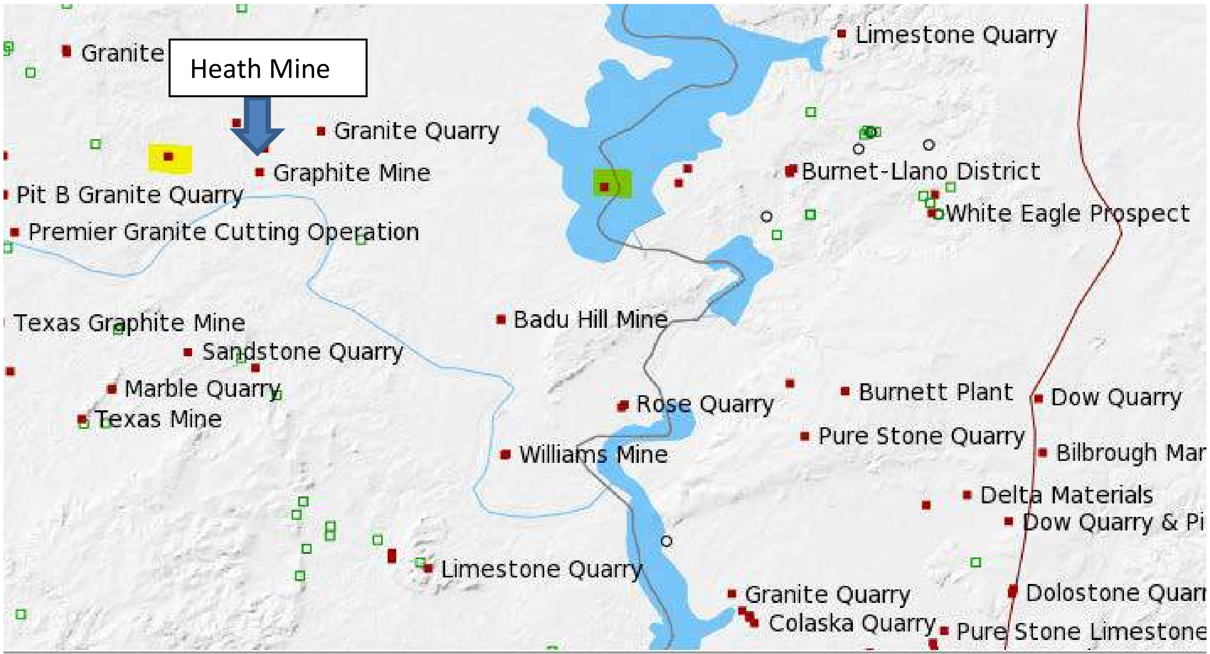


Figure 9. Heath Gold Mine.

Note from U.S. Geological Survey Mineral Resources On-Line Spatial Data under Dixie Graphite Mine as to Heath Mine location North of FM 2241. LAT LONG for Old Heath Gold Mine, which is located at or near the Dixie Graphite Mine.

Llano Gold & Rare Metal Mining Company built a mill in 1911 (see Figure 8 above); it reportedly produced more 8,000 fine ounces of gold by 1942 but this claim has not been verified. In 1916, the U.S. Geological Survey Mineral Resources on-line spatial data website reported that the Heath Mine mill had been converted to process graphite.

Minerals reported at the Heath Mine, located in the Packsaddle Schist Formation (see Table 5), included: gold, vermiculite, bismuth, and vanadium. Minerals also reported at the nearby/same Dixie Graphite mine location included: gold, graphite, malachite, molybdenite, powellite, pyrite, quartz, schorl, and possibly tetrahedrite (both lists are based on from U.S. Geological Survey, Mineral resources on-line spatial data, 2015).

Table 5. Formation Mined in Lake Buchanan Area in 1915 (source: USGS, 2015).

Name	Packsaddle Schist
Geologic age	Precambrian-Proterozoic [Llano]
Map label	pCps, members descending order pCc, pCr, pCs, pCh
Comments	Comstock and Dumble (1890) included unit in the Packsaddle series, described as metamorphosed shaly beds and marble (near base) forming top div. of Texan system. Barnes (1952) described the unit as mostly feldspathic amphibole, biotite schist, chiefly dark colored. (from Llano Sheet, Geol. Atlas of Texas) From top down: Click Fm.-mostly hornblende schist, underlain by leptite and qtz-feldspar-mica schist which grades into hornblende schist SE; thickness ca. 7,800 ft. Rough Rider Fm.-gray leptite, qtz-feldspar-mica schist, and biotite-cordierite gneiss muscovite schist, biotite schist, biotite-microcline gneiss; thickness ca. 5,200 ft. Sandy Fm.-alternating units of hornblende schist, quartz-feldspar mica schist, leptite; thickness ca.2,100 ft. Honey Fm.-upper part graphite schist, hornblende schist, and marble with graphite schist interbeds; middle part-muscovite schist, changes to leptite, graphite, schist, and hornblende schist toward SE, one prominent marble; lower part-hornblende schist, graphite schist, leptite, and marble; thickness ca 7,800 ft.
Primary rock type	amphibole schist
2nd rock type	quartz-feldspar schist
Other rock types	mica schist; schist; amphibolite; quartzite; marble; granulite; gneiss
Lithologic constituents	Major: Metamorphic > Schist (Amphibolite) Dominantly dark basic rocks including biotite, amphibolite, and graphitic schists and crystalline limestone also light-colored feldspathic bands resembling quartzite. Mostly feldspathic amphibole and biotite schist, predominantly dark colored.
Operator	Llano Gold and Rare Metals Company
Production	At least 26 sacks of about 1 opt AU ore mined before 1912. A small quantity of bullion produced 1915. Inactive little developed producer.
Workings	About 60 pits, shafts with drifts and crosscuts.
Deposit	Quartz stringers associated with pegmatite. Residual gold in soil. Assays yielded 0.01 to 0.08 OPT AU in wall rock and 0.99 OPT AU from sorted ore. Small amounts of vermiculite in schist found in old shafts and pits.

The U.S. Geological Survey reports the location of the Heath Mine (see Figure 10).

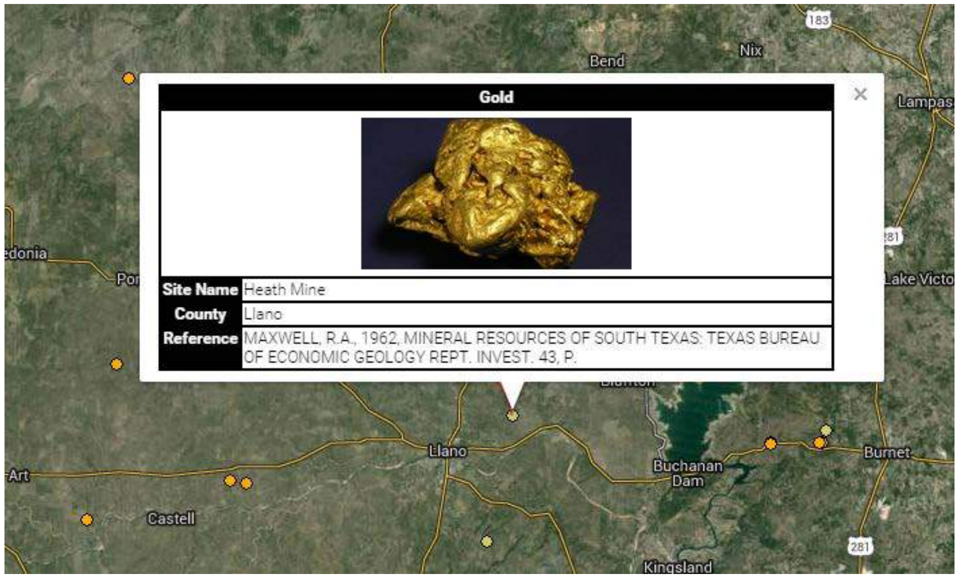


Figure 10. Gold Report in the Llano Uplift.

Llano Sheet

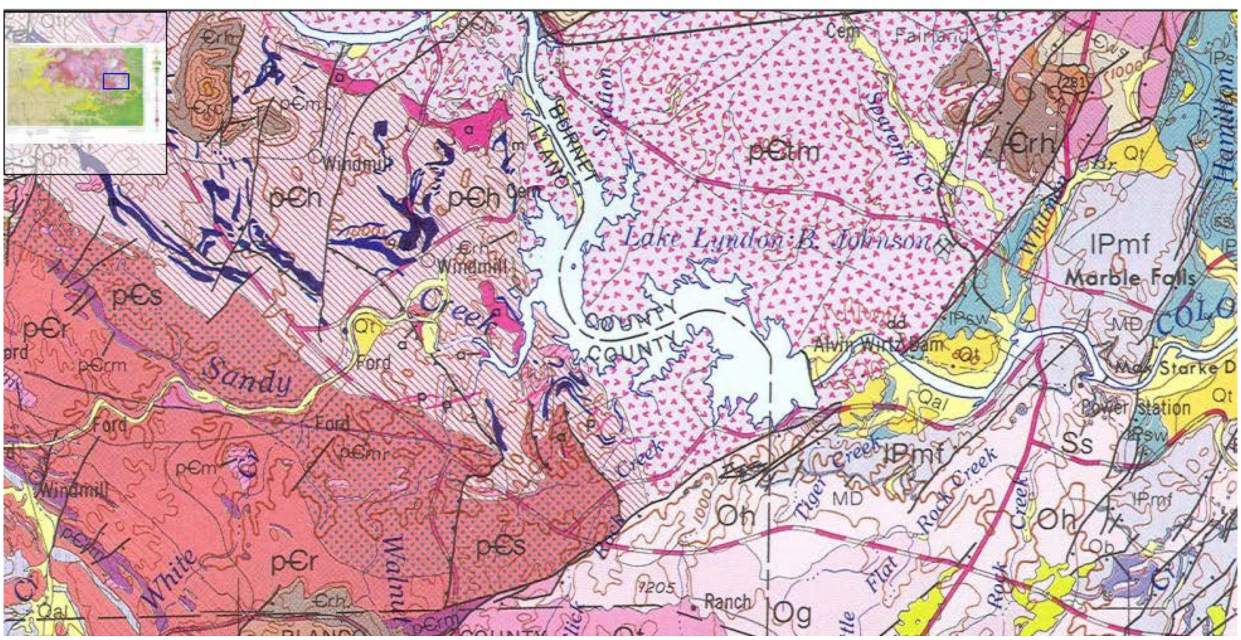


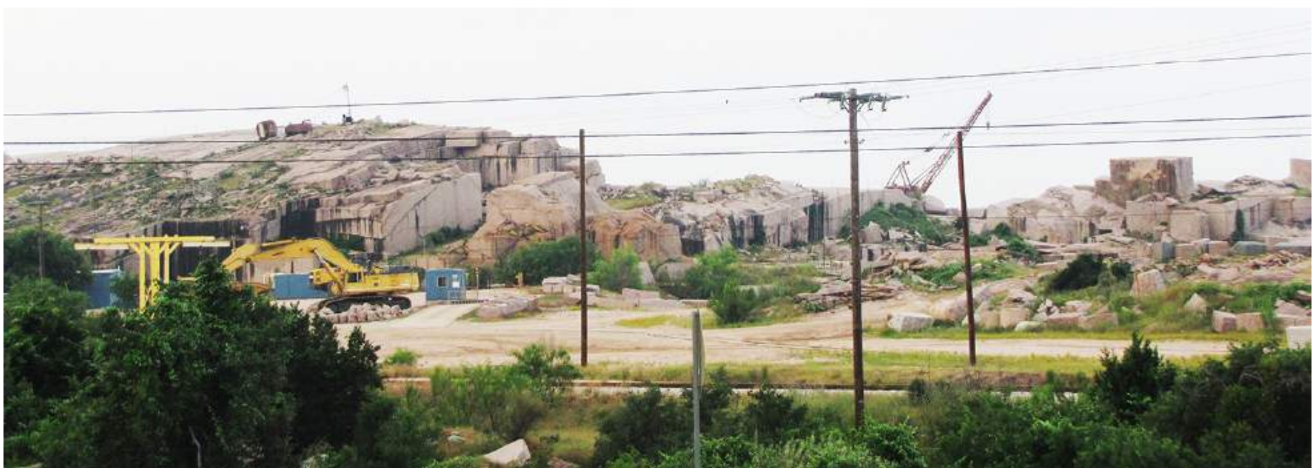
Figure 11. Geologic Map near Marble Falls and Llano, Texas

Source: Texas Water Development Board, 2015, Geologic Atlas of Texas, accessed October 7, 2015, http://www.twdb.texas.gov/groundwater/aquifer/GAT/index.asp

Dimension Stone Production

Stone quarried for slabs, such as limestone, granite, marble, sandstone, and slate, are called dimension stone. These days it might be hard to imagine a kitchen without new granite or marble countertops. In 1900, dimension stone producers had concerns about the future of the market because of reinforced concrete and steel being used in larger buildings such as high-rise development. Tastes changed in 1931 with the Empire State Building being covered in limestone, fueling the hottest production rate of the 20th century that same year. This single building is credited for creating a new U.S. market for decorative stone for interior and exteriors.

From 1900, the 1.6 million metric tons quarried decreased to 1.3 million metric tons in 2000, except for that all-time high of 6.0 million metric tons in 1931. This slow decrease is primarily due to the increase of global imports mainly from Italy, Brazil, India, and Canada. Texas was the fourth largest dimension stone producer by tonnage, but not in the top five producers by value. Texas limestone production was the third largest producer by tonnage, but not in the top three producers in value.



Town Mountain Granite Mine

According to the U.S.G.S. the mined slabs (for counter tops, etc) consist of coarse-grained, pink, quartz-plagioclase-microcline rock, in part porphyritic with large microcline phenocrysts. Occurs in plutons up to 13 miles in size that tend to be concordant circular vertical cylinders with concentric textural variations; boundaries range from sharp and regular to highly irregular with wide zones of mixed rock. The rock unit makes up Enchanted Rock granite mass in Gillespie and Llano Counties.

Reference:

Thomas P. Dolley, 2001, "Stone, dimension," http://minerals.usgs.gov/minerals/pubs/commodity/stone_dimension/800400.pdf , accessed October 5, 2015. Published by the U.S. Geological Survey.

Saturday, May 14, 2016 Fall Field Trip to the Llano Uplift

Stops 1 and 2

Roadside Historical Overlook at Marble Falls Granite Mine

Newer, more tangible forms of considerable wealth other than gold in the Llano uplift area are dimension stones such as granite, and sand and aggregate (see Figures 12).

Groundwater from the Hickory, Ellenburger-San Saba, and Marble Falls aquifers increases land values and provides domestic, livestock, and mining water, but does not likely occur as voluminously and near enough to large population or industrial production centers for leasing consideration as do other aquifers in the state.

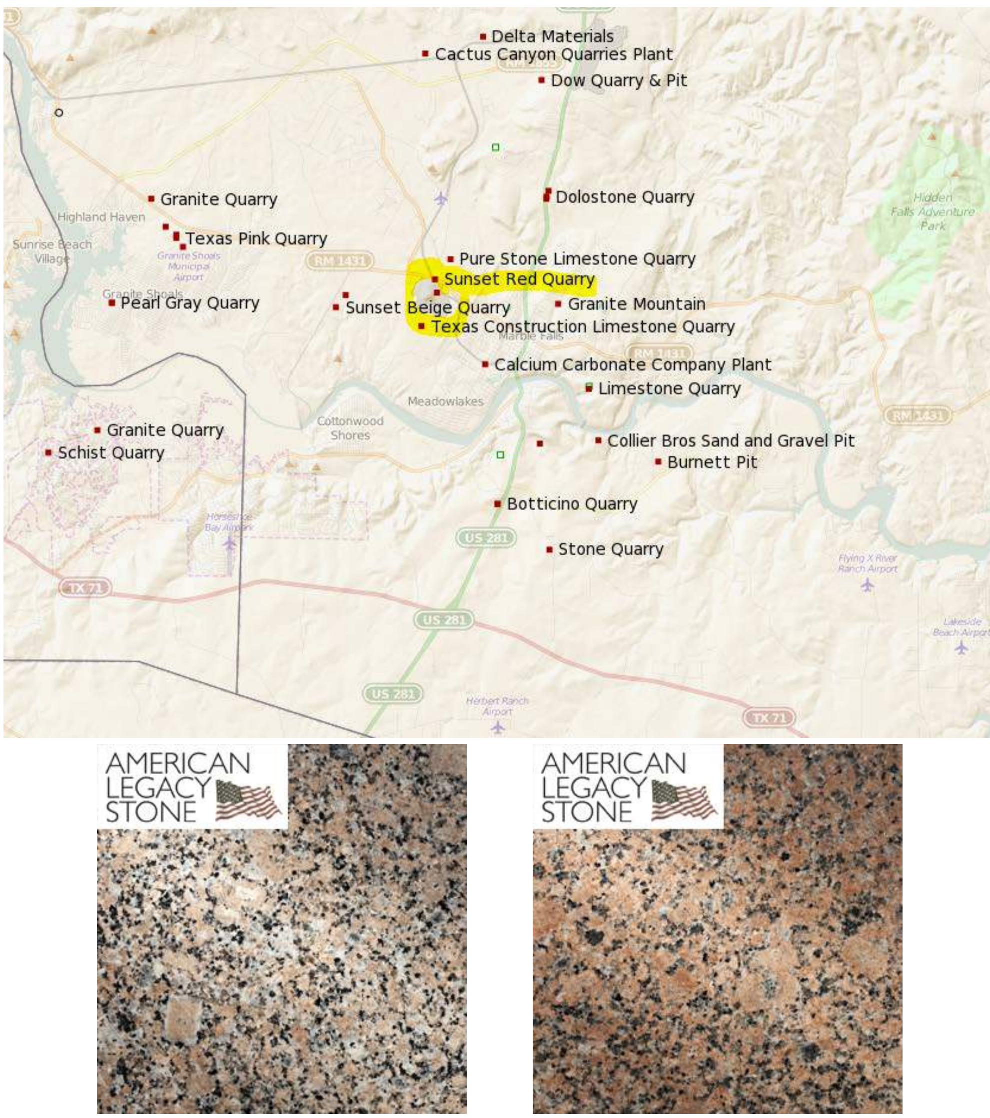
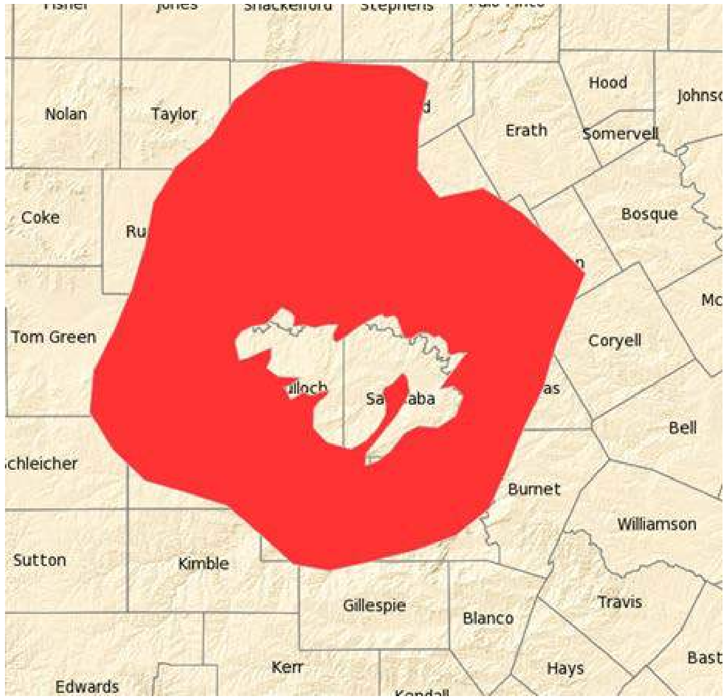


Figure 12. Granite Mines near Marble Falls, Texas

Photo of Sunset Beige (left) and Sunset Red (right) granite mined in Marble Falls, Coldspring USA, Inc. Photo courtesy of Coldspring USA.

In 1998, the U.S. Geological Survey released a report for each state describing mineral production potential (undiscovered) for gold, silver, copper, lead, and zinc. Included here are two maps of potential production areas near the Llano Uplift, the only two areas identified in central Texas as potential prospects (see Figure 13).



Potential Mississippi-type lead/zinc skarn deposits boundaries (USGS, 2015).

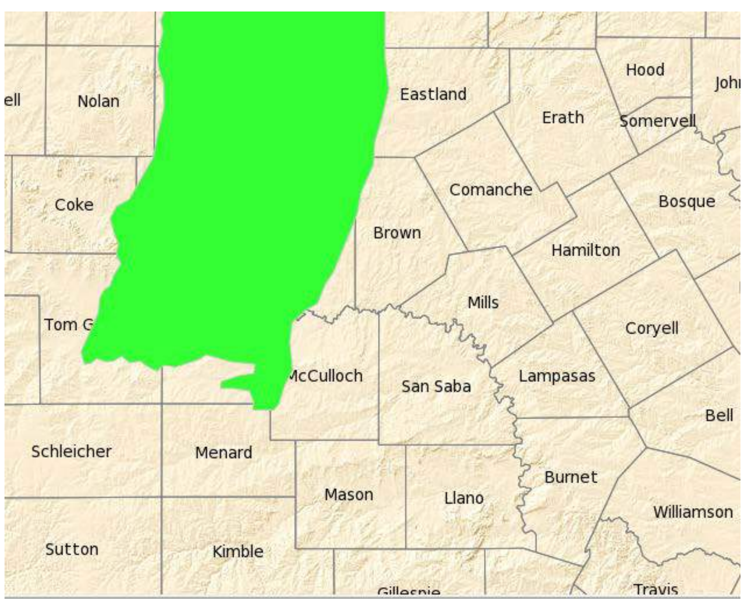


Figure 13. Potentially Commercial Prospects, Llano Uplift Area.

Potential sediment-hosted copper redbeds, boundaries extend north through Kansas (USGS, 2015)

In 2003, the U.S. Geological Survey reported on active mines being tracked for commodities production including building materials, metals, and industrial materials (see Figure 14).

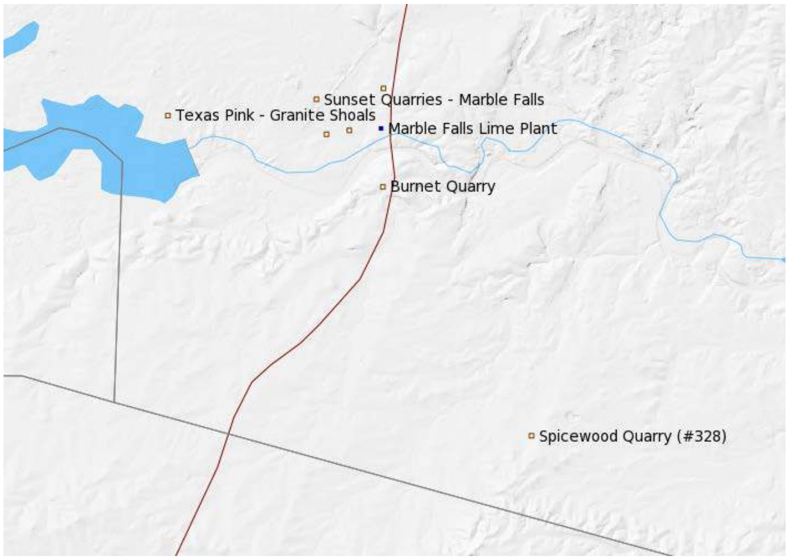


Figure 14. Commodities mined in Burnet County in 2003, near Stops 1 and 2.

Table 6 shows details about the four formations being mined (U.S. Geological Survey, 2015) in Burnet County. Near Stop1 and Stop 2, mining locations include:

- Cold Spring Granite Company mining dimension stone from **Town Mountain Granite Formation**,
- Vulcan Materials Company mining crushed stone (Spicewood Quarry) from the **Honeycut Formation**,
- Dean Ward Co. mining crushed stone (Marble Falls Quarry) from the **Smithwick Formation**
- J.M. Huber Corporation mining crushed stone (Calcium Carbonate Quarry) from the **Smithwick Formation**,
- Collier Materials Incorporated mining sand and gravel (Fairland Granite Gravel Pit) from the **Smithwick Formation**,
- Hanson Aggregates Central Incorporated mining crushed stone (Burnet Quarry) from the **Marble Falls Limestone Formation**, and
- Chemical Lime Company mining lime (Marble Falls Lime Plant) from the **Marble Falls Limestone Formation**.

Table 6. Four Formations being Mined in the Marble Falls Area in 2003 (USGS, 2015).

Name	**Honeycut Formation**
Geologic age	Phanerozoic | Paleozoic | Ordovician-Early
Original map label	Oh
Comments	Limestone and dolomite, thickly to thinly bedded, cherty; ls. aphanitic, lt-gray; dolomite mostly fine-grained to microgranular, lt- to medium-gray and yellowish-gray to brownish-gray; fossils preserved in chert include trilobites, cephalopods, the sponge Archaeoscyphia and gastropods including silicified Ceratopea; thickness 680 ft in SE area, truncated to NW by erosion.
Primary rock type	dolostone (dolomite)
Name	**Marble Falls Limestone**
Geologic age	Phanerozoic | Paleozoic | Carboniferous Pennsylvanian [Morrow]
Original map label	IPmf
Comments	(fr. Llano Sheet, 1981) Along Colorado River in type section, upper 270 ft mostly limestone, some spiculite beds in upper part; limestone. mostly v. fine grained, some fine to medium grained, in part cherty, thin to thick bedded, oolitic near middle, various shades of brownish-gray, med.-gray, and olive-gray, microfossils abundant in most beds, megafossils common(marine algae, crinoids, brachiopods, and Chaetetes); lower 115 ft mostly massive hi-calcium ls reef, v fine grained, med-dk-gray ls, with abundant blk chert, laterally reef grades to dk-gray spiculite, in part cherty; meas. thickness of formation 385 ft. (from Brownwood Sheet, 1976) Limestone and shale, mostly limestone, v.fine to coarse-grained, oolites and pellets common, locally cherty and siliceous, thin beds to massive, gen. resistant, forms ledges and slopes, rapid changes in aspect laterally and vertically, white to black, weathers lt gray to dk gray. abundant marine fossils, esp. algae, crinoids, brachiopods, and Chaetetes; thickness average: 300 ft, varies from 35 to more than 400 ft.
Primary rock type	limestone
Secondary rock type	shale
Name	**Smithwick Formation**
Geologic age	Phanerozoic | Paleozoic | Carboniferous Pennsylvanian-Middle [Atoka]
Original map label	IPsw
Comments	(fr. Llano Sheet, Geol. Atlas of Texas, 1981) In type locality east of Marble Falls, claystone, siltstone, and ss. Claystone predominantly. laminated or burrowed, carbonaceous; illite with less than 15% quartz and muscovite silt; ss mostly contains rock frags. (sublitharenite of Folk) and minor but stratigraphically important sandy lms.-pebble conglomerate derived from the Marble Falls Limestone; sole marks and a wide variety of sedimentary structures present in sandstone; plant material abundant in sandstone and claystone.; fossils includes some plants, locally abundant trilobites,

	brachiopods, and cephalopods, thickness about 300 ft. In Mason County, Smithwick consists of black shale with lms. beds in lower part, which is laterally gradational to Marble Falls Lms., lower boundary climbs stratigraphically westward.
Primary rock type	fine-grained mixed clastic
Secondary rock type	limestone
Other rock types	shale; sandstone; conglomerate
Name	**Town Mountain Granite**
Geologic age	preCambrian-Proterozoic
Original map label	pCt
Comments	Coarse-grained, pink, quartz-plagioclase-microcline rock, in part porphyritic with large microcline phenocrysts. Occurs in plutons up to 13 mi in size that tend to be concordant circular vertical cylinders with concentric textural variations; boundaries range from sharp and regular to highly irregular with wide zones of mixed rock. Makes up Enchanted Rock granite mass, Gillespie and Llano Counties.
Primary rock type	granite
Secondary rock type	porphyry

Source: U.S. Geological Survey, Mineral resources on-line spatial data, 2015.

Los Almagres Mine

The Stotts Ranch, owned by Mr. James Stotts and family, is located in eastern Llano County. The property covers a large portion of Packsaddle Mountain (see Figure 14), an isolated hill that is the type locality of the Precambrian Packsaddle Schist. A number of small prospecting holes and small shafts/mines are located on the Stotts Ranch, some of which probably date to the Spanish Colonial era (middle 1700s to early 1800s), whereas others were opened or reworked in the late Nineteenth to early Twentieth centuries. Evidence supports the conclusion that a mine discussed in a letter and report from the 1750s is one of those on the Stotts Ranch, although this conclusion is not shared universally. The history of this region is laced with legends of lost mines of silver and gold, many of which are predicated on events that probably occurred at the Stotts Ranch.

The zone targeted for prospecting or mining at this locality was a *gossan* (zone of intense weathering and iron mineralization) along the unconformity separating the Packsaddle Domain from the overlying basal Cambrian Hickory Formation locally. The earliest period of excavation was characterized by the exclusive use of hand tools and manual labor, which produced distinctive, small, angular boulders of relatively uniform size. Later excavations primarily relied on mechanized drilling and blasting.

The resulting sizes of the adits and shafts were small. Nominal ore materials consisted of the *gossan* and associated altered bedrock. Geochemical analysis of these rock materials failed to disclose concentrations of any precious or base metals exceeding background levels. Nonetheless, the record of mineral exploration at the Stotts Ranch adds a fascinating chapter to the early history of central Texas. Figures 15 and 16 add to the mystery of what early explorers had found (more).

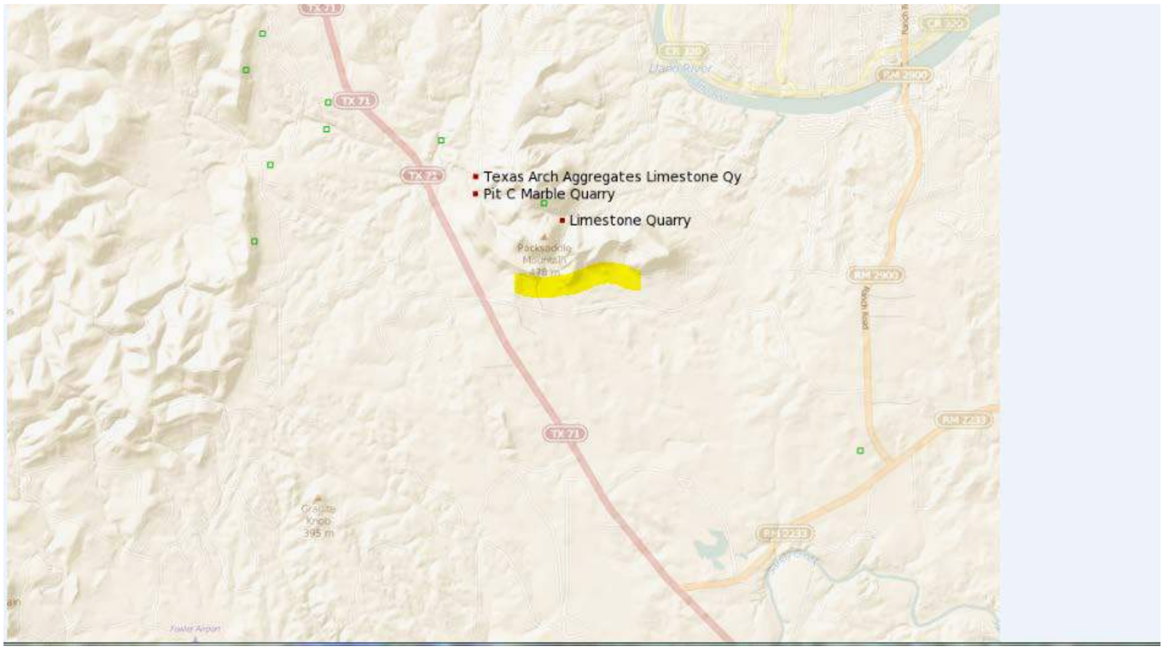


Figure 15. Packsaddle Mountain and Mines.

Is the Kiam Prospect a source of productive gold and legendary 16th Century mine?

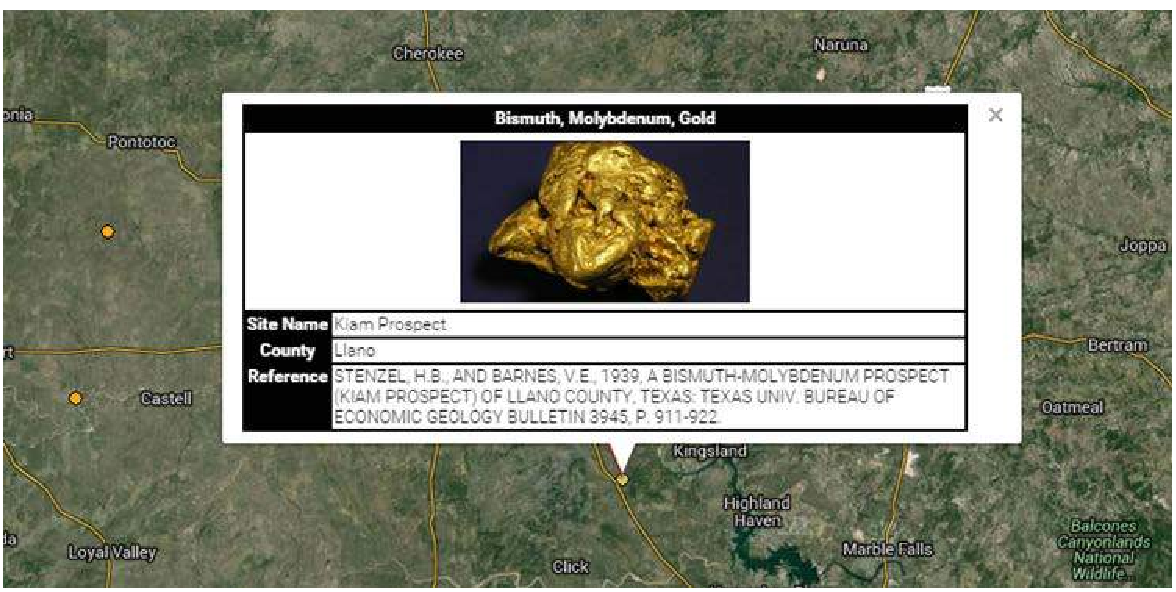


Figure 16. Kiam Gold Prospect, Packsaddle Mountain area.

Or is the nearby Sheeton's Place pictured next a probable source of a fool's errand?

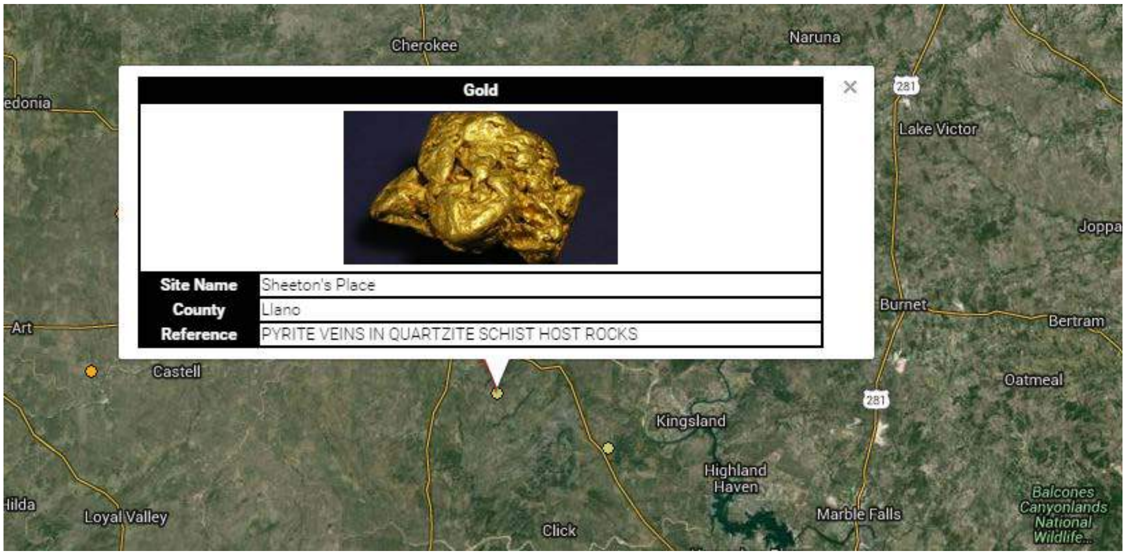


Figure 17. Fool's Gold in the Llano Uplift.
Source: U.S. Geological Survey, 2015

References:

Thomas J. Evans, Gold and Silver in Texas (Mineral Resource Circular 56 [Austin: Bureau of Economic Geology, 1975]). University of Texas, Texas Looks Ahead: The Resources of Texas (Austin, 1944; rpt., Freeport, New York: Books for Libraries Press, 1968).

"GOLD MINING," Handbook of Texas Online (http://www.tshaonline.org/handbook/online/articles/dkg01), accessed September 29, 2015. Uploaded on June 15, 2010. Published by the Texas State Historical Association.

Mike Kingston. "European exploration and development," Texas Almanac- 1986-1987, (http://texasalmanac.com/topics/history/timeline/european-exploration-and-development), accessed September 25, 2015, Published by the Texas State Historical Association.

Julia Cauble Smith, "SHAFTER MINING DISTRICT," Handbook of Texas Online (http://www.tshaonline.org/handbook/online/articles/gps02), accessed September 29, 2015. Uploaded on June 15, 2010. Published by the Texas State Historical Association.

Texas Water Development Board, Minor Aquifers,

Robert S. Weddle, "ALVAREZ DE PINEDA, ALONSO," Handbook of Texas Online (http://www.tshaonline.org/handbook/online/articles/fal72), accessed September 25, 2015. Uploaded on June 9, 2010. Published by the Texas State Historical Association.

U.S. Geological Survey, Mineral Resources Data System, http://mrdata.usgs.gov/mineral-resources/mrds-us.html, accessed September 25, 2015. Published by the U.S. Geological Survey.

Stop 3: Voca Mine: Sand Used in the Oil and Gas Industry

Premier Silica, Inc. hosted a mine visit as part of this field trip. The photographic record of this visit is available beginning on page 52 of this Guide.

Table 7. Hickory Sandstone Formation in the Llano Uplift area (U.S. Geological Survey, 2015)

Name	Hickory Sandstone Member
Geologic age	Phanerozoic | Paleozoic | Cambrian-Middle
Original map label	Ch
Comments	The Hickory Sandstone Member is basal member of Riley Formation (of the Moore Hollow Group of middle(?) to late Cambrian age. Riley Formation in Llano uplift (in Moore Hollow area of Riley Mtns., central Texas) is about 600 to nearly 800 ft thick; thickest in southeast Llano Co., thinnest in northwest corner of uplift. The Riley overlies Precambrian rocks and underlies Wilberns Fm. The Hickory, in NW part of Llano area is described on the Llano Sheet (Geologic Atlas of Texas, 1981) as follows, Upper part--medium to coarse-grained sandstone, exceptionally well-rounded grains, hematite-cemented, iron content averages about 10%, dusky-red; a scarp slopes down to a cultivated bench that centers on the contact between the red and the silty parts of the unit; thickness about 90 ft. Middle part, mostly fine to medium-grained ss., argillaceous, silty, commonly thinly bedded and micaceous; forms a low hilly scarp, thickness about 270 ft. Lower part--mostly fine- to coarse-grained ss, poorly sorted grains rounded to subrd., light-yellowish-gray; granitic (and quartz) (Mutis-Duplat, 1982) pebble conglomerate locally as much as 75 ft thick at base (Paige, 1912); forms gently rolling land, mostly irrigated using water from this unit, thickness 100 +-ft, varies owing to relief on the surface on which the lower part was deposited. All the upper and most of the middle units grade laterally southeast to Cap Mountain Limestone. Thickness of Hickory Ss. Mbr. 275-470 ft, locally missing where monadnocks on underlying Precambrian rock are present.
Primary rock type	sandstone
Secondary rock type	sandstone
Other rock types	conglomerate
Lithologic constituents	Major Sedimentary > Clastic > Sandstone *(Bed)*

Source: U.S. Geological Survey, Mineral resources on-line spatial data, 2015.

"Frac sand," used as a propping agent to create additional permeability for extracting additional oil and gas from otherwise low permeability reservoirs or residual oil from conventionally extracted reservoirs, is found in primarily three formation types in the United States. To the north in Minnesota and Wisconsin, is the Ordovician St. Peter Sandstone (also called "Northern White or Ottawa" sand) and Ordovician and Cambrian Jordan Formation, Wonewoc, and Mount Simon Formations. In Texas, the Cambrian Hickory Sandstone (also called "Brown or Brady" sand) and in Oklahoma the Ordovician Oil Creek Formation are also used for such purposes.

The sand, used as a physical additive along with water and chemicals to form an injection mixture, is critical to propping open fractures created by injected fluid pressure to allow the oil or gas product to escape the formation (see Figure 18).

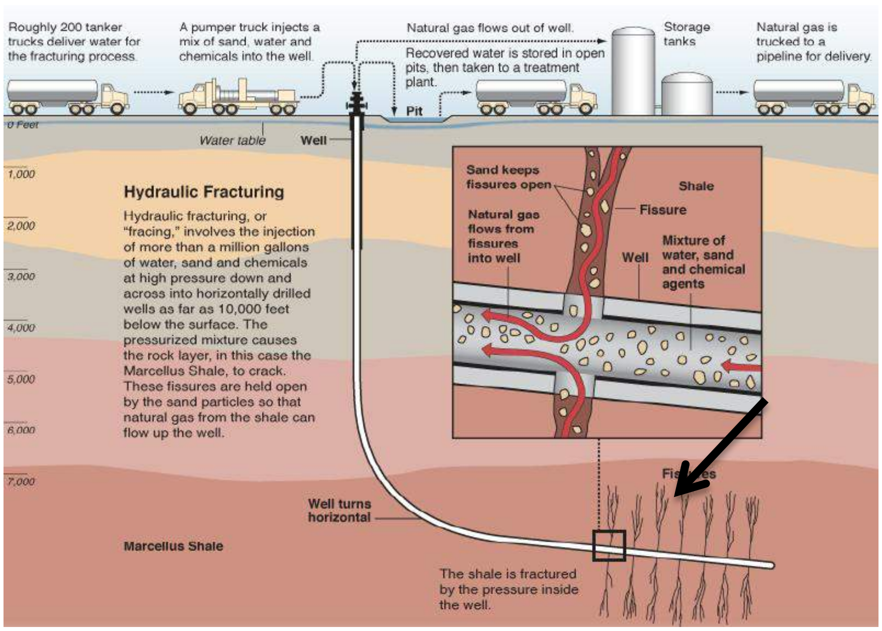


Figure 18. Schematic of Hydraulic Fracturing.

Source: Industry Minerals, Frac sand, accessed October 16, 2015, http://www.indmin.com/FracSand.html

Grain size and sphericity are important to quality of the frac sand which is primarily greater than 99 percent silica, but greater than 95 percent is also effective. Older sandstones that are well-sorted and mature through reworking have fewer impurities and fines, providing effective proppant characteristics.

Additional desired characteristics include higher roundness and sphericity, high-crush resistance, poorly consolidated formations with less clay, silt or other fine grains, little soluble matrix, and at or near the surface. Smaller sand grains are stronger and larger sand grains provide better permeability. Alternatives include synthetic beads and coasted sand particles and compete with natural sands in the world market (Benson and Wilson, 2015).

Table 8 shows the volume, percentage share, and location of frac sand consumption which includes parts of Texas and neighboring states.

Table 8. Estimated Frac Sand Consumption in Texas in Last Three Quarters 2013, First Quarter 2014

Major active shale plays/basins	Million metric tons of frac sand consumed	Percentage of share of total consumed	Estimate of frac sand to total proppants consumed (percent)
Eagle Ford-Woodbine	9.5	30	95
Permian Basin (Texas and New Mexico)	5.3	17	90
Anadarko Basin (Kansas, Oklahoma, Texas)	2.1	6.6	91
Haynesville-Brown Dense Play (Louisiana, Texas)	1.3	4.1	93
Barnett Shale	0.9	2.9	99

Source: Benson and Wilson (2015)

Reference:

A.B. Benson and M.E. Wilson, Frac-sand in the United States- A geological and industry overview, U.S. Geological Survey Open-File Report 2015-1107, 78 p., http://pubs.usgs.gov/of/2015/1107/pdf/ofr20151107.pdf

The geologic formations in the general region of the Voca Sand Mine are shown in Figure 19.

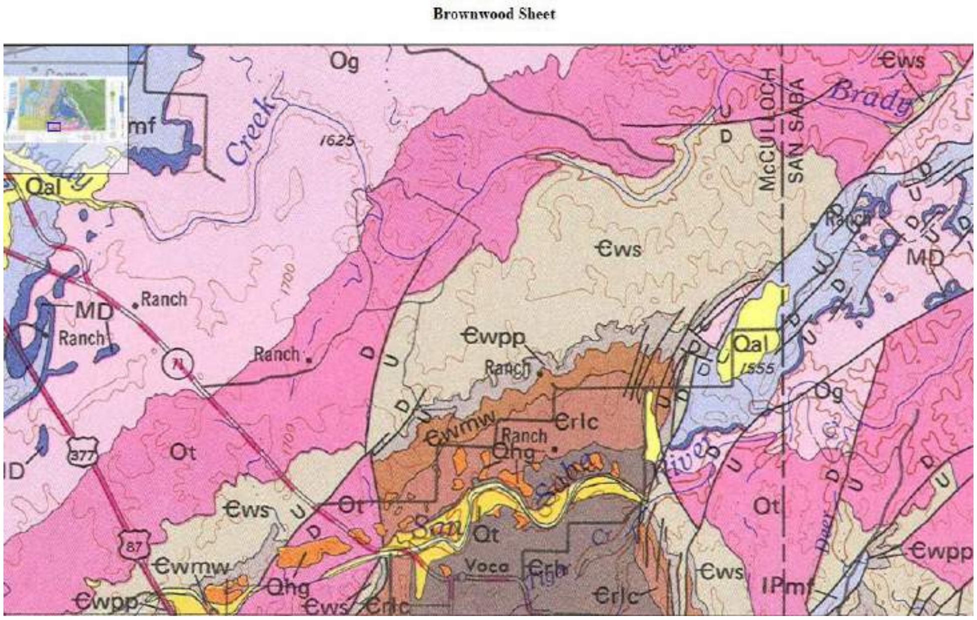


Figure 19. Geologic Formation Outcrops Near Voca, Texas.

Source: Texas Water Development Board, 2015, Geologic Atlas of Texas, accessed October 7, 2015, http://www.twdb.texas.gov/groundwater/aquifer/GAT/index.asp.

Figure 20 shows the areas in the U.S. where frac sands are being produced or could be produced in the future (more).

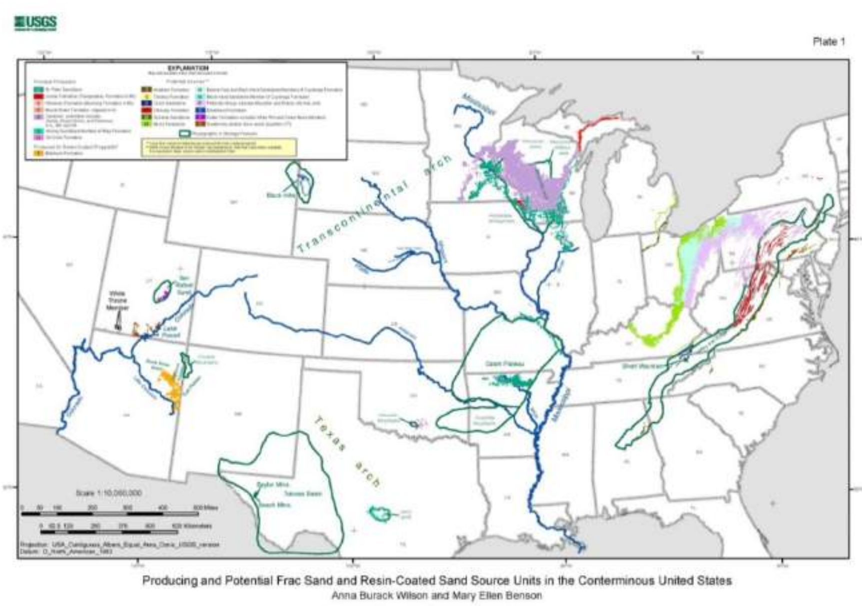


Figure 20. Producing and Potential Production Areas for Frac Sands.
Source: U.S. Geological Survey, 2015
(Click to Enlarge Map)

Sunday, May15, 2016 Fall Field Trip to the Llano Uplift

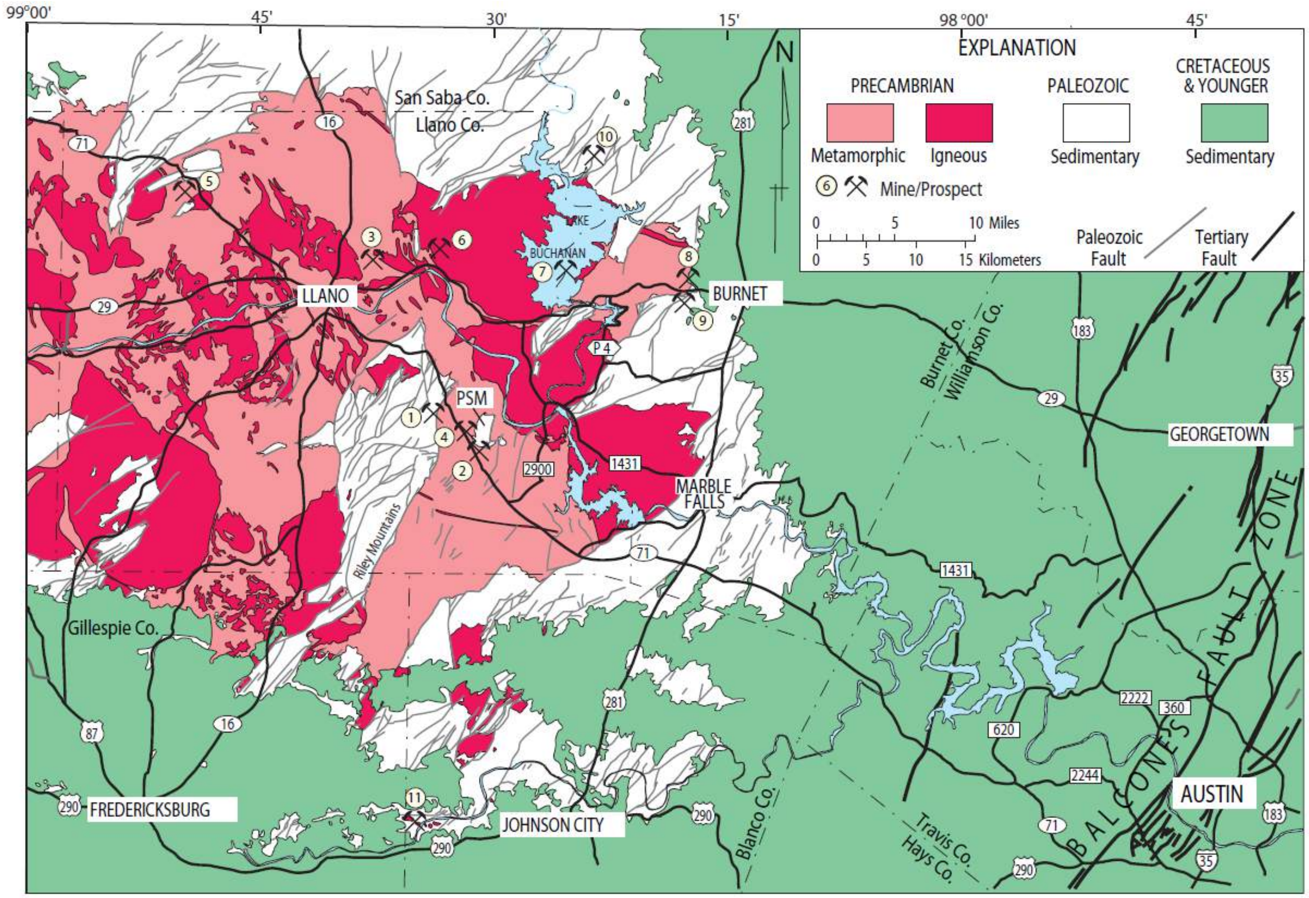


Plate 1. Generalized geologic map of the eastern Llano uplift showing selected mineral occurrences. Packsaddle Mountain (PSM) is indicated.

Figure 21. Llano Uplift Geologic Map.

Source: Geologic Map of Llano Uplift from Kyle, J. Richard, 2000, Geology and Historical Mining, Llano Uplift Region, Central Texas, Guidebook 20, Austin Geological Society, Austin, TX

Pegmatite Genesis in the Llano Region

The Llano Uplift of central Texas contains the largest exposure of Late Precambrian (Mesoproterozoic) rocks along what was the southern margin of the North American continental craton known as Laurentia. These rocks underwent an orogenic event (the Grenville orogeny) during the creation of the major supercontinent Rodinia.

The igneous and metamorphic rock exposures within the Llano uplift provide evidence of the northeast-trending Grenville orogenic belt that records arc-continent and continent-continent collision. Orogenesis along the southern margin of Laurentia culminated between ca. 1150 to 1120

Ma (Mosher, 1998) with the creation of the three lithotectonic domains of deformation and metamorphism – the Coal Creek, Valley Spring Gneiss, and Packsaddle Schist.

The Coal Creek Domain is interpreted to be an exotic island arc terrane that evolved separately from the Packsaddle and Valley Spring domains (Hunt, 2000). Two other major periods of igneous activity have occurred in the uplift. The first period, de-fined by almost continuous crystallization ages from 1288 ± 2 Ma to 1232 ± 4 Ma and the second period defined by coarse-to fine-grained granite plutons that intrude all lithotectonic domains across the entire uplift and make up nearly half the exposure in the uplift.

This second pulse of igneous activity occurred between 1126 +5/-4 Ma to 1070 ± 2 Ma. Igneous activity is thought to have occurred both during and shortly after the Mesoproterozoic tectonic events. Baringer Hill and other pegmatites are likely related to residual fluids after crystallization of the Proterozoic granitic batholiths.

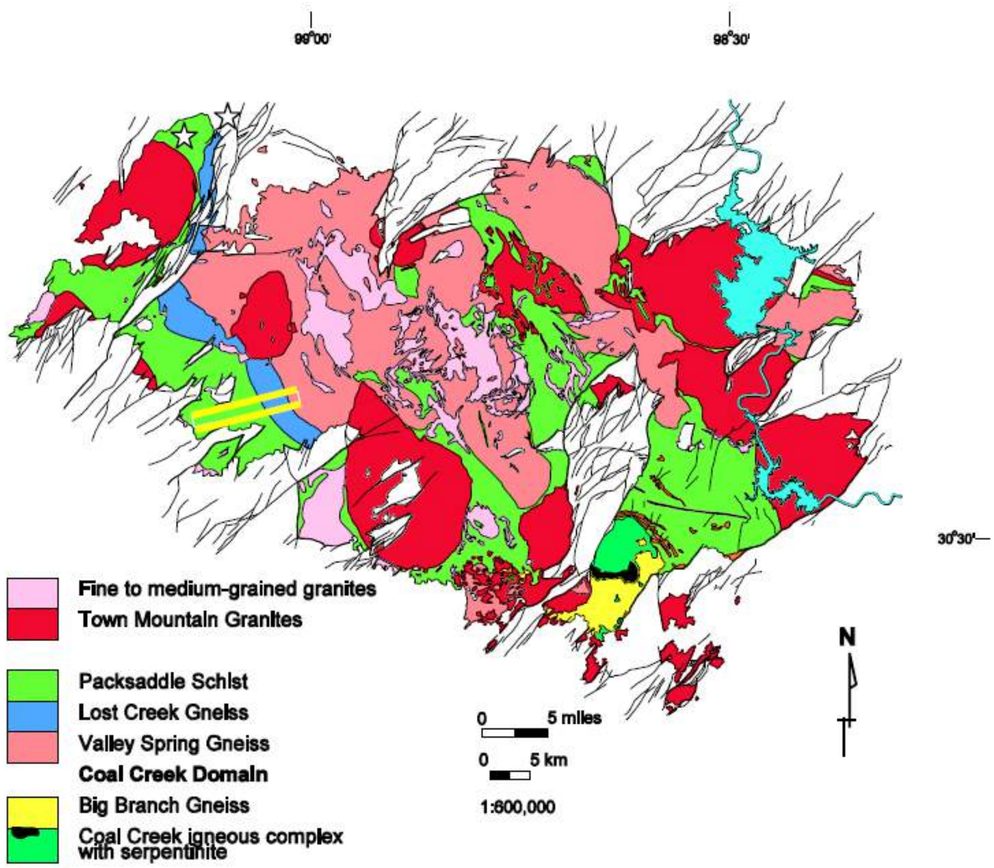


Figure 22. Geologic Map Showing Precambrian Igneous Outcrops.

(From Hunt, 2000)

The above geologic map of the Llano Uplift, central Texas, shows Precambrian igneous and metamorphic units; Phanerozoic sedimentary rock are shown as white. Precambrian units are cut by normal and oblique-slip faults (black form lines) related to the Ouachita orogeny. The Map has been modified after Barnes (1981) and Reed (1996a). Approximate location of Hunt (2000) study area in the western Llano Uplift is between the yellow lines.

Star in Lost Creek Gneiss indicates approximate location of Lost Creek Gneiss described by Ragland (1960), the sample site for the crystallization age of 1252±3 Ma (Walker, 1992). The Star in the Town Mountain Granite show the sample site for the crystallization age of 1070 ±2 Ma for the Katemcy Pluto (Rougvie, *et al.,* 1996).

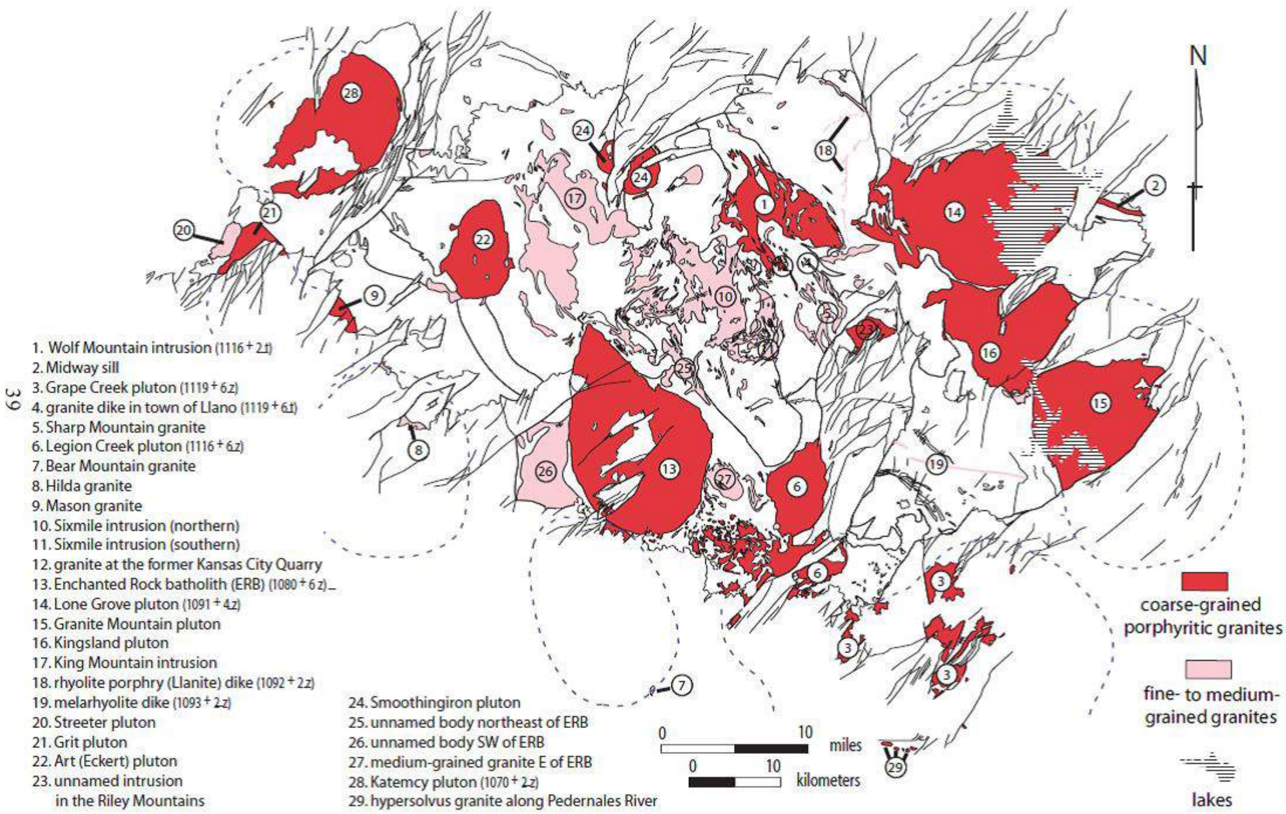


Figure 4. Major granite intrusions of the Llano uplift (from Reed, 1999). Dashed lines show boundaries inferred from geophysical and well data after Muehlberger and others (1967) and Barnes and others (1954, 1955). Numbers in parentheses after granite names are U-Pb zircon (z) and titanite (t) dates, in millions of years, as tabulated in Mosher (1998).

Figure 23. Geologic Map showing Granitic Intrusions.

Source: Granite intrusion map from Kyle, J. Richard, 2000, Geology and Historical Mining, Llano Uplift Region, Central Texas, Guidebook 20, Austin Geological Society, Austin, TX

McGookey (2017) just published a review the Llano Uplift which we have added to this guidebook as an update.

Noteworthy Precambrian Mineral Locations

Several of the better documented igneous mineral occurrences found in the Llano region and their locations are described below.

The Baringer Hill Pegmatite was discovered in 1887 and, until its disappearance beneath the water of Lake Buchanan in 1937, was an important location in America from a mineralogical standpoint. Described by the U.S. Geological Survey as one of the greatest deposits of rare-earth minerals in the world, the pegmatite was the first place geologists discovered fergusonite, monofergusonite, thorogummite, yttrialite, and nivenite.

Of the 47 minerals discovered at Baringer Hill, gadolinite, a radioactive form of yttria, triggered the most interest at the time. This greenish-black ore had previously only been found in small amounts in Russia and Norway.

Because of its economic potential as a material for light filaments, both Thomas Edison and George Westinghouse attempted to obtain the hill, with the Piedmont Mining Company, which was owned by Edison, winning out in 1889. In 1903, German chemist Walther Nernst, who later became famous for discovering the Third Law of Thermodynamics, was working for Westinghouse when he developed a street light that used raw gadolinite as a filament. The mineral species rich in yttrium-erbium were more particularly sought after because thorium and uranium were not used in the "glower" of the Nernst lamp.

The Nernst Lamp Company, a subsidy of Westinghouse, then bought Barringer Hill and began mining, extracting a few hundred pounds of ytrria minerals annually for a few years. Eventually, Nernst Lamp Company ceased operations as newer technologies surpassed the lamp. (Based on information provided by (more).

The Petrick Pegmatite in Llano County**, a**lso known as the Petrick (peet-rick) Quarry, was quarried for the Rapakivi granite used in the construction of several state office buildings in Austin. The site ceased operation in early 1942. A very prominent rare-earth pegmatite bisects the granite dome from southwest to northeast and is the source of the unique rare-earth minerals found here.

The mineralization of Petrick closely resembles that of its more famous cousin, the Baringer Hill Pegmatite, two miles to the north, 90 feet beneath the waters of Lake Buchanan. Numerous minerals are found here including radioactive yttrialite, the "puce" variety of chlorophane fluorite (initially discovered two miles to the north, at Baringer Hill, by William Hidden in 1905), black biotite mica, sanidine or moonstone**,** molybdenite (more).

The Emerald Ridge Pegmatite is a former topaz mine located in the Katemcy Granite Batholith, north of Mason. Most of the gem bearing pegmatite is unexcavated. The pegmatite itself is composed of miarolytic granite studded with pockets of fluorescent emerald-green fluorite. 100 meters east of the Emerald Ridge pegmatite is another outcrop containing many small 1-5 cm terminated quartz points, many colored pink, red or orange with inclusions of hematite. Occasionally these are iridescent. Known locally as "strawberry quartz", the crystals occur singly or in clusters and plates. Zoned purple amethyst has been found here as well. This pegmatite also contains crystals of pink microcline weathered from the granite (more).

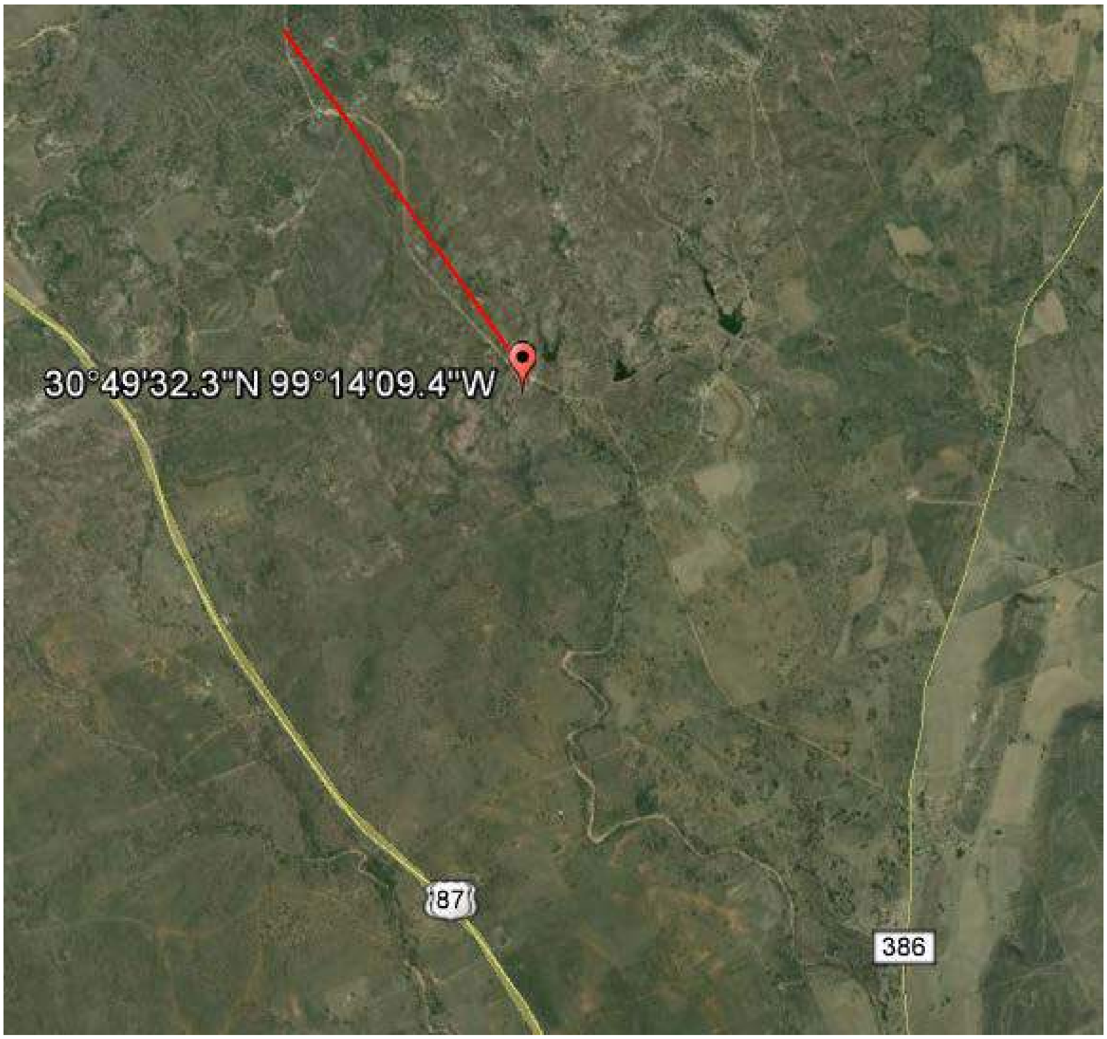
Just south of Mason on US Hwy 87 are roadcuts where pegmatite dikes criss-cross the dark gneiss and schist units of the Packsaddle Schist. (Spearing, Roadside Geology of Texas, 1991)

The Badu Hill Pegmatite, discovered in 1936 by Tillie Badu Moss, is a late-stage hydrothermal pegmatite located about four miles southwest of Lake Buchanan, in Llano County. Classified as an NYF or "rare-earth" pegmatite, Badu Hill contains a large number of rare-earth minerals, many of which are radioactive due to the presence of uranium and thorium daughter elements. Large deposits of a dark purple fluorite variety known as chlorophane are found as veins in quartz and feldspar throughout the site. Chlorophane is an extremely rare variety of fluorite that glows with a bright blue-green light when heated. (more).

The Coal Creek Serpentine Prospect is visible from space as a splash of bluish-green in miles of pink granite and gneiss of the Llano Uplift. It is located just off the Willow City Loop, about halfway between Llano and Fredericksburg, Texas. One of the oldest rock units in the state and is thought to be part of an island arc accreted during the Grenville (ca. 1.13 Ga) orogeny to the Precambrian Laurentian continental margin (Kyle, 2000). It is composed chiefly of calcium magnesium silicates with large amounts of magnetite, chromium and nickel.

The serpentine exhibits a wide range of colors - green, blue, black, brown and even orange and red varieties. Nearly all of the serpentinite from this site is strongly attracted to a permanent magnet due to the high chromium, nickel and iron content. Other minerals found at Coal Creek include crysotile asbestos, soapstone, talc, actinolite, tremolite, chromite, apatite, vermiculite, chlorite, quartz and zaratite, a bright green nickel carbonate (more).

Optional Stop 4: Pegmatite Road



Source: GoogleEarth, 2015

Figure 24. Pegmatite Road near Mason, Texas.

Llano Sheet

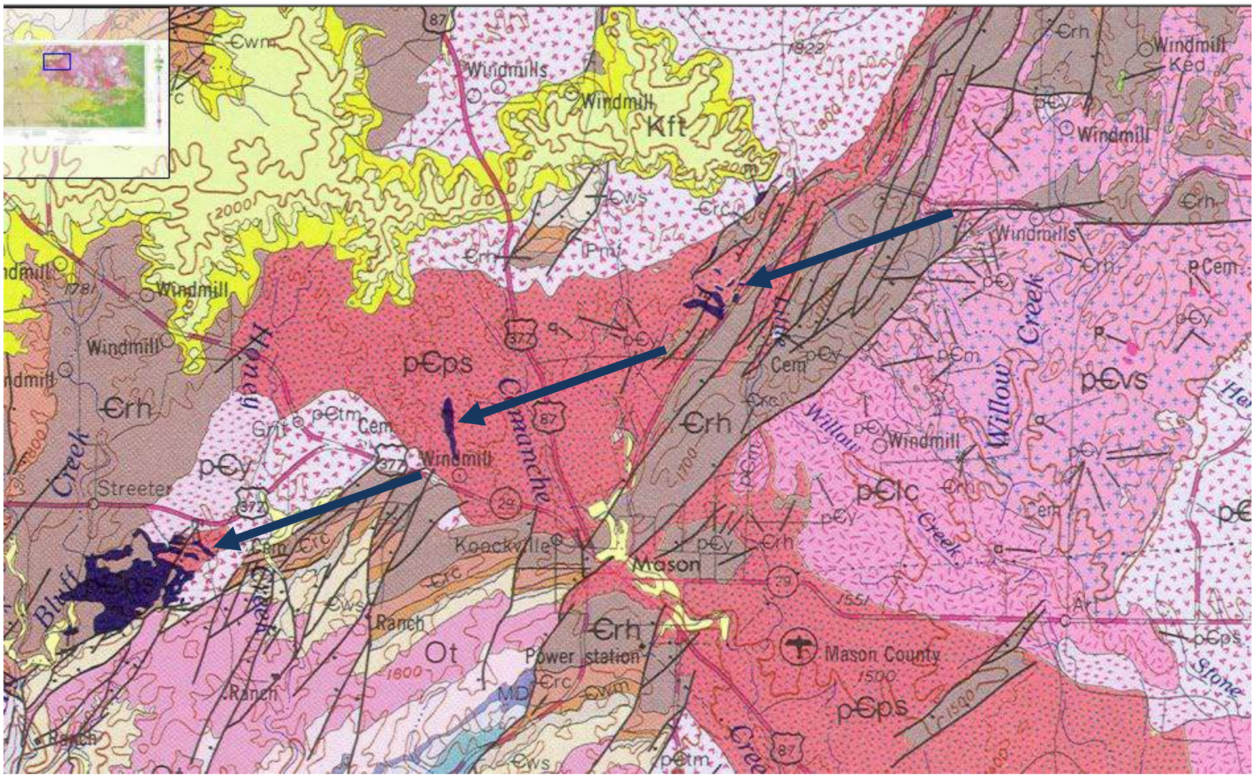


Figure 25. Geologic Map showing Pegmatitic Locations in Dark Blue.

Source: Texas Water Development Board, 2015, Geologic Atlas of Texas, accessed October 7, 2015, http://www.twdb.texas.gov/groundwater/aquifer/GAT/index.asp.

Directions to Pegmatite Road: Going south out of Brady, take a left (east) onto Kruse Road, about 20 miles south of Brady. Travel to Old Katemcy-Mason Road (end of Kruse Road). Take a right, heading south. Start looking for roadside outcrops at about 1.4 miles south of turnoff.

There should be several good outcrops along the road for the next two miles, there will be a good outcrop at the end of those two miles, right before the start of a gradual 90 degree turn to the east at 3049’32.3” N 9914’09.4”W (see Figure 24).

Stop 5: Topaz Gulch in Precambrian Granite

Figure 26. Topaz, Texas State Mineral.

Source: Seaquist Family Ranch, http://www.masontexastopaz.com/

Topaz in Mason County can be found in pre-Cambrian granite (younger granitic intrusions) near the city of Mason. This stop will be at Emerald Ridge private ranch that allows rockhounds to collect for a fee. For this stop, we will meet the owner/guide in town and travel out together. Large outcrops occur west of Mason near Streeter along with some tin deposits.

Further information about mineral production, including gold, silver, gemstones, and sand in the United States can be found at the U.S. Geological Survey website, although topaz has not been commercially mined in Texas (more).

Stop 6: Optional Road-Side Pegmatite Fly Gap Road, Mason County

Additional pegmatite outcrops in eastern Mason County may yield sources of specimen-quality epidote, ilmenite, spessartine garnet, and mica. Travelling east of Mason on Route 29, turn north or left onto Ranch Road 1900 (circled red on Figure 27). Head north to a T in the road, about 7.5 miles, to the left is Ranch Road 2618, and to the right is a dirt road called Fly Gap Road. Outcrops, particularly in gullies and washouts, may yield some good specimens. The right turn to Highway 71 is about 5.5 miles after the turn-off onto Fly Gap Road.

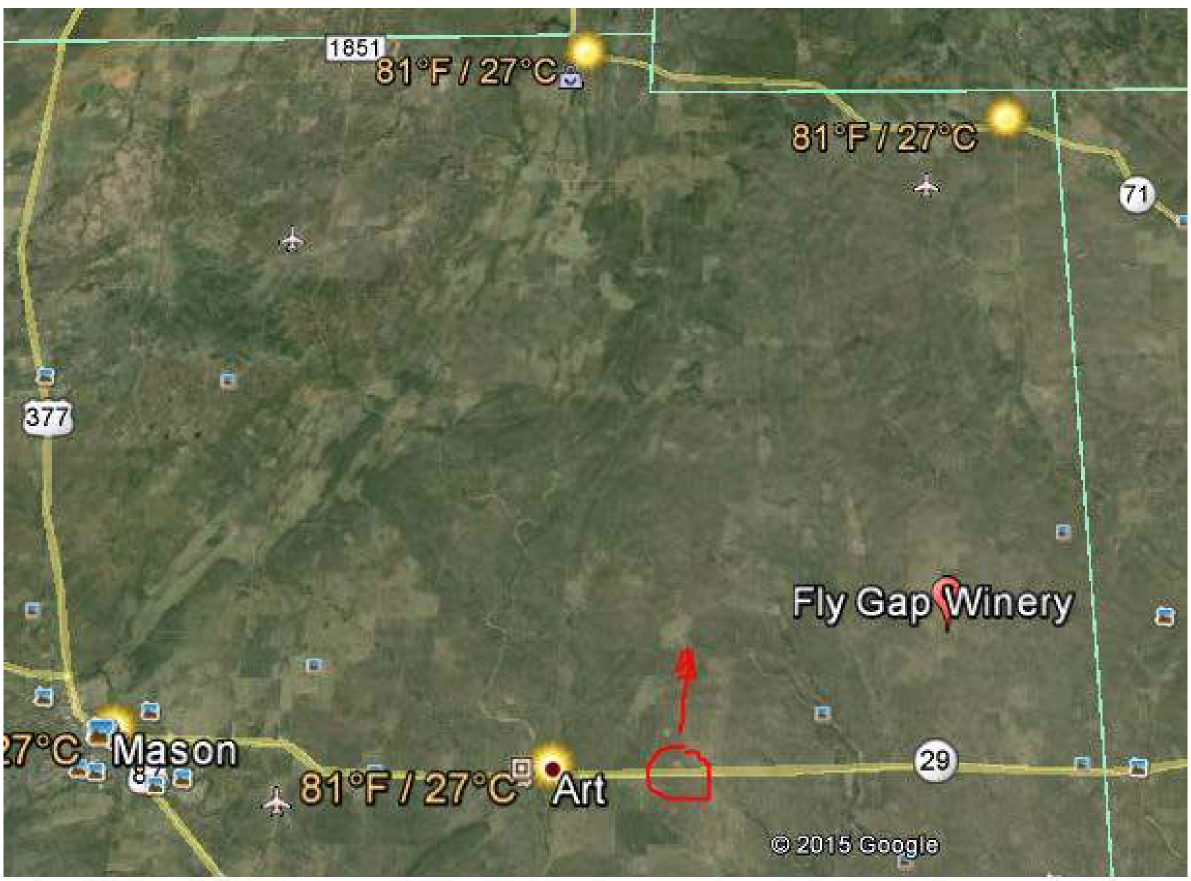
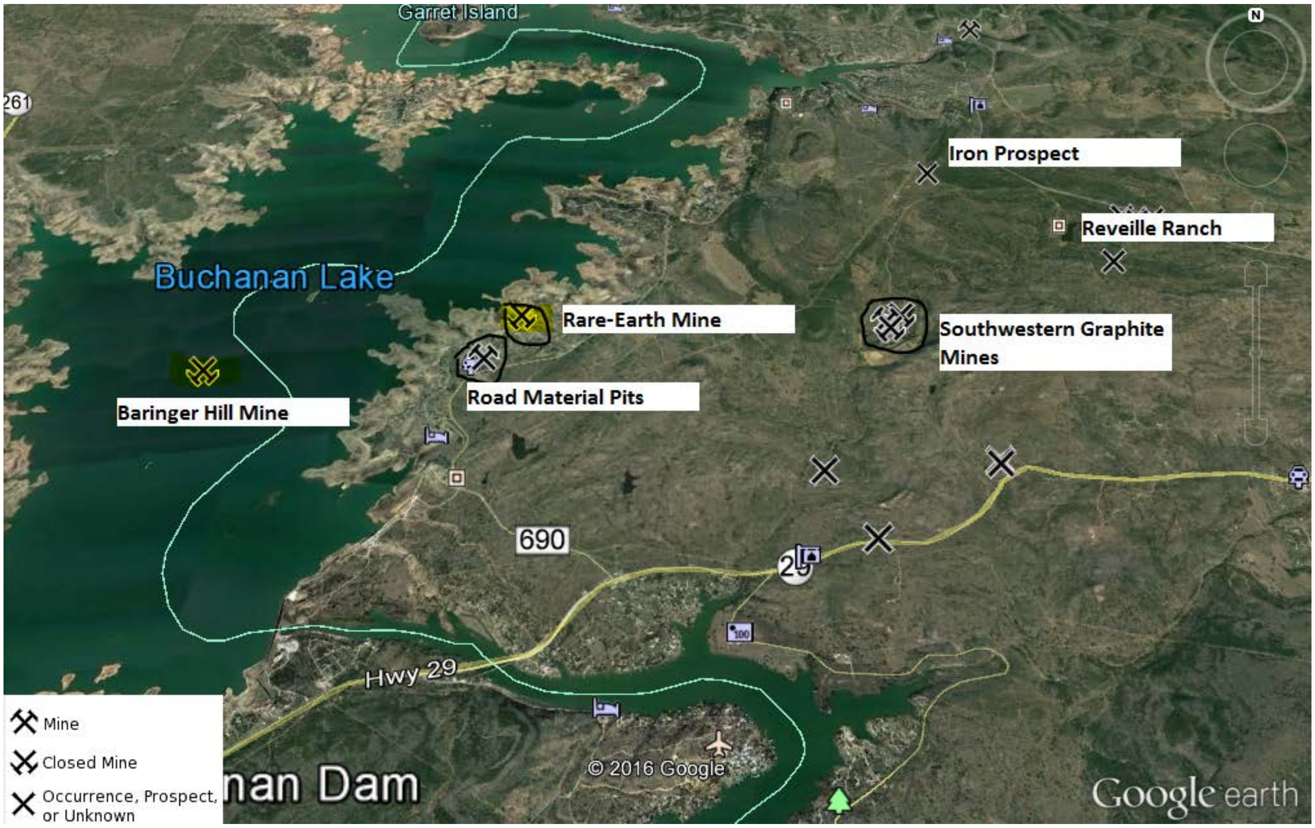


Figure 27. Fly Gap Road Off of Route 29.

Optional Overlook Stop 7: Buchanan Lake Eastern Shore

Figure 28. Baringer Hill, Underwater in Lake Buchanan.

Head east on Highway 29 out of Mason, go through Llano, and turn north (left) onto FM 690 just past Inks Lake. Beginning at about 1.25 miles on the right, you will see graphite and rare-earth mineral quarry pits (see map below) off the road (or just know that the pits are there). As you continue along the road, it begins to turn due east and is called FM114. About five miles after you start heading east on FM114 will be the Reveille Ranch entrance on the right or south.



In a large former graphite-granite country rock quarry just northeast of these pits, the newest full-cycle mine investment is a private business called Reveille Peak Ranch. This 1,300 acre ranch is open to the public as a fee-based park and conference center with a 100 foot deep scuba-diving lake and 62 miles of granite pebble mountain biking trails. You might be able to look for free at the graphite quarry/scuba park, if you appear to be scouting for an underwater mine tour location for a bunch of geologists. As you continue on FM 114 after turning right out of Reveille Ranch, at the T with FM 2341 just a short distance, turn right or south onto FM 2341 to get back to Highway 29.

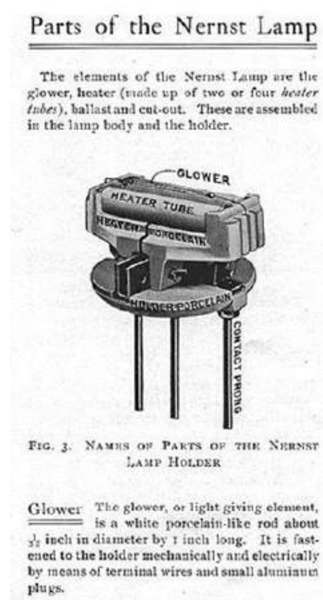
Photo and Information Source: Reveille Peak Ranch website, www.rprtexas.com

Historical Note about Rare-Earth Mineral Production

In 1904, gadolinite, a mineral used in producing chemical compounds for constructing the Nerst lamp glower components came exclusively from Llano County, Texas. German chemist Walther Nernst designed the lamp in 1897 at Goettingen University and later sold the patent to Westinghouse who began producing the lamp in 1901. Minerals for the glowers came from Baringer Hill (pegmatite) mine in Texas (discovered in 1887 but submerged about 100 feet beneath the waters of Lake Buchanan after 1937). You cannot see it anymore but you can imagine it out there in the middle of the lake (see yellow crossed hammers in Figure 28).

Nernst Lamp Company extracted several hundred pounds of rare earth elements for several years around 1907. In the 1930's, when Lake Buchanan was planned, the value of the water supply exceeded the value of continued mining. Mine production included commodities feldspar, fluorine-fluorite, zirconium, REE, beryllium, uranium, titanium, metal, thorium, molybdenum, lead, lithium, rubidium, phosphorus-phosphates, copper, and zinc.

By 1904 a total of over 130,000 Nernst lamps had been produced, which were twice as efficient as carbon-based lamps but not as efficient as tungsten-based lamps which replaced them. Of note is that at the 1900 World's Fair in Paris 800 Nernst lamps illuminated the German Electric Company display which reportedly was fantastically brilliant.


Parts of the Nernst Lamp

The elements of the Nernst Lamp are the glower, heater (made up of two or four *heater tubes*), ballast and cut-out. These are assembled in the lamp body and the holder.

FIG. 3. NAMES OF PARTS OF THE NERNST LAMP HOLDER

Glower The glower, or light giving element, is a white porcelain-like rod about 1/32 inch in diameter by 1 inch long. It is fastened to the holder mechanically and electrically by means of terminal wires and small aluminum plugs.

Figures 29-30. Nerst Lamp

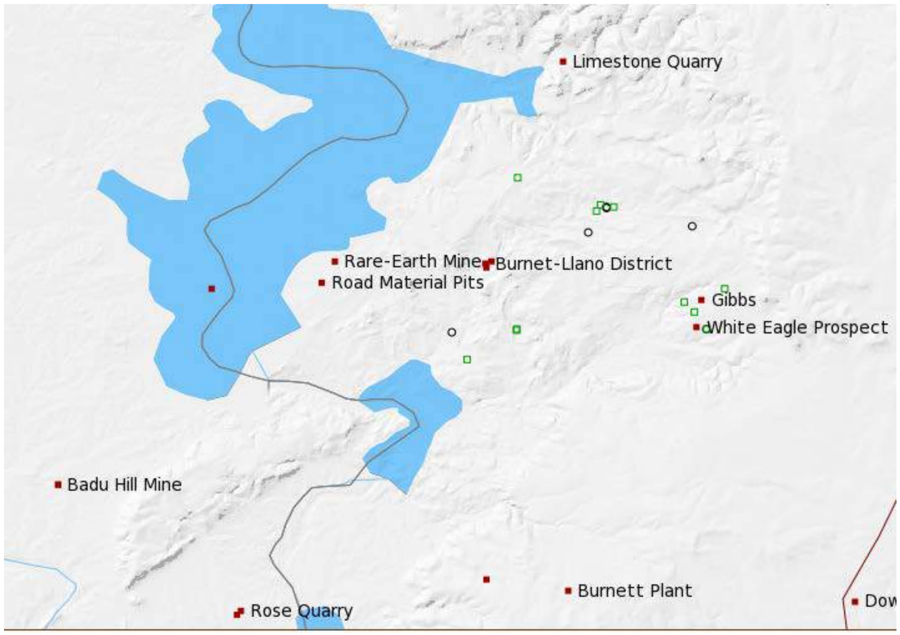


Figure 31. Rare Earth Mineral Mines near Lake Buchanan.

Rare-earth elements, also mined in the past via small operations, are located to the east of the Lake Buchanan shoreline (see Figure 31). Commercial rare-earth mining is about to begin in Hudspeth County, Texas, located some 380 miles west of the Mason, Texas area covered by this field trip., about 6 miles north of I-10 Interstate highway. A summary of the geology involved in the Round Top deposit is provided at the end on this guide.

Gemstone and minerals zircon and gadolinite locations exist in Mason County and Llano County. Additional metals of interest include tin in Mason County; locations shown below are not part of this field trip.

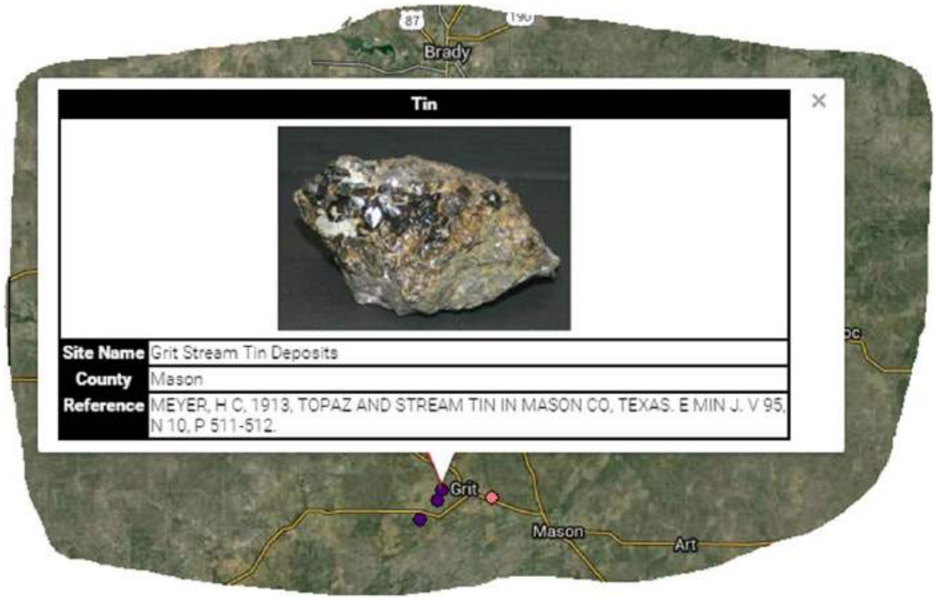


Figure 32. Tin Deposits, Mason County.

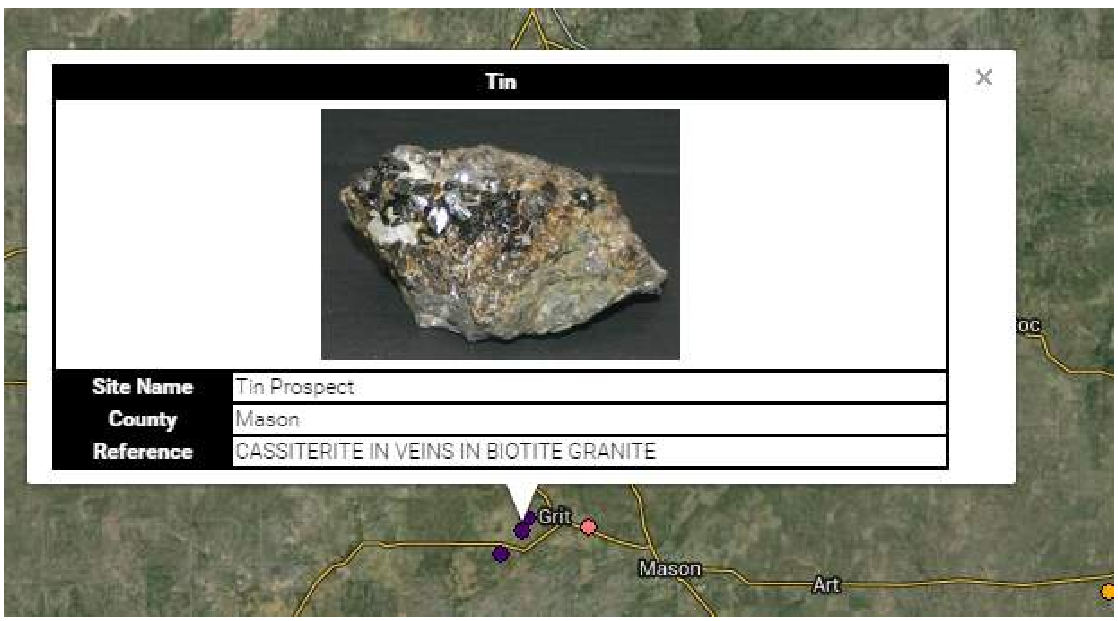


Figure 33. Cassiterite in Veins of Biotite Granite

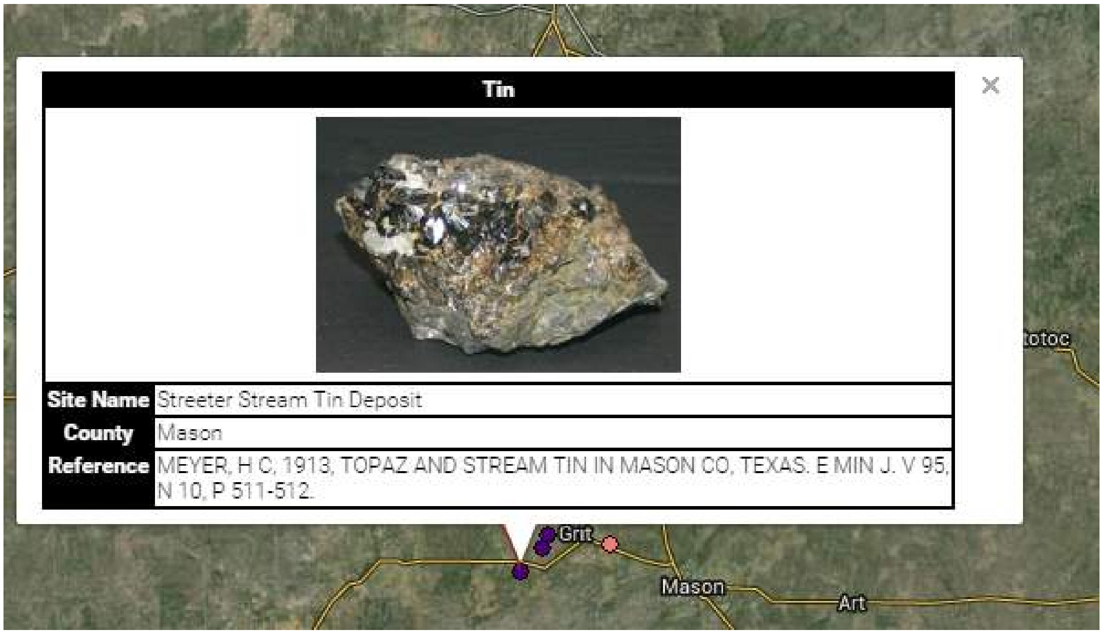


Figure 34. Streeter Stream Tin Occurrence

References:

Joseph H. Pratt, 1905, Minerals for the manufacture of electric and gas lamps, Mining Magazine, Volume 12 July to December, pp. 152-153.

U.S. Geological Survey, Mineral Resources Data System, http://mrdata.usgs.gov/mineral-resources/mrds-us.html, accessed September 25, 2015. Published by the U.S. Geological Survey.

Other Texas Rare-Earth Deposits

Round Top Deposit, Hudspeth County, Texas

A new rare-earth deposit has been discovered a few hundred miles west of the field-trip area. Hulse, *et al.*, (2013) report that a large porphyry-style rare-earth deposit found at Round Top, Texas has been drilled indicating large tonnage, high in so-called light rare-earths and heavy rare-earth oxides, plus additional metals of economic interest. For example, the deposit also contains significant uranium, thorium and other specialty metals, as well as other incompatible elements such as Li, Be, F, U, Th, Nb, Ta and Hf (see Table 9), and evenly distributed yttrofluorite and yttrocerite with minimal overburden (more). Those metals included in the primary mine plan are shown in Table 10.

Table 9. Round Top REE-U, Th, etc. Deposit in Hudspeth, Texas

Round Top REE-U-Th Deposit: **Mineral Resource Estimate**

	Element Symbol	Conversion Factor	Tonnage	Measured		Indicated		Measured + Indicated		Inferred	
				(x 1000)	230,984	(x 1000)	297,960	(x 1000)	528,944	(x 1000)	376,955
			Element Oxide	gpt	oxide (kg)	gpt	oxide (kg)	gpt	oxide (kg)	gpt	oxide (kg)
Lanthanum	La	1.1728	La_2O_3	19.9	4,889,520	20.1	6,370,672	20.0	11,260,192	20.3	8,139,857
Cerium	Ce	1.1713	Ce_2O_3	78.7	19,312,214	79.8	25,260,171	79.3	44,572,385	79.9	31,997,181
Praseodymium	Pr	1.1703	Pr_2O_3	10.32	2,530,265	10.4	3,289,242	10.37	5,819,507	10.43	4,173,288
Neodymium	Nd	1.1664	Nd_2O_3	28.203	6,891,789	28.482	8,978,075	28.360	15,869,864	28.613	11,410,579
Samarium	Sm	1.1596	Sm_2O_3	10.23	2,485,267	10.32	3,234,098	10.28	5,719,365	10.35	4,103,414
				Total LREO	**36,109,055**	**Total LREO**	**47,132,258**	**Total LREO**	**83,241,313**	**Total LREO**	**59,824,319**
Europium	Eu	1.1579	Eu_2O_3	0.13	31,536	0.14	43,809	0.14	75,345	0.14	55,424
Gadolinium	Gd	1.1526	Gd_2O_3	10.19	2,460,605	10.27	3,199,001	10.24	5,659,606	10.27	4,047,118
Terbium	Tb	1.151	Tb_2O_3	3.52	848,804	3.54	1,101,143	3.53	1,949,947	3.55	1,397,013
Dysprosium	Dy	1.1477	Dy_2O_3	30.93	7,436,995	30.96	9,602,727	30.95	17,039,722	30.83	12,097,586
Holmium	Ho	1.1455	Ho_2O_3	7.84	1,881,483	7.87	2,436,324	7.86	4,317,807	7.82	3,062,659
Erbium	Er	1.1435	Er_2O_3	32.63	7,817,042	32.55	10,058,945	32.58	17,875,987	32.28	12,620,207
Thulium	Tm	1.1421	Tm_2O_3	7.13	1,706,015	7.14	2,203,777	7.14	3,909,792	7.09	2,768,517
Ytterbium	Yb	1.2699	Yb_2O_3	56.99	15,162,030	56.91	19,530,950	56.94	34,692,980	56.52	24,539,656
Lutetium	Lu	1.1371	Lu_2O_3	8.89	2,117,823	8.89	2,731,906	8.89	4,849,729	8.79	3,417,310
Yttrium	Y	1.2699	Y_2O_3	219.2	58,317,548	219.5	75,330,231	219.4	133,647,779	217.3	94,346,555
				Total HREO	**97,779,881**	**Total HREO**	**126,238,813**	**Total HREO**	**224,018,694**	**Total HREO**	**158,352,045**
				Total REO	**133,888,936**	**Total REO**	**173,371,071**	**Total REO**	**307,260,007**	**Total REO**	**218,176,364**
Niobium	Nb	1.4305	Nb_2O_5	383.29	114,869,448	381.12	147,338,029	382.07	262,207,477	376.44	184,111,291
Hafnium	Hf	1.1793	HfO_2	86.7	21,420,647	86.3	27,504,284	86.5	48,924,931	85.6	34,513,965
Tantalum	Ta	1.2211	Ta_2O_5	67.3	17,216,921	67.1	22,143,130	67.2	39,360,051	66.4	27,721,460
Tin	Sn	1.2696	SnO_2	138	36,705,842	139	47,692,157	139	84,397,999	138.4	60,075,833
Uranium	U	1.1792	U_3O_8	45.43	11,223,270	45.03	14,350,091	45.20	25,573,361	45.15	18,202,960
Thorium	Th	1.1379	ThO_2	179.13	42,703,317	178.29	54,827,234	178.66	97,530,551	176.13	68,522,662

The Round Top Project involves an Eocene-aged peralkaline rhyolite-hosted rare-earth deposit with a high ratio of heavy rare earth elements (HREEs) to light rare earth elements (LREEs). The rhyolite body is a mushroom-shaped laccolith, slightly elongated northwest-southeast and dipping gently to the southwest. The REEs are primarily contained in the minerals yttrofluorite, cerofluorite and bastnaesite, which are very fine-grained and disseminated throughout the rhyolite mainly in microfractures, voids and coatings on predominantly alkali feldspar phenocrysts.

The stratigraphy is relatively simple, with Tertiary rhyolite laccoliths cutting Tertiary diorite dikes and intruding Cretaceous marine sedimentary rocks. The Project is located in the Trans-Pecos region, and has been structurally affected by Laramide thrusting and folding, subduction magmatism, and Basin and Range crustal extension. The main structures on the property are landslide and slump faulting, and north-northwest-trending normal faults. REE mineralization occurs primarily as disseminated microcrystals of varieties of fluorite (such as yttrium-rich yttrofluorite) where HREEs have substituted for calcium, and as other REE-bearing accessory minerals.

Table 10. Products in the Mine Plan of Round Top Deposit in Hudspeth, Texas

Round Top REE-U-Th Deposit: Summary of Material included in the Mine Plan*

Round Top – Material included in the Mine Plan Summary									
Classification		Measured		Indicated		Measured & Indicated		Inferred	
Metric ton (x1000)		75,225		46,349		121,574		26,290	
Symbol	Oxide	Grade REE (ppm)	REO Content (metric tons)	Grade REE (ppm)	REO Content (metric tons)	Grade REE (ppm)	REO Content (metric tons)	Grade REE (ppm)	REO Content (metric tons)
La	La_2O_3	19.77	1,744	19.79	1,076	19.78	2,820	20.10	620
Ce	Ce_2O_3	77.21	6,803	77.84	4,226	77.45	11,029	79.59	2,451
Pr	Pr_2O_3	10.27	904	10.28	558	10.27	1,462	10.37	319
Nd	Nd_2O_3	28.13	2,468	28.34	1,532	28.21	4,000	28.86	885
Sm	Sm_2O_3	10.20	890	10.26	551	10.22	1,441	10.58	323
Eu	Eu_2O_3	0.13	11	0.13	7	0.13	18	0.13	4
Gd	Gd_2O_3	10.05	871	10.11	540	10.07	1,411	10.42	316
Tb	Tb_2O_3	3.47	301	3.50	187	3.48	487	3.62	109
Dy	Dy_2O_3	31.06	2,682	31.01	1,650	31.04	4,332	31.58	953
Ho	Ho_2O_3	7.88	679	7.91	420	7.89	1,099	8.07	243
Er	Er_2O_3	33.02	2,840	33.05	1,752	33.03	4,592	33.50	1,007
Tm	Tm_2O_3	7.12	612	7.16	379	7.13	991	7.27	218
Yb	Yb_2O_3	57.48	5,491	57.32	3,374	57.42	8,865	57.35	1,915
Lu	Lu_2O_3	9.00	770	9.00	474	9.00	1,244	9.03	270
Y	Y_2O_3	220.84	21,096	221.42	13,032	221.06	34,128	225.84	7,540
Total REO			48,162		29,756		77,919		17,172

* Readers are cautioned that this is not a mineral resource estimate. The mineral resources estimate for the Round Top Project is shown in Table 1-1.

REE minerals occur mainly in vugs and as crystal coatings, suggesting late stage crystallization from an incompatible element-rich fluid. Other incompatible elements were concentrated in these late magmatic fluids. Uranium occurs as fine disseminated grains of uraninite and coffinite. Niobium-tantalum bearing columbite is relatively abundant. Zircon also is relatively abundant and is a mineral containing the zirconium and hafnium. Several unidentified tin minerals are present and thorium is contained in thorite and within zircon. Beryllium has also been reported nearby (more).

Based on the authors' experience, the field trip area remains underexplored and offers potential prospects for base metals, precious metals, and other minerals of potential importance similar to that of the Round Top Deposit in Hudspeth, Texas to the southwest. For a quasi-visit to the Round Top operations, see (here).

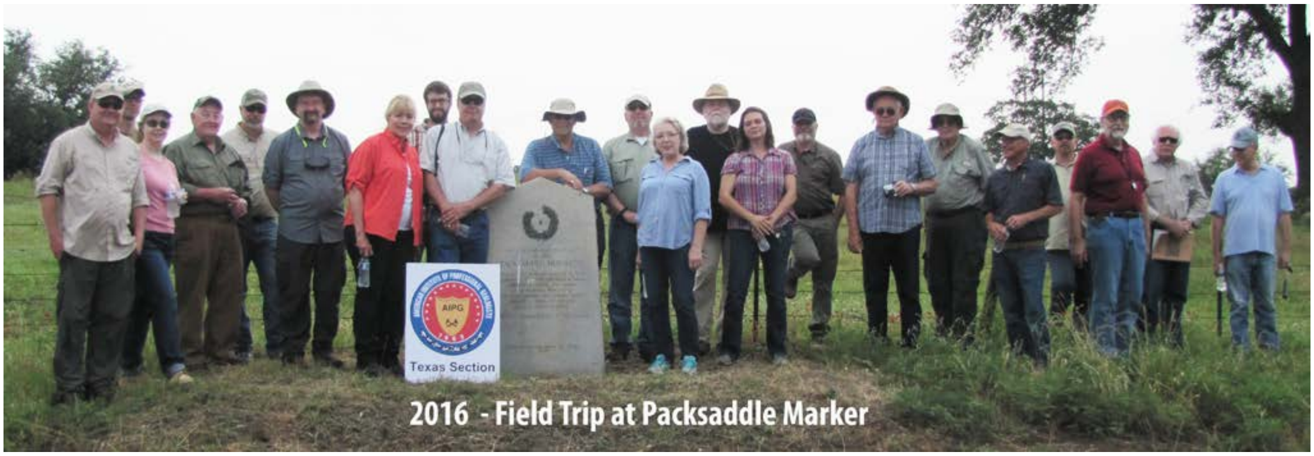
For updates on rare-earth mining in Texas, the U.S. and around the world, see the I2M Web Portal (more).

Photos of Field-Trip Activities

Saturday, May 14, 2016

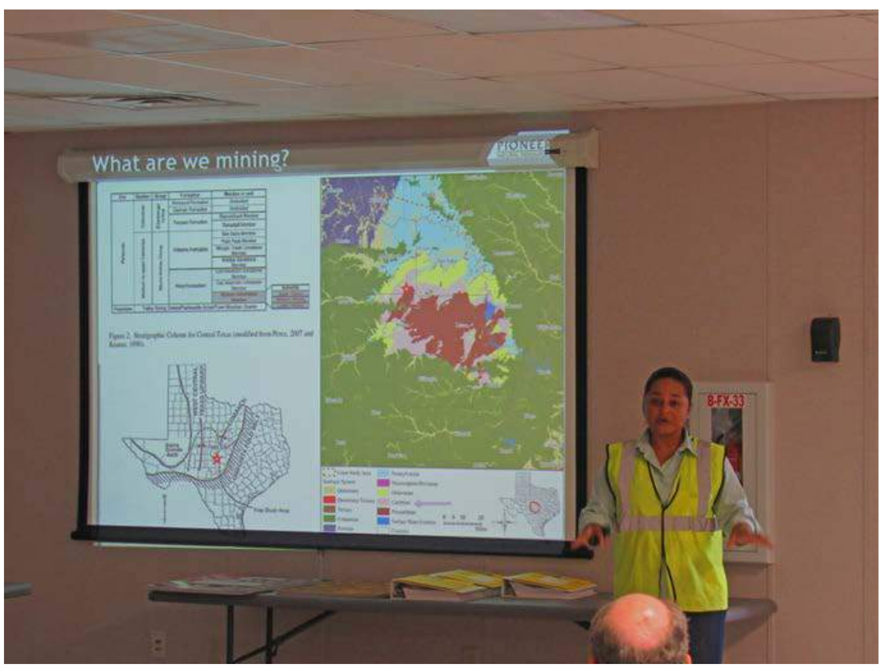
Stop #1

Chris Caran Discussion on Los Almagres Silver Mine at Packsaddle Mountain.
(For additional information on the Mine: (more))

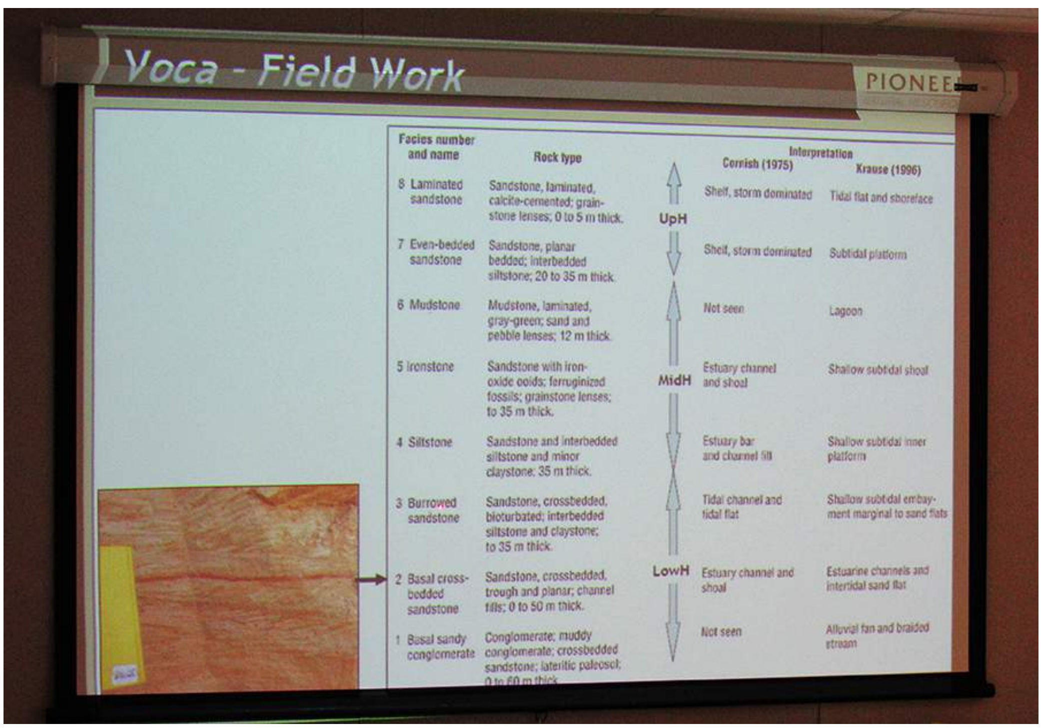


Premier Silica's Voca Mine, Texas

Produces High-Quality Frac Sand
for
Oil and Gas Drilling in the U.S. and Overseas.



Orientation Lectures



Lithology of Mining Section

(Click to Enlarge)

Health and Safety Lectures

Voca Mine

Voca Mine Pit (Current)

Working Face of Producing Frac Sand Mine

Cross-Section Mine Face
(Click to Enlarge)

Sandstone Lithologic Features:
e.g., cross-bedding, flazer bedding, disturbed bedding, bioturbation

Iron precipitation and oxidized along preferred bedding planes, and hiatal interruption of sedimentation

Discussion of mining procedures, plans, and health and safety matters.

Mined Premier Silica Sand Products

Shallow and Deep Drilling

Sunday, May 15, 2016

Emerald Ridge Area

Quartz and Weathering Feldspars.

Packing Up

Taking Samples for Later Examination under Microscope and UV light.

Close-up of Shovel Contents

Notice Sorting and Angularity of Quartz and Feldspar, and ….??

Vegetation Growing over Pegmatites

Stromatolites of Central Texas

Background to the Local Geology

Thornberry-Ehrlich (2008, beginning on PDF page 21) reports that the Llano Uplift records the Grenville orogenic event of the Proterozoic Eon (Mosher and Levine 2005). This event involved much of the continental crust in existence at that time. A northern landmass, Laurentia (present day North America), collided with one or more southern landmasses and island arcs (Mosher, et al. 2004). These intermittent collisions caused the uplift of a long, east-trending mountain range and the intrusion of several igneous plutons over a long time period (≈1165−1068 Ma) (Li and Barnes 2005; Reed and Rougvie, 2002).

Many valuable mineral deposits in central Texas are associated with the high pressure and high temperature that accompanied deformation of these rocks (Hentz 2001). Grenville- age structures are found in northeastern Canada, in patches along the length of the Appalachians, and through central and western Texas. The Carrizo Mountain Group, some 500 km (310 mi) to the west of the Llano Uplift, continues the Grenville trend (Grimes and Copeland, 2004). Corresponding deformational structures and rock assemblages occur in the western Amazon craton, possibly marking the South American continent as the southern landmass involved in the Grenville orogeny (Tohver, et al. 2002). (more).

Carbonate beds, such as the Cambrian Wilberns Formation, formed during periods of marine highstands, dominating the rock record in the basin to the southeast, as well as in several small- scale failed rift areas farther inland (Harrison 1997; Hentz 2001). When regional sea level dropped, sediments that became shale and intercalated sandstone were deposited across the basin (Harrison, 1997).

Cambrian Stromatolites in Wilbern Formation (Limestone)

Apparent fossil looks artificial (?)

Microfossills such as Finkelnburgia sp. and macrofossil pelecypods such as: Calvinella, Scaevogyra cf. S. *elevata*, and S. *swezeyi*, plus a variety of trilobites, associated fragments, oolites, and stromatolites can be expected to occur within the Wilberns Formation (Thornberry-Ehrlich (2008), PDF page 20).

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