DESCRIPTION OF THE LLANO AND BURNET QUADRANGLES.

By Sidney Paige.

GEOGRAPHY.

LOCATION, AREA, AND CULTURE.

The Llano and Burnet quadrangles, in Texas, are bounded by parallels 30° 30′ and 31° north and meridians 98° and 99° west. Each quadrangle covers one-fourth of a square degree, or an area of about 1025 square miles. They include nearly

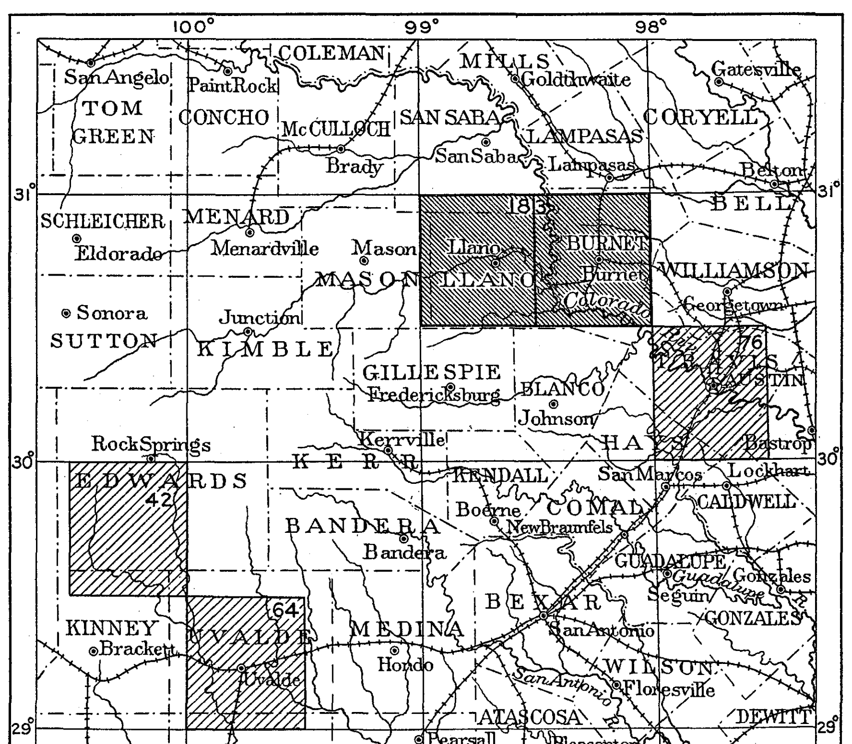


FIGURE 1.—Index map of central Texas.

The location of the Llano and Burnet quadrangles is shown by the darker ruling (No. 183). Published folios describing other quadrangles, indicated by lighter ruling, are as follows: Nos. 42, Nueces; 64, Uvalde; 76, Austin

all of Llano and Burnet counties and parts of Mason, San Saba, Travis, and Williamson counties. (See fig. 1.) The greater portion of each quadrangle lies within the county of the same name.

The more important towns are Llano, in the Llano quadrangle, and Burnet, Marble Falls, and Bertram, in the Burnet quadrangle.

Llano County is distinctly a stock-raising country, but much farming is carried on there. Burnet County is more characterized by farming but also raises much stock.

The region is accessible by the western division of the Houston & Texas Central Railroad, which traverses the central part of Burnet County and terminates at Llano, the county seat of Llano County. A spur from Burnet to Lampasas, 20 miles north, connects this railroad with the Gulf, Colorado & Santa Fe Railway and a short spur runs to Marble Falls.

GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION.

The broad physical and geologic features of the State of Texas have been well described by Hill and Vaughan.[a] Hill recognized six great provinces in the State—the trans-Pecos, the Great Plains, the central, the east-central, the eastern, and the southern—each of which he subdivided into small physiographic units. Of the broader features of relief he says:[b]

> In a broad sense the Greater Texas region consists of a vast and diversified plain bordered on the west and north by mountains. That portion between the eastern front of the Cordilleras and the sea may be primarily conceived as an elongated plain. This plain inclines gently from the Cordilleras toward the sea. The inclination from the foot of the Cordilleras to the Gulf is generally in an easterly direction, but there are slight variations of direction. The area having this general inclination may be specifically called the regional coastward slope, and its variation in gradient and direction, as will be explained later, has an important relation to the physiographic history. Except in the extreme northwest corner of Texas, where the great plains continue north unbroken, and on the east, where the Coastal Plain borders the sea or continues into Louisiana, the regional coastward slope is terminated by the Cordilleran and the Ouachitan mountain systems, which extend at approximately right angles to each other, diverging so as to inclose the plain in a triangle having its wide base toward the sea. The plain is rudely comparable to a wide, low stairway, leading upward from the sea to the Cordilleras, in which the various subdivisions of the plain represent the treads, local escarpments the risers, and the limiting mountains the balustrades. This analogy can not be carried far, for great irregularities occur in the width and tread of the steps, and the wear and tear of time has scarred and disfigured their relief, etched valleys where the drainage depressions have crossed the plains, and lowered the mountain walls. Some escarpment steps in exceptional instances face westward, or upstairs, while other subdivisions of the plain succeed one another without any well-defined feature of relief. Furthermore, the structure of the inclosing mountain systems is of two entirely different types and periods of architecture. The formations which underlie some of the plains are crumpled up in the Cordilleras and are deposited against the Ouachitas. Hence, parts of the plains are older than the Rocky Mountains and younger than the Ouachita uplifts.

[a] Hill, R. T., and Vaughan, T. W., Geology of portions of the Edwards Plateau and Rio Grande plain adjacent to Austin and San Antonio, Tex., with special reference to the occurrence of underground waters: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 183-322.

Hill, R. T., Physical geography of the Texas region: Folio 3, Top. Atlas U. S., U. S. Geol. Survey, 1900.

Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1900.

[b] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 29.

Hill subdivides the Great Plains province on a geologic basis into the Llano Estacado and the Edwards Plateau, the former being underlain by nonmarine Tertiary sediments and the latter, which merges imperceptibly northward into the Llano Estacado, being formed by the resistance to erosion of a marine Cretaceous limestone—the Edwards limestone. He differentiates the central province from the great plains largely because of its deeper erosion, the capping of Edwards limestone having been in the central province in great part worn away. The Llano-Burnet region lies along the northern border of the Edwards Plateau near its easternmost extension and along the southern edge of the central province. The area is basin-like, being etched below the level of the Edwards Plateau, and its form is due to a combination of structural and erosional conditions which will be described later.

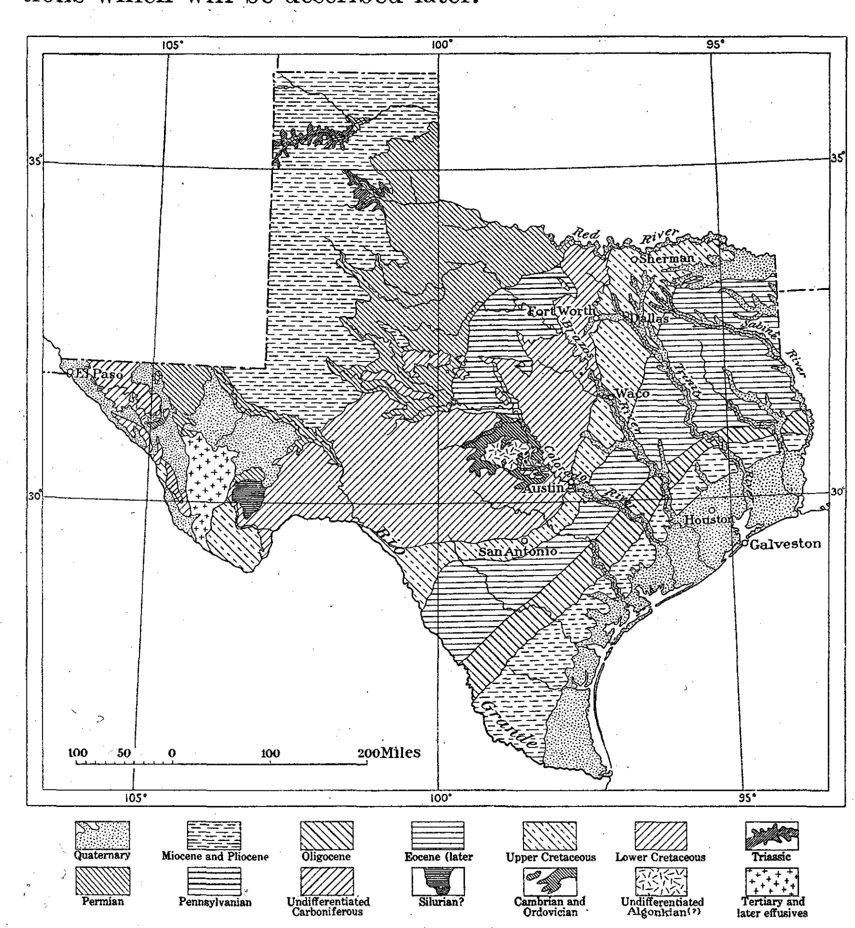


FIGURE 2.—Geologic map of Texas.

Shows geologic relation of the central Texas region. Reduced from Geologic Map of North America, U. S. Geol. Survey, 1912.

As may be seen by reference to the general geologic map of Texas (fig. 2) more than half the State is covered by marine Cretaceous and Tertiary sediments. In a broad way these rocks outcrop in successive northeastward-trending bands, the youngest occupying the Gulf Coastal Plain and the oldest overlapping the older rocks of the northern and northwestern parts of the State. Much of the northern part of the State is covered by Carboniferous rocks and terrigenous deposits of Tertiary sediment, and the western portion includes geologically complicated and diverse mountain ranges.

TOPOGRAPHY OF THE LLANO AND BURNET QUADRANGLES.

RELIEF.

General features.—Though the Llano-Burnet region may seem mountainous as compared with the relatively flat and featureless plateau country to the south, yet the relief of the region is hardly so great as really to warrant such a characterization. Llano River enters the Llano quadrangle at an elevation of 1175 feet. The highest points north of it within the quadrangle attain about 1900 feet—a difference of 725 feet. The hills near Hobson Mountain south of Llano reach altitudes of 1625 feet. Putnam, Prairie, Riley, and Cedar mountains reach elevations between 1800 and 1900 feet. Colorado River leaves the Burnet quadrangle at an elevation of 650 feet. The Cretaceous hills to the north do not rise much above 1500 feet—a difference of 850 feet. When measured from the general level of the surrounding country differences of elevation do not generally exceed from 400 to 600 feet, a vertical range which precludes the term mountains, steep and rugged though the hills may be.

The area included in these quadrangles may be divided into four physiographic units—the basin on pre-Cambrian rocks; isolated mountainous masses within the pre-Cambrian basin; the plateau on Paleozoic rocks; and the Edwards Plateau, on Cretaceous rocks.

Pre-Cambrian basin.—The most casual observer of the broad valley of Llano River will be impressed with its basin-like form. From such an eminence as Town Mountain, near Llano, a broad rolling plain may be seen stretching east, west, north, and south, interrupted here and there by hills and encircled by a scarp of Paleozoic rocks. Though many minor irregularities are encountered in traversing this broad stretch of territory, the shallow basin is mainly a feature of erosion in a pre-Cretaceous land surface. The steps in the development of this basin will be discussed more fully under "Physiographic development."

Isolated mountainous masses in the pre-Cambrian basin.—The irregularities within this plainlike area are of two types—(*a*) such mountain-like elevations as Riley, Packsaddle, Putnam, House, and Smoothingiron mountains; and (*b*) such heights as the groups of hills west of Oxford and northeast of Babyhead and the many isolated hills north and south of Llano. These eminences are all more or less modified parts of a pre-Cretaceous erosion surface, partly reduced remnants left by the erosion which formed the pre-Cambrian basin.

The first type is characterized by a general table-like outline formed by a capping of nearly horizontal beds, with steep marginal scarps. Smoothingiron Mountain, in the northwestern part of the Llano quadrangle, and Riley Mountain in the southern part, are examples. The main mass of Smoothingiron Mountain extends in a north-south direction about $1\frac{1}{2}$ miles and has a maximum width of about three-fourths of a mile. The mountain rises steeply 400 feet from the relatively even pre-Cambrian floor at its base. Its flat top is composed of the basal Cambrian sandstone (Hickory). Riley Mountain and its southern extension, Cedar Mountain, form a table-like mass about 15 miles long and several miles across at its widest point, standing well above the surrounding country. It is formed by subhorizontal Cambrian strata. Both of these mountain masses are broken by faults and folds which, as will be pointed out at another place, have had an important bearing on their formation.

The second mountain type is characterized by maturely dissected mountain groups and by isolated asymmetric conelike hills which rise abruptly from the surrounding plain. Such forms are Hobson Mountain, the irregularly dissected group of hills in the south-central part of the Llano quadrangle, and the mountain group in the vicinity of Babyhead. Sharp, Fox, Kings, Bullhead, and Watch mountains and Enchanted Rock (Pl. X) are likewise of this type. The slopes of these hills are in most places steep, and their summits are either sharp ridges or points. It seems probable that these eminences have been rather recently uncovered by the removal of Cambrian strata.

Plateau on Paleozoic rocks.—Encircling the pre-Cambrian basin just described is a more or less maturely dissected plateau, a surface cut in Paleozoic rocks. This upland is bordered by an exceedingly irregular scarp, a marked topographic feature of this region, of the same character as the scarps surrounding the isolated mesa-like mountain masses. It owes its position to erosion governed by faulting, and its structural significance will be discussed in another place. When approached from the plains below it appears as a more or less steep mountain flank, but when surmounted its true character is at once apparent.

The northern part of the Llano quadrangle lies within this plateau, the western portion of which is a rolling plain, becoming more broken and irregular to the east, toward Colorado River. East and southeast of this river the plateau is maturely dissected, though on the southern border of the Burnet quadrangle its plateau-like form is partly reassumed.

These differences of dissection which in detail are imperceptibly merged are clearly evident when separated areas are examined. The extreme northwestern part of the Llano quadrangle, for example, compared with other portions of the plateau, is almost flat. In the northeast corner of the Llano quadrangle dissection has proceeded further, producing numerous low rounded hills. In the northern part of Burnet quadrangle, along the Colorado, steep canyons are developed and the country is in every way more rugged. This sharply dissected portion does not continue southward. In the region southwest of Burnet only a rolling remnant of the plateau remains, represented by Backbone Ridge and its northeast extension.

Edwards Plateau.—The territory underlain by Cretaceous rocks, topographically considered, is all a dissected portion of the Edwards Plateau, and is confined in the main to the eastern half of the Burnet quadrangle. The remnants of the plateau level formed by the Edwards limestone extend as a number of ridges in a northwest-southeast direction from the town of Burnet. Within this Cretaceous territory nearly flat-lying rocks produce a distinct topographic type—benched and terraced slopes, conical hills contoured by hard and soft beds, and wide stretches of smooth, grass-covered plains. (See Pl. XI.) The extreme southern portion is maturely dissected, though here also the nearly horizontal attitude of the alternating softer and harder layers results in forms of extreme regularity. The relief in this portion is considerable, being greater than in any other part of the Cretaceous area.

DRAINAGE.

The whole of the Llano quadrangle and about two-thirds of the Burnet quadrangle is drained by Colorado River and its tributaries. The northeastern third of the Burnet quadrangle drains into tributaries of Brazos River, the chief of which are North Rocky Creek and the forks of San Gabriel River.

Colorado River.—Colorado River is a perennial stream rising northwest of this region on the flank of the Llano Estacado and flowing into the Gulf of Mexico. It enters the Burnet quadrangle near the northwest corner and flows southward and eastward in a series of winding curves, leaving the quadrangle near the southeast corner. For the first 7 or 8 miles of its course in this area the river has cut deeply into the Ellenburger limestone, forming precipitous bluffs along a portion of this section. Passing through the canyon-like stretch by a series of rapids and quiet reaches, the stream, after crossing Cambrian strata for a few miles, enters the pre-Cambrian basin, through which it meanders past generally low banks. Where it again flows upon Ellenburger limestone and then upon the Carboniferous rocks, however, in the southeastern part of the quadrangle, another canyon-like stretch is developed, and at Marble Falls the river descends 25 to 30 feet within a short distance. In this portion of its course, where the river crosses areas underlain by shale, it has a relatively broad flood plain.

Colorado River falls in its journey of about 70 miles across the quadrangle from an elevation of approximately 1025 feet to one of 650 feet. This gives a total fall of 375 feet and an average grade of nearly 5.4 feet to the mile. Its volume of flow varies through a wide range, and the stream is known and feared for its sudden rises or floods. At low stages of water the Colorado occupies only a portion of its bed, but during periods of high water it becomes an impassable, raging torrent.

The more important tributaries of the Colorado from the east and north are Deer, Beaver, Morgan, Sparerib, Hamilton, and Cow creeks. From the west and south, besides Llano River, the largest tributaries are Fall, Campground, Redrock, Sandy, Pecan, Slickrock, Flatrock, and Doublehorn creeks. Sandy Creek, which flows eastward and joins the river in the Burnet quadrangle, drains the southeastern part of the Llano quadrangle.

Llano River.—Llano River enters the Llano quadrangle near Castell, flows eastward across the quadrangle, and joins the Colorado at Kingsland. The stream is perennial, though, like the Colorado, subject to wide fluctuations in volume. Its course in this area lies entirely within the pre-Cambrian basin, and it descends by a series of deeps and shallows, due to the variable hardness of the rocks over which it flows, from an elevation of 1200 feet near Castell to one of 800 feet at its mouth. The river carries a heavy burden of sand and during low water occupies only a part of its channel. Its flood plain is limited to narrow strips along its course.

Its principal tributaries from the north are Little Llano River and Elm, San Fernando, Johnson, Pecan, and Mitchell creeks. On the south the larger streams are Hickory, Bullhead, Sixmile, Flag, Oatman, and Honey creeks.

Subsidiary drainage.—For convenience in pointing out the salient features the smaller streams of the region may be grouped with respect to the geologic age of the rocks over which they flow. The streams in the area of pre-Cambrian rocks owe their character both to the nature of the rocks and to the maturity of the erosion which has taken place. The pre-Cambrian area, as has been stated, is a broadly eroded, shallow, and plainlike basin. The streams within it are characterized by broad, open valleys and moderate gradients and are generally overloaded with waste. In most of these streams little or no water is visible during much of the year, especially in seasons of light rainfall, and the slowly moving currents can be found only by digging through a variable thickness of sand. The streams rise rapidly during torrential downpours but soon fall again and disappear beneath the sand. During protracted droughts even relatively large streams, such as San Fernando Creek, Johnson Creek, Sandy Creek, and others of their type, become partly or wholly dry.

Many of the streams flowing in the areas underlain by Paleozoic rocks have more sharply cut valleys than those just described and are apt to flow for longer periods on account of the more general prevalence of perennial springs in these areas. Deer Creek, Beaver Creek, and Morgan Creek, for example, have, along their lower or middle reaches, rather steep walled canyons cut in more or less horizontal limestone and are fed by springs at several places along their courses. Unlike the streams of the basin area, these streams are generally actively cutting but are often limited in the dissection which they can accomplish by a scanty supply of water. (See Pl. VII.)

Most of the streams in the areas of Cretaceous rocks erode their channels when water is supplied by abundant rains. The valleys of many of these streams, especially in the southeastern portion of the area, where the plateau is rather sharply dissected, take the form of walled canyons, on account of the flat-lying, alternating hard and soft limestone layers which here make up the Cretaceous strata. Back from these bluffs the valley sides slope away more gently, being cut as with a lathe into terraced subconical hills. It may be said in general of the minor streams that their flow is more or less intermittent and directly dependent on a fluctuating and rather meager rainfall. Exceptions are Cold Creek, Little Llano River, Hurley Creek, and a few other streams fed by strong springs.

In the northeastern portion of the area, a region removed from the stimulating effects of the Colorado drainage, the relief is more gentle and the streams are characterized by relatively broader and more open valleys.

Springs. — Almost all the springs are situated in areas bordered or underlain by Paleozoic rocks. They are especially abundant along the outcrop of unconformities and are also localized by such structural features as faults. In addition they occur at other horizons in the Paleozoic sediments.

Of the springs associated with a definite horizon, the most numerous perhaps are those at the basal contact of the Cambrian strata. These springs owe their origin to downward-percolating water reaching and flowing along the relatively impervious pre-Cambrian floor. Where the unconformity cuts the surface, as at the foot of the scarp surrounding the pre-Cambrian basin, this underground flow issues as springs, most of which are of excellent quality.

Springs occur also, perhaps in as great numbers as those just described, at or near the base of the Ellenburger limestone, which is an especially favorable horizon for their formation. The overlying Cambrian and Ordovician rocks, being wholly calcareous, afford many opportunities for water channels to develop. The water, working its way downward, reaches the practically impervious beds of the Wilberns formation and must perforce flow laterally. If opportunity is afforded, as along scarps or in stream canyons, it issues as springs.

Fault planes, too, have played an important part in the localization of springs. Cold Creek and Little Llano River are instances of streams fed by springs which owe their position to fault planes acting as barriers to underground flowage and at the same time permitting water to rise along these planes under more or less head. West of Burnet, at the fault contact of the Hickory sandstone with the Ellenburger limestone, the same condition exists.

In the Ellenburger and also in the overlying Carboniferous limestone springs occur at favorable localities, where water from channels that have formed in the easily dissolved limestone finds egress to the surface.

CLIMATE.

The uncertainty of rains renders more or less precarious the maturing of crops, and, although the droughts cause serious injury to cattle owners, the small farmer is the greatest sufferer during such periods. An average of about 20 inches of rain falls during the year,[a] the heaviest precipitation occurring in the spring and fall. The region is rarely visited by snow, but destructive hail storms are not uncommon. High temperatures at midday, ameliorated in the spring and fall by cool nights, are the rule for half the year, but during the winter cold rains and winds from the north, commonly termed "northers," add severity to the season. When grass is plentiful, however, stock does well without shelter.

VEGETATION.

On the rolling plains of Llano County mesquite, persimmon, several varieties of thorny bushes, and cacti of various types abound, giving to the landscape a semiarid aspect. Many varieties of grass afford good pasture for herds, and along stream courses there are numerous deciduous trees, oak, gum, elm, pecan, and cottonwood being the more important. The cutting of cedar, which abounds on the slopes and tops of ridges in the areas underlain by Paleozoic limestones, has been carried on for years. Post oak and blackjack are the dominant woods in areas underlain by granite, though these trees with their associated types, live oak and shin oak, are well distributed over much of the region.

The rolling grass-covered plateau, stretching northward for miles in San Saba County and northern and northeastern Burnet County, affords grazing land for large flocks of sheep and herds of cattle.

[a] Summary of the climatological data for the United States, by sections, U. S. Weather Bureau, 1908.

DESCRIPTIVE GEOLOGY.

PREVIOUS WORK.

Before the detailed account of the geology of the Llano-Burnet region is given, reference should be made to the results obtained by earlier workers. Theodore B. Comstock[a] gives a brief and concise account of the results accomplished in the region prior to his studies, and it is not advisable to repeat such an account here. It is sufficient to mention the names of B. F. Shumard, J. W. Glenn, Frederick Roemer, Arthur Schott, S. B. Buckley, A. R. Roessler, W. E. Hidden, Robert T. Hill, Ralph S. Tarr, and Charles D. Walcott, all of whom contributed to the knowledge of the region. Inasmuch as certain important conclusions announced by a number of the earlier writers, especially by Comstock, are at wide variance with those reached by the author of this folio, it is necessary to state clearly the more important differences.

B. F. Shumard[b] made valuable contributions to the knowledge of the region by measuring a number of sections and making important collections of fossils. His work, with a few exceptions, was excellent as far as it went. He gave the following section at Morman Mill:

Section at Morman Mill, Tex.

	Feet.
1. Massive beds subcrystalline calcareo-magnesian limestone, variegated with brown and purple and forming rough cliffs	290
2. Gray micaceous sandstone made up of fine grains cemented with argillo-calcareous matter	5

Shumard considered the limestone of this section as part of his Calciferous sand group and the sandstone as Potsdam. He therefore did not recognize the fault at that place. (See Pl. III.) The limestone is mapped in this folio as the Ellenburger limestone, of late Cambrian and early Ordovician age, and the sandstone is regarded as a lentil in Carboniferous shale. Again, though Shumard seemed to recognize that his basal sandstones were "based on granite," he appears to have regarded at least a part of the granite as intrusive into Paleozoic beds, for he speaks of these beds as being "highly metamorphosed near the granite." No evidence of post-Cambrian intrusion was noted by the author of this folio, and the lowest Paleozoic beds were invariably found overlying intrusive rocks of the pre-Cambrian complex.

Charles D. Walcott[c] states that the base of the rocks of Potsdam age rests unconformably on a great formation that is stratigraphically the equivalent of Powell's Grand Canyon series (Unkar and Chuar groups). For this series of pre-Potsdam strata he proposed the local name Llano group. He says: "Massive reddish-colored sandstones rest on alternating beds of shale, sandy shale, sandstone, limestone, and schist. The strata exhibit but little evidence of metamorphism, being indurated but little more than the beds of the overlying Potsdam and Carboniferous." On the same page he says: "Across the valley of Honey Creek, 4 miles west of Packsaddle Mountain, the strata of the Llano group have been more metamorphosed, plicated, and broken by intrusive dikes of granite."

The Llano series has proved to be a completely metamorphosed series of schists, marbles, and gneisses and can be classified as Algonkian in contradistinction to Archean only on the very broadest evidence, such as the preponderance of metamorphic sediments over igneous material. Roessler's description of these rocks as granitic, metamorphic, and igneous was therefore concise and, possibly except for his reference of the series to the Archean, correct.

Lack of space prevents individual discussion of all the statements made by Comstock which are now considered to be misinterpretations and to be readily traced to a few broad misconceptions, as noted in the succeeding paragraphs.

1. He did not recognize in full the nature of the unconformity at the base of the Cambrian and did not sufficiently consider the unevenness of the floor of deposition and the consequent variations in the texture and composition of the beds deposited on it.

[a] First Ann. Rept. Texas Geol. Survey, 1889, pp. 239–378.
[b] The primordial zone of Texas, with descriptions of new fossils: Am. Jour. Sci., 2d ser., vol. 32, 1861, pp. 213–221.
[c] Am. Jour. Sci., 3d ser., vol. 28, 1884, p. 431.

2. Though he seemed to recognize the presence of faulting, he did not use this knowledge to explain the presence of contemporaneous beds in apparently illogical positions.

3. He connected granitic intrusion (of pre-Cambrian age) with movements due to faulting (of post-Paleozoic age).

4. He did not recognize the danger of correlating pre-Cambrian schists over distances as great as from Canada to Texas.

5. He recognized "trends" and unconformities in the pre-Cambrian but failed to delineate any such divisions.

6. He was misled into making statements regarding the iron ores of the region because of his misconceptions regarding the pre-Cambrian structure and stratigraphy.

Each of these points will be very briefly discussed.

1. Comstock divided the strata which he assigned to the Cambrian into three series—the Katemcy (Upper Cambrian), the Riley (Middle Cambrian), and the Hickory (Lower Cambrian). He says in describing his Hickory series:

> Whenever I have seen good contacts of the Cambrian with the Texan strata [one of his pre-Cambrian divisions] and in many cases where the granites directly underlie the Cambrian, there is a set of beds which differ from the typical Potsdam sandstone. In every case in our region in which the upper contact of the terrane can be determined there is an unconformity, although this is not always detected by casual observations. * * * Probably the best outcrops of the lowest member of the series are those in the neighborhood of House Mountain in the valleys of Hickory Creek and its tributaries, * * * in many other places, as at the summits of Smoothingiron, Fox, Town, Sandstone, Sharp, Packsaddle mountains, etc.

These basal beds which Comstock describes are geologically contemporaneous with all the basal Cambrian beds of the region. Their varying altitude is due partly to faulting and partly to folding, as in Smoothingiron Mountain, or to an original unevenness in the pre-Cambrian floor. The unconformity at the top of his Hickory series to which he calls attention has never been observed by the writer.

2. In describing his Riley series he fails to recognize the structure at the east end of Packsaddle Mountain, where faulting has dropped the western portion of the mountain with respect to the smaller eastern portion. He does not recognize the fact that Smoothingiron Mountain owes its relative elevation to a downthrown block to the east and that the beds exposed on its summit are equivalent, where faulting has not cut them out, to those forming the base of the scarp to the northeast.

3. On page 286 he says:

> On the top of Sandy Mountain * * * this Hickory layer has been considerably altered by heat so as to exhibit in different parts a gradual transition from above downward, between the compact massive sand rock and a rock which most lithologists would call a granite. Similar conditions exist on Sharp Mountain, House Mountain, Smoothingiron Mountain, and elsewhere, but not on Packsaddle Mountain. * * * It seems clear that the pulsations of the granite magma produced several broad folds in the Hickory strata, leaving certainly two great synclinal basins to be afterward partly filled by the later Cambrian sediments.

He could not therefore have observed accurately the nature of the granite intrusions, as is also shown by the following statement on page 259:

> Most of the exposures of granitic rocks in direct contact with the Potsdam sandstone and later strata are of different character from the Burnetan gneisses * * * and their relations to the overlying beds show that their eruption has been later than the deposition of the capping material.

The writer found no instance of contact metamorphism in any post-Cambrian beds, nor was any intrusive into these beds noted. Moreover, the basal Cambrian beds in many places contain fragments of the underlying igneous rocks.

4 and 5. Comstock divided the rocks he called pre-Cambrian into an Archean and an Eparchean system; the former contains two unconformable groups and the latter a third group. Each of his Archean groups he divided into three series and his Eparchean group he also divided into three series—nine series in all. It is impossible to follow his distinctions, nor were such structures observed by the writer as would warrant any such detailed division. Though the danger of making long-distance correlations has been recognized for many years, nearly all his divisions are compared or correlated with Canadian or other distant occurrences.

6. In directing attention to prospecting for iron ores he lays too much stress on the presence of bands of red soil as favorable indications and in a map[a] he shows a series of straight lines, or "trends," of economic importance, which do not represent any structures observed by the writer.

DESCRIPTION OF THE ROCKS.

The Llano-Burnet region lies within and is nearly surrounded by the lowermost Cretaceous rocks. Within the depression which forms this region ancient crystalline schists and granites are exposed and upon them are deposited unconformably Cambrian, Ordovician, and Carboniferous strata. The Lower Cretaceous rocks lie as a blanket over these older strata except where they have been removed by erosion.

[a]Second Ann. Rept. Texas Geol. Survey, 1890.

COMPARISON WITH OTHER REGIONS.

As the rocks exposed in this region represent geologic time intervals extending from possibly the earliest recorded sedimentation to a relatively recent geologic date (the Cretaceous), it may be well briefly to compare the nature of the pre-Cambrian complex and the broad characteristics of the Paleozoic section with those of the rocks in similarly denuded areas in neighboring regions. Such areas are found in the Ozark, Arbuckle, and Wichita regions to the northeast, in the El Paso and Van Horn quadrangles to the west, and at many localities in Arizona and New Mexico.

On comparing the central Texas region with the areas to the northeast marked differences, both in the pre-Cambrian and Paleozoic rocks, are at once noted. In central Texas the pre-Cambrian complex is made up largely of schist and gneiss, much of which is of undoubted sedimentary origin. In the Ozark region and in the Arbuckle and Wichita mountains the pre-Cambrian rocks are wholly igneous, granite, granite porphyry, and some gabbroic rocks forming the floor on which the basal Paleozoic beds were deposited. An examination of the Paleozoic column reveals also wide differences in the sedimentary record, that of central Texas showing great gaps that represent intervals of time during which deposition was not taking place, or areas where erosional unconformities have been produced. In the Arbuckle Mountains the Upper Cambrian, Ordovician, Silurian, Devonian, and Carboniferous (Mississippian, Pennsylvanian, and Permian) are represented. In the central Texas region the late Cambrian and early Ordovician rocks are decidedly thinner than to the northeast, and part of the Ordovician, the Silurian and Devonian systems, and the Mississippian and Permian series are lacking. In the Wichita Mountains of Oklahoma much the same sequence as in the Arbuckle region is believed to exist beneath the overlapping Permian red beds, which cover a part of the Ordovician, the Silurian, the Devonian, and a part of the Carboniferous strata.

The sections in southwestern Texas also show striking differences from those of central Texas. The pre-Cambrian rocks of the El Paso quadrangle have been divided into a lower formation composed of 1800 feet of quartzite and a rhyolite porphyry flow 1500 feet thick resting on the quartzite. On this rhyolite flow were deposited the basal beds of the Cambrian system. In this region, moreover, post-Carboniferous granite intrudes the Paleozoic formations. In central Texas there is no post-Cambrian granite. In the Van Horn quadrangle, 60 miles east-southeast of the El Paso, metamorphic rocks probably similar in type to those of central Texas are reported to occur in the pre-Cambrian complex. In the Paleozoic section the most marked differences lie in the presence in the El Paso quadrangle of Upper Ordovician and Silurian rocks. As in the central Texas region, however, Devonian and Mississippian strata are absent. The sequence represented in the Van Horn quadrangle is perhaps, of all those under comparison, most similar in a broad way to that of central Texas, for Silurian, Devonian, and Mississippian rocks are absent and the Pennsylvanian series is represented. It is true that the Van Horn area contains Upper Ordovician rocks, which are not found in central Texas, but it is very probable that the upper part of the Ellenburger limestone of central Texas is equivalent to a portion of the El Paso limestone of the Van Horn quadrangle. The Van Horn area differs distinctly, however, from the central Texas region in containing a thick series of rocks which carries a fauna not found elsewhere in America, having Permian affiliations, and named Guadalupian by G. H. Girty.

ALGONKIAN (?) ROCKS.

SUBDIVISIONS AND GENERAL DISTRIBUTION.

Four principal subdivisions of the pre-Cambrian rocks have been recognized in mapping this area—(1) the Valley Spring gneiss, which includes acidic gneisses, quartzite and its derivatives, light-colored mica schist, and bands of wollastonite, with some bands of dark basic schist; (2) a series of dark-colored, predominantly basic rocks called the Packsaddle schist, comprising amphibolite, graphite and mica schist, limestone, and basic intrusives (some intrusive granite is mapped with each of these formations); (3) a very coarse grained pink granite which could not be separately mapped in some parts of the area; and (4) all the remaining granitic rocks, including a number of varieties. These are all regarded as probably of Algonkian age. The Valley Spring gneiss and the Packsaddle schist together compose the Llano series. In addition to these major distinctions, bands of crystalline limestone and wollastonite have been separately mapped wherever possible. The outcrops of a quartz porphyry of peculiar type, locally termed opaline granite, a mass of serpentine (altered peridotite) near Oxford, a mass of metadiorite, and a felsite dike east of Click have also been mapped separately.

The areal distribution of the gneisses and schists is dependent primarily on their major structural relations but is modified by igneous intrusion. The major axes of folding have a general northwest-southeast trend, but the continuity of the formations is broken by faulting and by intrusive granite masses. There are two major anticlinal axes, one passing through the center of the mountains just west of Oxford, the other extending from Packsaddle Mountain northwestward to a point west of Babyhead. Between them lies a major synclinal axis, which passes a short distance west of Llano. This broad synclinal belt is occupied chiefly by the Packsaddle schist; the anticlinal axes are marked by areas of the Valley Spring gneiss. The Packsaddle schist overlies the gneiss and therefore, where the relation is not disturbed by granite masses, is found on the eroded flanks of these great folds. The major axes of folding do not represent a simple structure, for minor folds, some of which have been recognized, are superimposed on the major folds, and local complexities of structure are numerous. The thickness of the gneisses and schists has not been determined.

LLANO SERIES.

Llano series is the name applied to the metamorphosed series of schists, marbles, and gneisses which represent the pre-Cambrian sedimentary rocks of this region. The series, which is tentatively regarded as of Algonkian age, is divided into two formations, the Valley Spring gneiss and the Packsaddle schist.

VALLEY SPRING GNEISS.

Definition.—The name Valley Spring gneiss, which is given to the lighter-colored series of metamorphosed pre-Cambrian sedimentary rocks, was first applied by T. B. Comstock[a] to one of his pre-Cambrian subdivisions. The term is redefined by the author of this folio, and its use strictly limited by the geologic interpretation herein set forth. The type locality is Valley Spring, in Llano County.

The mapping of this formation was attended locally by many difficulties, partly in separating it from the Packsaddle schist but chiefly in distinguishing it from granitic intrusions, which, especially if slightly schistose, in many places closely resemble the light schists of the Valley Spring gneiss and in some places have been mapped with this formation, though not considered to be a part of it. As the contacts are exceedingly irregular, the boundaries shown on the map do not, in all places, definitely separate distinct formations but rather indicate changes in the dominance of rock type. In a region where there are all gradations from pure granite to pure schist and where molten magmas have intricately interleaved and in many places have fairly impregnated a rock mass, generalized boundaries such as have been used are necessary to express the geologic facts. In many other places, however, the boundaries are sharp and definite, but it is not practicable to discriminate these on the map from the less definite ones. In addition to the difficulty above noted there is evidence that older gneisses of igneous origin are associated with the schists and gneisses of sedimentary origin.

Distribution.—The Valley Spring gneiss, as has been said, underlies the Packsaddle schist and structurally occupies the major anticlinal axis.

In the Llano quadrangle, therefore, two broad bands more or less interrupted by granitic intrusions are well defined. One extends from Pontotoc, near the northwest corner of the quadrangle, southeastward to Sandy Creek, a few miles south of Oxford. This band, with its inclusions of granite, is about 15 miles wide in its northwestern portion, but narrows to 3 or 4 miles at its south end and at the nose of a steeply pitching anticline sinks beneath a band of Packsaddle schist which is broken by a granite mass.

The second area, about 7 miles wide at its north end, extends from the region east of Magill Mountain in a narrowing band to a point just north of Packsaddle Mountain, where again a pitching anticline carries the formation below the Packsaddle schist.

A third small area whose structure is ill defined, though probably synclinal, lies south of Castell, near the western border of the quadrangle.

The formation is exposed in the Burnet quadrangle northeast of Long Mountain. Here the aspect of considerable areas suggests granitic gneisses and here, also, the structural relations are obscure.

Character.—The Valley Spring gneiss is dominantly light colored and pinkish toned and comprises feldspathic and quartzitic schists, quartzites, wollastonite bands, granular acidic gneisses (see Pl. II) and rare amphibolitic portions.

The light-colored portions are as a whole more or less schistose, are sugar-granular or aphanitic in texture, and are in many places distinguished with difficulty from rocks which may be granular granitic gneisses. These granular phases are in places intensely plicated or contorted and apparently have passed through severe pressure and heating. The quartzites are light-colored, fine-grained, recrystallized equivalents of very quartzose sediments, and the amphibolites are not materially different from those in the overlying Packsaddle schist. The wollastonite bands are metamorphic equivalents of limestones and present the same structural relations.

[a]First Ann. Rept. Texas Geol. Survey, 1889.

The broadest and perhaps most marked distinction of the rocks of this formation from those of the overlying one is their more massive character. This difference is more apparent when the formations are compared as wholes, rather than in individual small areas. A study of areas occupied by this formation leaves the impression that a thick series of sediments of rather uniform composition has been subjected locally to intense granitic intrusion and metamorphism, in a zone where rock flowage and minor folding have been dominant. The dark Packsaddle schist as a whole does not present the massive appearance characteristic of the Valley Spring gneiss.

Petrography.—Below are given the results of the microscopic examination of a number of specimens of the Valley Spring gneiss.

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 (altered to chlorite in part) in linear arrangement. Little calcite. Little apatite.

Feldspar-quartz schist.

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

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

Quartz-feldspar schist.

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

Microscopic character.—Altered microcline dominant feldspar. 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 rocks. Banding brought out by quartz and feldspar arranged in lines. Fine dust of magnetite, little muscovite, and little garnet.

Microscopic character.—Holocrystalline grains of quartz, potash feldspar, mostly microcline, and abundant muscovite. Approximate composition: 68.6 per cent SiO_2, 16 per cent Al_2O_3, 11 per cent K_2O, 1.48 per cent CaO, 2 per cent magnetite.

PACKSADDLE SCHIST.

Definition.—The dark-colored series of metamorphic rocks is named the Packsadddle schist, from Packsaddle Mountain, which crosses the line between the two quadrangles and at the base of which the rocks are well exposed. The name was first used by T. D. Comstock,[a] for the same rocks, but in this folio it is redefined and limited strictly in usage according to geologic principles as now understood, to include mica, amphibole, and graphitic schists and crystalline limestone. Some lighter-colored, more feldspathic bands, resembling quartzites, are included. There are also intrusives of diorite and gabbro, older than the granites and found locally in considerable amount. They have been separately mapped in only one locality, in the southeast corner of the Llano quadrangle and the southwest corner of the Burnet quadrangle. Elsewhere they have been included with the Packsaddle schist, though they are not a part of it.

Distribution.—As the Packsaddle schist overlies the Valley Spring gneiss and as the major axes of folding determine its distribution, it flanks the major anticlinal folds and occupies major synclinal areas. A broad band passes nearly centrally in a northwest-southeast direction through the Llano quadrangle and divides northwest of Riley Mountain, one portion passing westward around the nose of the western anticline, the other portion passing southeastward into the Burnet quadrangle and likewise swinging around the nose of a major anticline. These two divisions both pass again northwestward, the western one terminating near Llano River and the eastern one extending in a narrow interrupted band to the headwaters of Little Llano River, where the formation passes beneath Paleozoic rocks.

In the Burnet quadrangle small areas of Packsaddle schist, whose structural relations are not clear, are found west and northeast of Long Mountain, and in the southwest corner of the Llano quadrangle there are small areas in which much granite has disturbed the rocks. North of Llano River, just southeast of Rough Mountain, there is an isolated area of the Packsaddle schist whose structural relations are those of a shallow syncline lying upon the surrounding Valley Spring gneiss.

Character.—As a whole the schists are characterized by an excellent cleavage, which in the main coincides with the original bedding of the sediments of which they are the metamorphosed equivalents.

The graphitic schists contain varying amounts of graphite—locally, it is believed, enough to be of commercial value. A microscopic examination of a specimen of graphite schist from Cottonwood Creek showed about 60 per cent of quartz, 30 per cent of orthoclase, fairly abundant grains of augite, a little titanite and apatite, and flakes of graphite lying parallel to the schistosity of the rock. The graphitic schist is commonly, though not everywhere, closely associated with limestone, which is developed to varying degrees. There are numerous limestone bands east of Oxford and many more in the region south and west of Llano. These limestone bands are in places interbedded with the graphite schist, leaving little or no doubt as to the sedimentary origin of the carbon mineral. Mica, tourmaline, and quartz-feldspar schists are among the remaining types of sedimentary origin. All these rocks contain much quartz and are characterized by potash felspar and biotite, with occasional pyroxene (augite). The tourmaline schist is an exception in not containing feldspar. Magnetite, titanite, and apatite are common accessories.

[a]First Ann. Rept. Texas Geol. Survey, 1889.

Amphibolite schists are fairly abundant and are characterized by very little or no quartz. Their origin is a matter of some doubt. As they are interbedded with limestones, a sedimentary origin is suggested. It is possible, however, that they may represent old flows and sill-like intrusions, for amphibolites of undoubted igneous origin are found in the region in considerable masses, and in one place a rock transitional between a basic porphyry dike and an amphibolite schist was noted.

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	1000
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
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

Petrography.—Microscopic examination of a number of specimens of the Packsaddle schist gave the following results:

Quartz-feldspar schist.

Megascopic character.—Whitish-pink, sugar-grained, finely banded rock; bands straight and narrow, made by pink and white constituents. Speckled with magnetite having a slight tendency to follow bands. Rock cleavable along bands.

Microscopic character.—Equidimensional grains of microcline, orthoclase, and quartz. Flakes of brownish-yellow biotite and magnetite (not clearly in bands). Considerable alteration of feldspar.

Measurements showed 68 per cent of feldspar and 32 per cent of quartz, which gives 76 per cent SiO_2+, approximately 12 per cent Al_2O_3, and approximately 12 per cent K_2O.

Quartzitic feldspar schist.

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

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

Amphibolite schist (1).

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

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

Amphibolite schist (2).

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 of light-green hornblende, considerable augite, quartz, and orthoclase in the interstices of the hornblende laths. Quartz greatly in excess of feldspar.

Amphibolite schist (3).

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. Scattered grains of augite.

Amphibolite schist (4).

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 quartz.

Biotite-quartz-mica schist.

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

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

Mica schist (1).

Megascopic character.—Gray banded schist. Bands due to lines of pink feldspar in general 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. Abundant biotite in linear parallel arrangement. Abundant grains of iron oxide.

Mica schist (2).

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, the former in slight excess. Biotite in fine parallel alignment. About 6 to 9 per cent of 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 the bands. Much of the quartz has wavy extinction.

Hornblende-biotite gneiss.

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

Microscopic character.—Granitoid texture. Quartz, albite-oligoclase, and abundant biotite. Some hornblende and chlorite. Titanite. 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 (3).

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

Microscopic character.—Crystalline granular quartz. Microcline and a little albite-oligoclase. Biotite in laths or plates parallel to the schistosity. Quartz also arranged roughly in direction of schistosity. Microcline is slightly altered. Composition: 79 per cent SiO_2, 9.64 per cent Al_2O_3, 8 per cent K_2O, 3.36 per cent Fe, Mg, and Ca.

ORIGIN OF THE SCHISTS AND GNEISSES.

The schists described above, of both the Valley Spring and Packsaddle formations, are all completely recrystallized rocks—that is, the arrangement, the size, and, in part, the composition of their mineral constituents are due to the influence of heat and pressure and, to some extent, to flowage as a mass. (See Pl. II.) The existence of bands of crystalline limestone and of graphite and mica schist, traceable for long distances and retaining the characteristics of beds, leaves no room for doubt that, in great part, these rocks were formed by the metamorphism of a sedimentary series. It is believed that the presence of iron ores also points to the same conclusion, a matter more fully considered in a previous bulletin[a] by the author. The amphibolites, as has been stated, because of their basic character probably represent in part old basic intrusives or flows, or perhaps sediments of a tuffaceous nature.

Gneisses formed almost certainly by the metamorphism of intrusive granites occur in the region. For example, a granitic crosscutting dike possesses much the same schistose nature as the beds which it cut. Red Mountain, a granite ridge in the southeast corner of the Llano quadrangle, is a noteworthy example of the same phenomenon. The granite of this ridge becomes progressively more gneissoid northwestward, until, at a point near Walker Peak, laminated structure is so evident that were the rock exposed only in this phase it could not be distinguished from beds that are believed to represent sedimentary strata.

Again, the gneissoid rocks in the area immediately east of Long Mountain have much the aspect of granites with a foliated structure, and in the northwestern part of the Llano quadrangle, south of Field Creek, near San Fernando Creek, similar features may be noted. It should be understood, then, that the Valley Spring gneiss probably includes material of igneous origin.

As has been stated, bands of dark schist occur, though not abundantly, in the Valley Spring gneiss, as well as bands of wollastonite, the metamorphosed equivalent of limestone beds. These bands suggest that metamorphism has been more intense in that formation. In general, intrusion has been most extensive along synclinal axes, as the position of the great granite areas indicates, but evidently wherever the Packsaddle schist is nearly obliterated by intrusions of granite, the underlying Valley Spring gneiss must have been similarly destroyed.

IGNEOUS ROCKS.

FELSITE, DIORITE, GABBRO, AND SERPENTINE.

Distribution and character.—The dark intrusive rocks are most abundant in the southeast corner of the Llano quadrangle, but they have not been separately mapped except in one locality. A considerable mass of gabbro was observed in the vicinity of Goldmine Creek, north of the Moss ranch, and, as has been stated, some of the amphibolites included with the Packsaddle schist may represent old intrusives of gabbroic or diabasic type. In the area south of Click, especially, there are several bodies of very dark green to black amphibolite, probably derived from a gabbro or diorite magma. The talc deposits in this vicinity are presumably alteration products of such rocks. The serpentine rocks of Oxford are probably derived from peridotitic magmas.

Two dark aphanitic dikes which cut the schists and which are apparently rather basic proved to be felsites, one a spherulitic mica felsite, the other a hornblende-mica felsite. The hornblende of the latter rock showed a bluish pleochroism parallel to the C axis, suggestive of a soda amphibole. Hornblende-soda granite forms a small intrusive mass a short distance east of Click.

The rocks of this group were intruded earlier than the granites, but, though it is possible that those varieties of the granites which show evidence of pressure and metamorphism may be of nearly the same age, no relations were observed that might establish this point.

[a]Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. U. S. Geol. Survey No. 450, 1911.

Petrography.—The results of a microscopic examination of a number of specimens of these rocks are as follows:

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

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

Hypersthene-olivine gabbro, Goldmine Creek.

Megascopic character.—Dark blue to black medium-grained rock.
Microscopic character.—Holocrystalline texture. Labradorite in lath-like prisms, diallage, hypersthene, 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 to cleave more easily in one direction than in another, due to pressure.
Microscopic character.—Mat of light-green hornblende with plagioclase in interstices. Shows evidence of crushing.

Metadiorite porphyry in hornblende schist series near Aaron Moss ranch.

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

Diorite from Cedar Mountain.

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 in groundmass of unstriated orthoclase. 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 southwestern part of Burnet quadrangle.

Megascopic character.—Dark-green medium to fine grained hornblende rock.
Microscopic character.—Mass of interlocking hornblende crystals with interstices filled with untwinned plagioclase. Abundant grains of magnetite largely confined to 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 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 southeast of Rough Mountain, west of San Fernando Creek.

Megascopic character.—Medium-grained dark-green rock.
Microscopic character.—Holocrystalline texture. Weathered andesine-labradorite 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.

GRANITE.

Structural relations.—The granite is invariably intrusive. It cuts the Valley Spring and Packsaddle formations in large and small masses, in dikes and sills, and, in the form of pegmatite, in both minute veinlets and huge dikes and sheets. It is present nearly everywhere in the pre-Cambrian area.

Almost perfect gradation may be found between pure granite and pure schist. Certain areas, such as that underlain by coarse granite in the southwestern portion of the Llano quadrangle, the area immediately west of Cedar Mountain, and the area east of Lone Grove, are occupied by pure granite masses of batholithic type. In other areas there is an intricate mixture; the schists appear to have literally soaked up granitic material. Such features are best developed at the edges of large granitic masses, though not at all confined to these bodies.

The manner of intrusion differed in different places. Evidently the schists were locally in a plastic state and flowed under the pressure accompanying intrusion. Elsewhere, the contacts of dikes being sharp, a condition of considerable rigidity is indicated. Yet here and there the temperatures were so high that schist masses lost their identity and passed by gradual melting into solution. (See Pl. V.) In many places granitic material, following planes of least resistance, was forced between the layers of the schists, forming injection gneisses.

Each of the phenomena noted above may be observed on both a small and a huge scale. The combination is a fine example of the complex conditions existing about the borders of a great batholithic mass.

Worthy of special mention are dikes, sills, and broad sheets of pegmatite which occur in great abundance and in all sizes, the broad sheets of special interest being locally developed at contacts of schist with crosscutting granite masses. Such sheets are prominent in the areas about Hog Mountain and, it is believed, indicate the former proximity of schists now removed by erosion.

Distribution.—Three types of granite have been separately mapped on the areal-geology maps—a very coarse grained rock, a medium to fine grained granite including some coarse-grained varieties, and an opaline quartz porphyry. Microscopic examination has shown that the differences between these types are largely textural, the mineral constituents in the three types being essentially the same.

The coarse-grained granite has been mapped in two localities—one in the southwest corner of the Llano quadrangle, forming a large oval area about Prairie Mountain as a center, and the other several miles to the north, in the vicinity of Smoothingiron Mountain. The same type has been noted east and southeast of Lone Grove and in other small areas, but it could not be consistently differentiated in mapping. The age of this coarse granite is not conclusively known, but tentatively it may be considered intrusive in the finer-grained granites.

The second type, the prominent rock of the region, has a widespread distribution. Though it comprises various textural phases from very coarse to very fine grained, it has been mapped as a unit.

The opaline quartz 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 south of Miller Mountain, northward for 6½ miles and northeastward to Wilberns Glen, where it turns westward, passing north of Babyhead and being last seen about a mile southwest of that town.

Petrography.—The very coarse grained granite has a reddish tone, due to the large, finely developed potash feldspars, many of which attain a length of an inch and a breadth of half or three-fourths of an inch, the average length being perhaps half an inch. The space between these well-crystallized, finely developed feldspars is filled with quartz. Biotite, the dominant ferromagnesian mineral, is well developed and abundant in stout columns. In the vicinity of Bullhead Mountain a parallel arrangement of the large feldspars was noted, a phenomenon probably due to movement while the magma was still more or less viscous.

In a specimen of very coarse granite from Watch Mountain, near Walnut Springs, the feldspars are microcline, orthoclase, and albite-oligoclase, microcline being dominant. The length of the crystals is one-half inch to 1 inch or more, the width one-fourth to one-half inch. Quartz fills the space between the feldspars. Biotite is abundant in stout columns one-eighth inch or more in length. A perthitic intergrowth of microcline and albite was noted.

The medium to fine grained granites include many varieties, from fine to coarse, but they are in general similar in chemical and mineral character. Differences in texture and in amount of ferromagnesian minerals account for most of the variations. An examination of numerous specimens revealed an abundance of microcline, with orthoclase, albite-oligoclase, biotite, quartz, and hornblende. The granites are distinctly potash rocks, though soda is almost invariably present. The usual accessory minerals, magnetite, apatite, titanite, etc., may generally be found. Several hornblende granites were noted, but their distribution is limited. Some petrographic notes on the granites of this class are presented below:

Granite from Parkinson group of quarries.

Megascopic character.—Medium to fine grained gray granite. Biotite, quartz, and feldspar. Mica evenly distributed in fine flakes.
Microscopic character.—Composed largely of microcline with subsidiary orthoclase, rare plagioclase. Micrographic intergrowth of quartz and some feldspar. Rare zonal arrangement. Alteration has set in on nearly all the feldspar. Quartz shows some strain phenomena. Biotite locally altered to chlorite. Alteration of feldspar more pronounced at center than elsewhere. One or two grains of magnetite.

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

Megascopic character.—Medium to coarse grained light-gray granite with slightly gneissoid aspect. Quartz, feldspar, mica.
Microscopic character.—Quartz 32 per cent, feldspar (microcline and orthoclase) 62 per cent, mica (biotite with rare muscovite) 6 per cent; SiO_2 71 per cent. Micrographic intergrowths finely developed in some quartz and in some feldspar.

Hornblende granite, northwest of 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. Groundmass between the blotches is barren of ferromagnesian minerals.
Microscopic character.—Microcline, orthoclase, and albite-oligoclase dominant in order named. Dark-green hornblende apparently poikilitically arranged about quartz. Measurements with microscope show quartz 31 per cent, feldspar 69 per cent; SiO_2 75 per cent.

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. Holocrystalline seriate porphyroid texture.

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.—Seriate porphyroid texture. Microcline, orthoclase, and albite-oligoclase rather abundant. Quartz abundant. Little magnetite, mica, titanite, and hornblende. Ferromagnesian minerals very scant. The feldspars where altered are replaced by a red decomposition product.

Granite from Greys Mountain.

Megascopic character.—Coarse pinkish granite. Feldspars as large as one-fourth inch in length. Mica very abundant; sufficient to give dark tone to rock.
Microscopic character.—Oligoclase and microcline, former dominant and both dominant over quartz. Biotite abundant but not evenly distributed. Apatite. Feldspar altered.

Hornblende granite, chip only, from Elver's pasture, south edge of Llano quadrangle, small creek above house.

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

Pink granite 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, with biotite and segregations of magnetite and titanite. Part of the quartz one of the first things to separate out. Apatite needles abundant.

Granite from Heine's well, near South Willow Creek, 4 miles north of Llano River, 1 mile west of San Fernando Creek.

Megascopic character.—Red granite, medium to fine grain, glassy aspect.
Microscopic character.—Microcline and orthoclase and quartz. Microcline and orthoclase badly altered. Scanty biotite, chloritized. Sericite developed in feldspars. Red tone very probably accentuated by alteration.

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

Megascopic character.—Fine-grained light-pink granite, evenly distributed ferromagnesian minerals in tiny flakes.
Microscopic character.—Microcline dominant feldspar; 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. Quartz. Biotite. Little magnetite.

The opaline quartz-feldspar porphyry is a rock having a dark aphanitic groundmass, mottled with abundant phenocrysts of pink feldspar and opaline quartz, the latter being very prominent on weathered surfaces. These quartz phenocrysts break with a glassy fracture, are of light-bluish tone, and possess a certain iridescence when polished. The microscope shows the following features:

Phenocrysts of quartz, with a great number of minute inclusions, microcline, and microperthite (albite and orthoclase). Groundmass of quartz, orthoclase, and small flakes of biotite. A little magnetite with associated sphene. Some fine zircons. Little apatite. Local chloritization of mica.

J. P. Iddings proposed the name llanite for this rock some years ago. It is known in Llano County as opaline granite. Iddings estimated that the rock is composed of quartz 34.6 per cent, feldspar 55.7 per cent, biotite 8.6 per cent, fluorite 1 per cent, apatite 0.13 per cent.

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 [inclusions], 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 a 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.

CAMBRIAN SYSTEM.

UPPER CAMBRIAN SERIES.

GENERAL DISTRIBUTION.

Upper Cambrian sedimentary rocks rest unconformably upon the pre-Cambrian schists, gneisses, and granites. They are invariably found, therefore, except where faulting has occurred, at the base of and forming a part of the Paleozoic escarpment. The areal-geology maps will clearly illustrate this feature. Cambrian strata also form isolated elevations, such as Riley, Cedar, Packsaddle, and Putman mountains, in the erosional pre-Cambrian basin. As faulting has disturbed the rocks in places, various portions of the Paleozoic section rest against the pre-Cambrian basement; and as the pre-Cambrian floor is very uneven, beds high in the section, such as the glauconitic sandstones on Beaver Creek, locally overlap lower beds and form basal members. (See Pl. I.) The Cambrian rocks are divided, from the base upward, into the Hickory sandstone, the Cap Mountain formation, and the Wilberns formation. (See fig. 3.)

HICKORY SANDSTONE.

Definition.—The name Hickory sandstone is adopted from Comstock,[a] who applied the term Hickory series to beds in the valley of Hickory Creek and its tributaries in Llano County.

In Llano and Burnet counties the formation ranges from a thin bed to a section 350 feet or more in thickness. It includes a conglomeratic base and a succession of white, red, or brown siliceous and calcareous sandstones. Its upper limit is determined by the highest dominantly sandy beds. The identification of these upper beds at particular localities is necessarily a matter of judgment, for, instead of an abrupt change, there is a transition from sandstone to the limestone of the overlying Cap Mountain formation.

Character.—As a rule the basal portion of the formation consists of a few feet to about 75 feet of coarse material. At some places this is composed of fine-grained, cleanly washed sands; at others of coarse conglomerate with pebbles from 6 to 8 inches in diameter. The composition of the basal layer is closely related to that of the underlying pre-Cambrian rocks. For example, certain coarse granites containing pink feldspar have furnished material to a pinkish-white conglomerate in which rounded quartz grains averaging one-fourth inch in diameter and numerous angular feldspar fragments are cemented by a clean white matrix of small quartz grains, feldspar fragments, and calcium carbonate. At another place a coarser,

[a] Comstock, T. B., First Ann. Rept. Texas Geol. Survey, 1889.

red-stained conglomerate contains subangular quartz fragments as large as half an inch and coarse feldspar fragments up to an inch in length, cemented by fine-grained quartz containing particles of iron oxide.

In another coarse sandstone fragments of hematite 1 to 2 inches long make up the basal layer. The iron was probably derived from the underlying schist in the form of magnetite and later altered to hematite. In still another locality where pegmatite dikes are abundant the overlying basal beds contain many large angular masses of quartz. Again, where the lower beds rest on a coarse-grained granite surface they are formed largely of arkose.

The conglomerate is overlain by sandstone, commonly cross-bedded. In places this is colored deep red or brown by iron oxide. Toward the upper portion of the formation the beds become decidedly calcareous and grade into the limestone of the overlying formation.

Distribution.—The Hickory sandstone, where not displaced by faulting, occupies the base of the Paleozoic scarp which surrounds the pre-Cambrian basin and forms the capping of a number of isolated hills, such as House, Smoothingiron, Rough, and Putnam mountains. In some areas, such as those northeast of Pontotoc, northeast of Smoothingiron Mountain, and south of Sharp Mountain, the formation is but a thin skin or apron extending out from the scarp.

Section.—The following sections are representative of the formation. The Packsaddle section illustrates the transition to limestone at the top of the formation.

Section of Hickory sandstone at northwest end of Prairie Mountain, showing transition beds at top.

	Feet.
Thin-bedded calcareous sandstone	15
Solid sandstone, with lime and little iron	5
Thin bedded calcareous sandstone	15
Calcareous red and brown sandstone, more or less thin bedded (red due to iron)	30
Heavy beds of sandstone, little lime at top	5
Heavy bed of sandstone	5
Calcareous sandstone	7
Heavy cross-bedded red iron-bearing sandstone	13
Bedded sandstone, 1 to 2 foot layers, little calcareous	10
Compact massive sandstone, weathers brown	20
Sandstone, more thinly bedded than that above; shows signs of lime	15
Heavy-bedded sandstone weathering brown and red; carries iron and sufficient lime to effervesce	65
Covered	80
Red and white cross-bedded sandstone	20
	305

Section of basal portion of Hickory sandstone 2 miles west of Oxford.

	Feet.
Pure limestone	15
Red sandstone and limestone mixed	20
Red sandstone with considerable iron	10
White honeycombed sandstone	10
Fine white conglomerate	4
Very coarse conglomerate, almost a breccia of granitic material	10

Section of Hickory sandstone, Cap Mountain formation, and Wilberns formation on Packsaddle Mountain.

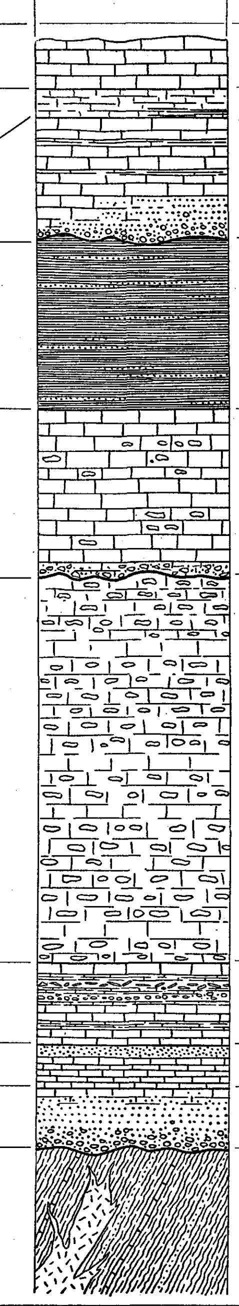
	Feet.
Wilberns formation:	
Grayish slabby, slaty crystalline limestone, very little glauconitic; more massive beds toward top of peak	40
Thinner-bedded crystalline limestone; some glauconite	20
Heavy-bedded pink limestone, somewhat oolitic; contains some glauconite	10
Cap Mountain formation:	
Yellow and white sandstone with small amount of glauconite grading up into sandy pink limestone	14
Glauconite sand and coarse quartz sands; iron concretions on surface	6
Massive-bedded grayish-brown crystalline limestone, somewhat oolitic; increasing glauconite toward top	35
Flaggy subcrystalline limestone with small amount of glauconite; yellowish discolorations	30
Hickory sandstone:	
Grading into purer limestone. Number of red bands of sandstone alternating with beds of hard subcrystalline limestone and fine-grained whitish sandy limestone. Crystalline limestone contains some glauconite grains	35
Thin-bedded calcareous dirty-white sandstone, grading upward into very fine-grained hard reddish-brown sandstone. Weathers rough but generally shows a brown sand on surface. Fresh fracture shows reddish-brown sandstone with crystalline faces of calcite. Makes cliffs which weather irregularly and show bands of red, yellow, and dirty-brown cross-bedded sandstones alternating with very calcareous beds	200
Ledge of calcareous sandstone, conglomeratic and containing a few shell fragments, also a few glauconite grains	2
Massive and thin-bedded red and yellow sandstone and some shale, probably covered	35
Covered; mostly sandy shales. At bottom a 2½-foot bed of red conglomeratic sandstone with flat pebbles. A few shell fragments in this ledge	10
Mostly fine-grained sandstone; dirty white, brown, yellow, and red	45
Massive conglomeratic sandstone, pink and white, with white quartz pebbles mostly half an inch in diameter, cross-bedded, prevailingly of reddish tones. Near top, grains become smaller and more rounded. Secondary infiltration of quartz in cross fractures gives honeycomb structure on weathering	85
	567

CAP MOUNTAIN FORMATION.

Definition.—The Cap Mountain formation is named from Cap Mountain, in the Llano quadrangle, where the entire thickness is displayed. As previously stated, its base is not sharply separable from the top of the Hickory sandstone, but it is determined by the lowermost predominantly calcareous beds. Its upper limit, however, is well defined by the top of a glauconitic sandstone which is almost invariably present. This sandstone bed, composed of quartz sand, calcium carbonate, and glauconite grains, ranges in thickness from a few feet to over 50 feet in some places. Generally, however, it is from 10 to 20 feet thick.

Character.—The formation includes about 90 feet of beds, the lower portion grading from sandy limestone to fairly pure limestone. The sandstone member, though of irregular thickness, as just stated, is as a rule very well defined both below and above. The limestone is well bedded, in places flaggy, bluish or grayish, and mottled by impure streaks of brown sandy material.

Glauconite.—The distribution of glauconite in this formation and in the Cambrian strata generally is interesting. It occurs in the lower part of the formation as scattered grains in the pure limestone and is most abundant in the cross-bedded sandstone marking the top of the formation. Above this sandstone the glauconite gradually diminishes in amount.



System.	Series.		Formation.	Section.	Thickness in Feet.	Character of Rocks.	Character of Topography.
Cretaceous	Comanche	Fredericksburg group	Edwards limestone.		0-150	Massive well-bedded white limestone.	Caps many nearly flat-topped hills in Cretaceous area.
			Comanche Peak limestone.		40-70	White chalky limestone.	Usually barren chalky slopes, with a bench at base.
			Walnut clay.		10-15	Yellow indurated clay, representing Walnut clay, included with Comanche Peak limestone on map.	
			Trinity formation.		0-500	Conglomerate and sandstone in basal portion, merging horizontally into white and yellowish banded limestones of various thicknesses, flaggy and marly in places.	Slopes terraced by harder beds, vertical cliffs along stream bluffs, and locally prairies.
			UNCONFORMITY				
Carboniferous	Pennsylvanian		Smithwick shale.		300-400	Very dark carbonaceous shale, containing thin sandstone lentils. Weathers yellowish brown.	Relatively low-lying areas near Colorado River.
			Marble Falls limestone.		250-450	Dove-colored, gray to dark-blue or black limestone, locally carrying considerable dark chert.	Rather maturely dissected plateau. Rough surface.
			UNCONFORMITY				
Ordovician			Ellenburger limestone.		700-1000	Poorly bedded limestone and dolomite, white to grayish. Locally carries great abundance of chert.	Rolling plateau over large areas and bold cliffs on Colorado River. Surface generally rough but in part smooth, grass covered, and rolling. Abundant chert in soil.
Cambrian	Upper Cambrian		Wilberns formation.		150-220	Limestone and calcareous shale. Upper third largely shale with flat and rounded shale-pebble conglomerate. Lower portion mottled and flaggy and carries glauconite grains.	Largely scarps surrounding the pre-Cambrian lowlands, with some smooth slopes and vertical-walled stream channels.
			Cap Mountain formation.		90±	Glauconitic calcareous sandstone, 10 to 50 feet thick at top. Lower portion flaggy mottled gray limestone, glauconitic.	Largely scarps surrounding the pre Cambrian lowland and in isolated hills. Good farm land.
			Hickory sandstone.		0-300	Conglomerate, locally 75 feet thick, at base, passing upward into red, gray, brown, and white sandstone and finally grading into limestone at top.	Hills, scarps, and slopes at base of scarps in pre-Cambrian lowland.
			UNCONFORMITY				
Algonkian?	Llano		Packsaddle schist.			Amphibolite, graphite, and mica schists, with limestone bands.	Gently rolling interior lowland with a few isolated round-topped hills.
			Valley Spring gneiss.			Acidic gneisses, quartzite, light-colored mica schist, wollastonite bands, and limestone. Intruded by granite.	

FIGURE 3.—Generalized columnar section for the Llano and Burnet quadrangles.

Scale, 1 inch=400 feet.

Where observed in the limestone, the glauconite grains exist essentially as such, but in the sandstone the material is more apt to form the matrix in which the well-rounded clean quartz grains are embedded. Partial analysis of a specimen from a bed carrying perhaps as high a content of glauconite as any other in the field gave the following result:

Partial analysis of greensand from south fork of Morgan Creek.

[Analyst, Chase Palmer, United States Geological Survey.]

K_2O	3.46
FeO	1.70
Fe_2O_3	10.64
Water (loss on ignition)	6.12
Insoluble in HCl	70.38

The composition and origin of glauconite and its sedimentary significance have received considerable attention from a number of investigators, but there is not space in this folio to discuss in detail this interesting question. It may be said that the glauconite sands of the Llano-Burnet region are found locally resting upon a granite floor; that the origin of the glauconite in this region is apparently not connected with the presence of Foraminifera; and that its position, at least locally, in what was strictly a littoral zone is unusual. The mineral here probably owes its origin to the decomposition of abundant potassium feldspar with iron in solution, the subsequent synthesis of the several elements being probably aided by organic matter.

Distribution.—As the Cap Mountain formation lies immediately above the Hickory sandstone, its distribution is much the same. As a rule, however, its area of outcrop is considerably narrower than that of the sandstone, which in a number of places spreads as a thin veneer over considerable territory. The outcrop of the Cap Mountain formation is more ribbon-like and, except where cut out by faulting, as along the scarp north of Phillips Rock and in the north scarp of Backbone Ridge, is invariably present in the rimlike Paleozoic escarpment. It is found also on the flanks of a number of the mountain masses, such as Cap, Riley, Cedar, and Long mountains.

WILBERNS FORMATION.

Definition.—The Wilberns formation, named from Wilberns Glen, on Little Llano River, in the Llano quadrangle, is of irregular thickness, in places attaining 220 feet. It is composed of limestone and shale, with intraformational conglomerates. The base of this formation is well defined by the top of the glauconitic sandstone which forms the upper member of the Cap Mountain formation. Its upper limit is at the base of the overlying massive chert-bearing beds. This horizon is not difficult to locate and the contact therefore is not difficult to follow. The exact stratigraphic relation, however, is not always so clear. In Riley Mountain, at the locality where the cherty limestone is mapped as bounded by an assumed fault, there is some indication of an unconformity. Yet, although here chert beds seem to lie unconformably on both the Cap Mountain and Wilberns formations and although the locality was studied in some detail, a definite conclusion could not be reached. As in most places where the contact between the rather flaggy limestone of the Wilberns formation and the overlying heavy chert-bearing beds was observed there is apparently perfect conformity between the two, and as there are many faults in this vicinity, it is possible that the apparent unconformity at this point is due to faulting. Hence an assumed fault has been shown on the map. The evidence from the fossils points to the conclusion that at least a part of the chert-bearing beds are considerably later than the Wilberns formation, and that there is an unconformity at a horizon not far above the base of the overlying formation.

Character.—The Wilberns formation may be divided on lithologic criteria into a lower and an upper portion. The lower portion, comprising about two-thirds of the whole, is rather thin-bedded flaggy limestone generally mottled by sandy impurities and containing locally a small amount of glauconite. The upper portion is largely shale, with more limestone at the top. In the shaly portion there are several conglomerate lentils. (See Pl. VIII.) These are not persistent along the strike, nor is their number everywhere the same. They are of two kinds—one composed of perfectly flat shaly limestone fragments, such as could be formed only in place or from material transported a very short distance, the other composed of rounded or almond-shaped calcareous clay pebbles in a matrix of decidedly oolitic texture containing locally considerable glauconite. In one place what appeared to be a sun-cracked shale fragment was found.

Distribution.—The Wilberns formation lies immediately above the Cap Mountain formation and in general is found where that formation is exposed. It is present in the Paleozoic scarp and in many of the higher mountains of the interior basin. On a number of them, however, such as Smoothingiron, House, Prairie, Putnam, and Sharp mountains, this formation has been eroded and only one or more of the underlying formations remain. In a number of places, as may be seen on the maps, the formation is faulted out.

Sections.—The following sections illustrate the sequence of beds:

Section of Wilberns formation on the east bank of Colorado River, about one-third mile above old tanyard crossing.

	Ft.	in.
Top at base of Ellenburger limestone.		
Impure mottled-brown bedded limestone	15	
Ledge of impure limestone	5	
Shaly limestone	20	
Heavy-bedded limestone, containing abundant exceedingly small shell fragments and minute globular remains	10	
Impure sandy limestone, having conglomeratic aspect in the hard layers, shaly material predominant	10	
Débris-covered slope	10	
Debris-covered slope; contains layers of a shale conglomerate composed of cemented flat fragments of thin shale accompanied by layers containing bowlder-like forms composed of a lime sand	60	
Dark reddish-brown semicrystalline limestone		6
Slope in which occur impure limestone layers breaking down to $\frac{1}{4}$-inch to 1 inch in thickness, carrying very fine sand, weathering light brown	30	
Predominantly pink flaggy semicrystalline limestone	5	
Predominantly pink flaggy semicrystalline limestone on a gentle slope	5	
Almost white crystalline limestone; carries impurities; a few scattering grains of glauconite; makes broad bench	5	
Light-brown crystalline and semicrystalline heavy-bedded limestone weathering into hard layers; a few scattered grains of glauconite and shell fragments	5	
Crystalline and semicrystalline bedded limestone weathering into hard layers	5	
Light-brown crystalline and semicrystalline limestone weathering into beds 6 to 8 inches thick	6	
Heavy layer of light-brown limestone mottled with impurities	4	
Alternating beds of crystalline limestone 4 inches to 1 foot thick with crinkly-weathering beds, slightly more sandy, the whole carrying finely disseminated glauconite	10	
Medium-hard layer of sandy limestone carrying glauconite	1	4
Soft layer		4
Hard layer of crystalline limestone carrying abundant glauconite grains	1	8
Hard and crinkly-bedded limestone	2	
Layers of hard limestone	1	6
Gray and greenish-tinged hard flaggy crystalline limestone		9
Layer weathering to a crinkly form, with disseminated glauconite grains; rock of greenish tinge		6
Gray and green hard flaggy crystalline limestone	1	
Layer weathering to a crinkled surface	1	4
Hard layer of gray and green-tinged flaggy crystalline limestone	1	
Greenish flaggy crinkly limestone, with disseminated glauconite grains	1	4
	208	3

The base of the foregoing section is probably about 30 feet above the top of the Cap Mountain formation.

Section of Wilberns formation near the head of Little Llano River.

	Ft.	in.
Ellenburger limestone at top.		
Gray calcareous shale	9	
Hard gray oolitic limestone	2	
Alternating hard and soft thin calcareous shale beds; 1-foot hard layer near top	12	
Gray oolitic limestone	1	
Gray calcareous shale	9	
Subcrystalline to crystalline grayish, somewhat oolitic limestone	1	6
Shale, calcareous	4	
Limy band containing pistachio-green fragments, slightly oolitic		8
Thin flaggy limestone with some sandy layers	10	
Band of oolitic limestone containing greenish fragments		7
Shale, calcareous	3	
Hard subcrystalline layer with shell fragments, iron stained; weathers dark gray	1	
Gray shaly limestone	7	
Conglomerate containing small (1 to $\frac{1}{2}$-inch), slightly rounded pebbles, weathering yellow; limestone matrix	1	
Greenish-gray shales	6	
Two beds of conglomerate, each about 8 inches, separated by 8 inches of shale; small, slightly rounded calcareous pebbles, weathering yellow	2	
Fine-grained greenish-gray shaly limestone	3	
Conglomerate of long, flat, thin shaly calcareous fragments overlain by fine-grained calcareous muds	3	
Greenish-gray shaly limestone	5	
Conglomerate composed of small, slightly rounded calcareous pebbles, weathering yellow	1	6
Light-gray shaly limestone weathering to a covered slope	25	
Thicker-bedded gray crystalline limestone, scattered grains of glauconite, a few hard layers about 9 inches thick	20	
Gray flaggy limestone	8	
Light-pink to gray thin-bedded crystalline limestone; brown mottling colorations caused by fine-grained sand	9	
Pink crystalline limestone	1	
Grayish-white limestone, with glauconite grains at base	5	
Pinkish limestone beds, subcrystalline; color caused by iron surrounding sand grains	7	
Sandy limestone with a little glauconite	2	
Practically base of formation.		
	159	3

This section was measured in inclined beds and the total thickness is believed to be rather too small. It is of value, however, as indicating the succession.

PALEONTOLOGY AND CORRELATION.

The data which follow were brought together with the collaboration of E. O. Ulrich.

The fauna of the Upper Cambrian rocks consists chiefly of brachiopods and trilobites, with fewer representatives of other classes. The collections were obtained largely from the upper part of the series. Of these fossils only the brachiopods have been sufficiently studied to warrant the presentation of a list. The following brachiopods are ascribed to Cambrian beds of Texas by Charles D. Walcott:[a]

Lingulella acutangula.
Lingulella perattenuata.
Lingulella (Lingulepis) acuminata.
Obolus matinalis.
Obolus nundina.
Obolus sinoe.
Obolus tetonensis ninus.
Acrotreta microscopia.
Eoorthis iddingsi.
Eoorthis remnicha texana.
Eoorthis wichitaensis.
Eoorthis wichitaensis læviusculus.
Syntrophia alata.
Huenella texana.
Huenella texana læviusculus.

The three Upper Cambrian formations, Hickory sandstone, Cap Mountain formation, and Wilberns formation, are correlated with the Reagan sandstone of Oklahoma and with the Upper Cambrian beds of Missouri. There are also marked general lithologic resemblances between the Texas beds and the Deadwood formation in the Black Hills of South Dakota and eastern Wyoming and in the Bighorn Mountains of central Wyoming. The faunas, too, have many species in common. Among these are trilobites, but only the brachiopods have been studied sufficiently by Walcott to insure safety in comparisons. Of the 14 species of brachiopods listed by Walcott from the Reagan sandstone (Upper Cambrian) in Oklahoma, chiefly from the calcareous upper part, 8 species are found in Texas, 6 in Wyoming, 5 in Missouri, 4 in the upper Mississippi Valley, and 2 in Tennessee and Alabama. Of 19 species collected from central Texas, 7 occur in Wyoming, 7 in Missouri, 2 in the upper Mississippi Valley, and 2 in eastern Tennessee.

Ulrich says:

> While the faunal similarities above noted are believed to be sufficient to establish the general contemporaneity of the formations in the widely separated areas mentioned, the more or less striking dissimilarities suggest impeded communication between the several areas. It is not improbable, further, that oscillation and shifting of seas occurred, with deposition going on in one place while slight emergence prevailed at another, so that none of the fossiliferous beds in certain of the areas is strictly synchronous with richly fossiliferous beds in any of the others. If oscillation of this kind occurred during the Upper Cambrian we should expect to see it manifested, especially on comparing the sequence of faunas and deposits in the Appalachian and Cordilleran provinces with those in the interior continental provinces. Here, in fact, is where the greatest discrepancies are encountered. On comparing the interior areas with each other, decided community of species is observed. It is strongest between Texas, Oklahoma, Colorado, and Wyoming, good between these and Missouri on the south and the upper Mississippi area on the north, and surprisingly weak between Missouri and the upper Mississippi localities. Evidently there was no direct communication between the latter two areas.

LATE CAMBRIAN AND EARLY ORDOVICIAN ROCKS.

ELLENBURGER LIMESTONE.

Definition and character.—The boundary between Cambrian and Ordovician rocks has not been established in this area. The late Cambrian and early Ordovician are represented by the Ellenburger limestone, a formation which contains much dolomite and chert in addition to the limestone and is perhaps 1000 feet thick. It is named from the Ellenburger Hills, in the northwest corner of the Burnet quadrangle. The evidence from the fossils indicates that sedimentation could not have been continuous during Ellenburger time, and it is possible that there is a hiatus somewhere near the top of the formation.

At most places the base of the formation is apparently conformable with the Wilberns formation. At several localities on Riley Mountain, however, there is an angular limestone conglomerate, and at one place the beds appear to overlap upon the lower formations. Again, about 5 miles west of Burnet the relations of the Ellenburger limestone are obscure. At this place there is so much faulting as to cast some doubt on the overlap that has been expressed on the geologic map. Indeed, in most of the places where the conglomerate was noted concordance of beds was the rule, and many observations were made where no unconformity could be detected and there was an apparent transition from the lower formations. It must be noted, however, that the basal beds of the Ellenburger limestone are not uniform in texture and appearance, and that this is in itself a suggestion of unconformity.

At the top of the Ellenburger limestone there is in most places a conglomeratic limestone. The upper surface of the Ellenburger on Doublehorn Creek, just south of the road crossing half a mile north of the mouth of Cordova Creek, illustrates excellently the condition of the pre-Carboniferous land surface. Here the upper 25 feet is composed of large, very irregularly disposed angular blocks, revealing a peculiar breakage of the surface prior to submergence beneath the sea. As there is no coarse sediment, shallow, quiet Carboniferous seas are to be inferred. Rocks showing the same type of surface breakage may be observed in places in stream channels and should not be confused with the basal conglomerate.

Certain characteristics of the formation are pronounced. (1) Bedding as a rule is ill defined, preventing correlation by lithologic units. (2) Coarse or fine grained phases of the limestone occur in alternation, but comparisons are difficult between individual beds in different places, because of their great similarity. (3) There is an abundance of white and yellow chert through nearly the whole formation (see Pls. III and IX), though some layers are quite free from this material. (4) Where the relief is considerable and the plateau is much dissected, the surface of the area occupied by the formation is exceedingly rough, and this condition, in general, is a means of recognizing the formation. This statement does not apply to the high, rolling grass lands to the north. (5) In certain layers near the base the chert has evidently been dissolved and replaced by crystalline quartz filling irregular cavities. A study of this formation in greater detail than was possible during the preparation of this folio would undoubtedly lead to its local subdivision, but probably such separation could not be consistently mapped over the area.

Distribution.—As the Ellenburger limestone lies immediately above the Cambrian beds, it is found at the crest of the Paleozoic scarp except where faulting has disturbed this relation, and it occupies the greater part of the area underlain by Paleozoic strata in the Llano and Burnet quadrangles. Large areas are exposed in the rolling uplands of the northern portion of the Llano quadrangle and a considerable portion of the Riley Mountain cap is formed by it. The formation is widespread likewise in the northwestern part of the Burnet quadrangle. Southwest of Burnet it forms a wedge-shaped mass tapering to a point at the southwestern extremity of Backbone Ridge. A considerable strip also outcrops north and south of Sudduth and south of Marble Falls.

Sections.—Complete sections of this formation are not easy to obtain. The general massiveness of the beds, gentle folds, and faults all combine to break the 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 1000 feet of beds would include all the strata deposited in this region.

The following section represents the upper portion of the Ellenburger limestone as measured near the mouth of Flatrock Creek, in Burnet County:

Section of Ellenburger limestone near the mouth of Flatrock Creek.

	Feet.
Carboniferous at top, 50 feet.	
Grayish crystalline limestone with much chert	15
Crystalline limestone, brown and gray, sugar-grained texture, with light-colored chert; coarsely crystalline near top; greenish stains in calcite crystals	25
Massive hard smooth-textured beds at base, grading up into brown crystalline and coarse gray limestone; some chert	22
Alternating sugar and smooth grained beds; at top a bed of cherty limestone, weathering in honeycomb fashion	11
Alternating sugar and smooth grained beds; but little chert	11
Brown sugary banded limestone, with some chert	5
Smooth light-gray limestone, with whitish chert, weathering bluish gray; smooth rounded pieces simulating waterworn bowlders on surface	50
Smooth limestone light gray, with conchoidal fracture; contains some chert which weathers out into rough surface; alternating thin and massive beds	22
Brown sugar-grained limestone containing layer of white chert	2
Irregularly bedded dark and light-brown sugar grained limestone; tesselated weathering in cliff	11
Brown and gray crystalline limestone; lowest portion contains some chert	$3\frac{1}{2}$
Rough-weathering, somewhat concretionary limestone, sugar grained, brown and mottled pink	2
Massive beds of brownish-gray smooth limestone; irregular fracture	4
Gray crystalline limestone, massive bedded, sugar-grained, mixed with smooth, noncrystalline variety	$5\frac{1}{2}$
Brown and light-colored fine sugar-grained crystalline limestone, mostly thin and irregularly bedded	17
Local bowlder bed resembling conglomerate; sandy material	$1\frac{1}{2}$
Brown and light-colored fine sugar-grained crystalline limestone, mostly thin and irregularly bedded, but makes jagged cliff	$27\frac{1}{2}$
Bottom at level of Colorado River.	

Paleontology and correlation.—The notes which follow were brought together with the collaboration of E. O. Ulrich.

Though there are at present no paleontologic data regarding the lower part of the formation mapped as the Ellenburger limestone, it is believed to be of Upper Cambrian age. The upper part of the formation is early Ordovician and from it fossils have been collected in a few places. The writer is not able to state what proportion of the Ellenburger limestone is Ordovician. The fauna of these beds has been collected at only two or three points. The species collected so far—about 15 in number—are also represented in the particular facies of the Yellville fauna (assigned to the Ordovician) found at Lutesville, Mo. At both localities the most

[a] Cambrian Brachiopoda: Mon. U. S. Geol. Survey, vol. 51, 1912.

common fossils are *Ceratopea keithi* (curved variety) and the *Helicotoma?* usually associated with it and with *Bathyurus amplimarginatus*. Two species of *Helicotoma?* and two species of *Ceratopea* were abundant in Texas.

The lower part of the Ellenburger limestone may be correlated with the basal division of the Arbuckle limestone in Oklahoma.

There is a fair development of limestone of Lower Ordovician age in the Franklin Mountains of western Texas. The greater part of the collections from that area, like the fauna in the upper part of the Ellenburger limestone, indicate the *Ceratopea* zone.

CARBONIFEROUS SYSTEM.

PENNSYLVANIAN SERIES.

The Carboniferous system is represented in this region by the Marble Falls limestone and the Smithwick shale, both of lower Pennsylvanian age. The limestone is the lower formation. The shale includes some sandstone lentils. The deposition of upper Carboniferous strata on the Ellenburger limestone marks a great gap in sedimentation in this region, including lower Carboniferous, Devonian, Silurian, and part of Ordovician time. Partial records of all these periods are found to the northeast, in the Arbuckle Mountains of Oklahoma, and rocks of Ordovician and Silurian age are exposed near El Paso, west-northwest of Llano.

MARBLE FALLS LIMESTONE.

Definition.—As has already been stated, the bottom of the Marble Falls limestone is in most places marked by a thin limestone conglomerate and in one place by a very coarse angular conglomerate or breccia. There are localities, however, as in the small basin 5 miles northeast of Bluffton, where little or no discordance in sedimentation could be observed. At the top the formation is sharply limited and the Smithwick shale succeeds it with perfect accordance in dip. The formation is named for the typical exposures at Marble Falls, Burnet County.

Thickness and character.—The Marble Falls limestone, it is believed, does not exceed 450 feet in thickness. It is composed of alternating beds of dark and light gray, dove-colored, and dark-blue to black limestone. Many beds contain abundant cherty nodules, largely of a dark or black color. The color of this chert is diagnostic in distinguishing this formation from the underlying Ellenburger, in which the chert is decidedly lighter colored. The Marble Falls limestone may generally be distinguished also when struck a sharp blow with a hammer by its odor of petroleum.

Distribution.—The formation is confined largely to the southeast quarter of the Burnet quadrangle, though two isolated areas also are occupied by Carboniferous strata—one northeast of Bluffton, the other in Riley Mountain.

Sections.—The two following sections illustrate the lithology of the Marble Falls limestone:

Section of Marble Falls limestone along north bank of Colorado River from the new dam to point above bridge at Marble Falls.

	Feet.
Top, black shale.	
Thin-bedded black shale	20
Fine-grained dark-gray limestone	15
Thin-bedded and massive black limestone	30
Brownish-gray subcrystalline to crystalline limestone	30
Thin-bedded dark-gray or black fossiliferous limestone with *Productus* and crinoids	4
Fine-grained crystalline gray limestone	4
Fine-grained gray limestone with molluscan fossils	20
Dense black or dark-gray limestone	2
Light and dark gray mottled limestone with chert nodules	5
Mottled gray limestones with crinoid stems 26 inches long	5
Limestone conglomerate	1
Gray limestone without chert	2
Gray cherty limestone	8
Black limestone with cherty layers	8
Black evenly bedded limestone with cherty layers	9
Massive gray crystalline limestone	8
Gray cherty limestone	25
Gray crystalline limestone	6
Fault.	
Irregular-bedded gray limestone	17
Black shaly limestone with chert layers and lenses	22
Massive gray limestone, with crinoid stems	60
Fault.	
Dark cherty limestone	7
Dove-colored limestone with black bands and lenses	40
Conglomerate	20
Ellenburger limestone.	
	368

Section of Marble Falls limestone in Riley Mountain, in tributary of Honey Creek.

	Feet.
Carboniferous disappears in valley.	
Very hard compact, nearly black limestone; some chert; nonfossiliferous.	
Thin, dark, very hard limestone, conchoidal fracture, weathers buff; platy; considerable black chert	10
Rather massive gray limestone, some black chert	10
Thin-bedded, very fine grained black slaty limestone	20
Rather massive dove-colored limestone	20
Thin-bedded slate or slaty limestone, black or dark gray; weathers yellow; apparently no fossils	35
Massive coarse brown limestone	5
Thin-bedded limestone with chert, gray-brown, marly in some places; weathers light yellowish; few fossils noted; talus slopes	50
Crystalline grayish-brown limestone; some fossil fragments	12
Massive brown limestone with large amount of chert	7
Coarse-grained brown limestone containing considerable light chert; weathers into a slope of talus	9
Irregular limestone, gray to brown fine grained, nonfossiliferous	32
Thin-bedded, very dark, fine-grained limestones with a large quantity of black chert; a few fossils.	
Irregularly bedded fine-grained brown and gray limestone, very fossiliferous at base; bituminous odor strong; some parts of base are mostly *Productus* remains	23
Mostly thin-bedded fine to coarse grained brown and dark-gray limestone, highly fossiliferous	8
Thin-bedded hackly limestone, brownish, sugary; bituminous odor	6½
Conglomeratic limestone containing pebbles of white chert and fine-grained light limestone	2
Ellenburger limestone.	
	248½

SMITHWICK SHALE.

The Smithwick shale, named from the old town of Smithwick, in Burnet County, consists of soft, very dark or nearly black carbonaceous shale in which are included a number of sandstone lentils. Being soft and easily disintegrated, the formation is not sufficiently well exposed for accurate measurement of its thickness. It is, moreover, overlapped by the Cretaceous strata. Probably the thickness of the beds exposed in Burnet County does not exceed 400 feet. The base of the formation is everywhere well defined, the change from the underlying limestone being abrupt. The formation comprises the latest Paleozoic rocks of the region, and the period of erosion indicated by the beveling of its beds corresponds to the great interval between Paleozoic and Cretaceous sedimentation. The formation is confined to the southeastern part of the Burnet quadrangle and to a small area on Riley Mountain in the Llano quadrangle.

PALEONTOLOGY AND CORRELATION.

The Carboniferous rocks of the Llano-Burnet region are equivalent to a part of the Bend series of the Texas Geological Survey as exposed at Bend, Lampasas, and San Saba, and are of lower Pennsylvanian age. George H. Girty says:

> The typical Bend series of the Texas Survey is divisible into three portions—an upper and lower shale, separated by a series of limestones * * * . The lower division I am referring to the Mississippian * * * . According to the canons at present used for determining the Pennsylvanian by paleontologic evidence the middle and upper divisions would be called Pennsylvanian.
>
> I feel no hesitation in recognizing the Marble Falls limestone as the middle division of the typical Bend of the Texas Survey. Although I did not see or collect fossils from the shale at Marble Falls, it seems a fairly safe inference that this [Smithwick shale] is the upper division. It is somewhat doubtful whether the lowest division is represented in the Burnet and Llano quadrangles. I did not myself observe it in any of the sections studied and at one point (on Colorado River below Marble Falls) it is either absent or reduced to an inconsiderable thickness. At this point the Marble Falls limestone was observed within 5 feet of the top of the Ordovician limestone, the interval not exposed. About 2 feet from the base of the Marble Falls limestone I collected a small fauna in which the following species are provisionally identified:
>
> | | |
> |---|---|
> | Acervularia n. sp. | Derbya sp. |
> | Michelinia sp. | Aulosteges n. sp. |
> | Fistulipora sp. | Spirifer rockymontanus. |
> | Lioclema sp. | |
>
> It is clear that this is not the fauna of the lowest division either lithologically or paleontologically.
>
> * * * * * * *
>
> I have revised the identifications of the collection from Marble Falls, upon which a report was made to R. T. Hill a number of years ago, and I now recognize the following species:
>
> | | |
> |---|---|
> | Textularia sp. | Acanthopecten carboniferus? |
> | Campophyllum torquium. | Streblopteria herzeri? |
> | Chætetes milleporaceus. | Myalina perniformis. |
> | Productus cora. | Pseudomonotis sp. |
> | Productus inflatus? | Conocardium obliquum. |
> | Productus sp. | Pleurophorus occidentalis? |
> | Marginifera? sp. | Pleurophorus? sp. |
> | Dielasma bovidens? | Phanerotrema grayvillense? |
> | Spirifer rockymontanus. | Schizostoma catilloides? |
> | Spirifer marcoui? | Phillipsia missouriensis? |
> | Composita subtilita? | |
>
> This seems to be a composite lot consisting of a collection made by R. T. Hill and Cooper Curtice combined with one made by T. W. Stanton and T. W. Vaughan, both from Marble Falls and presumably at about the same place. Hill's collection is reported to have been obtained near the bottom of the Carboniferous limestone at Marble Falls, the original (supposed) Devonian locality of B. F. Shumard and the same locality as reported by R. T. Hill (Am. Geologist, vol. 3, 1889, p. 290). The Stanton label reads "Below the *Productus* limestone, Marble Falls." As in my original determination, I now regard this fauna as of Pennsylvanian age.

CRETACEOUS SYSTEM.

COMANCHE SERIES.

GENERAL FEATURES.

The great unconformity at the base of the Cretaceous system in this area is a most striking feature. It affords a remarkable example of the progressive encroachment of the sea over an eroded region—a region displaying on the one hand the complexities of its structure, yet showing perfectly on the other hand the competence of erosion to bring about a relative leveling of the surface.

R. T. Hill and T. W. Vaughan[a] have treated in a comprehensive manner the nature and relations of the Cretaceous system in this province and they also have described in great detail the geology of the Austin quadrangle, lying just southeast of the Burnet quadrangle. As the Cretaceous formations of these two quadrangles are in part identical, the reader is referred to the Austin folio (No. 76) for details not given here.

In the Austin quadrangle the Cretaceous system is represented by rocks of both Lower and Upper Cretaceous age; in the Llano-Burnet region the system is represented by Lower Cretaceous rocks alone. The following table shows the classification of the rocks, as made in the Austin folio:

Classification of Cretaceous rocks in the Austin quadrangle, Texas.

Series.	Division or group.	Formation.
Gulf series (Upper Cretaceous).	Montana.	Webberville formation. Taylor marl.
	Colorado.	Austin chalk. Eagle Ford formation.
	Dakota.	Missing.
Comanche series (Lower Cretaceous).	Washita.	Buda limestone. Del Rio clay. Georgetown limestone.
	Fredericksburg.	Edwards limestone. Comanche Peak limestone. Walnut clay.
	Trinity.	Glen Rose formation. Travis Peak formation.

In the Llano-Burnet region only the Fredericksburg and Trinity groups are present. The formations included under these groups in the Austin folio have been mapped in a different manner in the Llano-Burnet area. The changes made are two. (1) The Travis Peak and Glen Rose formations of the Austin area are combined in the Llano-Burnet region as the Trinity formation for the reasons that no boundary between the two formations could be established which was sufficiently well marked to be recognized or followed in geologic mapping, and that the extension into the Burnet quadrangle of the Glen Rose as measured in a section in the Austin quadrangle shows an overlapping of the Glen Rose upon the typical Travis Peak—that is, the upper part of the typical Travis Peak in this area represents lower beds of the Glen Rose as mapped in the Austin quadrangle. (2) The Walnut clay, separately mapped in the Austin quadrangle, has here been mapped with the Comanche Peak limestone, being too thin to delineate separately on the scale of the maps.

The Cretaceous formations which have been delineated in the Llano-Burnet area are therefore as follows:

Fredericksburg group:
  Edwards limestone.
  Comanche Peak limestone (including the Walnut clay).
Trinity formation.

TRINITY FORMATION.

Character.—The Trinity formation in the Llano-Burnet region includes the equivalents of the Travis Peak and Glen Rose formations. The name is a group name and was originally applied by Hill to describe the beds at the head of Trinity River. Of the Trinity division in general Hill[b] says:

> The Trinity division is especially marked by strata of friable white pack sands, which do not occur in the other divisions and which in places constitute nearly the entire rocks of the division. In some places, especially south of the Brazos, these sands alternate with marly clays and chalky clastic limestones, the latter being composed of minute shells or fragmental particles of shells and sands having a lithologic and paleontologic individuality by which they can usually be distinguished. All the calcareous strata are white or yellowish and occur in numerous persistent alternations of hard and soft strata of various thicknesses. * * * In general rocks of the Trinity division were laid down upon a subsiding bottom of a former land surface. * * * The varying composition and near-shore character of the Trinity division are due to the fact that they were laid down against the nearly steep slope of the subsiding land from which the material was derived.

The distinctive characteristic of the Trinity formation in the Burnet quadrangle is the wide range in the thickness and nature of the beds composing it. This condition is the natural result of deposition near a gradually subsiding land surface on which, owing in part to the relief, various sorts of rocks were exposed to erosion. The composition of the basal beds is closely related to that of the rocks of the adjacent land that was undergoing erosion, and the texture of the beds depends largely on the relief of the land near the subsiding shore line. For example, a little east of the head of the north fork of Morgan Creek the formation is lacking in several small areas

[a] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol Survey, pt. 7, 1900. Hill, R. T., and Vaughan, T. W., Geology of portions of the Edwards Plateau and Rio Grande plain adjacent to Austin and San Antonio, Tex., with special reference to the occurrence of artesian and other underground waters: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 193-322.

[b] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 128-129.

and the Walnut clay rests directly on the uneven eroded surface of the Paleozoic limestone, but on Colorado River near the southern border of the Burnet quadrangle 50 feet of coarse conglomerate and about 450 feet of Cretaceous limestone and marl occur beneath the Walnut clay. (See Pl. VI.) The conglomerate contains pebbles of schist, granite, and Paleozoic rocks derived from the denuded area to the west. The beds to the north, lacking in conglomerate, indicate by their character moderate topographic relief along the encroaching shore line, but the beds to the south, on Colorado River, suggest quite the opposite.

Above the conglomeratic basal member, which is about 50 feet thick in the southeast corner of the Burnet quadrangle, are beds of shale, sandy oyster-shell breccias, sands, thin conglomerates, and calcareous sandstones. Higher in the section occur alternating series of buff, white, and yellow sandy and chalky limestones with thin beds of clay and sandy clay.

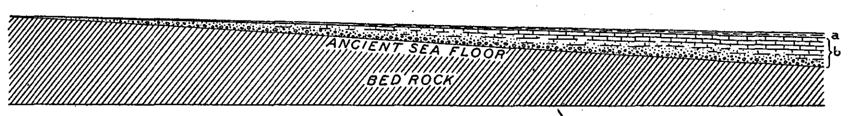


FIGURE 4.—Ideal section illustrating the lateral change in sedimentation of the Trinity formation from limestone and marl to conglomerate adjacent to the ancient sea floor.

a, Comanche Peak limestone, including Walnut clay; b, Trinity formation.

The base of the Trinity formation rises gradually from an elevation of 750 feet on Colorado River to about 1200 feet in the northern part of the Burnet quadrangle. Figure 4 illustrates in an ideal section the condition which is believed to have existed, namely, that the conglomeratic basal beds were progressively less coarse, thinner, and more calcareous as the distance from the land increased, until, at points remote from shore, pure limestones were formed. It is therefore clear why in the Llano-Burnet region sands are found at horizons which are marked farther southeast, in the Austin quadrangle, by limestones referred to the overlying Glen Rose formation.

Sections.—The following sections describe in detail the character and thickness of the various beds:

Section of the Travis Peak formation, beginning at the top of the divide between Hickory and Cow creeks and continuing to the Colorado River level at the mouth of Hickory Creek, Burnet County.[a]

[By J. A. Taff.]

	Feet.
12. Bands of conglomeratic and calcareous sandstone, alternating with beds of arenaceous limestone, the arenaceous limestone predominating	40
11. Marly magnesian limestone	40
10. Calcareous sand at base, grading upward to a siliceous limestone at the top, barren of fossils	55
9. Yellow calcareous sand, stratified	15
8. Conglomerate similar in character to No. 1, with the exception that the pebbles are smaller and more worn, grading into sand below and into calcareous sand above	25
7. Red sand, unconsolidated	3
6. Friable yellow sand	5
5. Cross-bedded shell breccia, containing many small rounded grains and pebbles of quartz, flint, and granite sand. Fossils: *Trigonia* and small bivalves, and *Ammonites justinæ*	7
4. *Ostrea* beds, magnesian lime cement, fossils en masse	3
3. Brecciated grit, composed of worn fragments of oyster shells, and shells of other Mollusca, with sand and fine pebbles, stratified in false beds	5
2. Bands of friable bluish shale and calcareous sand, stratified. Fragments of oyster shells are common in the calcareous sandstone	15
1. Basal conglomerate of pebbles of limestone, quartz, chert, granite, and schist, well rounded in a cement of ferruginous yellow and red gritty sand. Some of the pebbles at the base are from 5 to 6 inches in diameter. They decrease in size, however, upward from the base, until a false-bedded calcareous shell grit appears at the top	50
Total thickness of Travis Peak beds	263
Laminated flaggy Carboniferous sandstones and friable light-blue clay of Carboniferous (Coal Measures) age, from the Colorado River level upward to the base of the Cretaceous conglomerate, the laminated sandstones containing prints of ferns, nearly	100
Total thickness of section	363

Section at Post Mountain, 1 mile west of Burnet.[b]

	Feet.
Fredericksburg division:	
5. Barren Edwards limestone and Comanche Peak limestone	95
4. Walnut clay	10
	105
Trinity division:	
3. Impure arenaceous limestone and marl with aragonite crystals	25
2. Limestone agglomerate of shells with asphaltum	25
1. Reddish sandy clays and conglomerate	20
Paleozoic limestone.	
	70
	175

Section of Trinity formation on road from divide west of Cow Creek southwest to bench mark 834.

	Feet.
Chalky white limestone, porous, or weathering honeycombed; fossils	15
Similar but not honeycombed; weathers knotty	20
Covered slope	40
Wagon road.	
Buff-weathering limestone; no fossils	12½
Porous honeycombed limestone; no fossils	2
Buff limestone, massive, somewhat nodular weathering; 2 feet at base somewhat shaly	7½
Fine-grained sandy limestone	10
Fine-grained sandy limestone, shaly	1
Yellowish limestone, more massive and less sandy	4
White clay	1
Coarse buff limestone	4
Oyster shells in sandy layer	2
Massive limestone, yellow weathering	4
Shaly, yellow limestone, nodular and full of oysters	8
Shaly, with limestone layers	6
Hard porous dense buff-weathering limestone	1½
Oyster-shell breccia	3
Clay or sand containing chalky nodules	5
Chalky layer	½
Clay or sand containing chalky nodules	3
Hard dense buff limestone, shaly at bottom	5
Nodular limestone, weathering into nodular clay	8
Siliceous limestone	3
Oolitic fossiliferous shaly-weathering limestone	10
Coarse reddish limestone	5
White clayey limestone with shaly weathering	3
White sandy honeycombed limestone	2
Sandy and nodular-weathering limestone	6
Dense dull-white limestone	1
Nodular-weathering limestone	10
Dense brown limestone	1
Clayey limestone, weathering nodular	4
Dense buff nodular-weathering limestone, with calcite films and sand grains	10
Nodular-weathering limestone, possibly conglomerate	7
Dense buff limestone containing coarse grains of quartz	16
Stream at bottom of slope.	
Clays, yellow, honeycombed at base	10
Light-colored limestone, somewhat gritty; makes small bench	5
Soft layers, covered	5
Hard layer limestone	2
Alternating hard and soft beds of clay and marly limestone, not very fossiliferous; makes small terraced slopes	30
	293

[a] Taff, J. A., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 140.

[b] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 136.

Section from top of slope east of bench mark 834.

	Feet.
Sandy limestone; few fossils	5
Sandy limestone, with many shells	15
Covered	5
Fine sandy limestone, with fossils	5
Fine sandy limestone; not many fossils	8
Fine-grained conglomerate, in places shaly	5
Covered	5
Conglomerate, nodular weathering	5
Covered	18
	71

Section downstream from bench mark 834.

	Feet.
Sandy conglomerate	10
Oyster shells	1
Sandy conglomerate	1
Sand and sandy conglomerate	9½
Conglomerate of oyster shells	4
Sand; may be Pleistocene	20
	409½

Section of portion of Trinity formation 2½ miles west of the southeast corner of the Burnet quadrangle at its southern edge.

	Feet.
Soft sandy marl containing lamellibranchs	5
Covered terrace	5
Buff massive, slightly honeycombed limestone containing fragments of shells	2½
Sloping terrace of softer marly limestone	7½
Steeply sloping surface underlain by nodular gray limestone with 2-inch layer of slightly gritty material	9
Buff sandy limestone	6
Light-buff calcareous shale, nodular, containing some fossils	10
Sandy limestone, containing numerous fossils	5
Sandy limestone	10
Covered slope, probably underlain by soft bedded limestone	14
Sandy limestone	1
Soft, knotty, marly buff limestone	5
Covered gentle slope	5
Cream-colored limestone, slightly sandy	1
Clayey marl; 1 foot at top strongly fossiliferous; 5-inch band of buff limestone 2 feet from top	19
Marly beds with hard layers, containing some fossils	8½
Yellow porous limestone, containing shells	5½
Similar, but more massive	6
Similar, but thin bedded	5
Similar, but shaly	14
Solid yellow limestone	6
Thin-bedded fossiliferous limestone	9
Massive chalky limestone, with fossils	6
Massive chalky limestone	15
Shaly limestone, transition from bed above	8
Fine-grained massive yellow limestone	7
Calcareous shale	10
Fine-grained gray sandstone, calcareous	5
Covered slope	10
Conglomerate with many pebbles	27½
Total in cliff and side of hill	247

Distribution.—The Trinity formation underlies most of the eastern half of the Burnet quadrangle. In the plateau areas, especially toward the south, it is covered by the overlying formations, but it everywhere occupies the slopes and the valleys, save in one or two places where the streams have cut through it into the underlying Ellenburger limestone. Along the escarpment about 5 miles northwest of Burnet it is absent for several miles, and the Comanche Peak limestone rests directly on the Ellenburger limestone. In two small areas, also, southeast of Bunker Hill the formation is lacking beneath the overlying Walnut clay. This absence of the Trinity appears to be due to nondeposition in these localities.

Paleontology.—The Trinity formation contains a number of characteristic fossils. The following notes are abstracted from the Austin folio:

Fossils are found in the Travis Peak formation as low as the basal conglomerates, but they are neither plentiful nor well preserved. The upper or coquina-like beds of the Travis Peak are full of casts and molds, among which are *Ammonites justinæ* and undetermined species of *Cucullæa*, *Trigonia*, *Pholadomya*, and *Cyrena*. In these beds also appears the first of the several oyster agglomerates of the Comanche series. This is composed of a solidified mass of large oyster shells forming a stratum 7 or 8 feet thick, which outcrops just below the junction of Postoak and Cow creeks.

At the top of the sandy beds in the Hickory Creek section of the Travis Peak there is a yellow arenaceous fossiliferous limestone. This limestone marks the first or lowest appearance of the peculiar fossils *Monopleura* and *Requienia* and indicates the beginning of the conditions which finally produced the Glen Rose limestone (not separated in this folio). In the middle third of the Glen Rose formation occurs the foraminifer *Orbitolina texana*, besides many casts of large mollusks.

FREDERICKSBURG GROUP.

The Fredericksburg group is composed of three formations, named, in ascending order, the Walnut clay, Comanche Peak limestone, and Edwards limestone. The group name is derived from the exposures of the formations at Fredericksburg, Gillespie County, Tex.

WALNUT CLAY.

Overlying the Trinity formation is a bed of yellow calcareous clay, generally more or less indurated in this area. It is extremely rich in two species of oysters, *Exogyra texana* Roemer and *Gryphæa marcoui* Hill and Vaughan. Its thickness is from 10 to 15 feet. This bed is extremely persistent in both its lithologic and its paleontologic characters. It was named the Walnut clay by Hill[a] from the town of that name in Bosque County, Tex.

This clay, where not indurated, commonly occupies a terrace or bench resting upon a hard stratum of the underlying formation. (See Pl. IV.) It is not separately mapped in this folio on account of its thinness but is included with the overlying Comanche Peak limestone.

COMANCHE PEAK LIMESTONE.

Definition, thickness, and character.—The Comanche Peak limestone succeeds the Walnut clay and is in turn followed by the Edwards limestone in perfect conformity. Its thickness in the Burnet quadrangle ranges from 40 to 50 feet, or even to 70 feet in the extreme northern part of the quadrangle. This thickness does not include the Walnut clay, which in this area is mapped with the Comanche Peak limestone.

The formation consists of a white chalky limestone, which in places acquires a broken reticulated appearance on weathering. It contains an abundance of *Exogyra texana*. It is named for its occurrence at Comanche Peak, near Austin, Tex.

Distribution and relations.—The Comanche Peak limestone forms the tops of the broad divides in the northeastern part of the Burnet quadrangle. In the southeastern part it is overlain by the Edwards limestone and outcrops in narrow bands encircling the plateau areas and forming the upper parts of the slopes.

Its base slopes from an altitude of 1530 feet on the peak about 5 miles west of Bunker Hill to one of 1200 feet in the southeast corner of the quadrangle, with a gradient of somewhat less than 10 feet to the mile. Its regularity of bedding indicates different conditions of sedimentation from those under which the lower beds of the Trinity formation were deposited. As has already been stated, along the escarpment northwest of Burnet the Trinity formation is absent and the Walnut clay rests directly on the uneven floor formed by the Paleozoic limestone.

The Walnut clay is practically a fossil oyster bed deposited in shallow water, and it may be inferred that in this area limestones were being formed as shallow-water, near-shore deposits, the calcium carbonate being derived by solution from the limestone land mass to the north. The absence of sand or other detrital material is an illustration of the fact that the erosion of a limestone region of slight elevation is confined almost wholly to the removal of material by solution.

EDWARDS LIMESTONE.

General description.—The Edwards limestone conformably succeeds the Comanche Peak limestone. The following description is quoted from the Austin folio:

> This formation is the most conspicuous and extensive in the Texan-Mexican region. It is composed mostly of limestone strata, but there are some marly layers. It shows slight variations in color, composition, texture, and mode of weathering. In general the beds are whitish, although layers of buff, cream, yellow, or dull gray are frequent. In composition many of the beds are as nearly pure calcium carbonate as can be found in nature, but some have small admixtures of silica, epsomite, chloride of sodium, and perhaps other salts as yet undetermined. The formation can usually be distinguished by the immense quantity of flint nodules embedded in and between the limestones and scattered over the surface everywhere.

[a] Bull. Geol. Soc. America, vol. 2, 1891, pp. 503, 512.

The flint nodules are not displayed in the Burnet region, possibly because only the lower part of the formation is exposed. In hardly a single exposure was there sufficient chert to be a noticeable feature of the formation. The type locality is the Edwards Plateau, in the Nueces and Uvalde quadrangles, Texas.

Paleontology.—According to Hill and Vaughan, the formation may usually be distinguished by the "peculiar aberrant mollusks of the genera *Monopleura*, *Requienia*, and *Radiolites*—bivalve fossils which have cornucopiate forms suggesting a resemblance in shape to the horns of cows, goats, and sheep."

Distribution.—In the Burnet region the formation does not attain a greater thickness than 150 feet and in places it has been reduced by erosion to a thin film of cap rock. It is confined to the summits of the ridges, which may be readily distinguished by their table-like form. In much of the northern part of the area and in some of the southern part it has been entirely removed by erosion.

STRUCTURE.

GENERAL RELATIONS.

Reference to the small geologic map of Texas (fig. 2, p. 1) will immediately call attention to the peculiar position that the central region occupies with respect to the remainder of the province. It will be seen that the area is nearly surrounded by flat-lying Cretaceous rocks, and that immediately bordering the pre-Cambrian basin an inner rim of Paleozoic rocks, open on the north side, forms an escarpment about the interior denuded area. This area, in which are revealed rocks of the oldest known periods, is located about midway in the broad coastward slope extending from the western Cordillera to the Gulf of Mexico.

There are three types of structure in these quadrangles, displayed in (1) the pre-Cambrian metamorphic complex, (2) the folded and faulted Paleozoic beds, and (3) the practically undisturbed, nearly horizontal Cretaceous strata.

STRUCTURE OF PRE-CAMBRIAN ROCKS.

The structure of the pre-Cambrian schists is highly complex and can be indicated only in general terms. The rocks, especially those of sedimentary origin, have been deeply buried and in consequence subjected to deep-seated metamorphism. They have as a mass been thrown into broad folds, on which in turn minor folds have been formed. The process was carried so far that the rocks are completely foliated, and individual beds undoubtedly outcrop repeatedly, perhaps many times. Dips are in most places though not everywhere steep, and the dominant trend of the folds is northwest.

While this metamorphism was going on granitic intrusions of great relative magnitude took place, fracturing the rocks, aiding in their recrystallization, locally forming impregnation gneisses, and generally disturbing the regularity of the series. There is reason to believe that before this granitic intrusion the rocks had been disturbed by older granite masses, as well as by still earlier more basic intrusions.

The structure is therefore complex. Faults of considerable magnitude undoubtedly exist and are indicated by the sudden termination of limestone beds and other lithologic units, when traced along the strike. The major structural lines are shown on the sheets of structure sections. Two nearly parallel anticlinal axes are especially noteworthy—one a few miles west of Oxford and the other between Llano and Lone Grove. The latter plunges southeastward and ends in the southwestern part of the Burnet quadrangle, as shown by the bending of a number of limestone beds around the nose of the arch. North of Llano River in the western part of the Llano quadrangle the arch of the western anticline flattens and the schists dip at lower angles.

A few of the many minor folds are indicated on the map. The great granite masses—at least the one in the southwestern part of the Llano quadrangle and that in the southern part of the Burnet quadrangle—occupy positions corresponding in general to synclinal axes. The central syncline, lying a little west of Llano, does not seem to have suffered such extensive intrusion.

The pre-Cambrian complex has also been involved in the extensive faulting to be described under "Structure of the Paleozoic rocks."

STRUCTURE OF THE PALEOZOIC ROCKS.

General considerations.—Perhaps as forcible a method as any other by which to accentuate the dominant movements that have been at work in bringing about the present structural relations in the central Texas region would be to describe briefly the conditions prevailing in the well-known Black Hills region of South Dakota and then point out the sharply defined differences between that region and central Texas. Darton[a] says:

> The Black Hills uplift, if not eroded, would present an irregular dome rising on the north end of an anticlinal axis extending northward from the Laramie or Front Range of the Rocky Mountains. * * * The greatest vertical displacement * * * amounts to about 9000 feet. * * * *Faults are rarely to be observed*, and except for some short breaks due to igneous intrusion, few have been found which amount to more than a few feet in vertical displacement.

In the Black Hills region then, a great fold combined with erosion produced the present domelike, denuded mass.

Quite different are the forces which have been at work in the central Texas region, where faulting combined with differential erosion produced the present basin-like form. The faults, which border and intersect this basin and are indicated by heavy black lines on the areal geology maps, all have one important similarity. The structurally downthrown block now forms the high or scarp side of the fault and presents toward the basin a more or less steep escarpment. In other words, the central denuded pre-Cambrian area, now relatively lower, was at one time topographically as well as structurally higher than the surrounding country.

The rocks which were uplifted by the faulting must have been exposed to accelerated attack by the elements and the ensuing planation stripped the Paleozoic cover from the underlying schists and granites. The resulting surface was covered by Cretaceous sediments, but in Pleistocene time erosion had again succeeded in exposing the ancient rocks. From this point on the metamorphic complex has disintegrated more rapidly than the surrounding limestone-capped strata, and the present erosional basin has been carved out. The Paleozoic sediments involved in the uplift are locally folded and are inclined at various degrees from the horizontal.

Character of the faulting.—The system of faults which aided in bringing about the structure above described may now be studied more closely.

The prominent physical relations of the faults are as follows:

1. They are pre-Cretaceous.
2. Most of them are straight breaks.
3. The greater number are vertical—that is, their trace on the surface is a straight line.
4. Movement along the fault plane has been generally in a vertical direction, for in many places two faults combine to include a V-shaped block. A close inspection of a number of such breaks proves that the faults die out horizontally, for they fail to show evidence of any folding that might suggest horizontal movements. At one locality a block inclosed by faults has such a configuration as to preclude any appreciable movement except in a vertical direction. It is therefore inferred that in the main the relief afforded by the breaks was in a vertical direction.
5. They have a northeast trend, with only one important exception.
6. They are closely related to folds—that is, they are parallel to and locally pass into folds.
7. The throw or displacement varies from a few feet to 1800 feet.

These facts combined with a few considerations of a general nature serve as a basis for a geologic interpretation, which will deal with the age of the faults, their localization, and the forces involved.

Date of faulting.—Nearly flat Cretaceous sediments overlap the Paleozoic beds and are deposited unconformably upon an irregular erosion surface cut in folded and faulted strata. For example, along the basal contact of the Cretaceous northward from the southeast corner of the Burnet quadrangle the beds overlie successively Carboniferous, Ordovician, and late Cambrian strata. Moreover, the Paleozoic beds are both folded and faulted, whereas the Cretaceous rocks lie nearly flat and have suffered neither of these disturbances. The faulting therefore took place prior to or at the time of the subsidence of the pre-Cretaceous land. As the erosion is demonstrably later than the faults, it is probable that the faulting occurred during the uplift following the deposition of the Smithwick shale.

Localization of the faulting.—It has already been pointed out that in the Llano-Burnet region the phenomenon of overlapping formations is well developed. The basis for this statement lies principally in the fact that in the Paleozoic succession there are important sedimentary gaps marking periods during which deposition was not taking place in this region. As beds deposited during these periods are found in regions farther north and northeast, it is a reasonable inference that the Paleozoic cover becomes progressively thinner toward this area of relatively high level, and that here it was comparatively thin. Such an area, if subjected to regional compression, would afford a place for relief of the strain.

Forces involved in the faulting.—An examination of the structure near Marble Falls (see section C–C, Burnet structure-section sheet and fig. 5) throws light on the stresses which have been active in this region. At this point a number of folds and faults are developed in the late Cambrian, Ordovician, and Carboniferous strata. Both folds and faults have a general northeast trend, and the faults are in the main nearly vertical. The conditions here point rather conclusively to compression as the cause of the faulting; for if the folds were produced by tensional stresses (such, for example, as would be involved in doming by direct vertical uplift) elongation of the beds would follow and normal faults with inclined hades would be developed. No faults with such markedly inclined hades were observed. Moreover, vertical or nearly vertical faults alone do not admit of an appreciable elongation of the surface, and when combined with folds they indicate rather that they are an expression of relief from compression by vertical movement.

A consideration of the ancient geography of North America suggests that during the entire period or succession of periods during which deposition was taking place in this region there were land masses both to the northwest and to the southeast, and it is believed that such a condition existed immediately prior to the post-Permian uplift[a] which again brought this region above sea level. It is probable that the seas in which these sediments were deposited occupied troughs trending in a northeast-southwest direction.[b]

Subsidence in the floor of the Gulf of Mexico would initiate deep-seated rock flowage, under the influence of which the central Texas region would be compressed between the two land segments mentioned above. Such compression might have produced the folding of the strata parallel to the shore of the Gulf of Mexico in the Llano-Burnet region, accompanied by vertical faulting, the expression, it is believed, of relief from compressive stresses in this lightly loaded area where vertical movement might more easily take place.

Details of faulting.—The faulted structure of the Carboniferous strata near and southeast of Marble Falls is an excellent example of the type of faulting which has taken place in this region. An examination of the section southeastward from a point near Marble Falls, as represented in section C–C of the Burnet structure-section sheet, will make clear the "block"

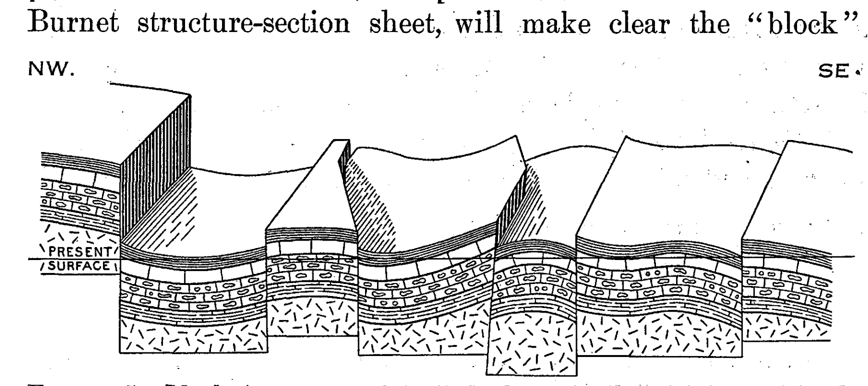


FIGURE 5.—Ideal stereogram of faulted blocks in the vicinity of Marble Falls, Texas.

The relative vertical movement of the blocks is shown by the amount of displacement of the Paleozoic sediments which rest on the pre-Cambrian rocks.

nature of the movements. Figure 5 is a stereogram showing in an ideal way the relative movements of the individual blocks. Attention is called especially to the manner in which the highest rocks in the local Paleozoic sequence are brought against the pre-Cambrian granite.

Backbone Ridge, Long Mountain, Riley Mountain, and such scarps as that bordering Little Llano River and that north of Smoothingiron Mountain are examples of downthrown blocks whose present surface lies at a higher elevation than that of the interior basin. Figure 6 is an ideal drawing showing the rela-

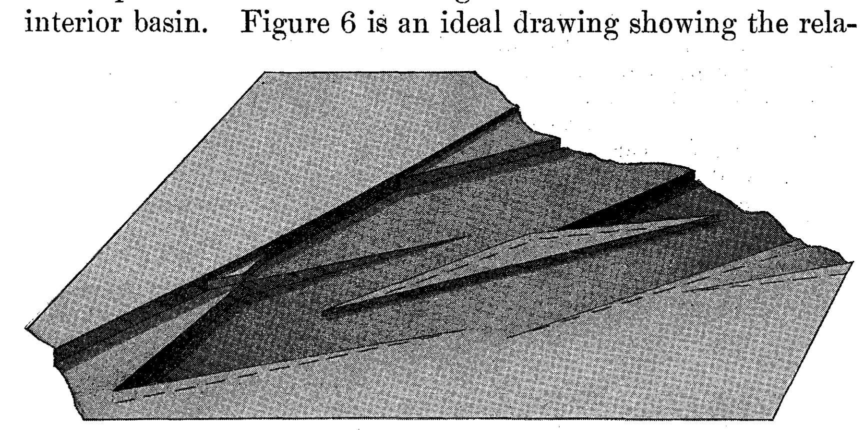


FIGURE 6.—Stereogram of the faulted blocks in the area north of Smoothingiron Mountain.

The relief sketch shows the faulted blocks as they would appear if no erosion had taken place. The downthrown blocks now form the high lands.

tions of the blocks north of Smoothingiron Mountain. It shows clearly that what was once a relatively low area is now a relatively uplifted mass. Of special note is the structural relation between Smoothingiron Mountain and the north-south fault. This mountain is formed by a sharp fold, Cambrian sandstone at its south end being nearly continuous from its summit to its base. It may be seen from this that the break forming the fault to the north has passed here into a fold which dies out farther south before reaching Slick Mountain.

No less than thirteen faults break the continuity of the strata forming Riley Mountain. The series of breaks which follow the western scarp have the greatest throw. In the valley of Honey Creek Carboniferous shale is faulted down against pre-Cambrian schists, a break representing a vertical movement of about 1800 feet. (See section D–D, Llano structure-section sheet.)

STRUCTURE OF THE CRETACEOUS ROCKS.

The undisturbed, nearly horizontal attitude of the Cretaceous strata in the Llano-Burnet region is direct evidence of

[a] Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper U. S. Geol. Survey No. 65, 1909, p. 62. Italics by the present writer.

[a] Schuchert, Charles, Paleogeography of North America: Bull. Geol. Soc. America, vol. 20, 1910, pls. 83–86.

[b] Idem, pls. 48, 49.

the slightness of deformation since they were laid down. The position these rocks now occupy would seem to be a result of simple uplift from beneath sea level to their present position. This uplift was accompanied by a gentle tilting which the slight Gulfward dip of these beds perhaps reflects. Otherwise this series of rocks may be considered as a pile of nearly undisturbed sedimentary strata, unaffected by the post-Cretaceous faulting which is so well developed to the southeast in the Austin quadrangle.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

As has been noted in describing the structure, the sedimentary rocks of pre-Cambrian age have passed through the various stages of deep burial, regional metamorphism, and active igneous intrusion. The character of the individual beds composing the schist-gneiss series leaves little or no doubt that the processes of sedimentation and conditions of life at the time they were formed were in their broad essentials the same as during Paleozoic and later periods. Igneous activities, too, played in those ancient days quite as important a part as in later times. Marbles and graphite schists point to the existence of animal and vegetable life; amphibolites and basic intrusives indicate igneous activity. After their formation the entire series of rocks was subjected to deep burial and consequent metamorphism. Mashing and crushing of the rocks were followed by more complete alteration; minerals were rearranged, a schistosity was impressed upon the series, major and minor folds were developed and were undoubtedly accompanied by faults. Basic intrusives broke the beds, themselves to be later affected by sufficient pressure to create incipient schistose structure. Finally granitic intrusives of great magnitude added their quota to the complexity of the mass, perhaps in two stages—one while the rocks were still deeply buried and under considerable pressure, the other later and probably much nearer the surface. These ancient geologic processes were followed by uplift and long-continued denudation. Later the sea again covered the land and Paleozoic deposition began upon a nearly leveled surface.

PALEOZOIC ERA.

To present more clearly the history of the sedimentary succession in the central Texas region during Paleozoic time it would perhaps be well to outline, in a broad way, the relation of the region to sea level throughout that era.

It is evident from paleontologic data that great gaps occur in the sedimentary record, and it is very probable that these gaps represent periods of elevation above the sea. The evidence for this belief lies in the phenomena of overlap, in comparison with the Ozark and other regions to the northeast, and in general stratigraphic and paleogeographic considerations. Some of these will be set forth below. All point to the important conclusion that the central Texas region was one of relative elevation during several long periods.

As the earliest Paleozoic sediments in this region are of Upper Cambrian age, it is clear that prior to their deposition (that is, during Lower and Middle Cambrian time) the region must have stood above sea level. The indications of shallow seas during the Wilberns epoch, the gaps in the Cambrian-Ordovician sequence, the absence of Silurian, Devonian, Mississippian, Jurassic, and Triassic sediments points to the same conclusion—that during much of Paleozoic and Mesozoic time a land area existed in this region.

The relation of the basal conglomerates and sandstones of the Upper Cambrian series to the underlying complex of pre-Cambrian schist, gneiss, and granite indicates in a striking manner the profound nature of the unconformity at the base of the Paleozoic. The Cambrian beds were deposited upon a relatively even floor, probably a land surface worn down nearly to base-level, a feature indicating, by the manner in which preexisting structures were truncated, a long interval of erosion.

The sea gradually spread a deposit of gravel and sand over this plain. The lower areas were filled, while here and there islands remained above the general level of the water. Finally these also were covered by more calcareous sediments.

As the land continued to subside and the shore line receded farther from this area the water grew clearer, more calcium carbonate was deposited, animal life began to leave a more varied record, and finally pure limestones entirely replaced the sands. The subsidence, however, was not regular and uninterrupted. An uplift is indicated by the glauconitic sandstone at the top of the Cap Mountain formation. Though this movement may have been insufficient to expose the sea bottom, it at least allowed the deposition of coarse sands from a near-by shore. This sandstone stratum is persistent in this area and is characteristic of the Cambrian in other regions. After its deposition the waters again cleared and calcareous deposits replaced the sands. This change may have been brought about by a recession of the shore line or perhaps by a failing supply of coarse material and a shifting of currents, yet the wide geographic extent of the change points almost conclusively to a deepening of the sea.

During this entire period the sea attained only very moderate depths in this region, as is clearly indicated by the abundance of glauconite grains characterizing portions of these lower formations and still more clearly by the character of the Wilberns formation. Near the upper portion of the Wilberns thin alternating shale and limestone beds, numbers of shale-pebble conglomerates, "edgewise" (shale fragments) conglomerate, sun-cracked surfaces and fragments, and peculiar bowlder-like forms of lime muds all suggest the presence of widespread flats alternately flooded by the tide and dried by the sun. This extreme shallowness gave way to relatively deeper water, as shown by the bedded limestone at the top of the formation.

From this point on the history of sedimentation, as revealed by the series of beds mapped as the Ellenburger limestone, is obscure. Paleontologic evidence casting doubt on the idea of continuous sedimentation suggests a hiatus somewhere near the base of the formation and another near its top. At neither of these horizons does it seem that erosion had an opportunity to affect the surface of the underlying beds. Probably the elevation above the sea was slight, and under such conditions, though great lapses of time might intervene, little discordance would be apparent in the sedimentation.

The next great break occurs at the top of the Ellenburger limestone. It would be fruitless, with the knowledge at hand, to attempt to state definitely the several oscillations which may have ensued from the time when Ordovician sedimentation ceased until Pennsylvanian deposition began. It may be suggested, however, in accordance with the hypothesis that the Llano region has often been an area of elevation, that the missing formations were never deposited and that the Pennsylvanian beds represent a transgression of Gulf and possibly Pacific waters following a long interval during which the land stood relatively very low with respect to the sea.

Limestones of the Pennsylvanian series afford the earliest record of Carboniferous deposition. The beds are introduced generally by a thin limestone conglomerate with little or no discordance in dip. Evidently the topography was rather featureless at this time. The black shale at the top of the Pennsylvanian in this area suggests a return to low, swamp-like conditions, perhaps prevailing over extensive areas. Though Carboniferous strata, both earlier and later than these, may have been deposited in this region there is now no evidence of them.

MESOZOIC ERA.

Folding and faulting were marked accompaniments of the uplift which closed the Paleozoic era and marked the initiation of Mesozoic time. During the Jurassic and Triassic periods the area probably remained a land mass and erosion was the important process at work. This fact is clearly proved by the beveled beds which appear beneath the basal formation of the Cretaceous, forming a surface cutting alike across hard and soft strata and across such features as faults and folds. That this surface was partly cut in pre-Cambrian rocks is strongly suggested by the fact that in places basal Cambrian beds now stand at a higher elevation than basal Cretaceous beds, and, though Cretaceous strata resting directly upon pre-Cambrian rocks do not occur in the area, there is almost no doubt that such relations existed and have been erased by post-Cretaceous erosion. It is evident, therefore, that erosion had probably slightly changed the topographic forms of the ancient pre-Cambrian plain prior to the post-Cretaceous erosion which next brought these rocks to light.

After this pre-Cretaceous planation and presumable partial exposure of the ancient crystalline rocks, the region subsided and was covered by Cretaceous sediments. In its significance this overlap quite parallels the great transgression of the sea in early Paleozoic time.

PHYSIOGRAPHIC DEVELOPMENT.

The remaining history of the region may perhaps be best described in a discussion of the physiographic development, for it is deduced from present topographic forms.

There is only a fragmentary record in the Llano-Burnet region of the geologic events which took place after the long period of Cretaceous deposition. All the Upper Cretaceous rocks have been removed by erosion and there is no record of Tertiary time. An examination of the geologic history recorded in the Austin quadrangle and in the Gulf Coastal Plain, however, will throw some light on these later periods, and it may thus be possible to show how and when the major physiographic features of the region were developed. In brief, Cretaceous deposition in this area was closed by a widespread uplift of the sea bottom and followed by a prolonged period of subaerial erosion. This erosion interval was terminated by subsidence, as is proved by the deposition of Eocene sediments upon Upper Cretaceous strata in the Austin quadrangle. The data at present available are insufficient to permit statements as to the extent of the Eocene sea. It is stated in the Austin folio that the shore line of this sea probably bordered the Balcones fault scarp in the Austin quadrangle, and it must be assumed for the present, therefore, that Eocene strata were never deposited in the Llano-Burnet area.

The later Tertiary history of the Gulf Coastal Plain is now undergoing detailed study. It is complex and many data have yet to be procured before a consecutive account can be written of the oscillations of the sea bottom and the manner in which deposition took place. It is not yet certainly known what portions of the later sediments were laid down on subsiding or rising sea bottoms, and many correlations have yet to be made. It would be but speculation, therefore, to present an account of Tertiary time in the Llano-Burnet region. It may be suggested, however, that probably the area has remained above sea level ever since the Upper Cretaceous sediments emerged from beneath the sea. This presumption is consonant with the fact that all the Cretaceous strata which once overlapped the Edwards limestone have been eroded from the Llano-Burnet region, that is, the Edwards limestone is the youngest of the Cretaceous formations exposed. This formation has had an important effect on the topography of the Cretaceous rocks throughout an area of wide extent in Texas. Because of its resistance to erosion it was competent to maintain a summit level and thus form an extended plateau, beneath which the mesa-topped hills characteristic of the areas underlain by Cretaceous rocks have been carved. This plateau has been named the Edwards Plateau by Hill.[a] It is now everywhere dissected and it is probable that at no time during the past has this formation constituted an unbroken plain. In the Llano-Burnet region it once extended over the entire area. The table-like summits trending southeastward from the town of Burnet are all that remains of it in the Burnet quadrangle, and only a fragment remains in the northwest corner of the Llano quadrangle. It is this limestone, however, that may be said to be the keynote to the Cretaceous physiography. It expresses clearly the practically undisturbed structure of the Cretaceous beds and at the same time affords a reasonable explanation of the table-like plateau remnants. In fact, it permits the surface of the Cretaceous area as a whole to be epitomized as a dissected plateau.

The physiography of the area underlain by older rock—Paleozoic and pre-Cambrian—is not quite so simple.

It has been shown that prior to the deposition of the Cretaceous rocks there had ensued a long period of erosion which reduced to a general level a region of diverse rock structure. Folds were planed off; fault scarps were eliminated; limestone, sandstone, and granite alike were included in the relative leveling. The remains of this surface (not a perfect plain) are to be seen to-day. The plateau-like area at the northern border of the Llano quadrangle and continuing into the Burnet quadrangle is a part of it. Long Mountain, Backbone Ridge, the Paleozoic highlands along the southern edge of Burnet quadrangle, and Riley, Putnam, House, and Smoothingiron mountains are all remnants of this surface, altered, it is true, by later Pleistocene erosion.

Just why these remnants have persisted, standing as elevations within and about a shallow though maturely eroded basin-like area, may be explained briefly. It is necessary, first, to recall what has already been stated, that sandstones, granites, and schists were probably exposed by the great pre-Cretaceous planation. Prior to this planation the central area had been elevated by faulting to a relatively higher position than the surrounding region, and the subsequent planation had consequently brought these older rocks to the surface. Cretaceous seas next swept over the area and sediments aggregating a thousand feet or more buried the older rocks.

In the Austin quadrangle, immediately southeast of the Burnet quadrangle, there is direct evidence to show that not until Pleistocene time was erosion effective in again bringing to light the pre-Cambrian rocks. The Uvalde formation of the Austin region, of Pliocene age and derived in large part from the denudation of the Edwards limestone, shows no granitic or limestone débris among its constituents. On the other hand, the oldest recognized terrace of Colorado River, assigned to the Pleistocene by the authors of the Austin folio, is composed largely of granitic débris.

It is conceived, therefore, that when erosion in Pleistocene time succeeded in cutting through the basal Cretaceous beds, first by such major streams as Colorado and Llano rivers, the pre-Cambrian granite, schist, and sandstone were more easily removed than the Paleozoic limestone strata and the active cutting of the shallow pre-Cambrian basin has proceeded without interruption down to the present time.

As a result of faulting, masses of granite are found resting against limestones along straight fault contacts—such, for example, as that just west of Marble Falls and those contained in Backbone Ridge; likewise schist abuts directly against limestone and sandstone, as along the eastern bases of Cedar and Riley Mountains and along the scarp following the approximate course of Little Llano River. But it must be kept in mind that the present scarps are due to erosion, for the structurally downthrown block is in nearly every case now

[a] Hill, R. T., Bull. Geol. Soc. America, vol. 3, 1892, pp. 90-92.

the highland. In the past these blocks were the low areas and were preserved from erosion because the granite, schist, and sandstone of the high areas were more easily carried away. In large part the scarp which surrounds the basin may be thus accounted for, and also such table-like mountains as Riley Mountain, Long Mountain, and Backbone Ridge.

Certain peculiarities of the drainage developed on the Paleozoic and pre-Cambrian rocks deserve consideration here. Colorado River markedly and Llano River to a less degree are meandering streams. Sandy Creek cuts completely across the Riley and Cedar Mountain mass in a gorgelike valley, and Honey Creek, near the north end of Riley Mountain, also traverses a gorgelike valley within the mountains but flows out upon a broad plain when it reaches pre-Cambrian rocks. All these streams are adjusted to the major structural feature—that is, they have established normal gradients. The meanders of Colorado and Llano rivers are evidently inherited from some earlier period when possibly these streams flowed at an elevation nearer sea level, when their gradients were not so steep as at present, and when they flowed more slowly and were less actively cutting. It is not possible at present to place this period exactly, but certainly it followed soon after and perhaps was initiated by the uplift of the Cretaceous sea bottom. So the drainage lines of Sandy and Honey creeks must be considered as having been established when Cretaceous rocks covered all of this territory. As erosion progressed and the pre-Cambrian areas were etched out these streams were able to keep pace with the general lowering and incise their gorges in the Paleozoic rocks. Incidentally each of these streams affords additional evidence to support the idea that Cretaceous strata once covered the area. The depth to which erosion can take place within the pre-Cambrian basin is fixed by the levels of Llano and Colorado rivers. Both of these rivers are cutting rapidly. It is probable, therefore, that the topography of the basin will become more diverse in the future, for both of these master streams cut faster than the tributary drainage and will therefore allow tributary streams to deepen their channels.

At present, however, the physiography of this central denuded region may be summed up in the statements that a shallow basin has been etched beneath the level of a pre-Cretaceous erosion surface; that remnants of the surface still remain about and within the basin; and that the basin represents physiographically, for the older rocks at least, an early stage in a new erosion cycle.

MINERAL RESOURCES.

The mineral resources of the Llano-Burnet region comprise, in the order of their present importance, building stone, rare-earth minerals, iron ore, gold, graphite, serpentine, talc, sphalerite, lead ore, pyrite, copper ore, manganese ore, and oil, besides water resources. Of these only the first two are of commercial importance at present, the copper and manganese ores and the oil are probably valueless, and the value of the remainder is unproved. Only the general geologic and economic relations of the several deposits will be discussed here, as detailed descriptions have been given in another publication by the author.[a]

BUILDING STONE.

GRANITE.

Granite forms a considerable proportion of the pre-Cambrian rocks in the Llano and Burnet quadrangles, but unfortunately much of it is unfit for use as building stone, as it contains abundant schist fragments. Were it not that many extensive areas are underlain by clean stone the granite industry in this region could have but a small growth. It may be said at once, however, that an enormous quantity of clean granite is available and can be utilized when transportation and market are at hand.

There are two very different types of the granite—(1) the coarse to very coarse grained granites, (2) the medium to fine grained granites, among which a number of varieties may be distinguished. The former is in most areas free from such imperfections as would prevent its use; the latter, in some places, is marred or spoiled by the presence of included schist fragments or of pyrite.

An extensive area of very coarse grained rock occupies much of southwestern Llano County. Practically inexhaustible supplies lie above what would be railroad grade in the vicinity of Enchanted Rock. Again, at and north of Granite Mountain, in Burnet County, are broad areas underlain by coarse-grained stone. The fine-grained granites are widely distributed, but the selection of quarry sites in such granites should be made with great care and only after thorough examination. A number of quarries have been opened in areas more or less characterized by the presence of schist fragments. At other localities there are quarries which have evidently been abandoned because of the presence of pyrite.

One fact directly dependent on 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 the granite has intruded the schists in a complicated way) there can be no assurance that what is apparently an excellent quarry floor will remain so at a greater depth. It is probable, indeed, that schist fragments will be encountered, perhaps in such amount as to reduce profits to a minimum or even wholly to ruin the enterprise. The chance that the mass may continue clean is too small to be worth the risk.

[a] Bull. U. S. Geol. Survey No. 450, 1911, pp. 1–99.

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

At present most of the stone quarried, except in the Granite Mountain quarry, is especially suitable for and is used for monuments. The granite 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 eminently suitable for large structures, and with the increasing growth of large cities in the South and additional transportation facilities, the granite industry in this region should become more extensive than it is at present.

MARBLE.

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

It may be said that in general much of the marble in the pre-Cambrian complex is worthless because of the impurities it contains. It is probable, however, that some ledges are of sufficient width and length and carry marble of such color and purity as to warrant an attempt at opening a quarry. Such localities can be found only after diligent search and by careful sampling of the surface rock.

Practically all the marble of this region is of a fairly coarse crystalline type and is more or less mottled blue or black. Some pure white ledges undoubtedly exist, but as a whole the material is a rather inferior variety of stone and probably will never command a high price. It is reasonable to suppose, nevertheless, that at some future time this stone may be quarried at a fair profit.

LIMESTONE.

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

SANDSTONE.

Sandstone quarries have been operated intermittently for a number of years at a point north of Fairland, Burnet County. A considerable quantity of this stone has been shipped out of the county, though a market exists in neighboring towns. The quarry is opened in the Hickory sandstone, which at this point is light brown and rather fine grained. The beds dip gently into the hillside, and prominent bedding planes 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 present is small, as it must compete with abundant limestone building material at points outside of the Llano-Burnet region.

RARE-EARTH MINERALS.

The rare-earth minerals of the Llano-Burnet region have been described by Hess, who gives a detailed account[a] of the occurrence at Baringer Hill. Much of his report has recently been republished,[b] and therefore only the salient points need be presented here.

Baringer Hill is about 100 miles northwest of Austin, on the west bank of Colorado River, in the Burnet quadrangle. It is 12 miles north of Kingsland, the nearest railroad point; 16 miles west of Burnet, and 22 miles northeast of Llano. It is a low mound rising about 40 feet above the river, which has here a flood plain about one-fourth mile wide. The hill is formed by an irregular pipe or short dike of pegmatite, which has been more resistant to erosion than the surrounding rock, which is a coarse porphyritic granite with feldspar phenocrysts about an inch long and which disintegrates rapidly.

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

[b] Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. U. S. Geol. Survey No. 450, 1911, pp. 83–88.

At the borders of the intrusion is a graphic granite of peculiar beauty and definite structure, being more like the rock shown in text-book illustrations than that ordinarily found. The altered band is from a foot to 5 or 6 feet thick and apparently surrounds the pegmatite. There is no distinct segregation of the feldspar or quartz in particular parts of the dike, but the feldspar tends to be more abundant at the west and south sides and the quartz in the center and toward the east side. A large amount of feldspar has been mined and thrown on the dump, and it is possible that in time this material may be utilized, either for its potassium content as a fertilizer or for pottery making.

The greatest interest in the dike centers in the accessory minerals, particularly the rare-earth minerals. Few if any other deposits in the world, and certainly no others in America, outside of the localities where monazite is found, have yielded such amounts of the rare-earth metals as that at Baringer Hill. As yet the excavations are comparatively shallow and the minerals found are more or less weathered. Many retain their crystalline form, but owing to alteration the crystals are now imperfect. Hess[a] says:

> The economic interest in the rare-earth metal minerals centers in their incandescence on being heated, and owing to this property they have been mnch 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. * * *
>
> 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. 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 2¼ miles west-northwest of Kingsland, near a Mr. William'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 half a 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 seen.

IRON.

Distribution and general character.—Of the minerals which in the past have drawn attention to the Llano-Burnet region, iron has perhaps received the greatest notice. Yet, though many years have elapsed since the value of the ores was first recognized and though in places the ore is of high grade and very pure, there has been no mining on a commercial scale. Moreover, until very recently exploration has not been conducted in such a manner as definitely to establish the status of the more promising deposits.

During the geologic mapping of the quadrangles 32 more or less distinct occurrences of iron ore were noted and studied in such detail as was warranted by the generally poor natural exposures and the very small amount of exploratory development. Three of these perhaps warrant further exploration to determine their commercial value. The remainder, it is believed, do not justify any large expenditures for prospecting at the present price of iron ore. The permissible scope of the geologic work did not admit of magnetic surveys, but such surveys should be made in connection with any future exploration of the more promising iron-ore deposits of this district.

The ore occurs in the form of magnetite in the pre-Cambrian schists and gneisses. Though it is present at a few localities in eastern Mason County, most of the ore bodies are in that part of Llano County lying north of Llano River. So far as the geologic mapping indicates, the deposits are mainly associated with the Valley Spring gneiss. The difficulty of consistently discriminating between the pre-Cambrian formations, however, has proved so great that it is quite possible that the immediate country rock of the ores may, in certain localities, belong to the Packsaddle schist. The ore-bearing rocks are

[a] Hess, F. L., Bull. U. S. Geol. Survey No. 340, 1908, p. 293.

crystallized granular schists or gneisses, which have undergone the same degree of metamorphism as the associated rocks.

The ore proper consists of more or less concentrated grains of magnetite, with quartz, feldspar, and a little biotite. The deposits are typically bedded or stratiform bodies conformable with the foliation of the inclosing schistose rocks. So far as could be observed they form an integral part of the metamorphic series and have much the same relation to the other members as do the limestones and graphite schists. They can be traced along the strike where not concealed or interrupted by granitic intrusions, and they follow the convolutions of the inclosing beds. Their thickness is irregular, and the amount of ore varies from place to place, as does, for example, the amount of carbon in the graphitic schist. In places the ores merge into the inclosing rocks through a gradual decrease in the amount of magnetite. Nowhere were ore-bearing beds observed to cut across neighboring beds, as might be expected of intrusive sheets, nor do lean beds essentially change in character along the strike, at least not more rapidly than a sedimentary ore normally would.

Therefore, though there is a possibility that the iron ores owe their origin to processes connected with igneous intrusion, the conclusion has been reached after carefully weighing the available evidence, that they are contemporaneous deposits in a sedimentary series, which have been altered to their present form during regional metamorphism.

Olive mine.—The Olive iron-ore property is located on Little Llano River about 6 miles east-northeast of Llano, a mile south of Lone Grove post office, and a mile north of Llano River and 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. The shaft is situated on the east bank of Little Llano River just west of the boundary of the main granite mass in this part of the region and within the schists of the Packsaddle formation.

The rocks exposed in the vicinity include granite, hornblende-mica schist, graphite schist, and crystalline limestone. The granite is intruded into the other rocks in an intricate manner, which can not be fully made out because of the rather poor exposures. 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. The property has been opened by an incline and a shaft 230 feet deep, and from the shaft three crosscuts have been run out to the ore at depths of 110, 160, and 210 feet.

The following analyses are given through the courtesy of Messrs. Johnston, Eliot & Co., of Dallas, Tex. Both samples represent the stock pile at the Olive mine.

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

[Sampled and analyzed for Robert Linton, of Atwater, Linton & Atwater, mining engineers.]

	1.	2.
Iron	57.80	54.35
Silica	8.40	10.16
Sulphur	.28	.55
Phosphorus	Trace.	.021

No outcrops of the ore are to be seen. The deposit is evidently a tabular body ranging from 2 to 8 feet in thickness on the dip and of undetermined horizontal extent. As has been pointed out, the ore body is located at the very border of a large intrusive granite mass. The northeast trend of the ore body should carry it directly toward this mass, against which it should terminate. There is a chance that the layer may extend for some distance to the southwest. The proximity of the granite is unfavorable, however, inasmuch as crosscutting dikes and irregular masses are likely to interrupt the continuity of the deposit.

Iron Mountain mine.—The Iron Mountain prospect, comprising 640 acres, is located 12 miles northwest of Llano and about 1 mile northwest of Valley Spring. The ore body caps a low mound slightly higher than the surrounding country and trends about N. 60° W. in a slightly 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 to about 6 feet at the southeast end. A granite intrusion cuts across the mass at the northwest end, apparently cutting off the ore. The surface cover prevents observations at 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 do not accord in dip with it. On the north side there is a gneissoid rock of granitic type, which is believed to be intrusive into the ore but older than the granite which cuts across the northwest end. The complex intrusion of granite into the schists has obscured the exact relations of the ore body and the surface cover has added to this difficulty.

Both northwest and southeast of the ore body the surface is generally covered with soil and there are only scattered outcrops of weathered rock. About 450 feet to the northwest there is a small outcrop of magnetite in schist; granite, gneissoid granite, and schist are, however, evidently present in a complex mixture. There is a little float ore both northwest and southeast of the cropping, but much of this near the ore has evidently been derived from it and has, during the erosion of the ledge, been carried to its present position. Float ore, which is derived from the overlying Cambrian sandstone and some of which contains fossils, must not be confused with the magnetite float of the pre-Cambrian ores.

The property has been developed by a shaft, a crosscut at the 50 and 100 foot levels, and several drifts, as well as by a number of diamond-drill holes.

The exploration proves that the main mass is cut off below at some point between the 50 and 100 foot levels. The fact is also brought out that a flat-lying bed, the top of which is about at the 50-foot level, dips eastward at a low angle. This bed is about 16 feet thick and probably represents a portion of the vertical mass, displaced by faulting.

The presence or absence of a body of ore of commercial value can be determined by a few diamond-drill borings, in addition to those that have already been made. At present neither the drifts nor the borings have shown up a body of sufficient size to warrant the opening of the deposit on a large scale.

Bader tract.—The property known as the Bader tract lies about 9 miles west of Llano and 9 miles south of the Iron Mountain mine. It is adjoined on the north by the Otto tract, the east-west dividing line being somewhat less than 2 miles north of Llano River. Iron ore has been found at several places along a zone trending north-northwest, about 500 feet in width and nearly 700 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 to the northwest careful search by 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. No importance can be attached to any suggestion that might be made toward correlating the Bader range with other occurrences of magnetite in Llano County. Aside from very shallow pits or trenches at several points the Bader range has been explored only near its north end, where the original surface indications appear to have been the best. The Bader incline here reveals two ore layers estimated to lie between 10 and 15 feet apart. The lower ore may be described as gneiss carrying thin and discontinuous layers of magnetite. This lean material is not more than 16 inches thick. As exposed on the sides of the incline, which dips 20°–40° N., the second layer has a maximum thickness of 20 inches. All the ore on the dump is banded to a marked degree, much of it being sharply segregated into layers of more or less granular magnetite and of silicates. No definite conclusion concerning the possibilities of the Bader tract can be offered. It is believed that caution should be exercised in accepting an unfavorable view with regard to deposits of the sort here presented, for experience in other districts has shown that the importance of magnetite ore bodies in gneisses may be seriously misjudged from surface indications.

Deposit west of Click.—West of Click the basal part of the Hickory sandstone overlies the ancient crystalline schists. The boundary between them trends northeast and then east and meets the fault along the east face of Riley Mountain. Along this boundary about 1½ miles north of Click abundant float of very pure magnetite occurs in a small branch west of the Wilson house. This float is readily traced to its source at the sandstone contact. Part of the loose ore has undoubtedly been derived from the lowest part of the sandstone, for this rock contains fragments of magnetite. Another part may have been derived directly from ore occurring in the schist, but no such ore body has been discovered. On the whole it seems probable that all of the material is débris from the sandstone and that the original deposit in the schist does not come to the present surface because the sandstone caps it.

GOLD.

Small quantities of gold may be found at many localities in the pre-Cambrian area. It must be said, however, that in general the quantity is so small as to be commercially valueless. The results of a number of assays made of specimens said to contain gold were decidedly discouraging, as shown by the table in the next column.

The only prospect visited where there was sufficient gold 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, on a low spur sloping south.

The rocks in this vicinity are a part of the Packsaddle schist and comprise graphite and mica schist and limestone. At the prospect the regularity of the beds is much disturbed by intrusive granite, which outcrops to the south and east in large masses. Much quartz and pegmatite is interleaved with and cuts the schist beds, and pyrite occurs in places. The gold seems to be largely associated with the quartz stringers.

A cover of red and brown residual soil effectually conceals the underlying decayed schist and granites. This residual soil carries gold, undoubtedly concentrated by the removal of soluble and easily transported constituents of the rock. Gold is also reported to occur in the schists below. Except in the residual material, where 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 examination of many carefully taken average samples.

In the subsoil and in the partly decayed schist below, where exposed in crosscuts, a canary-yellow efflorescence or stain coats quartz stringers and is 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 Geological Survey, proves the material to be a compound of bismuth and vanadium. The only known mineral compound of bismuth and vanadium is pucherite, which, however, is always found in crystal form. The yellow compound has also been noted by Schaller in California, where he collected sufficient material for an analysis, the results of which he will publish at a later date.

The property has been developed by a number of shafts, some drifting, numerous crosscuts, and about 60 surface pits. The writer took carefully a number of average samples, which were assayed with the following results:

Assays of average samples from the Heath mine.

No.	Locality.	Gold.	Silver.
1	Surface pit (one of about 60)	$0.20	0
2	Incline, west wall, 30 feet from upper end (9 feet sampled)	1.60	
3	Incline, east wall, 42 feet from upper end (6½ feet sampled)	.20	0
4	Incline, west wall, 84 feet from upper end (4½ feet sampled)	0	0
5	Crosscut (south side), including 6 feet of schist and granite	0	0
6	Shallow crosscut sampled at three points (samples covered about 10 feet of material vertically)	0	0
7	Sample from tops of 26 sacks of ore and from ore pile (representing picked ore selected by panning tests)	20.40	$0.19

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

It seems probable that in large measure the values are confined to the quartz veins. These are abundant in places but are not persistent and are too small to be worked individually.

Results of assays for gold and silver.

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

No.	Locality.	Gold, per ton.	Silver, ounces per ton.
1	Sulphides from Mr. Sheeon's place, 4 miles south of Llano	Trace.	Trace.
2	Graphitic schist 2½ miles southwest of Niggerhead Mountain, three-fourths mile east of the Colorado (flowing south) and a scant half mile north of the river (flowing east)	None.	None.
3	Thomas prospect. Hooking Hollow	Trace.	0.56
4	Shaft near Gallihaw Crossing, pegmatite dike	None.	None.
5	Two and one-half miles east by north from Granite Knob and one fourth mile south of the east-west road near edge of Llano quadrangle, gossan from vein	None.	None.
6	Bailey prospect, 4 miles west of Burnet and north of Spring Creek	Trace.	0.38
7	Quartzite-like rock near Parkinson's quarries, 100 feet long, 30 feet wide	31 cents.	None.
8	Iron oxide 1¾ miles east-northeast of Field Creek village	10 cents.	None.
9	Prospect holes 5 miles east by south of Valley Springs, in Edwards pasture, near east boundary; 2-foot vein, 240 feet long (by float)	10 cents.	None.
10	Southeast of No. 9 and west of Pecan Creek, north of road to Edwards ranch, bedded layers in graphite schist	None.	None.
11	Willow Creek outcrop, about 2½ miles west of Valley Springs	10 cents.	None.
12	Heavy pyrite gossan in graphite schist on knoll 1½ miles west by south of Miller Mountain	10 cents.	None.

GRAPHITE.

A large part of the beds making up the pre-Cambrian formations were originally shales, sandstones, and limestones. As a result of their metamorphism to schists certain constituents have become of possible commercial importance. Such, for instance, is the graphite formed from carbonaceous matter originally in the shales.

Schists containing graphite in varying amounts are widely distributed throughout the pre-Cambrian area, but only in the Packsaddle schist. Most of the graphite schists are associated with limestone or marble, a natural occurrence, as carbonaceous shales are commonly associated with limestone. Many beds of these schists can be traced for long distances.

Graphite was noted at many localities, but at only one of these has sufficient development work been carried on to give some assurance of a deposit of commercial value. This locality is $1\frac{7}{8}$ miles due south of Lone Grove, approximately 1500 feet west of Little Llano River, and 800 feet north of the Houston & Texas Central Railroad. The graphite occurs in schists of the Packsaddle formation, which in this vicinity contains considerable limestone. Granite and pegmatite intrusions have locally disrupted the beds.

The schists can be traced with interruptions for half a mile northwestward from a point a little west of the railroad bridge through the present workings to a point where they disappear beneath overlying Cambrian sandstone. 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 crosscuts. About 5500 tons of 12 per cent graphite ore has been revealed.

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

As much of the territory included in this property has not been adequately tested by surface cuts, it is possible that a successful graphite industry may be established at this point. It may be said in general that it would not be advisable to spend money on prospecting or testing at other localities until this deposit is proved a commercial success. If any exception were to 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 manufacture of which very impure graphite can be used.

About 2 miles south of Llano graphite schists trend in a northwest-southeast direction toward Sharp Mountain. This vicinity perhaps affords the most favorable opportunity, except at the property described above, to prospect, though graphite schists, as stated, occur at many localities throughout the region. It must be borne in mind, when making an estimate of the graphite content of a band of schist, that a very little graphite makes a striking showing, and appearances are therefore likely to be deceptive.

SERPENTINE.

The Collins property, located 9 miles south of Llano and a little west of the Oxford road, contains about 250 acres lying in a north-south strip nearly $1\frac{1}{4}$ miles long. On a hillside near the north end of the property is a pit, perhaps 20 feet in diameter and 10 feet deep, dug in serpentine and exposing on its west side a contact with soapstone. Serpentine is exposed for perhaps 100 feet east and northeast, and for at least 500 feet southeast and south of this pit. At the foot of the hill a second pit about 30 feet in diameter and 10 or 15 feet deep exposes serpentine rock. Here a diamond-drill boring 275 feet deep did not pass out of the serpentine. 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, 20 feet long, and 10 feet deep has been opened. Except a small outcrop of schist the pit exposes only serpentine.

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

The dimensions given above indicate a considerable deposit of serpentine and talc at this locality. Specimens were seen which took a fine polish. The commercial value of such a deposit will depend directly on 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 there is no doubt that if more refined methods were used much larger blocks could be quarried and sawed into commercial sizes. An installation 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 facilities should be carefully considered before any extensive plan of operation is adopted.

The relation of the outcrop of the above-described body to the inclosing pre-Cambrian rocks leaves but 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 text, gabbroic and dioritic intrusive rocks occur 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 silica and iron derived from the breaking down of ferromagnesian silicates.

TALC.

Talc is found at a number of localities in addition to that associated with the serpentine deposit described above. In the area immediately east of Cedar Mountain numerous small outcrops were seen, though no deposit was mapped separately. A small deposit also occurs $1\frac{1}{2}$ miles west of Llano, and one upon which considerable work has been done is located a mile north of Graphite station.

The small deposit west of Llano is formed without doubt by the hydration of magnesian silicates developed by regional or contact metamorphism in pre-Cambrian limestone. A small pit has been opened on the ledge, but the stripping has been insufficient to establish the horizontal extent of the body. Then, too, the presence or absence of other silicates in the talc vitally affects its commercial value. This point can be determined only by exploration work. In places other silicates were noted in the material.

The talc deposits east of Cedar Mountain are associated with the Packsaddle schist. This locality, however, is exceptional in that considerable bodies of dioritic rock are intruded into the schist. The talc in this area is probably in large measure derived from limestones by the hydration of magnesian silicates. 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 the mineral and its tendency to break down and be covered up by soil, it is suggested that prospecting might reveal deposits of commercial importance.

Surface outcrops do not give much information as to underground conditions at a property of some 980 acres, situated a mile north of Graphite station. The openings, which are all within a few hundred feet of the Houston & Texas Central Railroad, lie along a general northwest-southeast line and consist of two shafts and a number of crosscuts. To judge from the notes made by W. Y. Westervelt, a mining engineer to whom part of the underground workings were accessible, it is probable that the mass of soapstone is at least 20 feet wide, 90 feet long, and 25 feet thick. The horizontal extent of this body can be determined only 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 physical characteristics of the talc are such as will permit it to compete with eastern varieties.

There is very little doubt that the deposit owes its origin to the hydration of magnesian silicates developed in pre-Cambrian limestone by metamorphism. Such an origin would produce a bedlike deposit, continuous in depth and horizontal extent only so far as the silicates 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 practicable method of determining the extent of the deposit.

LEAD.

About $3\frac{1}{2}$ miles north of Bluffton, Burnet County, on Silver Creek, a tributary of Beaver Creek, a small area of coarse pink granite is exposed underneath the Cambrian strata. About the borders of this outcrop galena occurs in the calcareous glauconitic quartz sandstone, which here rests on the granite. A mile and a half north by west of this locality, on Beaver Creek just downstream from an outcrop of pre-Cambrian granite, is a similar occurrence of galena in glauconitic sandstone and the underlying limestone. At each of these localities the local structure is due to an upward movement of the underlying granite mass that was of sufficient magnitude to flex the beds sharply but not sufficient to do more than slightly break them. At both localities quaquaversal dips occur along and are confined to the borders of the granite mass, and small faults, accompanied by zones of shearing and brecciation, are developed along the contact with the overlying sediments.

The galena occurs apparently as a replacement of the calcareous sandstone, though it is not confined to that member, being found in places in the limestone also. In some places it may follow the bedding. It is found near the granite floor and also 40 feet or more above it. Microscopic examination shows that the galena is probably a replacement of the calcite which binds together the quartz and glauconite grains of sandstone.

Two shafts and a tunnel have been opened on the property. Only the tunnel was in condition to be examined. It is located on the western contact a short distance south of Silver Creek and is run S. 68° W. in glauconitic sandstone. At 30 feet from the mouth a crosscut is driven 7 feet northwest and 18 feet southeast. A bed of sandstone about 18 inches thick here dips 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 bunch of ore which gave out. The tunnel was continued beyond the drift but is reported to have struck no galena.

From the 65-foot shaft two or three veins of galena are reported by Dr. Osborne, who owns the property. A vein stated to be $3\frac{1}{2}$ feet thick 16 feet from the top of this shaft is said to run 85 ounces to the ton in silver and to contain 20 per cent of lead.

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 to the ton. No silver was detected.

The origin of an ore deposit generally has an important bearing on a decision regarding the probabilities of development on a commercial scale. The following suggestions are offered as an explanation of the occurrence described above, but the writer does not thereby wish to create an optimistic sentiment regarding these ores. It can not be said that the prospects that were available for study would warrant such a view.

It is significant that in both the localities described the galena is concentrated in an area of local disturbance, where a domelike uplift has to some extent brecciated the rocks and formed small faults. It is noteworthy also that the pre-Cambrian basement is here about 100 to 150 feet higher than it is farther west. A thick shale member 70 to 90 feet above the glauconite horizon acts as a fairly impervious cover. Waters carrying lead in solution and 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 is due to any inherent quality of the inclosing rock the presence of glauconite may have played a part.

It is interesting to note that this galena occurs in a series lithologically very similar to the Lamotte sandstone of southwestern Missouri, where workable ore bodies are found both in that sandstone and in the overlying dolomitic Bonneterre limestone. If the Texas occurrences are similar 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 possibly as affording open spaces by fracturing the rocks.

FLUORITE AND SPHALERITE.

Deposits of fluorite carrying irregular amounts of metallic sulphides occur at two localities west of Burnet, in 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. The structural trends are east and west, the rocks, though poorly exposed, evidently being 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, with some interbedded masses of hornblende schist. In places the beds strike about N. 60° E. and dip southeast. A mixture of fluorite and hornblende with a little quartz, feldspar, and chalcopyrite occurs as a layer in 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 along a line trending N. 60° E. From what could be made out in 1909 it appears that fluorite was found along the strike for a distance of nearly 300 feet. At the southwest the mineral was encountered in five trenches showing an extent along the reef of 100 feet. The northeasternmost of these trenches shows a bunch of mineral which seems to represent the bottom of a shallow trough, as gneiss is exposed on both sides and below. The next opening lies 135 feet farther northeast. Here there is no evidence of the reef and the intervening ground is completely covered. However, about 40 feet farther on is the shaft, around which is piled a considerable amount of fluorite rock. This shaft contains water within about 20 feet from 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. Another excavation 30 feet beyond 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 southwestern 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 $2\frac{1}{2}$ 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 ounces of silver.[b] 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.

[a] By Munroe, Hall & Hopkins, chemists, assayers, and engineers, Washington, D. C.
[b] Assay by E. E. Burlingame, Denver, Colo.

Fluorite accompanied by sphalerite is found at several points on and near the Frank Thomas place, in the upper valley of the north fork of Spring Creek about 7 miles west of Burnet. The mineral is in layers conforming with the north-south trend of the inclosing dark hornblende schist. 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 3½ feet thick at the outcrop. The material thrown out of the shaft is a mixture of fluorite, sulphides, and a little quartz. Sphalerite is the most abundant sulphide, but galena, pyrite, and molybdenite also occur. The assay of a carefully taken sample of the material thrown out of the shaft shows zinc 7.60 per cent; lead, none; gold, a trace; silver, 0.56 ounce.[a]

Whether or not this reef has any degree of continuity along the strike can not be stated, as 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 why mining upon a small scale would not be profitable.

In the vicinity of the dwelling house fluorite has been discovered near the well east of the creek bed. The reef, which is not over 10 inches thick, trends north and south and stands nearly vertical. To the south along the strike the mineral has been uncovered in three or four places in a distance of somewhat more than one-fourth of a 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 half a 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 fluorite and black sphalerite, with a little quartz and pyrite. Such prospecting as has been done is not sufficient to demonstrate whether these deposits have any promising degree of persistence.

PYRITE.

Prospecting has been carried on at several places along the east base of Riley Mountain between Click and Packsaddle. Most of the showings are pyrite gossans, though one, a mile north of Click, is magnetite. 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 in June, 1909, had been exposed for a length of 25 feet. Adjacent to the Roberts pit and 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 pronounced fault which brings the stratified limestones of Riley Mountain against 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 formed by replacement of the limestone and to follow the bedding of the rock, which dips toward the west, away from the fault. The rocks are poorly exposed, but there is reason for believing that they are greatly broken adjacent to the main line of faulting, so that possibly the ore follows a zone of shattering rather than a layer of the limestone.

The structural conditions suggest that the deposits should continue in depth, but developments are not adequate to show whether 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 marked fault. The deposit 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 is red iron oxide and coarsely crystalline calcite. Brown iron ore in the crystalline form of pyrite (that is, limonite pseudomorphs after pyrite) was observed, but part of the red oxide may have been derived from the alteration of iron carbonate. 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 the deposits from which the gossan has been derived will ever be worked as a source of sulphur or arsenic can not be foreseen. Persons engaged in exploring the deposits state that the sulphide shows no valuable amounts of gold or silver.

[a] Assay by E. E. Burlingame, Denver, Colo.

COPPER.

No encouragement can be given that any copper prospect visited during the mapping of these quadrangles will ever be of commercial value.

On both sides of the road about half a mile northwest of Wilberns Glen some crosscuts and a shaft about 35 feet deep have been opened. Films of malachite were noted associated with epidote-garnet schist.

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

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

There has been some prospecting for copper on Adolf Schneider's place, 1½ miles north of Llano River, 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 about north and south 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 outcrops about 30 feet down the dip to the east. Chalcopyrite and a little chalcocite occur in the intrusive granite as well as in the schists, and a microscopic examination shows clearly the secondary nature of the ore—that is, it in part fills the cracks in feldspars. The solutions which brought in the copper therefore penetrated the rocks after the intrusions of the granite and took advantage of fractures existing at this locality. An assay of some specimens selected from a collection in Mr. Schneider's blacksmith shop gave the following result: Gold, $0.41 per ton; silver, trace; copper, 0.94 per cent.

Other prospect pits were seen at several localities, but none showed any possibilities for the development of an ore body.

MANGANESE.

On the southeast flank of Horse Mountain, 5 miles north of Llano, 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 were opened here, the southern one 15 feet long on the strike and 12 feet wide on the dip. About 2 feet of manganese oxide is exposed in this pit. The ore is banded with quartz. 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 silicates 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) occur 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. Microscopic examination of a specimen shows spessartite intergrown with piedmontite accompanied by much muscovite and quartz and some magnetite. Decomposition in this vicinity has extended to very shallow depths and it seems almost certain that the deposits below the oxidized zone, because of their high silica content, discontinuity, and leanness, are without commercial value.

An analysis of the Horse Mountain ore by R. A. F. Penrose, jr., follows:

Analysis of manganese ore from 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. It has been described in the report just cited.

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.)

[a] Ann. Rept. Geol. Survey Arkansas for 1890, vol. 1, p. 447.

The underlying late Cambrian and early 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 formation at Burnet is deposited on Ellenburger 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 sands of the Trinity formation and spread laterally as far west as Burnet.

As has been pointed out by Taff and Reed,[a] the sands of the Trinity formation are of such character as almost to preclude the idea that oil originated in them.

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.

CEMENT MATERIALS.

A number of specimens of limestone were examined for their magnesia content, with reference to their usefulness in the manufacture of cement. The results were as follows:

Percentage of magnesia in limestones of Llano-Burnet region.

Ellenburger limestone on Hairstone Creek near road running north from Mormon Mills	0.42
Carboniferous limestone east of Marble Falls	.51
Cretaceous limestone 1 mile northeast of Chalk Knob on west side of divide	.40
Ellenburger limestone near Burnet	.80
Cretaceous limestone in first railroad cut north of Lake Victor	.40

It is evident that magnesia in these rocks would not be a disturbing factor in the manufacture of cement.

WATER RESOURCES.

RAINFALL.

The central Texas region has a climate bordering on the semiarid. Cotton seems to thrive there, but the region has had a distressing record of other crops either injured or completely destroyed by droughts. The annual precipitation averages about 20 inches. Unfortunately, however, this supply is not distributed equally over the season, being concentrated more or less in the spring and fall, with occasional midsummer rains. The failure or partial failure of this supply at any one of these periods results in loss to either the farmers or the stockmen. The ranges depleted by cattle during the winter are dependent on the spring rains; the crops are directly dependent on occasional showers throughout the summer; and the winter supply of grass appears or fails to appear in response to the presence or absence of autumnal precipitation. A portion of the annual precipitation is lost by evaporation immediately or soon after falling; a portion sinks into the soil and crevices in the rocks; and a portion runs off in the streams. The recoverable portions will be briefly discussed.

STREAMS.

There are two types of streams in the region—(1) the through-flowing rivers, the Llano and Colorado, and (2) subsidiary drainage, tributaries of the Llano and the Colorado and of other streams.

The flow of Colorado River is extremely variable and is subject to rapid rises with occasional floods. At Austin the stream, when low, discharges from 300 to 400 second-feet; when "up" it discharges 8000 second-feet or more. Llano River discharges at low water about 75 second-feet and, like Colorado River, increases its discharge enormously when precipitation is heavy within its drainage basin. Along both of these streams irrigation has been practiced on a small scale, and on both also there are sites suitable for the development of water power. At Llano a concrete dam furnishes power for electric light and other purposes, and at Marble Falls a concrete dam of considerable dimensions is being built on Colorado River. As both of these streams have a perennial flow, ranches along their courses have an ample supply of water and can be irrigated by pumping with gasoline or other engines or by power derived from the streams themselves.

The smaller watercourses of the region may be grouped under two heads, depending on whether or not their surface flow is perennial. Such streams as Cold Creek, Honey Creek, and Little Llano River, in the Llano quadrangle, and Morgan and Fall creeks, in the Paleozoic areas of the Burnet quadrangle, are fed by relatively strong springs, either at their heads or along their courses, and afford sufficient water at all times of the year for stock on the ranches through which they flow.

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

Of a very different character, however, are most of the streams in the pre-Cambrian basin. The beds of these are filled with an increasing load of sand. During most of the year they are to all appearances dry, and it is only by digging in their beds that water can be found. Uninviting as they appear, however, they furnish with a little labor sufficient water for the ranges through which they flow. Among the factors which bring about this overloaded condition of the pre-Cambrian streams are the occasional torrential rains, the stripping of vegetation from the granite areas by overstocking of ranches, and the rapid disintegration of the bare rocks, a result of alternating hot days and cool nights.

SPRINGS.

The springs of the area have been described under the heading "Drainage." They are important in that they give rise to a number of perennial streams and afford water for cattle in many areas that would otherwise be quite worthless for grazing.

WELLS, TANKS, AND CISTERNS.

Where springs or streams are not available wells furnish the necessary water supply, if the season is favorable. Wells are very generally distributed throughout the region. In the pre-Cambrian area they are dug either in soil, granite, or schist, and to only moderate depths. The water which they furnish is derived entirely from the supply held in the porous surface material or in fissures or joints in the upper portion of the bedrock. As these joints and fissures are distributed with extreme irregularity, the successful location of wells becomes more or less a matter of chance. Inasmuch, however, as the rocks are generally much fractured, usually but little difficulty is encountered in obtaining a moderate supply of water. This supply, however, is dependent on rainfall, and in times of protracted droughts many wells go dry and water must be hauled.

In some areas underlain by limestone wells must be sunk to greater depths, for in these rocks water channels are likely to be more localized and unless a channel is struck a well may be sunk many feet without success.

In the Cretaceous areas wells usually encounter water at some horizon in the Trinity formation. Farther east, where deeply buried beneath overlying rocks, this formation is an extremely important factor in underground water supply.

In many places cisterns are constructed and the drinking supply for a season caught during the cold winter rains. Locally, too, cisterns are filled during winter with river water. This device insures a supply of cool water during the summer.

On the cattle ranges where other supplies are not at hand artificial ponds, locally termed tanks, are constructed by building earthen dams across small streams and are filled during heavy rains. Some of these tanks are of considerable size and water many head of stock. To guard against drought many of them are equipped with wells and windmills.

SUMMARY.

In conclusion it may be said that no abundant supply of underground water is to be expected in the area underlain by pre-Cambrian rocks; that in the Paleozoic areas the structure is not such as to promise more than a moderate supply for local use; that in the Cretaceous areas of the region the Trinity formation is not buried deeply enough to give more than a moderate supply for purposes of stock raising, etc.; that irrigation on a moderate scale can be practiced along both Colorado and Llano rivers by utilizing the rather steep gradient of the rivers either for power or small ditches; and that much of the country must continue to depend on rainfall for its water supply.

January, 1912.