DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 450

MINERAL RESOURCES
OF THE
LLANO-BURNET REGION, TEXAS
WITH
AN ACCOUNT OF THE PRE-CAMBRIAN GEOLOGY

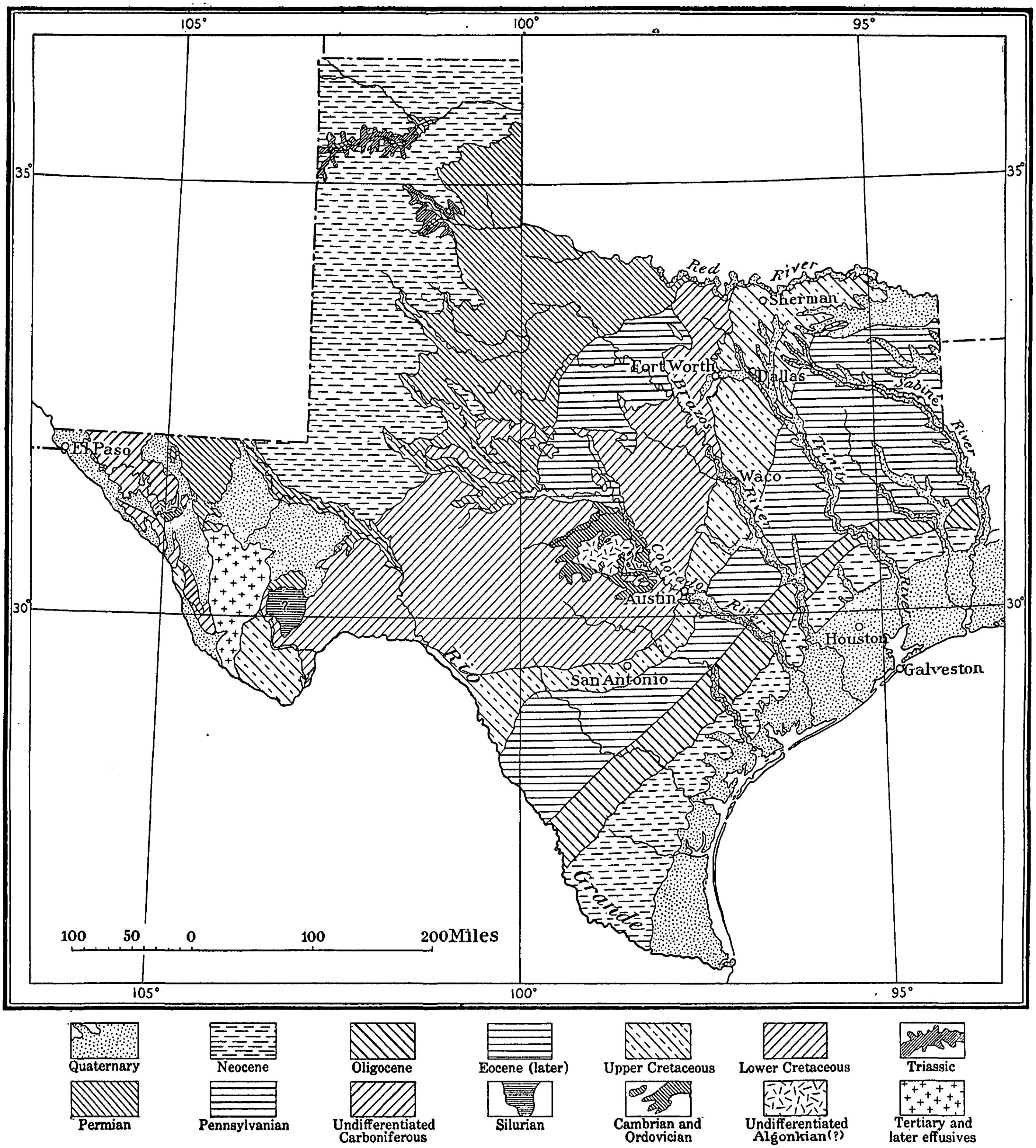
BY

SIDNEY PAIGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1911

CONTENTS.

ILLUSTRATIONS.



GEOLOGIC MAP OF TEXAS.

See page 7.

MINERAL RESOURCES OF THE LLANO-BURNET REGION, TEXAS, WITH AN ACCOUNT OF THE PRE-CAMBRIAN GEOLOGY.

By Sidney Paige.

INTRODUCTION.

The field work on which the following report is based was begun in the summer of 1908 under the direction of A. C. Spencer, who was assisted by the writer, and was completed in the fall of 1909 under the direction of the writer, who was assisted by Fred H. Kay. A. C. Spencer and W. S. Bayley cooperated in the field work, and Mr. Spencer has contributed descriptions of certain of the iron-ore deposits. Howland Bancroft also spent a short time in the field. A general report on the Llano and Burnet quadrangles, to be published in folio form, is now in preparation.[a] The present report deals chiefly with the geologic relations of the pre-Cambrian rocks and the associated iron ores. The stratigraphic and structural relations of the Paleozoic and Cretaceous rocks are only briefly treated, but will be discussed more fully in the later report.[a]

The writer wishes to express his indebtedness to Dr. Spencer, whose acquaintance with pre-Cambrian structure and iron ores has been of great value in both the field and the office work. Thanks are due also to Prof. W. S. Bayley for counsel and suggestion, and to Mr. N. J. Badu, of Llano, whose knowledge of Llano County was of great assistance during the field work.

The central Texas region lies in the broad regional coastward slope, of which Texas forms a part and which constitutes a great geologic province reaching from the Cordilleras to the Gulf of Mexico. (See Pl. I.) In this region, about midway between the Cordilleras and the Gulf the peculiar condition exists that erosion has exposed rocks of pre-Cambrian and Paleozoic ages within and about the rim of an oval structural and topographic basin which is nearly surrounded by Cretaceous rocks on its outer border. This area of old rocks is largely included in the Llano and Burnet quadrangles. (See Pl. II.)

[a] Paige, Sidney, Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

As the principal mineral resources of the region are confined largely to the Llano quadrangle, this report deals almost entirely with that area.

The Llano quadrangle includes portions of Llano, Mason, and San Saba Counties in central Texas. (See Pl. III, in pocket.) It is bounded by parallels 30° 30′ and 31° and meridians 98° 30′ and 99° west, and covers 1,024 square miles. The region is accessible by the Houston & Texas Central Railroad, which terminates at Llano, the county seat of Llano County. This road connects at Lampasas, about 20 miles north of Burnet, Burnet County, with the Gulf, Colorado, & Santa Fe Railway. Llano is the principal town of the quadrangle.

TOPOGRAPHY.

A casual observer, standing on an eminence, such as Town Mountain, near Llano, will be impressed with the basin-like form of the broad valley of Llano River. From such an eminence a broad rolling plain may be seen stretching east, west, north, and south to the horizon, which is marked by an encircling scarp of Paleozoic rocks. Within this broad area, however, there are many minor irregularities. These irregularities are of two types—first, mountain-like masses, such as Riley, Packsaddle, Putnam, House, and Smoothingiron Mountains; and second, smaller masses, such as the group of hills west of Oxford and that northeast of Babyhead, as well as the many isolated hills north and south of Llano. The masses of the first type are characterized by cappings of nearly horizontal beds and steep marginal scarps, and present to the observer mesa-like outlines; those of the second type are maturely dissected hills and isolated cones that rise rather abruptly from the surrounding plains. The form of the masses of both types depends on the nature of the rocks composing them. Encircling the pre-Cambrian basin described above is a plateau of Paleozoic and Cretaceous rocks, more or less maturely dissected.[a]

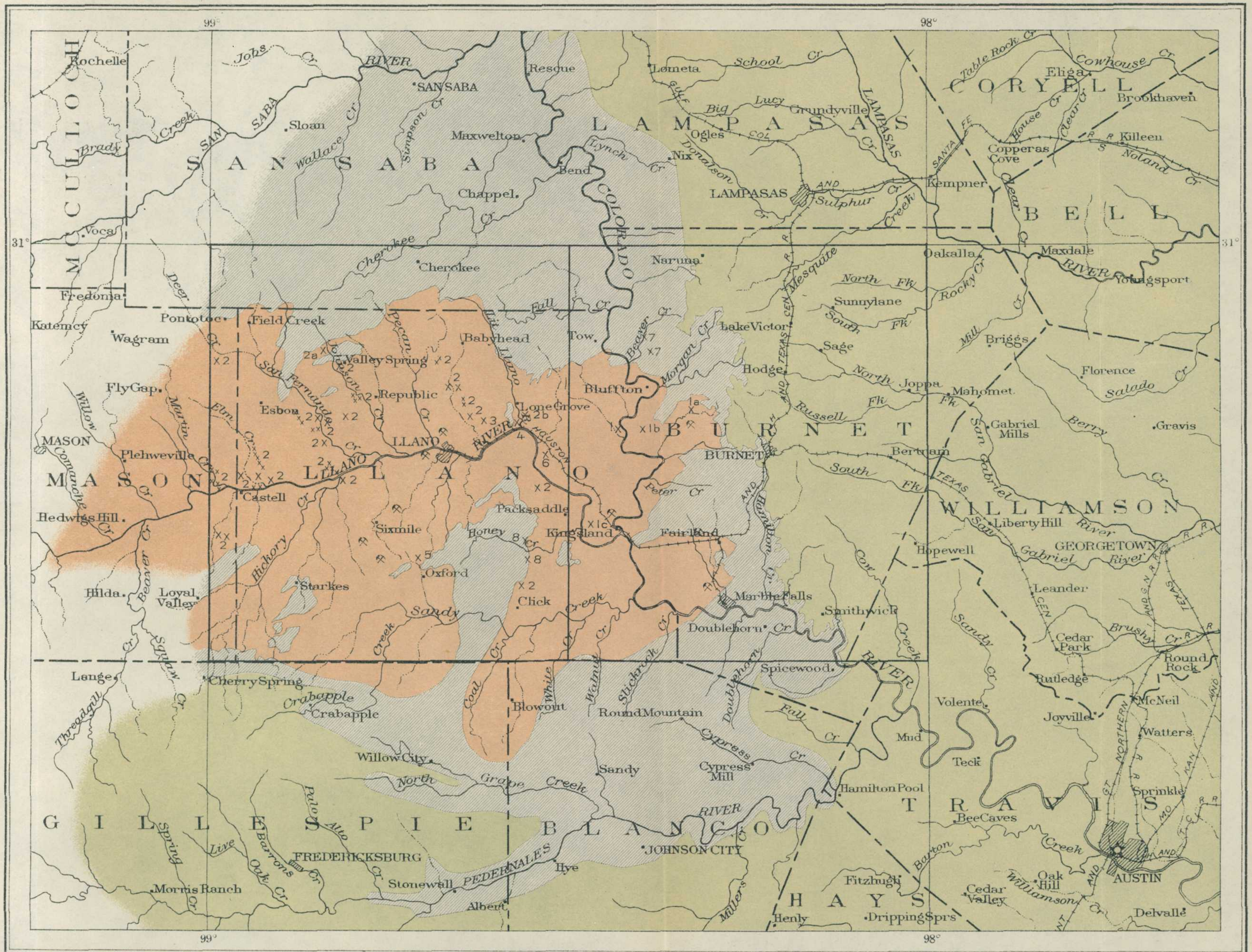
The northern border of the Llano quadrangle lies within the Paleozoic plateau; its western part is a rolling plain, which to the east and approaching Colorado River becomes more broken and irregular. The Paleozoic scarp to the west and south does not lie within the Llano quadrangle.

DRAINAGE.

The region included in the Llano quadrangle is drained almost entirely by Llano River and its northward and southward flowing tributaries. The quadrangle is nearly halved by Llano River, which flows eastward across it and enters Colorado River at Kingsland, in the Burnet quadrangle.

---

[a] For a detailed classification of Texas plateaus see Hill, R. T., Physical geography of the Texas region: Top. Atlas U.S., folio 3, U. S. Geol. Survey, 1900; Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

GENERAL GEOLOGIC MAP SHOWING LOCATIONS OF BURNET AND LLANO QUADRANGLES, TEXAS

With principal quarries, mines, and prospects

Scale $\frac{1}{750000}$

10 0 10 20 30 Miles

1910

Geology within Llano and Burnet quadrangles by A. C. Spencer, Sidney Paige, W. S. Bayley, and Fred H. Kay. Dotted boundaries compiled from maps by Robert T. Hill.

On the north, Elm, San Fernando, Johnson, Pecan, and Mitchell Creeks and Little Llano River are the important affluents of Llano River; on the south, Hickory, Bullhead, Sixmile, Flag, Oatman, and Honey Creeks are the large streams. Sandy Creek, in the southern part of the quadrangle, an exception, flows eastward into the Colorado.

Nearly all the streams of the region within the pre-Cambrian basin carry a great and increasing burden of sand. During most of the year their beds are apparently dry, and it is only by digging that water can be found. Llano and Little Llano Rivers and a few other spring-fed streams are exceptions. The infrequent but torrential rains, the stripping of the granite areas of vegetation by the overstocking of ranches, the alternation of intense heat by day and of coolness by night, which tends to disintegrate the rocks, all combine to bring about this condition of the streams.

GEOLOGY.

GENERAL FEATURES.

The rocks of the Llano-Burnet region fall naturally into three broad subdivisions—(1) pre-Cambrian schists, gneisses, and granites; (2) Paleozoic sandstones, limestones, and shales; and (3) Cretaceous sandstones, clays, and limestones. The Cretaceous rocks are confined almost entirely to the Burnet quadrangle, and appear in the Llano quadrangle in but one small area.

The Paleozoic strata, which completely surround the pre-Cambrian area, are more or less folded and faulted, and are separated from the pre-Cambrian by an unconformity representing a great time interval. The Cretaceous formations rest in almost undisturbed position on the Paleozoic rocks, but are separated from them by a great erosional unconformity.

ALGONKIAN (?) ROCKS.

GEOLOGIC UNITS.

Pre-Cambrian rocks underlie the larger part of the Llano quadrangle. A strip along the northern edge, however, ranging in width from 3 to 10 miles, and Riley and Cedar Mountains, Putnam Mountain, and a few other isolated areas are covered by Paleozoic sediments. In the geologic mapping of the area (see Pl. III) four major divisions of pre-Cambrian rocks have been discriminated, namely, (1) the Packsaddle schist, a series predominantly of basic type, including amphibolite and mica schists and old basic intrusive rocks; (2) the Valley Spring gneiss, a schist-gneiss series, including quartzites or their derivatives, light-colored mica schists, and acidic gneisses; (3) a very coarse grained pink granite, which could not be separately mapped over the area; (4) all the remaining granitic rocks, including a number of varieties. All these rocks are believed to be of Algonkian(?) age. In addition to these major distinctions, bands of crystalline limestone and wollastonite were mapped wherever possible. Likewise the outcrops of a quartz porphyry of peculiar type, locally termed opaline granite, have been indicated, and a serpentine mass near Oxford has been shown. Iron-ore prospects and some lean banded ores are also represented. The area surrounding the Llano-Burnet region is shown on a general map (Pl. II), on which the several economic resources are indicated.

A glance at the map forming Plate III (in pocket) will show clearly in a general way the northwest-southeast trend of the schist-gneiss series; also the complicated and irregular distribution of the granitic intrusive rocks.

GRANITES.

GEOLOGIC RELATIONS.

The granite in this area is invariably intrusive and is almost omnipresent. It cuts the schist series in large and small masses, in dikes, in sills, and, if pegmatite may be considered a phase of granite, it is found both in minute veinlets and in huge dikes and sheets. The area contains rock of every grade between pure granite and pure schist. Certain localities are characterized by pure granite masses of batholithic type, such as the area of coarse granite in the southwestern portion of the quadrangle, the area immediately west of Cedar Mountain, and the area east of Lone Grove. Other areas show an intimate mixture of granite and schist, the schist being literally the sponge which has soaked up and become permeated with granitic material. Such permeation is best developed about the edges of the large granitic masses, though not at all confined to those bodies. (See Pl. V, *B*, p. 76.)

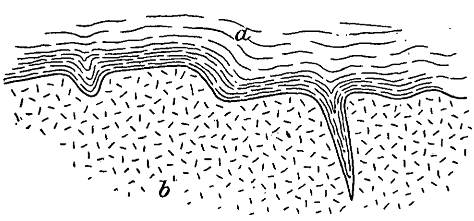
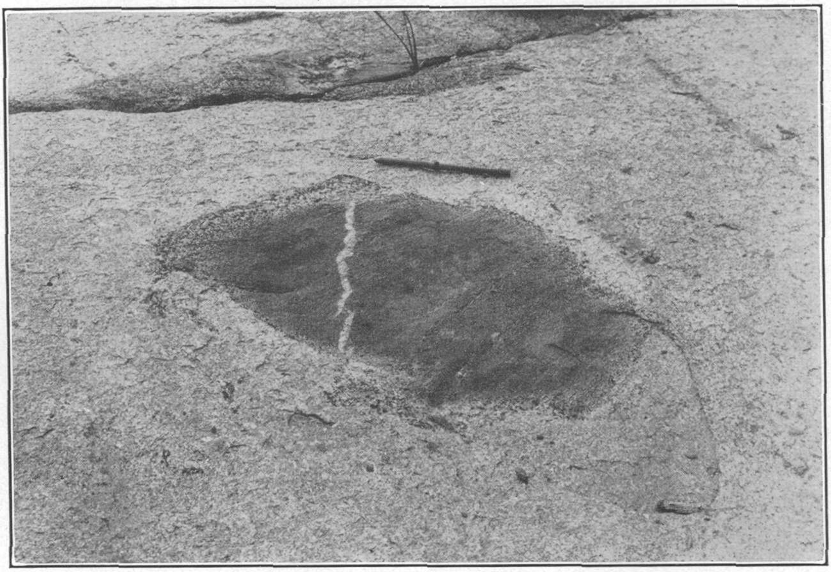


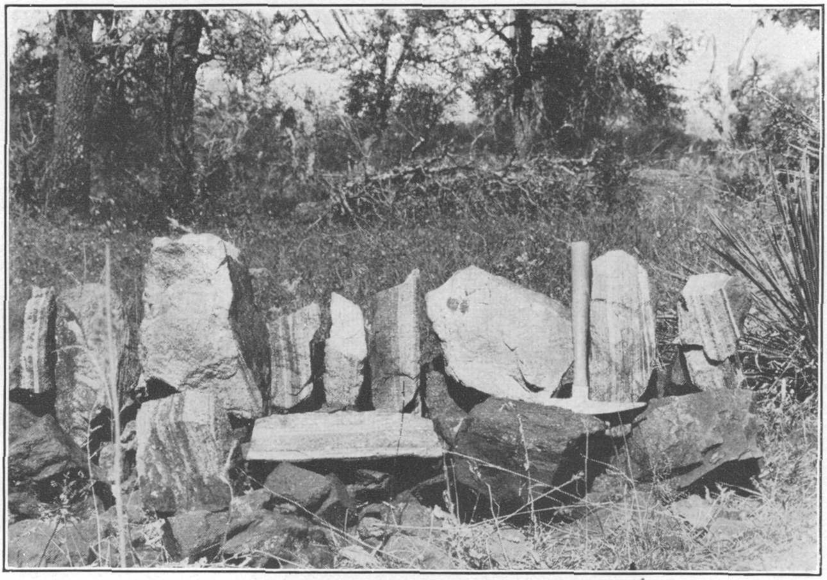
FIGURE 1.—Local flowage of schist at granite contact. *a*, Schist; *b*, granite.

The manner in which intrusion was effected varied. In some places portions of the schists were in a plastic state and flowed under the influence of pressure (see fig. 1); at other localities the contacts of the cutting dikes are sharp, indicating a condition of considerable rigidity; elsewhere the temperature of the intruding mass was so high that masses of the schist lost their identity and passed by gradual melting into solution (see Pl. IV, *A;* also fig. 18, p. 62); and elsewhere, again, granitic material, following planes of least resistance, forced itself between the layers of the schists and formed injection gneisses.



A. ASSIMILATION OF SCHIST FRAGMENT ALONG BORDERS AT CONTACT WITH GRANITE.

See page 10.



B. BANDING OF MAGNETITE ORE.

See page 58.

The results of the processes outlined above may be seen both on a small and on a huge scale, and afford a fine example of the conditions existing about the borders of a great batholithic mass that lies in contact with a deeply buried sedimentary series.

The dikes, sills, and broader masses of pegmatite, which occur in great abundance and in all sizes, are worthy of special mention, particularly the broader masses, which are locally developed at contacts of schist with crosscutting granite dikes. In the areas about Hog Mountain such sheets are finely developed, and it is believed that they indicate the proximity of schists now removed by erosion.

TYPES AND DISTRIBUTION.

Three types of granite have been distinguished on the geologic map—(1) a very coarse grained homogeneous rock; (2) a medium to fine grained granite, including some coarse-grained varieties; and (3) an opaline quartz-feldspar porphyry. Microscopic examination has shown that the distinction is largely textural, the mineralogical constituents in the three types being essentially the same.

The coarse-grained granite has been mapped in two areas—one in the southwest corner of the quadrangle, a large subcircular area with Prairie Mountain as a center; the other farther north, in the vicinity of Smoothingiron Mountain. Granite of the same type occurs east and southeast of Lone Grove and in other localities, but in areas so small that it could not be consistently differentiated in mapping. Conclusive evidence in regard to the relative age of this coarse granite was not discovered, but tentatively it may be considered intrusive in the finer-grained granites.

The granite of the second type, the widespread dominant rock of the region, includes various textural types, ranging in texture from very coarse to very fine grained, but has been mapped as a unit.

The granitic rock of the third type, the opaline quartz-feldspar porphyry, invariably occurs as a dike rock cutting both the schists and the intrusive granites which accompany them. Its outcrop may be followed, with interruptions, from a point about 3¼ miles east of Llano, on the Llano-Lone Grove road, northward through Miller Mountain for 6½ miles, where it bends to the northeast and forms a hook passing around the town of Babyhead and ending about a mile southwest of that place.

PETROGRAPHY.

COARSE-GRAINED TYPE.

The very coarse grained granite is of reddish tone, due to the large, finely developed potash feldspars, the largest an inch long and three-fourths of an inch broad, the average length being perhaps half an inch. The space between these well-crystallized, finely developed crystals is filled with quartz. Biotite, the dominant ferromagnesian mineral, is well developed in stout columns and rather abundant. Locally a parallel arrangement of the large feldspars was noted in the vicinity of Bullhead Mountain, a phenomenon probably due to movement under pressure while the magma was yet in a more or less viscous state.

A microscopic examination shows the following characteristics:

Very coarse granite from Watch Mountain, near Walnut Springs: Feldspars are microcline, orthoclase, and albite-oligoclase. Microcline dominant. Length one-half inch to 1 inch or more, width one-fourth to one-half inch. Quartz filling space between feldspars. Biotite mica abundant in stout columns one-eighth inch or more in length. Perthitic intergrowth of microcline and albite noted.

MEDIUM TO FINE GRAINED TYPES, INCLUDING SOME COARSE VARIETIES.

The granites mapped under this head include many varieties, from fine to coarse grain, but are, in general, chemically and mineralogically similar. Differences of texture and variations in the quantity of the ferromagnesian minerals account for most of the varieties.

An examination of numerous specimens reveals an abundance of microcline, with orthoclase, albite-oligoclase, biotite, quartz, and hornblende. The granites are distinctly potash rocks, though they almost invariably contain soda. They also contain the usual accessory minerals—magnetite, apatite, titanite, etc. Several hornblende granites were noted, but their areal extent is small.

Petrographic notes made on granites of the medium to fine grained type are given below:

Granite from Parkinson group of quarries.

Megascopic character.—Medium-grained to fine-grained gray granite. Biotite, quartz, and feldspar. Mica evenly distributed in fine flakes.

Microscopic character.—Largely composed of microcline with subsidiary orthoclase, rare plagioclase. Micrographic intergrowth with quartz in some feldspar. Rare zonal arrangement. Alteration has set in on nearly all the feldspar. Quartz shows some strain phenomena. Biotite occasionally altered to chlorite. Alteration of feldspar more pronounced at center than elsewhere. Grain or two of magnetite.

Granite from Kansas City quarry, 2 miles west of Llano.

Megascopic character.—Medium to coarse grained light-gray granite with slightly gneissoid aspect. Quartz, feldspar, mica.

Microscopic character.—Thirty-two per cent quartz; 62 per cent feldspar, microcline, and orthoclase; 6 per cent mica (biotite) with rare muscovite; 71 per cent SiO_2. Micrographic intergrowths of quartz and feldspar occasionally finely developed.

Hornblende granite from northwest Hog Mountain, near Wollastonite rock.

Megascopic character.—Pinkish toned medium crystalline granular, spotted with blotches of hornblende of various sizes up to one-fourth inch in diameter. Groundmass between the blotches is barren of ferromagnesian minerals.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars dominant in order named. Dark-green hornblende apparently poikilitically arranged about quartz. Measurements with microscope show 31 per cent quartz, 69 per cent feldspar, 75 per cent SiO_2.

Granite from Norton quarry.

Megascopic character.—Light-gray granite; abundant mica in very small flakes, evenly distributed.

Microscopic character.—Microcline, orthoclase, and little albite-oligoclase; quartz abundant. Biotite mica.

Red granite from Parkinson's quarry "well," camp No. 1.

Megascopic character.—Red, fine-grained granite, with ferromagnesian minerals scant and in very small particles.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase rather abundant. Quartz abundant. Little magnetite, mica, titanite, and hornblende. Ferromagnesian minerals very scant. Feldspars where altered are replaced by a red decomposition product.

Granite from Grays Mountain.

Megascopic character.—Coarse pinkish granite. Feldspars as large as one-fourth inch in length and mica very abundant; sufficient to give dark tone to rock.

Microscopic character.—Oligoclase and microcline. Former dominant. Both dominant over quartz. Biotite abundant, but not evenly distributed. Apatite. Feldspar altered.

Hornblende granite (a chip only) from south edge of quadrangle near small creek above house in Elver's pasture.

Coarse granite. Orthoclase, microcline, and oligoclase feldspars. Quartz. Hornblende, partly altered to chlorite. Feldspars badly altered. Zircon. Apatite abundant. Titanite.

Pink granite from west of road, east of direct route from Castell to Berry Spring (Goodes Spring).

Megascopic character.—Fine-grained pink granite, containing circular areas impoverished of ferromagnesian minerals, in the center of which are aggregations of titanite and magnetite.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars with biotite, and segregations of magnetite and titanite. Part of the quartz one of the first minerals to separate out. Apatite needles abundant.

Granite from Heine's well, south of Willow Creek, 4 miles north of river, 1 mile west of San Fernando Creek.

Megascopic character.—Red granite, medium to fine grain, glassy aspect.

Microscopic character.—Microcline and orthoclase feldspars and quartz. Microcline and orthoclase, badly altered. Scanty biotite; chloritized. Sericite developed in feldspars. Red tone very probably accentuated by alteration.

Pink granite from one-fourth mile west-northwest of Esbon post office on Kings Mountain.

Megascopic character.—Fine-grained, light-pink granite, ferromagnesian minerals evenly distributed in tiny flakes.

Microscopic character.—Microcline feldspar dominant; with orthoclase and quartz. Biotite (about average amount) in small flakes. Apatite needles. Feldspar, especially orthoclase, badly altered, though the hand specimen looks fresh.

Granite from breast of crosscut in shaft at Iron Mountain (1908).

Megascopic character.—Pink, medium to fine grained granite.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars. Quartz. Biotite mica. Little magnetite.

OPALINE QUARTZ-FELDSPAR PORPHYRY TYPE.

This rock, as its name indicates, is a quartz-feldspar porphyry. When rough in the hand specimen, it has a dark-reddish aphanitic groundmass mottled with abundant phenocrysts of pink feldspar and opaline quartz, the quartz being very prominent on weathered surfaces. The quartz phenocrysts break with a glassy fracture, are of light-bluish tone, and possess a certain iridescence when polished. The microscope shows quartz phenocrysts (with a great number of minute inclusions); microcline feldspar phenocrysts; microperthite phenocrysts (albite and orthoclase); a groundmass of quartz and orthoclase, and small flakes of biotite mica; a little magnetite with associated sphene; some fine zircons; little apatite; local chloritization of mica.

Dr. Joseph P. Iddings proposed the name of llanite for this rock some years ago.[a] It is known in Llano County as opaline granite. Dr. Iddings[a] estimated that the rock is probably composed as follows:

Mineral composition of opaline granite, Llano County, Tex.

Quartz	34.6
Feldspar	55.7
Biotite	8.6
Fluorite	1
Apatite	.13

In speaking of the bluish color of the quartz he says:

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

SCHISTS AND GNEISSES (LLANO SERIES).

DIVISIONS AND DISTRIBUTION.

The schists and gneisses of this area comprise the Llano series, and all are believed to be of Algonkian age. Two broad divisions may be recognized and have been mapped on Plate III (in pocket)—the one, a series dominantly basic and generally of dark color containing much limestone, biotite, amphibolite, and graphite schists and termed the Packsaddle schist, a name applied originally by Com-

[a] Phillips, W. B., Tests on Texas building stones: Mining World, June 24, 1905.

stock[a] to marbles and shaly beds near Packsaddle Mountain. In this report, however, the name is redefined and limited strictly in its usage by principles to be presented below. The other, a series dominantly acidic, of light color, containing some altered limestone and termed the Valley Spring gneiss, a name also applied by Comstock[b] and also redefined in this report. Bands of acidic material are found in the first series and bands of basic dark material have been included in the second. There is a transition zone between the two series, locally offering difficulties to the placing of definite boundaries. Likewise, within the acidic series, the distinction between invading granites and gneisses is often exceedingly difficult to recognize, because of a gneissoid texture that the granites locally possess.

The distribution of the two series is dependent primarily on major structural relations, modified by igneous intrusion. Their general northwest-southeast trend is determined by the major axes of folding, and the lack of continuity along their trends is due to the presence of granite (see Pl. III). Two major anticlinal axes are present, one passing northwest and southeast through the center of the mountainous mass just west of Oxford, the other passing from Packsaddle Mountain northwest to a point several miles west of Babyhead. Between these two anticlinal axes a major synclinal axis passes northwest and southeast a short distance west of Llano. The broad band determined by this synclinal axis is composed largely of the Packsaddle schist, while the anticlinal axes mark areas of the lighter Valley Spring gneiss. The basic Packsaddle schist overlies the acidic type, and therefore is found on the eroded flanks of these great folds, where not disturbed by granite masses. The major axes of folding do not represent a simple structure, minor folds, some of which have been separately mapped, being superimposed upon the major folds, with the result that local complexities of structure are frequent. No estimate has been made of the thickness of the series.

PACKSADDLE SCHIST.

DISTRIBUTION AND GENERAL CHARACTER.

The Packsaddle schist series includes mica, amphibole, and graphitic schists, and crystalline limestone. In the series are also lighter-colored, more feldspathic bands, resembling quartzites. Intrusive rocks of earlier age than the granite, of the diorite-gabbro type, are also present locally in considerable amount. They have been separated from the Packsaddle schist in only one instance, in the southeast corner of the Llano quadrangle and the southwest corner of the Burnet quadrangle.

---

[a] Comstock, T. B., Preliminary report on the geology of the central mineral region of Texas: First Ann. Rept. Texas Geol. Survey, 1889.

[b] Loc. cit.

As a whole, the Packsaddle schist is characterized by an excellent cleavage which for the most part accords in attitude with an original bedding in sediments, of which the schists represent the metamorphosed equivalents. Frequently, though not invariably, the graphitic schists are closely associated with limestones. The limestones are developed to a varying degree, as a glance at the map (Pl. III) will show. East of Oxford numerous limestone beds are present, and the region south and west of Llano includes many bands. In general they occur wherever the Packsaddle schist is found, but, though most abundant in the Packsaddle schist and in a measure characteristic of that schist series, they do also occur in the lighter series (Valley Spring gneiss), though usually in a still more altered form; that is, as wollastonite bands. The graphitic schists carry varying proportions of graphite—locally, it is believed, a sufficiently high content to be of commercial value. (See p. 77.) A microscopic examination of a specimen of graphite schist from Cottonwood Creek showed about 60 per cent of quartz, 30 per cent of orthoclase feldspar, fairly abundant grains of augite, a little titanite, a little apatite, and flakes of graphite arranged parallel to the schistosity of the rock. Often crystalline limestone bands are interbedded with the graphite schist, leaving little or no doubt as to the sedimentary origin of the carbon mineral. Among the remaining types of a sedimentary origin are mica, tourmaline, and quartz-feldspar schists. All these rocks carry a high content of quartz, and are characterized by potash feldspar and biotite with here and there some pyroxene (augite). The tourmaline schist is an exception and does not carry feldspar. Magnetite, titanite, and apatite are often accessories. Amphibolite schists are fairly abundant and are characterized by a very low content or lack of quartz. There is some doubt regarding their origin. As they are interbedded with limestones, a sedimentary origin is suggested; their origin as old flows and sill-like intrusions, however, must be kept in mind, as possible or even probable, for basic intrusive rocks are found in the region, and in one place a type transitional from a basic porphyry dike to amphibolite schist was noted. Amphibolites of undoubted igneous origin may also be seen in considerable masses.

The following section was measured on the west fork of Oatman Creek, about 3½ miles south of Llano:

Section of Packsaddle schist on Oatman Creek east-southeast of Bachelor Peak.

	Feet.
Schist with pencil cleavage	1,000
Hidden	400
Thin-bedded feldspar-quartz schist (strike N. 40° W., dip 65° E.)	3
Well-banded hornblende schist	30
Quartzite (feldspar-quartz schist)	1
Hornblende schist	15
Thin-bedded micaceous schist	75

	Feet.
More massive, micaceous schist with pegmatite and quartz injections	130
Graphitic slate schist	23
Crystalline limestone	24
Graphitic slate schist	35
Injection gneiss	30
Hornblende schist	91
Feldspar-quartz schist	62
Weathered hornblende schist	120
Thin-bedded mica schist, massive as a whole	60
Limestone	8
Graphitic slate or schist	6
Limestone	4
Heavy, thin-bedded mica schist full of quartz blebs and stringers	32
Friable mica schist (like pencil schist)	250
Hidden	40
Mica schist	50
Hidden	50
Mica schist	20
To granite contact	60
	2, 619

PETROGRAPHY.

The results of a microscopic examination of a number of specimens of the Packsaddle schist are as follows:

Quartz-feldspar schist.

Megascopic character.—A whitish-pink, sugar-grained, finely banded rock; bands straight and narrow, made by pink and white constituents. Speckled with magnetite showing a slight tendency to follow bands. Rock cleavage follows bands.

Microscopic character.—Equidimensional grains microcline feldspar, orthoclase feldspar, and quartz. Flakes of a brownish-yellow biotite mica and magnetite not clearly in bands. Considerable alteration of feldspar. Measurements showed 68 per cent feldspar, 32 per cent quartz—which gives 76 per cent SiO_2, approximately 12 per cent Al_2O_3, and approximately 12 per cent K_2O.

Quartzite-like feldspar schist.

Megascopic character.—Fine-grained, almost aphanitic, grayish and pink banded schist.

Microscopic character.—Even granular, fine-grained, holocrystalline rock, two-thirds orthoclase feldspar (altered), one-third quartz, light-green hornblende (partly altered to chlorite), and titanite. About 75 per cent SiO_2 and 12 per cent Al_2O_3.

Amphibolite schist.

Megascopic character.—Dark-green to black, finely-cleaved schistose rock.

Microscopic character.—Mass of hornblende laths in a matrix of feldspar. Abundant grains titanite. Little calcite, little apatite.

Amphibolite schist.

Megascopic character.—Dense, slaty, almost aphanitic, dark-green to black rock showing on weathered surface evidence of schistosity.

Microscopic character.—From 50 to 60 per cent light-green hornblende, considerable augite, orthoclase, and some plagioclase feldspar in the interstices of the hornblende laths.

Amphibolite schist.

Megascopic character.—Dark-green to black glittering schist.

Microscopic character.—Linear arrangement of abundant dark-green hornblende laths in a matrix of microcline and quartz, the former in great excess. Scattering grains of augite partly altering to hornblende. Epidote, magnetite, apatite.

Amphibolite schist.

Megascopic character.—Dark-green to black very fine grained glittering schist.

Microscopic character.—Interlocking grains of prismatic light-green hornblende evenly though not entirely equidimensional. The little space between the hornblende plates is filled with feldspar.

Biotite-quartz-mica schist.

Megascopic character.—Gray even and fine grained mica schist.

Microscopic character.—Even, granular quartz, orthoclase, and microcline. Abundant biotite laths parallel to schistosity. Some muscovite.

Mica schist.

Megascopic character.—Gray banded schist. Bands due to lines of pink feldspar in light-gray background. Feldspar is arranged in lentils which produce the bands. Abundant fine flakes of black mica.

Microscopic character.—About equally divided quartz and altered orthoclase feldspar. Abundant biotite in linear parallel arrangement. Abundant iron oxide grains.

Mica schist.

Megascopic character.—Dark-greenish, nearly black aphanitic glassy rock showing on surface striations which reveal its schistose nature.

Microscopic character.—Orthoclase and quartz in equidimensional grains, former in slight excess. Biotite mica in fine parallel alignment. About 6 to 9 per cent mica.

Quartz-tourmaline schist.

Megascopic character.—Dense dark-blue to black hornfels-like rock, with fine bands of quartz showing schistosity.

Microscopic character.—Fine bands of quartz and tourmaline. Tourmaline for the most part oriented parallel to schistosity and apparently crystallized first, as it appears in fine lines in the quartz parallel to bands. Much of the quartz has wavy extinction.

Biotite feldspar gneiss.

Megascopic character.—Blue-gray, granular, fine-grained rock with gneissoid aspect, rather evenly granular. Mica prominent as dark constituent.

Microscopic character.—Granitoid texture. Quartz, albite-oligoclase, and abundant biotite. Some hornblende, titanite, and chlorite. By measurements the following approximate chemical composition was calculated: 73 per cent SiO_2, 14 per cent Al_2O_3, 6 per cent Na_2O, 1 per cent CaO, 6 per cent Fe, Mg, etc.

Mica schist.

Megascopic character.—Pink and black banded schist, with finely developed schistosity due to mica.

Microscopic character.—Crystalline granular quartz. Microcline and little albite-oligoclase. Biotite, in laths or plates parallel to the schistosity. Quartz arranged roughly in direction of schistosity. Microcline is slightly altered. Composition: 79 per cent silica, 9.64 per cent alumina, 8 per cent potash, 3.36 per cent iron, magnetite, sodium, and calcium.

VALLEY SPRING GNEISS.

DISTRIBUTION AND GENERAL CHARACTER.

The mapping of the Valley Spring gneiss was locally attended with many difficulties, partly connected with separating it from the Packsaddle schist, but primarily because of its relation to granitic intrusions, which, as has been pointed out, are widespread and of all degrees of magnitude. As the Valley Spring gneiss often closely resembles the granites, especially where slight schistosity may have been impressed upon the granites, and as contacts are exceedingly irregular (a feature characteristic of the borders of large intrusive masses), all the boundaries shown on the map must not be considered as definitely separating distinct formations, but rather as indicating changes in the dominant rock type. In a region where intrusion has so completely interleaved and at places actually impregnated a rock mass, and where all gradations from pure granite to pure schist exist, such boundaries as have been used are necessary to express the geologic facts. In many places, however, the boundaries are sharp and form definite lines, but it is not practicable on the map to discriminate between the two classes of boundaries. It is believed, also, that with the schists and gneisses of sedimentary origin are included old gneisses of igneous origin.

Perhaps the most distinctive difference between the light Valley Spring gneiss and the dark Packsaddle schist lies in their difference of massiveness. This difference applies more particularly when the groups are taken as a whole and not when small areas are compared. The mountainous tract west, southwest, and northwest of Oxford, including Hobson and Blount mountains, and the area south and west of Babyhead, and including Babyhead Mountain, contain such massive rocks, typically representing the Valley Spring gneiss. A study of these areas leaves the impression that a thick series of sediments of rather uniform composition has been involved in a zone of intense granitic intrusion and metamorphism, locally in a zone where rock flowage and minor folding have been dominant. The dark Packsaddle schist nowhere presents as a whole this massive appearance.

It has already been noted that dark bands occur, though not abundantly, in areas mapped as Valley Spring gneiss, and also bands composed of the metamorphosed equivalents of limestones—that is, wollastonite. These bands of wollastonite lend plausibility to the hypothesis that metamorphism has been most intense in the light series (the lower series), though this hypothesis does not exclude the generalization that intrusion has been most intense along synclinal axes, as the position of the great granite areas indicates, for evidently wherever the dark series is nearly obliterated by areas of granite the underlying light series must have been similarly affected.

PETROGRAPHY.

The results of a microscopic examination of a number of specimens of the Valley Spring gneiss are given below.

Feldspar-quartz-mica gneiss.

Megascopic character.—Finely banded sugar-grained pink and black gneiss. Bands one-sixty-fourth to one-fourth inch in width.

Microscopic character.—Potassic feldspar, more or less altered, and quartz about evenly divided with feldspar. Biotite mica (altered to chlorite in part) in linear arrangement. Little calcite. Little apatite.

Feldspar-quartz schist.

Megascopic character.—Nearly white aphanitic schist. Banding due to quartz bands separated by 1-inch to ½-inch aphanitic bands.

Microscopic character.—Fine-grained, granular quartz and microcline, the former much in excess. Feldspar greatly altered. Little muscovite.

Quartz-feldspar schist.

Megascopic character.—Pink, fine sugar-grained rock with only slight schistosity in hand specimen. Flecked with small grains of magnetite evenly distributed.

Microscopic character.—Altered microcline feldspar dominant. Little albite-oligoclase. Quartz abundant, though less than feldspar. Few flakes of biotite. Magnetite scattered.

Quartz-feldspar schist.

Megascopic character.—Even-toned pink fine-grained rock. Banding brought out by quartz and feldspar, arranged in lines. Fine dust of magnetite, little muscovite, and little garnet.

Microscopic character.—Holocrystalline grains quartz, potash feldspar, mostly microcline, and abundant muscovite. Approximate composition: 68.6 per cent silica, 16 per cent alumina, 11 per cent potash, 1.48 per cent calcium, 2 per cent magnetite.

ORIGIN OF THE SCHISTS AND GNEISSES.

The schists described above, those of both the light and the dark series, are all completely crystallized; that is, the arrangement, the size, and the composition of their mineral constituents are due in part to the influence of heat and pressure and in part to flowage as a mass. The presence of crystalline limestones and of graphite and mica schists, traceable for long distances and retaining the characteristics of beds, leaves no room for doubt that these rocks were in great part formed by metamorphism from a sedimentary series. It is believed also that the presence of iron ores leads to the same conclusion—a point which will be more fully considered at another place. As has been pointed out, the amphibolites, because of their basic character, probably represent in part old basic intrusives or flows, or perhaps sediments of a tuffaceous nature.

Gneisses derived by metamorphism from intrusive rocks of a granitic type are almost without doubt present in the region. One crosscutting dike possesses much the same schistose nature as the beds which it cuts. Red Mountain also, a granitic ridge in the southeast corner of the Llano quadrangle, is a noteworthy example of the same phenomenon. This ridge trends northwest, and the dike which forms it can be traced to a point near Walker Peak. Toward the northwest a gradual change takes place in the appearance of the mass, and the rock at its northwest end shows decided lamination. Indeed, were the rock exposed only in the condition seen at this end, it could not be distinguished from beds which are believed to represent sedimentary strata.

In the area immediately east of Long Mountain also the gneissoid rocks have much the aspect of granites impressed with foliate structure; and south of Field Creek, near San Fernando Creek, in the northwest part of the quadrangle, similar features were noted. It should be understood, then, that the series of gneisses and schists of the acidic type mapped as Valley Spring gneiss probably contains material of igneous origin. It may be said here that no genetic relation could be shown between the iron-ore deposits and these old granitic intrusive rocks.

BASIC INTRUSIVE ROCKS OF A GABBRO-DIORITE TYPE.

GENERAL CHARACTER AND DISTRIBUTION.

The dark intrusive rocks are most abundantly developed in the southeast corner of the Llano quadrangle, and, though they have not been generally separated from the accompanying dark Packsaddle schist, they have been mapped in one instance. A considerable mass of gabbro was observed in the vicinity of Goldmine Creek, north of Moss ranch, but it has not been mapped; and, as has been stated, the dark Packsaddle schist probably includes amphibolites, which represent old intrusive rocks of gabbroic or diabasic type.

The area south of Click is especially characterized by very dark green to black amphibolite rocks, which were probably derivatives of a gabbro or diorite magma. The talc deposits in this vicinity are alteration products of such a series, and the serpentine rocks of Oxford are probably derived from a peridotitic magma.

Two dark fine-grained dikes (aphanitic in texture) which cut the schist series and which might have been expected to show a rather basic character proved to be felsites, one a spherulitic mica felsite, the other a hornblende-mica felsite; the hornblende of this latter rock showed a bluish pleochroism parallel to the C axis, suggestive of a soda amphibole. A short distance east of Click a small intrusive mass proves to be a hornblende-soda granite.

The rocks of this gabbro-diorite group were intruded earlier than the greater part of the granites. It is possible that some of the latter rocks, which show evidence of pressure and metamorphism, may have been nearly of the same age, though no relations were observed which might establish this point.

PETROGRAPHY.

The results of a microscopic examination of a number of specimens are as follows:

Soda-hornblende granite, chip only, taken a short distance east of Click post office.

Microscopic character.—Holocrystalline albite feldspar and considerable quartz; a little microcline feldspar. Large plates of green hornblende are abundant. Abundant titanite surrounding grains of titaniferous magnetite. The rock has suffered crushing and shows abundant granulation at the edges of the feldspar grains; the amphiboles are locally broken and bent and drawn into shreds.

Hypersthene olivine gabbro from Goldmine Creek.

Megascopic character.—Dark-blue to black medium-grained rock.

Microscopic character.—Holocrystalline texture. Labradorite in lathlike prisms. Diallage, hypersthene, and olivine. Biotite and hornblende poikilitically inclosing pyroxene and feldspar. Magnetite.

Amphibolite from high hill on Coal Creek.

Megascopic character.—Dark-green hornblende rock with slight tendency, due to pressure, to cleave more easily in one direction than in another.

Microscopic character.—Mat of light-green hornblende with plagioclase feldspar in interstices. Shows evidence of crushing.

Metadiorite porphyry in hornblende schist series near Aaron Moss ranch.

Microscopic character.—Altered andesine-labradorite feldspar phenocrysts in a fine-grained groundmass of feldspar and green hornblende. Flowage of hornblende around the phenocrysts of feldspar noteworthy. Shows an intermediate stage in the formation of an amphibole schist.

Diorite from Cedar Mountain under Cambrian.

Megascopic character.—Medium-grained dark gray to green rock.

Microscopic character.—Holocrystalline andesine-labradorite and hornblende in large plates.

Spherulitic mica felsite.

Megascopic character.—Black aphanitic dike rock.

Microscopic character.—Mass of very fine blades of biotite mica in groundmass of unstriated feldspar. Some quartz, and one quartz phenocryst, showing absorbed edges. A spherulitic arrangement of the feldspar is noteworthy and the mica seems to be arranged in a manner controlled perhaps by this spherulitic structure.

Amphibolite (meta-gabbro?) (partly crushed) from southwest part of Burnet area near edge of Llano area.

Megascopic character.—Dark-green medium to fine-grained hornblende rock.

Microscopic character.—Mass of interlocking hornblende crystals with interstices filled with untwinned plagioclase feldspar. Abundant grains of magnetite largely within the hornblende.

Mica-hornblende felsite.

Megascopic character.—Nearly black aphanitic dike rock.

Microscopic character.—Abundant hornblende in laths and grains set in a matrix of very finely granular feldspar and quartz. Biotite mica is also abundant in fine laths and tiny plates. Apatite needles are present. The hornblende has a blue pleochroism parallel to the elongation (C), and extinction angles as high as 18°.

Diorite from southeast of Rough Mountain and west of San Fernando Creek.

Megascopic character.—Medium-grained dark-green rock.

Microscopic character.—Holocrystalline texture. Weathered andesine-labradorite feldspar and abundant hornblende in large plates. Much pyrite in large part confined to hornblende. Hornblende altering to iron oxide along cleavage cracks. Some epidote. Some apatite.

PALEOZOIC ROCKS.

The Paleozoic formations in the Llano-Burnet region, as stated in an earlier portion of this report, surround a basin cut in pre-Cambrian rocks, and much of the section therefore is exposed about the edges of this relatively low-lying area.

The pre-Cambrian rocks, composed in large part of metamorphosed marine sedimentary beds, passed through all the stages of deposition, deep burial, folding, metamorphism, intrusion, elevation, erosion, and subsidence beneath the sea before the basal Paleozoic beds were deposited. It is evident, therefore, that a vast interval of time separates the periods during which the two series were formed. This time interval is expressed by the unconformity between the Paleozoic beds and the underlying schists and granites. As this report treats principally of the pre-Cambrian rocks and the relations of the economic resources thereto, the Paleozoic rocks will be very briefly discussed.

UPPER CAMBRIAN ROCKS.

The Upper Cambrian rocks of this area are believed to be essentially the equivalent of the Reagan sandstone in Oklahoma. They rest upon a pre-Cambrian complex of metamorphic rocks—the schists, gneisses, and intrusive rocks described above—and have been divided into three formations, namely, proceeding from the base upward, the Hickory sandstone, the Cap Mountain formation, and the Wilberns formation.[a]

A variable thickness of conglomerate and sandstone, up to 250 feet, comprises the lower formation to which the name Hickory sandstone is given, a name originally applied by Comstock [b] to sandstones in the valley of Hickory Creek and its tributaries. Next, but with a gradual transition from sandstone to limestone, are beds predominantly limestone, capped by a variable thickness (from 15 to 75 feet) of cross-bedded glauconitic sandstone; these strata, 90 feet thick, constitute the second formation, the Cap Mountain, which is typically exposed at Cap Mountain, in the Llano quadrangle. The third formation, the Wilberns, from 170 to 220 feet thick, includes limestones and shales, the shales occupying approximately the upper third of the formation. It is typically exposed near Wilberns Glen, in the Llano quadrangle.

---

[a] For detailed descriptions of these formations see Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

[b] Comstock, T. B., Preliminary report on the geology of the central mineral region of Texas: First Ann. Rept. Texas Geol. Survey, 1889.

CAMBRO-ORDOVICIAN ROCKS.

The Cambro-Ordovician rocks have not been subdivided. They are represented by the Ellenburger limestone (locally dolomitic).[a] There is believed to be an unconformity near the top of the formation, for, according to Ulrich, fossil evidence precludes the idea that continuous sedimentation could have been in progress during the deposition of the entire series of beds. The formation is composed of chert-bearing limestones and dolomites, which are typically exposed in the Ellenburger Hills, in the Burnet quadrangle. In the greater number of places where the base of these beds was observed, apparent conformity with the Wilberns formation existed, though in several places on Riley Mountain an angular limestone conglomerate was present. Here, also, some evidence of overlap was observed, but the writer, in view of the fact that faulting was found to be prevalent, wishes to leave this point open until opportunity may be offered to study the locality again. In the majority of places, however, where the conglomerate was noted, concordance of beds was the rule. Many observations were made where no unconformity could be detected, and also where apparent transition of the two formations could be followed. It must be noted, however, that the basal beds of the Ellenburger limestone varied in texture and appearance; and as this phenomenon is in itself a suggestion of unconformity, any conclusion must for the present remain tentative.

At the top of the Ellenburger limestone a conglomeratic limestone bed is generally, though not always, present, and the lowest portion of the upper Carboniferous succeeds. The deposition of upper Carboniferous limestone on beds of Cambro-Ordovician age marks a great gap in sedimentation, a period of great duration including lower Carboniferous, Devonian, Silurian, and part of Ordovician time, during which no deposition was taking place.

The Cambro-Ordovician rocks occur at the crest of the Paleozoic scarp (unless faulting has intervened) and form the greater part of the Paleozoic surface in Llano and Burnet Counties.

Complete sections of the Ellenburger limestone are not easy to obtain. The general massiveness of the formation, gentle folds and faults, combine to prevent continuous record. Thicknesses up to 600 feet may be observed in the bluffs of the Colorado, between Tanyard Crossing and Deer Creek, and it is probable that the formation is composed of beds aggregating 1,000 feet in thickness.

CARBONIFEROUS ROCKS.

Beds of Carboniferous limestone and shale of lower Pennsylvanian age are present in this region and have been divided into two formations—the Marble Falls limestone, composed of limestone, and the

[a] For detailed description of the formation see Sidney Paige, Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

Smithwick shale,[a] composed of nearly black shale accompanied by sandstone lentils.

As has been already noted the Carboniferous is in most places separated from the underlying Cambro-Ordovician by a thin limestone conglomerate, and, in one instance, a very coarse, angular conglomerate or breccia was observed. In some localities, however, little or no discordance could be seen, as in the restricted basin 5 miles northeast of Blufton in the Burnet quadrangle.

The Marble Falls limestone is believed to be not over 450 feet, possibly 500 feet, in thickness. The Smithwick shale, which immediately overlies the Marble Falls limestone, because of its soft nature is not exposed in such attitude as to permit a section measurement. Moreover, its top is overlapped by Cretaceous sediments. Probably the beds exposed in Burnet County do not exceed 400 feet in thickness.

The Carboniferous is confined almost entirely to the southeastern portion of the Burnet quadrangle, though a small area exists in Riley Mountain.

STRUCTURE.

A reference to the small map of Texas (Pl. I, p. 7), showing the geologic relations of the Llano-Burnet region and surrounding area, will immediately call forth the suggestion that some unusual condition has caused the exposure of these ancient pre-Cambrian rocks; and on turning to the detailed map (Pl. III, in pocket) and studying the faulting which has taken place, one is compelled to ascribe to this faulting, combined with differential erosion, the present basin-like form of the area.

The faults which border this basin, indicated by heavy black lines, all have one important similarity. The downthrown block forms the scarp side of the fault and presents a more or less vertical face toward the basin, or, in other words, the basin area, now topographically lower than the surrounding scarp and largely characterized by pre-Cambrian rocks, is structurally elevated with respect to that scarp.

Such an elevation in past time must have exposed the rocks which were carried up by it to accelerated attack by the elements with the result that the overlying sediments were stripped off and the core of schists and granite uncovered. From this point on, the metamorphic complex disintegrated more rapidly than the surrounding linestone-capped strata, and the present erosional basin was formed. The Paleozoic sediments involved in the suggested uplift are locally folded, and are inclined at varying degrees from the horizontal.

The structure of the pre-Cambrian schists (except the displacement they have suffered due to late faulting) is of a much earlier date and of a much more complex nature than the structures just described.

[a] For detailed descriptions of the Smithwick shale see Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

The rocks have suffered deep-seated regional metamorphism, have been impressed with a foliate structure, have usually steeply inclined dips, trend generally to the northwest, and are intruded both by old dioritic and gabbroic rocks and by late granitic and pegmatitic types. The major structural lines are indicated on the geologic map (Pl. III). Two nearly parallel anticlinal axes are specially noteworthy, one a few miles west of Oxford, the other, a few miles east of Lone Grove. The latter ends to the southeast in the Burnet quadrangle (not shown here), and is beautifully accentuated by heavy bands of limestone, bending around the nose of the arch.

Several of the many minor folds are indicated on the map. The great granite masses occupy positions corresponding to synclinal axes, as, for example, the mass in the southwestern part of Llano quadrangle and the mass in the western part of Burnet quadrangle. The central syncline does not seem to have suffered such intense intrusion.

North of Llano River in the western portion of the Llano quadrangle the anticlinal arch flattens and the schists dip at lower angles.

The manner in which intrusion has taken place has already been described and need not be repeated. A study of the map will indicate, in part, the extreme point to which this process has been carried. A discussion of the probable forces involved in the production of the post-Paleozoic faulting can not be given in this paper.

IRON ORES.[a]

GENERAL DESCRIPTION.

By A. C. Spencer.

Iron ores composed essentially of magnetic iron oxide (magnetite) (Fe_3O_4) or of admixtures of magnetite with hematite (Fe_2O_3) occur in deposits of noteworthy size in Llano and Mason Counties, Tex. During the progress of geologic mapping of the Llano quadrangle in 1908 and 1909 thirty-two more or less distinct occurrences of such iron ore were noted and studied with such detail as was warranted by generally poor natural exposures and a very small amount of exploratory development.

Though a few localities are in eastern Mason County, most of the iron showings are in that portion of Llano County which lies north of Llano River. All of the known occurrences of magnetite are described, but it is believed that not more than perhaps three of the deposits promise to become of industrial value. No assurance can be given that the three most likely deposits can be developed into profit-

[a] The examination of the iron-ore deposits was assumed as an especial task by Mr. Spencer in view of his familiarity with the magnetite ores of the northeastern portion of the United States, but the more notable showings were also studied by Mr. Paige. The notes of both have been used in the following descriptions.

able mines in advance of adequate exploration by means of diamond drills or by prospecting shafts in addition to those already opened, and it is considered that the less promising deposits will not warrant any large expenditure for prospecting unless the market value of iron ores increases.

The permissible scope of the geologic work did not admit of magnetic surveys, but it is suggested that such surveys should be carried on in connection with any future exploration of the more promising magnetic deposits of this district. Surveys with compass and dip needle would perhaps serve as adequate guides in the preliminary magnetic exploration of these iron-ore deposits, after which, if the results obtained warranted such a course, more refined methods and studies might be applied.

Financial interests that may take up the problem of the practical development of the Llano County iron ores will doubtless give due consideration to the possibility of applying magnetic concentration, as processes of this sort are becoming more and more firmly established in various parts of the world.

The deposits of magnetite in Llano and Mason counties, Tex., are typically layered or stratiform ore bodies conforming in attitude with the layering of the somewhat schistose rocks by which they are inclosed. The feature of layering is more marked in the leaner ore bodies than in the deposits of higher grade, but may be made out in nearly every locality where the ore-bearing rocks are adequately exposed for any sort of an examination. A single exception is noted in the case of a small ore mass opened by the Gallihaw shaft, which occurs in a dike cutting across the layering of the local gneiss.

In so far as the geologic mapping may be relied on the deposits are associated mainly with the lower of the two sets of gneisses which have been broadly separated. The difficulties of consistently discriminating between these rocks have, however, proved to be so great that it must be freely admitted that the immediate country rocks of the ores may be representatives of the upper set of schists in certain localities. If any mistake has been made in the proper classification of the country rocks, it is in places where the upper schists have suffered excessive metamorphism and where they constitute areas of minor extent.

Two extensive occurrences of magnetite were found within areas which are undoubtedly underlain by the upper dark schists, the Packsaddle schist, and a small amount of magnetite was noted at one other place in this rock. The Olive deposit, which is included in the foregoing, occurs in the dark Packsaddle schist near beds of limestone and very near the edge of a great intrusion of coarse granite.

SPECIAL LOCALITIES.

OLIVE PROPERTY.

By A. C. Spencer.

The Olive iron-ore property is located on Little Llano River about 6 miles east by northeast of Llano, 1 mile south of Lone Grove post office, and 1 mile north of Llano River and the line of the Houston & Texas Central Railroad. The property has been more extensively developed than any other in the district. It was opened by a shaft in 1892 or 1893.

An extensive area of granite covering the western-central part of the Burnet quadrangle and the adjacent portion of the Llano quadrangle is bounded on the southwest and west by a band of limestone-bearing schists extending along the railroad southeast and northwest from Graphite station and up the valley of Little Llano River. The Olive shaft is situated on the east bank of the Little Llano just west of the main boundary between the schists and granites, and therefore within the schists which belong to the upper set of metamorphosed sedimentary rocks characteristic of the region.

The rocks exposed in the vicinity include granite, hornblende-mica schist, graphite schist, and crystalline limestone. The granites are intruded into the other rocks in an intricate manner which can not be fully made out because of rather poor exposures, so that the representation of areal relations given on the geologic map is of necessity very much generalized. The material on the waste dump includes all the rocks mentioned except graphite schist.

The stock pile contains perhaps 400 tons of ore of very good physical appearance. Most of the ore contains hornblende, and some of it carries iron sulphide in addition to magnetite. It is all more or less distinctly layered in its make up. As the result of 17 years' exposure many of the ore chunks present a somewhat weathered appearance, the partial disintegration being due to oxidation of the iron sulphide present. Where this mineral is lacking, the ore shows no effects of weathering.

The following analyses show the character of the ore:

Analyses of iron ore from Olive mine, Llano County, Tex.

	Metallic iron.	Silica.	Sulphur.	Phosphorus.
1	57.80	8.40	0.28	Trace.
2	54.35	10.16	.55	.021
3	57.5	8.6	Trace.	Trace.

1 and 2 are samples taken by Robert Linton, of Atwater, Linton & Atwater, mining engineers, for Johnston, Elliot & Co., of Dallas, Tex.
3. S .H. Worrell, analyst, University of Texas.

Mr. Robert Linton has furnished also the following analyses, said to have been made in 1893 for the owners of the Olive property. Though the name of the analyst is not given, there is no reason to believe that these are not good commercial analyses. The samples taken together are stated to have come from the third mine level and to represent a section across 9 feet 6 inches of ore, 9 feet 2 inches of which is covered by samples 5 to 11 in the following table. These samples show an average content of iron of 58.71 per cent and of phosphorus of 0.0325 per cent, this average being figured with due consideration of the widths of ore stated in the table.

The analyses show a strictly Bessemer type of ore with a moderate iron content. Sulphur, though rather high, is not sufficient to lower the value of the ore appreciably.

Analyses of iron ore from third mine level, Olive mine, Llano County, Tex.

Analysis No.	Width of ore.		Fe_2O_3.	Fe.	P.	S.	SiO_2.	Mn.	TiO_2.	Total.
	Ft.	*in.*								
5	2		91.76	64.33	0.0264	0.58	81.52	....	....	100.51
6		1	87.17	61.02	.0177	.93	11.08	2.25	....	101.44
7		2	....	24.08	.0607	2.21	25.28	....	....	....
8	2	3	89.27	62.49	.0104	.32	8.87	....	....	98.47
9	2		69.81	48.87	.0279	.64	19.43	....	....	89.90
10		10	60.50	42.35	.0569	.53	22.41	....	....	83.49
11	1	2	61.06	42.74	.0663	.47	25.14	....	....	86.73
12		8	88.34	61.84	.0168	.64	10.54	....	....	99.53

The Olive ore was discovered at a point about 95 feet north by northeast of the working shaft. There is no surface showing and the ore is said to have been uncovered by accident in a shallow excavation. The first development was by means of an incline about 30 feet deep and of a southerly drift, which was afterwards connected with the vertical working shaft. The latter, which was started in the hanging wall, encountered the ore below the level of the drift mentioned above. It was carried down through and below the ore, and three crosscuts were run out to the ore.

The following notes by J. B. Dabney, former superintendent of the Olive mine, are furnished by Mr. N. J. Badu, of Llano:

The vein lies northeast and southwest. The ore was good on the first heading, but not so good as on the second, third, and fourth levels. On the fourth level the ore pinched to 2 feet. The heading on this level was carried 20 feet beyond the vein and then abandoned. Next an incline was driven to the vein which, as near as I can remember, was 8 feet wide. From the bottom of the incline the vein was opened to right and left.

The cross section of the mine given herewith (fig. 2) is adapted from a sketch by Mr. Dabney on the sheet bearing the notes already given. On his sketch he notes the thickness of the vein above the first level as 3 feet; between the first and second levels, 6 feet; between the third and fourth levels, 8 feet; at the fourth level, 2 feet; and at the bottom of the incline, 8 feet.

For the sketch plan of the mine workings here given the writer is indebted to Mr. Robert Linton, who secured it from mine records which passed through his hands during the summer of 1909.

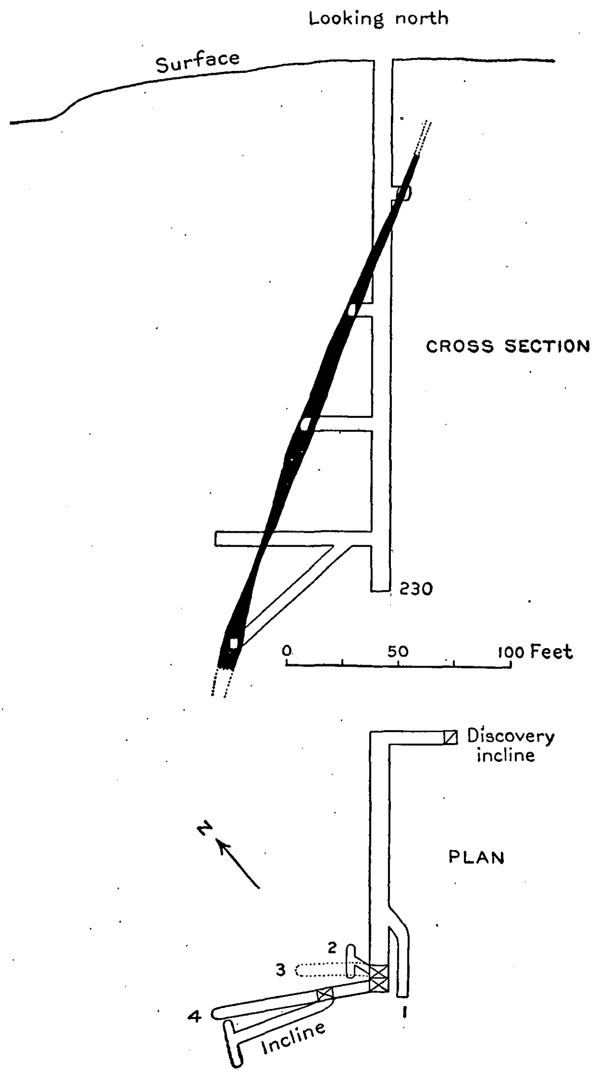


FIGURE 2.—Cross section and plan of Olive mine.

From the data at hand it may be concluded that the Olive ore body strikes approximately northeast and southwest and dips rather steeply toward the northwest and beneath Little Llano River. The relative positions of the mine levels and the apex of the vein at the discovery shaft suggest that the ore body may be a pod-shaped mass, plunging in a southerly direction, but it is not known that any horizontal limit of the ore was established at any point.

Observable relations at the Olive mine do not lead to any conclusion concerning the mode of origin to be assigned to the deposit. Lying at the edge of a great granite intrusion, the ore might have been segregated as an effect of igneous metamorphism. However, the material on the waste dump can not be regarded as in any way particularly characteristic of intense igneous metamorphism, the limestone and schist being quite like the general run of the rocks which compose the upper of the two sets of schist (Packsaddle schist) which have been delineated on the geologic map. The Olive deposit is one of two which may be assigned to this set of rocks without reservation.

It is suggested that magnetic observations might prove of practical value in any future exploration of the Olive ore body.

BADER TRACT.

By A. C. Spencer.

The property known as the Bader tract lies about 9 miles west of Llano and 9 miles south of the Iron Mountain mine. This parcel is adjoined upon the north by a tract known as the Otto, the east and west property line being somewhat less than 2 miles north of Llano River. Iron ore has been found at several places along a north by northwest trending zone about 500 feet in width and nearly 7,000 feet in length. A shaft in the extreme southwest corner of the Otto tract encountered magnetite, which represents the most northerly known extension of the Bader ore range. Farther northwest there is no trace of any exploratory work such as trenches, and careful search on the part of the geologists failed to reveal so much as a fragment of magnetite beyond the west line of the Otto tract. That the ore may continue in this direction is thought to be possible but improbable.

There is much more granite north of the Otto workings than on the Bader tract, and the metamorphic rocks are seriously broken and interrupted by the granite intrusions. This fact is shown in a very general way on the geologic map, though many slivers of schist are present in the areas which the map shows as granite. The impossibility of adequately representing the actual relations of the schists and the granites has been explained in former paragraphs.

No importance can be attached to any suggestion that might be made in the direction of correlating the Bader range with other occurrences of magnetite in Llano County. There is no adequate reason for regarding the range as in any way the extension of the Iron Mountain ore. Though the trend of the range would carry it to the ore on the Epperson tract 3 miles to the northwest, there is a wide area of intrusive granite north of the Bader, and beyond this intrusion structural trends are rather northerly than northwesterly.

A sketch map (fig. 3) has been prepared to show the general distribution of magnetite occurrences on the Bader and the adjacent tracts. Aside from very shallow pits or trenches at various points, the Bader range has been explored only in the vicinity of the northern end, where the original surface indications appear to have been the best. Here trenches and float ore extend for a total distance of 1,000 feet in a southerly direction from the Otto shaft. Two lines of outcrop about 80 feet apart are noted in the vicinity of the Bader incline.

South of the incline and about 110 feet distant an excavation in the lower ore layer shows 31 inches of fairly clean ore dipping about 30° NE. There is also a 5-inch rider lying 2 feet above the principal ore layer and separated from it by feldspathic gneiss. In an adjacent opening on the upper layer the grain or layering of the ore appears to be nearly horizontal.

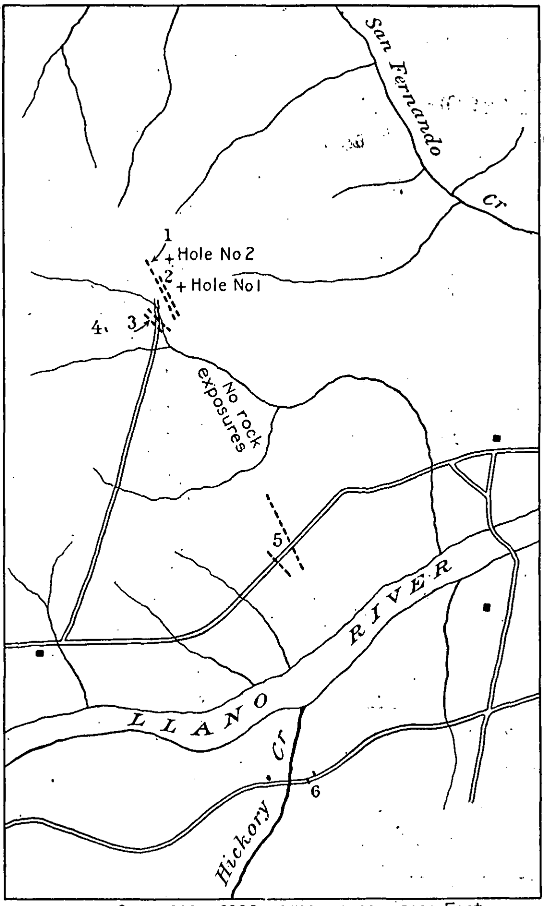


FIGURE 3.—Distribution of float and outcrops on Bader tract and vicinity. 1 Otto shaft; 2, Bader incline; 3, magnetite float; 4, barite-magnetite outcrop; 5, magnetite float and shallow pits; 6, Hickory Creek outcrops.

The Bader incline reveals two ore layers estimated to lie between 10 and 15 feet apart. The dip of these layers varies from 20° to 40°. The lower ore may be described as gneiss carrying thin and discontinuous layers of magnetite. This lean material is not over 16 inches in thickness. The incline follows the dip of this ore for about 25 feet to a point where the slope flattens so that the workings cut across the layering of the gneiss and encounter the upper ore bed. As exposed in the sides of the incline this second layer has a maximum thickness of 20 inches.

The dip length of the incline is estimated to be about 50 feet. All the ore on the dump is layered to a marked degree, much of it being sharply segregated into layers of more or less granular magnetite and layers of silicate minerals.

Standing on the surface one may judge that the lower of the two layers shown in the pits mentioned above is identical with the upper of the two opened by the incline, though this may not be affirmed. If this identification be correct there are at least three ore layers at this place, the lowermost being nowhere exposed at the surface. The approximate positions of the last two holes which have been drilled are given on the sketch map. No record of hole No. 1 is at hand. The following drill log is taken from a private report by E. V. D'Invilliers, who states that this record was furnished by G. M. Wakefield.

Copy of record of drill hole No. 2, Bader location, Llano County, Tex.

[Signed by Fred A. Wright, engineer in charge.]

	Ft.	in.
Stand pipe	1	6
Granite	301	6
Magnetite ore mixed	40	3
Granite	29	9
No core, probably ore	13	
Granite	27	
Chloritic rock and granite	6	
Ore	7	
Granite schist	13	
Granite	55	
Total drilled	494	

Angle of dip 29.5° E.
Strike of formation north-northwest and south-southeast.
Distance from cropping to point where drill was placed 600 feet.

Just where the wagon track from the south crosses the shallow valley southwest of the Bader shaft there is a heavy accumulation of magnetite float in solid pieces ranging up to 1 foot in diameter. This material, which is evidently derived from the veins that are in place on the hill slope to the east, is much more prominent than the float occurring along the veins themselves.

West of the wagon track two lines of magnetite débris may be made out, though it is impossible to trace these lines for any great distance. No trenching has been done at this place. About 1,000 feet west of the wagon track shown on the sketch map (fig. 3) and just south of an east-west wagon road long abandoned is a small outcrop of magnetite mixed with barite ($BaSO_4$). Only a few square inches of this material are exposed and its relations are unknown.

Along what may be called the main trend some float ore may be found to a distance of 500 feet southeast of the Bader shaft, where granitic material appears to interrupt the continuity of the ore. Though gneiss is present north and east of the small stream beyond the granite, no ore fragments are found in the soil. Farther to the southeast and across the stream there are no rock exposures for a distance of 3,000 feet, though a few small pieces of magnetite were noted northwest of the tributary plotted on the sketch map. South of this tributary a series of pits and small pieces of float from place to place show the presence of magnetite for a distance of 2,800 feet along a southeast trend in line with the northern ore occurrences. Also opposite the south end of this line of showings a second line of ore indications is present. Along this general zone the soil is much redder than elsewhere in the neighborhood.

On the sketch map (fig. 3) two occurrences of magnetite on the Mason-Llano road south of Llano River and east of Hickory Creek are indicated. Fragments of ore lying on the surface are massive and pure, but the size of the ore bodies in place can not be judged, as no work has been done upon them.

The ore occurrences at the Hickory Creek locality lie at the end of a curving tongue of more or less hornblendic gneiss inclosed by massive granite, and granite exposed along the river separates the Hickory Creek ore from the nearest exposures of ore on the Bader tract.

No definite conclusion concerning the possibilities of the Bader tract can be offered. Compared with the great cropping and the abundant float at Iron Mountain the surface showings would seem to be unimportant. It is believed, however, that caution should be exercised in accepting an unfavorable point of view in cases of the sort here presented, since experience in other districts has shown that the importance of magnetite ore bodies in gneisses may be seriously misjudged from surface indications. It is suggested that the Bader tract is worthy of more extensive exploration than it has received up to the present time, and particularly that preliminary work in this direction should include a magnetic survey of the range which, as already stated, has a length of about 7,000 feet. It is thought that dip-needle observations might give indications of ore in the covered territory between the two ends of the Bader range.

The following are analyses of the ore from the Bader property:

Analyses of iron ore from the Bader property, Llano County, Tex.

	Metallic iron.	Phosphorus.	Silica.	Titanic acid.	Specific gravity.
1	64.150	0.014	72.80	0.385	4.577
2	52.550	.019	19.225	.310	
3	65.800	.046			

1. General sample of outcrop ore (Mr. McCreath). Report of E. V. D'Invilliers.
2. Sample representing 4 feet 10 inches of the mixed lens ore from the drill core on the Otto property. Report of E. V. D'Invilliers.
3. Bader tract. Report of E. V. D'Invilliers; by Rattle & Nye, of Cleveland, Ohio.

IRON MOUNTAIN.

By Sidney Paige.

The Iron Mountain prospect is located 12 miles northwest of the town of Llano and one mile northwest of Valley Spring post office. The property consists of 640 acres and is owned by Robert H. Downman, of New Orleans, La.

The ore body caps a low mound slightly above the elevation of the surrounding country, and trends about N. 60° W. in a gently curving line. The surface outcrop has a length of about 114 feet and a width of 22 feet at its center. It is slightly narrower at the northwest end and narrows down to about 6 feet at the southeast end. (See fig. 4.) A granite intrusion cuts across the mass at the northwest end, appar-

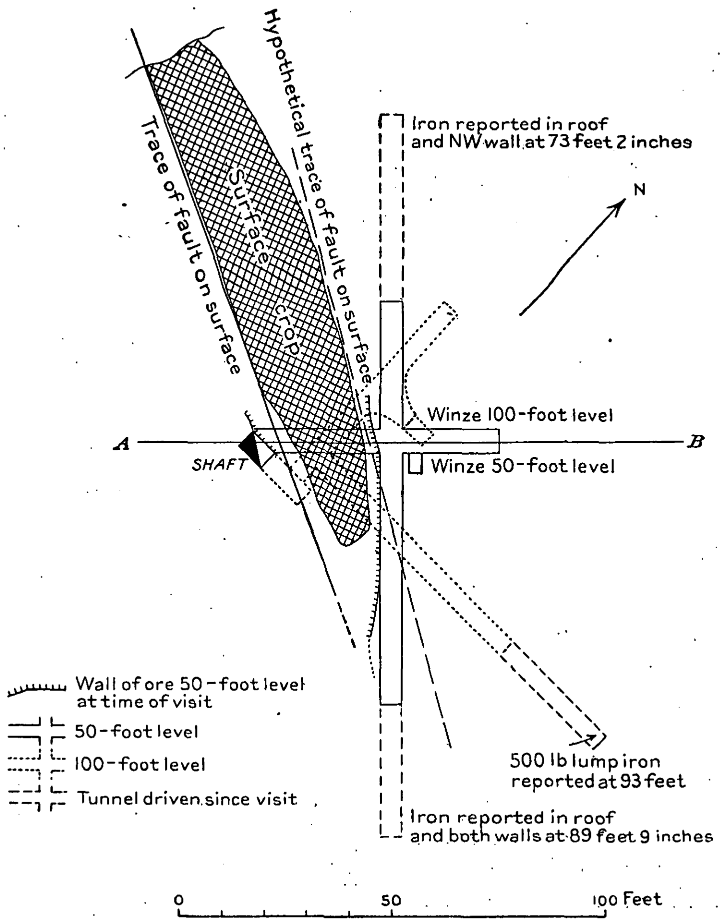


FIGURE 4.—Surface crop and underground workings at Iron Mountain prospect.

ently cutting off the ore. Covered surface prevents observations on the southeast end.

The ore body as revealed at the surface is a nearly vertical mass of very pure magnetite. Along its south side schists are exposed in several small cuts. They strike northwest with the ore, but in dip do not accord with the dip of the mass. (See figs. 4 and 5.) On the north side a gneissoid rock of granitic type forms the wall. It is believed to be intrusive into the ore, but is an older intrusion than that of the granite which cuts across the northwest end. Unfortunately the surface cover has rendered the exact surface relations of the ore body obscure; also the complex intrusion of granite into the schists, a condition described in an earlier part of the report, has at this locality obscured the original relations of the ore to the inclosing rock.

Both northwest and southeast of the ore body the surface is covered with soil and only occasional outcrops of weathered material may be seen. About 450 feet northwest a small outcrop of iron in schist was noted; granite, gneissoid granite, and schist are, however, evidently present in a complex mixture. Float ore can be found both northwest and southwest of the crop, but much of this in the near vicinity of the ore mass is evidently derived from it and has during erosion been carried to its present position. Some float ore derived from the overlying Cambrian sandstone and occasionally carrying fossils must not be confused with the magnetite float of the pre-Cambrian ores.

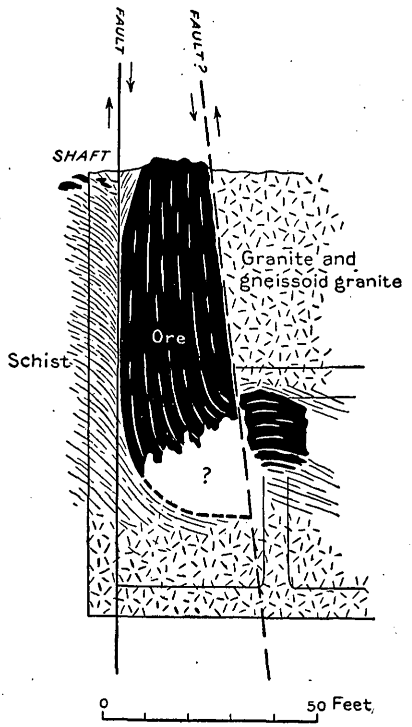


FIGURE 5.—Vertical section of ore body at Iron Mountain prospect.

A study of the plan and sections (figs. 4 and 5) will show clearly what is known of the structure of the body as revealed by developments. A shaft was sunk near the southwest wall of the ore body. A crosscut has been driven at the 50-foot level, showing 25 feet of solid ore. This crosscut was continued 54 feet. After passing through the 25 feet of ore a narrow mass of granitic schistose material was encountered, after which ore was again found. This second body was confined largely to the floor, and a winze was sunk in ore. (See fig. 5.)

On the 50-foot level two drifts were driven. (See fig. 4.) At the time of the writer's visit the northwest drift had been opened 30 feet, with no solid ore in any part of the working. Since that time the drift is reported to have been driven to 73 feet, with ore in the roof and northwest wall, at this point.

The southeast drift at the time of the writer's visit had been opened 60 feet, with solid ore on the south wall to a point 30 feet ± from the center of the crosscut. Since that time the drift is reported to have been driven to a point 89 feet 9 inches from the center of the crosscut, and to have had ore on the south wall the entire distance; and at that point is reported to have ore on both walls and in the roof.

At the 100-foot level crosscuts and drifts were run, as shown on the plan (fig. 4), but ore was not encountered under the vertical mass. The country rock is a mixture of schist and granite. A raise was made from the 100-foot level to connect with the winze, and revealed 16 feet of ore in a nearly flat-lying body of schist, grading downward into lean ore and granite. The schists containing the ore dipped at a low angle to the east.

The crosscut shown on the 100-foot level was driven 55 feet, but encountered no ore. At the time of the writer's visit the drift on the 100-foot level had been driven 62 feet, but no ore found. Since that time this drift is reported to have been driven to a point 93 feet from the center of the crosscut, and to have found at that point a lump of disconnected ore weighing about 500 pounds.

The relations described above may be hypothetically explained as follows: The vertical mass of iron ore is a layered body with the layering vertical. It is believed that formerly it occupied a position in accord with the schists, as does the mass exposed in the winze. Faulting is believed to have taken place on both south and north sides, though evidence for the latter is not as strong as for the former. (See fig. 5.) Several facts point to this conclusion. The schists on the south side dip sharply downward at their contact with the iron, suggesting fault drag, and a band of soft chlorite-like material about 2 inches wide is found at the contact. The drag was observed both at the surface and at the 50-foot level. The gouge material was not so well developed at this level. From the very fact also that the layering of the ores of the region has

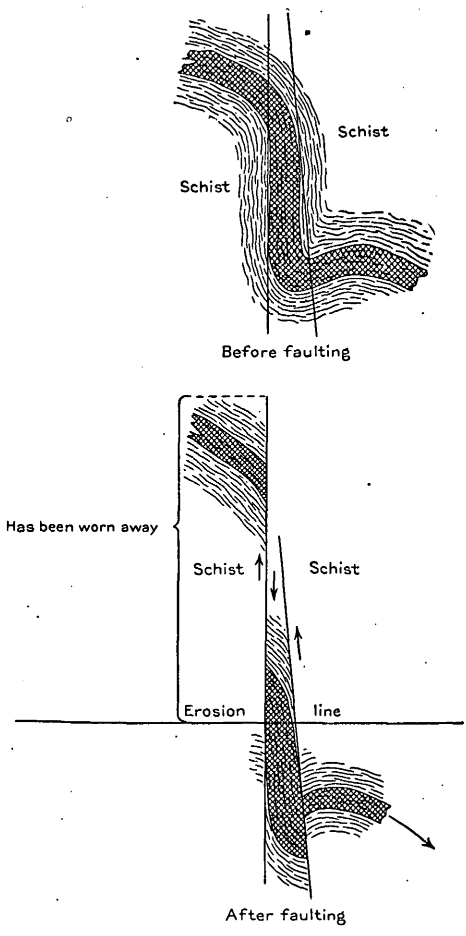


FIGURE 6.—Ideal section showing relation of faulting to folding and erosion.

elsewhere been invariably parallel to the schistosity the discordance here is excellent evidence of faulting. At the 50-foot level on the north side, there is also a suggestion of faulting.

The direction and dip of these hypothetical faults may be somewhat different from those indicated by the plan and section, but the structural results of their presence are believed to be as presented.

The vertical iron mass, therefore, is on the downthrow side of both faults No. 1 and No. 2. The fault plane was for a distance parallel to the limb of a fold and accounts for the vertical position of the large iron mass and its peculiar relation to the flat iron bed. The difference in thickness between the flat bed and the vertical bed may be

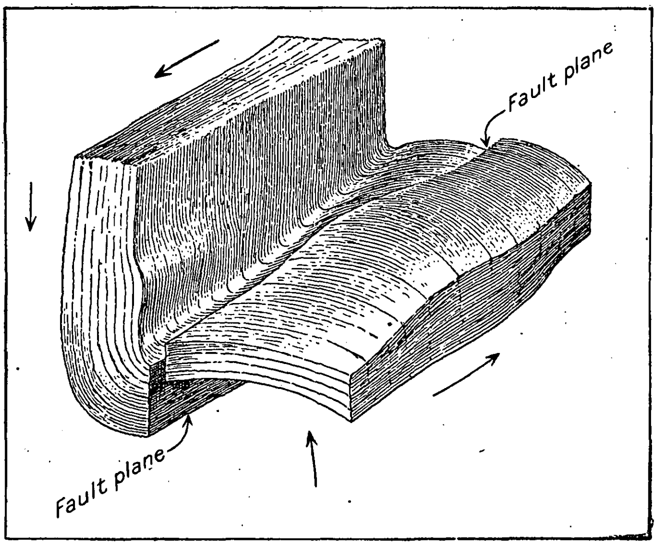


FIGURE 7.—Stereogram illustrating condition which would exist if the north fault passed vertically but at an angle to the strike of the fold.

accounted for by supposing a certain amount of movement to have taken place in a horizontal direction, bringing a thinner portion of the layer against a thicker portion. Intrusion of granite probably preceded this faulting. There is some reason to believe, however, that the fault on the north side was accompanied or followed by granite intrusion. Figure 6 is an ideal sketch of the probable conditions before and after faulting, and figure 7 is a stereogram showing the relation which might exist if the north fault plane passed at an angle to the strike of the bed.

Besides the development by shaft and tunnels above described the property has been prospected by several diamond-drill holes. They will be described in the order of their drilling.

The first hole, located 200 feet S. 57° W. of the shaft and inclined 37° toward it, was drilled to a depth of 169 feet. Two feet of ore was reported at 108 feet. This hole, to have reached the vertical plane of the ore body, should have been drilled 250 feet. It would have cut the plane at a depth of 150 feet.

The second hole, located 488 feet S. 72° E. from the northeast corner of the shaft, was drilled S. 4° W. at an angle of 43°. A foot of lean ore was struck at 18 feet. The drill jammed at 225 feet. Another hole at this same locality was drilled 290 feet S. 77° W. with a dip of 49°. Its record follows:

Record of hole drilled in Iron Mountain iron property, Llano County, Tex.

	Ft.	in.		Ft.	in.
Lean ore	14	11	to	16	..
Pink granite	16	..	to	25	..
Decomposed material	25	..	to	25	8
Granite	25	8	to	31	4
Black schist, little magnetite	31	4	to	35	8
Granite	35	8	to	198	1
Black schist and granite	198	1	to	199	..
Granite	199	..	to	215	5
Ore	215	5	to	216	8

Hole 253 feet deep on October 8, 1909, without commercial ore.

Next, a hole was drilled 500 feet northeast of the shaft. It was put down 500 feet. No ore was struck.

Then a hole was drilled on this same line, but only 216 feet from the shaft. It dipped 60° toward the shaft and was drilled to a depth of 606 feet. No ore was struck.

A hole approximately 1,400 feet northeast of the shaft and east of Johnson Creek was down 600 feet at the end of March, 1909, without striking commercial ore. It was drilled toward the shaft at an angle of 45°.

Analyses of ore from Iron Mountain, Llano County, Tex.

	Metallic iron.	Phosphorus.	Silica.	Specific gravity.
1	65.40	0.069	4.695	4.724
2	67.60	.093	4.690	4.677
3	65.45	.061	....	....
4	66.53	Not det.	....	....
5	64.90	Not det.	....	....
6	58.87	Not det.	....	....
7	61.45	Not det.	....	....
8	67.70	0.045	....	....
9	66.10	.034	....	....
10 [a]	63.23	.008	4.70	....
11 [b]	66.82	Trace.	4.65	....
12 [c]	66.30	0.146	6.30	....

[a] Sulphur, trace. [b] Sulphur, 0.30. [c] Sulphur, 0.04.

1. General sample of surface ore. Private report of E. V. D'Invilliers.
2. Sample 125 pieces of ore at depth of 50 feet in shaft. Report of E. V. D'Invilliers.
3. Surface ore clippings large bowlders (sampled by representative of McCreath). Report of E. V. D'Invilliers.
4. Surface ore main exposure (sampled by representative of McCreath, 1889). Report of D'Invilliers.
5. From shaft 8 feet deep, south side main exposure. (McCreath.) Report of D'Invilliers.
6. From shaft 12 feet deep, north side of main exposure, lower 8 feet of ore. (McCreath.) Report of D'Invilliers.
7. 150 yards east of main exposure, from cut 4 feet deep. (McCreath.) Report of D'Invilliers.
8. From shaft at main exposure, ore from lower depth than 5 or 6, chiefly magnetic. Report of D'Invilliers.
9. Iron Mountain tract, sampled and analyzed by Rattle & Nye. Report of D'Invilliers.
10. 50-foot level. Iron Mountain mine; taken by Robert Linton, of Atwater, Linton & Atwater, mining engineers, for Johnston, Elliot & Co., of Dallas, Tex.
11. 50-foot level, Iron Mountain mine; taken by Robert Linton, for Johnston, Elliot & Co., of Dallas, Tex.
12. 7 feet of new ore on east wall of winze, 48-foot level, sampled by William B. Phillips, Rinaldo Williams, analytical chemist, Birmingham, Ala.

It would seem advisable to confine prospecting largely to the north side of the line of strike of the ore body. If it can be shown that the flat bed has considerable extension in a northwest-southeast direction and also on the dip, a large body of ore may be present. If underground work is to be continued it would seem advisable to make a raise from the end of the east drift on the 100-foot level, at the point where iron was struck, to discover the presence or absence of the bed. A magnetic survey of the territory adjacent to the ore body would be of value.

KEYSER-JONES TRACT.

By A. C. Spencer.

In Mason County, about 4½ miles south and somewhat west of Castell, magnetite float and ore outcrops occur at several places within the drainage basin of Keyser Creek, otherwise known as Old Place Creek. The relative locations are shown on the accompanying sketch map (fig. 8.) The most noteworthy showing is on a subdivision of the tract belonging to Judge J. H. Jones, of Mason. Here massive magnetite outcrops along a low hillock for a total distance of 75 feet, the maximum observed width of ore being about 4 feet. The ore is distinctly layered in its make-up and is rather siliceous. The trend of the cropping is about N. 45° W. No rocks are exposed within several hundred feet except at a point 100 feet southeast of the ore where micaceous gneiss was noted. About a quarter of a mile northwest along the general strike of the ore a low hill is formed of hornblende schist. If the outcrop at Iron Mountain be excepted, this is the largest surface showing of magnetic iron ore in the Llano district. At present, however, there would be no adequate inducement to warrant the expense of drilling at this point, though in the future such exploration might be advisable.

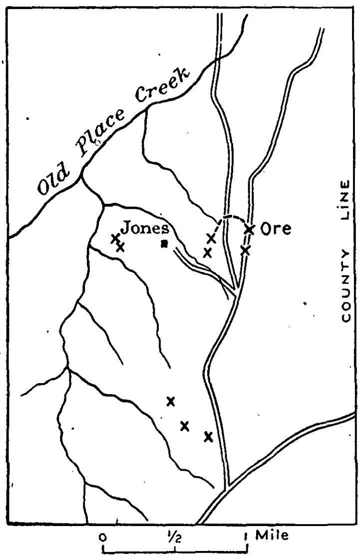


FIGURE 8.—Magnetite prospects on Keyser-Jones tract, southwest of Castell.

A second fairly good showing of magnetite may be seen on a hilltop somewhat less than half a mile east and a little south of Jones's house above the tank (stock reservoir). This ore is accompanied by red-weathering gneiss or schist, a curving band of which may be traced to the northeast and east across the two roads shown on the sketch map. Magnetite float may be found from place to place along this red band, but one does not gain the impression that excavation is likely to reveal any body of ore.

A mile or more farther south minor amounts of magnetite may be found in association with highly metamorphic schists, and in this case outcrops are adequate for a decision that no deposits of economic importance are to be expected. On the whole the possibilities of the tract seem to depend upon the Jones outcrop.

GOODWIN PROSPECT.

By Sidney Paige.

About 2½ miles S. 55° W. of Babyhead post office, small outcrops of iron ore may be seen on Mr. Goodwin's place. The rocks are believed to belong to the lighter (lower) gneiss and schist series (Valley Spring gneiss), and are, as is almost invariably the case, more or less intruded by granite.

A short distance north of Mr. Goodwin's house a small trench reveals a foot or two of lean hematite ore banded with quartz and feldspar, the latter minerals forming a very fine sugar-grained aggregate. The individual thin iron layers swell and pinch in an irregular manner. What appears to be secondary quartz is introduced in bands along the schistosity in considerable abundance. The hematite is feebly magnetic, and octahedral faces can be detected among the crystals. The mineral is probably martite, a pseudomorph of magnetite.

Farther west over the ridge may be seen white schists of very even, fine, sugar-grained texture, carrying finely disseminated hematite in minute grains. Abundant orthoclase feldspar, with quartz and muscovite, make up the rock, which is believed to be a metamorphic sediment.

About 1,000 feet S. 10° E. from the house a shallow pit in the schists reveals a small bed of magnetite lying nearly flat and striking nearly east and west. About 9 or 10 inches of ore is exposed for 50 feet. The dip is to the south, more pronouncedly so at the west end. Considerable garnet and abundant quartz with some pyrite are the gangue minerals.

Less than 1,000 feet west of the locality and S. 37° W. from the house just described, a small pit shows an apparently vertical bed of magnetite and quartz with 1 or 2 feet of lean ore. This deposit can be traced for 100 feet in the trend of the ridge. Locally there is an indication of about 5 feet of ore. The north end of the outcrop is apparently cut off by a swing in the beds of pink schist.

No encouragement can be given that these deposits have any commercial value.

PARKHILL PROSPECT.

By Sidney Paige.

About 1 mile east by south of the summit of Horse Mountain a small quantity of ore may be seen about 2,300 feet north of and between the forks of two creeks. The bed strikes N. 55° W., dips 20° S., and is about 2 feet thick. The magnetite is admixed with quartz and red feldspar, and the pit reveals decided irregularity in thickness. The deposit does not seem worthy of further prospecting at the present time.

About 1 mile northwest of Miller Mountain and east of the main north and south Babyhead road, a small trench shows a foot or a foot and a half of lean ore in schist. The country rock trends about N. 30° W. and dips south. This opening and another a short distance northwest of it do not offer any inducement to further prospecting.

IRON DEPOSITS NEAR CASTELL.

By A. C. Spencer.

Castell post office is situated on Llano River 18 miles west of Llano. North of the river within the radius of a few miles there are showings of iron ore at several places which may be described in two groups—the Deep Creek deposits and the Elm Creek deposits. The ores of the Deep Creek and Elm Creek drainage basins are regarded as of no probable value, because the deposits, though extensive, are both lean and thin. At the same time by way of caution against absolute disparagement it is to be noted that such development work as has been done is negligible, so that the impressions gained by the geologists have been derived from very imperfect surface showings. With due allowance made for this condition, the opinion may be expressed that although future work may lead to the discovery of ore masses of sufficiently high grade to warrant mining operations, such ore bodies will not prove to be of large size, so that it can not be expected that any large mines will ever be developed in the combined field of Deep and Elm creeks.

DEEP CREEK ORES.

Deep Creek (fig. 9) joins Llano River about 1½ miles above the Castell ford. From the river the creek valley extends a mile west to an elbow, above which it has a general north-south course for somewhat more than a mile before turning again to the west about one-fourth mile north of the Mason stage road.

The magnetite deposits occur in the Deep Creek valley near the lower elbow and again north of the Mason road.

The magnetite showings near the elbow of Deep Creek are disposed along a line about a mile in length. Downstream from the bend the presence of a little ore is noted on the north bank of the creek, and toward the southeast heavy float is noted at two points. At these localities the ore is massive and nearly pure, the only minerals present besides magnetite being a little feldspar and mica. The manner of occurrence is not evident, but the three localities lie along a line trending northwest and crossing the creek both below and above the elbow. Opposite the elbow none is noted, but west of the creek it again appears and abundant float may be traced along the hill slope

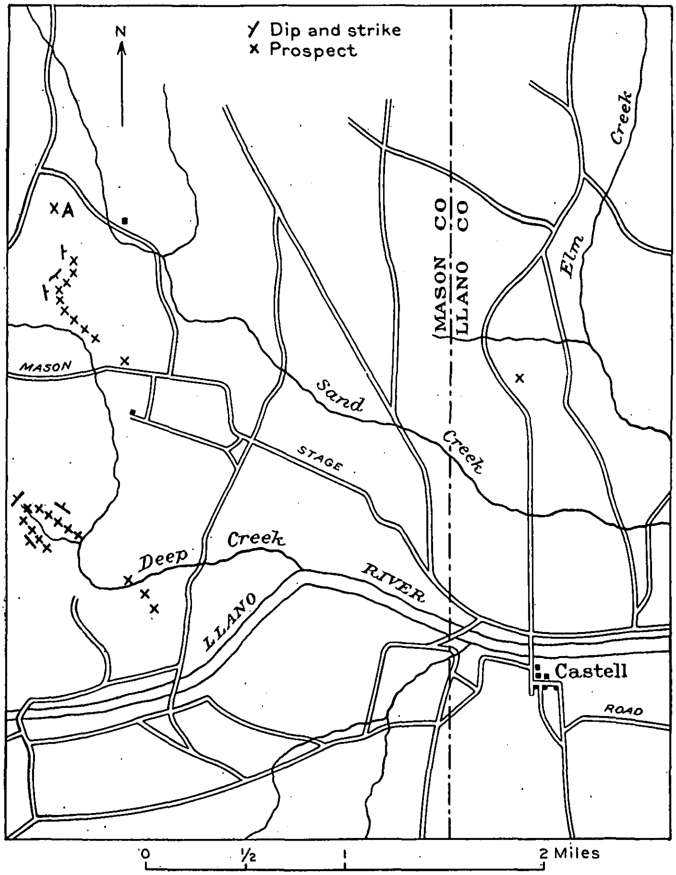


FIGURE 9.—Distribution of magnetite near Deep Creek.

north of a small drain. About 1,800 feet above the mouth of this drain the line of the ore crosses the shallow valley and turns back upon itself. The hook-shaped outcrop may be taken as evidence that the ore occurs as a conformable layer in the local schists and that the rocks are here thrown into a low arch or anticline.

A few outcrops of feldspathic schist in the neighborhood exhibit strikes and dips which bear out this impression of structure.

Though the exposures of ore are very inadequate, they serve to convey the impression that the iron mineral may be distributed through 3 or 4 feet of rock, and that the reef is made up of layers of rock and ore from 6 to 10 inches thick. Some of the component layers are high-grade ore; others are platy aggregates of magnetite and siliceous minerals; still others carry but little iron.

North of the Mason road, east and north of Deep Creek, magnetite is found at several points. A short distance north of the road a few isolated fragments of good ore were noted. Then a quarter of a mile or so to the northwest there has been some prospecting. Natural outcrops, shallow pits, and float lead to the recognition of a curving magnetite range perhaps half a mile in length (fig. 9). There are evidently two parallel reefs along part of the range which are estimated to be less than 20 feet apart, measured across the layering. The curving outcrop and observed dips show that the ore and associated schists are gently folded. The dips are low to the east, or, locally at the turn, approximately south.

The ore appears to be rather lean, much of it showing garnet mixed with magnetite. Specimens were seen which are composed of alternate thin layers of fairly clean magnetite and of quartz. The garnet-bearing reefs vary in thickness from 18 inches to 3 feet.

The ore reefs are by no means continuous along the strike. Part, but certainly not all, of the observed discontinuity is due to the presence of irregular intrusive masses of granite, both fine and coarse grained varieties being present.

North of the occurrences mentioned in the foregoing paragraph, at the locality marked A on the sketch map, figure 9, there is a rather noteworthy showing of magnetite float. In addition to good-sized chunks of pure ore there is an interesting exhibition of coarsely crystalline material composed of quartz, pink feldspar, and magnetite in various proportions. This material is not exposed in place, but it has every appearance of being pegmatite (extremely coarse granite) of very siliceous and ferruginous composition, and is therefore believed to be intrusive in its nature. Magnetite-bearing pegmatites were noted in small amounts at many places in the Llano district, but no other instance of any great amount of the mineral in this association was seen. Though the ore at this particular place is regarded as almost certainly of igneous origin, it is not regarded as possible to use this conclusion in any definite way in working out the general origin of the iron ores of the district.

If the layered ores of Deep Creek valley are not merely ferruginous strata which have suffered simple metamorphism in company with sedimentary beds originally associated with them, as suggested by Mr. Paige elsewhere in this report, they were formed by some process the nature of which can not be stated—some process, as yet unrecognized, involving secondary rather than primary or original segregation.

ELM CREEK ORES.

The distribution of magnetite showings northeast and east of Castell is given on the sketch map (fig. 10). It should be noted that the area shown on this map overlaps that of the Deep Creek sketch map (fig. 9).

Between the southward-flowing portion of Elm Creek and the next considerable valley to the east the land rises to form a rolling plateau. Along the west edge of this plateau, just at the break to the Elm Creek slope, or locally somewhat down this slope, an iron-bearing reef may

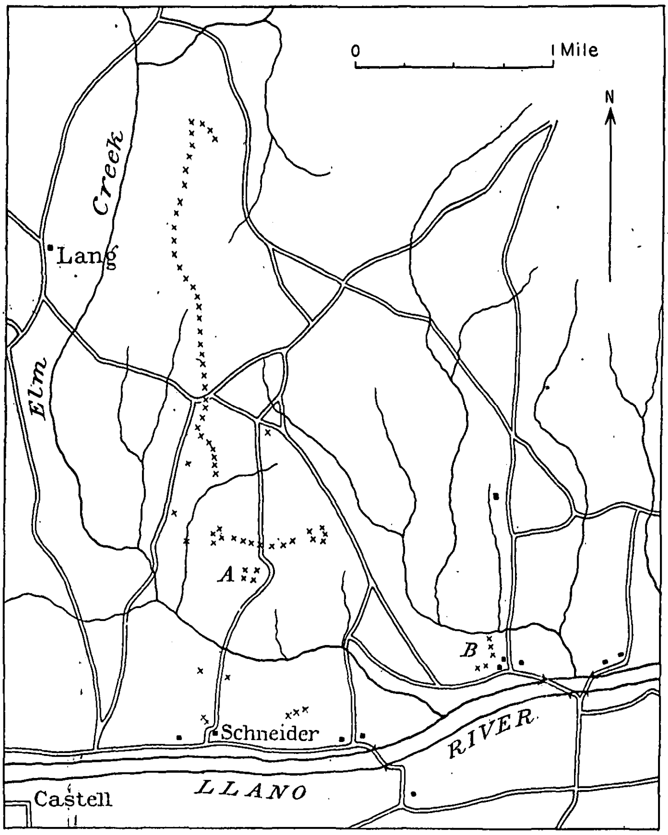


FIGURE 10.—Distribution of magnetite near Elm Creek, northeast of Castell. *A*, Area shown in figure 11; *B*; area shown in figure 12.

be followed by means of float and occasional outcrops for a distance of 1½ miles. The trend of this reef is nearly north-south, the north end (in the form of a hook) being situated 1 mile northeast of the Lang house. Though there is no difficulty in following the lead by means of the surface showings, the ore is seen not to be really continuous, being interlayered with the associated feldspathic gneisses. Locally there are evidences of two ore layers, neither one of which can be more than 2 feet thick. Dips are uniformly low to the east. All of the ore is lean in appearance, and scarcely any of it would analyze above 30 per cent of iron.

The south end of this line of croppings is north of a small drain in the northeast corner of Dr. Donges's pasture, and for a distance of about 1,000 feet to the south along this trend there are no signs of magnetite. West of the trend, however, minor amounts of float were noted at two points, and a 6-inch seam of ore outcrops in the stream bank at a point indicated on the sketch map (fig. 10). In the vicinity of this stream the rocks appear to be greatly disturbed, as there are great variations in strikes and dips from place to place. At the 6-inch capping noted above the dip is about 45° NNE.

Directly east of the exposure last mentioned and west of the Donges-Ebers property line, on the edge of the plateau, a flat-lying layer of lean ore about 2 feet thick has been stripped of its original cover over an area of perhaps 250 square feet. This flat constitutes the western limit of a line of outcrops extending in an easterly direction along the southern break of the plateau for a distance of approximately 3,000 feet. The western exposure lies due south of the termination of the north-south line of croppings already described, the barren interval between being about 1,200 feet.

Locally along this east-west trend there are indications of magnetite in two layers, perhaps 20 feet apart, but usually there is only one layer. At the east end of the line of outcrops the ore layer is complexly folded and also disrupted by granite intrusions. Along the cropping the dip is to the north at a very low angle.

Wherever exposed, the ore is lean in appearance, because of the amount of quartz and potash feldspar which it contains. Its thickness was nowhere observed to be greater than 2 feet, and nearly everywhere it is less than 18 inches. The associated rocks are feldspar gneisses and granite. At many points thin sill-like masses of coarse granite (pegmatite) lie under the ore layer, but no genetic relation may be made out between this rock and the magnetite.

Four samples collected to represent the ore of this eastward-trending outcrop may be taken as typical of the ores of the Elm Creek occurrences, since there is very close resemblance in the material observed in all of the several localities. Samples 1 to 3 came from near the east end of the line of outcrops and sample 4 from a point near where the reef crosses the wagon track.

Analyses of Elm Creek iron ores, Llano County, Tex.

[R. C. Wells, analyst, United States Geological Survey.]

	1.	2.	3.	4.
Fe	25.68	26.04	14.60	24.70
SiO_2	54.56	52.23	62.53	55.36
Mn	Trace.	.06	None.	Trace.
P	.04	.05	.01	.05
S	.06	.10	.04	.07
TiO_2	.10	.20	.11	.10

In the northern part of Christian Schneider's pasture, about a quarter of a mile south of the east-west ore belt described above, similar lean material occurs within an area about half an acre in extent. The ore evidently occurs as a layered deposit thrown into shallow folds, though the rock layers are not exposed with sufficient completeness to clearly reveal the structural details (figs. 10 and 11). Considerable intrusive granite is noted within the area, including the different outcrops of ore.

The thickness of ore observed varies from 15 inches to 3 feet.

South of Elm Creek ore is to be observed at four points. Near the north side of Schneider's horse pasture is a single outcrop of an ore

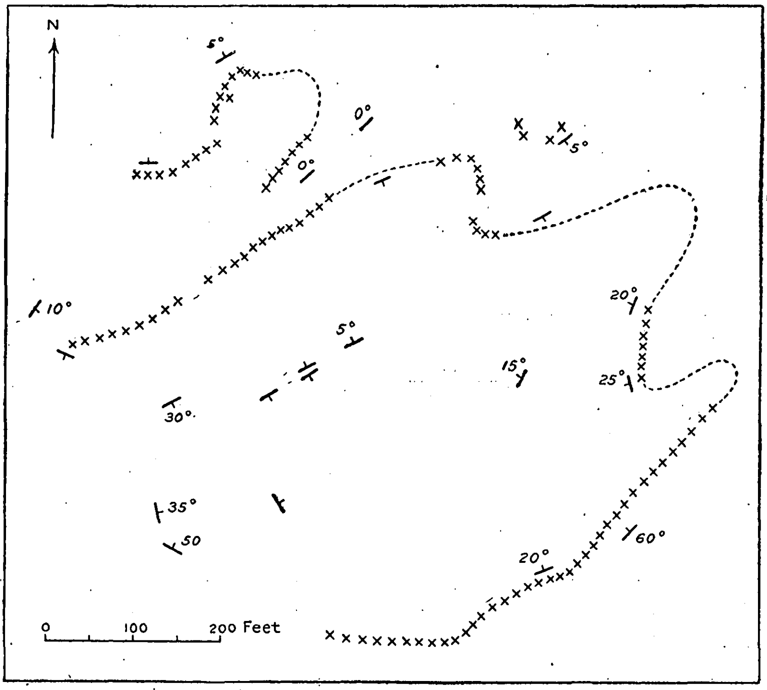


FIGURE 11.—Distribution of magnetite showings in northern part of Schneider's pasture (A, fig. 10).

layer 2 feet thick. East of this a small amount of float is encountered along the wagon track, and as the local trends are east and west it may be suggested that prospecting would reveal a more or less continuous lead between these two points. A short distance north of the Schneider house the presence of float suggests the existence of a nearly east and west trending ore layer extending west of the wagon track for perhaps 200 feet. The fourth locality south of Elm Creek is on the hilltop between the creek and the river, partly within the Schneider tract, but extending across the east boundary line. The rocks are layered feldspathic schists, weathering of which produces a very red soil. The ore, which is interlayered with the schist, may be seen to have a local thickness of 18 inches, though it is thinner in places. A sample of the best-looking material in sight gave the following analysis:

Analysis of Elm Creek iron ore, Llano County, Tex.

Iron	35.40
Silica	34.68
Manganese	Trace.
Phosphorus	.03
Sulphur	.04
Titanium oxide	.15

The ore layer may be traced by means of outcrops and float for a distance of approximately 600 feet along a general northeast course, but the stronger showings are confined to the southwest part of the area of outcrop. Here the ore and the associated rocks are evidently folded to a considerable degree, and possibly have been duplicated by dislocation.

About 2 miles east of Castell and 1 mile east of the locality described in the foregoing paragraph magnetite is found in two places about 1,000 feet apart. (See figs. 10 and 12.)

On the north the ore may be traced along a low ridge in a southerly direction for a distance of 825 feet. The reef as seen in natural exposures, no trenching having been done, may have a maximum thickness somewhat in excess of 6 feet, though throughout much of its length it is almost certainly thinner. No sample was analyzed, but from the general nature of the material it can hardly carry above 35 to 40 per cent of iron. The better portions of the ore closely resemble lean portions of the Iron Mountain ore. The reef is cut across by two granite dikes 30 and 50 feet wide. The dip of the ore was not satisfactorily determined, though it is probably low toward the east.

South from the last outcrop is a belt of red soil within which, at a distance of 930 feet, strong magnetite float again appears. Near by is an outcrop of lean ore dipping about 10° E. From this outcrop there are almost continuous showings along a curving zone for a distance of 400 feet or more. Beyond where the zone turns from south to west the ore lies nearly flat and is obscurely exposed for a width of about 50 feet. The material is of very lean appearance. It can hardly be more than 3 feet thick and is probably thinner.

LIVELY TRACT.

By A. C. Spencer.

The Lively property lies somewhat more than 1 mile southeast of Iron Mountain and three-fourths of a mile southwest of Valley Spring. There has been no development, and the showing is confined to magnetite float in the wagon road northeast of Johnson Creek. The position of this locality is near a line joining the ore at

Iron Mountain to the northwest and the Becton ore 4 miles to the southeast. Although the three localities are thus in alignment there is no adequate basis for the suggestion of any connection between the several deposits or for any expectation that intermediate deposits are likely to be discovered.

Between the Lively ore and Iron Mountain the ancient gneisses are buried beneath Cambrian sandstone, the northern edge of an east-west band of this rock being situated about 1,000 feet southeast of the Iron Mountain shaft.

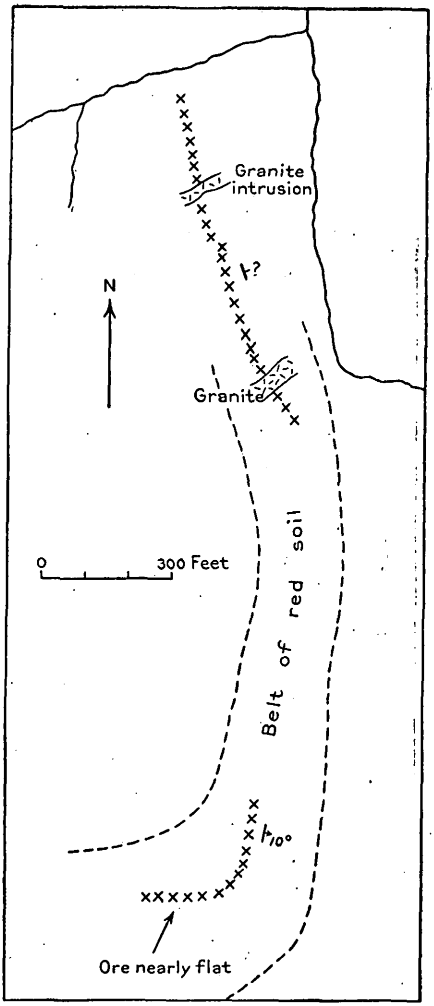


FIGURE 12.—Distribution of magnetite 2 miles east of Castell (*B*, fig. 10).

SECTION THIRTEEN AND VICINITY.

By A. C. SPENCER.

The tract of 640 acres known as H. and G. N. Section Thirteen lies about 4 miles south of the Iron Mountain property, on the southwest side of San Fernando Creek, at the mouth of Willow Creek. Magnetite has been found at several places on this tract and at several localities in the neighborhood on both sides of San Fernando Creek. The distribution of these showings is indicated on the accompanying sketch map (fig. 13).

There has been some prospecting south of the east-west road leading to Epperson's house, about 2 miles east of San Fernando Creek, and east of Epperson's boundary line. The old trenches are so badly filled that they afford no indication of what may have been found, and all that can be seen at present is rather sparse float of magnetite in small pieces. This float may be found at intervals for about 400 feet along a line trending a little west of north.

Three-quarters of a mile southeast of Epperson's house, where the road crosses a small ravine, heavy float of magnetite in solid chunks is noted. This float may be traced to a small outcrop near by, but nothing may be said of the prospects of this occurrence until some development work has been done. The ore closely resembles the material on the surface at the Iron Mountain mine.

About $1\frac{1}{2}$ miles southwest of the locality mentioned in the foregoing paragraph and half a mile south of the Otto house chunks of solid magnetite a pound or more in weight were noted in the wash of a small drain. Though hornblende gneisses outcrop in the vicinity, the ground is largely covered by rock waste, so that no suggestion is warranted as to where this ore would be found in place. East and south of this locality granite is very much in evidence, though as noted in the description of the Bader tract, slivers of gneiss are

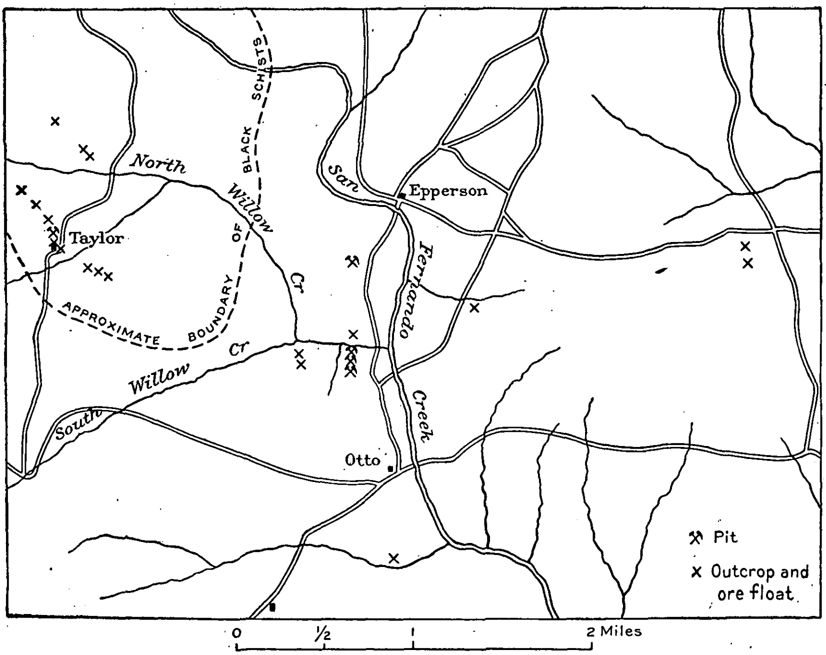


FIGURE 13.—Magnetite prospects in H. & G. N. Section Thirteen.

included in the area northwest of the Bader workings. Careful search in this interval of 2 miles failed to reveal any iron-ore float.

West of San Fernando, in section 13, magnetite has been discovered at three localities, the relative positions of which are roughly indicated on the sketch map. The presence of float ore led to the digging of several pits, some of which are still in such condition as to show that the magnetite occurs in gneiss. The ore and the country rock are distinctly layered, with dips toward the east. A study of the southeasterly pits suggests the presence of at least two leads somewhat less than 100 feet apart, trending a few points east of north.

Fairly abundant float may be found for a distance of about 600 feet along this zone, and three pits have been dug. On the south an opening 8 feet deep has exposed 1 foot of solid ore dipping east with a granite footwall. At a depth of 3 feet the granite cuts off the ore along a flat contact.

A hole 6 feet deep situated somewhat east of the last-mentioned shows 7 feet of layered material-carrying ore. The strike is N. 10° E. and the dip about 25° E. The lead is complex, being made up of two fairly solid layers of ore separated by light-colored granitic rock carrying a minor amount of magnetite. The upper ore layer is from 10 to 14 inches thick and the lower layer about 2 feet thick. The immediate footwall is whitish granite gneiss about 1 foot thick, and below this is hornblende gneiss carrying considerable magnetite. (See fig. 14.) A short distance east of this pit is an exposure of hornblende gneiss carrying garnet and epidote.

The next opening to the north is 4 feet deep. Here the rock layers exhibit a low dip to the east. At the bottom is hornblende gneiss, then a layer of white gneiss varying from 1 foot to 18 inches in thickness and carrying irregular masses of ore, one of which was noted to have a diameter of 10 inches; next above this layer comes 8 inches of hornblende rock, and this is followed by gneissoid granite. Magnetite is disseminated through the hornblende rock in fine grains, but in the white gneiss the iron mineral is coarsely granular. This occurrence strongly suggests that the ore was generated in a layer of intrusive material, or, more definitely stated, the impression is given that this ore is of igneous origin. The reader will, however, note that the general features of the Llano ores have not been interpreted as particularly favoring a hypothesis of igneous origin.

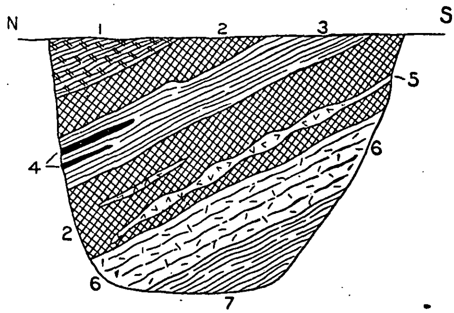


FIGURE 14.—Relation of ore layers in pit south of Willow Creek in section 13. 1, Feldspar-magnetite gneiss; 2, ore; 3, gneiss; 4, magnetite; 5, pegmatite; 6, granite gneiss; 7, hornblende gneiss.

About 90 feet west of the 4-foot pit a shallow excavation shows a 10-inch layer of magnetite embedded in white gneiss. This ore contains flakes of mica and closely resembles ore from the Deep Creek locality described on a subsequent page.

The surface indications just south of Willow Creek forks are rather meager, as very little work has been done.

North of Willow Creek, on the top of the hill, is a single pit 9 feet deep which affords a good exposure of magnetite-bearing gneiss. The strike of the layering is N. 35° W. and the average dip about 50° NE. Approximately 8 feet of rock is exposed and about half its bulk appears to be magnetite. The casing material of the lead is mica-bearing granite gneiss of the same general appearance as that at the Iron Mountain mine. The general character of the ore is like that taken from the Bader incline, but the rock layers exhibit more irregularity and are more contorted than at the Bader locality. Layers of solid magnetite are in no place more than 8 inches thick, but a 30-inch layer of rock is estimated to be three-fourths magnetite. Most of the magnetite is fine grained, but here and there strings and bunches of coarse-grained mineral are noted. As represented in the sketch given as figure 15, the immediate hanging wall is feldspathic gneiss carrying mica and magnetite; the footwall is light-hued granitic rock nearly free from dark minerals. Immediately under the contorted layer of heavy ore represented on the left side of the sketch is a layer of granitic material with ore irregularly distributed through it. This portion of the lead presents the appearance of an injection which has been forced into the ore-bearing rock; if it is actually invading material, fragments of ore torn from the walls have been drawn out and incorporated in its mass.

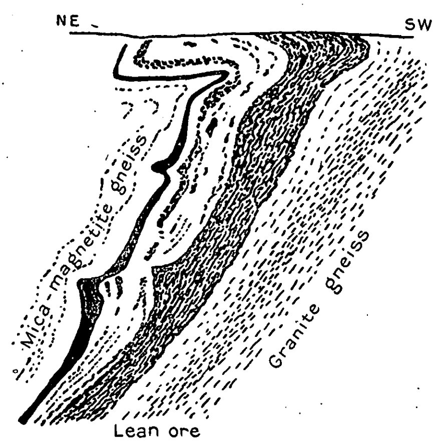


FIGURE 15.—Sketch of 8-foot ore surface in magnetite gneiss.

The immediate environs of the pit exhibit no exposures, bedrock being covered by an apparently deep mantle of residual sand. Float ore is not noted along the strike of the lead.

Though there is some doubt concerning the proper classification of the rocks with which the ore in section 13 is associated, they have been mapped as belonging to the lower (lighter) series of schists (Valley Spring gneiss). Another possibility is that they represent the dark schists very extensively injected by granitic material.

West of section 13, in the drainage basin of the north fork of Willow Creek, iron ore has been found at several points, and here the rocks are definitely recognized as belonging to the dark series (Packsaddle schist) with associated limestones. Aside from the Olive mine, this is the only occurrence of really noteworthy segregations of magnetite which can be unequivocally assigned to this set of rocks.

The approximate boundary of the dark schist area is shown on the sketch map (fig. 13, p. 50). It is to be noted that the principal showings of ore are aligned parallel to this boundary as it is represented upon the map. The ore layers dip toward the interior of the dark schist area.

Southeast of the main fork of North Willow Creek ore float a few shallow openings show the presence of magnetite at various points along a curving line about 5,000 feet in length and at a few isolated points north and east of this line. The ore material exhibits a somewhat siliceous aspect, and all of it is distinctly layered. Near the main creek and again southeast of the tributary which passes the Taylor house, fragments of ore lying on the surface are made up of alternating layers of dense, fine-grained magnetite and of quartz, the layers varying in thickness from one-half inch to 2 inches. It seems that there are at least two distinct layers of this material in the northern portion of the range. Their maximum thickness appears to be less than 2 feet.

In the central part of the range more massive ore is exposed, and at a pit north of the Taylor house a 17-foot section of the ore is exposed. The ore is a mixture of magnetite and hornblende, and it is judged from what may be seen on the surface that a layer of similar material at no place less than 4 feet thick has an extent along the strike of about 600 feet. Near the house the ore mass is probably more than 20 feet wide.

A sample representing the entire 17 feet of ore exposed in the pit mentioned above gave the following analysis:

Analysis of iron ore from sec. 13, Llano County, Tex.

[R. C. Wells, analyst, U. S. Geol. Survey.]

Fe	35.87
SiO_2	34.57
Mn	1.05
P	.07
S	.04
TiO_2	.15

From the surface indications it is believed that this body of iron-bearing material may be expected to hold its size and character to a depth of several hundred feet along the dip. Only the lean nature of the material stands in the way of the suggestion that the lead is worthy of detailed exploration; but it seems hardly likely that any but high-grade ores will warrant the railroad construction required for transportation. Enrichment of this material by means of magnetic concentrators would appear to be feasible from the technical standpoint, but at present certainly not practically advisable.

Three or four minor outcrops of magnetite north of the north fork of the creek appear to be of no particular interest. They exhibit the same general trend as the main range, but it is not possible to correlate them in any way with the more prominent line of outcrops.

From the structural features of the ore range which has been described it appears to be obvious that the ore is developed along a definite horizon in a set of sedimentary rocks; any additional characteristics which have been observed as bearing on the origin of the ores will be discussed later in more detail.

RILEY MOUNTAIN.

By A. C. Spencer.

Prospecting has been carried on at several places along the east base of Riley Mountain between Click post office and Honey Creek, and also north of Honey Creek. (See fig. 16.) Most of the surface showings are pyrite gossans, though one, situated 1 mile north of Click, is magnetite.

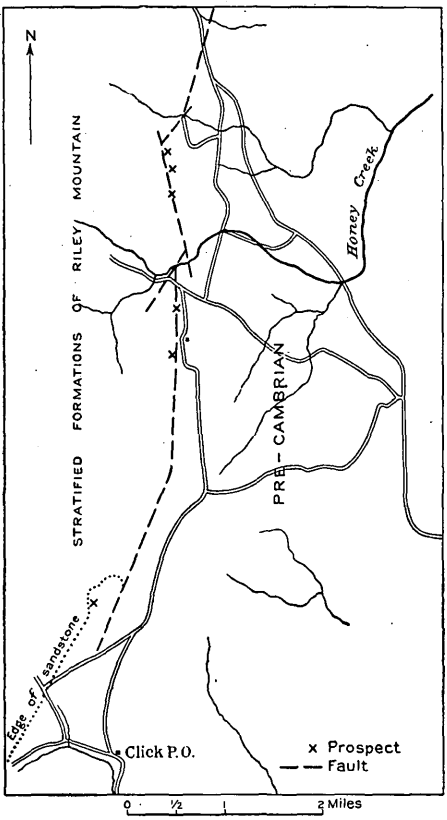


FIGURE 16.—Map showing location of pyrite deposits north of Click post office and their relations to faults.

The pyrite bodies were under exploration during the summer of 1909, so that a fair opportunity of studying their features was afforded.

Development work on the Roberts place, south of Honey Creek, shows that the iron cap gives place to the original sulphide within 20 feet of the surface. At this place the sulphur-bearing material is arsenical iron pyrites. The mass has been shown to have a width of 15 feet and has been exposed (June, 1909) for a length of 25 feet. Adjacent to the Roberts pit (an incline) float may be traced for a distance of 500 feet along the lower slope of the mountain; somewhat farther north are other showings along the same general trend. The deposit is in limestone adjacent to a very strong fault which brings the stratified limestones of Riley Mountain against very much older crystalline schists on the east. The ore is not on the fault but about 50 feet west of it. It appears to have been deposited by replacement of the limestone and to follow the bedding of the rock which dips toward the west and away from the fault. The rocks are poorly exposed, but there is reason for believing that the rocks are greatly broken adjacent to the main line of faulting, so that it may be that the ore follows a zone of shattering rather than a layer of the limestone.

The conditions of structure suggest that the deposits should exhibit considerable continuity in depth, but developments are not adequate to show whether or not such is the case. The fault adjacent to which the pyrite ore occurs is traceable for several miles southward from Honey Creek, though evidences of iron capping were not recognized far beyond the Roberts opening.

About a mile north of Honey Creek, on the Bedford tract, is a shaft said to have been opened prior to the settlement of the district. Near by a shaft was sunk in 1909 to a depth of 70 feet. Here there is evidently a crush zone adjacent to a strong fault. The lead which has been opened by the shaft appears to be a filling of crushed material along a fault which brings together cherty limestone on the west and red sandstone on the east. The material of the lead is red iron oxide and coarsely crystalline calcite. Brown iron ore in the crystalline form of pyrite (that is to say, limonite pseudomorphs after pyrite) was observed, but part of the red oxide may have been derived from the alteration of carbonate of iron. East of the shaft there is a band of red sandstone 60 feet wide, then another fault bringing up the crystalline schists.

It is evident that the showings of iron gossan in the neighborhood of Honey Creek can have no value as a source of iron ore. Whether or not the deposits from which the gossan has been derived will ever be worked as a source of sulphur or arsenic can not be foreseen. Parties engaged in exploring the deposits state that the sulphide shows no valuable quantities of gold or silver.

West of Click post office the basal sandstone of the sedimentary series of Riley Mountain laps over the ancient crystalline schists. The line between the sandstones and the schists trends northeast and finally curves out toward the east to meet the fault along the east face of Riley Mountain. Along this boundary, about 1½ miles north of Click, abundant float of very pure magnetite is noted in a small branch west of the Wilson house. This float is readily traced to its source at the sandstone overlap. Part of the loose ore has undoubtedly been derived from the lowest part of the sandstone, as fragments of magnetite may be seen in this rock. Another part may have been derived directly from ore occurring in the schist, though the position of a lead has not been discovered. On the whole it seems probable that all of the material is really débris from the sandstone and that the bedrock deposit does not come to the present surface because it is capped over by the sandstone.

A few hundred feet southeast of the point where the sandstone containing magnetite fragments is exposed there is a shaft said to have been opened in search for copper ore. Though the material taken from this shaft does show the presence of copper minerals, there is nothing to encourage further work.

ORIGIN OF THE IRON ORES.

By Sidney Paige.

POSSIBLE HYPOTHESES.

Three possibilities have been recognized in an endeavor to arrive at a definite conclusion concerning the origin of the iron ores described in this report. They are as follows:

1. That the beds represent igneous segregations from a granitic magma and owe their tabular form to flowage under pressure; that is, they represent granitic magmas impressed with a foliate structure.
2. That the ores are replacements of sedimentary beds, either before or during metamorphism, due to emanations from a granitic magma.
3. That the ores represent metamorphosed iron-bearing sediments.

Since the arguments presented to substantiate the last mode of origin will necessarily involve arguments against the first and second, a separate treatment of those hypotheses is not necessary.

A modification of the third hypothesis would recognize the possibility that iron had been introduced into unmetamorphosed beds, which were subsequently metamorphosed.

The writer alone is responsible for the views here set forth and realizes the difficulty of arriving at a definite conclusion. The value of various classes of evidence varies with the problem in hand; only by a careful weighing of these values can a legitimate conclusion be reached; and speculation, unless demanded, should be relegated to its proper place. The writer will endeavor to distinguish between considerations that are speculative and those that are not.

The considerations presented will fall under the following heads:

(1) The general distribution of iron throughout geologic formations and the character of the accompanying beds; (2) the geologic relations of the iron ores; (3) the characteristics of the ores having a bearing on origin; (4) the relations of the igneous rocks of the region; (5) the chemical factors involved; (6) comparison with other regions.

GENERAL DISTRIBUTION OF IRON THROUGHOUT GEOLOGIC FORMATIONS AND THE CHARACTER OF THE ACCOMPANYING BEDS.

The Upper Cambrian sandstones and limy sandstones of Llano County, Tex., carry disseminated iron oxides—hematite and limonite. Locally there is a fairly high content of iron (though not from a commercial standpoint) and the iron-bearing horizon is persistent. Within this series are also beds bearing glauconite—hydrous potassium-iron silicate.

The specular hematite ores of Virginia and other Appalachian States occur in rocks of Cambrian age.

In the lower Silurian of central Bohemia, composed of quartzites associated with slates, graywacke, conglomerates, diabases, amygdaloids, and diabase tuffs, occur hematite and carbonate iron ores, the former in diabase tuffs, the latter in quartzites between graywacke[a] slates.

The Clinton ores of the Silurian are interbedded with clay shales, sandstones, and impure limestones.

Iron ore accompanies the "Coal Measures" of the Carboniferous on the Continent, in England, and in the United States.

The ores of the northern Alps (probably Permian) are in a so-called graywacke zone.

The minette ore beds of the Dogger formation are found in the Jurassic of Alsace-Lorraine in beds of a limy and sandy composition. Green iron silicates are noted.

In the Eocene of Bavaria oolitic ores occur. Glauconite and quartz sand are noted.

Finally, deep-sea investigations have proved the very wide distribution of highly ferruginous sediment.

These facts point at once to two conclusions—that the presence of iron ore is to be expected in the sedimentary record of all periods, and that this means of accumulation, that is, sedimentation, illustrates at least one potent factor in ore segregation.

The nature of the metamorphic rocks found in the pre-Cambrian complex leaves little room for belief that the processes of sedimentation during pre-Cambrian time could have been appreciably different from those which proceeded during the more easily read periods which followed. It is therefore natural that bedded iron ores derived from primary sedimentary deposits should be present in the pre-Cambrian complex.

J. J. Sederholm[b] has described in great detail the manner in which granites have intruded the schist-gneiss series of Finland, and a remarkable similarity may be noted between the processes at work there and those observed in the Llano region; but he makes no note of iron ore. It seems to the writer that this absence of iron is more than a mere accident which might be explained away by referring to the vagaries of granite intrusions (introducing iron in one locality and not in another). It is more logical to believe that the reason for the absence of iron ores in the above-cited locality lies in the fact that that portion of the schist-gneiss series which is there (in Finland) exposed to observation represents beds barren of sedimentary iron deposits.

GEOLOGIC RELATIONS OF THE IRON ORES.

So far as could be observed the iron ores are an integral part of the Llano series and exhibit much the same relationship to the other

[a] "Sandstone-like rocks which in addition to the quartz and feldspar of an arkose contain rounded or angular bits of other rock. Some varieties * * * composed largely of feldspar may be difficult in the hand specimen to distinguish from some felsite."—Pirsson, L. V., Rocks and rock minerals, p. 326.

[b] Om Granit och Gneis: Bull. Comm. géol. Finlande No. 23. (English summary.)

members as do the limestones and the graphite schists. They are tabular in form, can be traced along the strike where not covered or interrupted by granite, follow all the convolutions of the rocks which inclose them, vary in thickness and in iron content as do graphite-bearing strata in carbon, and locally grade into the surrounding country rock by a gradual decrease of iron. They are layered deposits, even in the locality of their heaviest development.

No locality was observed where the beds in which the ore occurs cut across neighboring beds, as might be expected in the case of intrusive sheets, nor were beds observed where great unexplained irregularities of iron content were present; a lean bed following along the strike did not essentially change its character, at least not more rapidly than would be found in a sedimentary ore. There are, interbedded with the iron ores, barren or lean layers composed of the same minerals as the ore gangue.

CHARACTERISTICS OF THE ORES.

The ore-bearing rocks are crystallized granular schists or gneisses which, so far as observed, have undergone the same degree of metamorphism as the remaining beds of the series. The ore occurs as more or less concentrated grains of magnetite (or hematite, in part), with quartz and feldspar and a little biotite. (See Pl. IV, *B*, p. 10.) The magnetite seems to have crystallized either just before or simultaneously with the feldspar and the quartz. A microscopic examination of a specimen of lean ore gave as its result plagioclase feldspar, largely albite, magnetite, and quartz, in the following proportions: Quartz, 50 per cent; feldspar, 26 per cent; and magnetite, 22 per cent. This is roughly equivalent to the following composition:

Composition of lean iron ore, Llano County, Tex.

Silica	67
Alumina	5
Soda	3
Magnetite	22

The wall rock of the ore (which is but a lean portion of the ore) showed approximately the following composition by microscopic analysis:

Composition of wall rock of iron ore, Llano County, Tex.

SiO_2	71
Al_2O_3	12
Na_2O, K_2O, CaO (largely Na_2O)	7
Magnetite	5
Biotite	3

A partial chemical analysis of the gangue of the Bader ore gives the following result:

Analysis of lean iron ore from the Bader incline, Llano County, Tex.

[W. T. Schaller, analyst, U. S. Geol. Survey.]

Silica (SiO_2)	57.31
Alumina (Al_2O_3) [a]	10.15
Ferric oxide (Fe_2O_3) [b]	26.66
Lime (CaO)	1.20
Potassa (K_2O)	.16
Soda (Na_2O)	5.93
	[c] 101.41

The same analysis, recalculated to 100 without iron to show composition of the remaining material, is as follows:

Analysis of lean iron ore from Bader incline recalculated without iron.

[W. T. Schaller, analyst.]

SiO_2	76.66
Al_2O_3	13.57
CaO	1.60
K_2O	.21
Na_2O	7.93
	99.97

The most interesting point in this analysis is the presence of sodium in excess of potassium, for the sediments of the region as a whole, including some of the iron ores, showed the latter in much greater abundance. This point will be discussed later.

The relations thus far pointed out indicate more or less strongly that the iron was present in the rock before metamorphism, for it follows the convolutions of the schists, may be traced long distances, was apparently crystallized before or at the same time as the accompanying minerals, and occurs in much the same relation as does graphite, a mineral without much doubt developed in this field in sedimentary material. Light is also thrown on the presence of iron in the rock before metamorphism by an occurrence of lean ores northwest of Bodie Peak, where the banded material carrying the magnetite has suffered brecciation by intrusion of granite. A thorough intermixing of the brecciated fragments and the intruding rocks has taken place. Locally the angular outlines of the broken fragments are very evident, but passing northward the fragments appear stretched and lentil shaped, and if the angular material had not been observed one might be at a loss to account for the lentil-like streaks. A microscopic examination showed an interesting distribution of the magnetite. It occurs both in the brecciated fragments and also between them, whereas the concentration was much less between the

[a] Including TiO_2 and P_2O_5, etc. The TiO_2 is present in small quantity, probably less than 0.5 per cent.

[b] Total iron, that is, $FeO+Fe_2O_3$.

[c] Summation high on account of reckoning FeO as Fe_2O_3. The correction to be deducted from the total is about 0.83 per cent.

fragments than in them. This feature may indicate a more or less mobile state of the iron, due to the injection of granitic material. The microscope showed a granular mass of quartz and microcline feldspar (the latter dominant) and magnetite, with certain lens-shaped areas where the magnetite was heavily concentrated (the mashed fragments). In these areas quartz was almost wholly lacking, magnetite and feldspar being the minerals present. The writer believes that the magnetite found between the fragments was derived from the fragments of the intruded sediments and not from the intruding magma.

BEARING OF IGNEOUS ROCKS OF THE REGION ON ORIGIN OF IRON ORE.

The basic intrusive rocks described above have no genetic relation, so far as observed, to the iron ore and they will not be discussed in that connection. That they may have been important, however, in effecting chemical changes in the sediments at the time of their intrusion will be pointed out later. The granitic rocks of the region, on the other hand, are intimately associated with the ores, and the hypothesis of a genetic connection with them may not be so readily dismissed.

As has been indicated, the iron ores are found in rocks believed to represent a sedimentary base and owe their origin either to replacement of metamorphosed beds, or to original deposition with or secondary introduction into unmetamorphosed strata. The granite, wherever found in association with iron ores, is intrusive into them, cuts across the bedding, or is interleaved with the ore beds. In fact, it presents exactly the same relations to the iron ore that it presents in numerous places to the mica, the graphite, or the hornblende schist series, into which group of rocks it can hardly be argued that the mica, the graphite, and the hornblende were introduced by the granite. In the case of the ore-bearing rocks, however, and also in the case of certain feldspathic schists, the mineral composition of the invading and the invaded rock is strikingly similar. The writer believes this to be a fortuitous condition, for, as is well known, certain metamorphosed sediments have a composition very similar to that of granite.

A very small percentage of magnetite, not more than ordinary, occurs in the granites of the region. In the pegmatites there are a few exceptions and in one instance a notable one. Near Gallihaw Crossing a pegmatite dike several feet thick was observed cutting across the schistosity of the mica schist series. It was composed of feldspar, magnetite, garnet, epidote, and limonite. The magnetite, which was abundant, occurred in irregularly shaped, often elongated masses throughout the dike and apparently crystallized simultaneously with the feldspar, though this is not certain. Bedded iron ores may exist not far distant from the locality, as small outcrops were seen. The dike apparently has had little contact effect on the schists which it cuts. It is suggested that it may have acquired its magnetite in passing through beds of iron ore. Where pegmatites occur in a region of abundant amphibole schist, hornblende was noted in the pegmatite, a fact certainly suggestive; and where pegmatite had cut limestone, scapolite was formed in the dike, clearly exhibiting the absorption of lime, though whether from the immediate vicinity or elsewhere is not certain.

In certain localities, where the effects of intrusion and impregnation have been most intense, abundant magnetite crystallized with feldspar has all the appearance of an original mineral in the granite magma; but never is the possibility absent that an iron-bearing sedimentary base has been absorbed by the intruding mass.

It is evident from what has just been said respecting the geologic relations of the granite to the schists that if the iron is a result of replacement, by means of magmatic emanations, some granite, other than the one now observed, was involved in the process.

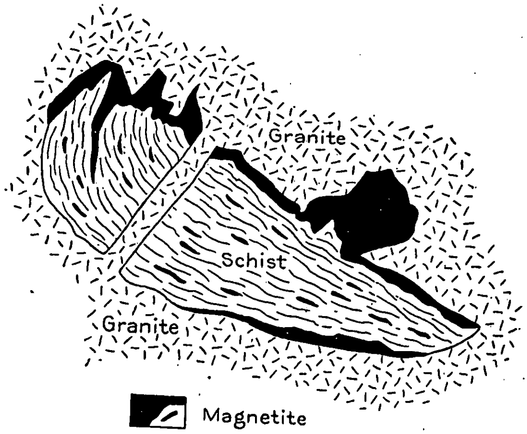


FIGURE 17.—Concentration of magnetite along edges of schist fragment at granite contact.

It is hardly conceivable that a granite presenting such indubitable evidences of its intrusive nature could have been the principal factor in the intense metamorphism observed, which is believed to be largely the effect of dynamic forces other than intrusion. The metamorphism was complete, or at least well under way, before the injection of the granite took place.

Though this statement seems to the writer a reasonably safe conclusion, it should be said that phenomena are observed locally which might be used as an argument for igneous introduction of the magnetite; such, for example, as the locality shown in the accompanying sketch (fig. 17). The clear evidence of crosscutting should here be noted, however, and the possibility of original iron in the schist kept in mind. On the north side of Llano River a short distance west of Hickory Creek the granites show almost completely absorbed schist fragments, in which but the faintest outline of the original fragment remains, indicated by broadly spaced lines of magnetite. (See fig. 18.)

It seems more probable that the granite, acting on an iron-bearing base, had by assimilation rearranged the quartz and feldspar, the iron remaining approximately in its original position, than that the granite had introduced this iron and then absorbed the schist.

CHEMICAL RELATIONS.

With the schist-gneiss group considered as a metamorphosed sedimentary series and the intrusive nature of the granite borne in mind, certain facts of general geologic application may have weight in arriving at a conclusion regarding the nature of the iron. It is a recognized fact in geologic science that the important result of regional metamorphism, in general, is a change of form rather than a chemical addition or subtraction. The schists of Llano County might well be the result of such metamorphism without any considerable additions. They are generally high in potassa and silica, two elements which Bastin[a] and others have shown are likely to be dominant in metamorphic sediments. Van Hise[b] points out that "quartz and acid feldspars have very nearly the same specific gravity, and unless such material be gradually contributed to the water so that it can be handled by strong waves and currents for a long time before final deposition quartz and acid feldspar will not be separated" and as the mica is carried away, "consequently in the comparatively shallow water along the shore, many nearly pure quartz-feldspar sands may be built up." Glauconite also is a deposit restricted largely to the borders of the continental shelf. He also says:[c] "From * * * muds carbonates are mainly removed in solution, the hydroxides are removed to some extent, and the highly oxidized iron largely remains." In regard to the pelite gneisses he says in part:[d] "While the greater part of the potassium probably passes into muscovite, where the potassa is abundant, a portion of it passes into feldspar, producing orthoclase and microcline, since these minerals are rather abundant in many of the schist pelites and gneiss pelites."

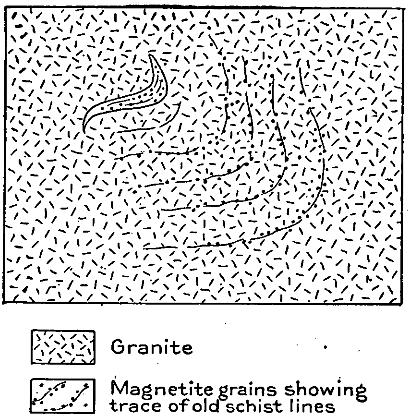


FIGURE 18.—Remnant of schist fragment in granite mass. Note lines of magnetite.

[a] Bastin, E. S., Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, No. 5, 1909.

[b] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 873.

[c] Idem, p. 889.

[d] Idem p. 900.

Grubenmann [a] also points out that "there occur marly sandstone or argillaceous marls, whose chemical composition approaches so nearly that of igneous rocks that confusion may arise in their discrimination."

The analysis of the wall rock at the Bader incline shows soda as dominant over potash. This relation was also observed at the Iron Mountain ore body. Iron ores in the western part of the quadrangle, however, are associated with a decidedly potassic gangue, as indicated by the prevalence of microcline feldspar. As normal sediments are in great part or entirely of the potash type, an explanation should be offered for the high soda content of this particular sediment.

As described earlier in this report, amphibolite and mica schists form a fairly definite unit in the schist series; it was also noted that amphibolites are occasionally found within the lighter schist series, and it was suggested that in many places they might be derived from basic sills intrusive into the sedimentary series prior to its deep burial and foliation. The contact metamorphism produced by such intrusion into clay shales has been studied in various localities throughout the world and in several places, at least, with the very definite and similar result of finding that soda and silica have been added and potash removed, but in the cases to be cited, without the addition of iron.

Though it can not be proved that the relations about to be presented existed in Llano County, they are given as a possible if not a probable explanation of present conditions; at the same time it is assumed that the introduction of soda took place prior to the deep burial of the rocks, with the result that under conditions of intense regional metamorphism and accompanied by complete recrystallization of the rocks albite was formed in place of microcline or orthoclase.

Teall, in British Petrography,[b] says:

A striking feature [speaking of adinole, a rock produced by contact metamorphism of clay shale by diabase intrusion] is the large percentage of soda which the rocks contain. This has been proved by Schenck [c] to be due to an actual impregnation of the sediment with alkali derived from the eruptive rock. Thus at Bochtenbeck, by Niedersfeld, the unaltered rock contains 1.16 per cent of soda, the altered rock 4.94, 4.56, and 3.59 per cent; at Kuhlenberg, by Silbach, the unaltered rock contains 1.15, the altered rock 7.14 per cent; at Silberberg, the unaltered rock contains 0.50, the altered rock 6.03 per cent. We are thus led to the important conclusion that *the albite of the rocks altered by diabase is largely if not wholly a secondary product, due to the actual impregnation of the surrounding sediment by material derived from the eruptive rock.*

Rosenbusch,[d] in describing the contact effect of diabase sills on clay shale, says:

These products of the innermost parts of the diabase contact areas are called adinole and are composed of an extremely fine-grained mixture of allotriomorphic albite and quartz, with which are very sparingly associated actinolite, epidote, rutile or anatase or even titanite.

The chief difference between this and the deep-seated contact zone lies in the complete chemical changes of the schists.

---

[a] Grubenmann, U., Die Kristallinen Schiefer, 1904, p. 12.
[b] Teall, J. J. H., British petrography, 1888, p. 220.
[c] Die Diabase des oberen Ruhrthals: Inaug. Diss. Bonn, 1884.
[d] Rosenbusch, H., Elemente der Gesteinslehre, 2d ed., 1901, pp. 346–347.

Analyses 1a–1c and 2a–2c and 4a–4c show different stages of change with increasing distance from the diabase.

One sees that the oxides RO and K_2O strongly decrease, while, on the other hand, SiO_2 and Na_2O considerably increase—that is to say, silica and soda are added in appreciable amounts to the schist substance.

	1a.	1b.	1c.	2a.	2b.	2c.	4a.	4b.	4c.
SiO_2	69.27	73.74	75.25	54.02	55.06	72.63	60.28	57.77	74.16
TiO_2							.69	.92	.37
Al_2O_3	13.12	14.81	11.80	21.22	19.75	15.81	22.61	19.35	11.85
Fe_2O_3	.62	.02	Trace.	2.51	1.83		2.53	1.29	.82
FeO	5.24	1.31	1.76	6.48	7.55	.74	.45	3.37	1.66
MnO	.09	.11		1.74			Trace.	Trace.	.06
MgO	1.36	1.29	1.57	3.01	2.21	1.21	1.35	4.35	2.10
CaO	.12	.61	.32	1.64	3.59	1.02	.13	1.71	2.10
Na_2O	2.25	5.47	7.54	3.36	7.51	8.33	.54	8.22	6.57
K_2O	4.31	1.51	.61	3.71	.84	.75	5.73	.22	.15
H_2O	3.36	.70	.81	1.97	1.83	.61	3.62	2.34	.52
CO_2	.04								.09
FeS_2	.62	.84	.49				.03	.04	.08
Organic substance	Trace.	Trace.		Trace.	Trace.		.97		.18
	100.40	100.41	100.15	99.66	100.17	101.10	99.57	99.76	100.76
Specific gravity	2.653	2.658	2.653	2.678	2.813	2.778			

J. Morgan Clements[a] has well shown the metamorphism produced in sediments by the intrusion of diabase dikes and sills. The changes resulting in a clay slate due to this influence are indicated in the following analyses. Clements was not able, because of poor exposures, to select his specimens with absolute certainty as to their exact distance from the diabase. He says:

From previous determinations in other regions it is well known that the adinoles are next to the contact, while the spilosites (and desmosites) are intermediate between them and the clay slates. The following series of analyses are arranged in the order of approach to the dolerite, as determined by the character of the rocks:

Analyses of rocks from Lake Superior iron region.

	1.	2.	3.	4.
SiO_2	60.28	52.51	57.77	74.16
TiO_2	.69	1.70	.92	.37
Al_2O_3	22.61	19.00	19.35	11.85
Cr_2O_3		None.	None.	
Fe_2O_3	2.53	3.31	1.29	.82
FeO	.45	7.19	3.37	1.66
MnO	Trace.	Trace.	Trace.	.06
CaO	.13	1.55	1.71	2.10
BaO	.04	Trace.	None.	None.
SrO		Trace.	Trace.	
MgO	1.35	3.29	4.35	2.10
K_2O	5.73	.70	.22	.15
Na_2O	.54	6.72	8.22	6.57
Li_2O		Trace.	None.	
H_2O at 100°−	.60	[b] .34	[b] .18	.05
H_2O at 100°+	3.62	[c] 3.26	[c] 2.34	.52
P_2O_5	.03	.15	.04	.08
CO_2	None.	None.	None.	.09
S and SO_3		None.	None.	
C	.97			.18
Cl		None.	None.	
F		Trace.	None.	
	99.57	99.72	99.76	100.76

[a] A contribution to the study of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 7, pp. 81-91.
[b] H_2O at 110°.
[c] H_2O above 110°.

1. Clay slate, specimen No. 32497, U. S. Geol. Survey. Analyst, George Steiger.
2. Spilosite, specimen No. 32861, U. S. Geol. Survey. Analyst, H. N. Stokes.
3. Spilosite, specimen No. 32827, U. S. Geol. Survey. Analyst, H. N. Stokes.
4. Adinole, specimen No. 32465, U. S. Geol. Survey. Analyst, George Steiger.

In these analyses the usual increase of silica as the dolerite is approached is at once noticeable, and hand in hand with it goes the diminution in percentage of alumina and iron oxides. The content of water and carbonaceous[a] matter also suffers diminution, as was to be expected.

The most noteworthy difference between the clay slate and the contact rocks is shown in the relations of potash and soda. This is well brought out in an examination of analyses Nos. 1 and 2. It will be seen that there is only about one-eighth as much potash in the contact rocks as in the normal clay slate; while, on the contrary, about 12 times as much soda as there was in the slate has been added to the contact rock. This causes a reversal of the relations of the soda and potash, so that, whereas in the clay slate there is present 10 times as much potash as soda, we find in the contact rock taken as an example very nearly 10 times as much soda as potash. * * *

The very considerable changes which are shown by the above analyses to have taken place in the metamorphism of the slates, especially the changes in the amount of silica and soda resulting in the production of albite in large quantity, seem to add weight to the supposition that in such contacts an actual transfer of material, possibly in the form, as has been suggested by others, of the soda-silicate, does take place from the basic igneous rock to the intruded slate.

In summing up, then, it may be said that the light-colored schist series as a whole are eminently quartzose potassic rocks; that it is important to recognize the fact that introduction of material in the deep-seated zone, except on a very minor scale, is not necessary to account for their chemical composition; and that the introduction of soda may have taken place at the intrusion of the diabase-like rocks prior to deep-seated conditions.

Attention should here be called to the potassic composition of the lean ores in the extreme western part of the area and to the possibility of their derivation from glauconitic sediments. That glauconite is capable of altering to magnetite can not be questioned. J. K. Prother[b] says, in describing the glauconite from the greensands of New Jersey: "In some glauconite grains are rows of small grains of magnetite. All gradations are noted from unaltered glauconite to glauconite changed to a network of magnetite—magnetite is seen filling the cracks of glauconite."

It is reasonable to suppose that such a process may have operated in the case of the ores under discussion.

It would seem extremely probable that if the siliceous glauconite beds of the Cap Mountain formation, for example, were subjected to metamorphic conditions, potassic feldspars, quartz, and magnetite would result.

PROBABLE CONDITIONS AT TIME OF INTRUSION.

In attempting to state the reactions taking place at contacts of igneous masses with sedimentary rocks at great depths, one is forced to base conclusions on phenomena only imperfectly understood. It

[a] The carbon in Nos. 2 and 3 was not determined.
[b] Jour. Geology, vol. 13, p. 511.

is all the more important, then, to refrain from speculation and to confine oneself to reasonable analogies.

If we make the assumption for a moment that gaseous solutions capable of carrying iron into the schists were present at the time of intrusion, an examination of the conditions probably obtaining in the wall rock at that time do not give much if any support to the idea that such replacement would have taken place.

Field evidence shows that the schists were in large part in the zone of flowage, where openings in the rocks, if existing at all, were subcapillary, producing practically impervious strata. The crystalline interlocking of the iron with its accompanying minerals indicates that the iron was present at the time of crystallization, which preceded the intrusion of the granite. Many crystalline limestones were observed which showed no evidence of replacement, and where limestone has been converted into wollastonite, as is the case in the lower (lighter) schist series (Valley Spring gneiss), it is not certain that the effect was not due to thermal metamorphism of impure limestone. In this case CO_2 was expelled. Barrell [a] holds that—

Carbonic acid is only expelled when the siliceous impurities of the limestone are sufficient to combine with the lime set free, forming lime silicates. This ability of *deeply buried* [b] limestones to retain their carbonic acid when intensely heated, if free from other impurities, has been noted by a number of observers.

A consideration of the chemical nature of the remaining beds other than limestone places them in a class even more chemically inactive than the limestone, so far as replacement is concerned; for they are siliceous rocks, and as such notably inactive except where pore space (including fractures) exists.

The study of rock magmas has shown the probability that when molten they exist as silicate solutions (various silicates in mutual solution); further, that as crystallization ensues, the remaining magma becomes progressively more siliceous. In such a system pegmatites become end products of crystallization. Harker [c] regards a rock magma as—

A definite mixture of silicate compounds, the only free oxides present, at least in a magma approaching the point of crystallization, being those parts, if any, of the silica, alumina, ferric oxide, and water, which after crystallization appear as quartz, corundum, hematite, and free water.

Moreover,[d] he regards mineralizing substances such as water, chloride, fluoride, etc., as "an integral part of the rock magma itself," and considers them "operative throughout the whole progress of consolidation of the magma. * * * The pegmatites [e] themselves represent the watery residual magma, except that the greater part

[a] Barrell, Joseph: Am. Jour. Sci., 4th ser., vol. 13 p. 279.
[b] Italics by present writer.
[c] Harker, A. H., The natural history of rocks, p. 166.
[d] Idem, p. 288.
[e] Idem, p. 295.

of the water and other volatile substances was expelled in the final crystallization."

At this stage of consolidation should exist the most perfect opportunity for a liquid substance to permeate the rocks; but this has not taken place except in a mechanical way by interleaving or crosscutting, though these processes have locally proceeded in a most intricate manner. It is probable that the water and the silica of the final product are represented in the quartz veins, which are very numerous in this region; but this mode of entrance into the schist shows clearly that the easiest avenues were chosen, namely, fractures and cleavage planes.

With the completion of crystallization in a rock magma[a] the contained water and other volatile substances * * * must be disengaged. We must suppose a certain leakage by diffusion into and through the contiguous country rocks; but it is probable that this escape is not important until the temperature has fallen considerably.

High temperature,[b] which in liquids diminishes viscosity and so promotes diffusion, has the opposite effect in gases; and in view of all the conditions it is likely that a large part of the volatile constituents is in general retained down to a late stage. Nevertheless, more or less of the water and other gases must pass into the neighboring rocks while these are still heated by the intrusion.

Such transition, it is believed, can occur only where pores or fractures exist, or where pressure is so slight as to permit the ready expulsion of CO_2 (in the case of limestones) to admit the entrance of solutions, or where chemical interchange is possible. It is extremely doubtful if solutions capable of producing magnetite, quartz, and albite can permeate a nearly impervious siliceous formation for any great distance. Assuming that they have done so in this region, they could not do more than progressively fill the minute cavities found; for it is known that silicate rocks are those which offer the greatest resistance to attack, and the relation of the iron minerals in the schists is of the same nature as that of the albite and the quartz which accompany it.

The local abundance of magnetite in the pegmatite might be advanced as an argument for the igneous introduction of the iron into the schists; if, however, a quantitative analysis were possible over a broad area the writer believes it probable that the iron ratio to pegmatite would be shown to be much the same as is the iron ratio in the granites to the parent magma. The extreme fluidity of the pegmatite material should offer favorable opportunities for such segregations of iron minerals as are found, without postulating any great quantity of iron when compared with that found in the body of the schists.

The ratio of phosphorus to iron in the Llano ores is interesting. Practically all the analyses at hand show a very low content of

[a] Harker, A. H., op. cit., p. 299. [b] Idem, p. 303.

phosphorus; that is, Bessemer grade. An examination of sedimentary ores the world over shows, for the most part, phosphorus in greater quantities than Bessemer practice permits. It would seem necessary, therefore, if these ores are to be assigned to a sedimentary origin, to offer some explanation of this divergence. It should be pointed out that the Bessemer limit, as a point on a scale of phosphorus content, is a low point, and that its delicacy being considered, this limit might easily have been disturbed by conditions not understood and now hidden by the metamorphism which has taken place.

Van Hise[a] gives as the result of an analysis of 78 shales an average content of 0.17 per cent phosphorus; of 624 sandstones, 0.07 per cent. The Llano ores may well have been deposited with arkosic sandstone. It must be admitted, however, that the presence of the iron in sedimentary deposits seems to involve the presence of phosphorus and that therefore this comparison loses some of its value.

It is credibly reported that certain stock piles in the Lake Superior region originally above Bessemer grade have by processes of weathering been leached of sufficient phosphorus to render them of Bessemer grade.

It is possible, then, that in the case of the Llano ores, first, that only a small percentage of phosphorus was deposited with the ore; or, second, that by some process of leaching phosphorus was removed; or, third, that unknown reactions due to metamorphism have served to remove or lower the phosphorus content.

It should be said also that those magnetite deposits of the Adirondacks to which an igneous origin has been ascribed by careful workers contain from 0.01 to 2 or 3 per cent of phosphorus; but this fact, though it could be legitimately used as an argument against igneous origin, does not alter any value the low content of phosphorus may have as an argument against sedimentary origin.

COMPARISON WITH OTHER REGIONS.

Beck,[b] in describing the iron ores of Krivoi-Rog, in southern Russia, says:

These ore deposits,[c] ordinarily grouped as those of the Saxagan basin, lie on the Inguletz, a western tributary with north-south course entering into the Dnieper River above Cherson. They are of exceedingly great importance to Russia, because they lie close to the Donetz coal basin extending east of the Dnieper. The ores occur in a strongly folded crystalline schist striking north-south, whose geologic age is as yet uncertain. In its upper part this rock consists of carbonaceous slate with but

---

[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 975.

[b] Beck, R., The nature of ore deposits (tr. by W. H. Weed), p. 75.

[c] See reviews of the works of Kontkiewitsch, Piatnitzky, Domherr, Monkowsky, Karpinsky, and others in Zeitschr. prakt. Geologie, 1896, p. 271; 1897, pp. 182, 186, 278, 374; 1898, p. 139 (Macco). See also Stripelmann, L., Süd-Russlands Magneteisenstein und Eisenglanzlagerstätten in den Gouvernements Jekaterinoslaw und Cherson, 1873; and Cordeweener, J., Géologie de Krivoï-Rog et de Kertsch, Paris 1902.

few layers of ore; next below come the ore-bearing quartzite schists, underlain by clay slate, actinolite schist, quartz chlorite schist, talc schists, arkose, and itacolumite, like mica schists, and finally by gneiss (probably dynamometamorphic granites) and true granites. The ore-bearing strata form a long-extended fold, and show a close minor plication by which quartzite beds have, according to Macco, changed into a succession of quartzite nodules, like conglomerate cobbles in a clay slate. In the double row of deposits extending parallel to the Saxagan River the two most important ore bodies are those near Krivoi-Rog; the lower one about 98 feet (30 meters) and the uppermost about 262 feet (80 meters) thick. The ores consist of magnetite, for the most part altered to red hematite, with 45 to 70 per cent of iron and 0.01 to 0.02 per cent P_2O_5. The very irregular ore masses lie in a finely banded yellowish white, red, or brown ferruginous quartz schist whose crystalline quartz grains inclose numerous magnetite particles.

Newland,[a] referring to nontitaniferous iron ores in the Grenville series of the Adirondacks, says:

There can be no doubt that the form assumed by the ore bodies is conditioned by the structures of the inclosing rocks. * * * This feature is least apparent in the gneisses of the igneous series, and most evident in the banded gneisses and schists of the Grenville. The ores consequently must have been deposited before the great regional disturbances took place, or at least before the rocks received their present structural arrangement.

Though Newland found it difficult or impossible to determine the origin of some of the iron-ore deposits in the Adirondack region, he regarded the origin of others as quite obvious. For example, describing the deposits near Crown Point, on Lake Champlain,[b] he says:

The magnetites * * * are associated with banded gneisses and schists that can be classed without reserve in the sedimentary or Grenville series. They have a simple tabular or lenticular form, swelling and narrowing to some extent along the strike and dip, but otherwise are little disturbed. * * * The Grenville rocks which occur near the ores are mostly hornblende and biotite quartzose gneisses with occasional intercalations of thin-bedded schists. They are conspicuously foliated and variable in their composition from layer to layer. * * * The Grenville has been broken up into patches and larger irregular areas by granite which has invaded the series from below. * * * The granite frequently cuts across the stratification of the sediments and sends off dikes and stringers which penetrate the latter in all directions.

Other instances might be cited where field relations point to the conclusion that metamorphosed sediments are the base of the iron-ore formation and that metamorphism has in all probability preceded granitic invasion, but the localities mentioned are sufficient for the purpose.

SUMMARY.

In conclusion it may be said, as Van Hise[c] has so well pointed out in referring to the distribution of the elements—

that a general result of metamorphism and accompanying processes is that many of the secondary rocks are depleted in reference to each metal and that correlative with

[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: New York State Mus. Bull. 119, 1908, p. 27.

[b] Newland, D. H., op. cit., pp. 40-41.

[c] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 1035.

such depletion other deposits are formed in which each metal is segregated. Since these processes result in deposits in which each of the common metals is segregated, why should we hold that the metal of a present deposit of gold or silver or copper [or iron][a] is derived solely from an immediately adjacent igneous rock unless evidence for this be conclusive. The natural view is that the metallic ore deposits of the world are broadly accumulated results of the processes of segregation carried on throughout geological time.

The geologic events probably involved in the formation of the Llano ores may be indicated as follows:

1. Deposition of iron as oxide, carbonate, etc.,[b] with the sediments, either in extended basins or along borders of the sea.
2. Burial and intrusion of dikes and sills of a diabasic type with possible local introduction of soda. Possibly granitic intrusions.
3. Deep burial with following folding and metamorphism, and second intrusion of basic types.
4. Intrusion by granite magma with great local disruption.
5. Elevation above sea, and exposure by erosion.

GOLD.

Small quantities of gold may be found at many localities throughout the pre-Cambrian area. It must be said, however, that in general the quantity is so small as to be valueless from the standpoint of a mining enterprise. Results of many assays made of specimens said to contain gold were decidedly discouraging. The following table shows the results of a number of assays:

Results of assay for gold and silver, Llano County, Tex.[a]

	Gold, per ton.	Silver, ounce per ton.	Locality.
1	Trace.	Trace.	Sulphides from Mr. Sheeon's place, 4 miles south of Llano.
2	None.	None.	Graphitic schist 2½ miles southwest of Niggerhead Mountain, three-fourths of a mile east of the Colorado (flowing south) and a scant half mile north of the river (flowing east).
3	Trace.	.56	Thomas Prospect, Hooking Hollow.
4	None.	None.	Shaft near Gallihaw Crossing. Pegmatite dike.
5	None.	None.	2½ miles east by north from Granite Knob and one-fourth mile south of the east and west road, near edge of sheet. Gossan from vein.
6	Trace.	.38	4 miles west of Burnet and north of Spring Creek, Bailey Prospect.
7	$0.31	None.	Quartzite-like rock near Parkinson's quarries, 110 feet long, 30 feet wide.
8	.10	None.	Iron oxide 1¾ miles east-northeast of Field Creek village.
9	.10	None.	Edwards's pasture, near east boundary 2-foot vein, 240 feet long (by float). Prospect holes 5 miles east by south of Valley Springs.
10	None.	None.	Southeast of No. 9 and west of Pecan Creek, north of road to Edwards's ranch. Bedded layer in graphite schist.
11	.10	None.	Willow Creek above Burnet-Valley Springs road; outcrop about 2½ miles west of Valley Springs.
12	.10	None.	Heavy pyrite gossan in graphite schist on knoll 1½ miles west by south of Miller Mountain.

[a] Assays 1-6 by E. E. Burlingame Denver, Colo. Assays 7-12 by Ledoux & Co. New York City.

On Henry H. Sheeon's place, about 4 miles south of Llano, a shaft has been sunk to prospect pyrite veins in the quartzite schist. The

[a] Inserted by present writer.

[b] The chemistry of the possible manner of original deposition need not be discussed here, as little or no evidence is at hand for discrimination.

pyrite nearly or quite accords with the bedding of the schists which at this point dip steeply to the southeast. The iron mineral is accompanied by much quartz in narrow veins swelling and pinching in the layers of the schist. Apparently the two were introduced together. An assay of this pyrite, which is very abundant, judging from the dump (the shaft, unfortunately, was not open at the time of the visit), shows no gold.[a]

The only prospect visited where gold was present in sufficient quantity to warrant further prospecting is called the Heath mine. This prospect is located 5 miles northeast of Llano, just north of the Llano-Lone Grove road. At the present time the property is controlled by Mr. McCarty Moore, of Dallas, Tex., though during the past 25 years a number of persons have been interested in the prospect.

The rocks in this vicinity are a part of the dark (Packsaddle) schist series. Graphite and mica schist and limestone are present. At the prospect, intrusive granite, which to the south and east occurs in large masses, has broken the regularity of the beds, and strikes and dips with quite variable angles may be observed. Much quartz and pegmatite have interleaved and cut the schist beds, and pyrite is locally present. It is with the quartz stringers that the gold seems to be largely associated.

In the subsoil and in the partly decayed schists below, where exposed in crosscuts, a canary-yellow efflorescence or stain may be noted coating quartz stringers and distributed in spots through the decayed rock. This stain has been mistaken occasionally for an oxidation product of gold tellurides. An examination by W. T. Schaller of the United States Geological Survey proves the material to be a compound of bismuth and vanadium. The only known mineral compound of bismuth and vanadium is the mineral pucherite, which, however, is always found in crystal form. The yellow compound has been noted by Mr. Schaller in California where he collected sufficient material for an analysis, results of which will be published at a later date.

The prospect is located on a low spur rising to the north. A cover of residual red and brown soil effectually conceals the underlying decayed schists and granites. This residual soil carries gold, undoubtedly concentrated by the removal of soluble and easily transported constituents of the rock. Values are also reported in the underlying schists.

Figure 19 is a sketch map on which are shown the positions of some of the open cuts and shafts by which the property has been prospected. The map also shows the general northwest trend of the schists and the variable dips and strikes that may be observed.

In 1900–1901 a shaft 615 feet deep was sunk. Gold is reported from this shaft, but little definite information could be obtained as to

---

[a] See table on page 70, assay 1.

its value or the depth at which it occurred. The writer was informed that an 8-foot band of black schist carried fair value in gold associated with molybdenite.

The material on the dump shows that the lower portion of the shaft penetrated feldspar-mica schist and fine-grained pink intrusive granite.

At points 5 and 6 shown on the sketch map two 50-foot shafts have been sunk and connected by a drift. The results of any systematic sampling of these openings are not at hand. High values are not reported. At point 7 shown on the sketch map two shafts 45 feet deep are sunk in schist and intrusive granite. An open cut following a quartz vein is also located at this point. The presence of pyrite with the quartz and in the granite is noteworthy. Open cuts are located also, as indicated at 1, 2, 3, and 4, and a shaft is sunk as indicated at 11.

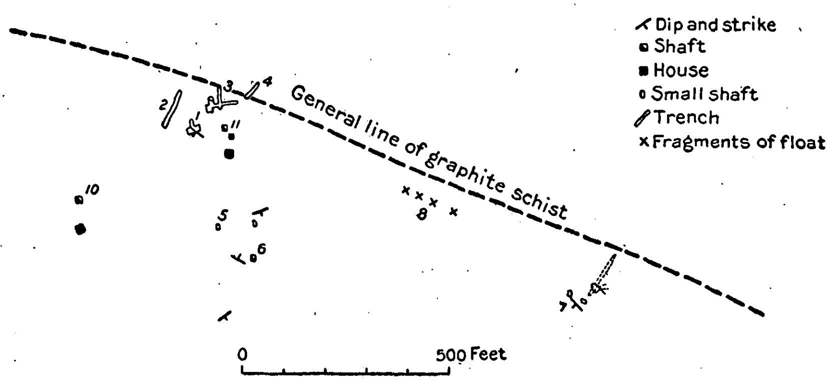


FIGURE 19.—Prospect pits and shafts at Heath gold prospect.

It has been pointed out that a foot or more of residual soil covers most of the bedrock in this vicinity. This soil has been sampled by 60 shallow pits in addition to the open cuts shown on the sketch map. A sample selected with great care by the writer from one of these pits gave an assay of 20 cents in gold.

An incline has been run from the surface crosscut shown at 1 on the sketch map (fig. 19), southward down the dip of the schists for about 90 feet. A sample from the west wall of this incline, about 30 feet from its upper end, was cut from the grass roots down to the bottom of the cut, a distance of 9 feet. The sample was crushed on a canvas sheet, mixed and quartered twice, and assayed for gold and silver, and $1.60 in gold was reported by the assayer.[a] A second sample from the east wall and 12 feet farther down the incline was cut from 6½ feet of material. The top of this cut was 7 feet below the grass roots. The sample was quartered once and assayed for gold and silver, and 20

[a] Assays made for the U. S. Geol. Survey by E. E. Burlingame, of Denver, Colo.

cents in gold was reported. A third sample was taken from the west wall 42 feet down the incline from second sample. This sample covered $4\frac{1}{2}$ feet of material and was 5 feet from the face of the incline. It was quartered once and assayed. No values were reported.

A sample was taken from crosscut 3 (see sketch map) on its south side. It included 6 feet of schist and a little granite. It was quartered once and assayed. No values were reported.

Crosscut 2 (see sketch map) was sampled at three points about 75 feet apart, two on its northwest side and one on its southeast side near the northeast end. The three samples, covering in all about 10 feet of vertical material, weathered schist and soil, were mixed together and quartered once and assayed. No values were reported.

A sample was taken from the top of 26 ore sacks and from an ore pile representing picked ore selected by panning tests. This sample assayed $20.59 a ton in gold and silver, of which 19 cents was silver.

The company has had many assays made of material from the surface and from the cuts and the incline. Separate assays of quartz from veins have also been made. In all these instances, values higher than those found by the writer are reported. In some instances single stringers of quartz are reported to carry exceptionally high values. The sample from the ore sacks, noted above, was of very quartzose material.

It seems very probable that in large measure the values are confined to the quartz veins; these are abundant locally, but are not persistent and are not of such size that they could be worked individually.

Except in the residual material, in which there has been opportunity for enrichment by the removal of soluble constituents of the rock during its decay, it is doubtful if sufficiently high values in gold could be relied on to insure profitable mining. This point, however, can be determined only by assaying many carefully taken average samples.

COPPER.

No encouragement can be given that any copper prospect visited during the course of the investigation on which this report is based can ever be of commercial value.

About one-half mile northwest of Wilberns Glen on both sides of the road some crosscuts and a shaft about 35 feet deep have been opened. Films of malachite were noted associated with epidotized and garnetized schist.

About three-fourths of a mile beyond the western edge of the Llano quadrangle and about 400 feet south of the Mason road prospecting has been done on what is known as the Bauer prospect. At this point schists striking east and west are near the edge of a large mass of fine-grained granite. A shaft (slope) of unknown depth dips 50° S. Carbonates are noted over about 150 feet of prospected ground. No sulphides were seen on the dump. A little garnet was noted. Two carloads of ore are reported to have been shipped.

In May's pasture, 2 miles south of Babyhead and a short distance east of the Llano-Babyhead road, a fine-grained pink granite is seen carrying malachite and some azurite. About two tons of 3 per cent rock is at the surface. A small trench has been made.

There has been prospecting for copper on Adolf Schneider's place, 1½ miles north of Llano River, and 5 miles east of the Mason County line, on a stream joining the Llano above Bauer's ford. Three holes from 15 to 30 feet deep have been sunk in schists which strike north and dip about 35° E. A little chalcopyrite associated with black garnet, epidote, quartz, and a little calcite may be seen in a layer of schist. Carbonates extend down only a few feet, and but little gossan is seen. The occurrence is on the west side of a tongue of fine-grained red granite which crops about 30 feet down the dip to the east.

Chalcopyrite and a little chalcocite were seen in the intrusive granite as well as in the schists, and a microscopic examination showed clearly its secondary nature—that is, it in part fills the cracks in feldspars. The solutions therefore which brought in the copper penetrated the rocks later than the intrusion of the granite and took advantage of existing fractures.

An assay of a sample representing about 200 pounds of ore selected by Mr. Schneider gave the following result: Gold, $0.41 per ton; silver, trace; copper, 0.94 per cent.

About 2 miles east of Magill Mountain and a short distance east of Pecan Creek, prospecting for copper has been carried on. Several shafts and crosscuts have been opened. At this point the pre-Cambrian schist series is cut by a network of pegmatite and quartz veins, the latter often paralleling the lamination of the flat-lying schist. The schist and the pegmatite also contain disseminated pyrite, chalcopyrite and bornite, with malachite and azurite. The prospects do not indicate a deposit of value.

In the town of Llano and in the near vicinity several pits have been sunk in the hope of developing a copper property, but nothing was seen which would invite further work.

Other prospect pits were seen at various localities, but in no instance were any of the showings of such a nature as to warrant further prospecting.

LEAD.

About 3½ miles north of Bluffton, Burnet County, on Silver Creek, a tributary of Beaver Creek, a small area of coarse pink granite protrudes beneath the Cambrian strata, and around the edges of this outcrop galena may be observed in the limy glauconitic quartz sandstone, which here rests by overlap on the granite. About 1½ miles north by west of this locality a similar occurrence is found on Beaver Creek, where again galena occurs in glauconitic sandstone near the base of the sandstone series and just below an outcrop of pre-Cambrian granite (on the creek). The locations of Beaver and Silver Creeks are shown on the map (fig. 20), and the geologic relations at the Silver

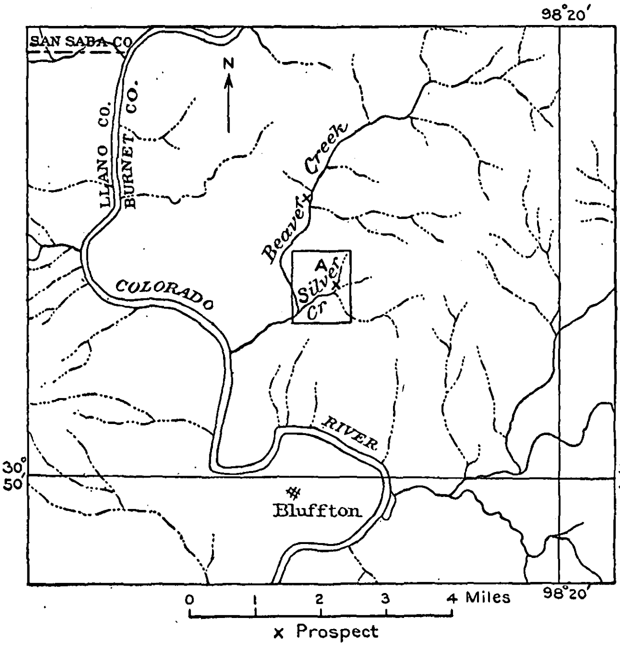


FIGURE 20.—Map showing location of lead prospects north of Bluffton and area (A) covered by figure 21.

Creek locality are shown in figure 21. It may be seen from these figures that at this point overlap occurs, because of the unevenness of the pre-Cambrian floor on which the sediments were deposited. It will be noted also that quaquaversal dips occur along the borders of the granite mass. In the field small faults accompanied by zones of slipping and brecciation were developed along this unconformity. These, with the steep dips (confined entirely to the contact), plainly indicate an upward movement of this granite mass, a movement of sufficient magnitude to flex the beds sharply, but not sufficient to do more than break them slightly. The structure at the locality on Beaver Creek is of the same type, though in that locality the folding of the beds due to a sharp uplift is even more beautifully shown (Pl. V, *A*).

The lead occurs apparently as a replacement of the limy sandstone, though it is not confined to that member, being found also locally in the limestone. It can not be said to follow the bedding consistently, though locally it may do so. It is found both near the granite floor and also a considerable distance, 40 feet or more, above it. A microscopic examination shows that the galena is most likely a replacement of the calcite which binds together the quartz and glauconite grains making up the sandstone.

Two shafts and a tunnel have been opened on the property. Only the tunnel was in condition to be examined. From the 65-foot shaft two or three veins of lead are reported by Dr. Osborne, who owns the property. Sixteen feet from the top of this shaft a vein reported 3½ feet thick is said to run 75 ounces in silver and 20 per cent lead.

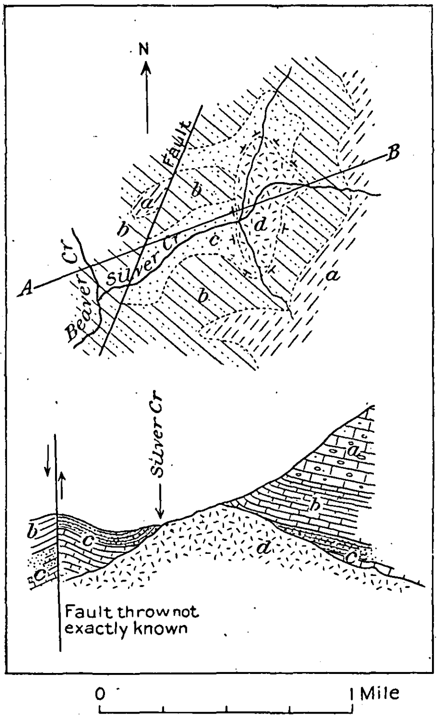


FIGURE 21.—Plan and ideal section showing relations of Upper Cambrian to underlying pre-Cambrian granite at lead prospects north of Bluffton. *a*, Ellenburger limestone; *b*, Wilberns formation; *c*, Cap Mountain formation; *d*, pre-Cambrian granite.

Some of the galena from this locality was examined for its silver content.[a] The method used, with the quantity of sample submitted, would not detect less than 8 ounces of silver per ton. No silver was detected.[b]

The tunnel is located a short distance south of Silver Creek on the western contact. It is run S. 68° W. in glauconitic sandstone. Thirty feet in, a crosscut is driven 7 feet northwest and 18 feet southeast. A bed of sandstone about 18 inches thick is here seen dipping 23° SW., and shows a little disseminated galena. At the end of the crosscuts and also at a point near the tunnel the drift has been widened, evidently for the purpose of following a body of ore which gave out. The tunnel was continued beyond the drift, but is reported to have struck no lead.

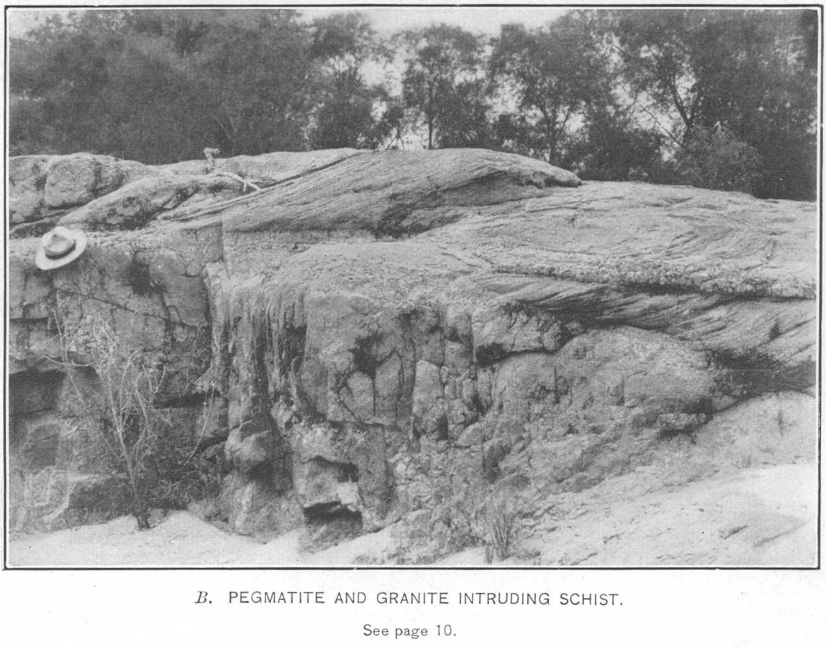
The origin of an ore deposit generally has an important bearing on a decision regarding the probabilities of developing a commercial deposit. The following suggestions are offered as an explanation of the occurrence described, but the writer does not thereby wish to

[a] W. B. Phillips (Eng. and Min. Jour., vol. 77, 1904, p. 364) reports the lead-bearing strata on Silver Creek to be 6 to 12 feet thick. Assays show between 10 and 20 per cent lead with no silver or gold.

[b] Munroe, Hall & Hopkins, chemists, assayers, engineers, Washington, D. C.

A. FOLDING OF UPPER CAMBRIAN SANDSTONE ON BEAVER CREEK, NEAR LEAD PROSPECT.

See page 75.



B. PEGMATITE AND GRANITE INTRUDING SCHIST.

See page 10.

create an optimistic sentiment regarding these ores; it can not be said that the prospects which were available for study would warrant such a view.

It is significant that in both the localities described the lead is concentrated in an area of local disturbance, where a dome-like uplift has to some extent brecciated the rocks and caused small faults to appear. It is noteworthy also that the pre-Cambrian basement at this point is about 100 to 150 feet higher than the pre-Cambrian floor to the west. Seventy to 90 feet above the glauconite horizon occurs a shale member of sufficient thickness to act as a fairly impervious cover. Waters carrying lead in solution circulating under artesian conditions might flow upward along the unconformity, reach this locality of relatively open space, and deposit lead sulphide. The chemical reaction which caused this precipitation must remain conjectural. If the deposition be due to any inherent quality of the inclosing rock, one would suspect that the presence of glauconite might have played a part.

It is interesting to note that this galena occurs in a series which is lithologically very similar to the Lamotte sandstone and the dolomitic Bonneterre limestone of southwestern Missouri, where workable ore bodies are found both in that sandstone and in the limestone above. If these Texas occurrences are of a similar type to those of southwestern Missouri, much irregularity may be expected in their distribution. Though many faults occur in the Texas region, some of considerable throw, they have no apparent connection with the galena other than the local effect due to the formation of open space by the brecciation described above. Considering their proximity to the basal unconformity and the presence of the shales above, it is suggested that the deposits owe their origin to lead-bearing solutions more or less controlled by the relatively impervious pre-Cambrian floor below and the relatively impervious shale above, moving laterally in past time under artesian conditions, the lead in solution having been derived by leaching from many feet of higher strata perhaps many miles distant from the present deposit.

GRAPHITE.

As the series of pre-Cambrian rocks described above were in part originally shales, sandstones, and limestones, they are now represented by schists of varying composition. Moreover, certain constituents have become, through metamorphism, of possible economic importance. Such an instance is the change of carbonaceous matter originally in the shales to graphite.

Graphite-bearing schists are widely distributed throughout the pre-Cambrian rocks, though the content of graphite is variable. In most places the graphite schists are associated with limestone or marble, a natural occurrence, for carbonaceous shales are often associated with limestone strata. Many of these schists can be traced for long distances.

Graphite-bearing schists were noted at many localities, but since only one of these is as yet considered of importance, a description of the occurrence at this locality will serve as a measure of those left undescribed; for it may be said in general that it would not be advisable to spend money on prospecting or testing at other localities until the deposit in question is proved a commercial success. If any exception be made to this statement, it would be that perhaps certain beds carry sufficient graphite to be of value as a source of paint pigment, in the industrial manufacture of which a very impure graphite can be used, as not more than 35 or 40 per cent of graphite is required in the paint pigment, the remainder being generally siliceous, aluminous, or ferruginous material.[a]

The locality which has received and warranted the most attention is located 1⅞ miles due south of Lone Grove, is approximately 1,500 feet west of Little Llano River and 800 feet north of the Houston & Texas Central Railroad.

The graphite occurs in graphitic schists of the upper or black series which in this vicinity contains considerable limestone. (See map, Pl. III, in pocket.) Granite and pegmatite intrusion has locally disrupted the beds to a greater extent than can be expressed on a map of the scale here published.

The graphite-bearing schists can be traced with interruptions for one-half mile northwestward from a point a little west of the railroad bridge, through the present workings, to a point where the series disappears beneath overlying Cambrian sandstones. Graphite is also reported across the river in the same trend.

The deposit has been prospected by a shaft with underground workings and by a number of surface cuts, four or more in a distance of about 500 feet. Two to the southeast of the shaft (about 150 and 300 feet from it, respectively) only show granite débris. One to the north of it about 150 feet is badly filled. A 70-foot cut about 25 feet north of the shaft gives an excellent exposure.

At the west end of the cut, a mixture of schist and pegmatite with calcite veinlets is exposed for 22 feet. There is a little graphite in the schist. Limestone is exposed in the extreme west end. Next to this 22 feet of lean material, an irregular mass is exposed, about 3 feet across and extending from the bottom to the top of the cut. It contains considerable graphite, mixed with quartz, feldspar, and calcite and represents a rich graphite-bearing layer intruded and broken by pegmatite with subsequent filling of fractures by calcite.

---

[a] Bastin, E. S., Graphite: Mineral Resources U. S. for 1908, pt. 2, U. S. Geol. Survey, 1909, p. 720.

At a first glance the impression might be formed that pegmatite had introduced the graphite. A careful examination of the graphite bunches in the pegmatite shows, however, that they represent broken fragments of schist. A specimen was polished and etched with hydrochloric acid, which by dissolving out the calcite contained between the laminæ of the schist fragments showed clearly the schistose nature of the graphite.

Following this mass is 6½ feet of fine-grained mica schist, carrying a small content of graphite, after which is exposed 6 feet of material similar to the 3-foot irregular mass described above. Seven feet of schist, practically barren of graphite, is followed by 25 feet of material similar to the irregular mass of graphite, feldspar, and quartz,

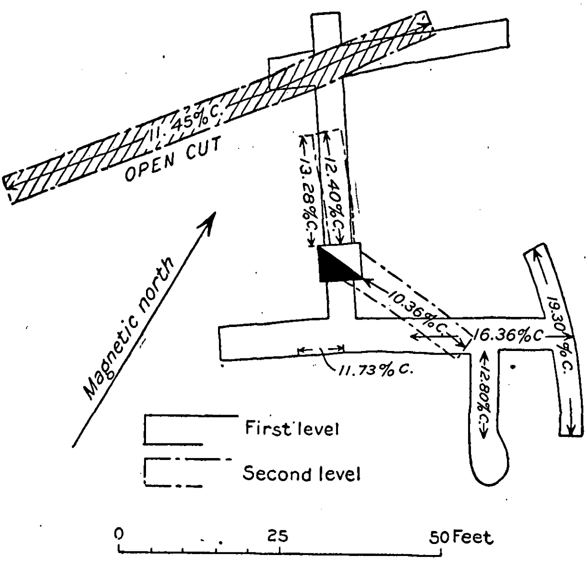


FIGURE 22.—Plan of workings at graphite property near Lone Grove.

but containing more of the latter material as the end of the cut is approached. Decayed granite appears in the east end of the cut.

The underground workings were not open at the time of the writer's visit.

An average sample taken over the length of the cut described above showed a carbon content of 11.45 per cent.

The locations of the shaft, cut, and underground workings are shown in figure 22. The first level is 55 feet below the collar of the shaft, the second 28 feet below the first. In addition to the workings shown in this figure is an exposure of some 5 feet of graphitic material in a small pit about 150 feet northwest of the shaft, and about 300 feet northwest of the shaft is a long crosscut 10 or 12 feet deep in greatly decomposed schist and gneiss, practically barren.

A private report made in 1902 by William Young Westervelt and furnished by the courtesy of Mr. R. H. Downman contains many interesting data on this property, and the following notes are abstracted from it:

The only point at which sufficient development work has been done to actually place "ore in sight" is at the shaft and associated workings, represented by the accompanying plate.

The shaft, for the first 5 feet, is built up through the dump, but with this exception is entirely in a mass of graphite ore from its collar to the first level. There being neither timbers nor ladderway in the shaft, except at the collar and levels, it was impracticable to take a sample of it. Careful samples of the levels and of the sump being secured, however, sampling of the shaft was not deemed necessary. On the first level, a drift runs northwest on a seam of graphitic shale about 5 feet wide, which is proved to exist for about 30 feet northwest of the shaft center and continues beyond. Sample No. 8 of this seam assays 12.40 per cent graphite. Southeast of the shaft, it is shown to exist at least 15 feet in this direction, and sample No. 7 across the seam, as shown in figure 22, assays 11.73 per cent graphite. The crosscut near the end of the northwest drift is barren. The crosscut at the end of the southeast drift, however, though barren to the southwest, enters a mass of graphitic material some 10 or 15 feet northeast of the drift and passes through 25 feet of the crystalline material.

A first and second drift on this ore, as shown in figure 22, are also largely on the ore. Samples Nos. 3, 4, and 6, taken in the drifts and crosscut, contain 19.30 per cent, 12.80 per cent, and 16.36 per cent graphite, respectively.

Between the first and second levels, graphitic shale is shown on the northeast side of the shaft; the balance of the shaft, however, is barren.

At the second level, as is shown in short dash lines in figure 22, there is a 20-foot drift running northwest. This drift is on a 2 to 4 foot seam of graphitic shale. Sample No. 2 of this seam contains 13.28 per cent graphite. East of the shaft a drift has been run in 25 feet, the south side and bottom of which are entirely in graphitic shale containing, according to sample No. 1, 10.36 per cent graphite. The width of the seam at this point is not, however, determined. Below the second level, in the 8-foot sump, graphite shale appears on the southwest side, and sample No. 5 shows it to contain 12.50 per cent graphite. The balance of the sump, however, including the bottom, is barren.

* * * * * * *

In addition to this ore in the mine, there are two dumps of ore, taken from the workings lying next the shaft. These I sampled by cutting trenches through them and drawing samples from the sides of the trenches. One, an annular dump, formed to make a walkway for the horse-whim, shows by sample No. 11, 12.20 per cent graphite, and contains according to my measurements about 1,747 cubic feet of loose material, or, according to my determination of specific gravity (see Laboratory tests et seq.), 80 tons.

Another dump, which I estimate to contain 1,800 cubic feet, or 89 tons, contains, according to sample No. 10, 10.47 per cent carbon.

A third dump, which shows practically no value on its surface, and which I was assured contained only waste from the barren portion of the workings, also contained about 1,800 cubic feet, but was not sampled.

To sum up, allowing for inevitable inaccuracies, there are in sight on the property at least 5,500 tons of 12 per cent graphite ore.

* * * * * * *

As the value of graphite in commerce depends not only on the percentage of the pure mineral present, but also on the physical qualities of this mineral, together with the composition of the impurities present, and as the value of graphite, in common with that of any ore, also depends on the economy with which a marketable product can be produced, I have undertaken a number of laboratory tests on the samples which I secured with a view to securing some indication of these points.

A brief description of these tests and their results is as follows:

A general sample was made up of all the samples secured underground, and crushed to pass a 10-mesh sieve. It was assayed and found to contain 14.50 per cent graphite. A portion was separated into various sizes and carefully examined. Flakes of graphite being noted, a series of tests were undertaken to determine the amount and quality of this material. Flaked graphite is largely used in the manufacture of crucibles and receives the highest price of any grade. In order to be classed as such, however, the flakes must be sufficiently large not to pass through a 60-mesh sieve. Accordingly, in making this set of tests, finer material than 60 mesh was first carefully screened out of weighed portions of the general sample, and the balance was washed on a vanning plaque.

These tests indicate that ore containing 14.50 per cent carbon (the assay of the made-up general sample) will yield from 1 per cent to 4 per cent of its weight of flaked graphite containing from 56 per cent to 40 per cent carbon, whose impurities contain less than 2 per cent each of iron (Fe) and lime (CaO)—the most common of the objectionable impurities for crucible manufacture.

After taking out the flaked graphite, the residues were crushed to pass the 60-mesh screen, and added to the fines which had originally passed through it. These were then also washed on a vanning plaque, and results were produced indicating that fine graphite could be produced amounting to from 27 per cent to 28 per cent of the original ore and containing from 29.75 per cent to 25.80 per cent pure graphite, the total recovery of graphite in the form of flake and fines being 60 per cent to 61 per cent of the total graphite in the original sample.

Another series of tests of a similar nature was then made on a selected specimen of the ore representing a class which I am inclined to think could readily be secured on a practical scale by hand sorting. This specimen contained the graphite in nodules of more or less pure mineral and showed, on assay, 21 per cent carbon. It was found to contain practically no value in flake graphite, but yielded a product amounting to 31 per cent of the original, containing 37 per cent carbon. This represents a recovery of 55 per cent carbon in the specimen.

A third set of tests was then made on a specimen of the graphite shale, which also could be very readily secured in practice by itself. This was found, on assay, to contain 16 per cent carbon, and yielded on vanning no flake, but a product representing 55 per cent of the whole, containing 24 per cent carbon. This represented a total recovery of 81 per cent of the carbon present in the original.

A fourth series of tests were made on the sample taken from the Lyman lot, which it will be recalled contained 15.27 per cent carbon. It yielded 1.44 per cent of the original as flake graphite containing 42.40 per cent carbon, and 21.8 per cent of fine material containing 40.40 per cent carbon. This represented a recovery of 61.6 per cent of the carbon present in the original.

Experiments were also made to determine the effect of bolting the fine product of vanning through 200-mesh bolting cloth, the vanned, graphitic material having first all passed 100 mesh. Before bolting the sample contained 25.80 per cent pure graphite. Twenty-two per cent of this material failed to pass through the 200-mesh bolting cloth, and was found to contain 41.30 per cent carbon. The balance was either passed through or lost in extremely fine dust and in the mesh of the cloth.

In order to estimate the tonnage of ore in the dumps at the shaft collar, a series of determinations of the specific gravity of the well-packed crushed ore was made. The average of these on sample No. 11 of the annular dump is 1.482. Of sample No. 10, the other ore dump, 1.591. This gives a factor of 21.6 cubic feet per ton of 2,000 pounds for the former and 20.2 cubic feet per ton for the latter.

To determine the tons of ore in sight underground a series of specific gravity tests were made on some of the specimens of the various classes of ore. The averages of these determinations are as follows:

Specimen No. 1	2.488
Specimen No. 2	2.448
Specimen No. 3	2.598
Average specific gravity	2.511

This gives a factor of 12.8 cubic feet per ton of 2,000 pounds.

When it is understood that much of the territory included in this property has not been adequately tested by surface cuts, it may be seen from these extracts that possibilities exist for the successful establishment of a graphite industry at this point.

About 2 miles south of Llano graphite schists trending in a northwest-southeast direction toward Sharp Mountain may be observed. This vicinity is, perhaps, with the exception of the property just described, the most favorable locality to prospect, though graphite schists do occur at many other localities throughout the region. It must be borne in mind, however, in estimating the graphite content of a given band of schist that a little graphite makes a very striking showing.

The graphite bands are confined entirely to the areas mapped as Packsaddle schist.

MANGANESE.

Five miles north of Llano, on the southeast flank of Horse Mountain, prospecting has been done on what is known as the Griffy manganese deposit. The schists and gneisses at this point strike N. 11° W. and dip 24° SW. Two pits are opened at this locality; the southern one is 15 feet long on the strike and 12 feet wide on the dip. About 2 feet of manganese oxide is exposed in this pit. Quartz is banded with the ore. About 90 feet north on the strike a second pit reveals much leaner material.

Both north and south from these pits at intervals small showings of oxide and silicate may be seen. An examination of the pits shows clearly that the oxide present is a decomposition product formed from the silicates, which are observed in place. Both spessartite (a manganese garnet) and piedmontite (a manganese epidote) may be found in considerable abundance. They are associated with quartz and feldspar in grains, forming layers and probably represent metamorphic equivalents of the original elements in the sediments. A microscopic examination of a specimen showed spessartite garnet intergrown with epidote accompanied by much muscovite and quartz and some magnetite. Decomposition in this vicinity is very shallow, and below the oxidized zone the deposits, because of the silicate nature of the minerals and their discontinuity and leanness, are without commercial value.

An analysis of the Horse Mountain ore, from a report of the Arkansas Geological Survey in 1890, by R. A. F. Penrose, jr., is given below:

Analysis of manganese ore, Horse Mountain, Llano County, Tex.[a]

Manganese	24.60
Iron	3.22
Silica	35.93
Phosphorus	None.
Lime	8.48

In Mason County manganese occurs in somewhat the same manner as at Horse Mountain and has been described in the report quoted.

RARE-EARTH METALS.

The Llano region was visited by Frank L. Hess in 1907[b] for the purpose of studying the rare-earth minerals, and the following notes are quoted from his report:

GENERAL DESCRIPTION OF THE DEPOSIT.

Baringer Hill is located about 100 miles northwest of Austin, Tex., on the west bank of Colorado River, near the western edge of the Burnet quadrangle as mapped by the United States Geological Survey. It is 12 miles north of Kingsland, the nearest railroad point, 16 miles west of Burnet, and 22 miles northeast of the town of Llano. It is a low mound rising above the flood plain of the Colorado and formed by the resistance to erosion of a pegmatite dike intruded in a porphyritic granite.

Few if any other deposits in the world, and certainly no other in America, outside of the monazite localities, have yielded such amounts of the rare-earth metal minerals as Baringer Hill.

The writer visited this region in the latter part of February, 1907, fortunately at a time when Mr. William E. Hidden, who has been largely instrumental in making this locality famous through his contributions to mineralogical literature on the rare minerals found here, was conducting mining operations.

The hill is named for John Baringer, who discovered in it large amounts of gadolinite about 1887. No one in the neighborhood knew what the mineral was, and specimens were sent to a number of places before it was identified. A piece fell into the hands of Mr. Hidden, who at once looked up the deposit and afterwards obtained possession of the property. Meanwhile Mr. Baringer had taken out a quantity of gadolinite estimated at 800 to 1,200 pounds, which was largely picked up and carried off by persons in the neighborhood as curiosities. Some of the choicer pieces, showing crystal form, found their way into various museums. The property is now controlled by the Nernst Lamp Company, of Pittsburg, Pa., and is worked by that concern for yttria minerals. Since its acquirement by this company a considerable amount of work has been done on the deposit, consisting mostly of open cuts around the edge of the pegmatite, reaching a depth of 30 or 40 feet. A large block, 30 feet in height and more in diameter, consisting mostly of quartz, is left standing in the middle.

* * * * * * *

Baringer Hill * * * is a small mound which, before mining was begun, rose, perhaps, 40 feet above a surrounding flat, was about 100 feet wide, and from 200 to 250 feet long. The longer axis runs east and west and is nearly at right angles to the course of the Colorado River at this point. The country rock is a coarse porphyritic

[a] Penrose, R. A. F., jr., Manganese: Ann. Rept. Ark. Geol. Survey for 1890, vol. 1, 1891, p. 447.

[b] Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 286-294.

granite with feldspar phenocrysts about 1 inch long. This granite seems to weather and erode rather easily, and the river has cut a flood plain perhaps one-fourth of a mile wide at this point, while the dike, owing to its greater hardness and freshness, has better withstood the erosion. The pegmatite, an unsymmetrical body with irregular walls, is intruded into the granite in what seems to be a pipe or short dike.

At the edges of the intrusion is a graphic granite of peculiar beauty and definite structure, being more like the textbook illustrations than the usual graphic granite found in the field. The altered band is from 1 foot to 5 or 6 feet thick and apparently surrounds the pegmatite. No segregation of the feldspar or quartz in particular parts of the dike can be noted, except that the feldspar may possibly be more inclined to occupy the sides of the intrusion. As far as shown it occupies most of the western and southern sides, and the quartz occupies the center and much of the eastern side.

One quartz mass is more than 40 feet across. The quartz has distinct white bands, from one-eighth to one-half inch wide, which seem to be due to a movement akin to flowage and are similar to those found in many pegmatitic masses in other portions of the country. The white banding is due to small liquid inclusions, many of them containing bubbles which either do not move from change of inclination of the fragment containing them, or do so but slowly. The cavities are minute, largely of irregular, angular shapes, suggesting at first glance particles of broken minerals, and occur in straight or broken lines that probably follow fine cracks which were later cemented. Groups of these cracks, with their inclusions, form the bands, which seem to lie approximately parallel to the walls of the dike or at such angles with them as might easily be formed by the flowage of the material into the space it occupied in the granite. The condition of the quartz seems to show that the pegmatite, after being forced into the granite, partly cooled and solidified and then made another small movement, or a series of slight movements, at which time the minute fractures were formed in the quartz and the magmatic fluids were forced into them, but as the mass was not yet totally solidified the cracks were effectually healed and the fluid was inclosed. Such movements may be supposed to have been consequent on the readjustment of the mass on cooling. Between the fracture bands the quartz is glassy and clear. At one place a vug was found large enough for a man to enter, lined with "smoky" quartz crystals reaching 1,000 pounds or more in weight. This would seem to indicate that the pegmatite had been intruded in a pasty or semifluid condition and that the vugs represent the spaces occupied by segregated water that was squeezed from the magma as the minerals took their final solidified form.

The feldspar is an intergrowth of microcline and albite, of a brownish flesh color, beautifully fresh, and occurs (1) in large masses reaching over 30 feet in diameter, and (2) as huge crystals, many of which, though they rarely show terminal planes, have one or more sharply defined edges, especially where partially surrounded by quartz. An edge 34 inches long was measured on one crystal thus embedded. A smaller crystal was seen which was about a foot long, weighed perhaps 20 pounds, and showed fine terminations and twinning planes.

A large amount of feldspar has been mined and thrown on the dump, and it is possible that in time the dump material may be utilized, either for its potassium content, as a fertilizer, or for pottery making.

Large crystals of fluorspar, measuring a foot along the edge, occur in the quartz, but this mineral does not form any considerable percentage of the mass. The fluorspar ranges from almost colorless to violet so dark that it is practically opaque. Where found alone in the quartz it was, so far as observed, of lighter color than where found with dark-colored minerals. Mr. Hidden informed the writer that it sometimes becomes luminous at the temperature of a living room.

Ilmenite occurs in radiating bunches of sheets or blades ranging from 1 inch to 10 or 11 inches in width and from one-sixteenth to one-fourth of an inch in thickness. In cross section the ilmenite looks like the ribs of a fan, with the outer ends from one-fourth to three-fourths of an inch apart. Similar aggregations take different angles, and numbers of such groups are found lying close together. With them occurs biotite mica in like bunches, the sheets of which are said to reach 3 feet in width by an inch in thickness. The mica is reported by Mr. Hidden to contain cæsium and rubidium, and to be close to lepidomelane in constitution. Small flakes of lithia mica reaching half an inch in diameter are found, generally along cracks in the quartz. No muscovite was seen, but it is said to be found occasionally. Compared with the mass the total amount of mica is very small.

THE RARE-EARTH MINERALS.

The greatest interest in the dike centers in the accessory minerals, particularly in the occurrence of the rare-earth metal minerals, which, as stated, probably have never been found at any other place in such large masses and in such quantities as in this locality. So far the excavations are comparatively shallow, and such minerals as are found are more or less weathered. Many show their crystalline form, but owing to alteration the crystals are now imperfect.

Allanite, a variable silicate of calcium, iron, aluminum, the cerium metals (cerium, praseodymium, neodymium, and lanthanum), and in smaller amount those of the yttrium group, occurs in large masses, one of which weighed 300 pounds and was embedded in purple fluorspar. It is a dense black mineral with a fine luster, and a hardness of about 6. Around the edges and along cracks it shows alteration to a brown substance having a hardness of about 5.5. The percentage of yttria ordinarily occurring in allanite is small and rarely exceeds 2½ per cent.

Cyrtolite is rather common in the dike in peculiarly fine, polysynthetic groupings with curved faces. It is brown on the surface, with a darker or nearly black interior, and is evidently a mixture of substances. It carries a considerable amount of zirconia and some yttria, and is supposed by Mr. Hidden to be an alteration product of zircon. If it is such a derivative, the original mineral was probably much more complicated than ordinary zircon. It makes a fair radiograph, which also gives evidence of its nonhomogeneity.

Fergusonite, a variable columbate of the yttrium group and other of the rare-earth metals, occurs in four varieties, so different as to be almost distinct minerals. The difference between them is due to oxidation and hydration. No anhydrous varieties are found. It is found in crystalline form surrounded by decomposition zones. Bunches of irregular crystals have been broken out, weighing over 65 pounds. It is generally a mixture of minerals, as may be easily seen on a smooth surface from the different colors. The difference in composition is strikingly shown in a radiograph, the variations being marked by difference in radiation. According to the two analyses by Hidden and Mackintosh,[a] the fergusonite obtained here carries from 31.36 to 42.33 per cent of yttria and accompanying rare-earth metals, and 42.79 to 46.27 per cent of columbium dioxide. The two analyses give 1.54 per cent and 7.05 per cent of uranium oxides. These are probably very irregularly distributed through the material, as shown both by the mineral itself and especially by its radiographs, which are of striking beauty.

Gadolinite, a silicate of beryllium, iron, and yttrium, is the most important of the minerals found here. It contains about 42 per cent of the yttrium oxides, with a molecular weight of 260, and occurs in crystals and masses of irregular shape up to 200 pounds in weight. The outer portion of the mineral and that adjacent to the cracks is altered to dense brick-red material, but the mineral itself is of a fine, glassy black, with a smooth conchoidal fracture. Thin splinters are bottle-green in color.

---

[a] Hidden, W. E., and Mackintosh, J. B., Yttria and thoria minerals from Llano County, Tex.: Am. Jour. Sci., 3d ser., vol. 38, 1889, pp. 483–484. The minerals of this locality have been well described by these writers in a number of papers.

It has a specific gravity of a little over 4.2 and a hardness of 6.5 to 7. A specimen collected makes no impression on a photographic plate with 50 hours' exposure.

Polycrase, a columbate and titanate of yttrium, erbium, cerium, and uranium, occurs in grains, small masses, and plates, the last associated with ilmenite in such a manner as to suggest the probability of replacement. It normally contains between 20 and 30 per cent of yttrium oxide, but is in too small amount to be commercially important. It is very radioactive and quickly affects a photographic plate.

Other rare-earth metal minerals found in the dike are yttrialite, rowlandite, nivenite, gummite of several varieties, thorogummite, mackintoshite, and tengerite. These minerals are apt to occur in any part of the dike, either in the quartz or the feldspar, but have so far been found mostly along the outer portions. A peculiarity of their occurrence is that they are found in bunches from which, if in quartz, radial cracks extend in every direction, and by following such cracks the minerals are found. An illustration of such an occurrence was published by William E. Hidden in 1905.[a] The cause of these "stars," as they have been called by Mr. Hidden, is not clear, but the thought suggests itself that the rare-earth metal minerals may have crystallized first from the magma and the solidifying quartz, being unable otherwise to accommodate itself to the incompressible nucleus cracked in this manner.

Mr. Hidden stated that in mining one of the largest pockets the faces and hands of himself and his assistant were affected as if by sunburn, and, as in sunburn, the covered flesh was not irritated. He suggested radioactivity as the cause, and inasmuch as the minerals under consideration are radioactive, the explanation seems plausible.[b]

The following was given by Mr. Hidden in a personal communication as a complete list of the minerals found in Baringer Hill:

Minerals found in Baringer Hill, Llano County, Tex.

Silicates.

Albite; } occur as intergrowths making up the mass of the feldspar.
Microcline; }

Allanite; a variable silicate of calcium, iron, the cerium metals, and less amounts of the yttrium group, in masses weighing up to 300 pounds, embedded in purple fluorspar.

Biotite; close to lepidomelane.

Cyrtolite; hydrated silicate of zirconium, yttrium, and cerium. Radioactive, abundant.

Gadolinite; a silicate of beryllium, iron, and yttrium in masses weighing up to 200 pounds.

Lithia mica; apparently a later deposition in cracks in quartz. Small flakes one-half inch or less across.

Orthoclase; not abundant.

Yttrialite; an anhydrous silicate of thoria, yttrium, and cerium earths. Contains about 30 per cent silica, 46 per cent yttria, 10 to 12 per cent thoria, and 5 to 6 per cent ceria. Does not occur in large quantity.

Rowlandite; practically a hydrated yttrium silicate. Contains 5 per cent fluorine.

Columbates.

Fergusonite; four varieties, due to oxidation and hydration. Neither is anhydrous. Purest, 5.65 specific gravity. So different as to be almost distinct minerals. Crystals surrounded by decomposition zones.

Polycrase; columbate and titanate of yttrium, erbium, cerium, and uranium. Contains about 25 per cent of yttria.

---

[a] Some results of late mineral research in Llano County, Tex.: Am. Jour. Sci., 4th ser., vol. 19, 1905, p. 432.

[b] Mr. Hidden has described this incident in the article referred to.

Oxides.

Hematite; specular, small quantity.
Magnetite; without metallic acids or rare earths.
Ilmenite; iron-titanium oxide in beautiful crystals, as well as plates up to 8 or 9 inches broad.
Rutile; titanium oxide, in prismatic and reticulated forms one-fourth inch thick.
Quartz; large masses and crystals of white quartz and "smoky" crystals up to 1,000 pounds in weight. Amethysts of gem quality reach 1 inch by one-half inch.

Uranates.

Mackintoshite; 3 parts thorite to 1 part uraninite; contains 13 per cent silica and a small amount of yttria. Radioactive; several times more so than its alteration product.
Thorogummite; formed from mackintoshite by addition of H_2O and alteration of UO_2 to UO_3.
Nivenite; a uranate of uranium, thorium, yttrium, and lead. Contains 10 per cent of lead. The most soluble uranate yet discovered; soluble in 5 per cent solution of SO_3. Prints well and gives great detail. Occurs in cubes and masses. (See Dana's System of Mineralogy, p. 889, for two analyses.) Alters to gummite.
Gummite; several varieties.

Phosphate.

Autunite; hydrous phosphate of uranium and calcium; secondary, not analyzed.

Carbonates.

Tengerite; carbonate of yttrium and beryllium. Generally globular, but occurs also as crystals up to one-sixteenth inch in length singly and as little nests. May be a mixture of beryllium and yttrium carbonates.
Lanthanite; carbonate of lanthanum, containing also cerium, praseodymium, and calcium. In incrustations on allanite.

Sulphides.

Chalcopyrite; iron-copper sulphide, massive, in small amount.
Pyrite; iron sulphide, cubic and octahedral.
Sphalerite; zinc sulphide; the purest fergusonite contains some zinc.
Molybdenite; molybdenum sulphide in scales 5 inches wide, which form masses weighing up to 10½ pounds. Alters to powellite.

Molybdate.

Powellite; calcium molybdate, in white crusts lining cavities where MbS has been. Sugary white radiating or plumose crystals, one-fourth to three-fourths inch long. Locally greenish.

It is interesting to note that among the numerous minerals in this dike no tourmaline, zircon, beryl, monazite, cassiterite, garnet, or tungsten minerals have been found. Cassiterite has been reported from the neighborhood, but its occurrence is extremely doubtful.

With the exception of the alteration products and probably of the lithia mica, which as noted, occurs along cracks in the quartz, all the minerals are believed to be original constituents of the dike.

The possibility of finding dikes having a like variety of minerals at once suggests itself, and much prospecting has been done for them. A few specimens of the rare-earth metal minerals have been found at other places in the neighborhood, but only a few, and in small quantity. However, similar dikes occur, as already stated, and these have not all been thoroughly investigated. It is to be remembered that these minerals form but a small fraction of 1 per cent of the mass, and it might easily happen that comparatively large amounts could exist in a dike and not be exposed at the outcrop. They are minerals which are altered to softer products by exposure, and would thus be easily removed by erosion and weathering. The cracks surrounding nuclei of the minerals should be useful in prospecting.

ECONOMIC VALUE.

The economic interest in the rare-earth metal minerals centers in their incandescence on being heated, and owing to this property they have been much sought. Thoria, beryllia, yttria, and zirconia show it in the greatest degree. It was found, however, that thoria and beryllia, which form the bulk of the incandescent oxides used in gas mantles, are too easily volatilized to be used in an electric glower, such as that of the Nernst lamp. Yttria and zirconia, however, will stand the necessary high temperature. Up to the discovery of this deposit it was practically impossible to get sufficient yttria-bearing minerals to manufacture the lamps, but fergusonite and gadolinite, with lesser amounts of cyrtolite, are found here in large enough quantity to meet the requirements. The zirconia is obtained from zircon brought from other localities.

In the manufacture of the glowers for the Nernst lamp, a paste consisting of 25 per cent of yttria and 75 per cent of zirconia is squirted into strips of the proper thickness, baked, and cut into the required lengths. When cold the mixture is nonconducting, but after being heated it becomes a conductor and gives a brilliant light.

The needs of the Nernst Lamp Co., which owns the deposit, require only the occasional working of the mine. After enough yttria minerals are obtained to supply its wants for a few months ahead, the mine is closed. But a few hundred pounds per year are extracted.

Rare-earth minerals have been noted at several localities besides Baringer Hill.

Professor Hidden mentions the discovery of two crystals of gadolinite about a mile south of Baringer Hill. Several pounds of allanite were taken from a mass of pegmatite outcropping as a low knoll about 2½ miles west-northwest from Kingsland, near Williams's garden. Fluorite occurs with the allanite at this place. The amount of prospecting is practically negligible.

In Burnet County, 2 miles due east of Baringer Hill and about one-half mile west of Shiloh Church, is another gadolinite locality. The matrix rock is like the pegmatite of Baringer Hill, but the mass is obviously smaller. The old workings consist of a shallow trench from which a few tons of pegmatite have been removed.

All the above-mentioned localities are in the area of coarse red granite. Outside of the granite area only one locality came under observation. Near the east side of Mr. Dorbant's pasture, south of the Burnet-Bluffton road, small masses of weathered rare-earth minerals are to be found in irregular narrow dikes of pegmatite inclosed in dark schists. This locality is about 4½ miles from Colorado River and 7 miles from Burnet.

ZINC BLENDE WITH FLUORITE GANGUE.

Deposits of fluorite carrying irregular amounts of metallic sulphide minerals occur at two localities west of Burnet within the drainage basin of Spring Creek. A fluorite-bearing reef has been opened on the Bailey place, about 4 miles from Burnet and a mile west of the Bluffton road. In this vicinity the rocks are pre-Cambrian gneisses and schists cut by minor masses of granite and pegmatite. Structural trends are east and west, the rocks, though poorly exposed, being evidently complexly folded. The outcrop of the fluorite reef is on top of a ridge between two of the upper tributaries of Spring Creek. The bulk of the rocks adjacent are feldspathic gneisses, but with these are interlayered masses of hornblende schist. Locally the strike of the different layers is about N. 60° E., and dips are to the southeast.

A mixture of fluorite and hornblende with a little quartz, feldspar, and chalcopyrite occurs in the form of a layer inclosed by light-colored gneiss. The material carries scattered grains of galena.

The deposit was prospected several years ago by means of a shaft and nine shallow excavations. A line joining the several openings trends N. 60° E. From what could be made out in 1909, it appears that fluorite was found along the strike of the layer for a distance of nearly 300 feet. On the southwest the mineral was encountered in five trenches, showing an extent along the reef of 100 feet. Counting toward the northeast, trench No. 5 shows a bunch of mineral which seems to represent the bottom of a shallow trough, as gneiss is exposed on both sides and below it. The next trench lies 135 feet northeast of No. 5. Here there is no evidence of the reef and the intervening ground is completely covered. However, about 40 feet farther on is the shaft, about which is piled a considerable amount of fluorite rock. This shaft contains water within about 20 feet of the surface. Its lower portion is evidently in feldspathic gneiss.

About 15 feet northeast of the shaft is a pit sufficiently deep to expose 20 feet of the fluorite-bearing layer measured down the dip, the dip being less than 10° SE. Thirty feet beyond, another excavation appears to have revealed no mineral, and the same is true of a long trench 325 feet northeast of the shaft. All the fluorite from this locality is white.

The purest masses of the mineral appear in the southwesterly pits, where the reef averages perhaps less than a foot in thickness. In the part adjacent to the shaft on the northeast, the reef has a maximum thickness of 2½ feet, but pinches and swells to a marked degree. Here the fluorite constitutes about 60 per cent by bulk of a granular rock containing hornblende, quartz, feldspar, and a little chalcopyrite. A carefully taken sample of the fluorite rock piled up about the shaft showed on assay a trace of gold and 0.38 ounce silver. Copper was not determined, but from the small amount of chalcopyrite in the fluorite rock this metal can hardly amount to more than 1 per cent.

Fluorite accompanied by zinc blende is found at several points in the upper valley of the north fork of Spring Creek on and near the Frank Thomas place. The locality is about 7 miles west of Burnet. The occurrence of the mineral is in layers conforming with the north and south trending structure of the inclosing dark hornblende schists. About half a mile north of the dwelling house a shaft has been opened to a depth of 25 feet. Here the layer or reef is about $3\frac{1}{2}$ feet thick at the outcrop. The material thrown out of the shaft is a mixture of fluorite sulphide minerals and a little quartz. Zinc blende is the most abundant metallic mineral, but galena, pyrite, and molybdenite may be observed. The assay of a carefully taken sample of the material thrown out of the shaft shows[a] zinc 7.60 per cent; lead, none; gold, a trace; silver, 0.56 ounce.

Whether or not this reef has any degree of continuity along the strike can not be stated, since no adequate surface explorations have been made. In the absence of any assurance of a continuous vein no estimate of the prospective value of this deposit is warranted. It may be said, however, that if only a few thousand tons of 7 per cent zinc ore could be developed there is no apparent reason against the possibility of profitable mining upon a small scale.

In the vicinity of the Thomas dwelling house fluorite has been discovered near the well on the east of the creek bed. The reef, which is not over 10 inches wide, trends north and south and stands nearly vertical. Going south along the strike the mineral has been uncovered in three or four places within a distance of somewhat more than one-fourth mile. At one point a shaft sunk in black schist encountered fluorite and chalcopyrite disseminated in black hornblende schist.

Other outcrops of fluorite were seen south of the eastward-flowing drain one-half mile south of the house.

Some of the fluorite in this vicinity is nearly free from other minerals, but specimens may be found which are made up of nearly equal parts of black zinc blende and fluorite, with a little quartz and a little pyrite. Such prospecting as has been done is not sufficient to demonstrate that these deposits have any promising degree of persistence.

SERPENTINE AND TALC.

Talc deposits have been found at a number of places within the pre-Cambrian rocks and serpentine has been found in a body of considerable size at one locality. Prospecting has been carried on with a view to proving commercial deposits at several places.

[a] Assay by E. E. Burlingame.

Serpentine.—The Collins property, located 9 miles south of Llano, a little west of the Oxford road, contains about 250 acres lying in a strip about 1½ miles long in a north-south direction. Near the north end of the property and on a hillside is a pit perhaps 20 feet in diameter and 10 feet deep. This pit is in serpentine and exposes on its west side a contact with soapstone. For perhaps 100 feet east and northeast of this pit and for at least 500 feet southeast and south serpentine is exposed.

At the foot of the hill a second pit about 30 feet in diameter by 10 or 15 feet deep exposes serpentine rock. At this point a diamond-drill hole was bored 275 feet deep without passing out of serpentine rock. Over the next pass to the south, serpentine is exposed for 100 feet or more down the slope, and a third pit about 10 feet wide by 20 feet long and 10 feet deep has been opened. Except a small outcrop of schist, the pit exposes only serpentine.

To the west and also partly surrounding these exposures of serpentine are very considerable exposures of soapstone, in which occur veinlets of asbestos and geodes of quartz and amethyst crystals.

It may be seen from the dimensions given above that a considerable deposit of serpentine and talc exists at this locality. Specimens were seen which took a fine polish. The commercial value of such a deposit will depend directly upon the demand that can be created for the serpentine.

Though blasting has been the only method employed in taking out material, blocks of considerable size have been extracted, and if more refined methods are used, there is no doubt that much larger blocks would be quarried and sawn into commercial sizes. An installment to carry on such work on a large scale would involve a considerable investment, and the opening of the property on a small scale would seem for the present more advisable. Market conditions and transportation would need to be carefully considered before any extensive plan of operation were adopted.

The relation of the outcrop of the body above described to the inclosing schist-gneiss series leaves little doubt that the deposit is an alteration product of a pyroxenic or peridotitic intrusive mass. As has been shown in an earlier portion of this report gabbroic and dioritic types of intrusives are present in the region. The presence of quartz and amethyst geodes and the occurrence of iron oxides in connection with the deposit point to the same conclusion; that is, they represent the silica and iron content derived from the breaking down of magnesian iron silicate minerals.

Talc.—Talc is found at a number of localities in addition to that associated with the serpentine deposit already described. In the area immediately east of Cedar Mountain, numerous small outcrops were seen, though in no case was any deposit mapped separately.

A small deposit also occurs 1½ miles west of Llano, and a deposit on which considerable work has been done is located about 1 mile north of Graphite station.

The small deposit west of Llano is formed without doubt by the hydration of magnesian silicate minerals developed by regional or contact metamorphism in pre-Cambrian limestone strata. A small pit is opened on the ledge, but stripping has been insufficient to prove the horizontal extent of the body. The presence of silicate minerals in the talc would destroy its commercial value. This point can only be determined by exploration work. Locally silicate minerals were noted in the material.

The talc deposits east of Cedar Mountain are associated with the dark series of schists described earlier in this report. This locality, however, is exceptional in that considerable bodies of dioritic rocks are intruded into the schist series. The talc in this area is probably in a large measure derived from limestones by the hydration of magnesian silicate minerals. It is almost certain, however, that some of the deposits are due to the alteration of basic intrusives or their equivalents, the amphibole schists. No large deposits of talc were seen in this vicinity, but considering the soft nature of talc and its tendency to break down and be covered up by surface soil, it is suggested that prospecting might reveal commercial deposits.

Surface outcrops do not give much information as to underground conditions at the property located a mile north of Graphite station. The following notes regarding underground developments are abstracted from a private report by William Young Westervelt, to whom part of the underground workings were accessible. The open cut described was poorly exposed at the time of the present writer's visit.

The property contains in all some 980 acres and the openings are all within a few hundred feet of the Houston & Texas Central Railroad. The workings are along a general northwest-southeast course and consist, commencing at the southeast end, of the following openings: A small shaft has been sunk 28 feet, from the bottom of which two crosscuts have been driven in northeast and southwest directions. At the time of visit the northeast crosscut was 13 feet from the center of the shaft. The southwest crosscut was too nearly filled to be accessible, though it was stated to be 9 feet long from the center of the shaft and, like the northeast drift, all in soapstone. The shaft itself was noted to be entirely in soapstone.

At 33 feet northwest of the shaft is an open crosscut 14 feet wide, 14 feet deep at one end, and sloping up in a northeasterly direction to a depth of but a foot or so at its northeast end, 40 feet distant. At the southwest end a schist wall is exposed, but for a distance of about 25 feet from the wall the cut is made entirely in soapstone. This soapstone in the deepest part exhibits considerable solidity, and apparently blocks of some size could be taken from it.

At 83 feet northwest of the first shaft is a second shaft 32 feet deep, but it was inaccessible. The dump consists entirely of soapstone, and it is probable that the shaft is wholly in that material. From the workings described there is good evidence that a mass of soapstone 20 feet wide by 90 feet long by 25 feet deep is present. The horizontal extent of this body can only be determined by more crosscuts and shafts, the outcrop being hidden by the surface mantle of soil.

The successful introduction of this material into the market will depend, first, on the size of the deposit that can be proved to exist, and second, on whether or not the several physical characteristics are present which are necessary in such material to permit competition with quarries operating in the East.

There is very little doubt that the deposit owes its origin to the hydration of magnesian silicate minerals developed in pre-Cambrian limestone by metamorphism. Such an origin would give to the deposit a bedlike character continuous in depth and horizontal extent only in so far as the silicate minerals had been developed and later altered to talc. As this process might result in deposits of great extent or in podlike masses of small size, it follows that exploration by crosscuts and shafts is the only practical method of exploring the deposit.

OIL.

A small oil seepage in a spring near the town of Burnet has deposited at the surface asphaltic material in the cracks and interstices of the neighboring limestones. In Post Mountain, also, a little oily residue is found about 20 feet above the base of the Cretaceous. The beds in which this oily residue is found are very near the base of the Cretaceous system, and consequently only a few feet above the underlying Paleozoic beds. (See geologic map, Pl. III.)

The underlying Cambro-Ordovician limestones, shales, and sandstones have not shown any indication of oil throughout the Llano-Burnet region. The Carboniferous strata of the region, on the other hand, have a decidedly petroliferous odor. Though the Trinity sand at Burnet is deposited on Cambro-Ordovician limestone, it is quite possible that a short distance to the east Carboniferous beds, raised by faulting, may be the basement upon which the Cretaceous sands rest. It is possible therefore that oil has passed from the underlying Carboniferous into the porous Trinity sand and spread laterally as far west as Burnet.

As has been pointed out by Taff and Reed,[a] the Trinity sand is of such character (being a beach or shallow-water deposit of siliceous

[a] Taff, J. A., and Reed, W. J., The Madill oil pool, Oklahoma: Bull. U. S. Geol. Survey No. 381, 1910, p. 513.

sand with thin beds of clay) as almost to preclude the idea that oil originated in that formation.

The lack of other indications of oil in other portions of the Trinity in this region, the structurally broken and eroded condition of the underlying Paleozoic, and the petroliferous odor of the Carboniferous beds point to the conclusion that though a small quantity of oil may have passed upward from below, it is extremely improbable that oil in commercial quantities is present in the Burnet and Llano quadrangles.

STRUCTURAL MATERIALS.

Limestone, sandstone, and granite are present in large quantities in the central Texas region, and in the pre-Cambrian schist series marbleized limestone beds also are found.

MARBLE.

Only a few attempts have been made to utilize the marbleized limestone beds occurring in the pre-Cambrian rocks. A small amount was quarried from an opening near Bachelor Peak and was used in part in the construction of the Llano courthouse. Recently an opening has been made by Messrs. Sellman and Bernard, of Llano, on a marble ledge on the northern edge of the town of Llano. The operators propose to work the deposit, at least at first, on a small scale to supply a local demand for such material.

It may be said in general that much of the marble in the pre-Cambrian is of slight value because of its impurities. It is not improbable, however, that ledges exist of sufficient width and length and of such color and purity that quarry floors could be successfully opened. Such localities can only be found by diligent search, with careful sampling by surface cuts or pits.

The marble is practically all of a fairly coarse crystalline type, more or less mottled blue or black. Some pure white ledges undoubtedly occur, but, taken as a whole, the material represents a common variety of stone and probably will never command a high price. That operations may be carried on at a fair profit, however, at some time in the future is probable.

SANDSTONE.

A sandstone quarry has been operated intermittently for a number of years at a point north of Fairland, Burnet County. A considerable quantity of this material has been shipped out of the county, and the stone is used also in neighboring towns. The quarry is opened in beds of the Hickory sandstone. At this point the material is a light brown, rather fine-grained sandstone. The beds dip gently into the hillside, and bedding planes are prominent and add to the ease with which the stone may be worked. A spur connects the quarry with the Houston & Texas Central Railroad. The demand for this stone at the present time is limited, competing as it must with abundant limestone building material at points beyond the Llano-Burnet region.

LIMESTONE.

Portions of the Edwards limestone and certain layers in the Trinity formation can be used for building purposes. The latter beds, of yellowish to white color, are quite easily extracted and in the quarry are often so soft that they may be sawed into blocks. This material becomes harder when exposed to the air.

GRANITE.

Granite forms a considerable proportion of the pre-Cambrian rock of the region. Unfortunately, however, from the viewpoint of the quarryman, all of this material is not available for use. In an earlier part of this report it was shown how the intrusion of granite had locally produced areas characterized by the presence of abundant schist fragments intermixed with the intruding rock. The condition is a very common and unfortunate one, and if it were not that many extensive areas also are underlain by clean stone the quarry industry in this region could have only a decidedly moderate growth. It may be said at once, however, that granting transportation and market, there is available an enormous quantity of clean granite in the region.

Of this material two very distinct types are present—(1) the coarse and very coarse grained granites and (2) the medium to fine grained granites, among which a number of varieties may be distinguished.

Of these two types the former is commonly free from such imperfections as would prevent its use, while the latter is locally marred or spoiled by the presence of schist fragments or iron pyrite.

By a glance at the map (Pl. III, in pocket) it may be seen that an extensive area of very coarse grained rock underlies the territory in southwest Llano County. Practically inexhaustible supplies of this granite lie above what would be railroad grade in the vicinity of Enchanted Rock. A further examination will show that both at Granite Mountain in Burnet County and north of that point are broad areas underlaid by coarse-grained stone. The wide distribution of the fine-grained types may also be seen, but of them it is not possible to predict that any given spot consists of clean granite, for, as explained above, various impurities may be present. In such areas only by careful examination can excellent quarry sites be selected.

A number of quarries have been opened in areas more or less characterized by the presence of schist fragments, and at other localities abandoned quarries were seen where the presence of iron pyrite must have been one of the factors leading to their disuse.

One fact directly dependent upon the geologic relation of the granite to the schists and having a decidedly practical bearing on the selection of quarry sites is this: In areas of mixed schist and granite (that is, where granite has intruded the schists in a complicated way) there can be no assurance that what is apparently an excellent quarry floor will hold its valuable qualities in depth. It is in fact probable that schist fragments will be encountered in such amount as either wholly to ruin the enterprise or to reduce profits to a minimum. It is of course true that the mass may continue clean, but the chance is too small to be worth the risk.

At the present time transportation facilities deeply affect the growth of the granite industry, the Parkinson group of quarries, for example, being so situated that a wagon haul of 6 miles is necessary. The haul for other quarries is as much as 11 miles. A number of quarries, however, have been operated near the railroad, the quarry at Granite Mountain (the most extensive operation in the region), on the Houston & Texas Central Railroad being a notable example.

At the present time, exclusive of that from the Granite Mountain quarry, by far the greater part of the stone quarried is used for monumental purposes. The stone, for example, from the Gootch & Wells quarry, on the Parkinson tract, and from the Norton quarry, 11 miles south of Llano, is a medium to fine grained gray granite, and takes a fine polish. Much of the granite is well suited for large structures and could be so utilized were transportation better and a more active market available.

Granite Mountain quarry.—The Granite Mountain quarry is located on the Houston & Texas Central Railroad at Granite Mountain, Burnet County, near the town of Marble Falls. The owners since 1893 are Darragh & Catterson. Before that date the property was owned by Lacey, Westfall & Norton.

The quarry is opened in the side of a broad, low, bare, granite hill. No stripping is necessary. Sufficient granite is exposed above the present railroad grade to furnish material for a great many years.

The rock is coarse-grained pink granite, consisting of quartz, microcline (dominant), albite-oligoclase, some orthoclase, and biotite. Though portions of the mass are intruded with pegmatite, an enormous quantity of fine material is at hand. A well-defined rift aids quarrying. Sheets of any desirable thickness can be lifted, and facilities for handling impose the only limit to the size of blocks that may be obtained. The greater part of the rock quarried has been shipped in 5 to 10 ton blocks to the Galveston jetty. This work was begun in 1891 and continued to 1898. Little work was done from 1898 to 1902 From 1902 to the present time about 1,000,000 tons of rock were shipped. Before that, however, 2,000,000 tons were shipped, and in addition 120,000 yards of crushed rock have been used on the same work. Probably 2,000,000 tons were used as cap rock.

The capitol building at Austin, begun in 1884 and finished in 1899, and courthouses in Galveston, Houston, and at other localities, are built of this granite. Nevertheless, but a small part of the output has been dimension stone. This class of stone will probably grow in importance.

The quarry is equipped with 20-ton rigging. There are 5 derricks, a 1,500-foot cableway, and a tram. The rock is generally swung direct to the cars. A No. 7½ Gates crusher is also installed. About two-thirds of the labor employed is white. Engineers are paid $2.50 to $3.50 per day; derrick men, $2.75 to $3; foremen, $4; common laborers, $1.50 to $1.75.

Freight rates per ton of rough granite to points in Texas range from $1 to San Antonio to $1.40 to Aransas Pass.

Teich quarry No. 2.—This quarry is a short distance west of Kingsland, Llano County, and is connected by a spur with the Houston & Texas Central Railroad. It is owned by Mr. Frank Teich, of Llano, and was opened in 1908. The rock is a coarse-grained pink granite, and takes a fine polish. The Memorial Church of Orange, Tex., is built of this rock. About 50,000 cubic feet have been extracted, valued at 50 cents a cubic foot. The quarry was not being worked when it was visited.

Mr. Teich operated a small quarry on the Parkinson tract 6 miles south of Llano during the summer of 1909. About 6,000 cubic feet was extracted and manufactured into monuments at Teich's polishing works near Llano. This quarry was abandoned in the summer of 1910. A new quarry, Teich No. 3, is being opened about 4 miles south of Llano on Mr. Sheeon's land.

Gootch & Wells quarry.—Gootch & Wells are operating a quarry on the Parkinson tract about 6 miles south of Llano. The quarry presents a very rough and irregular appearance. The pit is from 25 to 50 feet deep and about 150 long in an east-west direction. About 100 feet wide at the east end, it narrows to 15 or 20 feet at the west end. The rock lies in somewhat irregular sheets broken by vertical joints. N. 50° E. is the easiest break.

The following section will give an idea of the sheeting:

Section showing sheeting in Gootch & Wells quarry, Llano County, Tex.

	Feet.
Top ledge, not used (low dip northwest)	5–10
Rotten granite	1– 2
Thick ledge	12±
Rotten seam	½
Ledge	8
Ledge	4

The thickness of the sheets varies considerably, and the presence in parts of the quarry of pegmatite and schist inclusions spoils much rock. The stone is a beautiful gray granite, somewhat resembling the Barre, Vt., stone. It consists of quartz, microcline feldspar with a little albite-oligoclase and orthoclase feldspar. Biotite in small flakes is the dark mineral. The quarries are equipped with 4 derricks, gasoline engines, and 5 air drills. Plug and feathers are largely used for breaking on the finish work. The quarry can produce 250 cubic feet per day.

The granite is hauled to the Houston & Texas Central Railroad at Llano in wagons at a cost of 15 cents per cubic foot. Freight on rough stock varies from 50 cents to $2.50 per ton within the State limits. From Llano to Houston the rate is $1.45. The entire product of the quarry is used for monumental work. The actual cost of quarrying is about 40 cents a cubic foot, varying with the nature of the seams in the quarry. The rough stone is sold from the quarry. Dressing costs from $1 to $25 per cubic foot, according to the nature of the designs.

The best quality of stock sells for $1.50 a cubic foot, this grade being used for best polished work. The cheapest stock used for hammered work sells for 90 cents per cubic foot.

The quarry produced during 1908 about 18,000 cubic feet and will produce during 1909 about 22,000 feet. The entire Parkinson tract produced during 1908 (including quarries operated by Messrs. Patterson, Blodgett, Leiter, and Teich) about 33,000 feet.

Norton quarry.—The Norton quarry, owned by Mr. Norton, of Llano, is located about 11½ miles southwest of Llano and about 3½ miles a little east of south of Sixmile post office. The quarry pit is nearly rectangular and measures 95 feet long in a north and south direction. It is about 35 feet wide and 12 to 15 feet deep. Natural walls, caused by small north and south seams, make the west and east sides. The north end, trending N. 60° E., is a very straight break. The rock breaks easiest the "capping way," while north-south and east-west breaks are about the same in this respect. The stone is a bluish-gray, fine-grained granite composed essentially of quartz, and microcline feldspar, with a little albite-oligoclase and orthoclase. The dark mineral is biotite mica in fine flakes. A little chlorite is present. Pyrite was noted, occupying almost invisible seams; it is not abundant, however, though some fine blocks are spoiled by its presence. Schist fragments also spoil some of the rock. The plant includes 2 derricks and a horse winze.

Stewart quarry.—E. L. Stewart, in August, 1908, opened a new quarry near the old Stewart quarry, about 10½ miles southwest of Llano and about 2½ miles a little west of south of Sixmile post office.

The rock is a fine-grained gray granite. Pyrite is very abundant in parts of the old Stewart quarry near by and may also interfere with the new opening. Schistose material is included in much of the granite of the vicinity and this fact, combined with the presence of pyrite and the long haul to the railroad will probably prevent extensive developments. Two carloads have been shipped to San Antonio and Paris markets, principally for monumental purposes. The rock is hauled for 25 cents a cubic foot loaded at quarry and unloaded at Llano. Quarrymen receive from $2 to $2.50 per day.

Other quarries.—Mr. Bradshaw has opened a small quarry one-fourth of a mile west of the Gootch & Wells quarry. Only the top rock has been removed over a small area.

Mr. H. P. Bailey is also opening a quarry three-fourths of a mile north of Bradshaw's. Only a few cubic feet of rock have been quarried.

Mr. George Patterson is operating a quarry on the Parkinson tract south of Llano, but no notes are at hand covering the operations.

A number of quarries have been worked in the past, but are, for the present at least, abandoned. Such are the Town Park quarry north of Llano, where pyrite marred a very beautiful coarse-grained gray granite porphyry; the Kansas City quarry, 2 miles west of Llano on the Mason road, and the quarry 7 miles northwest of Burnet, where a very dark gray, slightly gneissoid granite has been quarried.

INDEX.