

Barringer Hill

The Story of Barringer's Hill

by Jean Hackett and Robert Wilkes

At times during the 1990's, Lake Buchanan in central Texas has looked a little low. During the Drought of 1996, racked mud flats and ghostly tree stumps created a damp, stinking moonscape on what is usually the lake bed. Water-skiers, fishermen, and anyone who got water from the lake looked to the skies and prayed for enough rain to raise the lake level. Not so for geologists and rock hounds! Secretly, they wished the lake would continue to fall-- by about 90 feet or so--far enough down to expose what the United States Geological Survey has described as one of the greatest deposits of rare-earth minerals in the world: Barringer Hill.

Despite its geological significance, Barringer Hill was really only a "mound," 34 feet high and covering a few acres of floodplain, visible only because it proved to be more resistant to erosion than the surrounding granite. Prior to the construction of Buchanan Dam in 1937, it was located on the west bank of the Colorado River, 12 miles north of Kingsland, just downstream from Bluffton, between Redrock and Campground creeks. Its location is best shown on the [1912 USGS Areal Map](#) (11). (Click here to see > [More Maps](#).)

The late Virgil Barnes, a senior geologist from the Bureau of Economic Geology in Austin and professor emeritus at the University of Texas, visited the area on a number of occasions during the 1930's out of curiosity and to collect rocks from around the burned remains of the Barringer homestead. As he recalls the place, by that time, it was just a mass of milky quartz that "looked like a lot of other places in the Hill Country, except that it stood out like a sore thumb."



Barren quartz pillar near center of Barringer Hill pegmatite (8). [Full Size Image, 167K JPEG](#)

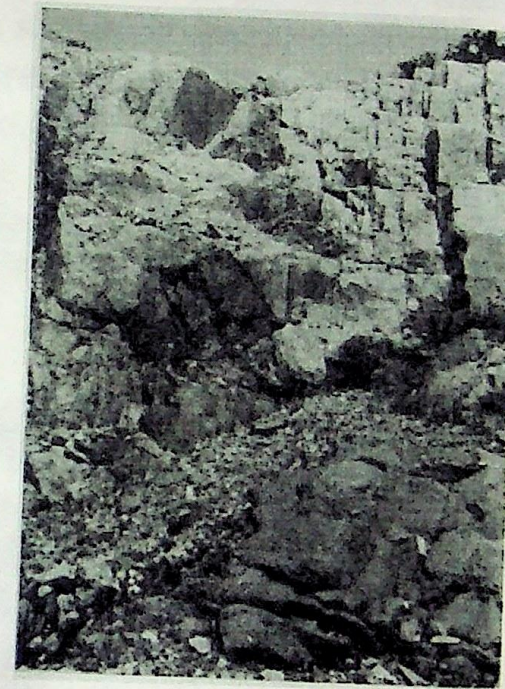
The origins of Barringer Hill lie deep in the past. Around 1.1 billion years ago, North America was on the march. As slowly churning convection currents in the mantle pushed the continent along, the relatively thin ocean crust of some long-forgotten ocean was being overrun and pushed deep into the mantle. When this wet ocean crust and its covering of sediments got deep enough and hot enough it melted and expanded.

Now buoyant, this blob of magma, now called the Lone Grove pluton, melted its way upward through the thick continental crust of Llanoria. As it neared the surface, the magma began to cool. Some of it may have even risen far enough to stoke the cauldrons of volcanoes. At a depth of about 20,000 ft (6 km) below the surface, crystals of hornblende, biotite, feldspar, and muscovite started forming, creating a 2000°F (1100° C) granite slushy. As it cooled slowly over millions of years, this molten slush and the surrounding rocks contracted and cracks opened. Water, volatiles and the minerals with lower melting temperatures filled these cracks because they were still liquid.

Among the last elements to crystallize were the heavy metals because they were too big to fit into the crystal lattices of ordinary minerals. Carried along with the molten silica and other fluids, they found refuge in a common place and crystallized. The minerals were deposited in this pegmatite in two distinct phases: a magmatic and a hydrothermal phase, which are described in detail by Landes (8).

At this time simple life forms like bacteria and algae had colonized the sea. The land, however, was as barren as Mars except for a few algae covered hot springs. As time marched on, the overlying mountains were eroded away and the pink granite plutons exposed. Later, when the supercontinent Pangea formed, the mountains of the Ouachita orogeny were built up just to east as this crustal block collided with western South America. After Pangea broke up these mountains were eroded away completely and the Cretaceous sea of central North America flooded the area laying thick sequences of limestones from Texas to the Arctic. Only in the last few million years did the Colorado River grind away at the bedrock to finally uncover this pegmatite in all its glory.

And glorious it was! To those who visited the area soon after its discovery, Barringer Hill made quite an impression. Frank L. Hess, who wrote a study of the area's rare earth elements in 1907, describes it as being composed of "graphic granite of supreme quality, having interlocked crystals of clear quartz and brown colored microcline . . . with distinct white bands. Between the bands, the quartz is glassy and clear." Like Barnes, he mentions a large, 40 foot wide quartz mass in the center of the pegmatite, but he also describes other geological wonders, such as a cavity "lined with smoky quartz crystals reaching 1,000 pounds or more in weight" and sheets of mica up to 3 feet across and an inch thick.



Large microcline crystals surrounded by quartz (8). Note size of hammer at center. [Full Size Image, 234K JPEG](#)

Barringer Hill was named for John Barringer, a young carpenter who acquired the land in 1886 as part of a swap, when a Mr. Wills was unable to pay him the \$50 due for a house he'd just had him construct. Mr. Wills considered it the most worthless part of his farm, and most likely felt he'd come out ahead on this deal. What good was a chunk of rocks in the middle of a floodplain, anyway? Barringer, however, soon realized he had something of interest. In 1887, he stumbled upon an outcropping of heavy, greenish-black ore while prospecting. Evidently, once this deposit was discovered conventional wisdom about the area also changed some. Between 800 and 1200 pounds of the mineral were carried off as curiosities by local people in the late 1880's.

When Barringer stumbled onto the ore, no one knew what it was; nothing like it had ever been seen before in these parts. That was about to change. Late in 1887, Professor N.J. Badu of Llano sent ore samples to Philadelphia and New York. Badu was one of those flamboyant characters who seems to flourish in Texas. A geologist by training, he is best remembered for numerous schemes to promote Llano and its surrounding environs in just about anyway possible. No doubt, he had high hopes for the mysterious greenish-black rock from Barringer's hill.

Sure enough, the samples were found to be composed primarily of a radioactive yttria mineral, known as gadolinite, that had previously only been found in small amounts in Russia and Norway. Because they were so rare, yttria minerals were extremely valuable. In 1887, pure yttrium brought \$144 an ounce. In comparison, pure gold brought \$19 an ounce on the London exchange that same year. Because the minerals from this deposit were so valuable, they were wrapped in tissue paper, packed in iron-bound boxes, and shipped by express at 100 pounds a box. At best, obtaining each pound of ore cost \$10.00.

As is true when anything of great economic value is found, the discovery of gadolinite at Barringer Hill triggered the interest of the rich and famous, in this case two of the most important inventors of the nineteenth century: Thomas Edison and George Westinghouse. The race for control of the area began when William E. Hidden, a Newark, New Jersey mineralogist with connections to both companies read a newspaper account about the discovery. At that time, Edison and Westinghouse were looking for gadolinite to use in the creation of a filament for electric light bulbs but had found no accessible sources of the mineral. Never one to miss an opportunity, Hidden dispatched Dr. William Niven, a Scottish born Texan, to investigate Barringer Hill in 1889. Niven identified forty-seven minerals there, including five previously unknown rare earth elements: fergusonite, monofergusonite, thorogummite, yttrialite, and rarest of all, nivenite. Years later, Hidden experimented on all the Barringer Hill minerals to ascertain the extent of the "new" form of energy present (e.g., radioactivity). When radiographs were produced by exposing photographic plates to the minerals in the dark, Nivenite produced the most beautiful radiographs because of its pronounced radioactivity.

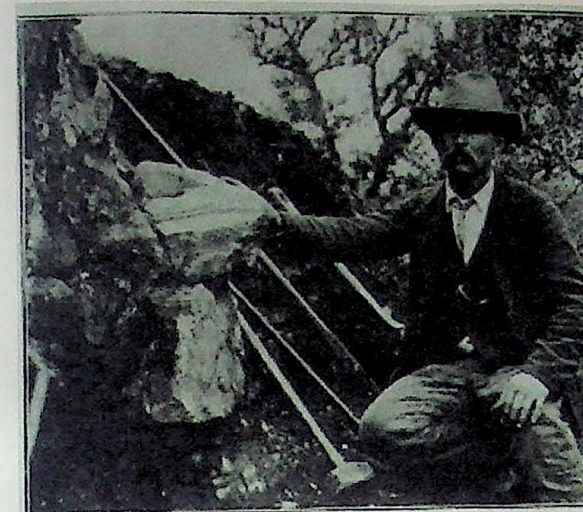
Hidden then commissioned Niven to buy the land. In 1889, during Niven's second trip, Barringer agreed to sell his land through Hidden and him to the

Piedmont Mining Company of London, England (which was owned by Edison.) Depending on the source, the company paid him either \$5000 or \$10,000 in gold because that was the only way he would take anything in exchange for his land. The gold was picked up in Burnet by Barringer and seventeen year old Tad Casner of Llano County, who was serving as his body guard.

Although Edison experimented with all 47 Barringer Hill minerals, by 1903, the company could find no use for any of them. Amazingly, during the same year, a German chemist named Hermann Nernst, working for Westinghouse, developed a street lamp that used raw gadolinite as a filament. Later, Nernst would become famous in his own right for discovering the Third Law of Thermodynamics (entropy approaches a minimum at absolute zero), which he won a Nobel prize for in 1920. His original design for the lamp required modification, however.

Initially, the Nernst lamp had a life of only two hours. Soon, this number was increased to seven hundred hours by another Westinghouse engineer, Marshall Hank. The lamp's design was also modified to accommodate a filament consisting of 25 percent yttria and 75 percent zirconia. These ingredients were made into a paste, squirted into strips, baked, and then cut into the proper lengths. When the mixture was cold, it was nonconductive, but after being heated, it became a conductor that gave off a brilliant light with wavelengths penetrating deep into the infrared. With its technical problems solved, the Nernst Lamp Company, no doubt a subsidy of Westinghouse, decided to put the lamp into production and bought Barringer Hill through William E. Hidden.

During the winter of 1902-03, the Nernst Lamp Company sent Hidden, himself, to begin excavation.



William E. Hidden next to a 73-lb. mass of Gadolinite in place at Barringer Hill, 1903 (6). [Full Size Image, 194K JPEG](#)

For four months that winter and six months the following year, a dozen or so miners worked full time for the company, including Tad Casner and Barringer, who was probably once again somewhat of a laughing stock for not getting as much money as he could have for the land. Work was slow because the minerals appeared in pockets. The miners struggled to remove ore using picks, shovels, and dynamite to quarry rock from open 40 foot deep pits around the edge of the mound. Despite the difficulty of their task, the men made progress. By 1904, they had blasted away the top of the hill. A 30 foot high quartz pillar, however, was left standing in the middle of the quarry because it contained almost no rare earth minerals.

Hidden and the miners made many curious discoveries about the minerals at Barringer Hill. Masses of purple and green coarsely crystallized fluorite up to 400 pounds were fairly common, as were enormous crystals of feldspar, some over five feet in diameter. From a cavity big enough to hold a horse, the miners removed a 600 pound single smoky quartz crystal which measured 43" X 28" X 15".

Other rock samples were radioactive, such as a seventy-three pound double crystal of gadolinite. Even seemingly common minerals could be radioactive. For example, in a [1905 publication](#), Hidden mentions that much of the fluorite from Barringer Hill exhibited "brilliant green light when strongly heated and viewed in the dark," and one piece was "self-luminous at night without heat."



William E. Hidden next to a 73-lb. mass of Gadolinite in place at Barringer Hill, 1903 (6). [Full Size Image, 194K JPEG](#)

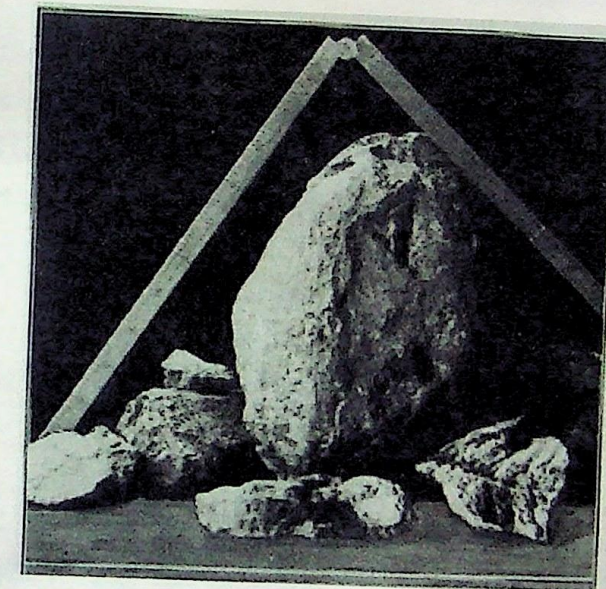
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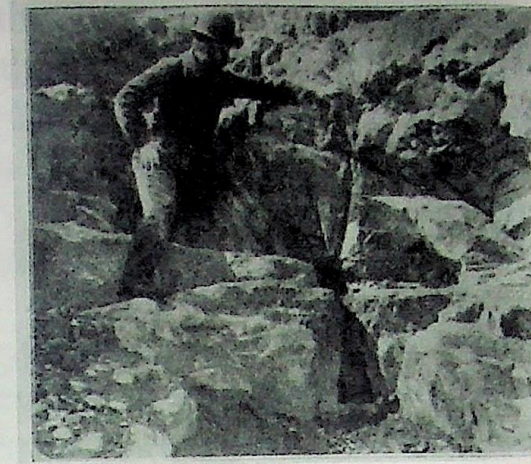


73 Pound double crystal of gadolinite (6). [Full Size Image, 167K JPEG](#)



18 Pound mass of Yttrialite (6). [Full Size Image, 198K JPEG](#)

More ominous still were crystals taken from areas where the rock matrix contained radiating lines that resembled stars. The stars possibly formed when rare earth elements crystallized from the magma before the quartz in the matrix did, thus causing the quartz to crack as it accommodated itself to the incompressible crystals.



70 Pound mass of mixed zirconium-yttrium-uranium and thorium ore which was a nucleus to one of the "stars" (6). [Full Size Image, 167K JPEG](#)

Hidden writes that while removing a mass of mixed zirconium-yttrium-uranium and thorium ore from one of the stars, his hands and face began to burn as if from the effect of strong sunlight. After two or three days of mining, he felt soreness in the parts of his hands and face that had been directly exposed to the minerals.

Because the effects of radiation were not well understood at the turn of the century, Hidden could only speculate as to the cause of his curious symptoms. He reports (6):

My assistant (Mr. J. Edward Turner) asked me "if these minerals could be poisonous?" As no arsenic was present . . . The thought came to me that this action might be the work of a radio-active element and it is offered now more as a suggestion than as a proven fact.

William Hidden was not the only employee Nernst/Westinghouse sent to work at Barringer Hill. In 1903, Marshall Hanks, the engineer who had improved the Nernst Lamp, arrived to run the mining operation. Although Hidden, at least in his writings, seemed to find no fault with the Hill Country or its inhabitants, Hanks did not fare as well. Hanks was unpopular with the miners because he kept secrets from them. In addition, he had heard many stories about what murderers and scoundrels Texans were. The miners, therefore, took every opportunity to play pranks on this "green as a gourd" Yankee.

In 1904, Westinghouse had enough gadolinite to suit its needs and decided to

recall Hanks. Availing themselves of this last, great opportunity, the miners decided to play one final trick on their boss. At that time, Wells Fargo was in charge of shipping Barringer Hill ore out of Kingsland by train, so the miners brought the Wells Fargo express agent in on the prank. The agent convinced Hanks that the only way he would get out of Texas alive was to mail himself to Pennsylvania in a crate of ore.

After he was loaded up, the miners pretended to search for him in the baggage car. Just as they threatened to shoot at the crates to flush him out, the agent bellowed out, "You fellows better not mess with Wells Fargo! Get out of this baggage car!" Hanks escaped in the crate and always believed the miners had wanted to kill him. Like Hidden, his life does not seem to have been cut short due to exposure to radioactive materials, and he went on to have an illustrious engineering career in Pennsylvania.

For several years, the Nernst Lamp Company continued to annually extract a few hundred pounds of yttria minerals from Barringer Hill. Eventually, however, Nernst ceased operations as newer technologies surpassed the lamp.

From the time mining operations ended until the building of Buchanan Dam flooded the area, Barringer Hill was of interest primarily to mineralogists. One of the best collections of minerals from the area was that of Tillie Badu Moss, Professor Badu's daughter. Among her specimens were pieces of quartz which had been beautifully colored through exposure to radiation. According to Tillie Badu Moss specimens are to be found in many museums, including the Houston Museum of Natural History and the New York Museum of Natural History. The University of Texas at Austin also possesses a number of rocks from Barringer Hill, including the 600 pound smoky quartz crystal that so impressed William Hidden. For many years, it was displayed on the Little Campus at UT until renovation began in the 1970's. Like many other exotic Texas mineral specimens, it is now squirreled away as part of the geology department's Barron Collection. (Note: Since the original publication of this article in 1996 we have been contacted by Rob Reed, a doctoral candidate at UT who is doing research on the granites in the vicinity of Barringer Hill. He once had a summer job updating the cataloging of the Barron Collection and has no recollection of a 600 lb. smoky quartz crystal.)

Other crystals found their ways into museum collections across the country. For instance, the Smithsonian Institute has a large, faceted piece of gadolinite

that was once part of a neckdrop. Supposedly the radioactivity from this gem led to the premature death of its original owner.

Although more amazing specimens of rare earth elements may remain embedded in Barringer Hill, don't count on being able to go out and collect them any time soon. Every year, the Colorado River brings in several thousand acre-feet of silt, which will continue to bury the area ever deeper until the lake is topped off with sediment in approximately 320 years. Unfortunately, the Lower Colorado River Authority has no immediate plans to "drain the lake for the rockhounds' sake."

Hope springs eternal, however, because other deposits of rare earth elements exist in the Llano Uplift. There are at least a half dozen other plutons exposed in the area, each one covering 30 or more square miles. Previously unknown rare earth elements are also still being discovered from time to time. For example in 1975, a 5 cm X 5 cm sample of Texasite, a radioactive apple green mineral, was discovered in the Clear Creek pegmatite in Burnet County. Who knows what's out there? Perhaps the next magnificent collection of minerals like Barringer Hill lies just beneath some pasture, road, or hill.

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Guidebook 6

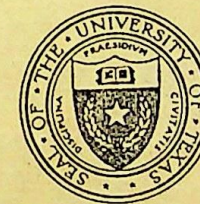
TEXAS ROCKS AND MINERALS

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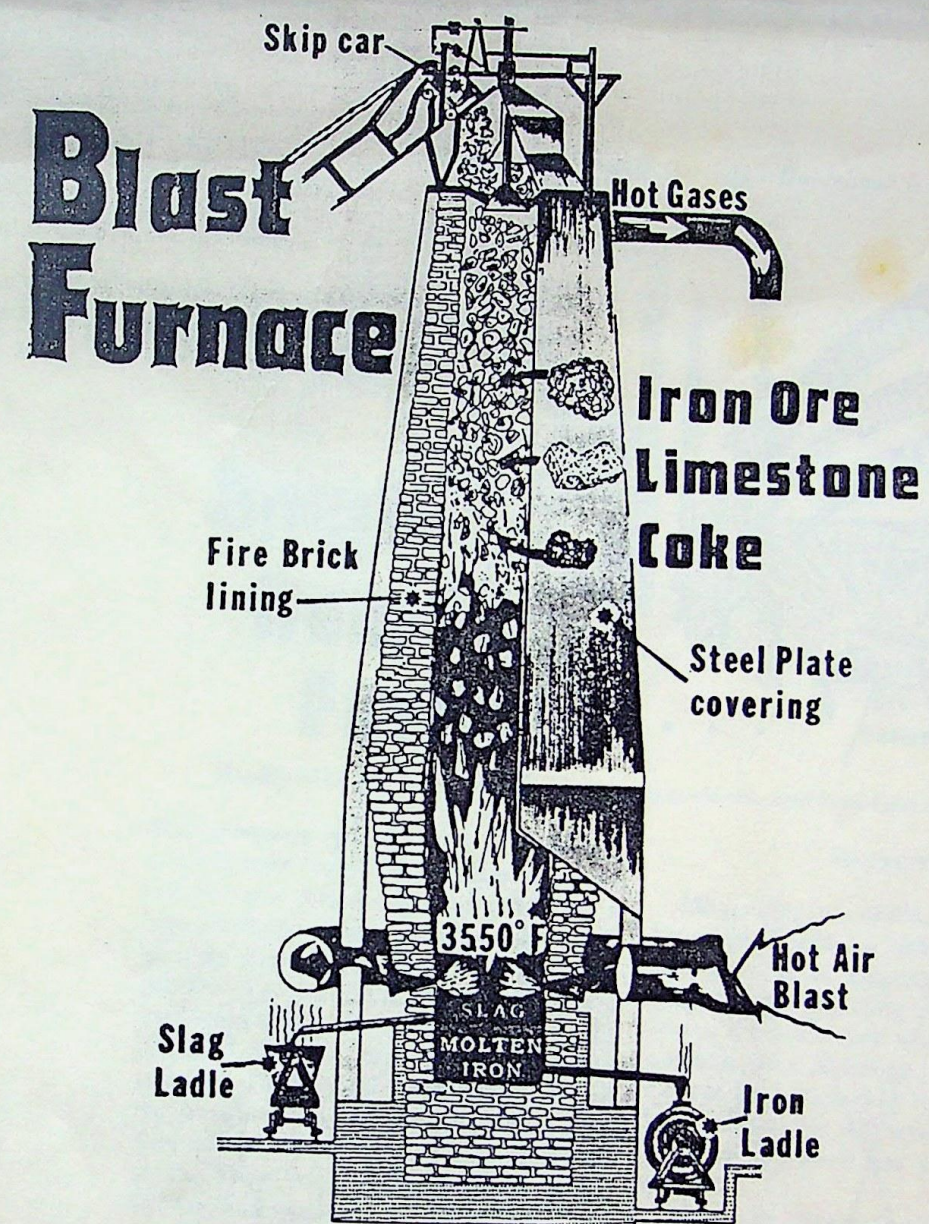
By

ROSELLE M. GIRARD

Sketches by Bill M. Harris



February 1964
Second Printing, April 1972



Limonite ore is changed to metallic iron in a blast furnace.

or nickel, are added to make steel with the right strength and toughness.

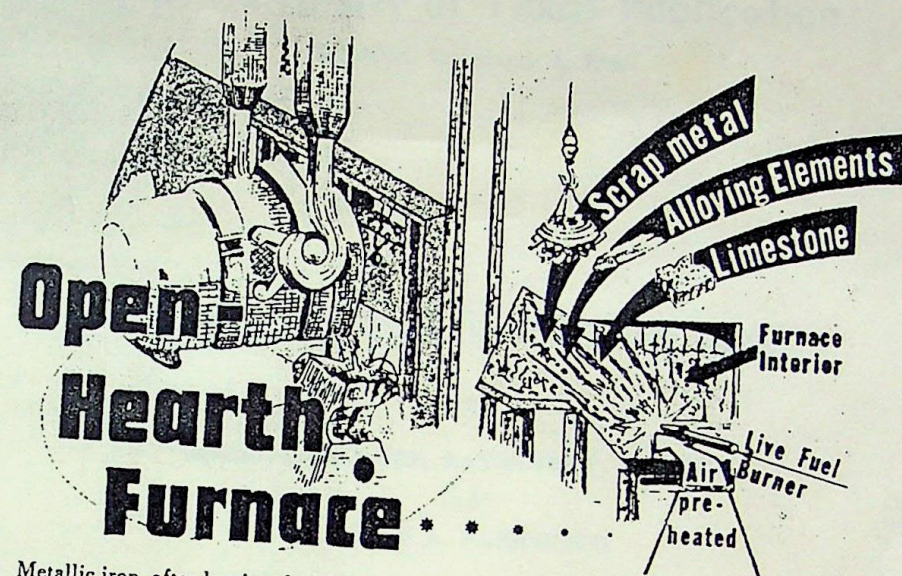
Steel mills alongside the furnaces in Texas turn out many products, such as steel plates for oil tanks, ships, and tank cars and steel beams for framework in buildings and bridges. Some of their other products include pipes for the oil and chemical in-

dustries and wire for nails and fencing material.

LITHOGRAPHIC LIMESTONE. See LIMESTONE.

LLANITE

Llanite is a unique rock that is found only in Llano County in central Texas.



Metallic iron, after leaving the blast furnace, is made into steel in an open-hearth furnace.

This intrusive igneous rock is made up of easily seen crystals and grains of quartz and feldspar that are scattered through a brown-colored mass of extremely small mineral grains. The quartz is beautiful, sky-blue, and opal-like; the feldspar has a rusty pink color. (Because the quartz looks like opal, this rock often is called *opaline granite*.) The mineral grains that make up the brown-colored mass are so tiny that they can be identified only with a microscope. They are quartz, feldspar, mica, fluorite, and apatite.

Llanite formed during Precambrian time. Molten rock material forced its way upward into cracks that cut across granite and schist rocks while the rocks were still far underground. This hot magma remained in the cracks where it cooled and hardened to form long, narrow, wall-like masses (called *dikes*) of llanite. We can see some of the llanite dikes exposed at the earth's surface to the north and northeast of Llano in Llano County because the overlying rocks have weathered away.

Llanite has been quarried from one of the dikes west of Babyhead in northern Llano County. Because llanite is both attractive and strong, it has been used as an ornamental stone and as a monument stone.

MAGNETITE

Magnetite, iron oxide, is a black, metallic mineral with an outstanding physical property: it is magnetic—fragments of magnetite readily cling to a magnet. It also leaves a black streak when rubbed across a streak plate. Although this mineral is too hard to be scratched by the average pocket knife, a steel file will scratch it. Magnetite is fairly heavy—it has a specific gravity of 5.18.

Magnetite occurs as compact or granular masses, as scattered grains, and as crystals. Most of the crystals are octahedrons, but some dodecahedrons are found. Magnetite helps make up a part of many metamorphic and igneous rocks, and it also occurs as tiny crystals and grains in some sands, sandstones, and other sedimentary rocks.

Most of the magnetite that has been found in Texas occurs in Precambrian gneiss and schist rocks of the Llano uplift area of central Texas, particularly in Llano County and in eastern Mason County. It occurs as thin layers, as thick lens-shaped deposits, and as scattered grains in the rocks. Probably at least a billion years ago these gneisses and schists were sedimentary rocks, such as shales and

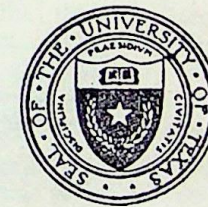
The University of Texas Publication

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BUILDING STONES OF CENTRAL TEXAS

By

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Bureau of Economic Geology
Bureau of Engineering Research

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plagioclase, quartz, and biotite. Accessory minerals are very scarce. Magnetite and zircon were recognized. Sericite and chlorite are present as alteration products. The microcline is mostly clear with occasional flecks of cloudiness. The zonal plagioclase is mostly cloudy at the center and clear or only faintly cloudy at the border. Some of the non-zoned plagioclase crystals are clear. The plagioclase is oligoclase in composition. The quartz has much undulatory extinction and much mosaic structure detectable when near extinction. The estimated mineral composition is microcline 41, plagioclase 27, quartz 31, and biotite 1 per cent.

Recommendations.—The granite is an excellent monumental stone, but the size of the mass is small, and at the surface the granite is much jointed. Large masses of very similar granite are described under Ll-41, Ll-31, and Ll-62, where satisfactory quarries can be established.

LOCALITY LL-35

Location and geology.—A quartz porphyry (llanite) dike is located just north of the Llano-Lone Grove road at a distance of about 3.5 miles from the railroad at Llano. It extends as a dike, or a series of dikes, for a distance of 9 miles northward and then swings sharply to the southwest for a distance of 4 miles, crossing the Llano-San Saba highway on the southeastern slope of Baby Head Mountain.

Quartz porphyry is probably the latest intrusive in the region. The quartz phenocrysts of the quartz porphyry are opalescent. It has been named llanite from the county in which it has been found and locally is called "opaline granite." The dike trends N. 10° W. and is about 10 feet thick at the place where the sample was obtained. It extends about 3 feet above the general ground surface and is marked by a linear pile of small, rounded boulders, not unlike the ruins of an old wall. The size of block which can be obtained at this locality is insufficient for most uses. Several miles to the north thicker dikes of quartz porphyry would yield sufficiently large blocks for most uses.

A quarry in opaline granite is located west of Baby Head and about one-fourth mile west of the Llano-San Saba highway.

The quarry is in a thickened portion of an opaline granite dike which at this point is less jointed than at most localities visited. Boulders up to 10 feet in size top the outcrop, and blocks of at least that size can be obtained in the quarry. It is free of pegmatites, aplites, quartz seams, inclusions, and other blemishes. Joints are numerous and trend in many directions. The opaline granite is fresh and unaltered to within a fraction of an inch of the surface, and much good stone could even be obtained from boulders. The outcrop forms a steep southeast-facing scarp and is a desirable quarry site. Much good stone has been quarried and piled alongside the quarry in blocks 3 to 5 feet long. The waste pile also contains much good small stone that can be used. This is the most desirable deposit of opaline granite seen, and there is no logical reason apparent why this premium stone should not be available on the market.

Physical tests.—Iddings³⁷ gives the following data which were determined in the laboratory of The University of Texas Mineral Survey: "Specific gravity, 2.64; corrected, 2.67. One cubic foot of the rock absorbs 9.47 ounces of water. Crushing strength 15,300 pounds per square inch of surface." The above absorption is about 0.36 per cent. The microscopic and megascopic appearance of the opaline granite indicated that the above crushing strength is too low. This property was redetermined, using present-day specification, and the average crushing strength was found to be 37,800 pounds per square inch.

Megascopic description.—The opaline granite has a dense chocolate-brown groundmass surrounding abundant rust-flecked feldspar phenocrysts averaging about 4 mm. in size. Hexagonal phenocrysts of bluish opalescent quartz averaging 3 mm. in size are also abundant. This combination of bluish opalescent quartz, rust-flecked feldspar, and dense groundmass produces a very unusual and attractive rock. It takes an excellent polish, showing little of the accentuation of grain boundaries which is so common in coarse-grained granites.

³⁷Iddings, J. P., Quartz-feldspar-porphyry (granulophyroliparoso-alaskose) from Llano, Texas: Jour. Geol., vol. 12, pp. 225-231, 1904.

Iddings (p. 225) has carefully described the llanite as follows:

The material submitted . . . is a gray porphyry with abundant phenocrysts of red feldspar and blue quartz, the matrix or groundmass being aphanitic to phanocrystalline. It appears to have a crystalline texture, but the individual grains are not distinctly visible without a microscope. The rock is therefore mottled red and gray with light blue spots of opalescent quartz.

The phenocrysts vary in size, the largest feldspars being 10 mm. in diameter, the largest quartzes 5 mm. The quartzes exhibit a beautiful blue color, which is light sky-blue in the central part of the crystal and dark at the margin. The crystals are not all colored to the same degree; some are lighter than others. The color does not change perceptibly with a change in the angle of incidence, or in the position of observation, except that in certain positions there is a brilliant light blue luster. The feldspars are rather uniformly colored light Indian-red, the larger crystals being mottled with gray.

The proportion of phenocrysts and groundmass estimated from the surface of the specimen and from three thin sections is:

Phenocrysts	{ quartz	10.7
	{ feldspar	26.5
Groundmass		62.8
		100.0

Microscopic description.—The microscopic description of the llanite as given by Iddings (pp. 225-227) is as follows:

Under the microscope the groundmass is seen to be holocrystalline and microcrystalline, and is composed of feldspar and quartz in nearly equal proportions, together with a small amount of brownish-green mica, and still less fluorite, magnetite, apatite, and zircon. The proportions in which these occur was determined by microscopical measurement to be approximately, in 62.8 per cent of groundmass:

Quartz, 23.9	Total
Feldspar, 29.2	34.6
Biotite, 8.6	55.7
Fluorite, 1.0	8.6
Apatite, 0.13	1.0
	0.13
62.83	100.03

The fabric of the groundmass is uniformly heterogeneous, being a mixture of automorphic granular and micrographic. It consists of anhedral quartz, very free from inclusions, except some minute gas cavities, with similarly shaped anhedral microcline slightly clouded with alteration products, besides anhedral twinned albite with an approach to automorphism. These anhedral grains vary in size from 0.1 to 0.01 mm. in diameter. Throughout the whole are scattered at short intervals granular clusters of graphic intergrowth of quartz and feldspar. The

crystallization of the graphic parts was almost contemporaneous with that of the anhedral, as these are developed in continuous orientation with the graphic clusters.

The mica is xenomorphic in great part, and is in about the same sized anhedral as the quartz and feldspar. It appears to have been almost contemporaneous in crystallization with these minerals. Its color is green to brownish-green.

Fluorite occurs in irregularly shaped anhedral, xenomorphic in form. It is colorless in thin sections, exhibits distinct cleavage, and is characterized by its low refraction and isotropic behavior. It is quite uniformly scattered through the groundmass.

Apatite occurs in colorless microscopic prisms. Magnetite and zircon both occur in anhedral in such small quantities that they were not measured. They appear to constitute a small fraction of 1 per cent of the rock.

A careful study of the feldspars in the groundmass showed that microcline and albite are present in nearly equal proportions, and that they form separate and distinct crystals not perthitically intergrown.

The feldspar phenocrysts are microcline, with extremely minute and regular multiple twinning in two directions. The delicacy of the twinning suggests a possible soda content in the potash feldspar approaching soda microcline. There is also a perthitic inclusion of albite in irregularly shaped shreds, and also a slight clouding due to alteration, which is probably kaolin with hydrous oxide of iron which gives color to the feldspar.

The quartz phenocrysts contain multitudes of minute inclusions, rather evenly distributed through each crystal, except for a margin of nearly pure quartz in some cases. The inclusions are of two kinds, generally intermingled: one consists of extremely thin, colorless prisms, sometimes passing into lines of minute grains, like broken prisms; the other kind is in equally thin tabular crystals with six sides and trigonal shapes, and a light brown color. The colorless prisms have higher refraction than quartz, but the double refraction is not recognizable. They resemble apatite rather than rutile, having lower refraction than rutile and not being so long as rutile needles often are. The width of these prisms varies from 0.000800 mm. to much less; that is, it is mostly a fraction of a wave-length of light. The brownish tabular crystals are equally thin, and range in diameter from 0.004 mm. to much less. Studied by incident sunlight, they exhibit metallic reflections of a bluish-white and also of other colors. They have the crystal form and color of ilmenite.

These inclusions lie at all angles within the quartz crystals, but there appear to be sets of parallel directions intersecting at various angles, so that in some positions many tabular microclites reflect light in one direction. The same is true of the colorless needles. They lie in parallel lines crossing at various angles, whose orientation with respect to the inclosing quartz does not appear to be definite.

The sky-blue opalescent color of the quartz phenocrysts is undoubtedly due to reflection of

blue light-waves from the minute colorless prisms, whose width is a fraction of the length of light-waves. It is similar to the blue color of the sky. It is probable, however, that there is also blue light produced by interference of the light reflected from both sides of the minute tabular crystals, whose thickness is also of the order of a fraction of a light wave-length; so that both kinds of phenomena occur within these quartzes.

In addition to the minerals mentioned in the above description muscovite, sericite, and chlorite were seen in the specimen examined by the present writer. The muscovite is present as flakes of the same average size as that of the other ground-mass minerals. The sericite is present as small irregular flakes and is an alteration product of feldspar. The chlorite is an alteration product of the biotite. The quartz is practically without undulatory extinction.

Chemical analyses.—Three chemical analyses have been made of opaline granite from the H. C. Harned land near Llano. These are analyses I and II, quoted from Iddings (p. 228), in Table 29, which also includes a recent analysis (IV) by Goldich.³⁸

Table 29. Chemical analyses of opaline granite.

	I	II	III	IV
	Per cent			
SiO ₂	74.9	75.90	74.52	75.20
Al ₂ O ₃	11.1	12.07	11.58	12.27
Fe ₂ O ₃	1.6	1.01	0.69	0.63
FeO	1.5	1.45	2.61	1.89
MgO		0.22	none	0.27
CaO	0.2	0.65	0.82	0.81
Na ₂ O	8.5	3.08	3.40	3.05
K ₂ O	tr.	5.32	5.46	5.00
H ₂ O+ }	0.3	{ 0.41 }	{ 0.36 }	{ 0.32 }
H ₂ O- }				
CO ₂		none		0.02
TiO ₂	0.5	0.38	0.29	0.35
P ₂ O ₅		0.15	0.05	0.06
MnO	1.9	n.d.	0.02	0.06
BaO		n.d.		0.04
F		n.d.	0.49	0.25
S		n.d.		0.01
	100.4	100.70	100.29	100.33
Loss O			0.21	0.11
			100.08	100.22
Sp. gr. t°/4°				2.650

- I. S. H. Worrell, analyst. (This analysis is inferior.)
 II. H. S. Washington, analyst.
 III. J. P. Iddings, calculated from microscopic measurements.
 IV. S. S. Goldich, analyst.

³⁸Goldich, S. S., *op. cit.*, p. 700.

Iddings calculated the chemical composition from a microscopic determination of the amount of the various minerals present, making an assumption that the biotite had a composition similar to that found in the soda granite of Cape Ann, Massachusetts. The calculation was made before a chemical analysis was available and is given as analysis III in Table 29. This shows that a rather accurate estimate of the chemical composition can be obtained by a petrographic examination.

The normative mineral composition calculated by Washington,³⁹ the modal mineral composition determined by Iddings, and the normative mineral composition calculated by Goldich are given in Table 30.

Table 30. Normative and modal mineral compositions of opaline granite.

	Washington Norm	Iddings Mode Per cent	Goldich Norm
Quartz	35.76	34.6	35.70
Orthoclase	31.14	27.8	29.47
Albite	26.20	27.9	25.68
Anorthite	2.50		2.22
Corundum	0.31		1.12
Biotite		8.6	
Hypersthene	1.79		3.74
Magnetite	1.39	tr.	0.93
Ilmenite	0.76	tr.	0.61
Apatite	0.34	0.13	0.13
Calcite			0.20
Fluorite		1.00	0.51
Pyrite			0.02
Normative			
plagioclase	Ab ₅₁ An ₉		Ab ₅₂ An ₈
Symbol	I.(3)4.1".3.		I.3(4).1".3.

Iddings classifies this rock as a quartz-feldspar-porphyry having the composition of a granite. Washington lists it as a quartz porphyry having, under the "Qualitative System of Analyses," the symbol I.(3)4.1".3. The name "llanite" is used for this rock by Iddings, and locally it is generally designated by the very descriptive name of "opaline granite."

Recommendations.—The opaline granite is extremely unusual in appearance and should have great value as a monumental and ornamental stone. Many of the outcrops examined are rather highly jointed, which may cause considerable waste in producing sound stone. The quarry west of Baby Head, however, contains much rock

³⁹Washington, H. S., Chemical analyses of igneous rocks: U.S. Geol. Survey Prof. Paper 99, p. 119, 1917.

from which large blocks can be obtained. The opaline granite should be made available for those wishing a stone of distinctive and unusual appearance.

LOCALITY LL-38 (PAINT HORSE QUARRY)

Location and geology.—A granite mass and quarry are located 2.5 miles southeast of Lone Grove and about 1 mile from the nearest point on the railroad. The granite outcrop covers about 10 acres and is a low-lying dome which stands a little higher than the surrounding surface. It is a very coarse-grained pink granite which contains sufficient femic minerals to cause the granite to appear gray with a pinkish cast when viewed at a distance. Inclusions are absent, but aplite dikes are so numerous that considerable waste will be produced if the rock is quarried for building stone.

Megascopic description.—The granite is coarse grained, somewhat porphyritic, and light pink, mottled by dark-colored areas. The feldspar is mostly of a light pink color containing some orange, and some is milky white. The clear quartz is somewhat dark in appearance from internal reflections. The femic minerals are in clusters averaging about 10 mm. across. The milky feldspar and quartz areas are somewhat smaller in size. These minerals average about 8 mm. in size and form a mesh surrounding some groups and individuals of the large pink feldspars. The large feldspars average 22 mm. in length, and the largest one measured is 40 mm. long. The granite takes a good polish.

Microscopic description.—The granite is composed predominantly of microcline, plagioclase, quartz, biotite, and hornblende. Accessory minerals are magnetite, apatite, zircon, allanite, and titanite. Minerals formed by alteration are chlorite and sericite. The microcline and plagioclase are present in about equal amounts and are rather uniformly cloudy. Microperthite is well developed. The quartz has undulatory extinction and mosaic structure detectable when near extinction. Some reticulated quartz is present which contains long slender needles of rutile and plates of ilmenite. The plagioclase is oligoclase in composition.

Recommendations.—The granite is of a rather pleasing color and is present in sufficient quantities for all types of building and construction for which a coarse-grained granite of this type is suited. Aplites are sufficiently numerous so that considerable waste will be produced. The femic mineral areas are rather large, and consequently the stone does not take a uniformly good polish. The femic mineral areas are rather pitted on a polished surface, but the rest of the minerals take an excellent polish.

LOCALITY LL-41 (SANDSTONE MOUNTAIN)

Location and geology.—A sample of granite was obtained from a quarry on the eastern side of the granite mass known as Sandstone Mountain. The quarry is about 4 miles east of Llano and beside a graded road. The railroad is within 1.5 miles of Sandstone Mountain but is across Llano River from it. A large mass of fine-grained, pink granite which is almost free of inclusions composes Sandstone Mountain. Some pegmatites and aplites are present. Much of the rock at the surface on the mountain is highly jointed. Rather flat surfaces of granite exposed along the road are not nearly so highly jointed.

Megascopic description.—The granite is fine grained and light rose-colored. The principal mineral is light rose-colored feldspar. Quartz is abundant, and the femic minerals are rather scarce. The granite is rather uniform in texture and averages about 2.5 mm. in grain size. The minerals are mostly uniformly distributed except for the biotite which appears to be slightly more concentrated in some areas than in others. The granite takes a good polish.

Microscopic description.—The granite is composed predominantly of microcline, plagioclase, quartz, and biotite. Accessory minerals are very scarce and consist of magnetite and a very small amount of zircon. Minerals formed by alteration are sericite and chlorite. The feldspars are very fresh and clear and are only slightly flecked by cloudiness. Some micropegmatite is present. The quartz has undulatory extinction and mosaic structure detectable