BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

JOHN T. LONSDALE, Director

Report of Investigations — No. 37

Mineral Resources of the Colorado River Industrial Development Association Area

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ABSTRACT

The Colorado River Industrial Development Association area consists of ten counties in the lower watershed of Colorado River in Texas. The rocks exposed in the upriver part of the area include Precambrian metamorphic and igneous rocks and Paleozoic and Lower Cretaceous sedimentary rocks. In the Austin region Upper Cretaceous sedimentary rocks are exposed. In the downstream part of the area the rocks are of Tertiary and Quaternary ages.

The principal mineral resource materials are industrial rocks and minerals. In the part of the area from Austin upstream, the most important materials are building stone, chemical limestone and dolomite, cement materials, graphite, soapstone, serpentine, vermiculite, and iron ore. From Austin downstream, the most important materials are sand and gravel, bleaching clay, burning clay, lignite, salt, sulfur, and oyster shell. There are small or low-grade deposits of many other materials, especially in the upriver region.

INTRODUCTION

The Colorado River Industrial Development Association, Incorporated (CRIDA) is an association of communities in Bastrop, Blanco, Burnet, Colorado, Fayette, Llano, Matagorda, San Saba, Travis, and Wharton counties, Texas, in the lower watershed of Colorado River, formed in October 1956 to advance the economic development of the area (fig. 1). The purpose of the Association will be accomplished through the promotion of industrial, agricultural, commercial, and tourist developments which will improve the standards of living and the income of the residents of the area.

In order to determine the resources of the area, evaluate its economic condition, and plan for possible development in various fields, the Association arranged for a series of surveys and studies. The Bureau of Economic Geology, The University of Texas, was requested to make a study of the mineral resource materials of the area in order to determine the possibilities of development in the mineral industries. The Lower Colorado River Authority, Central Power and Light Company, and Houston Lighting & Power Company made a financial grant-in-aid to defray the cost of the study and publication of results.

The study consists of a compilation of available information concerning the known mineral materials other than oil and gas with additional field work and physical and chemical testing of some of the materials. The objective as far as possible and practicable is to present an inventory of the mineral resources from which an evaluation of their commercial possibilities can be made. Treatment of the various resources is from the practical standpoint. Technical language and theoretical geological discussions are kept at a minimum. Published material has been summarized and publications have been cited for persons who wish additional technical details. These publications are available for examination at the Bureau of Economic Geology and in most larger libraries in Texas.

During this study Dr. Jack A. Walper spent a month in field studies in Bastrop and Fayette counties. Christian Dullnig, Jr., and James M. Pegg spent a number of days in the field and assisted in the office work. Chemical analyses and physical tests of lignite and clay were made by Daniel A. Schofield of the Bureau staff. Colleagues on the Bureau staff read and criticised portions of the manuscript.

GEOLOGICAL SETTING

Remarkably diverse geological conditions are present in the CRIDA area. The geological conditions determine the kinds of rocks and minerals present, and as a result of this diversity, possibly no other group of ten counties in Texas contains such a variety of rocks and minerals with such a range in geologic age. The oldest as well as the youngest rocks known in Texas are present. These include the three great groups of rocks—igneous, sedimentary, and metamorphic—and, because of differing conditions from place to place, a great variety of rocks and mineral types is present.

Plate I is a geologic map of the CRIDA area showing the geologic age, distribution, and general character of the exposed rock formations. A roughly circular portion, including parts of San Saba, Llano, Burnet, and Blanco counties, is near the center of the Llano uplift. Here the oldest rocks of the area have been elevated and exposed at the surface through erosion of the overlying formations. Successively younger formations flank the uplift. Along

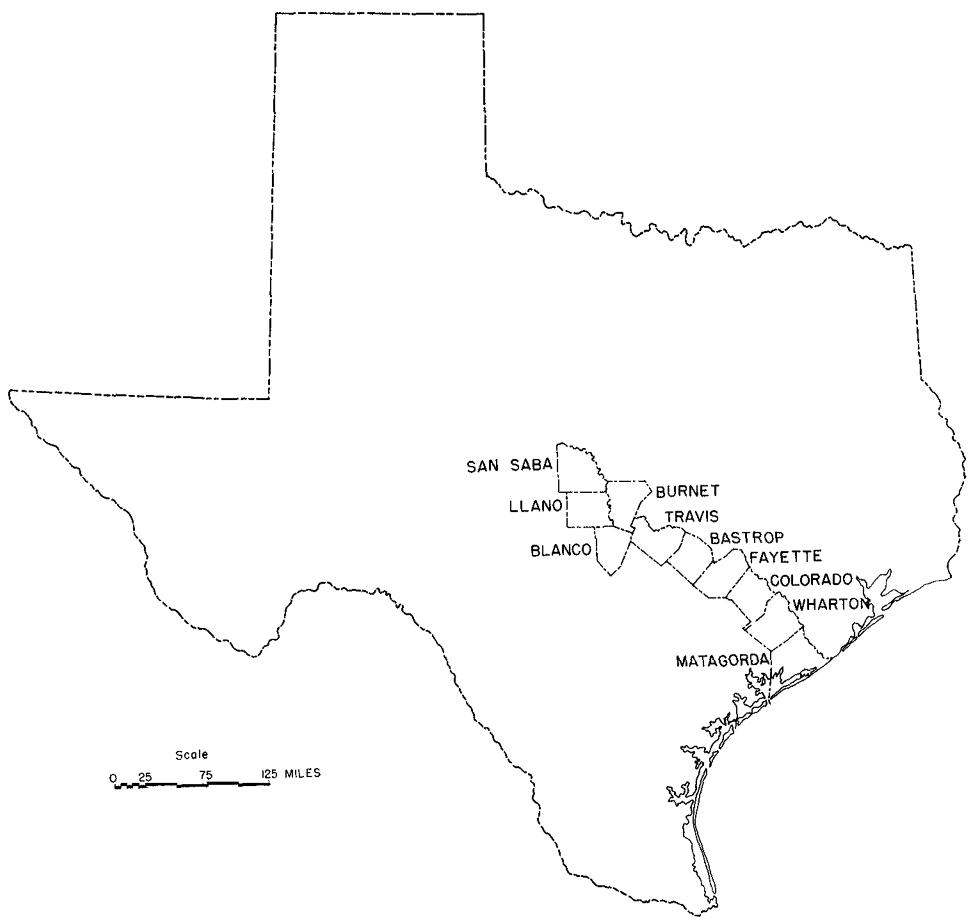


Fig. 1. Index map showing area of the Colorado River Industrial Development Association.

the Colorado River this arrangement persists to the coast so that formations exposed at the eastern margin of the uplift dip beneath those closer to the coast. Between the southeastern margin of the uplift and Austin, the CRIDA area is part of the Edwards Plateau. The plateau surface is interrupted by the deep valley of Colorado River and is generally less regular than elsewhere. A fault system, known as the Balcones fault system, trends northeast-southwest through the western part of Austin. The rocks southeast of the fault system have been displaced downward many hundreds of feet. From Austin to the coast, the area is part of the Coastal Plain in which the rock formations normally dip gently coastward at an angle greater than the general land surface. This results in a belted arrangement of outcrops trending or striking northeastward approximately parallel to the coast line.

In the upstream portion in the Llano uplift in extreme southern San Saba, most of Llano, western Burnet, and northwestern Blanco counties, the bedrock consists of a variety of igneous and metamorphic rocks. They are of Precambrian age and are the oldest rocks exposed in the CRIDA area. These rocks were formed at great depths beneath the surface under conditions of high temperature and pressure. It is characteristic of this type of geologic environment that a great variety of metallic and nonmetallic mineral materials is formed. In the Llano uplift these rocks and their associated mineral materials are the sources of building stone, graphite, soapstone, iron ore, feldspar, roofing granules, and other materials now being produced. In addition, the rocks contain deposits of a number of materials not in production at present but possibly of future value.

In a few places remnants of the original cover of sedimentary rocks are present, but mainly the sedimentary rocks crop out at the flanks of the Llano uplift. Thus in Mason, Llano, San Saba, Burnet, and Blanco counties, there are exposures of older Paleozoic (mainly Cambrian and Ordovician) sedimentary rocks mainly of marine origin. These include sandstone, limestone, dolomite, and shale. Some of the limestones and dolomites are of high quality and are extensively produced.

Flanking the older Paleozoic rocks in northern and northeastern San Saba County and in Burnet County in the Marble Falls region are younger Paleozoic (mainly Pennsylvanian) sedimentary rocks, chiefly limestone, shale, and sandstone. Some of the limestones in the Marble Falls area are of exceptional purity and have been used for chemical purposes. Some of the sandstones are suitable for construction uses.

From eastern Burnet County through Travis County to the Balcones fault zone, the rocks are of Lower Cretaceous age. During the time these rocks were deposited, conditions were such that much limestone and subordinate marl and clay were deposited. Some of the limestone is suitable for lime making, building stone, and crushed stone, and some probably for chemical use. The limestone with suitable admixture of clay or shale could be used to make cement.

From the Balcones fault zone at Austin to near the Bastrop County line, the rock formations are of Upper Cretaceous age. The rock types include impure limestone such as the Austin chalk, clays and shales like the Eagle Ford, and marls or calcareous clays like the Taylor. Conditions of deposition were less favorable for limestone deposits, and consequently high-quality limestone is practically absent among these rocks. In this area near Austin is Pilot Knob, one of the very few exposures of massive igneous rock except in the Llano uplift. Along Colorado River downstream from Austin there are extensive sand and gravel deposits in the valley itself, in terraces alongside the valley, and in places on the uplands. These deposits merge with some of the formations near the coast.

Between the Travis-Bastrop County line and the coast, the rocks with their mineral resource materials are in great contrast to those farther upstream. During Cenozoic time, when these rocks were deposited, shore lines were shifting and the sediments forming the rocks now exposed were deposited in a wide range of environments. These environments generally were markedly different from those in which sedimentary rocks now exposed farther upstream were formed. Sites of deposition included low-lying land near the sea, lagoons and swamps, and marginal areas of shallow seas. Accordingly, there is a virtual lack of limestone in this area and a great abundance of sandstone and clay. Swamp and lagoonal deposits, especially in the Bastrop and Fayette County area, contain beds of lignite. During a part of the geologic time represented there were falls of volcanic dust. These now are present in some of the rock formations as beds of volcanic ash or bentonitic clay derived from the alteration of the ash. In this downriver area the major mineral resources are lignite, clay of several kinds, volcanic ash, sand and gravel, and locally in Wharton and Matagorda counties salt and sulfur from salt domes. The only local source of lime is from oyster shell in Matagorda Bay.

MINERAL RESOURCES

According to figures compiled by the United States Bureau of Mines and the Bureau of Economic Geology, the value of mineral materials other than oil and gas produced in the CRIDA area in 1956 was $66,764,721. Commodities produced, in order of value, were sulfur, sand and gravel (construction, engine, filter, molding, and blast), crushed limestone and dolomite (riprap, fluxstone, construction, ballast, and agricultural), clay (burning, bleaching, and drilling mud), oyster shell, lime, dimension stone, soapstone, miscellaneous stone (granules and chips), marble, feldspar, grinding pebbles, and crushed granite.

In addition to these mineral materials, there are others, not produced in 1956, which have varying degrees of potential commercial importance. Some like lignite probably will be produced in the foreseeable future. Serpentine, present in large deposits, has been produced only as crushed stone because utilization based on its chemical composition has not been established. Other materials are too low grade or are present in deposits too small to justify development.

Table 1 lists the known mineral materials and shows those produced in 1957. It must be emphasized that many of the materials listed are included only to make the list complete: some do not and probably never will have commercial importance. Summaries of the mineral materials are also given for each county. Following this is descriptive information with available maps for each mineral material and locality. Some localities in counties bordering the CRIDA area are included.

A consideration of this and other available material shows that the mineral wealth of the CRIDA area is mainly in the nonmetallic materials commonly called industrial rocks and minerals. There is not much chance that major deposits of metallic minerals will be discovered. The production of industrial rocks and minerals is a highly specialized field, most of the materials are low priced, and most of them must meet rigid specifications in highly competitive markets. Processing of some involves complicated procedures. In general, the production of these industrial mineral commodities is more like conventional manufacturing than metal mining or oil production, which have a traditional, sometimes false legend of great and quick financial returns from small investments. Success in the development of the mineral materials in the area will require a realistic business approach toward every project along with accurate basic information and sound technical guidance.

Table 1. Mineral materials in the CRIDA area.

Asbestos	Lignite
Asphaltic limestone	Magnesite
Barite	Mica
*Bleaching clay	Molybdenum and bismuth
*Building stone	Oil shale
*Burning clay	Phosphate rock
*Cement and lime materials	*Quartz
*Chemical limestone and dolomite	Rare-earth minerals
Chromite	*Salt
Copper	*Sand and gravel
*Feldspar	*Serpentine
Fluorspar	*Shell
Gold and silver	*Soapstone
*Graphite and graphitic schist	Spiculite (tripoli)
*Grinding pebbles and mill liners	*Sulfur
*Iron ore	Tungsten
Lead and zinc	Uranium minerals
	Vermiculite
	*Volcanic ash

* Produced in 1957.

COUNTY MINERAL SUMMARIES

The mineral materials, with a few exceptions, known in each county are enumerated in the following summaries. More detailed descriptions of or statements concerning the deposits in the various counties are given in the next section.

Bastrop County.—In Bastrop County the rocks are mainly Tertiary sandstones and clays cropping out across the county in northeast-southwest belts and Quaternary sand and gravel deposits in the Colorado River valley and terraces. The mineral materials include burning clay, grinding pebbles, lignite, and sand and gravel. The clays range in quality and include some suitable for refractory products. Lignite is present in large deposits in the Wilcox beds in the central part of the county (Pl. IV). The Quaternary deposits contain large supplies of sand and gravel, including grinding pebbles. Clay, grinding pebbles, sand and gravel are currently produced and lignite was produced prior to 1944.

Blanco County.—Blanco County lies on the southeastern flank of the Llano uplift. Limited exposures of Precambrian metamorphic rocks are present in the extreme northwestern part of the county and igneous rocks crop out in the west-central part. There are limited exposures of Paleozoic sedimentary rocks along Pedernales River and Cypress Creek; the remainder of the county is covered by Lower Cretaceous sedimentary rocks. Mineral materials include asbestos (Pl. VI), building stone (Pls. II, VI), cement and lime materials, chromite (Pl. VI), feldspar, iron ore, lead and zinc (fig. 15), phosphate rock, sand and gravel, serpentine (Pl. VI and fig. 21), soapstone (Pls. VI, VIII, and fig. 21), and vermiculite. Building stone, serpentine, and soapstone are potentially of greatest importance. Some of the deposits are not favorably located. Additional prospecting for lead and zinc has at least some chance of success.

Burnet County.—In Burnet County, on the eastern flank of the Llano uplift, the surface formations include a great variety of Precambrian igneous and metamorphic rocks and Paleozoic and Cretaceous sedimentary rocks. Mineral materials reported from the county include asphaltic limestone (fig. 2), building stone (Pl. II and figs. 3, 8), cement and lime materials, chemical limestone and dolomite (figs. 3, 4), copper (fig. 8), feldspar (fig. 8), fluorspar (fig. 8), graphite and graphitic schist (figs. 8, 9), iron ore, lead and zinc (figs. 13, 14), phosphate rock (fig. 16), sand and gravel, spiculite (fig. 22), uranium minerals, and vermiculite (Pl. II). Building stone (including granite and terrazzo chips and granules), chemical stone, and graphite are produced extensively. The metallic minerals are present in low-grade or small deposits; additional prospecting for lead and zinc holds some promise of success. The most important resources are the industrial rocks, some deposits of which are not favorably located.

Colorado County.—The surface formations of Colorado County include late Tertiary and Quaternary clays, sands and gravels (Pl. I). The mineral materials include bleaching clay, burning clay of questionable quality, grinding pebbles, and sand and gravel. The county is the center of a large sand- and gravel-producing area along Colorado River and reserves are large. The sand and gravel deposits have been the source of grinding pebbles. An untested bentonitic clay on Sandies Creek northwest of Rock Island may have possibilities as a bleaching clay.

Fayette County.—Fayette County is in the central part of the Coastal Plain. The surface formations are Tertiary sandstones and clays cropping out in belts across the county and Quaternary sand and gravel along Colorado River in the valley and terraces (Pl. I). There are also upland gravels. Mineral materials are bleaching clay, building stone, grinding pebbles, lignite, sand and gravel, and volcanic ash. The clays are mainly bentonitic, but some types have not been tested for ceramic purposes. Building stone is limited to a hard sandstone along the Southern Pacific Railroad from Flatonia to Muldoon. Lignite beds, possibly of commercial promise, are present in the La Grange and Ledbetter areas (Pl. III). Bleaching clay and volcanic ash are produced in the Flatonia and Muldoon areas, and sand and gravel are produced in the Colorado River valley. Grinding pebbles were produced during World War II.

Llano County.—Llano County is near the center of the Llano uplift. The rocks are predominantly Precambrian igneous and metamorphic rocks; about one-eighth of the county is underlain by early Paleozoic sedimentary rocks. The mineral materials present include asbestos (figs. 18, 20), barite, building stone (Pls. II, V, VII, IX), copper, feldspar (Pl. V and figs. 5, 6), gold (fig. 6), graphite and graphitic schist (Pl. V and fig. 6), iron ore (figs. 10, 11, 12), lead, magnesite, molybdenite and bismuth (fig. 6), quartz (Pl. V and fig. 5), rare-earth minerals, serpentine (Pls. V, IX, and figs. 18, 20), soapstone (Pls. V, VIII, IX, and figs. 17, 18, 20), and vermiculite (Pls. II, IX, and fig. 20). Terrazzo chips and granules, iron ore, soapstone. and feldspar are being produced. Deposits of serpentine have future potential importance. Metallic minerals other than iron ores have little promise.

Matagorda County.—The surface formations in Matagorda County are the Beaumont clay and still younger coastal alluvial deposits (Pl. I). The mineral materials include burning clay, salt, and shell. Clay near Palacios is made into brick, patio stone, and other shapes, and shell is dredged from Matagorda Bay. A large supply of salt is present in the Gulf, Hawkinsville, and Markham salt domes.

San Saba County.—San Saba County is on the northern flank of the Llano uplift. Except for two small areas of metamorphic rocks in the extreme southern part, the surface formations are sedimentary rocks ranging from older Paleozoic to Lower Cretaceous (Pl. I). There are limited deposits of younger sands and gravels in terraces along Colorado and San Saba rivers. The mineral materials include barite, building stone (Pl. II), cement and lime materials, chemical limestone and dolomite, iron ore, lead, oil shale, phosphate rock, sand and gravel, spiculite (Pl. II), and vermiculite. There is a small production of sand and gravel. Building stone is the most promising undeveloped material, but the location with respect to markets and transportation probably will limit development to specialty products.

Travis County.—The northwestern part of Travis County is underlain by sedimentary limestones and shales of Lower Cretaceous age. Upper Cretaceous limestones marls, and shales and limited exposures of Tertiary rocks are present in the southeastern part. There is one mass of basaltic igneous rock near Austin and Quaternary sand and gravel deposits along Colorado River and on the stream divides (Pl. I). The mineral materials are asphaltic limestone, building stone (Pl. II), cement and lime materials, chemical limestone, grinding pebbles, phosphate rock, and sand and gravel. There is extensive production of Lower Cretaceous limestone for dimension stone, crushed stone, and chemical limestone north and northwest of Austin. Sand and gravel are produced from the valley of Colorado River and grinding pebbles from the upland gravels.

Wharton County.—In Wharton County the surface formations are the Lissie, Beaumont clay, and river valley and terrace sand and gravel deposits (Pl. I). Present mineral production consists of sulfur from the Boling dome and sand and gravel produced by the Texas Highway Department. There is a large supply of salt in Boling dome at depths below 975 feet. Some of the Beaumont clay can be used for making low-grade common brick, and some of the river valley clay is similar to that used elsewhere for expanded clay used in lightweight aggregate.

DESCRIPTIONS OF MINERAL MATERIALS AND DEPOSITS

ASBESTOS

The term asbestos is applied to the fibrous varieties of a number of minerals which occur in metamorphic rocks. Chrysotile, a variety of serpentine, is the asbestos mineral with the widest industrial application. Amphibole asbestos may be used where shorter fibers are satisfactory, but the fibers tend to be too brittle for many industrial applications.

Small, noncommercial deposits of asbestos have been reported from four localities in Blanco, Gillespie, and Llano counties. Although the information from these deposits provides little encouragement that asbestos will be found in commercial quantities, the possibility has not been completely eliminated.

Fibrous chrysotile has been collected from a locality in northwestern Blanco County. The mineral is present in one-fourth to one-half inch veinlets in the Coal Creek serpentine mass. The material cannot be broken into fibers sufficiently fine to be considered as asbestos (Barnes et al., 1950, p. 11).

Small deposits of amphibole asbestos, mainly associated with schist inclusions, have been observed at several places about the Coal Creek serpentine mass in Blanco and Gillespie counties (Pl. VI). Small deposits of amphibole asbestos have been reported from three localities in southern Llano County: (1) along the prominent serpentine ridge 0.2 mile west of State Highway 16 about 1.5 miles north of Oxford (fig. 20); (2) along a small west-northwest-trending ridge of serpentine just north of the Enchanted Rock—Llano road about 3 miles east of Enchanted Rock (fig. 18); and (3) at a locality near the southwest corner of Llano County about 0.7 mile north of milepost 10 on the Llano-Gillespie County line.

ASPHALTIC LIMESTONE

Asphaltic limestone has been reported from two localities near the town of Burnet, Burnet County, and from one locality near Waters Park, Travis County.

Burnet deposit.—The Burnet asphalt deposit is about half a mile east of U. S. Highway 281 along Dougherty Creek at the northern Burnet city limit (fig. 2). Investigation of the Burnet asphalt has been limited to the examination of old, poorly exposed, partially filled pits and poorly exposed outcrops (Plummer, MS.). The asphalt occupies cavities in and between shells in highly porous shell beds of Glen Rose limestone. The bed with greatest

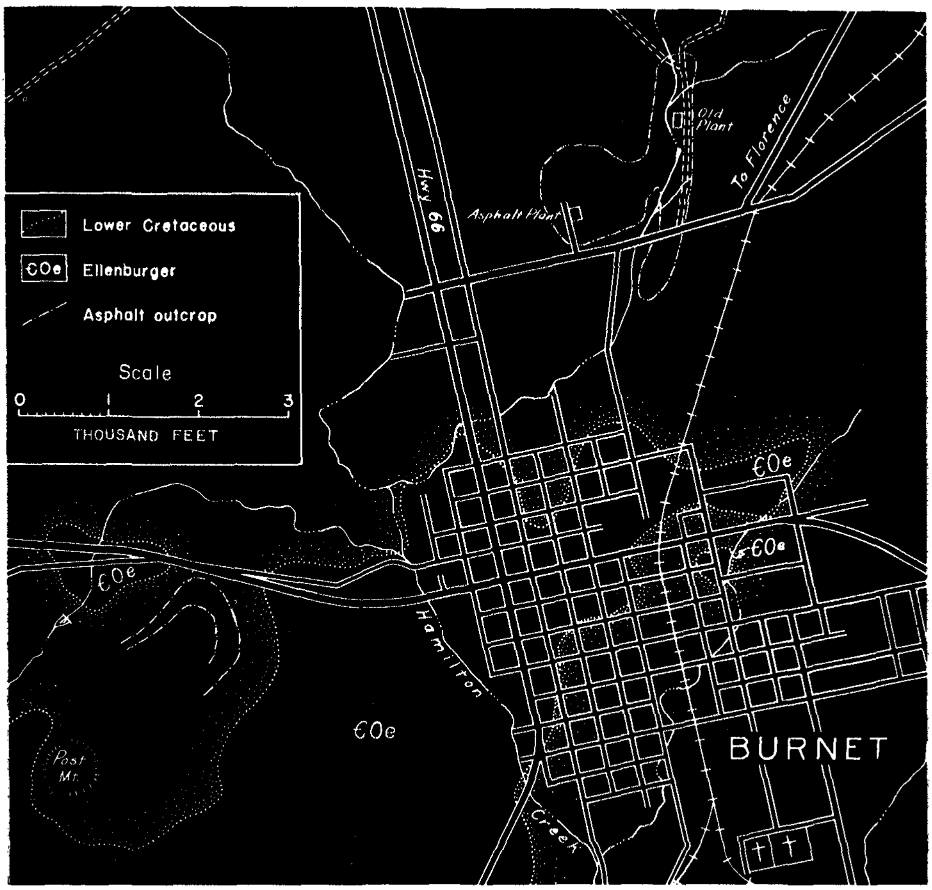


FIG. 2. Asphaltic limestone localities near Burnet. (Manuscript map by F. B. Plummer.)

asphalt content ranges from 1 to 3 feet in thickness, where exposed naturally or in pits, and extends irregularly over an area about one-fourth mile wide and half a mile long. The asphalt-bearing zones are lenticular and do not occupy the entire shell bed. Twenty-five samples of asphaltic limestone were collected from a trench at this locality. The bitumen content of the individual samples ranged from 1.06 to 6.80 percent; the average was 3.88 percent (Plummer, MS.).

Two unsuccessful attempts have been made to utilize the asphalt from this deposit. Prior to 1915, a plant was erected on the east bank of the creek and operated intermittently for a few years. Liquid asphalt distilled from the crushed limestone was reported to contain ichthyol, a substance used as a disinfectant and as a base for various medicinal preparations. The plant was abandoned about 1918 after several barrels of asphalt had been shipped to Oklahoma City for further refining and extraction of ichthyol. A company known as National Ichthic Oil and By-Products Interests was organized in 1933. Its plant, erected on the west bank of the creek, was operated for about one year and was abandoned in 1936.

Post Mountain deposit.—The Post Mountain asphalt deposit is on the eastern slope of Post Mountain just south of State Highway 29, three-fourths mile west of the center of Burnet. The deposit is similar to the Burnet deposit and the asphalt is present in two porous limestone beds separated by about 15 feet of calcareous sandy clay. The lower, more persistent bed has a maximum thickness of 5 feet. Its outcrop extends along the eastern slope of Post Mountain for a distance of about 2,700 feet. Barnes (1936c) estimated the reserves of this deposit to be about 119,000 tons of asphaltic limestone; of this amount about 69,000 tons is minable. The upper bed is excluded from the estimate because it is too thin for economical exploitation. No modern analysis of Post Mountain asphalt is available, but analyses of two samples of asphaltic limestone from this locality were reported by Phillips (1902, pp. 97–98), by Harper (1902, samples no. 1066 and 1113), and by Schoch (1918, samples no. 1125 and 1126). The total bitumen content of these samples was 14.51 and 10.30 percent, respectively.

Separation of liquid asphalt from the rock in the Burnet County deposits is impractical because of the low bitumen content, but according to Plummer (MS.) the asphaltic limestone could be crushed and used as a road material. The asphalt rock would meet most of the American Society for Testing Materials requirements for good asphalt surfaces if the bitumen content were increased 7 to 10 percent by the addition of liquid asphalt. The natural bitumen content may be higher where the rock has not been exposed to weathering, or there may be richer, more extensive deposits in the vicinity of the known deposits. No evidence was found in the field to support either of these possibilities.

Waters Park deposit.—There is an outcrop of asphaltic limestone on Walnut Creek about 1 mile east of Waters Park, Travis County (Sellards, 1930, p. 51). Waters Park is about 2 miles north of The University of Texas Balcones Research Center on Farm-to-Market Road 1325. No information is available concerning the quality or quantity of asphalt in this deposit.

An analysis of heavy crude oil obtained from a well drilled near Waters Park is reported by Harper (1902, p. 127) as sample no. 1601. Approximately 40 percent of the original sample remained as asphaltic residue after the distillation test had been carried to 662°F. Oil shows have been encountered in wells drilled for water in an area that extends a few miles southward and eastward from the asphalt outcrop.

BARITE

Barite has been reported in Gillespie, Llano, San Saba, and Travis counties. The only known production has been from small residual deposits in northern Llano County. None of the known deposits appears to have much potential commercial value. It is possible that prospecting by drilling might reveal larger and better deposits than those known at the present time.

Gillespie County.—A vein containing barite crops out west of Youngblood Creek on the Alfred Davis property in northeastern Gillespie County (Pl. VII). The vein is 40 feet long and has a maximum thickness of 2 feet. Its downward extent is not known, but 15 feet is exposed above water level in a shaft dug on the vein. A few small lenses of barite lie parallel to the main vein but no other deposits were observed. Because of the nature of this vein, there is a possibility that careful search might lead to the discovery of additional deposits (Barnes, 1939). Extensive prospecting for barite in the area has not been done. The barite content of the vein is about 68 percent. The predominant accessory mineral is quartz; minor quantities of hornblende and feldspar and their alteration products are also present. Most of the uses of barite, other than in a drilling mud, would require removal of the impurities. Commercial exploitation of this small body of impure barite would hardly be feasible unless other deposits are found in the immediate vicinity.

Freeman and Hiilsmeier properties, Llano County.—Several tons of barite have been produced from deposits on the Freeman and Hiilsmeier properties in northern Llano County. The deposits are located about 5.5 miles S. 15° W. from Cherokee, San Saba County, along the north-northwest-trending divide between Pecan and Wolf creeks. Most of the barite has been produced from concentrations of residual boulders in the soil.

The properties have been investigated for the purpose of finding the source of the residual boulders (Zapp, 1941). Several thin, highly irregular barite veins were found in the Precambrian metamorphic bedrock. The maximum vein thickness is on the order of 30 inches, but most of the veins are less than 1 foot thick. Although some veins are persistent, abrupt changes in thickness and abrupt terminations are common. In addition to barite the veins contain variable amounts of quartz, feldspar, and copper carbonate minerals. No commercial deposits of barite were found during the investigation. It is possible, however, that core drilling in this area might locate deposits large enough for commercial exploitation. Most of the barite in the residual deposits has been removed; the remaining barite is in fresh crystalline rock.

Other occurrences.—A small outcrop of barite mixed with magnetite is located near the north end of the Bader iron ore prospect (Paige, 1911, pp. 32–33), about 9 miles west of Llano. Only a small amount of barite is exposed, and the extent of the deposit has not been determined.

Barite nodules occur at several localities in San Saba and Travis counties. The reported occurrences are too small to be of commercial interest, but nearby deposits at the same stratigraphic positions may be larger. In San Saba County, barite nodules have been reported in an outcrop of the Barnett formation in a bluff west of Wallace Creek about 12 miles southwest of San Saba, in the Marble Falls formation on the Leonard ranch about 5 miles south-southwest of Richland Springs, and from either the Marble Falls or Barnett formation about 10 miles southwest of San Saba. Concretionary nodules of barite are exposed in outcrops of the Taylor marl in Travis County.

BLEACHING CLAY AND DRILLING MUD

Most of the clay from the Texas Coastal Plain used in various oil-refining processes and as drilling mud technically is bentonite and is so reported in production statistics. Bentonite varies widely in its properties. Certain bentonites adsorb large quantities of water, swelling or expanding greatly in the process. Others possess this property to only a slight degree and still others occupy an intermediate position in this respect. Most fuller's earth is bentonite which in its natural state has the capacity for adsorbing coloring material from oil or is said to be naturally active. Other bentonites become active after treatment with acid. Some bentonites, especially the high-swelling type, are neither naturally active nor activable. The bentonites generally are not suitable for ceramic products. Tests and specifications for various uses of bentonitic clays differ greatly, and the clays likewise vary in composition and properties. Various tests give general indications of possible uses of a clay, but the critical question is whether the clay will meet the demand of the user for a particular use.

Commercial classification and statistical reporting of fuller's earth and bentonite are not entirely consistent. In 1956 Texas produced 160,723 short tons of bentonite valued at $1,182,620, about 10 percent of the total production in the United States. The major uses were in oil refining, drilling mud, insecticides, and sweeping compounds. Only a small tonnage was used as a foundry-sand bond, a principal use of bentonite from some states. A small production of fuller's earth was reported from Texas; the uses were generally the same as those of bentonite.

Fayette County has been a producer of bleaching clay and drilling mud for many years. Bentonite of suitable quality for these uses is present in the lower part of the Jackson and possibly in the upper part of the Yegua formation in a belt extending across the county. The general outline of the area where these clays are present is shown on Plate III, as are also the active pits at localities C-1, C-2, and C-3. The clay from locality C-3 is classified by the producer as fuller's earth. At other bentonite localities shown on Plate III, the exposures are poor, and at some the clay is interbedded with volcanic ash. At locality C-5 at least 6 feet of pure brown bentonite with little overburden is present.

Bailey (1923) reported a deposit of bentonite on East Sandies Creek about 3 miles northwest of Rock Island in Colorado County. This clay appears to be of good quality and the results of tests made on it show that it resembles some of the clay in Fayette County. It is not known whether the Colorado County clay has been tested commercially.

In the present investigation, water of plasticity, swelling, and slaking were determined for samples of clay from localities in Fayette County shown on Plate III and for the clay on East Sandies Creek in Colorado County. Water of plasticity ranged from 70 to 165, swelling from 100 to 475, and slaking from 0 to 84 It is obvious from these results that the materials vary greatly and that every deposit must be tested and evaluated separately.

In both Fayette and Colorado counties, exposures are poor and brush covers much of the areas in which clays are present. Careful prospecting is necessary to locate suitable deposits.

BUILDING STONE

Building stone as used in this paper includes both dimension stone and crushed stone used for structural purposes. Dimension stone is the term applied to stone sold in blocks or slabs of specified shapes and sizes contrasted with crushed or broken stone. Cut stone, rough building stone, paving blocks, curbing, and flagging are among the common types. Riprap usually is not included.

At one time elaborate strength tests were made for dimension stone. These are largely disregarded today because any sound stone suitable in other respects is stronger than required for any ordinary use. General durability under weathering is of prime importance, and tests are available to give an index of the expected behavior of the stone. There are a few special specifications for special uses, such as sanitary uses, floors, and in laboratories.

Architects and builders exercise great freedom in selection of a stone for a specific structure, and specifications are in terms of workmanship and surface finish rather than color, texture, or general appearance. Once established in the trade a stone is difficult to displace even by one of equal quality and lower cost. In most buildings the cost of the stone is only a small part of the total cost, and many builders are willing to pay a higher price for a stone which is currently popular. The Bedford stone of Indiana is an example. Trade names are commonly applied to the product of individual quarries. Cordova Cream and Cordova Shell are such names applied to a widely used and widely advertised Cretaceous limestone from the CRIDA area.

The most common uses of crushed stone are in highways, reinforced concrete in various types of structures, railroad ballast, and filter beds. The basic physical properties of aggregates that affect their behavior when used for various structural purposes are hardness, toughness, and the properties that control the resistance of the rock to the disrupting action of weathering agents. Specifications and tests for the various uses have been established. The stone must meet these specifications and also must lend itself to economical production and preparation for the market. Crushed stone used for the purposes mentioned above is a low-cost product and generally is marketed locally. In 1956 the production of crushed stone in Texas was 18,991,772 short tons valued at $19,087,421, slightly more than $1.00 per short ton.

Granules and terrazzo chips are special types of crushed stone which command higher prices than crushed stone used for common construction uses. Granules are used to form a protective and decorative coating on the weather surface of composition roofing and siding and in built-up roofing. Resistance to weathering and stability of color are more important than strength or toughness, so that the specifications are different than those for crushed stone used in construction. However, many limestones and marbles used for construction purposes are suitable for granules. The material should be sufficiently tough to withstand handling by mechanical equipment and should be uniform in physical and chemical composition so that large quantities of granules with consistent color and sizes can be produced.

Color of the finished product is of special importance because shingles, roofing, and other materials using granules are sold on the basis of color appeal. A color once established in the trade must be maintained with only slight variation so that the product furnished at one time will exhibit only a little color difference from that produced at another time. Green, red, black, blue, and buff are among the colors of granules. A wide range of colors is available in granules produced at present with many of the colors imparted through processes developed since about 1925. In 1956 the production in the United States was 1,684,200 short tons valued at $33,727,283, with a unit price many times that of ordinary crushed stone.

Terrazzo chips are used to produce pleasing color patterns in the familiar terrazzo floors, base courses, and stairs much used in recent years. The chips are imbedded in a special colored or uncolored cement surface of the concrete slab, ground to a smooth surface, and polished. The great popularity of this material is attributed to the attractive appearance of the surface, ease of cleaning, and durability. The material is neither stronger nor more durable than ordinary concrete aggregate made from the same materials. In recent years terrazzo has been used as exterior decorative stone, roller-skating rink floors, outdoor cafes, and even bowling alleys, and probably these uses will increase.

Terrazzo aggregates for use in floors must meet specifications for abrasive hardness, bulk specific gravity, water absorption, and toughness. These are somewhat less strict than those for certain other types of concrete aggregate used in construction, but it is obvious the material, in many uses, is subject to continued abrasion and other external forces. Many kinds of materials are used for terrazzo chips, but compact noncleavable materials are desirable. In the CRIDA area various types of marble are used and probably are the best materials available.

As with granules, color and uniformity of product are important. Producers establish grades or types, many of which are designated by trade names, such as Texas Royal Green, Alpine Red, Red Rosa, under which the product is marketed. A wide range of colors is used; there is some artificial coloring of terrazzo chips but not to the extent as with granules. Separate production figures for terrazzo chips are not available because part of the production is included with crushed stone and part with granules. In 1955 about 78,000,000 square feet of terrazzo was laid in the United States, and in 1957 the figure had risen to about 84,000,000 square feet. Recent market prices in central Texas have been $15 to $25 per ton.

There is an abundant supply of a wide variety of building stones in the CRIDA area northwest of Austin. Granite, dark-colored igneous rocks, marble, and gneiss are present in Blanco, Burnet, Llano, San Saba, and other counties in central Texas (Pl. I). Many varieties of limestone and sandstone suitable for building stone are present in Blanco, Burnet, Llano, San Saba, and Travis counties. One sandstone formation in Fayette County has supplied stone used to a limited extent, but no other suitable stones are known in the area downstream from Austin. Magnesite and serpentine marbles present in the upstream area have potential uses in addition to building stone and are discussed in separate sections.

Many building stone localities for which information is available are shown on Plate II. The properties of the stone as *dimension stone* are listed in tables 2–5. In the following discussion, in the tables, and on Plate II, localities are designated by symbols, such as Bu-17, referring to a locality in Burnet County.

Information on the building stones as dimension stone was compiled mainly from a report on the building stones of central Texas (Barnes, Dawson, and Parkinson, 1947). Detailed descriptions of samples from many of the localities listed are contained in that publication.

Granite

There is an abundant supply of granite in central Texas suitable for use as building stone. The area is centrally located with respect to the major population centers of the State, and many of the granite masses are near rail transportation. The rail distance from Llano to Austin is less than 100 miles and from Llano to tidewater at Houston, approximately 250 miles.

Most of the granite is pink, but a large quantity is gray. The colors range from almost white to dark gray and from almost white to red. At a few localities the color of the granite is salmon pink, reddish brown, chocolate brown, or an attractive blend of larger pink crystals in a medium gray matrix. The gray granite is almost entirely fine to medium grained and of uniform texture; the pink granite ranges from fine to coarse grained and from uniform to distinctly porphyritic texture.

There are various grades of granite in central Texas. Although much of the granite is suitable for building, decorative, or monumental stone, some is less desirable because of nonuniform texture, mineralogical composition, inclusions, dikes, or closely spaced joints. Sound granite that contains inclusions or dikes or has nonuniform texture may be used where appearance is not important; for example, in the construction of jetties, breakwaters, or seawalls.

An adequate exploratory program should be a part of the selection of each new quarry site. In the past some quarries in the area were opened in granite of inferior quality. The mineralogical composition, not the chemical composition, should be used in determining the quality of the granite. An abnormally high iron content reported in a chemical analysis has been erroneously considered sufficient reason for rejecting the stone for exterior use, but the iron may be present either in stable minerals which do not affect the quality of the stone or as unstable minerals that decompose and cause unsightly stains on exposed surfaces. Also, the chemical analysis may not indicate the presence of an objectionable quantity of the mineral calcite.

In the following discussion the granites have been divided into two general groups —gray granite and pink granite. A few specimens that do not strictly belong in either group are included in the group of nearest affinity. Summaries of the localities and properties of the rocks are presented in tables 2 and 3. The discussion supplements the tables and supplies additional pertinent information concerning some of the granite masses. In the information presented in the tables and discussion, the granites are considered as dimension stone. Granite is used to a limited extent as ordinary crushed stone and only to a very slight extent as crushed stone in built-up roofs.

Gray granite.—Several of the gray granite masses in central Texas contain large quantities of stone equal or superior to that found elsewhere in the United States. Misrepresentation of the quality of Texas granite, due in part to the fact that some of the older quarries were opened in masses of inferior grade, has discouraged the development of a local granite industry.

The granites at localities LI-21, LI-22, LI-26, Ll-37g, LI-39, LI-40, M-6, and M-23 are exceptionally good for use, either as building stone or as monumental stone. The largest and most impressive of all the gray granite masses is at locality M-23. Several acres of smooth granite surface with no noticeable inclusions are exposed south of the quarry at this locality; a 200-foot cliff of the granite stands northeast of the quarry. Dark gray granites at localities Bl-20, Bu-17, and G-12 are of fair quality. The stone from locality Bu-17, the gray granite mass near the center of figure 8, is not suitable for use as monumental stone because there is little color contrast between the polished and unpolished surfaces.

The rock at locality Bl-6 is from one of several small, scattered bodies of near-white, fine-grained granite in a large mass of red to near-white granite containing many inclusions and cut by numerous dikes. Field examination indicated that the desirable stone is scarce; there may be too little available to warrant commercial development.

Granite at six localities has a pink cast to the gray color. Pink feldspar crystals give the granites at Ll-25 and Ll-37 an attractive, uniform pink cast. Near G-12 the color of the stone ranges from gray to pink; however, rock with uniform color probably is present in parts of the mass. The pink color at localities Ll-21, Ll-52, and Ll-65 is attributed to weathering. It is less noticeable near the bottoms of the present openings, and uniformly colored gray granite probably would be encountered at depth.

Pink granite.—Masses of pink granite in central Texas are numerous and large. Only a few have been mapped in detail. Information concerning the more important localities of pink granite available in the area is given in table 3. Some of the masses have been named, and localities in these for which information is available concerning the stone are listed below.

A wide range of color is exhibited by the pink granites. In table 3 the entry "pink" indicates the presence of an orange tint in the color; entries of "rose" or "rust" indicate that the orange tint is either minor or absent; "salmon" indicates a distinctive salmon-pink color.

The Granite Mountain mass is in the vicinity of Marble Falls and Kingsland in western Burnet and eastern Llano counties. A quarry at Granite Mountain, Bu-5, has been operated intermittently since 1882, when it was opened to provide stone for the Texas Capitol building. Stone from this quarry has been used in buildings in

GRANITE MASS	COUNTY	LOCALITY NUMBER
Enchanted Rock	Llano and Gillespie	G-15, Ll-13, Ll-28, Ll-29, Ll-30, Ll-63
Granite Mountain	Burnet and Llano	Bu-5, Bu-6, Bu-9, Bu-12, Bu-13, Ll-12, Ll-44
Grape Creek	Blanco	Bl-11, Bl-15
Grit	Mason	M-7
Katemcy	Mason and McCulloch	M-4, M-5, M-9, M-11, M-12, M-17, M-19
Llanite dike	Llano	Ll-35
Lone Grove	Llano	Ll-14, Ll-16, Ll-36, Ll-43, Ll-68
Oatman	Llano	Ll-45
Wolf Mountain	Llano	Ll-23

practically every state in the United States arid in many foreign countries and for seawall and jetty construction on the Texas and Louisiana coasts. Since 1950 this quarry has been operated by the Texas Granite Corporation; the present rate of production is about 30,000 square feet of finished stone per month.

The llanite dike, Ll-35, contains an unusual and attractive stone, locally called "opaline granite." It consists of hexagonal larger crystals of bluish opalescent quartz and rust-flecked feldspar in a chocolate-brown dense matrix. A dike or series of dikes of this rock extends northward for about 9 miles from locality Ll-35, then turns sharply southwestward for a distance of about 4 miles, crossing State Highway 16 on the southeastern slope of Babyhead Mountain about 10 miles north of Llano. For most of this distance the dike is thin and highly jointed, but limited quantities of stone have been quarried a short distance west of the highway at Ll-35a. There are possibly other potential quarry sites along the dike.

In the Lone Grove mass at Ll-68 clear stone would be difficult to obtain because of numerous inclusions and dikes. The same is true of the stone in the Wolf Mountain mass at Ll-23. Both localities are near rail transportation, and the granite is suitable for jetties, seawalls, and other uses where appearance is not important.

Granites from the Grape Creek mass at localities Bl-11 and Bl-15 should not be used for building stone because of a high calcite content. The stone at these localities would be suitable for use in seawall and jetty construction, but other deposits are nearer rail transportation.

Precambrian Marble

The Precambrian marbles of central Texas are true metamorphic rocks with a wide range of textures governed by the size, form, and arrangement of mineral grains in the rock. Many metamorphic minerals are present, and minor constituents in many of the rocks are concentrated in bands. Attractive patterns have been produced by the intricate folding of some banded marbles. Colors range from black through gray to white, from greenish black to light green, and from medium brown to cream. The marbles may be divided into five groups according to the predominant mineral in the rock: (1) calcite marble, (2) dolomite marble, (3) wollastonite marble, (4) magnesite marble, and (5) serpentine marble.

The magnesite and serpentine marbles have potential uses other than as building stone and are discussed under the headings "Magnesite" and "Serpentine" elsewhere in this report. A summary of the locations and physical properties of specific deposits of calcite, dolomite, and wollastonite marble is presented in table 4, with evaluations for dimension or decorative stone uses.

Beds of marble are common in the Precambrian rocks in four areas in Llano County (Paige, 1912) and one area in Mason County (Barnes et al., 1947). Scattered outcrops of marble have been mapped in other parts of the Llano uplift; detailed mapping may be expected to reveal additional deposits. Marble beds occur south and west of Kingsland in eastern Llano County in an area from 2 to 4 miles wide extending southward along the east side of Packsaddle Mountain, then northeastward to the east flank of Riley Mountains. Information is listed concerning marbles at localities L 1, Ll-5, Ll-7, Ll-8, Ll-9, Ll-11, and Ll-50 in this area. Three of these localities, Ll-8, Ll-9, and Ll-50, are also within the area covered by Plate V.

Marble beds and lenses are common in an area from 1 to 4 miles wide extending from about 3 miles southeast of Oxford to Llano then north-northwestward to the edge of the Precambrian outcrop area about 3 miles northeast of Valley Spring. The marble-bearing schist is covered by sedimentary rocks in the vicinity of Oxford and is intruded at many places by masses of granite. In the area southeast of Oxford, marble bands are closely spaced; between Oxford and Llano they are more widely spaced; and in the area north of the Llano River they are short and widely scattered. Localities Ll-18, Ll-20, Ll-34, Ll-53, Ll-54, Ll-55, Ll-58, Ll-59, Ll-71, and Ll-72 are in this area.

One persistent band and several smaller bands of marble crop out roughly parallel to Cottonwood Creek (12 miles southwest of Llano) for a distance of about 9 miles, from north of the Llano—Cherry Spring road to near State Highway 16. Localities Ll-27, Ll-42, and Ll-48, described in table 4, are on this band.

Outcrops of marble occur in an area about 2 miles wide and more than 4 miles long generally parallel to and west of Little Llano River in the vicinity of Lone Grove. No information is available on the properties of marble in this area.

There is a large area of Precambrian marble south of Streeter in western Mason County. Outcrops of massive marble are reported to extend for several thousand feet along the creeks. Localities M-2 and M-8 are outcrops near the northern edge of this marble area.

Wollastonite marble is not common in the Precambrian rocks of central Texas; it occurs in the zones of contact metamorphism near masses of granite. Although it has not been used for building or decorative purposes, it is an attractive, tough, and chemically stable stone. Its surface takes a uniform but not brilliant polish and has a silky, felted appearance because of the arrangement of the fibers in the mineral wollastonite. Special quarrying techniques would be necessary because the interlocking fibers produce a tough stone with no grain or preferred alignment to assist in making breaks. This type of marble should prove valuable where large slabs are used; the higher production costs should be at least partly offset by decreased breakage.

The Precambrian marbles are an important source of granules and terrazzo chips, and a large part of present Texas production is from them. A great variety of pleasing colors is available, and many of the beds have satisfactory physical properties. Size of individual deposits and uniformity of the stone are important factors as far as commercial development is concerned. Practically all of the marbles listed in table 4 could be used for the purpose. Details concerning serpentine marble, likewise used in terrazzo chips, localities are given in table 7.

Gneiss

Gneiss is rarely used as building stone, and information is available for only a few localities in the vast gneiss outcrop area in the Llano uplift. Within the outcrop of Valley Spring gneiss south and east of the Southwestern Graphite Company plant in the Clear Creek area (fig. 8), there is a large area of massive, pink gneiss that appears to be strong and durable. The stone has less banding and contains less mica than the other gneiss in this area and should be suitable for use as dimension stone. Gneiss has been quarried in Llano (Ll-38) for use in local buildings. Although the stone is well suited for this purpose, it has no value as cut stone.

The gneiss at M-24, northeast of Mason, is a good decorative stone with a strikingly attractive appearance. Cut surfaces expose elliptical areas of red feldspar up to half an inch in diameter in a groundmass of dark gray; the darker minerals in the groundmass are concentrated in bands that weave among the areas of feldspar. The quantity and distribution of gneiss at this locality are unknown.

Dark-Colored Crystalline Rocks

Dark-colored crystalline rocks, both igneous and metamorphic, occur in Blanco, Burnet, Gillespie, Llano, Mason, and Travis counties. Most of the rock masses are small, and those that have been examined in detail are not suitable for use as dimension stone because of closely spaced joints. Further search in the vicinity of the known occurrences might result in the discovery of other masses that could be used as dimension stone. Practically all of the stone appears to be suitable for use as crushed stone or possibly as terrazzo chips.

Several occurrences of basic igneous rocks in Llano County were mentioned by

Paige (1911), but the possible uses of the stone were not evaluated. Most of the rocks he described were from intrusive masses in southeastern Llano County. A number of basic igneous rock masses were described by Barnes et al. (1947). Diorite is present at localities Ll-61 and Ll-70. There are small outcrops of hornblendite north of the Coal Creek serpentine mass near Bl-25, also shown on Plate VI in northwestern Blanco and northeastern Gillespie counties, and at Ll-64 near the southwestern corner of Llano County. Many intrusive masses ranging from diorite to hornblendite crop out east of Cedar Mountain, within the area of Plate VIII, in southern Llano and northeastern Gillespie counties. Most of these masses are sill-like bodies and many are quite small.

A roughly circular mass of basalt, more than 1 mile in diameter, forms a hill called Pilot Knob (locality T-33), 8 miles S. 10° E. from the Capitol building in Austin. The basalt has potential value as crushed stone; similar basalt at Knippa, Uvalde County, is crushed for use as concrete aggregate and road material. Other small outcrops of basalt in Travis County are of no commercial importance.

Amphibolite at localities Bu-30, Ll-49, Ll-51, and M-15 and epidote rock at Ll-57 are of little value as decorative or dimension stone or as terrazzo chips because of excessive joints or the presence of deleterious minerals. Stone from some of the masses could be used for dark-colored flagging.

Sandstone

Although there is a large supply of sandstone in central Texas it has not been used extensively as building stone. Most of the sandstone sufficiently hard and resistant for use as building stone ranges in color from buff to brown. Unless building stones of somber hue regain their popularity, there will be little demand for most of the sandstones in this area. A specialty stone similar to the brown ledge stone now being shipped to central Texas from Arkansas probably could be produced at some locality in this area.

Within the transitional zone between Hickory sandstone and Cap Mountain limestone (Pl. I), there are uniformly and thinly bedded, buff to brown, fine-grained sandstones of building grade. Stone of this kind is present at localities Bl-13, Bu-43, Ll-3, M-1, and S-26. Stone from the quarry at M-1 has been used extensively in Mason for business buildings and residences.

The Welge sandstone member of the Wilberns formation is a brown, uniform-grained sandstone that is highly resistant to weathering. The sandstone is about 24 feet thick in Gillespie County; it also crops out in Blanco, Burnet, Llano, San Saba, Mason, and McCulloch counties. In Burnet County the sandstone is glauconitic. This stone has not been tested for building stone purposes.

There are sandstone beds up to 6 inches thick in the Smithwick shale in Burnet County. The equigranular, fine-grained sandstone ranges in color from gray to yellowish gray. This stone is present at localities Bu-2 and Bu-3 and is of value primarily for local building.

In San Saba and Lampasas counties the Strawn group contains alternating beds of predominantly fine-grained sandstone and shale. Sandstone suitable for use as building stone is present in many localities. Most of the stone is thin bedded, but the thickness of the beds in some places exceeds 3 feet. At most localities the color ranges from light buff to brown; attractive yellow-, red-, and gray-banded sandstones are locally abundant. Strawn sandstone is present at localities S-2, S-15, and S-21.

There is only one stone of possible commercial value as building stone in the area southeast of Austin. Hard indurated Carlos sandstone of the Jackson group in ledges suitable for quarrying crops out in western Fayette County (Pl. III). This stone has been quarried in the vicinity of Muldoon for use as crushed stone and in buildings. Its principal future use probably will be as crushed stone.

Limestone and Dolomite

Many limestones and dolomites crop out in the upstream part of the CRIDA area. Those of various Paleozoic ages are especially abundant along the inner flanks of the Llano uplift (Pl. I). Those of Cretaceous age are more abundant along the rim of the Llano uplift and as far downstream as Austin. Practically all of the Paleozoic limestones and dolomites and many of those of Cretaceous age are marbles in the commercial sense because they take a polish. The Paleozoic limestones and dolomites have been produced for crushed stone including chemical stone and terrazzo chips. Those of Cretaceous age have been produced for crushed stone and dimension stone.

Information is available on only a few of the vast number of outcrops. The following discussion includes general descriptions of the limestone or dolomite present in the stratigraphic units known to contain building stone. Table 5 contains information concerning the stone at localities for which information is available. The distribution of outcrops of the stratigraphic units is shown on Plate I.

Paleozoic Limestone and Dolomite

Wilberns and Cap Mountain formations.—There are five limestones and one dolomite within the unit mapped as Wilberns and Cap Mountain.

(1) The Cap Mountain limestone is a brown to gray glauconitic limestone that takes a fair polish. Although the stone is dark colored, it could be used as a polished building stone; it is also suitable for use as crushed stone or terrazzo chips. Table 5 gives information on the stone at localities Bl-12, Bl-26, Bu-15, Bu-22, and Bu-26.

(2) The Morgan Creek limestone is a clear gray limestone that contains a few grains of glauconite. It takes a brilliant polish and would be a good ornamental or decorative stone. Beds of this limestone are rarely more than 2 feet thick. The stone from locality Bl-21 is described in table 5.

(3) Massive limestone reefs up to 100 feet thick and several square miles in areal extent occur at various levels in the Wilberns formation; they are more common near the center of the unit. The larger reefs occur in Mason and Gillespie counties, but reef limestone has been found throughout the outcrop area. The limestone is light bluish green, somewhat mottled, and takes a fair to brilliant polish. Table 5 includes informations on the stone at localities Bu-21, Bu-27, Bu-28, and M-21.

(4) In the western and northern part of the outcrop area of the Wilberns and Cap Mountain formations, the Point Peak shale contains numerous thin beds of edgewise conglomerate that would be suitable for use as decorative stone. Flat pebbles of a variety of colors and types are regularly arranged in a greenish glauconitic matrix. Individual beds are of limited extent and rarely exceed 1 foot in thickness. Stone from locality S-13 is described in table 5.

(5) Within the San Saba limestone member, primarily in the western half of the outcrop area of the Wilberns and Cap Mountain formations, there is a series of beds that contain spherical white fossils one-fourth to one-half inch in diameter in a cream-colored to light yellow matrix. Heating changes the color of the matrix to red; the fossils remain white. Much of this stone is thinly bedded and suitable for use only as pitched face stone; however, beds up to 5 feet thick could be quarried at some localities. The matrix takes a dull polish; the white areas take a brilliant polish. Table 5 contains descriptions of this limestone from localities Ll-60 and S-12.

(6) Pedernales dolomite, which occurs principally in the eastern half of the outcrop area of the Wilberns and Cap Mountain formations, is a fine- to coarse-grained, yellowish-gray to silver-gray dolomite that contains very little chert. Purple bands and markings are common in some areas. This dolomite takes a fair to good polish and would be good as building stone or crushed stone. Samples were collected at Bl-2, Bl-16, Bl-17, Bl-18, and G-18.

Ellenburger group.—Extensive deposits of limestone and dolomite are present in the Ellenburger group. Detailed mapping has shown that rock suitable for use as polished stone is more likely to occur among the limestones of the Threadgill member of the Tanyard formation, the uppermost portion of the calcitic facies of the Gorman formation, and the upper calcitic portion of the Honeycut formation. The latter unit is present only in a limited area of Blanco County and possibly in eastern Burnet County. There is little chance of finding stone of decorative or monumental grade in the dolomites of the Ellenburger group.

Stone from all units of the Ellenburger group is suitable for use as crushed stone, including granules and terrazzo chips. There is little variation in strength or hardness and a considerable range in color is present. In the production of ordinary crushed stone, availability of transportation is highly important, and unfortunately many of the Ellenburger localities are far from railroads or improved highways. Most of the production except of granules and terrazzo chips has been along the railroad in western Burnet and eastern Llano counties. Figure 3 is a detailed geologic map showing the outcrops of these rocks in most of this area. Crushed stone for use as railroad ballast, road material, concrete aggregate, and chemical stone has been produced by Victoria Gravel Company from a quarry (now inactive) near Sudduth, Burnet County (Bu-35). Crushed stone for railroad ballast, highway and concrete aggregate, filter media, and chemical stone is produced by Texas Construction Material Company from a quarry east of the railroad about 3 miles south of Burnet (Bu-48). Figure 3 includes the localities of both quarries. Several small terrazzo chip quarries, both active and abandoned, have been opened in the Ellenburger outcrops in this same general region.

Table 5 contains information on calcite marbles from the Ellenburger group at localities Bu-11, Bu-16, Bu-24, Bu-25, Bu-29, Bu-31, Bu-33, Bu-37, Bu-38, Bu-40, Bu-42, G-22, G-23, G-24, Ll-4, Ll-47, S-1, S-3, S-8, S-10, S-14, S-18, S-19, S-23, S-24, and S-25 and dolomite marbles from localities Bl-22, Bu-4, Bu-20, Bu-34, Bu-35, Bu-36, Bu-39, Bu-44, Bu-48, G-17, S-6, S-11, and S-20.

Marble Falls formation. — Most of the Marble Falls limestone is rather dark colored, either brown or black. Much of the stone takes a dull polish and is suited principally for use as crushed stone or terrazzo chips. Table 5 contains information on the stone at localities Bu-14, Bu-19, Bu-45, S-5, and S-17.

Some of the dark-colored limestone contains light-colored fragments of crinoid stems. These stones take a fair to brilliant polish and could be used as decorative stone. Such stone is present at localities Bl-19 and S-7. Attractive light gray limestones are reported to occur in the Big Saline member of the Marble Falls limestone in San Saba County.

In the northern part of the outcrop area beds of tough, compact, highly porous siliceous residue have formed from spiculose limestone near the top of the Marble Falls limestone. This siliceous residue, although it has been used locally as building stone, is treated in this report under the heading of "Spiculite."

Trinity group. — Selected thin beds of Glen Rose limestone can be used as building stone. Most of the stone is of value principally for local construction. The color at most localities is light gray, and both fossiliferous and equigranular, nonfossiliferous limestone is present. Table 5 contains information on the stone at localities Bl-3, Bl-4, Bl-5, T-11, T-13, T-17, T-22, T-27a, and T-32.

Fredericksburg group. — An oolitic limestone and a shell limestone are quarried by Texas Quarries, Inc., from the Cedar Park member of the Walnut clay in northern Travis County (locality T-37). This stone has been used in buildings throughout the United States and is marketed under the names of Cordova Cream, Cordova Travertone, and Cordova

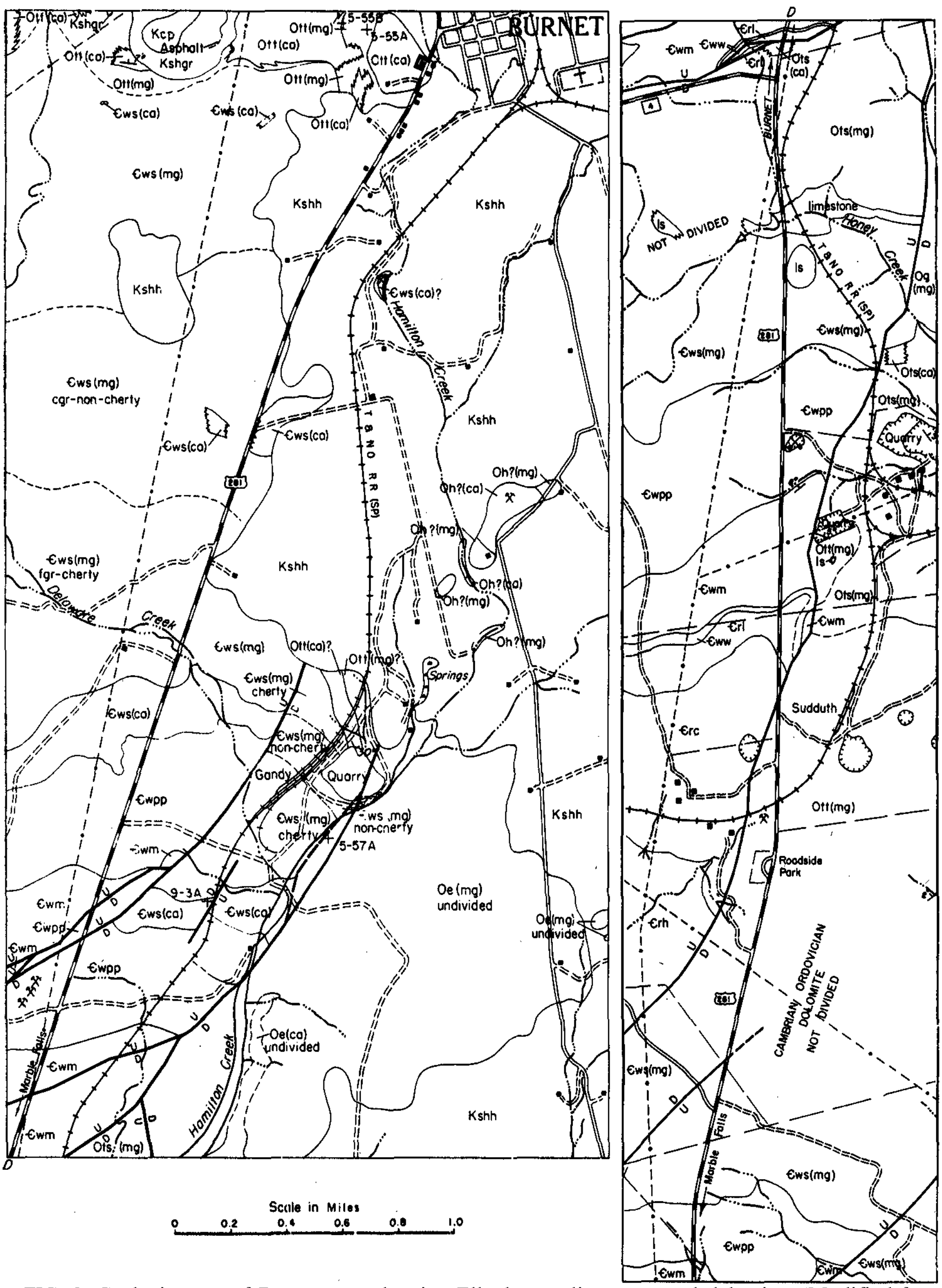


FIG. 3. Geologic map of Burnet area showing Ellenburger limestone and dolomite. (Modified from San Angelo Geological Society 1956 Guidebook and Bureau of Economic Geology Guidebook No. 1.) (Cretaceous rocks—Kcp, Kshgr, and Kshh; Strawn group—Cst(?); Ellenburger group—limestone, Oe(ca),Oh?(ca),Ots(ca),Ott(ca); dolomite, Oe(mg),Og(mg),Oh?(mg),Ots(mg),Ott(mg); Cambrian rocks—Єws(mg), Єws(ca), Єwpp, Єwm, Єww, Єrl, Єrc, Єrh.)

Shell. The limestone member has a maximum thickness on the order of 10 feet at the quarry. Fine-grained, uniform-textured limestone believed to be the Cedar Park member of the Walnut clay is present in large quantities also at T-2, T-5, T-30, and T-34 in Travis County.

Edwards limestone suitable for use as building stone is known at several localities. Both fossiliferous and equigranular, nonfossiliferous stone is present. The color of the Edwards limestone is cream, buff, or gray. At many localities the beds are less than 2 feet thick so that the stone is of value principally as pitched face stone or as terrazzo chips. Stone with uniform texture is present at localitiees Bu-23, T-14, T-15, T-18, T-24, T-27b, and T-28; fossiliferous stone is present at T-4, T-9, T-16, T-18, T-20, and T-36. Information on the stone from these localities is contained in table 5.

Quartz

Quartz is used in a special type of terrazzo called washed paneling, used as an exterior decorative stone. Quartz fragments are embedded in fine concrete and left protruding beyond the general surface. This is a specialty product with a limited use, the future popularity of which cannot be predicted.

Quartz occurs in veins and pegmatites in the Llano uplift. Masses of quartz are present in the Badu Hill pegmatite (fig. 5), and there are other veins and masses in the area covered by Plate V. Comstock (1890) reported outcrops of white quartz in the vicinity of Pecan and Wolf creeks west of Babyhead and also west of Lone Grove in Llano County. At the present time, quartz is being produced at locality Ll-103 (Pl. II) in southeastern Llano County.

BURNING CLAY

Clay is a fine-grained earthy rock which becomes plastic when wet and hardens when burned or fired. Shale, which in a general way is indurated clay, can be used for some of the same purposes as clay. Clay which is suitable for the manufacture of ceramic products is called burning clay, although there is a wide range in the character of the clay used. The significant properties of burning clays include plasticity, fired color, dry and fired strength, dry and fired shrinkage, dry and fired apparent porosity, softening point on firing (pyrometric cone equivalent, P. C. E.), vitrification range, bloating properties, absorption, and others.

Elaborate and time-consuming laboratory procedures are available to determine these properties, but practical ceramic tests are still employed. Preliminary firing gives information on the refractory character of the clay and qualitative information on many of the other properties.

Some clay which is suitable for various-shaped burned clay products also will bloat or expand under the proper heat treatment. Some clay not well suited to shaped products also will bloat. In recent years bloated or expanded clay or shale has been used widely in lightweight concrete aggregate.

Burned clay products of various kinds can be made from a great variety of clays. Brick, for example, can be made from almost any kind of clay, but the brick produced from some clays will be far superior to that from other clays. Common burned clay products are heavy, relatively low priced, and are made in many localities, so that these products do not move great distances to market. Some refractory brick and other types used for special purposes can be moved to distant markets.

The color or pattern of face brick, tile, and other shapes with exposed surfaces used in residential and even larger construction plays an important part in marketing. As with dimension stone, granules, and terrazzo chips, there are styles, almost fads, which may result in great popularity and great demand for a particular product. In some areas, face brick and other shapes of much lower quality than others made in the same region or available at the same or lower prices are sold in large quantities. The present demand for Mexican hand-formed soft mud face brick is an outstanding example.

There are many kinds of clay throughout the CRIDA area, and clay or shale formations are present in every county. The location of plants producing burned clay products has been determined by the quality of the clay available, transportation facilities, and markets. Among the clays for which information is available, those in the Wilcox group (Pl. I) interbedded with or stratigraphically close to lignite beds are of highest quality. These are used in plants near Elgin and from them have been made a variety of light to buff-burning products including low heat duty refractory brick. Clay from which medium duty refractory products could be made probably could be produced by careful selection. The area in which these clays are most abundant coincides with the lignite areas shown on Plate IV. Probably the next best clays in the area are other Wilcox clays not associated with lignite beds. Some of these are suitable for brick, tile, and pottery. Many of the clays north of the Wilcox outcrop contain lime, a deleterious constituent, and many of the deposits are not well located. South of the Wilcox outcrop, the clays mainly are either bentonitic with high shrinkage or high in lime. The bentonitic clays are especially abundant in Fayette County.

In many places throughout the area careful selection probably would supply clay from which usable common clay products could be made. Probably also, only the products with attractive finish or located advantageously with respect to markets could be produced profitably. At Palacios, for example, a clay carefully selected from among the Quaternary clays and very carefully fired is used for a variety of shapes, such as face brick and others. The clay fires to an attractive red and is marketed as far as Houston, Victoria, and Corpus Christi. Plants at Houston and Sugarland are in the same category.

Tests were made of the bloating properties of 33 clays from Bastrop, Fayette, and Matagorda counties. Only one, from Fayette County, showed any promise. However, clay similar to that near Rosenburg used for this purpose probably is present in the area.

Ceramic tests of clays from the CRIDA area are shown in table 6. These are mainly from Bastrop County because there is accurate information concerning locations and quantities. There are many tests of clays from other counties contained in various reports, but the locations are approximate and no details concerning the clay beds are given. The locations of samples from Bastrop County are shown on Plate IV and those from Fayette County on Plate III.

Table 6. Ceramic properties of clays in the CRIDA area.

BASTROP COUNTY

NO.	LOCATION	CERAMIC PROPERTIES
1	State Highway 20, 2 miles west of McDade[1]	No lime, good plasticity, burns dark buff at cone 04 with 15 percent total shrinkage. Possibly suitable for art pottery.
2	State Highway 20, 2.5 miles west of McDade[1]	No lime, good plasticity, burns light red at cone 04 with 11.5 percent total shrinkage. Possibly suitable for red-burning pottery.
2a	State Highway 20, 2.5 miles west of McDade[1]	From lower bed, 10 percent total shrinkage.
3	Old State road about 3 miles southeast of Elgin, south of railroad[1]	No lime, plasticity good, burns orange red at cone 04 with 11.5 percent total shrinkage. Probably suitable for pottery and possibly brick and tile.
4	Five miles southeast of Elgin, 0.2 mile east of M.K.T. Railroad at old Lasher brickyard	No lime, burns buff at cone 02, gray and steel hard at cone 7. Bloating properties negligible; possibly suitable for brick and tile.
5	Camp Swift, 1.5 miles northeast of Swiftex[1]	No lime, plasticity good, excessive cracking on drying, burns pink to red steel hard at cone 1 without additional cracking. Total shrinkage 18.4 percent.
6	Sandy Creek, 0.4 miles southeast of Sayersville, H. N. Bell property	No lime, plasticity fair, burns buff and steel hard at cone 02, burns gray with slight bloating at cone 7. Bloating properties negligible.

[1] Tests reported by Pence (1951).

7	One-half mile southeast of Sayersville, abandoned right-of-way, J. D. Owen property	No lime, burns buff at cone 02 and steel hard and dark gray at cone 7. Bloating properties negligible; possibly suitable for brick and tile.
8	East side of M.K.T. Railroad 1 mile south of Sayersville	Lime none, burns buff and steel hard at cones 02 and 7, burns gray green at cone 12. May be suitable for refractories. Bloating property negligible.
9	Along pipeline 3.3 miles west of Camp Swift, H. N. Bell property	Lime none, burns gray and steel hard at cone 7, bloating properties negligible. May be suitable for brick and tile.
10	One-fourth mile northwest of Wilbargers Creek, 4 miles west of Camp Swift, Zetty Green property	Lime none, burns light tan at cone 02 and dark gray and steel hard at cone 7. Bloating properties negligible. Possibly suitable for brick and tile.
11	Five miles north of Bastrop[1]	Lime high, plasticity good, burns pinkish red at cone 04 with cracking. Total shrinkage 13 percent.

BURNET COUNTY

Three miles southeast of Marble Falls (Pennsylvanian shale)[1]	No lime, plasticity fair, drying behavior good with slight warping. Burns red at cone 04, total shrinkage 10.3 percent.
Five miles south of Burnet[1]	No lime, plasticity good, burns light red and is mature at cone 04. Total shrinkage 13 percent.

COLORADO COUNTY

East Sandies Creek 200 yards north of pipeline about 3 miles northwest of Rock Island	Bentonitic clay, nonbloating.

FAYETTE COUNTY

Localities C1-C7 of Plate III	These clays vitrify or sinter at low temperatures with dark colors and do not bloat. They are not suitable for ceramic uses.

MATAGORDA COUNTY

Brick plant at Palac	Nonbloating
Near Markham[1]	No lime, sandy, plasticity fair, burns light brick red at cone 04 with 11.2 percent total shrinkage. Suitable for common brick.
Near Markham[1]	Burns medium brick red at cone 04 with 6.3 percent total shrinkage.
Near Markham[1]	Burns medium brick red at cone 04 with 16.2! percent (high) shrinkage.

SAN SABA COUNTY

One mile south of San Saba (shale)[1]	Plasticity good, burns light red and steel hard at cone 06 with heavy scum. Possibly suitable: for brick.

CEMENT AND LIME MATERIALS

Cement materials.—Common cement, usually called Portland cement, is the product obtained by calcining to incipient fusion a finely ground artificial mixture containing essentially lime, silica, alumina, and iron oxides in certain definite proportions and grinding the resulting clinker with a small quantity of gypsum. Some source rocks (cement rock) have the proper proportions of these substances so that it is only necessary to calcine the rock. Ordinarily, however, the raw materials are artificially mixed in the proper proportions.

The most common raw material combination is limestone and shale, but a great variety of materials has been used. Among others, limestone, marl, shell, and slag have been used as the source of lime; clay, shale, and slag as the source of alumina; and clay, shale, slag, and sand as the source of silica. It follows that while strict chemical control of raw materials is important, a wide range of materials can be used. As a result, cement is produced in 37 states in the United States.

The technology of cement is very advanced and efficient. The product is a low-priced material with a comparatively low margin of profit. Suitable raw materials, properly located with respect to transportation and markets, are essential for a successful operation. According to the United States Bureau of Mines, recent estimates of cost for a new plant range between $9 and $12 per annual barrel of capacity with the minimum annual economic capacity in the neighborhood of one million barrels.

There are no cement plants in the CRIDA area, but cement is made near Waco, San Antonio, Corpus Christi, and Houston from materials similar to those in the area. The shales, marls, and limestones of the Cretaceous in the Austin area (Pl. I) contain combinations of materials similar to those used for cement at Waco and San Antonio; probably material close to cement rock, like that at San Antonio, is present. Oyster shell and clay, the combination used at Houston and Corpus Christi, are present at the coastal end of the area. It seems likely that only a limited exploration and testing program would be required to establish sources of suitable raw materials close to rail and highway transportation routes. More important, probably, is the question of adequacy and permanence of markets.

Major markets for cement are directly related to construction. The great demand for cement in Texas in recent years has been met by expansion of plant capacity and construction of additional plants. Success of a plant in the CRIDA area would be determined by the available market in competition with existing plants at Dallas, Waco, San Antonio, Corpus Christi, and Houston.

Lime materials.—Lime is calcium oxide derived from calcination of limestone. Dolomitic or high-magnesium lime is derived similarly from dolomitic limestone or dolomite. High-calcium and dolomitic limes are interchangeable for many uses, but for certain uses only one or the other is suitable. The uses of lime fall into three main groups. The largest is chemical and industrial application, the second is in building-material applications, and the third is soil improvement.

The raw materials for lime must be of high purity, and those used are consistently 97 to over 99 percent carbonate. Lime is produced at McNeil in Travis County and in adjoining Williamson County from a high-calcium limestone of Lower Cretaceous age. Lime is produced in the Houston area from shell dredged from the bays. As with cement, only the upper and lower ends of the CRIDA area have suitable raw materials, and economic factors such as transportation and markets are fully as important as the raw materials. Adequate supplies of both high-calcium and dolomitic limestone close to rail transportation are present in the area mainly in Travis and Burnet counties (Pl. I). Drilling and sampling would be necessary to prove an adequate supply for any contemplated operation.

CHEMICAL LIMESTONE AND DOLOMITE

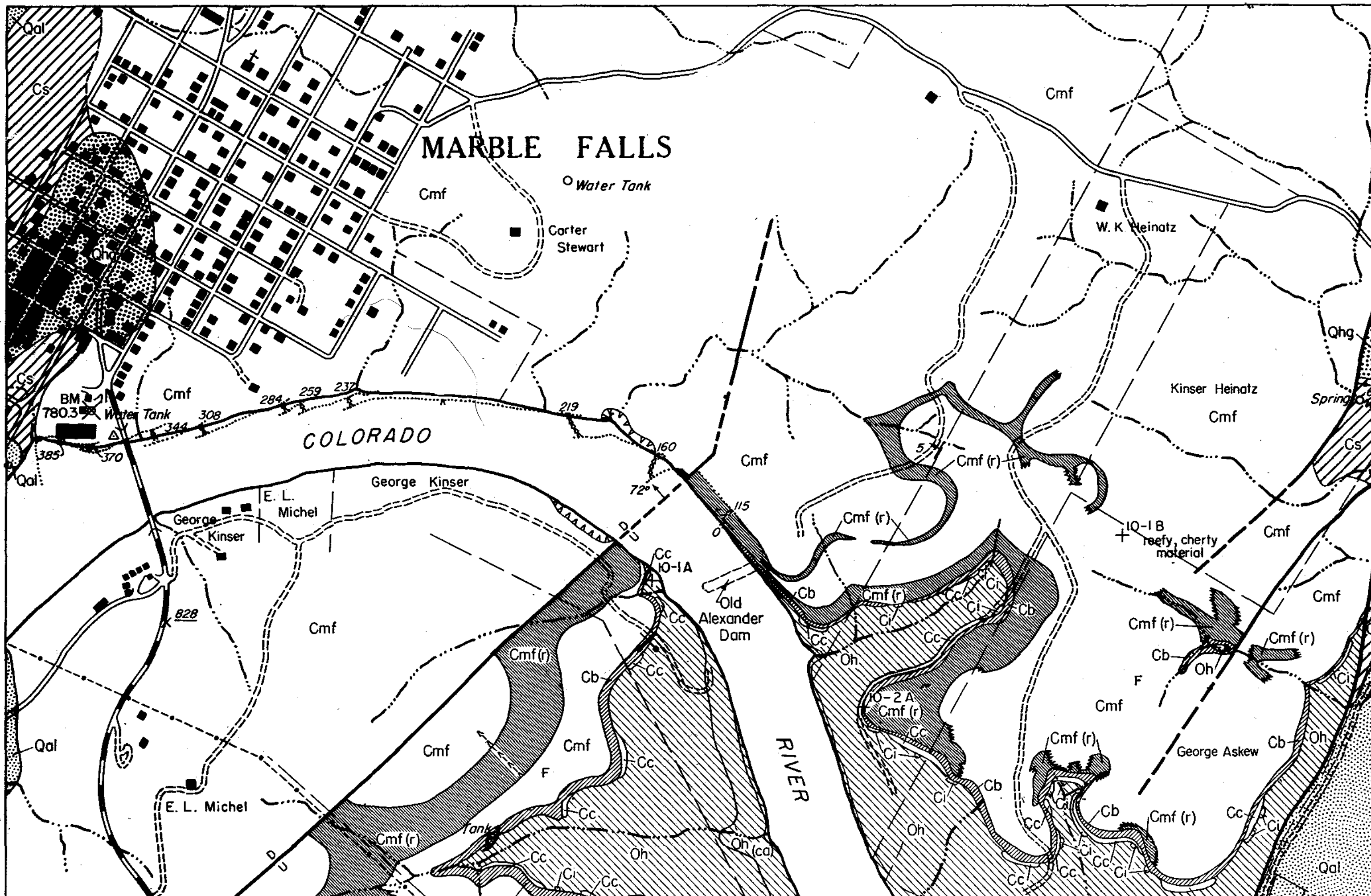
Limestone containing more than 95 percent of calcium carbonate is called high-calcium limestone and has many uses based on its chemical composition. Lime, metallurgical flux, agricultural limestone, glass making, water treatment, sugar refining, stock food, soda pulp, sulfate pulp, and calcium carbide are among the products or operations in which it is used. Many of the limestones used for these purposes contain 97 to 99 percent of calcium carbonate, and in general the highest calcium carbonate content possible is desirable. However, the specific use and user determine the chemical specifications the stone must meet. Limestone for chemical use commands a higher price than ordinary crushed stone but not as high as that used in granules and terrazzo chips.

Pure dolomite is a double carbonate of calcium and magnesium containing 54.35 percent calcium carbonate and 45.65 percent magnesium carbonate. Few dolomites are pure, the principal impurities being calcium carbonate, silica, iron oxide, and aluminum silicates. Dolomite does not have as many uses based on chemical properties as limestone. It is used in making dolomitic lime, as flux stone, agricultural stone, refractory, and filter. It was used during World War II as magnesium ore.

Ellenburger group.—Chemical limestone and dolomite have been produced from the Ellenburger group and large supplies are present in the CRIDA area. Dolomite was produced by the Victoria Gravel Company at Bu-35 (Pl. II) during World War II and converted to magnesium in a plant near Austin; a small quantity of dolomite was shipped from this quarry to a plant near Lake Charles, Louisiana. Dolomite for use as flux stone and agricultural stone is currently produced by the Texas Construction Material Company from a quarry at Bu-48 (Pl. II and fig. 3). Since 1955 the Pure Stone Company at Marble Falls has produced limestone, containing about 2 percent silica, from the Honeycut formation (Barnes, 1958). The quarry is in calcitic beds of the Honeycut formation (Oh(ca), fig. 4) in the valley of Flat Rock Creek about 0.5 miles southwest of the Marble Falls dam.

Detailed mapping of the Ellenburger group in central Texas (Cloud and Barnes, 1948) has shown that the purest dolomites occur in the Threadgill member of the Tanyard formation and in the coarse-grained portion of the Pedernales dolomite member of the Wilberns formation. The purest limestone is found in the upper part of the Gorman formation, the Threadgill member of the Tanyard formation, and the limestone facies of the Honeycut formation. Analyses from these rocks show that many dolomite beds contain more than 40 percent magnesium carbonate and some limestone beds more than 95 percent calcium carbonate. These formations are widely distributed in Blanco, Burnet, Llano, and San Saba counties, and many of the exposures are far from railroad transportation and improved highways. The markets mainly are in industrial areas so that transportation costs are very important. Figure 3 is a detailed geologic map showing these formations in most of the area along the railroad between Burnet and Marble Falls. Maps of other areas in which these rocks are present are available in the references cited. Detailed mapping has shown that abrupt lateral and vertical gradations from limestone to dolomite are common in the Ellenburger rocks. Closely spaced drilling and analysis of samples are necessary in prospecting for these materials in the Ellenburger.

Marble Falls formation.—In the spring of 1951 an exceptionally pure limestone reef about 100 feet thick was discovered in the lower part of the Marble Falls formation near the town of Marble Falls (Barnes, 1952b). Eight samples contained 96.59 to 97.23 percent calcium carbonate and less than 0.20 percent silica. Figure 4 is a map of the area in the vicinity of the reef outcrop. Subsequently, the Pure Stone Company opened a quarry in an outcrop northeast of the river. Caverns, mostly filled with sandy or silty clay, were encountered in the reef and the quarry was abandoned in 1957. Quarry sites that ap-


MARBLE FALLS
Water Tank
Carter Stewart
W. K. Heinatz
Kinser Heinatz
Spring
COLORADO
RIVER
George Kinser
E. L. Michel
Old Alexander Dam
10-1A
10-1B
reefy, cherty material
10-2A
George Askew
Water Tank
BM
780.3
Tank
Cmf
Cmf (r)
Cb
Cc
Ci
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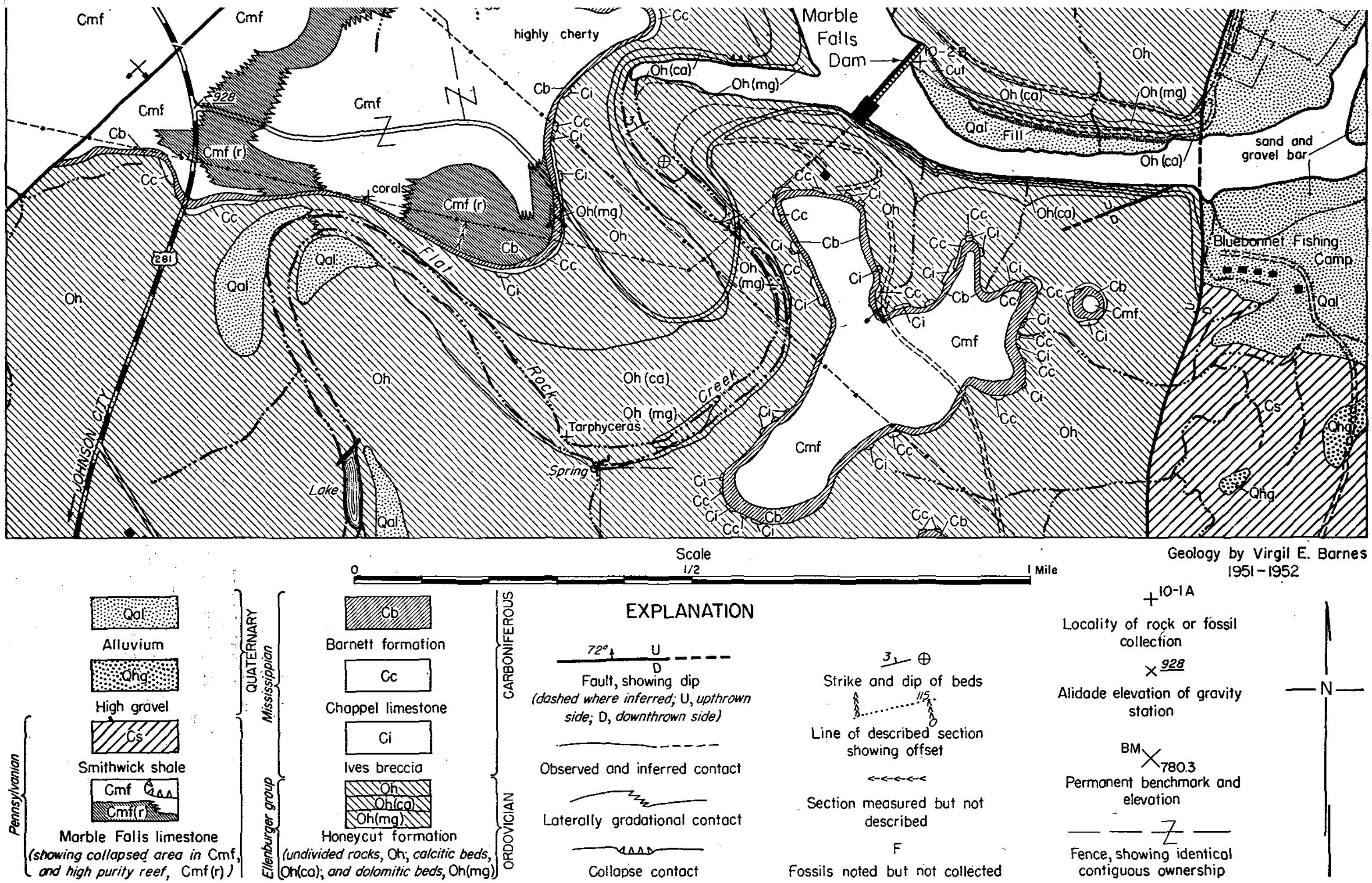


FIG. 4. Geologic map of area near Marble Falls, Burnet County. (From Bureau of Economic Geology Report of Investigations No. 17.)

pear to be more favorable are present along the outcrop southwest of the river. Barnes suggested that detailed surface mapping of the Marble Falls limestone may reveal other reef-like masses of high-calcium limestone. Commercial production should be attempted only after the purity and extent of such reef masses have been determined by extensive sampling and analysis.

Edwards formation.—Outcrops of the Edwards formation in Travis County include several layers of reef limestone. At present a bed from the lower part of the formation is used as flux stone in a plant sintering iron ore, and lime is being made from the formation at McNeil. It is possible that detailed prospecting would reveal other deposits sufficiently pure for chemical use. Deposits closest to railroad transportation are along the Missouri Pacific Railroad north of Austin. The formation is present south of Austin but several miles from the railroad.

Some zones within the Edwards are nearly completely dolomitized. Dolomite from the Edwards is produced near Round Rock in Williamson County, and other favorable sites could be found by prospecting. Deposits free from chert or chert nodules probably are less abundant than in the Ellenburger, and the same type of prospecting and testing in advance of development are necessary.

CHROMITE

Thin bands of chromite-bearing rock are present at a number of places around the margin of the Coal Creek serpentine mass (Pl. VI). About 2 tons of the material was recovered from several localities where prospecting was carried on. None of the prospects revealed commercially significant deposits, and in view of the detailed information available, little likelihood exists that such deposits will be found in this or other serpentine masses.

COPPER

Grains and small masses of copper sulfide and carbonate minerals are widely distributed in the Precambrian rocks of the Llano uplift. Nearly all of these are simply mineral occurrences without any possibility of commercial importance. A few of the larger bodies have been prospected without success.

The location of the White Eagle prospect (also called the Pavitte silver-copper prospect) is shown on figure 8. Barnes (1936a) concluded that the copper minerals were in a fissure deposit and that it was questionable whether a commercial block of ore could be outlined. Much barren rock would have to be moved to produce the small quantity of ore in sight. Subsequent drilling on the vein beyond the end of the old workings found ores that were too lean for successful production.

The Sheridan copper prospect is located near the southwest corner of the area covered by figure 8. Barnes (1936b) reported a mineral assemblage similar to that found at the White Eagle prospect. So far as could be ascertained, there had been no recorded production from the prospect.

Paige (1911) reported examining several copper prospects in the northern half of Llano County, primarily in the area west and south of Babyhead. He stated that none of the prospects was likely to be of commercial value.

FELDSPAR

In 1956 crude feldspar was produced in twelve states. North Carolina, Colorado, South Dakota, and Connecticut were the leading producers. The total production was 622.429 long tons valued at $5,763,-847, with an average price of $9.26 per ton. Forty percent of all marketable feldspar was obtained by flotation treatment. Producing states geographically closest to Texas are Arizona and Colorado.

The common feldspars are aluminum silicates of potassium, sodium, and calcium. In ceramic terminology they are a group of igneous minerals consisting chiefly of the aluminum silicates of potash, soda, and lime, in which one base generally predominates. Commercially the important species are orthoclase and microcline, in which potassium predominates, and albite, in which sodium predominates. The main uses of feldspar are in the ceramic industries (glass, enamel, pottery); other uses include roofing and cement granules, scouring compounds, poultry grit, and abrasives. Ceramic uses require a pure product which must meet rigid chemical specifications. Use as roofing granules depends on physical properties discussed in the section on "Building Stone."

The feldspar minerals orthoclase and microcline are prominent constituents of Precambrian pegmatite dikes and granites in Blanco, Burnet, Gillespie, Llano, and Mason counties. In the pegmatites, individual feldspar crystals range in size from 1 or 2 inches to as much as 1 foot. In the coarser granites the maximum size of feldspar crystals is about 2 inches. Quartz, biotite, and other minerals are present along with the feldspar in both pegmatites and granites. These are more abundant and more intimately mixed with the feldspar in the granites.

The production of pure feldspar requires separation of the mineral from the associated non-feldspar minerals. In the pegmatites this can be accomplished by selective mining, hand sorting, and hand cobbing. This results in a relatively high proportion of waste, but if the feldspar minerals themselves meet chemical specifications, the resulting product can be kept within the tolerances required. Some pegmatites lend themselves to milling procedures involving flotation and magnetic separation. A considerable capital outlay for the mill is required, but under favorable conditions a relatively pure and uniform product is produced.

Feldspar from pegmatites in the Llano uplift has been produced in small quantities intermittently since the mid-thirties. Most of it has been marketed in Mexico and used in glass making, but some has been used as roofing granules. Hand sorting and hand cobbing have been used to secure a pure product. At the present time pegmatites continue to be the best potential source of this material in the area. Unfortunately, many of these rock bodies are too small to support extensive operations.

It has been suggested that some of the granites, both fresh and disintegrated, are potential sources of feldspar. If these could be utilized, large supplies are available. Some type of benefication would be necessary, and extensive analysis, testing, and experimentation would be required to determine a suitable process.

There are many pegmatites in the Llano uplift. Barnes (1946) has presented data, chiefly preliminary, concerning the more important deposits in eastern Llano County. Sufficient unpublished information is available to indicate that few, if any, additional large pegmatite masses will be discovered in the region.

Badu Hill pegmatite.—The Badu Hill pegmatite (fig. 5), named and described by Chelf (1942), is 0.8 mile south of State Highway 29, about 2.3 miles west of its intersection with State Highway 261. The nearest shipping point is 0.8 mile southwest at Hobart Junction on the Southern Pacific Railroad. This pegmatite was first exploited for feldspar in 1936, and most of the feldspar produced in the Llano uplift has been obtained from it.

The main pegmatite dike forms a slightly elongated mound that rises about 50 feet above the surrounding area. It is about 700 feet long in an east-west direction and about 350 feet wide at the thickest point. Large masses of feldspar and of quartz crop out in an area about 300 feet long and 175 feet wide near the center of the mass; the surrounding material is graphic granite. Smaller dikes containing good feldspar occur east and west of the principal pegmatite dike.

An investigation of this deposit was made in 1946 by the United States Bureau of Mines in cooperation with the Department of Ceramic Engineering, The University of Texas (Huseman and McMillan, 1947). Three vertical core holes were drilled, six test pits were dug, and surface samples were collected. At the time of this investigation, an estimated 6,000 tons of feldspar had been obtained by selective

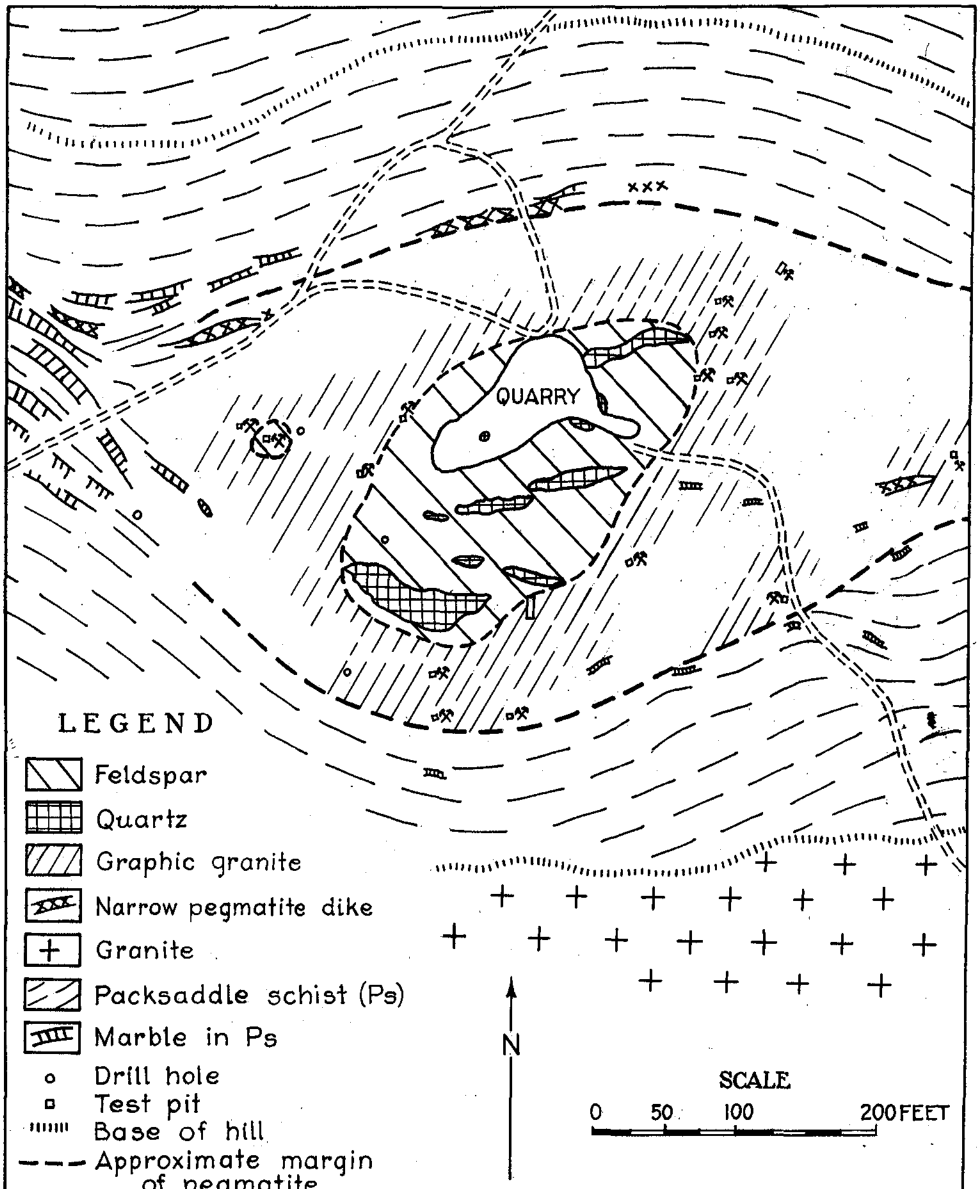


FIG. 5. Geologic map of Badu Hill pegmatite, Llano County. (From The University of Texas Publication 4301.)

mining and hand sorting from a pit approximately 200 feet long and 60 feet wide with walls up to 15 feet high.

The drill holes passed out of feldspar and into graphic granite at depths that ranged from 28 to 45 feet below the floor of the pit. Composite samples collected from those portions of the cores above the graphic granite had iron content that ranged from 0.37 to 1.5 percent. The iron content of sludge samples from corresponding depths ranged from 0.57 to 3.4 percent. The iron content reported is too high for ceramic use. However, analyses of the feldspar itself (Barnes, 1946) show iron within the required tolerance.

Williams pegmatite.—Feldspar has been produced from the Williams pegmatite located 2 miles west of Kingsland, Llano County. The pegmatite is composed of about equal quantities of quartz and feldspar with a few large books of dark mica. Two pits have been opened in the small, irregular outcrop which is about 130 feet long and not more than 40 feet wide.

Sandy Mountain area.—There are several feldspar-bearing pegmatite dikes in the Sandy Mountain area in eastern Llano County, south of Llano River, west of Colorado River, and north of Sandy Creek (Pl. V). Large masses of feldspar are known to be present in some of the pegmatite dikes. Barnes (1946) suggested that the pegmatites in this area (particularly the group near the western edge of the map) should be prospected as potential sources of feldspar.

Kiam pegmatite.—The Kiam pegmatite dike (fig. 6) crosses Honey Creek about 0.4 mile downstream from the bridge on State Highway 71, 5.5 miles S, 75°W. from Kingsland. The nearest railroad loading point is at Llano, about 14 miles by paved highway northwest of this prospect. The pegmatite outcrop is 2,500 feet long and has a maximum width of 15 feet. Underground workings that follow the pegmatite for about 350 feet have been opened at this locality during exploration for molybdenum, bismuth, and gold. The pegmatite, where exposed in the underground workings, has a maximum thickness of 9 feet.

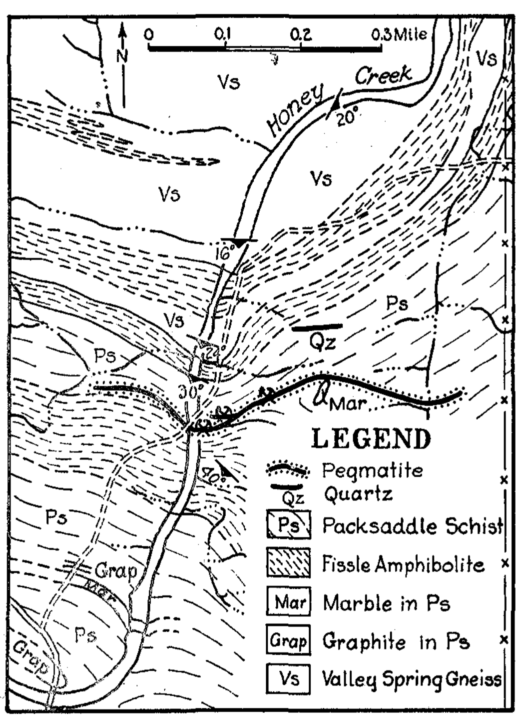


FIG. 6. Geologic map of Kiam pegmatite area, Llano County. (From The University of Texas Publication 4301.)

There is no known analysis of the feldspar in this pegmatite, but sight examination indicates that it is of good quality. It is possible that the dike could be mined primarily for feldspar; other ores, if encountered, might also be produced.

Althaus pegmatite.—A number of pegmatites, quartz masses, and two small outcrops of feldspar crop out on the Althaus ranch in eastern Gillespie County (fig. 7), and a small amount of feldspar has been shipped from this locality. Only a few carloads of feldspar are in sight, and there is little indication that prospecting would increase the reserves appreciably.

Clear Creek pegmatite.—A pegmatite dike 1,300 feet long is located in Burnet County on the north side of Clear Creek less than one-fourth mile west of the junction of the roads to the Southwestern Graphite Company mill and to Morgan Creek. This locality but not the dike is shown in the north-central part of figure 8. The dike varies in composition along its course, and only a small part is relatively rich in feldspar.

Disintegrated granite.—Deposits of deeply weathered granite occur at many localities in the region. Disintegrated granite from pits located near the northeast part of the area covered by Plate V has been used as railroad ballast. Although the pits are about 20 feet deep, they are entirely within disintegrated granite. These deposits are adjacent to the Southern Pacific Railroad and Ranch-to-Market Road 1431. An abundant supply of water is available in Granite Shoals Lake, and

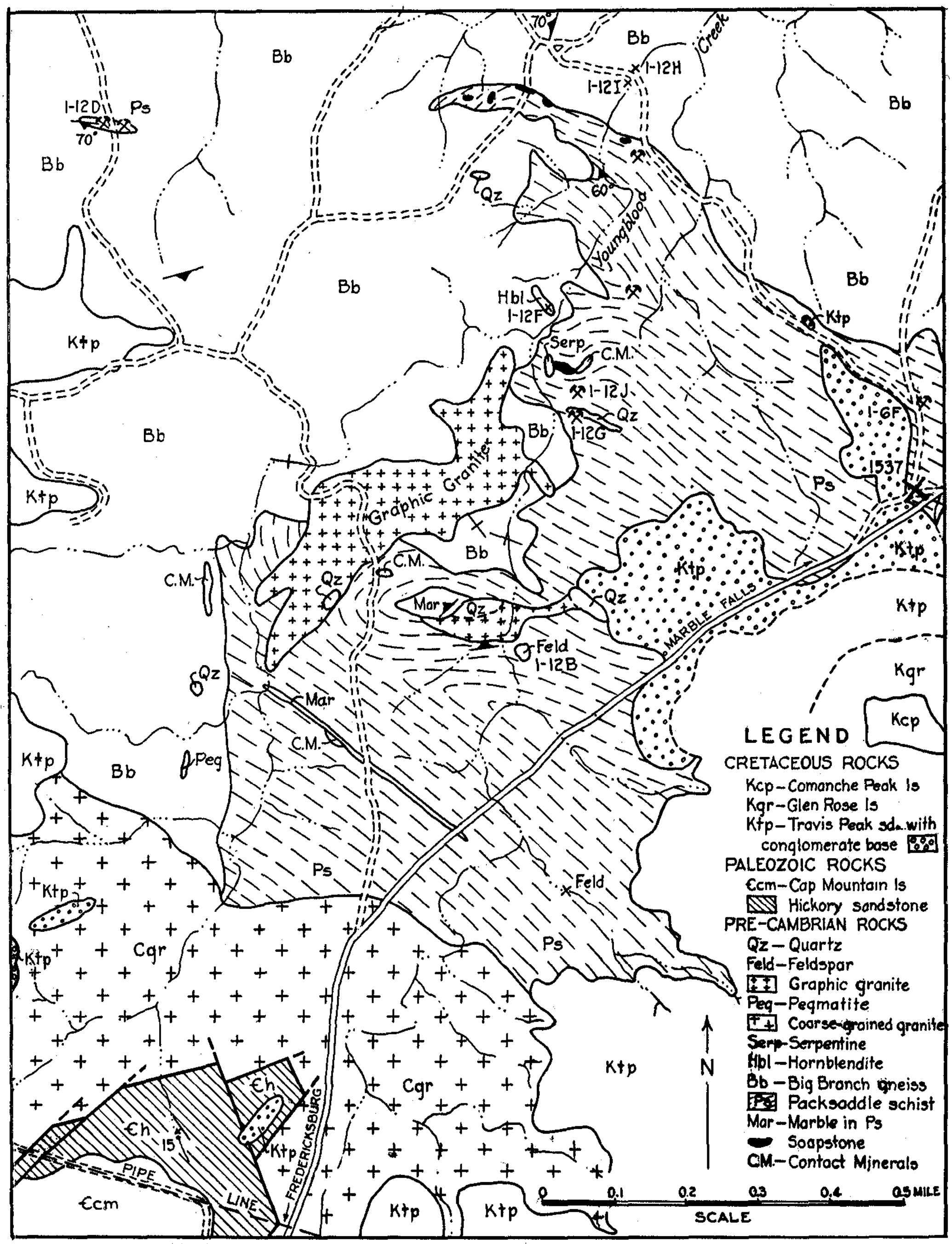


FIG. 7. Geologic map of Youngblood Creek area, Gillespie County. (From The University of Texas Publication 4301.)

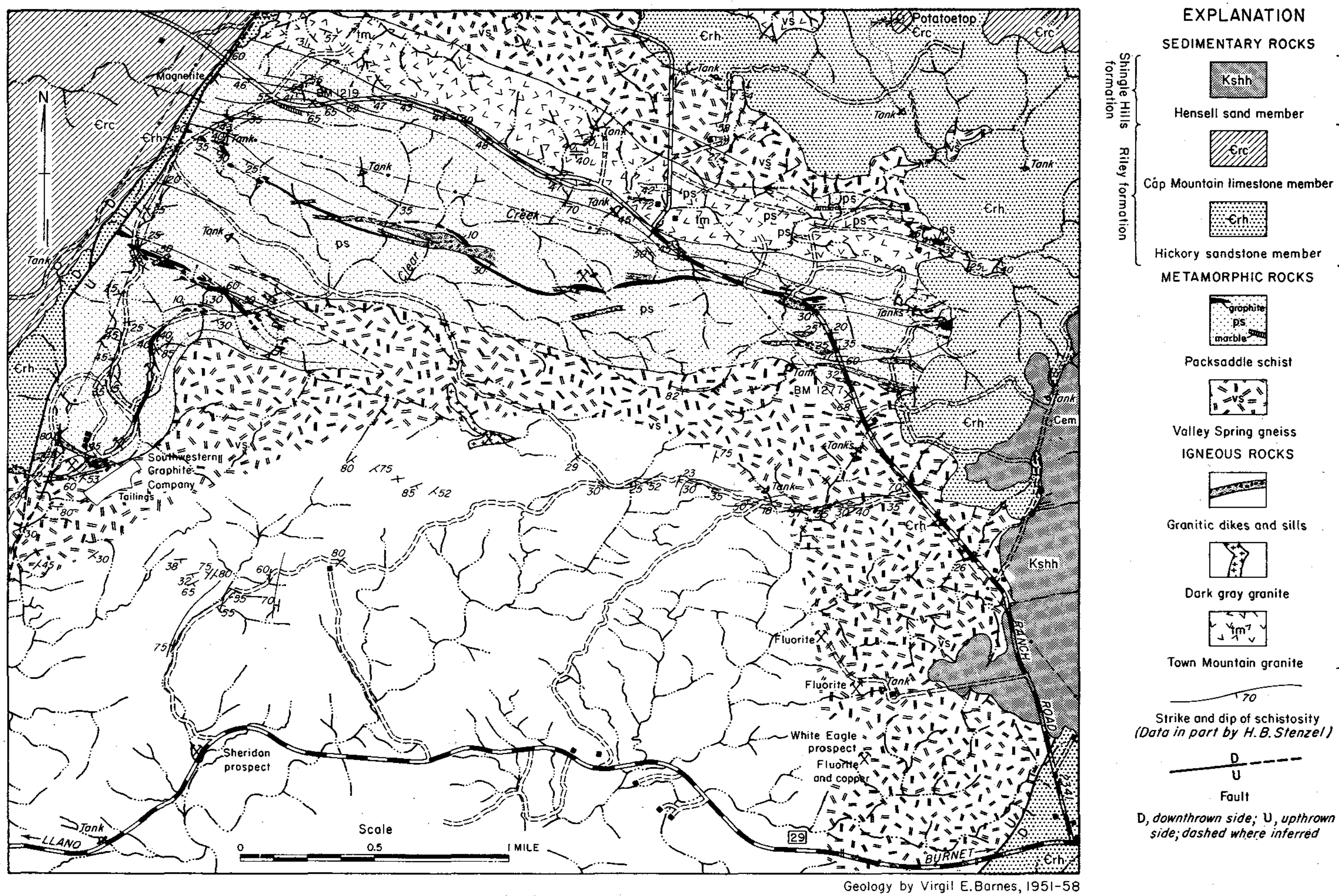


FIG. 8. Geologic map of Clear Creek area, Burnet County. (From Bureau of Economic Geology Guidebook No. 1.)

the deposits are near high-voltage transmission lines.

FLUORSPAR

Fluorspar is used mainly in steel metallurgy, in producing hydrofluoric acid, and in the ceramic industry. Grades are established for each of these uses with prices determined by the grade. Recent prices for domestic fluorite were $33–41 per short ton for metallurgical, $43–45 for acid grade, and $45–48 for ceramic grade. Imported fluorspar generally was quoted at slightly lower prices than domestic. In 1956 the United States produced 922,100 short tons of crude ore mainly from Illinois, Montana, and Kentucky. At the same time imports amounted to 485,600 short tons of processed fluorspar.

Grains and crystals of fluorspar (fluorite) are present in many of the granites and pegmatites of the Llano uplift. The only notable prospect, which has been known since 1909 (Paige, 1912, p. 14), is in the Spring Creek area 5 miles by road west of Burnet (fig. 8). Several attempts have been made to develop the property, the latest shortly after World War II.

According to Barnes (1943), two or more layers of possibly milling-grade fluorspar up to 2 feet thick were exposed in prospect holes and pits for a distance of half a mile. The prospect openings were inadequate to demonstrate the volume and grade of fluorspar present. In general, the showings were discouraging.

The fluorite at this prospect is white and many prospectors might confuse it with other light-colored minerals. If fluorite elsewhere in the general area is similar, the possibility exists that additional deposits possibly of commercial grade are present.

GOLD AND SILVER

During the last half century or so, gold in the Llano uplift has been reported many times. Small quantities of gold have been found and attempts (mostly ill-advised) have been made to mine the material. As far as known, no deposit of commercial promise has been found in all the years of search and prospecting.

The gold has been found in thin quartz veinlets in the crystalline rocks; it was reported from the Kiam pegmatite (fig. 6). Placer or alluvial gold also has been found in the sand in valleys which drain areas underlain by the crystalline rocks. Placer deposits are the most promising in the area, but as has been pointed out in many reports through the years (such as Baker, 1935, pp. 415–420), adequate prospecting would be very expensive and the probability of finding a minable deposit very slight.

Silver has been reported in a few assays of lead and other ores in the Llano uplift. The percentages reported were not commercial.

GRAPHITE AND GRAPHITIC SCHIST

Graphite-bearing schist is widely distributed in the Precambrian rocks of the Llano uplift. The more prominent known deposits are in Burnet and Llano counties. Graphite is being produced at one locality and granular graphite schist at another. In the Clear Creek area, Burnet County, the Southwestern Graphite Company is producing graphite from shist mined by open-pit methods. According to the United States Bureau of Mines, this mine is capable of supplying about 25 percent of the current demand for flake graphite in the United States and in 1956 was the only producer of crystalline flake graphite in the United States. The Grafilter Company is producing crushed graphitic schist for use, as a filtering medium. The mill is located east of State Highway 16 about 1 mile south of Llano, and the schist is mined from a deposit on the Gray Fowler property about 1.3 miles east of the highway on the Riley Mountains road.

Clear Creek area, Burnet County.— Three narrow, discontinuous bands of graphite schist crop out in the area drained by Clear Creek, 1 to 2 miles north of State Highway 29 from 4 to 8 miles west of Burnet (fig. 8). The graphite deposits on five different properties in this area were described by Barnes (1940). Mills were constructed at three localities in this area. Two mills, no longer in existence, processed very little ore; the other mill has refined most of the graphite that has been produced in Texas.

The property of the Southwestern Graphite Company includes most of the thicker part of the southern band of graphite schist. Figure 9 is a map of this property prepared in 1923. The original mill was built by the Southwestern Consolidated Graphite Company which was founded about 1916. A new mill was constructed after fire in 1927 destroyed the buildings shown on this map. The production of graphite ceased in 1929, and the property was inactive when it was acquired by Miller and Clemson interests in 1935. In 1942, at the request of the War Production Board, graphite production from this property was resumed by the Southwestern Graphite Company. Production has continued since then except during 1954 and the first quarter of 1955, when orders were filled from stock.

The graphite content of the ore averages 4.5 to 5.0 percent. The mill can recover graphite with a purity of 96 to 97 percent for special uses, but for most purposes the graphite need not be refined to so high a degree. All grades of graphite, except the coarser flake graphite required for certain types of crucibles, are now being produced by this company.

The middle band of graphite schist is cut by numerous pegmatites. It can be traced for less than 1 mile east-southeastward from the down-faulted Cambrian rocks. Prospect pits have been opened in areas that appear favorable, but there has been no commercial production.

The northern band of graphite schist is exposed for a distance of about 3 miles between down-faulted Cambrian rocks on the west and overlapping Hickory sandstone on the east. Throughout most of this distance the thickness of the band is on the order of 10 feet or less; locally the thickness may exceed 100 feet. A thickened area near the center of the band and the exposed part of a thickened area that passes beneath Hickory sandstone at the eastern end of the band have been extensively prospected. Small quantities of ore from these localities were processed by the Burnet-Texas Company which operated for a short period in 1928 and by the Texas Graphite Company which operated for a short period in 1936–1937.

Spring Creek area, Burnet County.—A poorly exposed layer of graphite schist with a maximum thickness of 14 feet and a dip of about 30 degrees toward the south has been traced for slightly less than half a mile in an area south of State Highway 29, 4 miles west of Burnet. The outcrop is just south of the area covered by figure 8.

Llano—Sharp Mountain area, Llano County.—Several outcrops of graphite schist occur in an area that extends more than 6 miles southeastward from Llano River, 2 miles west of Llano to about 1 mile south of Sharp Mountain where the graphite schist passes beneath Hickory sandstone. Deposits at six localities in this area have been described by Chelf (1943).

The northwesternmost deposit crops out about 2 miles west of Llano between the south bank of Llano River and Ranch-to-Market Road 152. Medium-flake graphite appears to be the predominant grade in this deposit. Ore near the surface is weathered and relatively soft, but it becomes siliceous and much harder at depth. This deposit has a geographic advantage over the others in this region because it is near a good supply of water and only 2 miles from rail transportation.

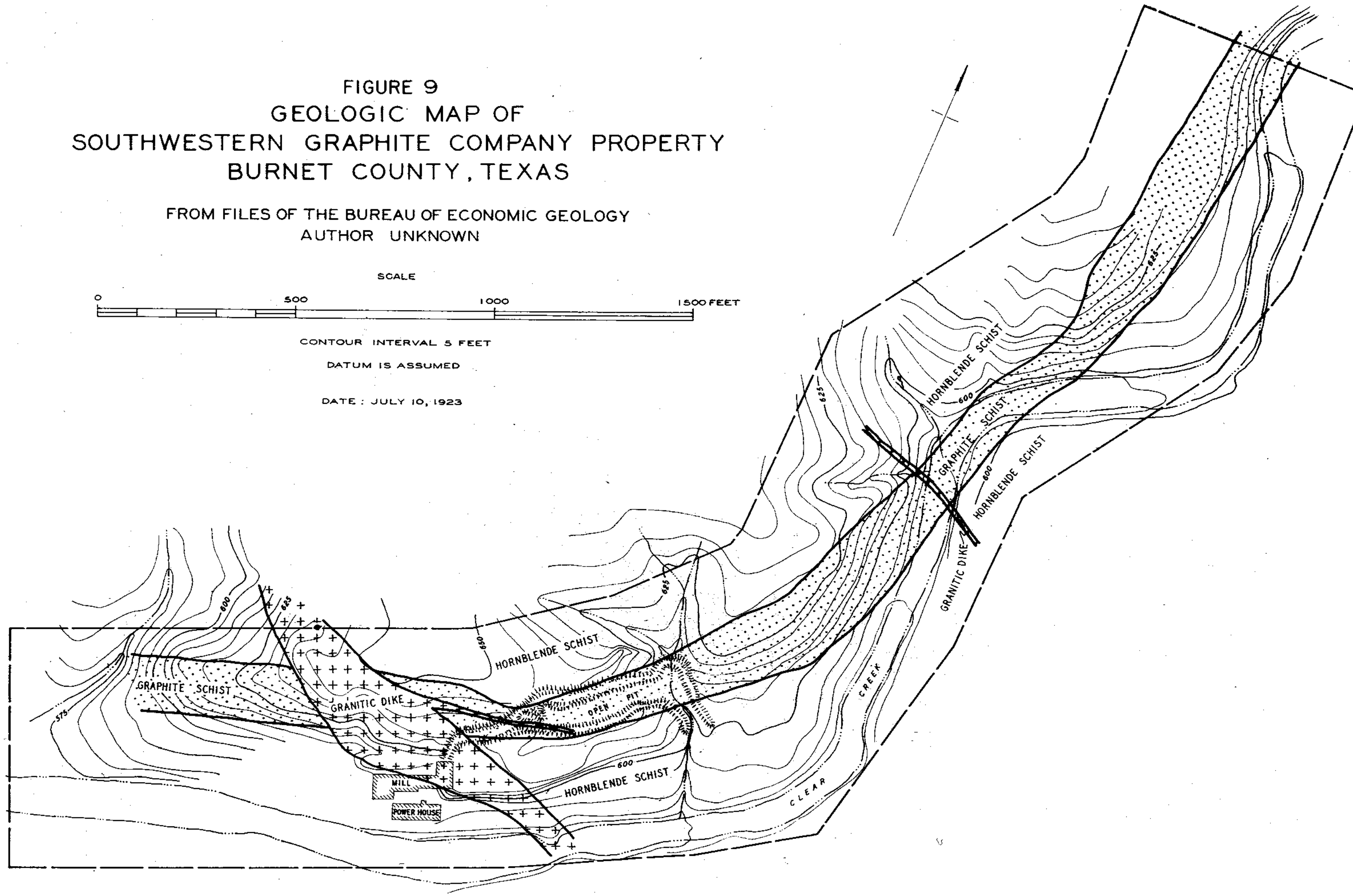
In 1940 the Texas Graphite Company built a mill at an extensive deposit of graphite schist east of State Highway 16 about 1 mile south of Llano. The mill was operated for only a few days and produced a small quantity of refined graphite from ore mined at the mill site. The ore in this deposit contains 10 to 17 percent graphite and can be mined by the open-pit method, but the fine grinding necessary to free the graphite from the schist produces a refined product classified commercially as amorphous graphite. The mill is currently operated by the Grafilter Company which

FIGURE 9
GEOLOGIC MAP OF
SOUTHWESTERN GRAPHITE COMPANY PROPERTY
BURNET COUNTY, TEXAS

FROM FILES OF THE BUREAU OF ECONOMIC GEOLOGY
AUTHOR UNKNOWN

SCALE
0 500 1000 1500 FEET

CONTOUR INTERVAL 5 FEET
DATUM IS ASSUMED
DATE: JULY 10, 1923



(From Bureau of Economic Geology Guidebook No. 1.)

produces crushed graphite schist for use as a filtering medium.

Lone Grove area, Llano County.—There are several occurrences of graphite schist in the vicinity of Lone Grove, about 7 miles northwest of Llano. The principal deposits are west of Little Llano River in a rectangular area 1.5 miles wide that extends about 4 miles northward from Llano River. Five localities where the graphite deposits have been investigated by prospect pits, open cuts, or underground workings have been described by Chelf (1943). The flake size of the graphite in this area is slightly smaller than in the deposits of the Clear Creek area, Burnet County. Although two mills, no longer in existence, were established in the area, only minor quantities of graphite have been produced. One mill at the Heath gold mine, located north of Ranch-to-Market Road, 2241 about 2.5 miles southwest of Lone Grove, was converted for graphite production in 1918 by the Dixie Graphite Company. During the three months the mill was in operation, it processed ore mined underground about 400 yards northwest of the mill. A minor quantity of graphite was shipped during this period. The other mill was constructed sometime prior to 1943 on the Lillie Templeton farm about 1 mile north of Lone Grove. There is no record of production from this mill; there are two deposits of graphite schist within 300 yards of the mill site.

Packsaddle Mountain area, Llano County.—Large deposits of graphitic schist similar to those in the Llano—Sharp Mountain area are located south of Packsaddle Mountain between the Riley Mountains and Colorado River. Some of the exposures are shown in Plate V and figure 6.

GRINDING PEBBLES AND MILL LINERS

Pebbles and rock mill liners are used as the abrasive material in grinding operations in which it is essential that contamination of the product by metal be avoided. During World War II, domestic pebbles were produced to supplement the short supply from foreign sources and their production has continued. The market is limited; in 1956, according to the United States Bureau of Mines, 2,330 short tons valued at $71,392 were produced in Minnesota, North Carolina, Texas, Washington, and Wisconsin. The Texas production was from Bastrop and Travis counties. In earlier years there was production from Colorado, Fayette, and Frio counties.

During World War II, most of the grinding pebbles produced in Texas were milled to improve their quality. The milling, in conventional ball or pebble mills, removed weathered skins from the pebbles and eliminated cracked and weak pebbles (Parkinson and Barnes, 1946, p. 53). The pebbles produced in recent years from the CRIDA area were hand sorted and were not milled to improve their quality.

The pebbles produced in Texas are flint and chert. Those produced recently were hand sorted from a number of localities along Colorado River from the stream divides or the terraces. There are no standard specifications for grinding pebbles. Of the kind now produced, there are large supplies in the extensive sand and gravel deposits from Travis County to Colorado County. Probably the higher and older deposits contain larger numbers of sound flint and chert pebbles. In view of the limited market, it is likely that hand sorting or crude methods of separation will continue to be employed by producers.

Production of natural mill liners in 1956 from Minnesota, North Carolina, and Wisconsin amounted to 1,061 short tons valued at $73,596. The materials used were quartzite and granite. Flint from the Edwards formation of western Travis County was used as liners to a limited extent in 1941 (Evans, 1946, p. 246). At about the same time, granite was used as the liner in a mill near Columbus employed to condition flint pebbles (Parkinson and Barnes, 1946, p. 54). The source of the granite is not known.

Liners, like the pebbles, must have high abrasive hardness, great toughness, and freedom from flaws. Liners are prepared as rectangular blocks more or less shaped to fit the curve of a mill. The most promising source of liners in the CRIDA area is the flint beds in the Edwards and other formations. Much of it is too thin but it is possible that suitable material could be found. Fine-grained highly siliceous granite from the Llano uplift is a less promising source. Establishment of a market in competition with current domestic producers and foreign material would be difficult.

IRON ORE

Iron ore deposits are widely distributed in the Llano uplift. The principal deposits are in Llano County, but iron ore deposits are present also in Blanco, Burnet, Gillespie, Mason, and San Saba counties. Figure 10 is an index map of the iron ore prospects in central Texas. There are four types of deposits. The most important consists of massive beds or lenses, relatively thin layers, or disseminated grain of magnetite or martite in Precambrian gneiss or schist. The magnetite deposits are of greater value than the martite deposits. A second type consists of residual concentrations of iron oxide derived from alteration of other iron-bearing minerals. Deposits of this type have been derived from iron sulfide vein minerals, glauconite in Cambrian sedimentary rocks, and siderite in Precambrian metamorphic rocks. The third and fourth types of deposits are in the Cambrian sedimentary strata which overlie the metamorphic rocks. Small, discontinuous deposits of iron ore in the basal Cambrian rocks are the result of a concentration of iron-rich debris by the processes of sedimentation. Other deposits consist of concretions and bands of hematite introduced into the porous sandstone after deposition. Weathering of the sandstone has resulted in local concentrations of the iron-rich portions of the rock.

Showings of iron ore are widespread in the areas in which Precambrian metamorphic rocks crop out. Some are accumulations of float that have not been traced to bedrock exposures; others are small, lean bodies of ore that have no commercial value. Only a few deposits are large enough to be considered as prospects. The majority of the prospects and showings of iron ore associated with metamorphic rocks are north of Llano River. Residual iron ores occur in the upper parts of veins in the sedimentary rocks and at localities where the ore is derived from siderite in metamorphic rocks or glauconite in sedimentary rocks. Deposits of the third and fourth types occur at many places, but none is large enough to be considered commercial. The iron content is high in selected samples from scattered deposits, but the iron-rich material is only a small part of the deposit.

The analyses of many iron ore samples are recorded in early reports by Comstock (1890, 1891) on the mineral resources of the region. The samples represent deposits of several types, including small unimportant deposits in sedimentary rocks. Reports by Paige (1910, 1911, 1912) include detailed descriptions of several major and minor iron ore prospects of the area. These descriptions were based on surface mapping and on data from pits, shafts, and tunnels opened at the various prospects. Detailed investigations of the iron deposits of the Llano region were conducted during the years 1942 through 1944 by the Bureau of Economic Geology of The University of Texas, the United States Geological Survey, and the United States Bureau of Mines. The results of dip-needle, gravity-meter, and diamond-drill core surveys at the major prospects are included in a report by Barnes, Goldich, and Romberg (1949).

Iron Mountain, Llano County.—The Iron Mountain magnetite prospect is 12 miles northwest of Llano. Iron ore crops out on a low knoll of Valley Spring gneiss less than 100 yards southwest of Ranch-to-Market Road 734 about 1 mile northwest of Valley Spring (fig. 11).

The iron ore reserve of this deposit was estimated to be about 65,000 tons. This estimate, by Barnes (Barnes et al., 1949, p. 14), was based on interpretation of core-hole data, observations at the surface and

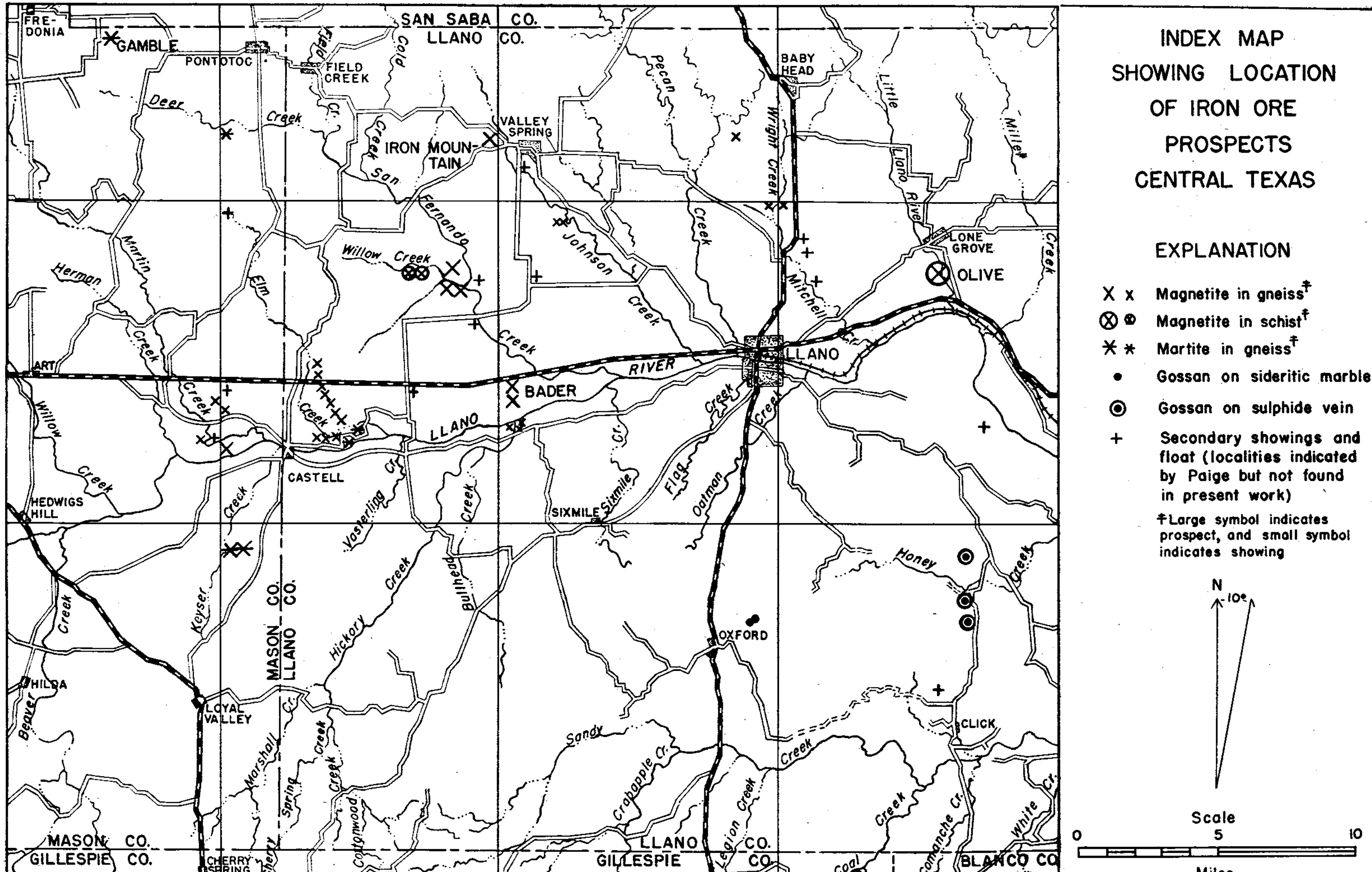


Fig. 10. Index map of iron ore deposits in central Texas. (From Bureau of Economic Geology Report of Investigations No. 5.)

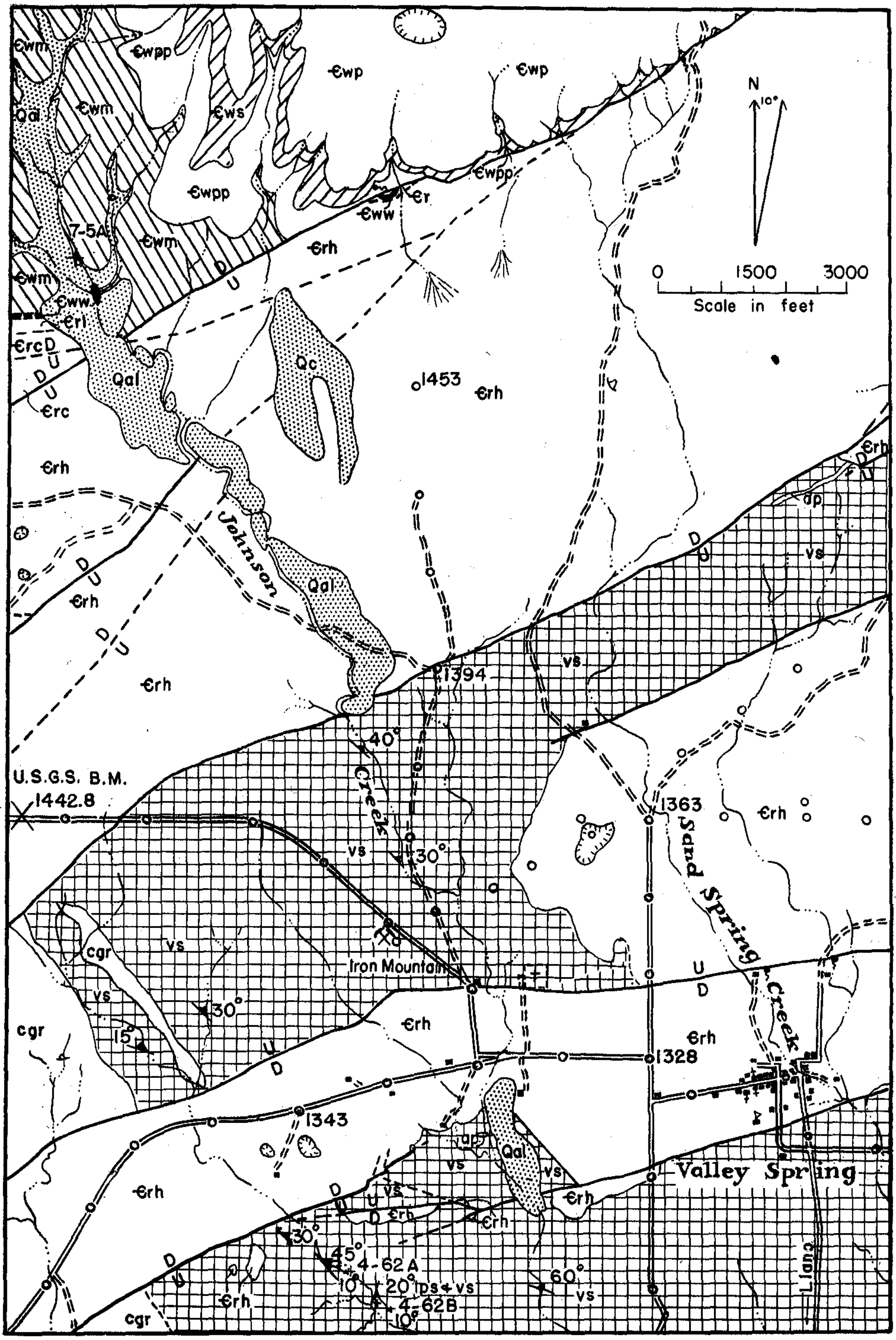


FIG. 11. Geologic map of Iron Mountain and vicinity, Llano County. (From Bureau of Economic Geology Report of Investigations No. 5.)

(Cambrian rocks—€wp, €ws, €wpp, €wm, €ww, €rl, €rc, €rh; Precambrian rocks—igneous rocks, ap, cgr; Valley Spring gneiss, vs; schist, ps.)

in the mine, and the assumption that 4.2 is the average specific gravity of the ore.

Test pits were opened at this prospect as early as 1890. Mine workings were under development when the prospect was visited by Paige in 1908 and 1909. Exploration at that time included a shaft to a depth of 100 feet, more than 250 feet of tunnels at the 50- and 100-foot levels, and six diamond-drill core holes. Descriptions of the prospect by Paige (1910, 1911, 1912) include discussion of the core-drilling program and sketches of the mine workings, ore body, and surface outcrops.

Modern investigations at this prospect include a dip-needle survey by Barnes and a gravity-meter survey by Romberg in 1942 (Barnes and Romberg, 1943). A thorough exploration of the prospect in 1944 by the United States Bureau of Mines included reopening of the 50-foot level in the old mine, collection of samples for chemical analysis, and the drilling of 1,623 feet of diamond-drill core holes. Information from the magnetic and gravity surveys was utilized in planning the twelve-hole-drilling program.

Partial analyses of many ore samples from Iron Mountain have been published in papers listed in the bibliography. The iron content generally exceeds 60 percent, and samples containing more than 65 percent iron are common. Sulfur and phosphorus determinations were relatively few, but in those reported, the sulfur content was generally less than 0.10 percent and the phosphorus content was generally less than 0.35 percent. The silica content of samples collected at the surface or from the mine workings rarely exceeded 6 percent, but the silica content of composite samples from the cores ranged considerably higher.

Little or no ore was removed until the years immediately preceding World War II when a small quantity of ore was produced from surface workings. Between 1942 and 1946 several hundred tons of ore were mined from an open pit which by the end of 1946 had been excavated to a depth of about 35 feet. About 3,500 tons of ore were shipped from this locality up to mid-year 1958 for use in heavy concrete aggregate.

Bader prospect, Llano County.—The Bader prospect (fig. 12) is 9 miles west of Llano. The main deposits crop out in an area a few hundred feet wide extending more than 8,000 feet north-northwestward from near the north bank of Llano River. Smaller showings are present south of Llano River along Hickory Creek in the vicinity of Ranch-to-Market Road 152. State Highway 29 has been constructed across the northern end of the area shown in figure 12. The area is accessible from Llano by either highway.

Exploration of the prospect began prior to 1900. Most of the early work was confined to the northwestern end of the deposit. Spencer (*in* Paige, 1911) reported that the Bader incline, the Otto shaft, and several shallow pits and trenches had been opened and two core holes had been drilled near the northwestern end of the prospect. Exploration farther to the southeast consisted of a few scattered shallow pits.

Magnetic surveys of this prospect were made early in 1943 by Goldich and Fayerweather. The area of magnetic anomaly was outlined by a reconnaissance survey of the whole prospect with a dip-needle. An area in the vicinity of the Bader incline and other openings at the northwestern end of the prospect was selected for further study, and a detailed dip-needle survey was made. Later, Romberg made a gravity-meter survey of the same area. Exploration by the United States Bureau of Mines during the year 1944 included the drilling of five core holes, excavation of a trench 175 feet long roughly parallel to and 50 feet south of the Bader incline, and the collection of samples for analysis.

Partial analyses of ore from the Bader prospect are reported by Spencer (*in* Paige, 1911) and by Barnes, Goldich, and Romberg (1949). The iron content of the samples ranged from 37.58 to 65.80 percent in the surface samples and from 6.05 to 51.53 per cent in samples taken from the cores. The phosphorus content was 0.10

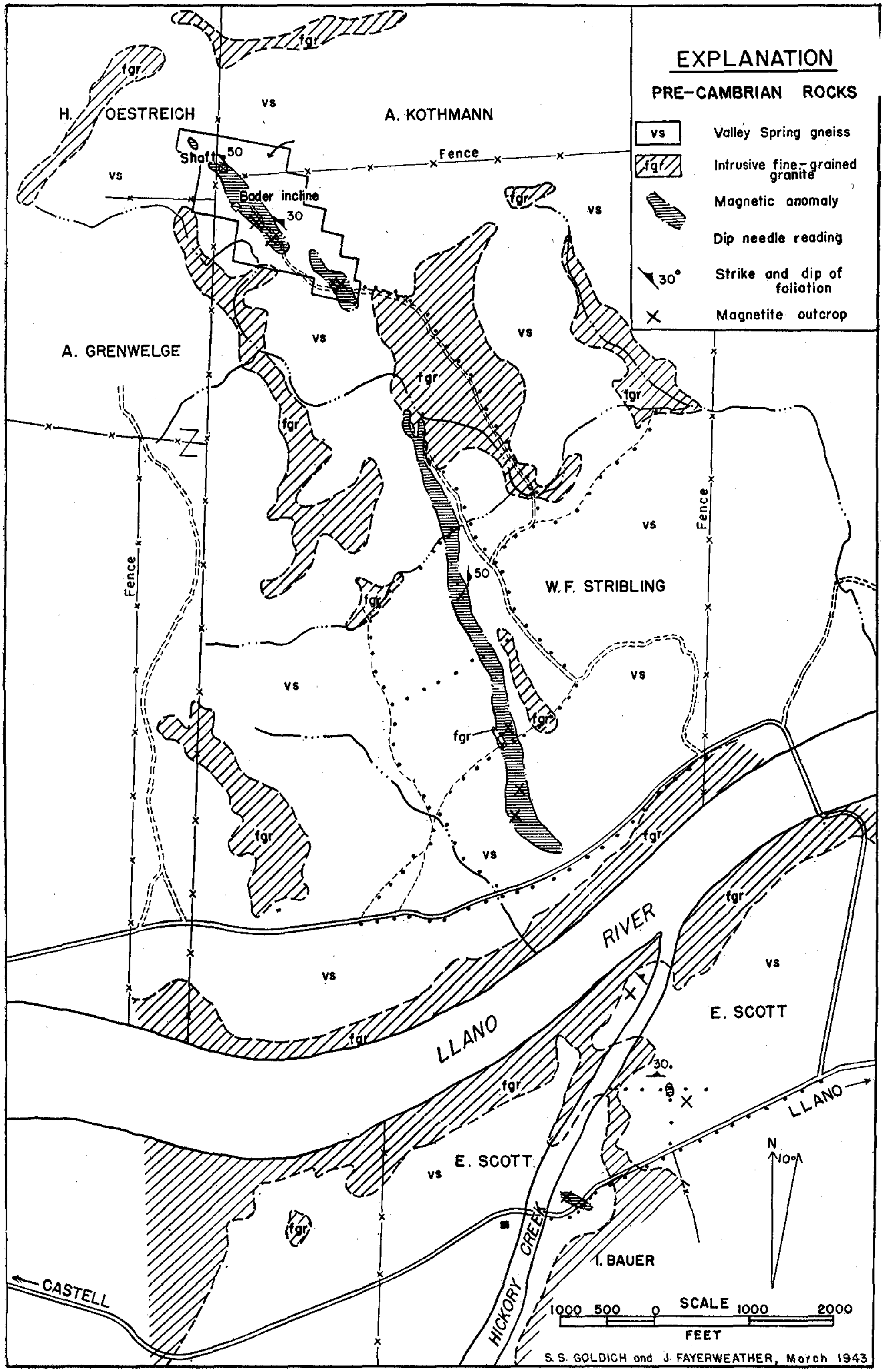


FIG. 12. Index map of the Bader prospect, Llano County. (From Bureau of Economic Geology Report of Investigations No. 5.)

percent or less, and the silica content ranged as high as 52.50 percent in the samples in which they were determined.

There is little high-grade ore in this deposit, but drilling has shown that magnetite is a common constituent of the gneiss. The reserve is estimated to be about 1,000,000 tons of magnetite gneiss with an average of about 15 percent iron (Barnes et al., 1949, p. 17). Very little ore has been mined from this prospect, and its overall grade is too low for any utilization at the present time.

Gamble prospect, Mason County.—The Gamble prospect is in northeastern Mason County, about half a mile south of the Mason-San Saba County line and 3 miles southeast of Fredonia. The prospect is on a small ridge of Precambrian gneiss about 1,700 feet northeast of the G. W. Miller ranchhouse. The ore occurs as layers or lenses in the gneiss and consists largely of hematite with minor amounts of magnetite. The reserves at the Gamble iron ore prospect are limited to the surface outcrop. A large part of the ore has been mined; the quantity of ore remaining is estimated to be on the order of a few hundred tons.

A dip-needle survey of the prospect that revealed only small, rather formless anomalies was not considered to be conclusive because the ore exposed at the surface was predominantly nonmagnetic. Core drilling was recommended to check the dip-needle survey and to determine whether mining operations, then being conducted at the prospect, could be expanded. Seven core holes were drilled by the United States Bureau of Mines, although a gravity-meter survey, made after the recommendation for drilling, indicated that there was no possibility of an extensive deposit at the prospect. Material worthy of analysis was encountered in only one hole.

Olive mine, Llano County.—The Olive mine prospect is about 6 miles east of Llano. The deposit of iron ore is located less than 100 yards from the east bank of Little Llano River and about 1 mile south of Lone Grove. A railroad spur formerly connected the mine property with the Southern Pacific Railroad about 1 mile to the south.

No large deposits of magnetite were revealed by a magnetic survey of the area. The principal ore body at this prospect is estimated to contain a few thousand tons. There are several hundred tons of magnetite in the stock piles of the abandoned mine. The value of ore from this prospect is reduced by the presence of the iron sulfide pyrrhotite, which is reported to be abundant in ore from the lower levels. A small amount of nickel is commonly present in pyrrhotite, but an analysis of a sample from this deposit did not report nickel.

The deposit was opened by an incline about 1892, after the ore was accidentally discovered in a shallow excavation. The incline was carried to a depth of about 30 feet and then continued southeastward in a drift until the magnetite body was encountered. A shaft 230 feet deep was sunk near this point in 1892 or 1893 and connected with the drift and incline. Crosscuts were driven on the ore at the 50-, 100-, 150-, and 200-foot levels, and an incline from the 200-foot level encountered the ore at a depth of 250 feet.

The shaft, which is reported to have been boarded over, had filled to within 30 feet of the surface and the incline had collapsed prior to 1943 when Goldich and Fayerweather conducted a dip-needle survey of the area in the vicinity of the mine. The greatest magnetic disturbance detected by the survey is a small, sharp anomaly about 150 feet west of the shaft. Although a positive statement is precluded by uncertainty as to the location of the underground workings, this anomaly probably is associated with the magnetite mass, part of which was mined.

Willow Creek area, Llano County.—The several occurrences of magnetite along Willow and San Fernando creeks about 11 miles west-northwest of Llano have been discussed by Spencer (*in* Paige, 1911, pp. 49–53) and by Barnes, Goldich, and Romberg (1949, p. 23). The most important occurrence is about 1,000 feet southwest of the junction of Willow and San Fernando creeks where several pits have exposed two beds of magnetite dipping about 25 degrees eastward. The beds are about 1 foot thick in the vicinity of the pits and are separated by feldspathic magnetite gneiss. A consistent magnetic anomaly indicates the presence of a third bed of magnetite a few hundred feet east of the pits. The magnetic anomalies associated with these magnetite beds are narrow but they can be traced for several hundred feet. Magnetic anomalies associated with other deposits in the Willow Creek area are of small magnitude and of limited extent.

Elm Creek area, Llano County.—There are several small deposits of iron ore along Elm Creek near the west line of Llano County. Outcrops of iron-bearing gneiss rarely exceed a few feet in width but some are on the order of several hundred feet in length. Most of the ore is highly siliceous, although individual thin stringers of ore are relatively rich in iron. Most of the deposits are too small or too lean to be of commercial value.

Keyser Creek area, Mason County.—At least four small outcrops or showings of martite occur along Keyser Creek in eastern Mason County about 4 miles south-southwest of Castell. Float near the outcrops appears to be relatively pure, but the unweathered ore contains larger amounts of silica. The observed magnetic anomalies indicate that all of the ore bodies are small.

Martin (Deep) Creek area, Mason County.—There are three groups of magnetite deposits in gneiss that crops out along Martin Creek (also known as Deep Creek) about 3 miles northwest and west of Castell. The ore occurs as lenses and beds that commonly contain about 30 percent magnetite. Small bodies of ore contain as much as 80 percent magnetite. The ore probably is of little value because of its high silica content.

Coal Creek area, Gillespie County.—A prospect hole about 800 feet east of Coal Creek at the northern edge of the Coal Creek serpentine mass (Pl. VI) exposes 21 inches of blocky magnetite in schist within a few feet of the serpentine-schist contact. A dip-needle survey indicated that the magnetite extends for only a few feet on each side of the pit. No other deposits were detected in this vicinity.

Showings.—Many magnetite showings of minor importance are found in the metamorphic rocks of the Llano uplift. The small extent of these showings can generally be demonstrated by a brief, careful inspection of each locality together with a few dip-needle observations.

Residual ores.—Residual ores occur at many localities in Blanco, Burnet, Llano, and San Saba counties. The ore of most deposits was derived from iron sulfide minerals in veins or from glauconite-rich layers in the Cambrian sedimentary rocks. Most of the deposits are too small or too lean to be of commercial interest. Comstock (1890, 1891) published analyses of ore samples from several deposits of this type; later investigators reported only the larger, more promising deposits.

One of the larger residual deposits in the area is on the J. T. Garrett ranch about 10 miles south of Llano and about 2 miles east of Oxford. The ore is a residual weathering product of siderite-rich layers in marble of the Precambrian Packsaddle schist. It contains quartz and other siliceous impurities. Limonite crops out in an area 25 to 50 feet wide and almost one-half mile long, but there is a limited quantity of ore present because the weathered zone is only a few feet thick. Although the ore has been reported to contain manganese, bead tests indicate only faint traces of this element.

Another occurrence of residual ore is in the Riley Mountains area about 10 miles southeast of Llano where a major north-south fault drops Paleozoic sedimentary rocks against Precambrian metamorphic rocks. Deposits of iron oxide are present in veins which parallel the fault but which crop out 50 to 100 feet west of the fault trace. Only a small quantity of ore is present; the original sulfides were encountered at depths of a few feet.

Deposits of ferruginous sandstone in the Cambrian strata have received little attention because of their small size and iron content generally too low to constitute ore. Comstock (1890, 1891) published analyses of samples from a few deposits in sedimentary rocks. One type of deposit consists of detrital fragments of magnetite concentrated by processes of sedimentation at favorable localities when the sandstone was deposited. One such deposit is about 13 miles south-southeast of Llano and about 1.5 miles north of Click. Abundant float of relatively pure magnetite can be traced to the Cambrian sandstone — Precambrian schist contact (Paige, 1912). There is a considerable concentration of magnetite in the basal sandstone at this locality.

Iron minerals introduced into the sandstone after deposition form another type of deposit. This secondary iron material occurs as cement between the sand grains in uniformly cemented beds, in concretions, or as zones of nearly pure hematite. Much of the Cambrian sandstone in this region is ferruginous, but only locally is there sufficient iron content for the rock to be considered an ore. Selected samples from some of the deposits contain more than 60 percent metallic iron (Comstock, 1890, 1891), but only a small part of the ore is so rich. No known deposits contain sufficient ore to be of commercial interest.

Summary.—The considerable amount of work which has been done on the iron ore resources of the area makes it unlikely that major deposits will be discovered. The known deposits are insufficient in themselves to support an iron-making operation. As in the past, limited production and shipment to distant markets may be possible in times of national emergency or to meet temporary requirements for special types of iron ore. Special uses, such as heavy concrete aggregate, may be possible for the more favorably located better deposits.

LEAD AND ZINC

Lead or lead-zinc deposits have been reported in Blanco, Burnet, Gillespie, Llano, Mason, and San Saba counties, and a small shipment of lead concentrate was made from one property in 1930. Minor quantities of lead and zinc minerals are associated with other metallic minerals in Precambrian rocks, but more promising deposits occur in calcareous Cambrian strata. Although some of the deposits have been known since 1890, there has been little systematic prospecting. Additional properly planned prospecting, although expensive and speculative, might reveal deposits of commercial significance.

Deposits in Cambrian Sedimentary Rocks

Certain features have been recognized as characteristic of the lead deposits in the sedimentary rocks of the area. Comstock (1891) observed that the accumulations of lead minerals are present in older Paleozoic glauconitic sandstone or brown-weathering limestone along a line of faulting and near an outcrop of dense, moderately coarse-grained granite. Paige (1911, 1912), in his description of the Silver Creek—Beaver Creek area, recognized that the granite outcrops were the exhumed tops of hills around which the Cambrian strata had been deposited. He also considered noteworthy the relationship of the mineralized area to a disturbed zone where the limestone was brecciated.

Baker (1933) suggested that the dip of the sedimentary beds away from the granite outcrops was due, at least in part, to solution of underlying carbonate rocks. After observations in a limited area in western Blanco County, he reported that the galena was disseminated through the rock and concluded that it was an original constituent of the rock. Tarr (1933), in a discussion of Baker's paper, pointed out that many of the geologic factors cited by Baker were equally favorable to the interpretation that the galena was introduced after deposition. He suggested that the ore minerals might be of magmatic origin.

Analytical and mineralogical data on the known deposits and modern geologic maps of the vicinity of each prospect were presented by Barnes (1956) in a review of the lead deposits in the Upper Cambrian rocks of central Texas. The list of features characteristic of the deposits has been expanded. Without exception, the known deposits of lead minerals are in calcareous rocks, either limestone or calcareous sandstone, on the flanks of buried Precambrian hills composed of either Town Mountain or Oatman granite. The mineralization occurs only in the Cap Mountain limestone and Lion Mountain sandstone members of the Riley formation and the Welge sandstone and Morgan Creek limestone members of the Wilberns formation. Although glauconite is present in each of these units, there is no apparent relationship between the degree of mineralization and the glauconite content of the mineralized rock. All of the prospects are in tilted blocks of various sizes bounded by faults associated with the deformation of the Ouachita fold belt, but there are no known deposits along the major faults. The degree of mineralization appears to be related to the amount of disturbance of the rocks. The most highly mineralized prospect is in and adjacent to a collapse structure; prospects with minor mineralization are in areas of little structural disturbance.

Following this study, Barnes concluded that the lead and zinc minerals were probably deposited from upward-moving magmatic solutions, but he did not eliminate the possibility of origin by precipitation from meteoric water. The known deposits are in rocks composed partly or entirely of carbonate minerals; hence deposits are not considered likely in the carbonate-free Hickory sandstone. If the minerals were deposited from magmatic solutions, mineralization would be most likely in the first carbonate rock encountered by the solution, the Cap Mountain limestone.

Barnes recommended further examination of two types of areas by drilling. The Cap Mountain limestone in downthrown fault blocks adjacent to known areas of mineralization should be tested because the mineralizing solutions would have first encountered the limestone in the downthrown block. Also, the intersection of the Cap Mountain limestone—Hickory sandstone contact with buried Precambrian hills should be investigated because of known localization of deposits under similar conditions in southeastern Missouri.

It is probable that many of the buried Precambrian hills have not yet been exhumed. A detailed study of the joint systems in the Cap Mountain limestone may prove useful in detecting the presence of buried hills if any of the joints are related to subsidence around the topographic highs. Seismograph or gravity-meter surveys may locate hills that cannot be detected by surface methods.

Silver Creek—Beaver Creek area, Burnet County.—The two prospects in the Silver Creek—Beaver Creek area are on the R. D. Goodrich ranch about 13 miles northwest of Burnet (fig. 13). The Silver Creek prospect, most promising of the known lead-zinc deposits in the central Texas area, is on Silver Creek about 0.5 mile northeast of its confluence with Beaver Creek, which is now an arm of Lake Buchanan at the point of junction. The Beaver Creek prospect is on the west bank of Beaver Creek, 1 mile north-northwest of the Silver Creek deposit. Both prospects were opened prior to 1890 (Comstock, 1891).

The Silver Creek prospect is on the southwest side of a Town Mountain granite dome that must have stood about 600 feet above the general level of the Precambrian surface. Mineralization at the surface and in the workings is largely in the Morgan Creek limestone and the Welge sandstone members of the Wilberns formation. The mineralized Morgan Creek limestone is in and adjacent to a collapse structure, 35 by 100 feet, where the limestone has subsided at least 60 feet below its normal level. Mineralization extends outward from the collapse structure as far as 140 feet into the Welge sandstone and at least 30 feet into the Morgan Creek limestone. There are no surface indications of mineralization in either the Lion Mountain sandstone or Cap Mountain limestone members of the Riley formation, but lead-zinc-bearing Lion Mountain sandstone has been sampled at three places in the workings at this prospect. Test holes drilled near the workings

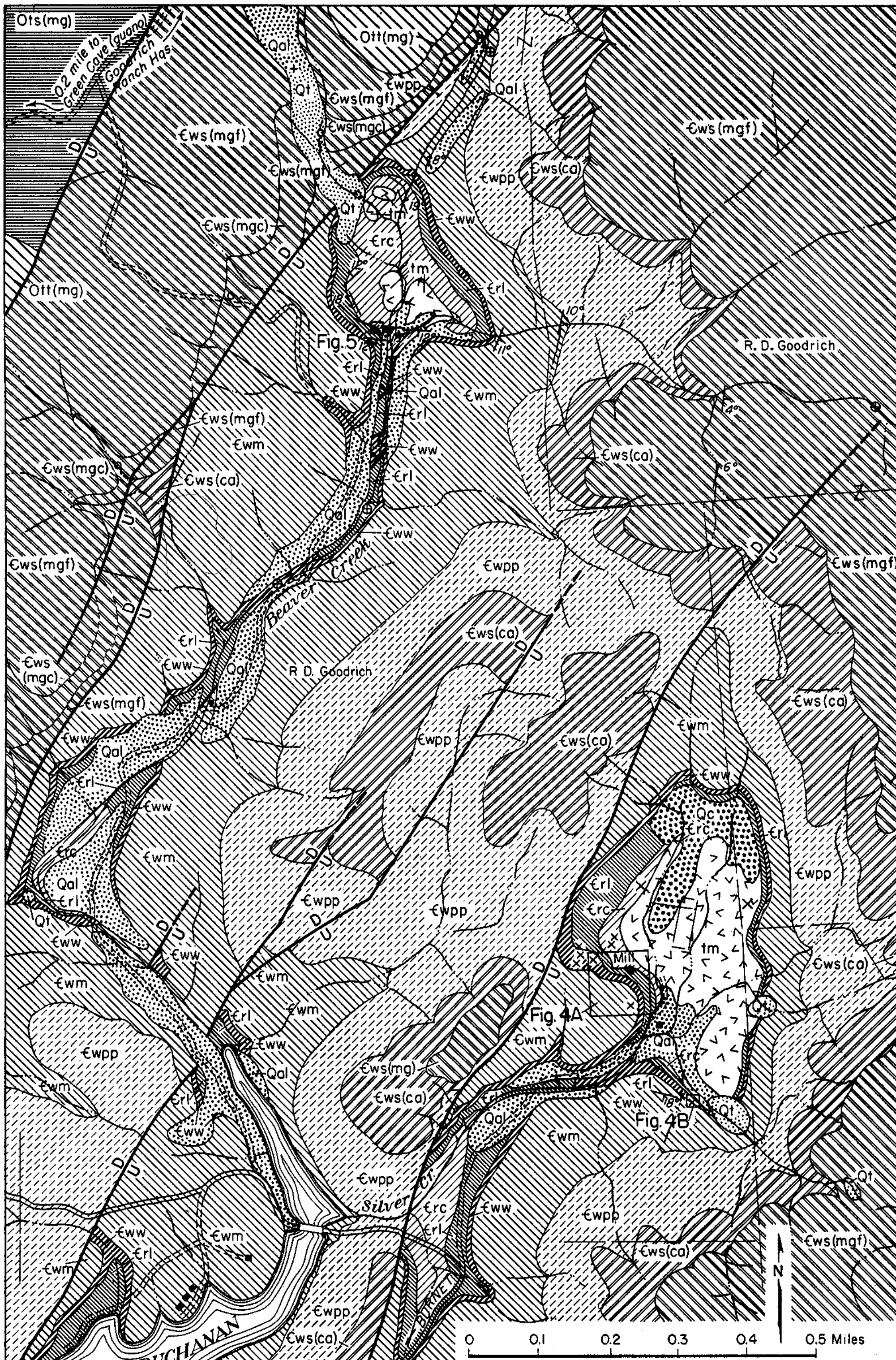


FIG. 13. Geologic map of the Silver Creek—Beaver Creek area, Burnet County. (From Bureau of Economic Geology Report of Investigations No. 26.)

(Ellenburger group—Ots(mg), Ott(mg) ; Cambrian rocks—Wilberns formation, €ws(mgf), €ws (mgc), €ws(ca), €wpp, €wm, €ww; Riley formation: Lion Mountain sandstone member, €rl; Cap Mountain limestone member, €rc; Precambrian rocks—Town Mountain granite, tm.)

encountered traces of lead in the Lion Mountain sandstone and several zones of "good lead" in the Cap Mountain limestone.

Barnes (1956) reported that in 32 samples collected on the surface and in the workings at this prospect, the lead content ranged from 0.00 to 5.47 percent and the zinc content from 0.03 to 1.00 percent. Development work at this prospect is insufficient to provide the data necessary for an accurate estimate of the quantities of lead and zinc or the quantity of mineralized rock present. From the data available, Barnes has estimated that possibly 330 tons of lead and 65 tons of zinc are present in about 13,000 tons of mineralized rock within the collapse structure, and there may be as much as 200 tons of lead in about 20,000 tons of mineralized Welge sandstone in the vicinity of the large collapse structure. There may be other collapse structures in the vicinity of this prospect. If the search for lead is continued, Barnes suggests that the collapse structures should be especially sought.

Baker (1935) reported that the Frank Pavitte Mining Company produced 29 tons of lead concentrate that averaged 66.45 percent metallic lead from 736 tons of lead sulfide ore mined at this locality in 1930. Barnes (1956) stated that this is the only recorded lead production from central Texas.

The Beaver Creek prospect is on the southwestern side of a Town Mountain granite exfoliation dome probably covered completely prior to the deposition of the lowest beds of the Lion Mountain sandstone. The prospect has been explored by a few shallow pits sunk in rocks of the transition zone between the Cap Mountain limestone and the Lion Mountain sandstone members of the Riley formation. Recent investigators (Barnes, 1956) found galena in place only in one of the pits and in a limestone outcrop in the creek east of the pits. A channel sample from the pit contained 0.32 percent lead; a chip sample from a pile of ore at the prospect contained 0.81 percent lead. There was no zinc in either sample.

There is little lead and almost no zinc at this prospect. No structural disturbance was observed and the control of mineralization is not apparent. There was no search for collapse structures during the recent investigation except at the site of the known mineralization. Barnes recommended that such a search be made as part of any further exploration for lead.

Slaughter Gap area, Burnet County.—There is a lead-zinc prospect on the Tom O'Donnel ranch, about 4 miles north of Marble Falls, 1 mile northeast of Slaughter Gap, and 1.5 miles south of Fairland (fig. 14). The mineralization occurs in Cap Mountain limestone along the northern side of an exhumed exfoliation dome of Town Mountain granite which probably stood about 200 feet above the general level of the surface when Cambrian deposition began. Workings at the prospect include a short incline, a shaft about 20 feet deep, and three small prospect holes. Galena mineralization occurs within a few feet of the limestone-granite contact and extends a little more than 100 yards along the strike of the limestone; a few specks of galena are distributed through about 20 feet of beds above the incline.

Partial analyses of three samples collected from the workings at this prospect were reported by Barnes (1956). The lead content ranged from 0.19 to 0.52 percent and zinc from 0.10 to 0.14 percent. Lead has been reported in two holes drilled about 100 feet north of the granite-limestone contact less than 0.2 mile east of the workings at this prospect. No lead was reported in a third hole drilled about 0.1 mile north of the contact.

A test hole drilled on the O'Donnel property about 2 miles north of Fairland encountered no lead mineralization. There is an unverified report of lead in Cap Mountain limestone about 1 mile north of Fairland.

Scott Klett area, Blanco County.—The prospect on the Scott Klett ranch is 5.4 miles slightly north of west from Johnson

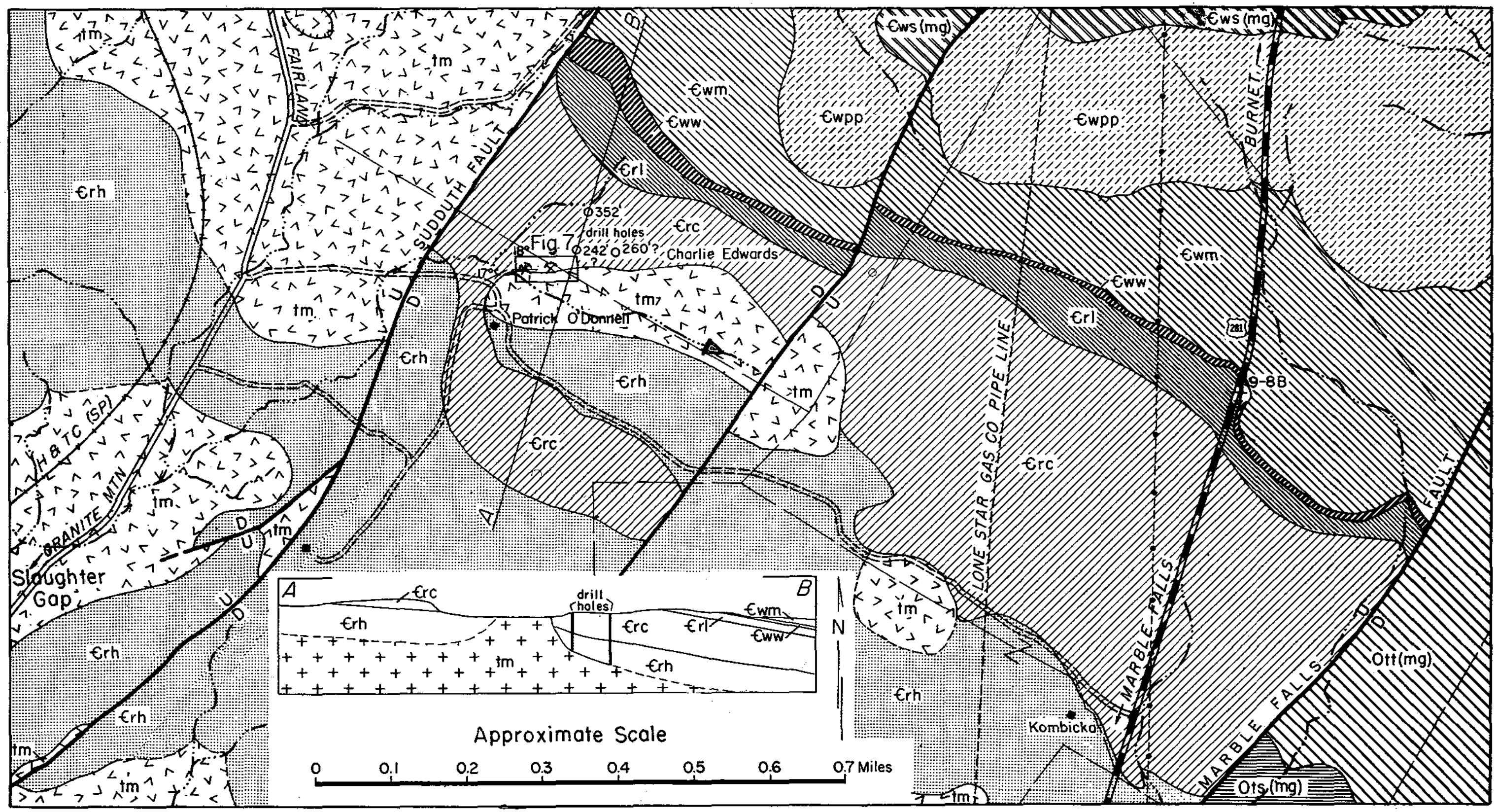


FIG. 14. Geologic map of an area in vicinity of Slaughter Gap, Burnet County. (From Bureau of Economic Geology Report of Investigations No. 26.)

The Lower Ordovician is represented by the Tanyard formation of the Ellenburger group, members of which are indicated by the following symbols: Ots(mg), dolomitic facies of the Staendebach member; Ott(mg), dolomitic facies of the Threadgill member. The Upper Cambrian is represented by two formations, comprised of seven members, shown by the following symbols: Wilberns formation: Єws(mg), dolomitic facies of the San Saba member; Єwpp, Point Peak shale member; Єwm, Morgan Creek limestone member; Єww, Welge sandstone member. Riley formation: Єrl, Lion Mountain sandstone member; Єrc, Cap Mountain limestone member; Єrh, Hickory sandstone member. The Precambrian is represented by coarse-grained Town Mountain granite, tm.

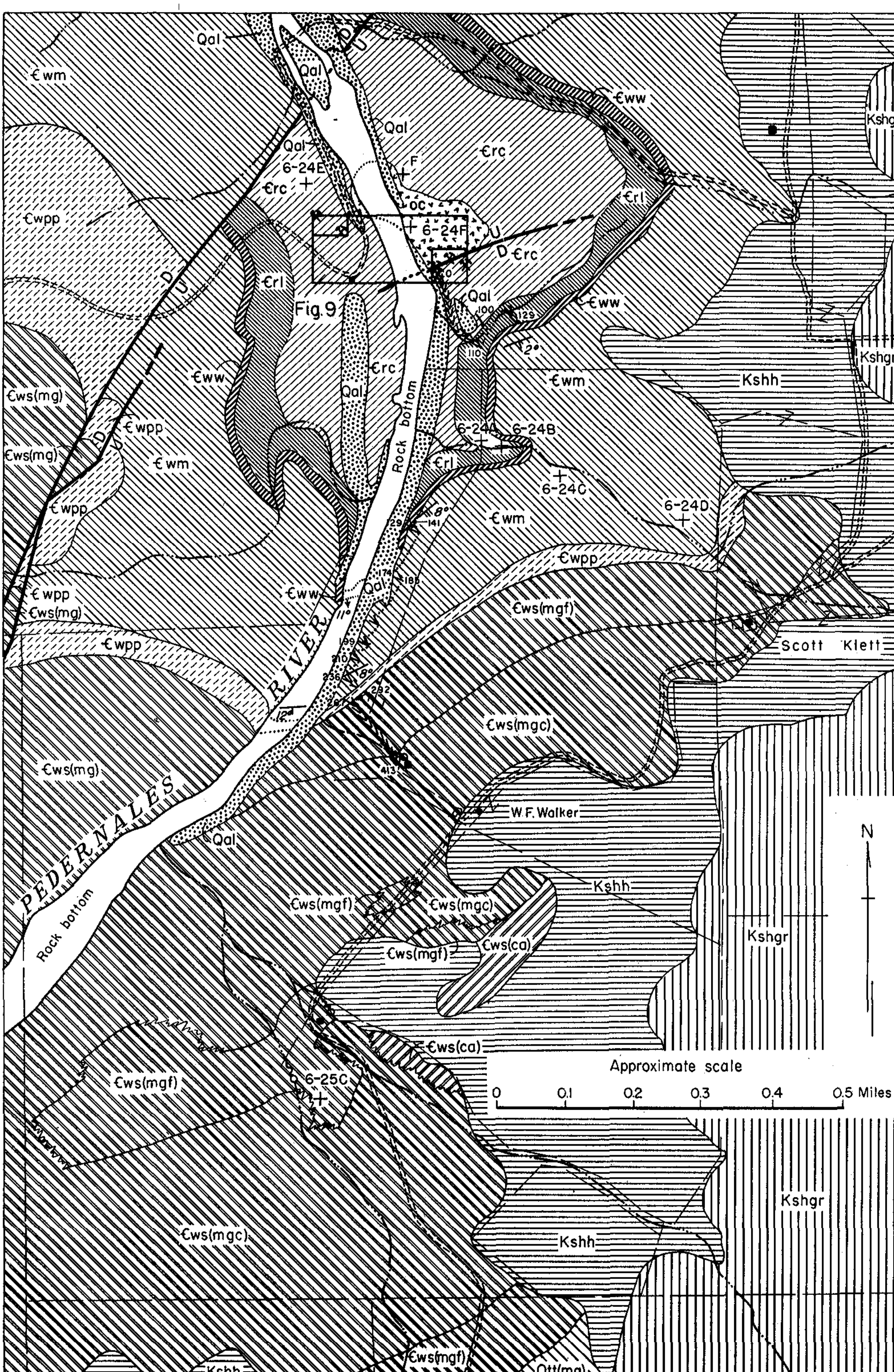


FIG. 15. Geologic map of an area in the vicinity of the Scott Klett prospect, Blanco County. (From Bureau of Economic Geology Report of Investigations No. 26.)

(Cretaceous rocks—Kshgr, Kshh; Ellenburger group—Ott(mg); Cambrian rocks—Wilberns formation, €ws(mgf), €ws(mgc), €ws(ca), €wpp, €wm, €ww; Riley formation, €rl, €rc; Precambrian rocks—Oatman Creek granite, oc.)

City and about the same distance northeast from Hye. There are two areas of mineralized Cap Mountain limestone about 250 yards apart on the flanks of an exhumed hill of Oatman granite. The hill stood possibly 700 feet above the general level of the surface at the beginning of Cambrian deposition in the area, and the top of the hill extended to within 100 feet or less of the top of the Cap Mountain limestone. Figure 15 is a geologic map of the area in the vicinity of the Scott Klett prospect.

Barnes (1956) reported that the degree of mineralization observed at this prospect is exceeded at only the Silver Creek prospect. The mineralized area south of the granite outcrop is separated from the granite by a normal fault; the mineralized area may be part of a collapse structure formed by solution of underlying limestone. Eleven samples were collected from the vicinity of the workings, which consist of three pits and two open cuts. The lead content ranges from 0.01 to 1.47 percent and zinc from 0.00 to 0.21 percent. West of the granite outcrop there are surface showings of galena near an incline and three prospect pits, but no galena was found in two of the pits at the time of Barnes' investigation. A sample collected from the dump at the third pit contained 0.39 percent lead and 0.21 percent zinc; a sample collected from the incline contained only 0.04 percent lead and 0.09 percent zinc.

The amounts of lead and zinc in the samples collected at the surface or from the workings do not indicate that the deposit is of economic importance. However, only the upper part of the Cap Mountain limestone has been examined. The limestone buried along the flanks of the granite hill may be as much as 400 feet thick. If the mineralizing solutions entered the rock from below, the limestone in the lower, unexamined portion of the formation may be more highly mineralized than the limestone that has been sampled at the surface.

Iron Rock Creek area, Blanco and Gillespie counties.—Small amounts of galena occur in the Cap Mountain limestone near the western end of an area of small granite outcrops about 2.5 miles north-northwest of Hye. The exhumed tops of a row of Precambrian hills form seven granite outcrops roughly aligned in an east-west direction in an area about 2.5. miles long and 0.3 mile wide. Iron Rock Creek and the Blanco-Gillespie County line cross the westernmost granite outcrop. Cap Mountain limestone surrounds the granite except at the eastern end of the area where the granite is locally in contact with Lion Mountain sandstone.

Two samples collected from prospect pits near the west and north sides of the westernmost granite outcrop contained less than 0.05 percent lead and 0.25 percent zinc. Traces of galena were found near the western end of the second most westerly outcrop which is wholly within Blanco County. A check of the Cap Mountain limestone in the vicinity of the other granite outcrops failed to reveal any indication of lead or zinc mineralization.

Llano County.—Galena has been reported from Packsaddle, Riley, and Cedar mountains (Baker, 1935), but there is no indication of the precise locations of such occurrences. Repeated rumors of the presence of a lead deposit in a canyon leading from Cedar Mountain into Sandy Creek resulted in a detailed examination of one such canyon by Barnes (1956). A buried hill of Precambrian metadiorite surrounded by Cap Mountain limestone is exposed in a canyon about 3 miles southwest of Click. Because of the association of known lead deposits with buried Precambrian hills, an area in the vicinity of this canyon was mapped; no lead mineralization was found in the mapped area. Other canyons which drain into Sandy Creek farther to the west were not explored during this investigation.

San Saba County.—A well on the Kuykendall ranch in southern San Saba County is reported to have encountered galena (Baker, 1935). The stratigraphic position of the galena was not reported.

Deposits in Precambrian Rocks

Burnet County.—Sphalerite accompanies fluorite at several points in the upper valley of the north fork of Spring Creek about 7 miles west of Burnet. The minerals occur in a bed up to 3½ feet in thickness in hornblende schist. Prospecting has been confined to the opening of shafts or shallow test pits inadequate for determining the size or grade of the deposit. A carefully selected sample from a dump at a shaft was reported to contain 7.6 percent zinc, 0.56 ounce of silver, trace of gold, and no lead (Paige, 1911). Galena, pyrite, and molybdenite were observed on the dump at the shaft.

Llano County.—Comstock (1890) reported the presence of galena in copper-silver ore from a locality south of Babyhead Mountain on a branch of Babyhead Creek. Another show of lead was reported from a quartz vein west of Lone Grove between the roads to Llano and Valley Spring. Neither of these occurrences has been considered as a lead prospect by later investigators.

Blanco County.—Barnes (1952a) reported the presence of galena in northwestern Blanco County near the northern boundary of Blowout quadrangle. A small quantity of galena occurs in a quartz vein that cuts gneiss.

LIGNITE

Lignite, formerly an important fuel in Texas, was mined in many counties from Medina County northeastward to Louisiana. The material was gradually replaced as a fuel by oil and natural gas, and mining for solid fuel ceased in 1946, although a small production used for the manufacture of activated carbon continued after that date. In more recent years interest in this material has revived, and since 1955 a large power plant at Sandow in Milam County has used lignite as fuel. The electric power produced is used by the Aluminum Company of America in the refining of aluminum. Pilot-plant operations at this power plant have employed the Parry char process which produces char, a solid fuel, and tar as a by-product. It is reported that eventually all of the lignite used by this plant may be treated by the char process.

The revival of interest in lignite as a fuel appears due to increasing prices for natural gas and the possibility that gas may become more valuable as a raw material than as a fuel, so that supplies for fuel purposes may become less abundant in the future. It appears also that lignite is a potential basic raw material for synthetic liquid fuel and other products. The most likely use for lignite in the near future appears to be in large power plants. Future large-scale utilization will depend on a number of factors, but it is apparent that lignite is potentially important in future industrial development in the State.

Much of the lignite mining in Texas prior to 1947 was by underground methods. Shallow strip mining was carried on at Sandow and at Darco, in Harrison County, by strip or open-pit methods. At Sandow such mining has been carried on recently where 150 feet or more of overburden has been removed to reach lignite. A ratio of 10 feet of overburden per foot of lignite is said to be a practical limit to the depth of strip mining at the present time.

It is believed that any major expansion of lignite mining in Texas for many years to come will be by strip or open-pit methods. It does not seem likely that lignite will again be widely used in small-scale installations or for household uses. Utilization presumably will be in very large installations such as major power plants located close to the lignite deposits. Strip or open-pit mining is better adapted to the large volume production required for such installations. It is more economical, recovers a higher percentage of the lignite since no roof support is needed, and water problems, which are present in many places where the lignite occurs, are less difficult. An installation of this type, however, requires a deposit or deposits of lignite of sufficient size for many years of operation determined by the contemplated life of the project and rate of consumption. Minimum thickness of approximately 5 feet appears to be a practical limit for such an operation, because lignite thinner than this figure is rarely in deposits of sufficient volume and in some instances is of lower quality than the thicker beds. About 2,500 acres would be required for a deposit of lignite 5 feet thick containing 20,000,000 short tons.

Bastrop and Fayette counties are among those in which lignite was formerly mined, and mining followed the pattern of the industry in the rest of the State. A little open-pit mining was carried on as early as 1886; shaft mining was established in 1892. The last shipment was from Bastrop County in 1944. In Bastrop County, mining was carried on near McDade on the Southern Pacific Railroad in the northern part of the county and between Bastrop and Elgin along the Missouri-Kansas-Texas Railroad. At one time fourteen mines were in operation. The lignite was used in municipal and private steam-power plants, for the manufacture of producer gas, and as household fuel. In Fayette County, lignite was mined near Ledbetter prior to World War I. Cessation of mining came not because of depletion of the deposits but because of the declining demand in competition with fuel oil and natural gas.

Bastrop County

Lignite in Bastrop County is present in the Wilcox group of strata. These crop out in the northwestern part of the county (Pl. I) along the general line of Butler, Sayersville, and Red Rock and dip toward the southeast, so that any stratum or bed normally is at greater and greater depths toward the southeast. This simple arrangement of beds is interrupted in places by faults which have displaced the beds. In this area the Wilcox conventionally is divided into three formations: a lower one, Hooper; a middle one, Simsboro sand; and an upper one, Calvert Bluff.

As far as has been determined, all of the lignite mined in the area was in the Calvert Bluff formation, and although lignite is present in the Hooper formation and as very minor beds in the Simsboro sand, available evidence indicates that the only lignite of immediate commercial promise is that in the Calvert Bluff. It is possible, therefore, to delineate an area which can be considered as the main lignite belt in the county (Pl. IV). Its northwestern boundary is the outcrop area of the lignite beds, and its southeastern limit is determined by the depth at which lignite mining is no longer feasible by either underground or strip-mining methods. Due to insufficient bore-hole information, it is not known how far the lignite beds extend to the southeast (down dip), but probably they are present several miles southeast of the outcrop area where the depth may be as much as 500 feet. Lignite probably is present everywhere along this main belt, but the number, thickness, and continuity of beds vary from place to place. In general, the area containing lignite of suitable thickness and depth for both strip and underground mining under present-day limitation is comparatively narrow and close to the outcrop. Lignite of suitable thickness and depth for underground mining only is present down dip beyond the strip-mining area. Limited data are available for the determination of quantities of lignite and depths of the lignite beds. It must be emphasized that conclusions presented here are only guides to exploration by drilling which is necessary for accurate determinations of volume and depths of the lignite beds, information essential for any contemplated commercial development.

The available data include bore-hole information from lignite exploration, records of mining operations, outcrop data, water-well data, and bore-hole information from holes drilled for oil. The last is the least reliable and can be used only for general information. The kinds and quantity of data available in Bastrop County vary, so that information in some parts of the county is better than in others. Available information permits generalizations about the three areas discussed below.

Bastrop-Sayersville area. — Practically all of the past lignite mining in this area was carried on near the Missouri-Kansas-Texas Railroad. The mining was all by underground methods, and shipment was by railroad. Spur tracks, as much as 1.5 miles in length, connected the mines to the main line of the railroad. The mining area was approximately 9 miles long, essentially parallel to the strike of the lignite beds, and 1 mile wide.

The mining area was generally along the divide between Big Sandy Creek and Piney Creek. The southern end extended nearly to Colorado River. Accordingly, there is considerable topographic relief in the area. The highest area is opposite Camp Swift where mine shafts were at an elevation of approximately 510 feet. One mine shaft at the south end of the area near the northwestern part of Bastrop was at an elevation of approximately 370 feet.

The most complete section of the coal beds available in this study is from a test boring near old Glenham Station drilled by the Bastrop Lignite Company. The elevation of the top of the boring probably was approximately 510 feet.

Log of lignite test boring drilled by Bastrop Lignite Company near Glenham Station

	Depth in Feet
Clay and sand clay	0– 49
Lignite (Bed No. 1)	49– 50
Sand and clay	50– 61
Lignite (Bed No. 2)	61– 62.5
Sand and clay	62.5– 80
Lignite (Bed No. 3)	80– 82.5
Sand and clay	82.5–120
Lignite (Bed No. 4)	120–124
Sand and clay	124–170.5
Lignite (Bed No. 5)	170.5–180.5
Sand with a little clay	180.5–255.5
Lignite (Bed No. 6)	255.5–258.5
Sand, loose, fine-grained, unlimited amount of good water (Simsboro sand).	

The numbers assigned the lignite beds conform to the general practice in the area. Beds 3, 4, and 5 were mined in various mines. Reported range in thickness is as follows:

	Feet
Bed No. 3	2.5–4.5
Bed No. 4	3.5–5
Bed No. 5	5–11

In some mines there was a clay parting in Bed No. 5 up to 1 foot in thickness, and the same condition is true at an exposure in the bluff about the middle of Powell's Bend on Colorado River about 1 mile west of the closest abandoned mine. Here there are two beds, each about 6 feet thick separated by 1 to 1.5 feet of clay. The bottom of the lower bed is about 45 feet above water level.

There are a good many exposures of lignite in this area, and correlation with the numbered beds is difficult. On Plate IV only exposures believed to be Bed No. 5 are shown because it is not likely that the thinner beds will be of commercial importance. The exposures, with the exception of L-1, fall along a fairly regular line. If the correlation of the exposures is correct, faulting probably accounts for the position of L-1. It is not known how far down dip Bed No. 5 extends; in the water-well field in Camp Swift it is believed to be present 220 to 250 feet beneath the surface.

Butler area.—The earliest mining in Bastrop County was a short distance north of the Southern Pacific Railroad, about 1.2 miles southeast of Butler. The only mine was opened in 1892 and apparently was operated for only a few years. Lignite is exposed in and around the clay pits of the Elgin-Butler Brick Company and at places northeastward to the Lee County line. Results of test drilling for lignite in the area have been made available for this study and are the basis for the conclusions reached concerning lignite in the area.

There appear to be two zones of lignite beds. The lower zone, which crops out in the Butler pits, consists of two beds of lignite with an average total thickness of 12 feet separated in places by 1 to 6 feet of clay, shale, or impure lignite. Parallel to the outcrop line and for a distance of approximately 1 mile down dip in much of this area, the top of this lignite zone is less than 100 feet beneath the surface.

The logs of the lignite test holes indicate that a second zone of lignite beds is present above the one exposed in the Butler pits. The early mining east of Butler probably was from this zone. Six beds of lignite were logged in a test hole about 2.5 miles northeast of Butler; the highest bed was encountered at a depth of 32 feet. At the mine the highest bed, 8 feet thick, was at a depth of 27 feet and was separated from a lower bed by 17 feet of clay. In the test hole the two lowest beds are 5 and 7.5 feet thick separated by 5 feet of clay. The upper one is at 197 feet. These are considered to be the two beds which crop out in the Butler pits. The lignite beds in the upper zone are 3, 2.5, 8, and 4 feet thick, respectively, and the bottom one is 76 feet above the top of the lower beds.

Data are insufficient to tell much about the continuity of the upper zone, but in some logs there is a grouping of beds with a maximum thickness of 11 feet, either as one bed or two beds 2 to 2.5 and 5 to 8 feet thick separated by a maximum of 6 feet of clay. The depth in these logs ranges from 67 feet to 107 feet.

No consideration has been given to faulting which may have affected the lignite beds in the Butler area. Faults are known to be present, but in the absence of detailed geologic mapping and precise locations of the test holes, only general conclusions concerning the lignite can be drawn.

Southern Bastrop County.—This area includes the part of the county south of State Highway 71 and west of Colorado River. Lignite data are limited to a few exposures and to logs of holes drilled for oil and water. Two beds of lignite, each at least 6 feet thick in places, are exposed along Cedar Creek (L-6) about one-fourth mile downstream from the crossing of Farm-to-Market Road 20, 2 miles southwest of State Highway 71. Six feet of lignite was reported in the bluff on Colorado River 2 miles below Bastrop (L-7).

The logs of many of the wells in the Hilbig, Carroll, and Bateman fields indicate lignite at depths that range from 35 to 300 feet. Reported thicknesses of the lignite beds are variable, some excessive, and cannot be used as accurate data because logging practice for lignite is not consistent. The fact that so many logs record lignite, however, warrants the conclusion that a number of lignite beds are present in this area and that some are of such thickness and depth as to be of potential importance. The data are sufficient to encourage exploration. A relatively small number of test holes would establish whether the area merits extensive exploration. The lignite reported in these wells may be in the Hooper formation. If so, this is the only locality where available data indicate that commercial lignite may be present in the formation.

Quality.—Lignite from Bastrop County varies considerably in quality. An average of many samples from shipments to the power plant at The University of Texas showed about 35 percent moisture and a heating value of 7200 B. T. U. In hot dry months some samples had as little as 20 percent moisture and a heating value of 8000 B. T. U. Sulfur was 0.80 to 2.50 percent on a dry basis. A selected sample from locality L-5 showed 25.5 percent moisture, 37.5 volatile matter, 29.7 fixed carbon, 7.3 ash, and 9162 B. T. U. as received. Sulfur was 1.04 percent. This sample probably is better than the average of lignite in Bed No. 5.

Reserves.—Sufficient information is not available for computing lignite reserves. There is sufficient information to indicate that deposits of potential commercial importance are present at depths not too great for strip mining. A considerable quantity of lignite was removed in past mining operations but this was only a small part of the original reserves. Probably the largest reserves are in the area between Sayersville and Bastrop. In the Butler area the lignite beds appear to vary considerably in thickness in short distances. The exposure on Cedar Creek (L-6) may be part of a deposit of major promise.

Determination of the volume, depth, and quality of lignite deposits can be made only by systematic drilling and sampling. Commercial development should be attempted only if exploration establishes a deposit adequate for a contemplated operation.

Fayette County

Lignite in Fayette County is in the Jackson group of strata which crop out in the central part of the county along the general line of Ledbetter, Plum, Muldoon, and southwestward to the county line. The beds dip southeastward. In this area the Jackson is conventionally divided into, in ascending order, the Caddell, Wellborn, Manning, and Whitsett formations. Lignite of any potential commercial importance, as far as known, is in the Manning formation. The Yegua formation below the Jackson, which elsewhere contains minable lignite beds, apparently does not contain important beds in Fayette County.

Lignite was mined prior to World War I near Ledbetter in the northeast part of the county. The mine was about 0.5 mile from the Southern Pacific Railroad. Little information is available concerning this operation. Lignite beds 8 and 7 feet thick were mined at depths of 55 and 95 feet, respectively. Caved workings cover several acres, but outcrops of the lignite were not found during the present investigation.

There are numerous outcrops of lignite along the outcrop of the Manning formation from Ledbetter southwestward. Many of these are of thin beds without commercial promise. The thickest bed is at Manton Bluff on Colorado River (L-1) where 18 feet of lignite is exposed in the west bank of the river for a distance of about 200 yards. Other exposures of promise are shown on Plate III. Lignite occurrences reported in the past but not verified during the present work include a bed 12 feet thick 12 feet beneath the surface near Lena, and a bed 8 feet thick 22 feet beneath the surface 3 miles north of Flatonia.

Quality.—Lignite from Fayette County generally is of lower quality than that from Bastrop County. The average of three samples collected during the course of the present work is moisture 30.48 percent, volatile matter 34.64, ash 12.27, fixed carbon 22.11, and B. T. U. 7029 on an as-received basis. Sulfur was 2.54 percent.

Reserves.—Information is not available from which to estimate possible commercial reserves of lignite in Fayette County. Individual beds seem to be less continuous than in Bastrop County. On Plate III two areas (near Ledbetter and west of Colorado River) are shown which are considered to be the most promising. If the thicker lignite beds in these areas are continuous, lignite deposits possibly of commercial size are present at depths suitable for stripping operations.

MAGNESITE

Magnesite is natural magnesium carbonate; when pure, it is composed of 47.8 percent magnesia (magnesium oxide) and 52.2 percent carbon dioxide. Common impurities include calcium oxide, silica, alumina, and iron oxide. It is one of the raw materials for magnesia which is used in refractories for use in the steel and copper industries, insulation, special cements for the building industry, fertilizer, and in rayon, rubber, and chemicals. Magnesite is also used for terrazzo chips.

There are several deposits of magnesite west and south of Sharp Mountain in an area from 3 to 7 miles south-southeast of Llano. During World War II magnesite was mined at the Meramec Minerals, Inc., mine (Ll-71, Pl.II) 3.1 miles S.13°E. from Llano and at the Texas Mines (Ll-72, Pl. II) 5.3 miles S.24°E. from Llano. The road distance from these mines to the nearest railroad, at Llano, is approximately 4 and 7 miles, respectively. Terrazzo-chip quarries have been opened in magnesite deposits in this area.

During the 1940's magnesite was mined at the Green Mountain quarry (Ll-102, Pl. II) for use as agricultural stone. The quarry, now filled, was located just south of the present route of State Highway 71, 7.5 miles S.60°E. from Llano.

A small deposit of magnesite (M-25, PL II) has been reported 3.5 miles N.56°W. from Mason in west-central Mason County. There has been no commercial utilization of magnesite from this deposit, which is approximately 30 miles from the nearest railroad loading point at Brady.

MICA

Mica in books, some of which are of commercial size for sheet mica, is present in many of the pegmatite masses of the Llano uplift, but most of it will not meet the rigid specifications required for this material. During the years, many samples of mica from the area have been submitted to the Bureau of Economic Geology but none was considered to be of commercial grade. Considering the extensive prospecting and collecting from pegmatites, it is doubtful whether commercial deposits of suitable material are present. It likewise is doubtful whether ground mica could be produced in commercial quantities.

MOLYBDENUM AND BISMUTH

The molybdenum mineral molybdenite and the bismuth minerals native bismuth and bismuthinite have been reported from a number of localities in Llano County, but no commercially significant deposits have been found. The most noteworthy locality is the Kiam pegmatite, where considerable prospecting was carried on. This pegmatite is discussed in the section on "Feldspar."

OIL SHALE

The highly petroliferous Barnett shale has a relatively uniform thickness of 30 to 40 feet at outcrops in San Saba County; the thickness is slightly greater in wells in the northern part of the county. Outcrops of the shale form narrow, sinuous bands, generally from 100 to 300 feet wide, interrupted locally by faulting. The outcrops occur along the lower (southern) boundary of the area shown on Plate I as Marble Falls formation, extending across the county from Richland Springs to near Bend.

According to Plummer (1940), the oil content of 63 samples collected at 1-foot intervals in pits opened with hand tools at eight locations in San Saba County ranged from 1.2 to 42.2 gallons per ton and averaged 13.4 gallons per ton. Oil content varied from location to location and from sample to sample at each location. The relationship between degree of weathering and oil content of the samples suggests that fresh shale farther from the outcrop may have at least a slightly higher oil content. Data obtained from properly located drill holes would be more representative of the true oil content of the shale than data collected from pits opened in the outcrop of the shale.

There is little possibility that the oil shale in this area will be developed while there are adequate reserves of petroleum that can be produced by wells, but the oil shale of San Saba County might have commercial importance at some future time.

PHOSPHATE ROCK

Deposits of phosphorite near Marble Falls, Burnet County, are the most promising known potential source of phosphate rock in the CRIDA area. Phosphatic zones or thin beds of phosphorite are known to be present in Blanco, Lampasas, Mason, McCulloch, and San Saba counties. Glauconitic sandstones in Bastrop and Travis counties contain small quantities of phosphatic material. Thin layers of phosphatic pebbles have been found in Upper Cretaceous rocks at several localities in Travis County, but the deposits are too small to be of commercial value as sources of phosphate rock.

In a publication discussing the phosphorite deposits in the eastern part of the Llano uplift, Barnes (1954) concluded that, although the known phosphorite deposits are of questionable commercial value, there is a possibility of finding commercial deposits in the area. He recommended that the base of the Marble Falls limestone be thoroughly checked along its outcrop. Concentrations of phosphatic material have been reported at two other stratigraphic positions in the eastern part of the Llano uplift. A thin bed of phosphorite occurs sporadically in Blanco, Burnet, Lampasas, and San Saba counties as the upper member of the Houy formation (Cloud et al., 1957), and the chert fragments of the Ives breccia member of the Houy formation are locally embedded in a matrix of phosphatic material.

Phosphorite is mildly radioactive so that a Geiger counter or other radiation detection instrument can be used as a rapid reconnaissance tool if the probe is lowered into holes made through the masking soil cover.

Marble Falls area, Burnet County.—A phosphorite bed about 11 feet thick is exposed in a road material pit one-fourth mile west of U.S. Highway 281 about 1.5 miles south of Marble Falls (fig. 16). The phosphorite occurs above the Barnett formation in a sequence of beds forming a small hill above a circular collapse structure. Three beds of impure limestone from 4 to 6 inches in thickness are present within the phosphorite. A similar deposit is believed to be present in another small hill about 500 feet northeast of the road-material pit. Although phosphorite is not exposed here, fragments of limestone similar to that in the road-material pit are present in the float which surrounds the hill. A Geiger-counter examination failed to detect the weak radioactivity normal to phosphorite, but the radioactivity may have been masked by the soil cover.

Chemical analyses of channel samples collected from the road-material pit deposit showed an average P_2O_5 content of 14.5 percent. Tests indicate that screening is of little value for increasing the grade of the material; the phosphate content of the plus 100-mesh fractions is only slightly higher than that of the fines.

The available data are insufficient for accurate estimate of reserves. A tentative estimate, based on the assumptions that the density of the one sample is representative of the entire deposit and that the thickness of the bed exposed in the road-material pit is constant throughout the area of both hills, indicates that there are 5,000 tons of phosphorite in the southwestern deposit and 35,000 tons of phosphorite in the northeastern deposit.

The phosphorite member at the top of the Houy formation crops out along two tributaries of Doublehorn Creek about 4 miles S.30°E. from Marble Falls. The bed is less than 1 foot thick at each of the exposures.

Johnson City area, Blanco County.—Thin beds of phosphatic material and phosphorite crop out at several localities north of Pedernales River between Honeycut Bend and Pedernales Falls, 4.5 to 10 miles east of Johnson City. In this area the phosphorite occurs at three levels: (1) at the top of the Barnett formation, (2) overlying the Doublehorn shale member of the Houy formation, and (3) associated with the Ives breccia.

San Saba County.—A thin glauconite-phosphate-pebble zone overlying the Barnett formation is exposed at many places in southern and southeastern San Saba County (Cloud and Barnes, 1948, p. 111). Two such exposures are along the east side of State Highway 16 and in the wall of a shale pit east of the highway 5.5 and 6.1 miles, respectively, south of the courthouse in San Saba. Barnes (1954) recommended that rocks at this stratigraphic position in the vicinity of the S. Aylor ranchhouse, 2.7 miles S.63°E. from Bend, should be checked for phosphorite.

The phosphorite bed at the top of the Houy formation is exposed at Davis Creek, 2.2 miles south of Chappel (Cloud et al., 1957). The bed has a maximum thickness of 2 feet and contains up to 32 percent P_2O_5.

Other occurrences, Llano uplift.—Globular glauconite and phosphate pebbles are commonly abundant in a zone about 1 foot thick at the base of the Marble Falls formation in the Bald Ridge area southeast of Brady, McCulloch County, and in the Bear Spring area southwest of Mason, Mason County. Southwest of Lampasas, Lampasas County, the Chappel limestone is separated from the Honeycut formation by less than 2 feet of phosphatic beds where exposed along Espy Creek southeast of the Hallenbeck ranchhouse.

Greensand beds, Bastrop and Travis counties.—Three persistent beds of greensand crop out in Bastrop and Travis counties. The outcrops of two thin beds in the Midway group are near, and approxi-

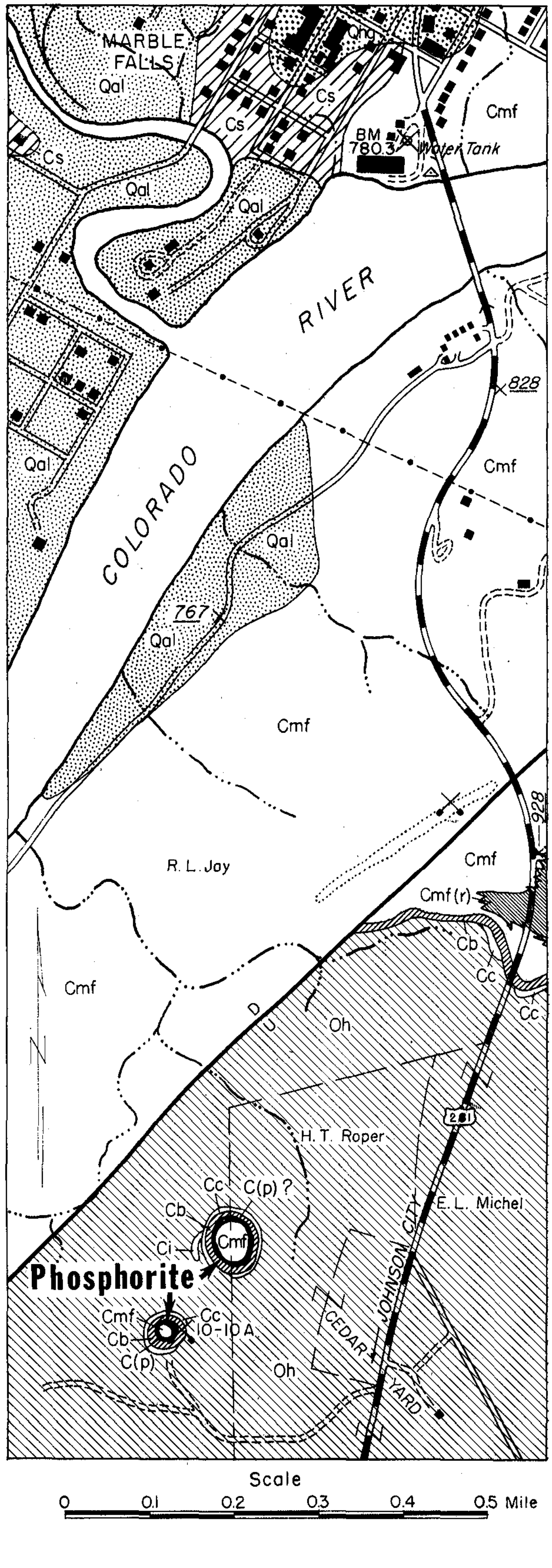


FIG. 16. Geologic map of an area near Marble Falls showing location of phosphorite deposit. (From Bureau of Economic Geology Report of Investigations No. 23.)

Areas underlain by alluvium are indicated by the symbol Qal, and an area underlain by high gravel is indicated by the symbol Qhg. Both Pennsylvanian and Mississippian rocks of Carboniferous age are present. The Pennsylvanian rocks are indicated by symbol as follows: Cs, Smithwick shale; Cmf, Marble Falls limestone showing reef facies, Cmf(r); and an unnamed phosphorite, C(p). The Mississippian rocks are indicated by the following symbols: Cb, Barnett formation; Cc, Chappel limestone; and Ci, Ives breccia. Of the Ordovician rocks only the Lower Ordovician, Honeycut formation, Oh, is present.

mately parallel to, the Bastrop-Travis County line. The outcrop of the Weches glauconitic sandstone of the Claiborne group forms a belt up to 3 miles wide in eastern Bastrop County. The phosphate content of the greensand is low and variable. Analyses of samples from beds at the same stratigraphic positions in other counties indicate that the P_2O_5 content ranges from less than 1 percent to more than 5 percent. In Bexar County, greensand containing phosphate pebbles has been produced from the lower of the two Midway beds for use as a soil conditioner.

Other deposits, Travis County.—Thin phosphatic zones are present locally in Upper Cretaceous formations in Travis County, particularly at the base of the Burditt marl. All known deposits are thin and contain too litle phosphatic material to be of commercial interest as sources of phosphate.

RARE-EARTH MINERALS

A famous deposit of rare-earth minerals is at Baringer Hill. The deposit is in a pegmatite dike about 100 feet wide which formed a mound about 40 feet wide and 250 feet long on the west bank of Colorado River about 2.7 miles north of Buchanan Dam. The mound is now covered by the waters of Lake Buchanan. In addition to the common quartz and feldspar of pegmatites, this mass contains an assemblage of rare-earth and other minerals including compounds of cerium, thorium, beryllium, uranium, yttrium, and zirconium. Many of the minerals are radioactive.

Exploitation of this pegmatite before World War I was for thorium compounds for use in Nernst lamps. It is of interest today only because it shows the type of mineralization possible in the pegmatites of the region, including uranium minerals. Through the years, because this pegmatite was so well known, there has been a search for similar masses. This was intensified after World War II when uranium materials became important. It is probable that detection devices such as Geiger counters have been employed over much of the area in which masses of this sort could be present. The chance for discovery of masses with potential commercial importance it not encouraging.

SALT AND SULFUR

Salt and sulfur are considered together in this report because some salt domes, the only source of salt in the area, also contain sulfur in the cap rock of the domes. Sulfur was produced from the Gulf dome in Matagorda County from 1919 to 1936 when the deposit was exhausted. Production commenced at Boling dome in Wharton County in 1935 and is continuing at the present time.

These domes and the Hawkinsville and Markham domes in Matagorda County are potential sources of salt (Pl. I). Data on the salt in the domes (Perkins and Lonsdale, 1955) are given below.

Mining of salt from these domes by the brine method probably is practicable. It must be remembered, however, that a substantial salt industry is already established in nearby counties and in northeast Texas, and present needs of Texas are being supplied from these sources. Any additional development presumably will depend on new markets or a combination of industrial factors making advantageous the production of salt in the CRIDA area.

SAND AND GRAVEL

The sand and gravel industry in the United States has grown since 1900 from a small industry to one which exceeds all

DOME	COUNTY	DEPTH TO TOP OF SALT (*feet*)	AREA OF SALT (*square miles*)	VOLUME OF SALT AT DEPTHS LESS THAN 2 MILES (*cubic miles*)
Boling	Wharton	975	17.19	31.29
Gulf	Matagorda	1,100	0.37	0.66
Hawkinsville	Matagorda	600	2.34	4.42
Markham	Matagorda	1,360	1.09	1.90

other non-fuel minerals in tonnage produced and ranks among the highest in dollar value. In Texas the industry likewise is important, and in 1957 the production was 26,680,000 short tons valued at $25,670,000. The great expansion in the industry is directly related to the development of Portland cement and its use in many types of reinforced concrete construction. About 90 percent of the production enters the construction industry.

Research on concrete has made great progress during this period of expansion, and the specifications for sand and gravel in various concrete structures have become increasingly severe. Early operations produced relatively large tonnages of "bank run" untreated sand and gravel. Today clean-washed products sized to meet strict specifications and other tests are demanded. As a result, the mining, milling, and preparation for market have become a complex highly technical operation. The average market price is under $1.00 per ton; accordingly, the operations must be highly efficient and the markets must be nearby to avoid high transportation costs. There still is some use of "bank run" sand and gravel for subgrades or bases of highways and airports, as surfacing material for secondary roads, and other minor uses. This material must have certain physical properties and some must be treated by addition of silt or clay.

Sand and gravel are among the most important mineral resources in the CRIDA area. Production includes paving, molding, blast, structural, and engine sand, and structural, paving, and ballast gravel. Most of the sand and gravel is used in construction of various kinds but the production of specialty sands is substantial. Colorado, Fayette, and Travis counties are the main producing areas, but there is production also in Blanco, Burnet, and San Saba counties.

The deposits of sand and gravel in the area are in the terraces along Colorado River and larger tributaries and on the stream divides on either side of the river. The most abundant and thickest deposits extend from Travis County to Colorado County. Deposits of major importance are unknown in Wharton and Matagorda counties, and the deposits in counties upstream above Austin are relatively small. In the upstream area, crushed limestone is the preferred construction material because of abundance and better location with respect to markets and transportation.

All of the washed or processed sand and gravel and some "bank run" material is produced from the terrace deposits, mainly from the lower terraces. Most of the terrace area is included on the geologic map (Pl. I) in the area with the symbol Q. In the lower terraces the ground-water surface is at shallow depths, and water for washing is available in the pits from which the material is produced. In these deposits the thicknesses, depths, and composition of the sand and gravel beds vary from place to place. It is necessary to explore and sample carefully all prospective areas prior to mining operations.

The earliest sand and gravel operations were in the higher terraces or on the divides. The material produced was "bank run" and it was used with little or no processing. This material is used currently in road construction in which a natural mixture of fine and coarse material will meet requirements. The deposits on the divides generally are thinner and less extensive than those in the lower terraces. Deposits as much as 10 feet thick are rare.

From time to time there has been a little production of sand from various formations for local construction use. The Simsboro sand, the middle formation of the Wilcox group, has been produced in central Bastrop County. The basal Trinity sand has been used locally in the Llano uplift. It has been reported that Cambrian Hickory sand in Mason County has been used for hydrofrac sand in oil-well drilling. Similar Hickory sand probably is present in the CRIDA area.

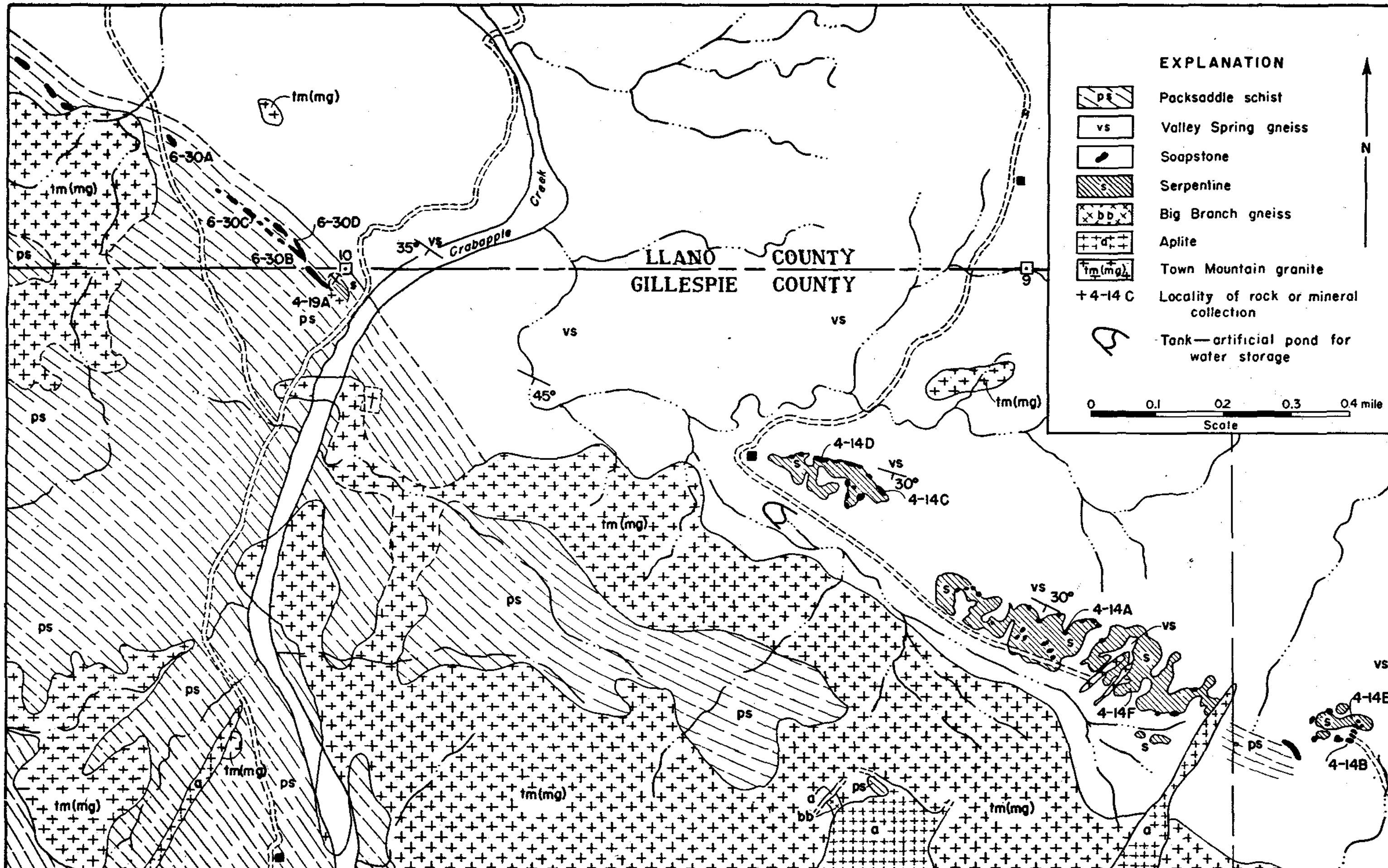


FIG. 17. Geologic map of soapstone and serpentine deposits in the Crabapple Creek area of Gillespie and Llano counties. (From The University of Texas Publication 4301.)

SERPENTINE

Large deposits of serpentine are present in the Precambrian rocks of the Llano uplift. The rock is used for terrazzo chips and road surfacing but because it is so highly jointed is probably not suitable for decorative stone.

The serpentine rock is relatively pure material containing large proportions of the hydrous magnesian silicate serpentine minerals. Uses based on its composition have some promise. A study of its utilization by Barnes, Shock, and Cunningham (1950) suggests that it is a potential source of magnesium, refractory magnesia, and magnesium compounds. It has possibility as a soil conditioner and a decolorizing agent. A recent report suggests that similar material from California has possible uses in the ceramic industry.

Table 7, based on the paper by Barnes, Shock, and Cunningham (1950), summarizes information on deposits in the Llano uplift.

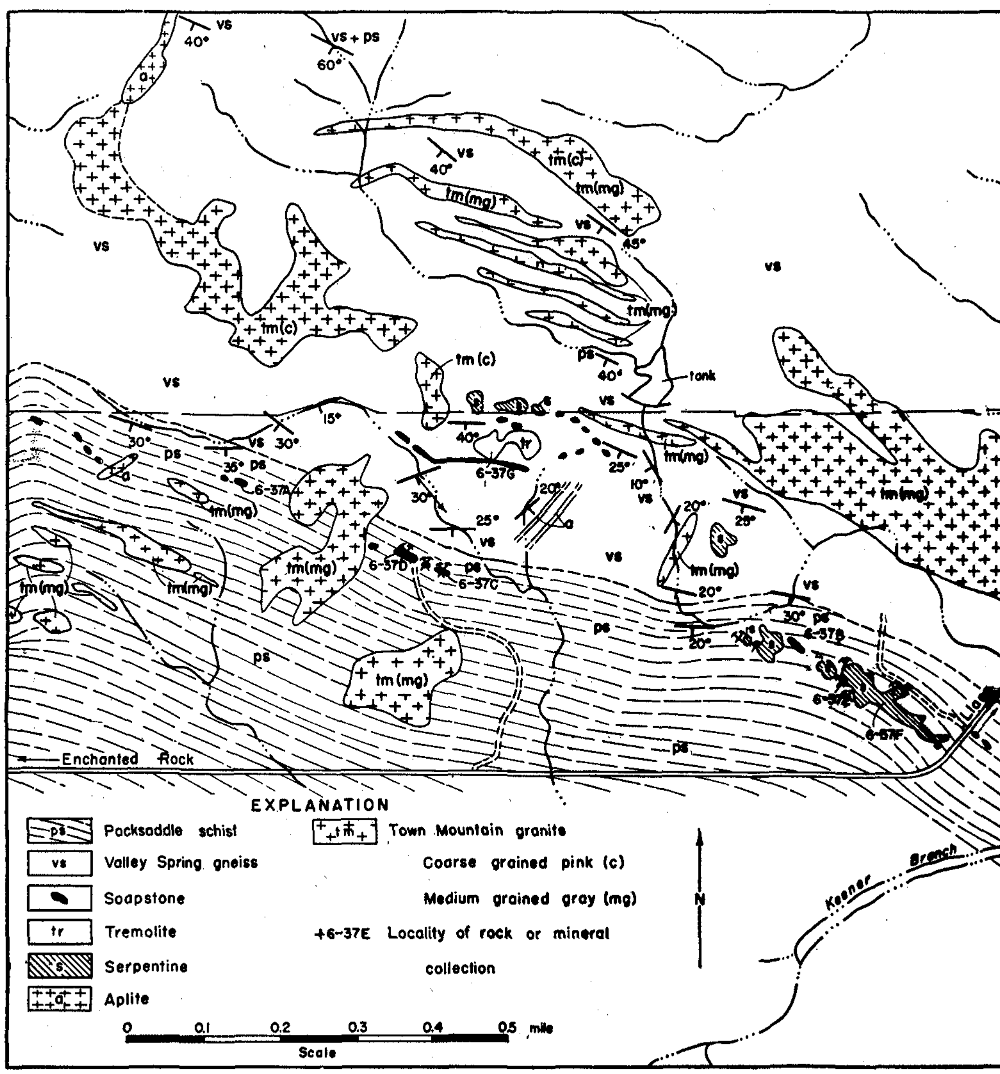


FIG. 18. Geologic map of soapstone and serpentine deposits in the Keener Branch area of Llano County. (From The University of Texas Publication 4301.)

SHELL

In the downriver end of the CRIDA area, the only substantial source of calcium carbonate material for chemical, cement, or construction material is shell in the bays. This condition prevails all along the coastal area so that a large industry has been established with a number of companies dredging and marketing shell for a variety of uses. There is substantial production from Matagorda Bay and from the other bays between Corpus Christi and the Louisiana line.

The reserves of shell in these bays are unknown. Available information indicates that no immediate shortage is likely. It is known that large reserves exist at depths below those reached by dredging equipment now in use. Construction of dredging equipment capable of recovering shell from considerably greater depths than at present may be entirely practicable.

SOAPSTONE

Deposits of soapstone are widespread in the Precambrian rocks of the Llano uplift, but the principal deposits are in southern Llano County, northern Gillespie County, and the extreme northwestern corner of Blanco County. Most of the soapstone is suitable for use only as a ground product. Limited quantities of soapstone blocks suitable for sawing or carving probably could be obtained from a few of

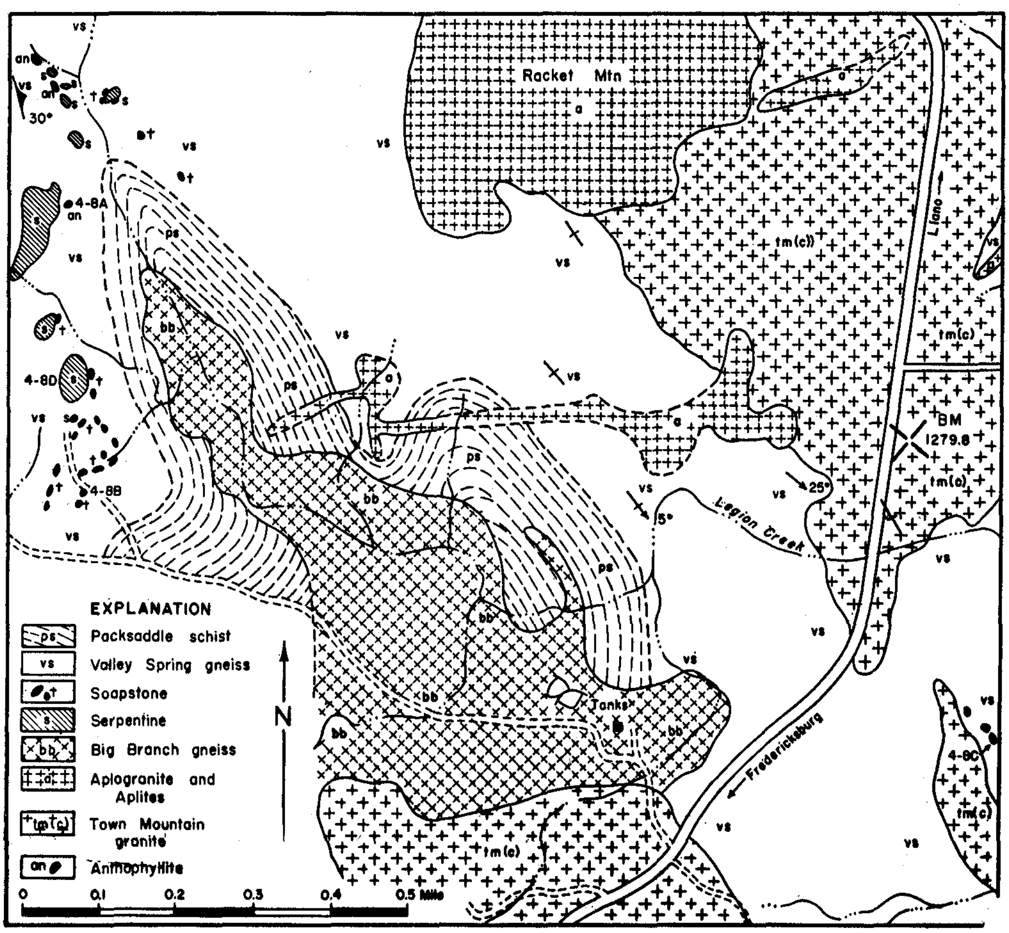


FIG. 19. Geologic map of soapstone and serpentine deposits in the Legion Creek area, Gillespie County. (From The University of Texas Publication 4301.)

the larger deposits, and the material has been used locally for fireplace and hearth linings. The material must be carefully selected. Most of the production has been from deposits in the vicinity of the Gillespie-Llano County line. The material is trucked to the grinding plant of the Southwestern Talc Company in Llano; after grinding it is used mainly as insecticide carrier. A variable amount of grit in the form of hard minerals such as quartz, magnetite, or other minerals, reduces the range of potential uses of soapstone from some of the deposits.

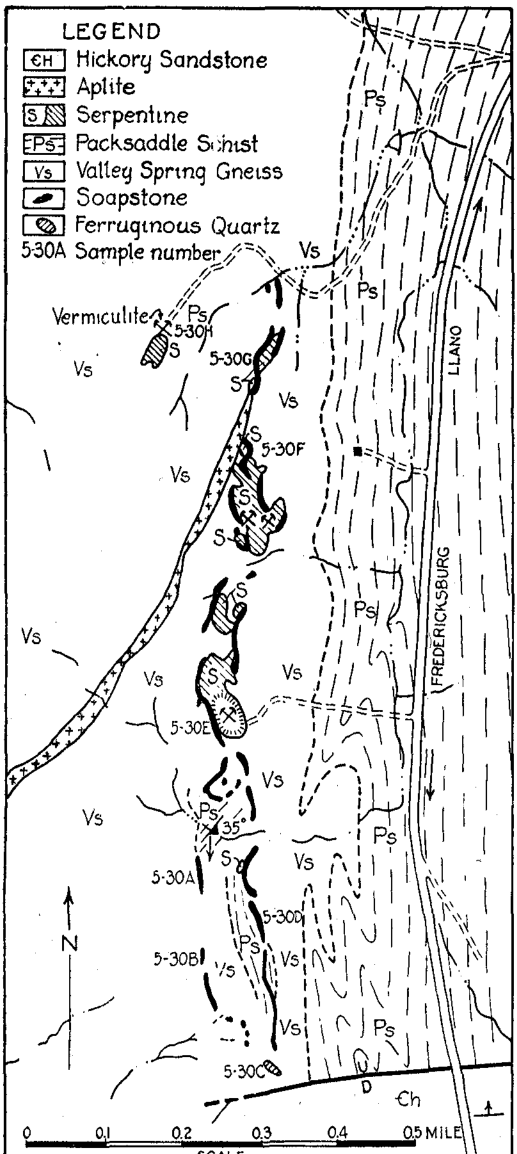


FIG. 20. Geologic map of soapstone and serpentine deposits north of Oxford, Llano County. (From The University of Texas Publication 4301.)

A summary of available information about the soapstone deposits of the region is presented in table 8.

SPICULITE
(Tripoli)

Spiculite as used in this report is a light-colored, lightweight rock composed of essentially pure silica in the form of fossil sponge spicules or finely comminuted fragments of spicules. It has many of the properties of tripoli and probably could be used for some of the same purposes. This material is present in a number of places in the CRIDA area where it has formed from spicule-bearing limestone near the top of the Marble Falls formation by the leaching of carbonate during weathering. Samples of unaltered limestone contain from a few percent to 42.50 percent of silica. Some spiculite samples are nearly pure silica. The deposits rest on, or are between, beds of spicule-bearing limestone. Lateral gradation to unaltered limestone in many places is abrupt so that careful examination is necessary to determine the extent of individual deposits.

Most of the known deposits are in southern Lampasas and northern Burnet counties (fig. 22) and have been described by Damon (1946). Deposits near Richland Springs, San Saba County, locally called "cotton rock," have been described by Barnes et al. (1947).

Lampasas and Burnet Counties

McNett Creek deposits.—Spiculite deposits are exposed in the valley walls and in the stream channel of McNett Creek (fig. 22). At least two persistent zones in the Marble Falls limestone have been altered to spiculite. The deposits which crop out in the bed of the stream and underlie the flood plain are well stratified, friable, and consist almost entirely of siliceous sponge spicules. The deposits exposed in the valley walls consist of alternating beds of consolidated, cherty material, friable spiculite composed mostly of sponge spicules, and clay.

Spiculite from the Milwhite quarry (Station 1, fig. 22) has been used in special drilling muds. A large part of the better-grade material was removed from this deposit during the two years that the quarry was in operation. At Station 5 the deposit consists of 15 feet of the better grade of material under a cover of more cherty material up to 10 feet thick. The prospects appear to be good for successful exploitation at this station and along the valley wall between Stations 1 and 5. Spiculite in the deposits at Stations 2, 3, and 4, west of McNett Creek, is generally of lower quality.

Good deposits of spiculite at Stations 6, 7, and 8 are covered by a variable amount of alluvial overburden. Successful exploitation of these deposits will require diversion of the stream and probably some pumping from the quarries. Only the upper, less pure zone is exposed at Stations 9 and 10.

Wheeler ranch deposits.—Spiculite deposits crop out along the west side of the ridge between McNett and Pillar Bluff creeks. A conglomerate or loose gravel

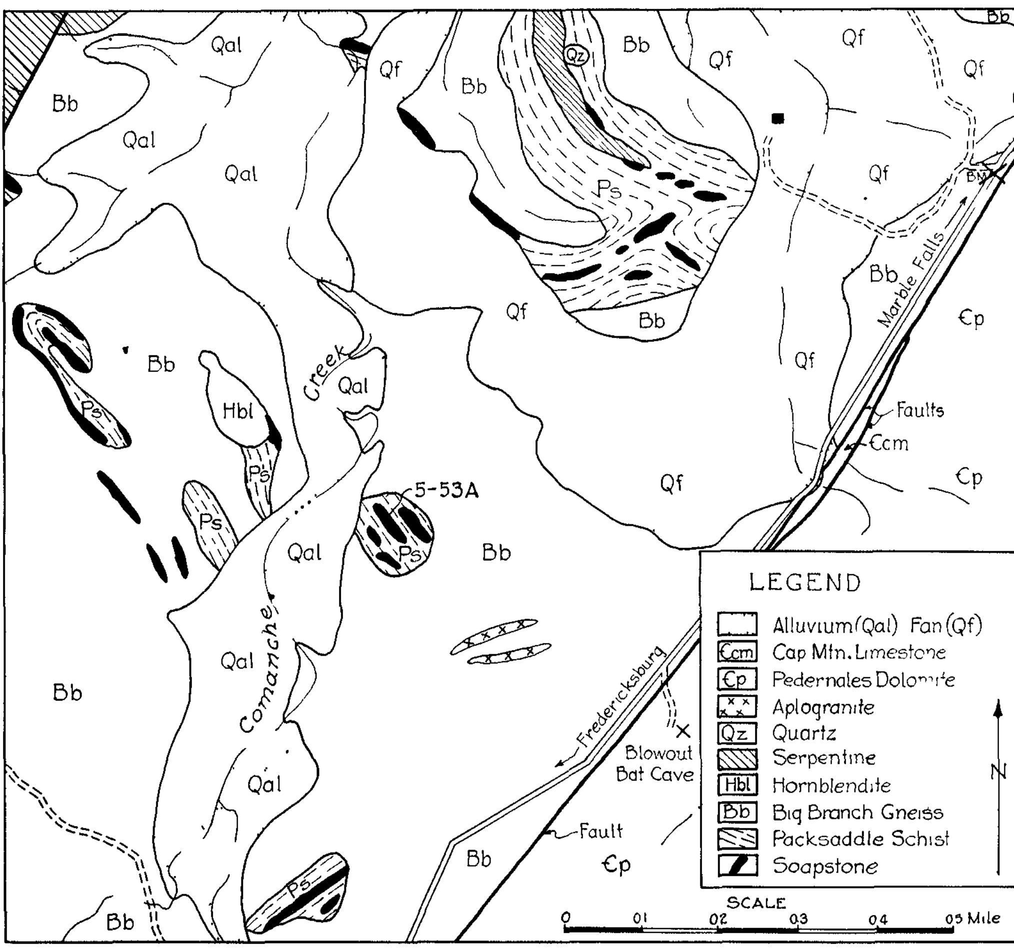


FIG. 21. Geologic map of soapstone deposits in the Comanche Creek area, Blanco County. (From The University of Texas Publication 4301.)

covers portions of the deposit, but good deposits crop out along the divide for a distance of more than 1,500 feet. At Station 12 the deposit is 12 feet thick; at Station 13 the material is covered by 8 feet of talus.

Pillar Bluff Creek deposits.—A ledge of hard, black limestone underlain by spiculite is exposed along the last half mile of Pillar Bluff Creek (Station 15 to Station 16) before it joins with Donalson Creek to form Sulphur Creek. The material is exposed where the black limestone ledge is cracked and tilted. Several small deposits occur south and west of Station 16 along Pillar Bluff Creek and its eastern branch. A 17-foot thick deposit is exposed in a bluff at Station 17. The lower 7 feet consist primarily of sponge spicules; the upper 10 feet consist of alternating layers of pure and cherty material. This deposit extends southward from Station 17 under the flood plain of the creek for a distance of about half a mile.

Donalson Creek-Pillar Bluff Creek divide.—The divide between Donalson and Pillar Bluff creeks is capped with a conglomerate that has a maximum thickness greater than 25 feet. South of the divide the base of the conglomerate is about 55 feet above the bed of Pillar Bluff Creek. A spiculite deposit more than 30 feet thick

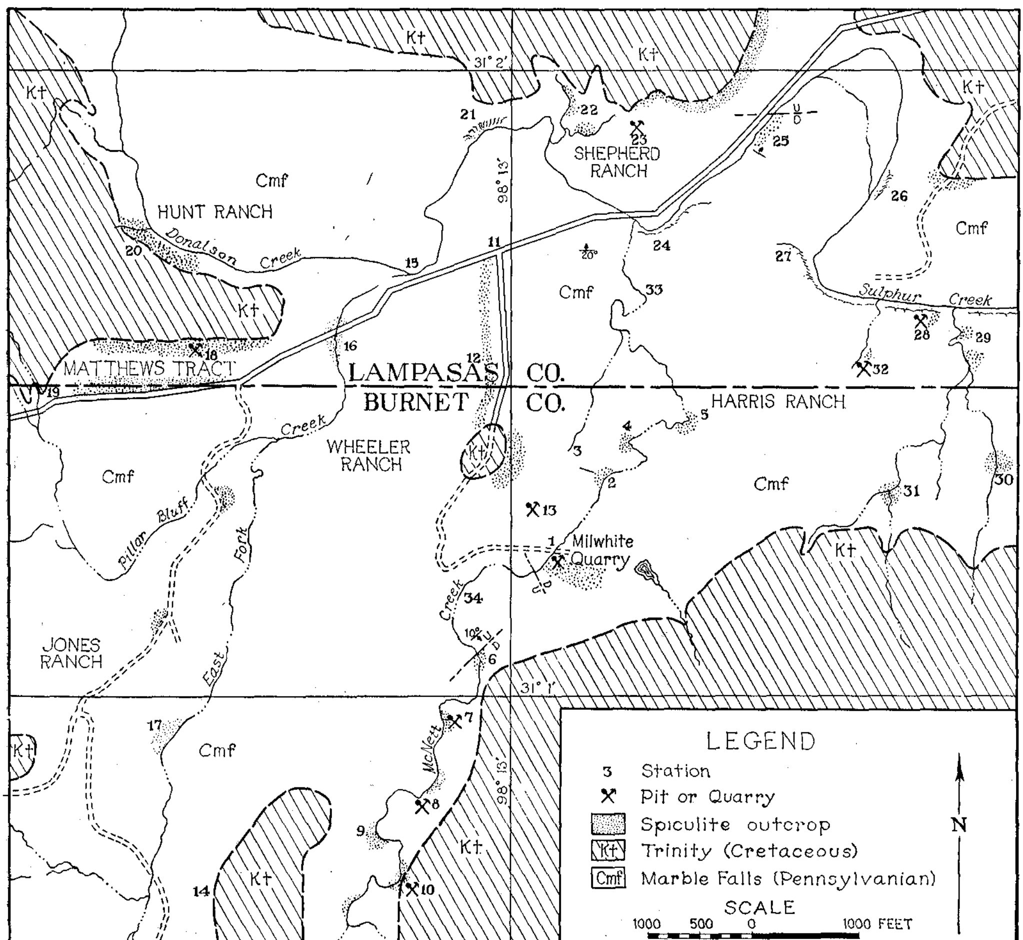


FIG. 22. Geologic map of parts of Burnet and Lampasas counties showing outcrops of spiculite. (From The University of Texas Publication 4301.)

is exposed in the upper half of this interval. The lower limit of the deposit has not been determined because bedrock outcrops are absent in the lower half of the interval. The deposit consists of beds composed almost entirely of sponge spicules and alternating beds of impure material and chert.

North of the divide, at Station 20, there is a 40-foot bluff capped by conglomerate. Unaltered limestone crops out along the lower 5 feet of the bluff. More than 30 feet of spiculite is exposed between the unaltered limestone and the conglomerate. The similarity of the deposits on the two sides of the divide suggests that the spiculite may be continuous beneath the conglomerate cap.

Shepherd ranch deposits.—Deposits of spiculite occur in two zones of siliceous limestone on the Shepherd ranch. A few small deposits occur in the lower zone which is exposed in the beds of creeks tributary to Sulphur Creek (Station 22). The second zone is exposed beneath the conglomerate cap on the scarp north of Sulphur Creek. A deposit about 15 feet thick crops out for more than one-fourth mile along the scarp north of the Shepherd ranchhouse.

Harris ranch deposits.—A bluff, up to 50 feet high, extends along the south side of Sulphur Creek near the eastern boundary of the map (fig. 22). Spiculite is exposed at Station 29 where a tributary stream passes through a gap in the bluff. The deposit, about 10 feet thick where exposed in the bluff, may be more or less continuous under the flood plain of the tributary creek for a distance of about 2,500 feet southward from Sulphur Creek. The material crops out at several places along the creek; the thickness of the deposit is generally less than 10 feet.

Miscellaneous deposits, Lampasas area.—There is a small deposit of the material at Station 25 on the south bank of Sulphur Creek. Unaltered siliceous limestone is present at the same stratigraphic position upstream from the deposit (Station 24) and south of the deposit in the vicinity of Station 27.

Northwest of the area covered by figure 22 there are several outcrops of spiculite along Donalson and Espy creeks. These exposures probably indicate an extension of workable deposits, but they have not been examined in detail.

A small bluff of spiculite 8 to 10 feet high forms the west bank of Sulphur Creek just northeast of the mapped area. Beds of the material several feet thick are reported to have been penetrated by water wells drilled north of this outcrop in the western part of the town of Lampasas.

San Saba County

Richland Springs area.—Spiculite deposits at two localities near Richland Springs were described briefly by Barnes et al. (1947) during a survey of building stones in central Texas. The report indicated that a large amount of similar material probably could be obtained throughout the Marble Falls limestone outcrop area, although individual deposits generally would be small.

A thin surface layer of spiculite is associated with an outcrop of siliceous limestone 7 miles S.7°E. of Richland Springs. Another deposit occurs as a bed about 2 feet thick that crops out for 100 yards along the bank of a small creek less than 1 mile S.25°W. from Richland Springs. These two occurrences are indicated as localities S-9 and S-16, respectively (Pl. II). The material differs from that in Burnet and Lampasas counties in that it consists largely of cryptocrystalline quartz with only a few sponge spicules.

TUNGSTEN

The tungsten mineral scheelite is present in traces on the G. A. Parkinson ranch 6 miles southwest of Llano, at a locality 5 miles south-southeast of Packsaddle Mountain, Llano County, and on the Alfred Davis ranch in eastern Gillespie County (Barnes, Parkinson, and Warren, 1942). The known occurrences are not of commercial significance, and extensive prospecting with ultra-violet lamps subsequent to the first discovery in 1941 has failed to reveal additional deposits.

URANIUM MINERALS

Deposits of uranium minerals of commercial promise have not been found in the CRIDA area. Uranium minerals and radioactive anomalies have been found in and around the Llano uplift, and radioactive anomalies have been located in Fayette County.

In the Llano uplift radioactive minerals and/or radioactive anomalies occur in rocks of three general ages: (1) Precambrian rocks, (2) older Paleozoic rocks, and (3) younger Paleozoic (Devonian, Mississippian, and Pennsylvanian) rocks.

In the Precambrian rocks of this area, rare-earth minerals (complex minerals containing small amounts of uranium and thorium are confined to pegmatites and isolated small quartz-rich masses. Many of these exhibit high radiometric values; however, there is little possibility of commercial tonnage of uranium ore in this type of occurrence.

One occurrence of uranium minerals is on a property located some 6½ miles west of Burnet and about 300 yards north of State Highway 29. This prospect is in the vicinity of but separate from the old Sheridan copper mine and is known as the Rainbow prospect. Mineralization apparently coincides with a discontinuous and irregular zone of granitization within the Valley Spring gneiss. Abnormal radioactivity and mineralization (uranium) are associated with fractures, joint surfaces, and small quartz-rich pods where magnetite, ilmenite, and some pitchblende occur. Some secondary uranium minerals were also noted at fracture surfaces.

The older Paleozoic rocks of the Llano region (those resting on the granitic and metamorphic rocks of the uplift) include a considerable and much-faulted thickness of sandstone, dolomite, and limestone. The arkosic Hickory sandstone and Cap Mountain limestone have been considered favorable for prospecting. To date, however, no significant occurrences of radioactive minerals have been reported.

In the younger Paleozoic rocks of the Llano region (Devonian, Mississippian, and Pennsylvanian), abnormal radioactivity *is* present in a layer of phosphate-rich material which occurs at the base of the Marble Falls formation (Pennsylvanian age). Two shale formations in the area show abnormal radioactivity; however, many similar shales throughout the United States give high reading, but they are not considered commercial prospects because of the very low uranium content.

Several radiometric anomalies have been located in Fayette County. Subsequent surface geological examination and radiometric surveys conducted by the Atomic Energy Commission failed to show these anomalies to be of sufficient interest to warrant further work. At none of the localities was mineralization (uranium) visible, although radiometric values at times were as high as 20 times background. Grab samples collected from these areas showed equivalent eU_3O_8 content of from 0.02 to 0.30 percent.

The host rocks are either Jackson or Catahoula in age (Pl. I). Radioactivity occurs in interbedded tuffs and silty sandstones underlain and sometimes overlain by lignite and reddish-brown shale. In many instances the radioactivity is confined to lignite material and in one instance to sparsely distributed concretionary nodules. All beds are sedimentary in nature and are flat-lying with no observed evidence of faulting.

A locality in Washington County approximately 5 miles east of Ledbetter showed visible uranium mineralization in a sandstone bed about 2 inches thick over a distance of 100 feet. This mineralized zone is terminated laterally by faulting. Selected sampling showed radioactivity values of from 0.05 MR/hr to 0.15 MR/hr. Although this locality warrants further attention, its potential is very questionable.

VERMICULITE

Vermiculite is a micaceous material that exfoliates or expands when heated. This material has more than forty industrial uses; continuing research probably will result in additional uses. The characteristics which make expanded vermiculite useful are its thermal insulating qualities, light weight, fireproofness, and granular form. It is used extensively in loose fill insulation and in insulating plaster and concrete aggregates. Vermiculite concrete is precast into blocks, tiles, and bricks of various types for special uses. Minor applications are in horticultural work, poultry litter, lubricant, or as a filler.

The major deposits of vermiculite in the United States now being produced are in Colorado, Montana, North Carolina, South Carolina, and Wyoming, far from major markets. Unexpanded vermiculite is prepared or concentrated at the mines and shipped to expanding plants in the market areas. The expanded material is too bulky to ship long distances, but the price of the expanded material is so much greater than that of the unexpanded material that relatively high freight costs can be paid on the latter. Vermiculite moves from Montana and South Carolina to Chicago where it is expanded and marketed. An expanding plant at Burnet in the CRIDA area operates on vermiculite from out-of-State sources. In 1955 the production of crude vermiculite in the United States was 204,000 short tons valued at $2,702,225, with an average value of about $13.25 per short ton. During the same period expanded vermiculite sold at an average price of $63.31 per short ton.

Vermiculite occurs in the Precambrian rocks of central Texas, the larger deposits being situated chiefly in Llano County and adjacent parts of Burnet, Gillespie, and Mason counties. Minor occurrences have been reported in northwestern Blanco County and southern San Saba County. All of the major deposits and most of the minor occurrences of vermiculite are associated with metamorphosed igneous rocks. The largest deposits occur in irregular bodies of biotite schist or hornblende rock within the Valley Spring gneiss. One important deposit occurs in a mass of hornblendite. Veins and disseminated flakes of vermiculite have been found in serpentine and soapstone at several localities. All potentially important deposits of vermiculite are within 25 miles of the railroad; most of the occurrences are within 15 miles of a hard-surfaced road.

Vermiculite deposits at five localities in Llano County were explored by drilling and surface sampling by the United States Bureau of Mines (McMillan and Gerhardt, 1949). The crude ore consisted of vermiculite in a gangue of hornblende; only minor amounts of feldspar were present. Composite samples from each of the prospects were expanded. Most of the expanded vermiculite passed through a 10-mesh screen; 22 to 50 percent of each sample passed through a 65-mesh screen.

Additional investigations of vermiculite deposits in the area by S. E. Clabaugh and V. E. Barnes, of The University of Texas Department of Geology and Bureau of Economic Geology, respectively, will be published in the near future. Clabaugh estimated that the reserves of ore containing 25 percent or more vermiculite in the deposits that are now known are on the order of 250,000 tons and that further prospecting will result in the discovery of additional deposits. The grain size of expanded vermiculite from samples collected during this study was larger than that reported in samples collected during the investigation by the United States Bureau of Mines. In the 61 samples tested, an average of 16 percent of the expanded vermiculite was retained on the 10-mesh screen, and an average of 22 percent of the expanded vermiculite passed through a 60-mesh screen.

The low vermiculite content of the ore and the small grain size has prevented development of the central Texas deposits. The loose bulk weight of samples expanded in the laboratory is comparable to that of commercial grades now in use. Development of a local vermiculite industry will depend on increased demand for fine-grained vermiculite, depletion of the higher-grade domestic and foreign deposits, and development of commercial methods of utilizing lower-grade ore.

Table 9 gives details concerning the deposits of vermiculite in the CRIDA area.

VOLCANIC ASH
(Pumicite)

Volcanic ash or pumicite is deposited from dust clouds accompanying volcanic eruptions. It is composed of minute angular grains of volcanic glass with or without grains and crystals of igneous minerals. It alters or weathers to clay minerals producing the material called bentonite. After deposition, the material may remain loose and incoherent or may become compact, hard, and stony.

The principal use for volcanic ash is as an admixture in cement for concrete. It is used especially in puzzolan cement which is resistant to attack by sea water and other chemically active water. It is also believed to inhibit chemical reactions which take place between some types of aggregate constituents. Other uses for volcanic ash are abrasives, special plasters, insecticide carriers, insulation products, paint fillers, and absorbents.

Beds of volcanic ash are present in the Jackson group in Fayette County. Ash in the various deposits varies in grain size, purity, and thickness; some of it is interbedded with bentonitic clay. The material is produced currently from a pit 3.5 miles northeast of Flatonia (Pl. III, A-1). The locations, of this and other deposits examined during the course of this investigation are shown on Plate III. The best deposits not in production probably are adjacent to locality A-1. The ash at A-2 is 4 to 5 feet thick and of good quality. At A-3 the ash bed is about 3 feet thick. The material at localities A-4, A-5, A-6, and A-7 probably is from the same bed, which has a maximum thickness of 12 feet. This is very impure and possibly should be called clay rather than ash. It might have special uses.

The Jackson group extends across the county from the general region of Flatonia to Ledbetter (Pl. I), cropping out in a belt several miles wide. The general area in which volcanic ash is present is shown in Plate III. Much of the country is covered with brush and exposures are poor. It is probable that a good many beds of volcanic ash are present along this belt. Close prospecting will be necessary to find them.

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