GEOLOGY OF AN AREA BETWEEN BLUFF AND HONEY CREEKS, MASON COUNTY, TEXAS

A Thesis

By

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June, 1954

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GEOLOGY OF AN AREA BETWEEN BLUFF AND HONEY CREEKS, MASON COUNTY, TEXAS

ABSTRACT

The thesis area, which is located about 6 miles west of Mason, Texas, is underlain by rocks belonging to the pre-Cambrian, Cambrian, and Ordovician systems.

The pre-Cambrian rocks consist of two metamorphic units, the marble and the gneiss, and two intrusive bodies, the coarse-grained granite and the fine-grained granite.

The Cambrian rocks are divided into the Riley and Wilberns formations. The Riley is further divided into the three members: Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone. The members of the Wilberns formation are: Welge sandstone, Morgan Creek limestone, Point Peak shale, and San Saba limestone. The Ordovician rocks are part of the Ellenburger group.

The pre-Cambrian deformation consists of a series of large east-west trending isoclinal folds that plunge steeply to the east. The Paleozoic rocks have a northeast strike and a ten degree southeast dip, and are complexly faulted by a northeast-trending major fault system and numerous minor faults. The attitude of the Paleozoic beds and of the fault systems suggests a gentle local uplift just west of the

thesis area.

The geologic history indicates a transgression of Paleozoic seas over the eroded pre-Cambrian surface and deposition of Cambrian sandstones, shales, and limestones. Devonian, Mississippian, and Cretaceous beds at one time covered the thesis area, but have since been removed by erosion. The faulting occurred in the middle Pennsylvanian.

The area has been unsuccessfully prospected for ores. Ground water and farm and ranch land constitute the only profitable natural resources.

INTRODUCTION

STATEMENT OF PROBLEM

The problem for this thesis is the investigation of the stratigraphy and structure of the rocks and the preparation of a geologic map (Plate IV) of a 10½ square mile area in western Mason County, Texas (Plate I). Considerations of secondary importance are the geologic history, economic geology, and physiography of the area.

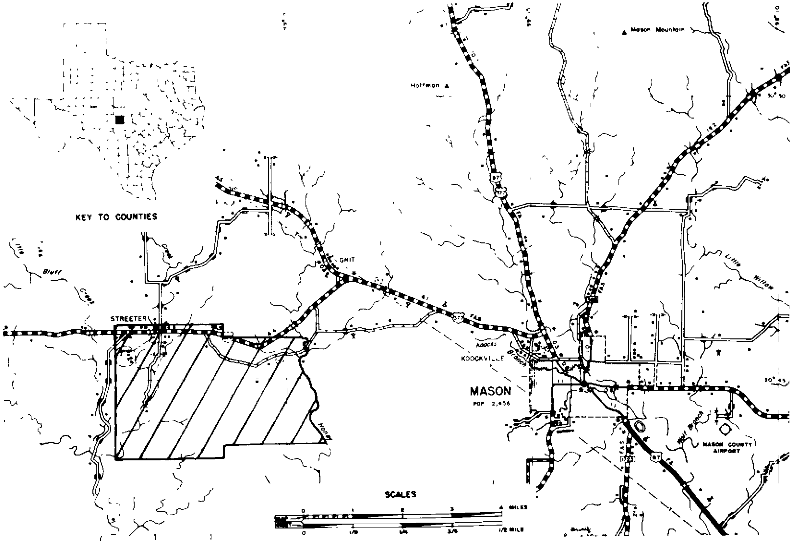
LOCATION AND ACCESSIBILITY

The thesis area lies on the western flank of the Llano Uplift, in Mason County, Texas. The eastern boundary of the thesis area is approximately 5.3 miles west from the western city limit of Mason, Texas.

Accessibility to the area is good, but not so to all points within the area. U. S. Highway 377 crosses the northern part of the area. The Old Junction Road is located to the south of this highway and somewhat parallel to it. The southern part of the area can be reached by automobile on two rough, but passable, private roads.

PROCEDURE AND EQUIPMENT

Most of the field work was done in the period from August 6 to September 8, 1953. Several supplementary trips to the thesis area were made before all of the information



LOCATION MAP OF THESIS AREA

PLATE I

was collected.

The base maps used were U. S. Department of Agriculture aerial photographs which had been enlarged so that the approximate scale was 1:10,000 or 6 inches to 1 mile. The original photographs have an approximate scale of 1:20,000 and were enlarged by Photographic and Visual Aids Laboratory, Agricultural and Mechanical College of Texas. The area was covered by photographs DFZ-4E-17 and DFZ-3E-192, both of which are dated 11-2-46.

The mapping was done on acetate covering the photographs. A stereoscope increased the usefulness of the photographs by adding the third dimension. Many geologic features noted with the stereoscope and photographs were later confirmed by observation in the field. The dips and strikes as plotted on the map generally represent the average of several readings taken at each point with a Brunton compass.

The measured section described in the Appendix represents the only sizable, practically unfaulted sequence of sedimentary rocks exposed in the thesis area. However, because of its nearness to a highly shattered area, some breaks of less than one foot displacement may cut this section. The beds were measured with a yardstick and hand level.

The basal Hickory-pre-Cambrian contact is difficult to map because it is a very irregular unconformity which in many places lies close to the present land surface. This results in a mixture of outcrops which on the aerial photographs resembles an area of uniform Hickory. However, the thin remnants of the basal Hickory are commonly represented only by a residual soil. Where the pre-Cambrian rocks do not protrude through this soil, the area was mapped as Hickory.

Another problem in the indurated basal Hickory was the measurement of dips (Fig. 11). The abundant crossbedding often cannot be distinguished from the true bedding planes.

PREVIOUS GEOLOGIC STUDIES

In 1845, 1846, and 1847 Ferdinand Roemer traveled through the Llano region with a group of German colonial explorers. In his descriptions (Roemer, 1846, 1847), he presents the first published information of the geology and fossils of the region. A significant feature of his work is the recognition of older Paleozoic rocks.

B. F. Shumard (1861) confirmed Roemer's work and described a Potsdam group (upper Cambrian) and its fossils.

Twenty-three years later Walcott (1884) visited the region, studied the rocks, and further confirmed the Cambrian age of the Potsdam group.

Hill (1887) mentioned the Llano region in his review of

Texas geology and noted the importance of Walcott's work.

Comstock (1889, 1890) discussed the geology and mineral resources of the Llano region in the reports of the newly-formed Texas Geological Survey. He introduced the terms Packsaddle Schist, Valley Spring gneiss, Hickory series, Riley series, and San Saba series.

Tarr (1890) made observations on the drainage patterns of central Texas.

Paige (1911, 1912) made the first comprehensive study of the rocks in the Llano region. He named and described the Wilberns, Cap Mountain and Ellenburger formations. His work includes discussions of the pre-Cambrian geology and of the mineral resources. His reports and maps are still used today, although parts of the region have been covered by more recent work.

Udden, et al. (1916) prepared the first state geologic map which was published by the Bureau of Economic Geology. The lower Paleozoic rocks were not differentiated.

Dean (1931) briefly discussed the Wilberns reefs (Point Peak) in Mason county. The glauconitic shales he described as overlying the reefs were not found in that position in the thesis area by the writer.

Dake and Bridge (1932), using paleontology, correlated several units of the Ellenburger limestone in the Llano region with similar units in the Ordovician beds of the Missouri section.

Stenzel (1932) discussed the sequence and structure of the pre-Cambrian rocks, reversing the order of succession given by Paige.

In their report on stratigraphy of Texas, Sellards, Adkins, and Plummer (1932) briefly reviewed the pre-Cambrian, Cambrian, and Ordovician systems of the Llano region. In the companion report on the structural and economic geology, Sellards and Baker (1934) described the Paleozoic deformation of the Llano region. In the latter report, Stenzel discussed the pre-Cambrian structural conditions.

Stenzel (1935) reported further on the stratigraphic relations of the pre-Cambrian rocks of the Llano region and outlined an intrusive sequence.

Darton visited the region in 1933, collected unpublished geological information, checked formation outcrops, and with other geologists prepared a new state geologic map (Darton, _et al._ 1937) on which are shown the locations of the principal formations.

Bridge (1937) studied the rocks on the western side of the Llano region, collected fossils, redescribed many of Roemer's type localities, and differentiated and named the Lion Mountain sandstone member. Bridge and Girty (1937) redescribed Roemer's Paleozoic fossils and commented on the geology of the area.

The occurrence and formation of dreikanters from the basal Hickory were described by Barnes and Parkinson (1938).

Cheney (1940) described the stratigraphy and structure of the Paleozoic rocks north of the Llano region. Using subsurface data, he reclassified the Pennsylvanian beds.

Keppel (1940) studied the structure and texture of the coarse-grained central Texas granite massif and found concentric textural patterns in each massif.

Bridge and Barnes (1941) divided the Wilberns formation into four members and discussed the correlation of various stratigraphic units within the Llano region.

Goldich (1941) presented chemical and petrographic data from certain granitic rocks and offered a theory of evolution of the central Texas granites to explain the chemical and textural characteristics.

The building stones of central Texas were thoroughly sampled and described by Barnes, Dawson, and Parkinson (1942). This publication includes a geologic map of the northeastern part of the thesis area, and descriptions of some of its pre-Cambrian rocks.

Plummer (1943) described quartz sand in the Cambrian of Mason County.

In his article on central Texas soapstone and serpentine, Barnes (1943) reviewed the pre-Cambrian stratigraphy and described and named the Big Branch gneiss in Llano County.

Barnes (1943) reported on gypsum in Cretaceous limestones immediately southwest of the Llano region and briefly described the underlying Paleozoic and pre-Cambrian rocks. He still referred to the Lion Mountain sandstone as a member of the Cap Mountain formation.

Barnes, Cloud, and Warren (1946) presented the first descriptions of Devonian rocks in the Llano region. They named the beds the Pillar Bluff and Stribling formations and assigned them to the lower and middle Devonian.

Cloud, Barnes, and Bridge (1946) redefined the Riley beds by reducing them to formation status, making the Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone members. The upper limit of the Wilberns formation was redefined and placed at the top of the Cambrian. The stratigraphy of the Ellenburger was also revised.

Plummer (1946) discussed the Hickory sandstone and Ellenburger limestone as water reservoirs in his report on the water resources of Texas.

The stratigraphy of the upper Cambrian was finally revised by Bridge, Barnes, and Cloud (1947). All units were thoroughly described, thereby providing a standard reference.

Barnes, Cloud, and Warren (1947) named two more younger Devonian formations and described all of the Devonian beds. In upward succession, the Devonian in the Llano region consists of the Pillar Bluff, Stribling, Bear Spring, and Zesch formations.

Cloud and Barnes (1948) published a very detailed report on the Ellenburger group of the Llano region, defining it as a group, and dividing it into the Tanyard, Gorman, and Honeycut formations. They also briefly described pre-Ellenburger beds at various locations.

Plummer (1950) made the first detailed study of the Carboniferous stratigraphy and paleontology of the region. A large scale map showing the distribution of the Carboniferous rocks accompanies his report.

Blank (1951) described certain weathering features found on some of the pre-Cambrian granites.

Alexander (1952) described and mapped in detail an area immediately south of Mason, Texas.

Cheney and Goss (1952) presented their concepts of the growth of the Llano Uplift and related structural features.

Polk (1952) described and mapped in detail an area immediately west of Mason, Texas. This area slightly overlaps the east boundary of the thesis area.

Barnes, Cloud, and Duncan (1953) reported the first discovery of upper Ordovician rocks in central Texas. The beds were called the Burnam limestone and correlated with similar beds in the Mississippi Valley.

Hutchinson (1953) made a very comprehensive study of the Enchanted Rock pluton and its relationships with surrounding rocks.

Barnes and Bell (1954) described pre-Cambrian to Pennsylvanian rocks in the western part of the Llano region in a guide book prepared for a field trip. This included a geologic map of a large part of the thesis area, but was published (March, 1954) after nearly all of the present writer's field work had been independently completed.

PHYSIOGRAPHY

GEOMORPHOLOGY

The Llano region, although a structural uplift, is topographically a broad basin. In its center, the easily weathered pre-Cambrian rocks have been eroded to form a lowland in which the more resistant pre-Cambrian and Paleozoic rocks stand up as rugged ridges and hills. This entire basin area is surrounded by the still higher escarpment of the flat Cretaceous limestones. The total relief in the Llano region is about 1600 feet, the highest point being about 2300 feet above sea level. In the thesis area the average elevation is roughly 1850 feet and the maximum relief is about 150 feet.

The thesis area may be divided into three geomorphic units: 1) the highly irregular area of granite and metamorphic rocks in the northern portion, 2) the flat area of easily weathered rocks in the central portion, and 3) the escarpment and rocky plateau in the southern portion.

Each type of pre-Cambrian rock has a characteristic topographic expression. The fine-grained granite and the metamorphic rocks form a composite surface made up of irregular, rocky hills. The fine-grained granite outcrop is very conspicuous because of the large round boulders strewn over its surface. The marble is a very resistant rock that forms sharp hills which trend parallel to the strike. Among some of the rugged hills of marble and fine-grained granite are the less resistant gneiss outcrops which weather to form lower undulating hills.

All of the coarse-grained granite and most of the Hickory outcrops are represented by a flat, rockless area. The coarse-grained granite is exposed only in creek beds and elsewhere forms a flat surface composed of granite grus, a mixture of coarse, angular microcline and quartz grains, commonly called "granite wash". This flat surface is farmed in a few places and resembles the sandy fields of the Hickory, which may be not quite as flat as those of the granite. Except for its conglomeratic basal beds and for portions recemented along faults, the Hickory sandstone weathers to a nearly flat sandy surface which is generally under cultivation.

The third geomorphic unit lies in the southern part of the thesis area and consists of the prominent fault-line scarp and the dissected limestone plateau south of the scarp. The topographic expression of the scarp ranges from a steep cliff 125 feet high to only a small change in the surface slope in the eastern part of the thesis area. South of the scarp are resistant Point Peak bioherms and San Saba and

Ellenburger limestones which form a youthfully dissected plateau that has as much as 75 feet of relief.

DRAINAGE

The Llano region is drained by the Colorado River system. Tarr (1890) was the first to observe that the drainage pattern of the major streams was established on a former eastward-tilted plain and that these rivers have since been superimposed on the domed Paleozoic strata and pre-Cambrian complex with only a slight modification of their original courses. One of these major streams, the Llano River, which flows eastward to meet the Colorado River on the eastern boundary of Llano county, is about three to five miles south of the thesis area.

The principal streams of the thesis area, Honey and Bluff Creeks, flow southward as tributaries of the Llano River. They and many of their minor branches owe their general courses to the superimposed dendritic drainage pattern. However, this ancient pattern is being modified to an angular pattern wherever the streams cross faults or meet fault-line scarps. Numerous small obsequent streams were found leading off the major fault-line scarp.

All of the streams in the thesis area are intermittent, flowing naturally only during periods of rainfall. A flowing well in the southwest corner of the thesis area usually maintains a pool in Bluff Creek.

Bluff Creek has a rocky or sandy bottom, while Honey Creek and many of its upper tributaries are choked with granite wash because they drain the easily eroded, coarse-grained granite.

CLIMATE AND VEGETATION

The thesis area is located in a semi-arid region of Texas. According to the Texas Almanac (1954-55), in Mason County the average annual rainfall is 22.5 inches and the mean annual temperature is 64 degrees. The diurnal temperature variation has been observed to be more than 50 degrees in January. The rainfall is irregularly distributed throughout the year, long periods of drought alternating with heavy rains. In August, 1953, several inches of rain fell in three days.

The vegetation in the thesis area is that typically found in regions where the terrain is rocky and the precipitation is unevenly distributed throughout the year. However, there is considerable local variation according to the nature of the rocks. No attempt to classify the grasses was made, but according to Polk (1952), buffalo, needle, curly, mesquite and crowfoot grasses grow in abundance. The following is a list of the predominant and noticeable vegetation found in the thesis area.

Catsclaw	*Acacia greggi*
Agarita	*Berberis trifoliolata*
Mexican persimmon	*Diospyros texana*
Cedar	*Juniperus mexicana*
Tasajillo (rat-tail cactus)	*Opuntia leptocaulis*
Prickly pear	*O. lindheimeri*
Mesquite	*Prosopis juliflora*
Shin (scrub) oak	*Quercus mohriana*
Post oak	*Q. stellata*
Red oak	*Q. texana*
Live oak	*Q. virginiana*
Spanish dagger	*Yucca treculeana*
Whitebrush	*Aloysia ligustrina*

Except for the grasses, the individual plants and vegetational characteristics for each separate rock unit are later described with the stratigraphy of each unit.

STRATIGRAPHY

GENERAL STATEMENT

Pre-Cambrian and early Paleozoic rocks are exposed in the thesis area. Paige (1912) and Sellards, *et al.* (1932) believe that the age of the pre-Cambrian rocks may be Algonkian, but conclusive proof for the age of all the pre-Cambrian rocks is lacking. The Paleozoic rocks are upper Cambrian and lower Ordovician in age. An angular unconformity separates the pre-Cambrian and Cambrian systems. The geologic column is:

- Paleozoic systems ERA
  - Ordovician system
    - Ellenburger group
  - Cambrian system
    - Wilberns formation
      - San Saba limestone member
      - Point Peak shale member
      - Morgan Creek limestone member
      - Welge sandstone member
    - Riley formation
      - Lion Mountain sandstone member
      - Cap Mountain limestone member
      - Hickory sandstone member
- Pre-Cambrian systems
  - Igneous rocks
    - Fine-grained granite
    - Coarse-grained granite

Metamorphic rocks

Gneiss unit

Marble unit

PRE-CAMBRIAN SYSTEMS

Metamorphic Rocks

General Statement

Walcott (1884) applied the term Llano group to a series of metamorphosed sedimentary rocks in the Llano region. Comstock (1889-1890) proposed the formation names Valley Spring gneiss and Packsaddle schist for these rocks. The type localities are at Valley Spring and Packsaddle Mountain, respectively, both in Llano County.

Paige (1911-1912) redefined these formation names and offered his ideas on the classification and origin of the metamorphic rocks of the region. He divided them into the Valley Spring gneiss (older) and Packsaddle schist, and his theory of origin was that both the Valley Spring and Packsaddle are metamorphosed sedimentary rocks, with perhaps some metamorphosed igneous material in the Valley Spring.

Stenzel (1932) revised Paige's (1911-1912) classification and theory of origin of the Valley Spring by stating that the Valley Spring is igneous in origin, having been intruded into the Packsaddle schist. This interpretation considers the

Packsaddle schist as the only sedimentary formation in the pre-Cambrian of the region.

Sellards, et al. (1932) has described the Packsaddle schist as a great thickness of metamorphosed sediments intruded by acidic and basic igneous rocks. The original sediments, shales, sandstones, and limestones, are now schists, gneissoid schists, quartzites, and marbles.

The Valley Spring has been described by Sellards, et al. (1932) as a light colored gneiss consisting of a predominance of feldspathic and quartzitic materials. Stenzel (1932) has described the Valley Spring as an orthogneiss intrusive, with conformable contacts, into the schist series. The Valley Spring gneiss is differentiated from the Packsaddle schist partly on the more massive character of the gneiss and partly on its greater content of acidic materials.

Barnes (1943) has described a third metamorphic unit, the Big Branch gneiss, from exposures along the Big Branch of Coal Creek in Gillespie and Blanco Counties. The Big Branch is a dark gray, medium- to fine-grained, quartz-diorite gneiss which has intruded the Packsaddle schist and Valley Spring gneiss.

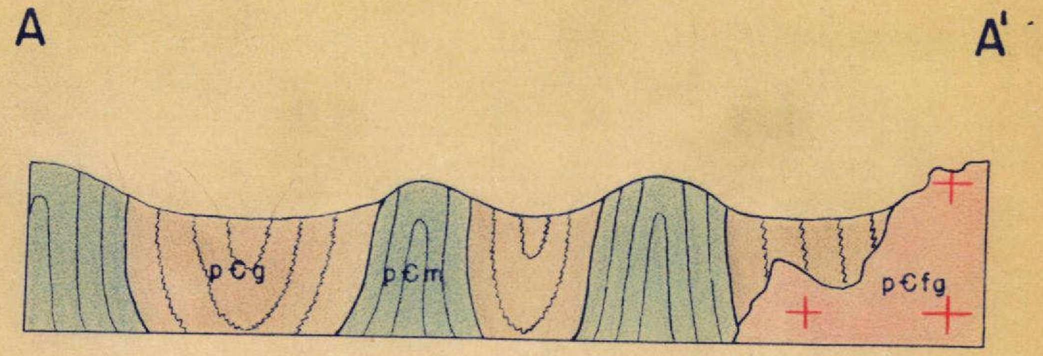
There are two metamorphic units in the thesis area. The marble is predominant and has been termed the marble unit. The remaining metamorphic rocks, consisting primarily of fine-grained gneiss with minor amounts of schist, phyllite, and quartzite, have been termed the gneiss unit. Both of the units definitely have a sedimentary origin and therefore probably are part of the Packsaddle schist. Barnes and Bell (1954) have assigned both units to the Packsaddle.

Marble Unit

Occurrence and relationships

The marble exposure in the thesis area is the largest known outcrop of that rock in the Llano region. The outcrop consists of a single broad expanse with two associated "tongues" which represent the interfolding of marble beds with the gneiss unit at the northeast edge of the main marble body (Plate IV).

The marble lies in a series of strata which have been folded so tightly that all of the beds have the same attitude nearly everywhere, being parallel or nearly so (Fig. 26). The average strike is N 85° W and the dips generally range from vertical (Fig. 1) to 80 degrees south. This consistent strike and southward dip indicates that the present structure of the marble is a series of slightly overturned isoclinal folds (Plate II). The exposed beds have an apparent thickness of about 8000 feet. However, occasional small fold noses within the main marble body prove that much of this



GENERALIZED CROSS SECTION ALONG A-A'

This section shows the structural position of the pre-Cambrian units and general topography.

PLATE II

apparent thickness is due to repetition of strata by the folding.

The marble unit is bounded by a variety of geologic contacts. The only original sedimentary pre-Cambrian contact, that between the marble unit and the gneiss unit, was found at the folds which form the marble "tongues". Field relations indicate that this contact represents the top of the marble unit, and that the base of the marble is not exposed in the thesis area. The strike and dip measurements taken in the gneiss unit indicate a parallelism of this unit with the marble; however, the sharp change in lithology at this contact (from marble to phyllite) suggests some sort of disconformity between the two units.

The remaining limits of the marble outcrop are 1) intrusive contacts with pre-Cambrian granites, 2) overlap by basal Paleozoic beds, and 3) fault contacts with lower Paleozoic beds. There are two different pre-Cambrian granites which have intrusive contacts with the marble unit. A coarse-grained granite bounds the eastern edge, and a fine-grained granite the northeastern edge of the marble. The remaining boundaries of the unit are normal or fault contacts with basal Paleozoic sandstones, except for the south-central edge, which is a fault contact with upper Cambrian limestones.

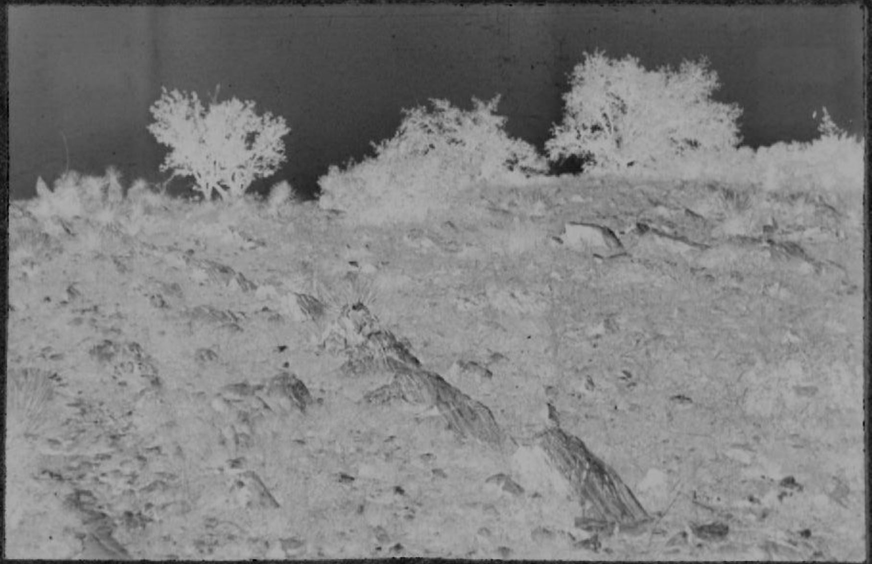


Fig. 1--Small "hogbacks" of marble beds by G. Loeffler's ranch house.

Fig. 2--Rocky marble surface. Note abundant Spanish dagger. Taken near southern end of Loeffler-Lange fence.

in ancient fractures and crushed zones.

The marble which weathers brown is medium-grained, gray on a fresh surface, and generally less calcareous than the marble which weathers gray. The brown marble does not show any marked banding, but is more homogeneous and compact, and has very few calcite veins when compared to the gray marble. Even with a hand lens, no reason for the brown weathering was noticed. Barnes, Dawson, and Parkinson (1942) reported abundant pyrite at one locality, but this mineral was not found megascopically in most of the marble.

Both the brown and gray marbles contain occasional thin (one inch) veins of white quartz. Although no contact metamorphism is present around these veins, they must have been intruded during metamorphism. The veins weather to form angular fragments about three-quarters of an inch in diameter. These fragments are thickly scattered on and are very characteristic of the marble surface.

The marble adjacent to the intrusive contacts with the granites is conspicuously lacking in contact metamorphism. The only location found where the marble changes character near a granite intrusion is near the southernmost tip of the fine-grained granite. Here the marble is locally pure white, medium-grained, and highly calcareous.

Microscopic description

Two thin sections of marble were prepared, one of the gray marble and one of the brown marble. Beside the colors to which they weather, these two types of marble show other differences in physical characteristics which must be determined microscopically.

The gray marble consists primarily of anhedral calcite grains which vary in size from 0.1 mm. to 0.4 mm. across. Some of the grains show polysynthetic twinning.

The second most abundant mineral, which comprises about 25% of the thin section, is doubtfully wollastonite. It is colorless and has a radiating structure, with the radii being as long as 1.5 mm. These radii are composed of acicular aggregates which do not show any extinction and give false interference colors. The interference colors are generally in the third and higher orders, but this high birefringence may be due to an intimate admixture of the needles with calcite. The index of refraction is greater than balsam, but its exact relation to the calcite is doubtful. Neither the elongation nor an interference figure could be obtained.

Associated with the wollastonite (?) is an opaque, brownish-black mineral which occurs as grains whose edges are somewhat parallel to the radiating structure. A few reddish-brown stains surround these opaque grains and indicate that the mineral may be hematite.

A few scattered grains of scapolite (?) are in the thin section. This mineral is very abundant in the brown marble thin section and is described with it.

The principal minerals in the brown marble are dolomite and calcite. The predominance of euhedral grains over anhedral grains indicates that dolomite comprises most of the carbonates in this thin section. Most of the carbonate grains range from 0.05 mm. to 0.10 mm. across.

The presence of another carbonate, siderite, is strongly suggested by many brown spots and iron stains which surround some of the carbonate grains. This brown material is limonite formed by the weathering of the siderite and is probably the cause of the brown color of the weathered surface of the rock.

A very abundant accessory (perhaps secondary) mineral found throughout the thin section is doubtfully scapolite. The mineral occurs as euhedral, rectangular and columnar grains which are about 0.1 mm. long and 0.05 mm. wide. The birefringence is rather strong; the maximum interference colors being second-order yellowish-green. Many grains show cleavage parallel to the prism sides, and the extinction is parallel to the cleavage. The interference figure is uniaxial negative. This mineral is in the isomorphous scapolite group and because of its relatively high birefringence it is probably close to the calcium end member, meionite. In this thesis the mineral will be referred to as scapolite (?).

The only opaque minerals in the thin section are pyrite and some of the hematite associated with it. The larger pyrite grains are six-sided in cross section and are surrounded by a rim of translucent red hematite. The two largest grains are about 1 mm. across. The remaining hematite is found as occasional specks, some of which are opaque.

The interstices between some of the grains in the thin section are filled with quartz. All of the pores and angular cavities are filled, making the rock non-porous and impermeable.

Topography and vegetation

The marble is a very resistant rock that forms sharp hills which trend parallel to the strike. The surface is very rocky and generally has small "hogbacks" of individual marble beds (Figs. 1,2).

The vegetation consists predominately of Spanish dagger, catsclaw, and shin oak with lesser amounts of agarita, prickly pear, cedar, and Mexican persimmon. The Spanish dagger and catsclaw are particularly characteristic of the marble surface.

Gneiss Unit

Occurrence and relationships

The outcrop of the gneiss unit has a very irregular outline and does not have many actual rock exposures within the thesis area. The attitude of the gneiss unit near the marble "tongues" seems to be parallel to that of the marble. However, farther to the northeast, the dips and strikes become slightly more erratic, but still generally follow the east-west trend. Whether the folding which caused the "tongues" continues northward was not determined.

The irregular outcrop is bounded by metamorphic, sedimentary, and intrusive rocks. The metamorphic contact with the marble has been previously described. The sedimentary contact is the overlap of the basal Paleozoic sandstones on the pre-Cambrian surface. There are two different intrusive contacts, with the fine-grained granite and with the coarse-grained granite.

Besides the main outcrop of this unit, several small "patches" of gneiss and one of phyllite are found in the southwestern part of the large marble mass. These small "patches" are less than ten yards long and seem to be interfolded with marble beds. Whether they represent an original clastic lens within the marble or whether they are equivalent to the base of the gneiss unit to the north is not known.

The small phyllite "patch" is found in a creek bed 0.33 mile southeast of G. Loeffler's ranch house. The phyllite here is in unconformable contact with the marble and may have been faulted into its present position.

Megascopic description and relationships

The gneiss unit contains a large variety of metasedimentary rocks, most abundant of which is massive gneiss. The unit generally erodes more readily than all of the adjacent units except the coarse-grained granite. Although fresh outcrops are rare, it is not uncommon to find many loose rocks scattered on the surface.

At the end of the northern marble "tongue" the marble is in contact with a dark phyllite. This phyllite is easily weathered, but is well exposed in a road metal quarry and in road drainage ditches. It is a thin-bedded, fine-grained, black rock rich in graphite, which forms a very black soil.

The phyllite is bounded on the east by the coarse-grained granite. This intrusive contact is well exposed 1) in the roadbed at the curve in the Old Junction Road immediately east of the junction of this road with the farm road to B. Lange's house, and 2) in the roadbed and drainage ditches of the above-mentioned farm road about 175 yards south of the junction. At both locations the granite is intruded into the phyllite (Fig. 4), but no contact metamorphism was seen. Lit-par-lit injection is also lacking, but a xenolith of phyllite in the granite is exposed on the Old Junction Road (Fig. 3). The last-mentioned contact contains some secondary white caliche-like material which might have been formed from the nearby marble.

This black phyllite seems to grade into a hard, black gneiss. The gradation seems to be both vertical and horizontal, because the distance between the outcrops of the two units both along and across the strike is less than 200 yards and no faults or unconformities were seen in this interval.

The predominant rock type is a massive, very hard, fine-grained, nearly non-calcareous, black and gray gneiss. The megascopic appearance of the rock suggests that the principle mineral is quartz. The black color is probably due to graphite. The amount of black material varies in some layers so that the rock has gray bands. This rock is very hard and forms most of the previously mentioned loose blocks found on the surface of the outcrop.

The next rock type within the gneiss unit is a metasedimentary quartzite. It is a pink, medium-grained, massive, granular rock. The grains are about one mm. in diameter and appear to be partially enclosed by a pink cementing material.

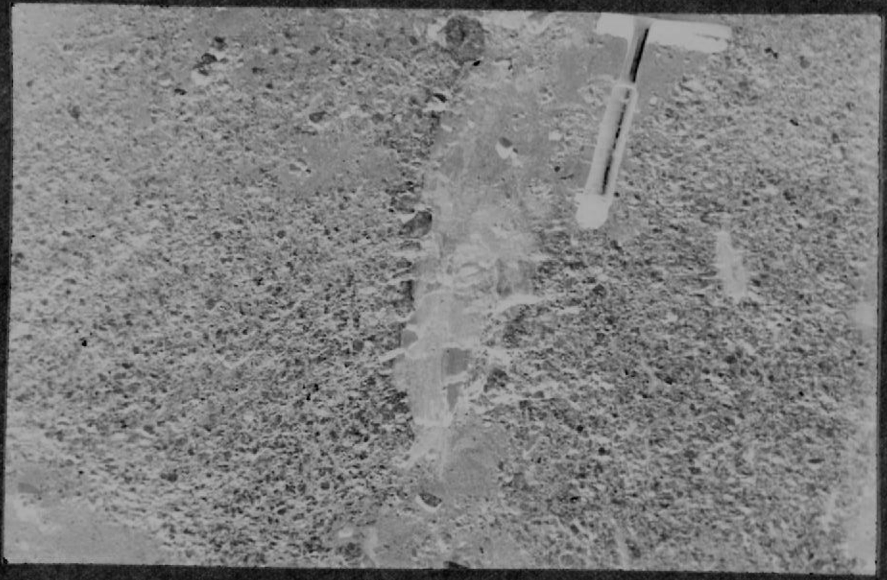


Fig. 3--Xenolith of phyllite in coarse-grained granite on Old Junction Road.

Fig. 4--Intrusion of coarse-grained granite into phyllite in drainage ditch beside farm road to B. Lange's house.

Fig. 5--Massive gneiss in road metal quarry on US 377.

Fig. 6--Angular blocks of the brown gneiss found in "patches" in the southwest part of main marble mass.

The weathered rock is somewhat friable. A few beds in this quartzite are finer grained, but otherwise have the same characteristics. The quartzite beds are extensively intruded by vein quartz where they are near the quartz dike on the north side of the northern marble "tongue". The quartzite is exposed between the two granite bodies and is north of the northern marble "tongue", but mostly south of the highway.

Although good exposures are rare and the metamorphic rocks are highly folded, the quartzite seems to be younger than the dark gneiss-phyllite beds and the marble unit unless large post-granite faults are present. North of the two "tongues" the top of the marble seems to "dip" deeper into the subsurface. Immediately next to the top of the marble are the dark gneiss-phyllite beds. The quartzite contact with the dark gneiss-phyllite beds is not exposed, but if the "dip" of the folded units is still northward, the quartzite bed would overlie the dark gneiss-phyllite beds, and therefore be the next younger rock type in the gneiss unit.

North of the quartzite the gneiss unit consists of interbedded gneiss and schist which are in bands from a few feet to about 25 feet wide. These rock types are exposed best in the road metal quarry on US 377, just off the northern edge of the map.

The weathered gneiss here generally is a yellowish-brown, micaceous, hard, very fine-grained, non-calcareous, massive rock that shows little banding (Fig. 5). The very abundant mica has a bronze color and probably is weathered biotite. It is generally found in $\frac{1}{4}$-$\frac{1}{2}$ mm. flakes, but there are some one inch bands which contain $\frac{1}{4}$ inch grains. Hornblende is also present as six-sided prisms, the largest of which has a diameter of 5 mm. The weathered grains are brownish-black to black.

The schist is an easily eroded rock and is nowhere well exposed, usually producing only a micaceous soil. In the quarry, the friable, deeply weathered rock consists mainly of partially decomposed biotite.

At the north side of the northern marble "tongue" and west of the fault, the contact between the fine-grained granite and the gneiss unit exhibit lit-par-lit injection of the granitic liquids into a dark gneiss to form a pink and black, banded, micaceous gneiss. This contact has been prospected for economic minerals, but no ores have been mined profitably. An odd rock which has been excavated here is an olive-green, slightly calcareous, fine-grained, metasedimentary rock that may be called a metamorphic claystone.

The gneiss found in small "patches" in the southwestern part of the large marble mass is a massive, light brown, fine-grained, very hard, non-calcareous rock. This gneiss does not weather easily and remains on the surface as angular blocks (Fig. 6).

The phyllite in the small exposure southeast of G. Loeffler's house is a highly weathered, dark pink, fine-grained, friable rock that resembles an unconsolidated siltstone. Because of the differences in appearance, it is doubtful if this phyllite or the brown gneiss correlate with beds of similar lithology north of the large marble mass.

Microscopic description

A thin section of the dark gneiss and one of the phyllite were prepared. These do not provide for microscopic descriptions of all of the different rock types in the gneiss unit, but the predominant types are represented. The following descriptions also confirm the field relations which suggest that these two rock types are gradational into each other.

The gneiss consists of quartz, graphite, calcite, and pyrite. The anhedral quartz grains are 0.05 mm. across. The graphite is abundant and occurs as a powdery, opaque mineral, both disseminated and in bands about 0.2 mm. wide. These bands alternate with the quartz and calcite to give the gneissoid appearance.

Fine granular pyrite is rather common. The grains are aligned and sometimes merge to form elongate grains of the mineral. One band of calcite is in the thin section. The calcite grains are the largest, having a diameter of 0.1 mm.

The predominant minerals in the phyllite thin section are quartz and graphite, with minor amounts of secondary minerals. The quartz grains are of two sizes: small grains 0.05 mm. across and larger elongate grains 0.5 mm. long and 0.1 mm. wide. The banding is caused by the very abundant minute specks of graphite which compose about 30% of the minerals in the thin section.

Scapolite (?) is also prominent, being about 15% of the thin section. It forms light-colored bands which may be seen megascopically. The mineral occurs in two grain sizes: fine crystalline aggregates, and columnar grains 0.5 mm. long and 0.1 mm. wide. Some of the smaller grains are turning yellowish-green, but still have the columnar structure. This is probably an alteration to muscovite.

Topography and vegetation

The topography of the gneiss unit is very variable, and nearly always devoid of fresh rock exposures. Except for the few hills of the metasedimentary quartzite, this unit generally forms the valleys between the surrounding units.

The vegetation is predominantely shin oak, mesquite, and catsclaw with lesser amounts of agarita, tasajillo, prickly pear, and cedar brush.

Igneous Rocks

General Statement

Paige (1911-1912) presented the first comprehensive classification of granites in the Llano region. The three types of granites shown on his maps are: 1) a very coarse-grained, homogeneous granite, 2) a medium- to fine-grained granite, including some coarse-grained varieties, and 3) an opaline quartz porphyry. This classification by textural differences has been criticized by Goldich (1941) who says that "Gradations in texture within a single mass are commonly pronounced, and the distinction of granite types on the basis of texture was found by Paige to be difficult and uncertain". Goldich's statement was prompted by Keppel (1940), who studied central Texas granite massifs and found concentric textural patterns in each massif.

Stenzel (1932, and in Sellards and Baker, 1934) has divided the igneous rocks into: 1) the batholitic intrusions, comprising the various granites and their aplite and pegmatite dikes, and 2) the later dike intrusions comprising the opaline quartz porphyry and felsites. He further divided the batholitic intrusions (from oldest to youngest) into: 1)

Town Mountain, which are coarse-grained to porphyritic granites with large flesh-colored feldspars, 2) Oatman Creek (or Oatman) which are medium-grained, gray to pink cataclastic granites, and 3) Sixmile, which are fine-grained, gray, biotite granites.

Parts of two separate intrusive granite bodies are in the thesis area. These have been termed the fine-grained granite and the coarse-grained granite.

Coarse-Grained Granite

Occurrence and relationships

The coarse-grained granite in the thesis area represents the western limit of a batholith which extends eastward for several miles. The exact extent and size of the body have not been determined.

This granite is intrusive into the metamorphic rocks, but not into the fine-grained granite. At no place was the intrusive contact between the two granites exposed, and therefore the age relationships between the two could not be determined by an intrusive sequence. However, an inspection of aerial photographs or the map by Barnes, Dawson, and Parkinson (1942) shows that the irregular intrusive outline of the coarse-grained batholith is indented by the curved outline of the younger fine-grained granite stock.

Barnes and Bell (1954) have correlated the coarse-grained granite in the thesis area with other pink, coarse-grained granites in the Llano region, called Town Mountain by Stenzel (1932, and in Sellards and Baker, 1934). Flawn in Barnes and Bell (1954) says that the Town Mountain granites have been dated with ages of 891, 1050, and 1100 million years. Because it is generally accepted that the age of the Archeozoic-Proterozoic "contact" is about 1 billion years ago, the Town Mountain is probably either late Archeozoic or early Proterozoic.

Megascopic description

This granite is coarse-grained and inequigranular. Some of the feldspar grains are as large as 25 mm. (1 inch) in diameter, and the remaining grains are about 5 mm. in diameter. The rock does not have any one particular color, rather the large grains of the pink, white, and black minerals cause a spotted appearance. The minerals seen megascopically in the granite are pink microcline, quartz, white plagioclase (albite or oligoclase), and biotite. The pink feldspar grains are most prominent, both in size and number, comprising about 35-40% of the rock. The remainder of the rock is composed of approximately equal parts of the quartz, plagioclase, and biotite. The quartz is smoky and the ex-

Fig. 7--Coarse-grained granite in Honey Creek. Note flat topography in background.

Fig. 8--Small knobs of coarse-grained granite near contact with marble (high ground in background). Picture taken immediately west of E. Lange's house.

posed edges of the biotite in a relatively fresh sample have already begun to weather to a bronze color. On a weathered exposure, black biotite is not seen, and the only evidence of the mica is an occasional bronze grain of weathered biotite. These easily altered flakes of biotite are the main cause of easy weathering and rapid disintegration of the coarse-grained granite.

The irregular intrusive contact which exhibits apophyses of granite in the phyllite (Figs. 3,4) is exposed at the previously described locations on and by the Old Junction Road. The character of the granite has not changed appreciably at these contacts.

The intrusive contact of the coarse-grained granite with the marble also does not exhibit contact metamorphism. In a few places apophyses of the granite are surrounded by marble, but even here the character of the rocks has not changed appreciably. The most conspicuous change in the granite near this contact with the marble is that the granite becomes slightly more resistant and forms occasional small knobs which protrude above the granite wash (Fig. 8). These knobs are generally one to two feet high and a yard or so in diameter. The largest of these knobs was found in E. Lange's back yard.

Microscopic description

The only unweathered rock from which a thin section could be prepared was found just north of the thesis area where US 377 crosses Honey Creek. Here some dynamited blocks of the coarse-grained granite have been discarded. Although the blocks were not in place, it is believed that the sample is representative of the coarse-grained granite in the thesis area.

The minerals found in the thin section are microcline, quartz, oligoclase, biotite, zircon, kaolinite, pyrite, and allanite (?). The microcline is most abundant, being in anhedral grains and having a cloudy incipient alteration to kaolinite. The characteristic "gridiron" structure due to albite and pericline polysynthetic twinning is present. Several small inclusions, probably quartz, were seen in some microcline grains.

The quartz is anhedral and appears both as large, solitary grains 1.80 mm. in diameter and in groups of fine-grains which are 0.15 mm. in diameter with an occasional small grain of microcline. The quartz extinction is generally sharp rather than undulatory.

The plagioclase was readily distinguished by its albite twinning and an occasional Carlsbad twin. The average grain is about 1.8 mm. in diameter. The maximum extinction angle found was 7 degrees on an albite twin. This value classifies the plagioclase as oligoclase.

The biotite is anhedral and subhedral and has associated zircon inclusions that are surrounded by pleochroic halos. The biotite color on 001 is a dark brown that transmits very little light. The color on 100 and 010 is olive-green. The absorption is strongest here (parallel to the cleavage traces).

Two small grains of pyrite appear in the thin section.

The thin section also contains an apparently subhedral grain of an uncommon mineral which is yellowish-green and appears to be banded near the edge by a slightly darker shade of the same color. The grain is 1.2 mm. across and is covered by a creamy gray film which is probably some alteration product. No pleochroism, absorption or extinction was seen. The reason for this lack of optical properties is that under the highest magnification (450 X) the grain seemed to be composed of minute grains and fragments. The grain is surrounded by radiating cracks which probably indicate radioactivity. The best classification of this grain is allanite (?) which has been inverted (from anisotropic to partly isotropic) to a heterogeneous, amorphous, metamict mineraloid.

Topography and vegetation

The coarse-grained granite is very susceptible to weathering. Except for the small knobs near the contact with the marble, the only outcrops are those found occasionally in stream beds. In these exposures the granite has little relief and may have some irregular boulders on its surface. The weathered surface of the granite is generally so "rotten" that the rock may be scraped away by rubbing the surface. This rapid disintegration causes a very flat layer of granite wash several feet thick to overlie the bedrock (Fig. 7).

The vegetation on this granite is predominately live oak and shin oak with lesser amounts of prickly pear, tasajillo, Spanish dagger and mesquite brush. The land has generally been cleared of brush and appears as a grassy flat area with many oak trees.

Fine-Grained Granite

Occurrence and relationships

The fine-grained granite in the thesis area represents the southern part of an elliptical granite stock which trends N 35 E. The stock has a maximum width of 1.1 miles and a maximum length of 3.0 miles. Barnes, Dawson, and Parkinson (1942) have published a map and descriptions of this granite for building stone purposes.

This granite is intrusive into the metamorphic rocks and into the coarse-grained granite. The contacts with the metamorphic rocks are at the northern and southern ends of the stock. The eastern side of the stock is the intrusive contact with the coarse-grained granite, and the western boundary of the outcrop is the unconformable contact with the Cambrian Hickory sandstone. Although the intrusive contact between the two granites is not exposed, it is believed that the fine-grained granite is the younger because the stock indents the irregular outline of the coarse-grained batholith.

Barnes and Bell (1954) have correlated the fine-grained granite with medium-grained, gray to pink, Oatman (Oatman Creek) granites described by Stenzel (Sellards and Baker, 1934).

The age of the fine-grained (Oatman Creek) granite stock is very probably Proterozoic if, as previously suggested, the coarse-grained (Town Mountain) granite batholith is no older than late Archeozoic. No absolute age determinations have been made on any of the rocks in the thesis area.

Megascopic description

The granite is equigranular, with grains appearing to be 2-3 mm. across. The minerals seen megascopically in this granite are microcline, quartz, and biotite. Microcline is most abundant and causes the rock to have a dark pink color. Quartz is second in abundance and with the microcline comprises most of the rock. The dark minerals are relatively scarce, biotite being the only such mineral recognizable with a hand lens.

The intrusive contacts of the fine-grained granite do not exhibit much contact metamorphism. Two xenoliths of gneiss were found at the boundary with the gneiss unit. The contact with the coarse-grained granite is not exposed. The only change of the marble next to the stock is at the southernmost tip of the stock. This fine-grained granite-marble contact is very straight in places and faulting between the two units is suggested, but apophyses of granite in the marble disprove this. This contact has attracted many prospectors who have dug numerous excavations along it.

The granite is broken with joints that are spaced as closely as four inches. However, most of the joints are generally much more widely spaced, as is seen by the large, unjointed boulders on the outcrop. Some of the larger joints or joint systems seem to control the drainage.

The fine-grained granite contains numerous granite pegmatite veins which, according to Barnes, Dawson, and Parkinson (1942), contain topaz, tourmaline, and cassiterite.

<u>Microscopic description</u>

The following microscopic description of the fine-grained granite is from Barnes, Dawson, and Parkinson (1942), who described the rock for building stone purposes.

Fig. 9

Fig. 10

Typical fine-grained granite

The granite is composed predominantly of microcline, plagioclase, and quartz with a small amount of muscovite and biotite. Accessory minerals are fluorite and zircon. Fluorite is abundant and in many cases is situated within plagioclase crystals. A few of the fluorite grains are colorless. The biotite has almost entirely altered to chlorite and some sericite has developed by alteration of the feldspars, which are uniformly but not densely cloudy. The plagioclase is oligoclase in composition. The estimated mineral composition is microcline 30, plagioclase 40, quartz 29, and muscovite 1 percent. The quartz has a small amount of undulatory extinction. Microscopically the granite is made up of grains less than 1 mm. in size, whereas megascopically the grains appear to be much larger.

Topography and vegetation

The granite is very resistant, and the topography is accordingly very rough and rocky. The outcrop consists of granite blocks as large as an automobile and of round boulders which have diameters varying from about one to four feet (Figs. 9,10). No part of the granite outcrop is suitable for cultivation.

The vegetation is predominantly shin oak, post oak, and mesquite, with lesser amounts of prickly pear, Spanish dagger, tasajillo, and Mexican persimmon.

CAMBRIAN SYSTEM

Riley Formation

Definition and Thickness

The Riley formation is the lowest Paleozoic formation in the Llano region, and rests unconformably on the pre-Cambrian basement. This formation should not be confused with the Riley series of Comstock (1890) and Paige (1912). As presently defined by Cloud, Barnes and Bridge (1945), the Riley formation includes all known Cambrian strata in central Texas beneath the Cambrian Wilberns formation. The three gradational members are, from oldest to youngest: 1) Hickory sandstone, 2) Cap Mountain limestone, 3) Lion Mountain sandstone.

The thickness of the Riley at its type locality, the Riley Mountains in southeastern Llano County, is about 780 feet. However, because of the irregular pre-Cambrian surface, depositonal differences, and erosional disconformities, the Riley may be as thin as 200 feet. The average thickness is about 680 feet. The complete formation is not represented continuously in the thesis area because of faulting. A composite section made up of beds measured in and around the thesis area is at least 600 feet thick.

Hickory Sandstone Member

Definition and thickness

The name Hickory was first used by Comstock (1890) for his Hickory series of Hickory Creek in Llano County. Paige (1912) retained the same unit, but changed the name to Hickory sandstone. Cloud, Barnes, and Bridge (1945) redefined the unit by assigning it a member status and lowering the upper boundary.

Bridge, Barnes, and Cloud (1947) state that the Hickory averages about 350 feet in thickness and ranges from about 415 feet thick to a feather edge. This great variation is due to pre-Cambrian topography, irregularities in deposition, and lateral gradation of the upper beds into Cap Mountain limestones. According to observations made by Alexander (1952) and Polk (1952), a short distance east of the thesis area, the complete section in this vicinity is estimated to be about 400 feet thick, but it is poorly exposed in the thesis area.

Lithology

Erosion has caused only the more resistant lower part of the Hickory to be well exposed in the thesis area. At many places it exists only as thin, isolated, erosion outliers on a pre-Cambrian surface having approximately 100 feet of relief.

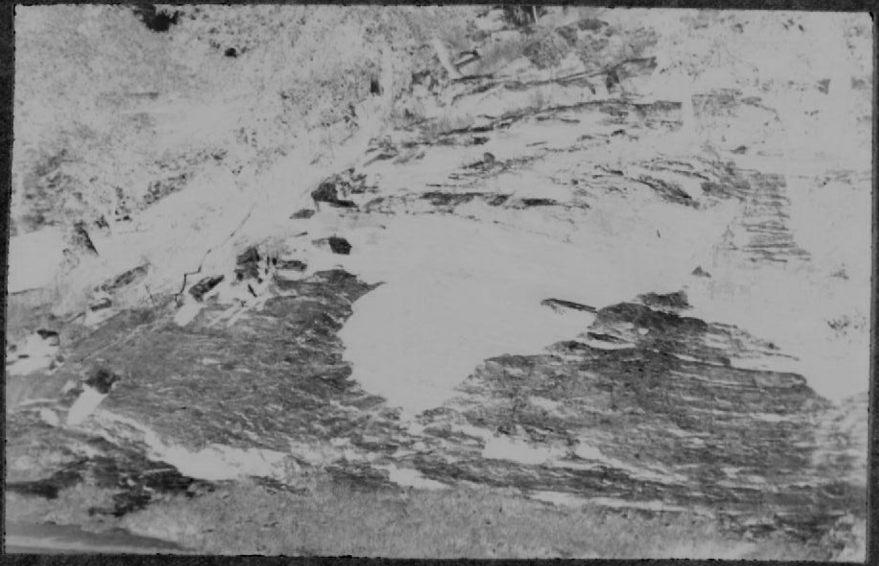


Fig. 11--Large scale cross-bedding in lower Hickory in stream in northwest corner of G. Loeffler's ranch. This shows why accurate dip measurements are hard to obtain.

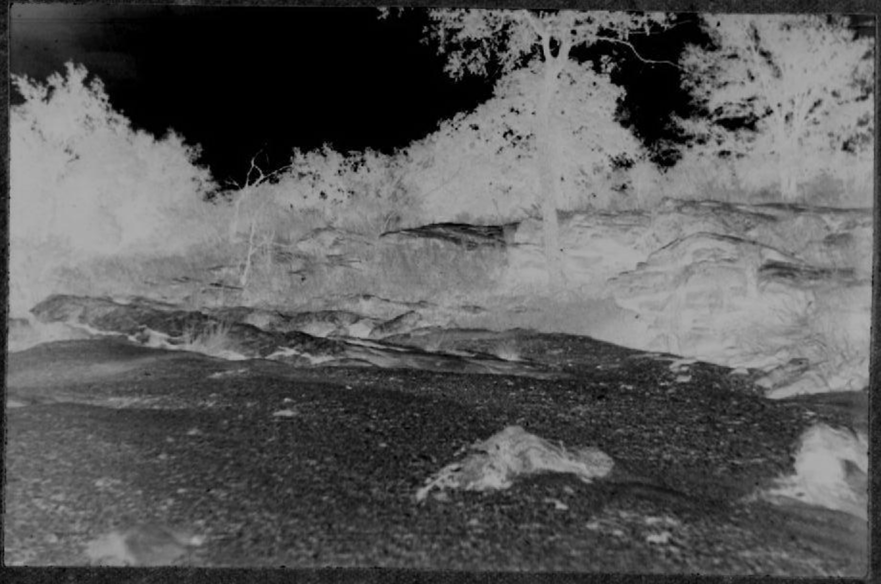


Fig. 12--Largest upper Hickory outcrop in thesis area exposed where Hickory-granite fault crosses Honey Creek.

Many of the basal Hickory beds may be called conglomerates because most of their grains are over 2 mm. in diameter, with occasional larger pebbles up to 2½ inches (Fig. 13). The pebbles are composed of milky and transparent quartz, which has been stained by iron oxides (hematite and limonite) to colors ranging from light brown to bright maroon. Some of them are wind-faceted.

The wind-faceted pebbles will be termed ventifacts rather than dreikanters because the latter term literally means "three corners". The facets on these pebbles are not limited to any certain number, but range from one to four or five. The average ventifact is a rough pyramid with an elliptical base of 3/4 by 1 inch.

Most of the pebbles in the basal Hickory have only one or two facets, which seem to be wind-frosted faces of quartz crystals or fragments rather than true wind-cut surfaces. Some frosted pebbles have recognizable crystal faces.

Ventifacts may be found by turning over basal sandstone slabs or by examining the float remaining on the exposed pre-Cambrian surface near a Hickory contact (Fig. 14). It would seem as if the transgressing Hickory sea should have washed all of the coarser pebbles into the valleys of the pre-Cambrian surface. However, at one or more locations in the thesis area, ventifacts and large, wind-faceted pebbles were found at various elevations.

The bedding of the lower Hickory is very variable, ranging from well-developed crossbedding to locally massive beds. The sand grains, which range from subangular to rounded, are predominantly quartz with minor amounts of feldspar, and the cement is silica and/or iron oxides. The colors are generally white to yellowish-brown to reddish-brown. The rock may be either very friable or very hard, depending on the type and amount of cementing material. Quartzite has been developed along some faults where secondary silica has completely indurated the sandstone.

A very common feature of the Hickory is the network of nearly vertical fractures which have been recemented with a relatively resistant siliceous material. These cemented fractures are also found in the Welge member, but not as closely spaced as in the Hickory.

The middle and upper parts of the member are not well exposed in the thesis area. The short description following is mostly from adjacent areas. Near the middle of the Hickory member is found a thin series of thin-bedded, yellowish, silty layers. These are generally overlain by an intraformational conglomerate. The upper part of the member consists of fairly regular, brownish to red, well-bedded strata.

Fig. 13--Conglomeratic basal Hickory at G. Loeffler's ranch house.

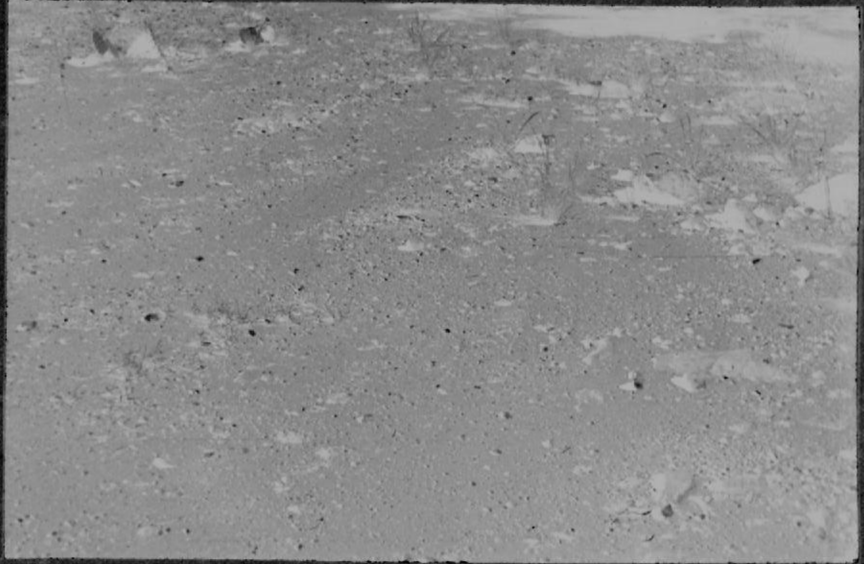


Fig. 14--Ventifact locality close to drag fold location.

The red color is due to hematite "ovules", which are believed to be a weathering product of glauconite. This indication of glauconite, ripple marks, and phosphatic brachiopods indicate a shallow water, marine depositional environment.

Topography and vegetation

The relief on the Hickory is generally low because most of the sandstone disintegrates readily. However, the thesis area contains an unusually large amount of Hickory which forms bold relief. These topographic differences are evidently related to the amount of cementation, regardless of stratigraphic position.

The Hickory supports a dense vegetation cover where the land has not been cleared. The plant life consists of abundant live oak, shin oak, mesquite, tasajillo, and whitebrush with lesser amounts of cedar, post oak, Mexican persimmon, and prickley pear. Areas of low relief are generally under cultivation.

Cap Mountain Limestone Member

Definition and thickness

Paige (1912) originally applied the name Cap Mountain to a formation which had a lower boundary somewhere above the present top of the Hickory and which included the present Lion Mountain sandstone member, so that its upper boundary was the present Riley-Wilberns contact. Cloud, Barnes, and

Bridge (1946) redefined the Cap Mountain as a member which includes more basal beds and not as many upper beds. The type locality is at Cap Mountain in Llano County.

Bridge, Barnes, and Cloud (1947) state that the thickness of the member ranges from 135 feet to 455 feet and averages 280 feet. The variation is due principally to lateral gradation of the lower beds into sandstone. Because of faulting, the complete Cap Mountain is not exposed in the thesis area. The following measurements and most of the descriptions are of the member in the South and West Mason areas. The average thickness is about 170 feet in the South Mason area (Alexander, 1952), and about 200 feet in the West Mason area (Polk, 1952). If this rate of thinning continues westward, the Cap Mountain in the thesis should be about 230 feet thick.

Lithology

The lower contact with the Hickory is gradational. The sandstone acquires a little calcareous cement toward its top and begins to alternate with brown, arenaceous limestone. The contact is chosen at the uppermost noncalcareous sandstone stratum. This approximately coincides with a vegetational break and a topographic change.

The lower Cap Mountain consists of alternating beds of dark reddish-brown, medium- to coarse-grained, arenaceous limestone and dark red, medium-grained, calcareous sandstone. This zone grades upward into another series of dark brown, medium-grained, slightly fossiliferous limestones and tan, fine-grained sandstones. Higher in the section are thick-bedded to massive, tan to brown, granular limestones with occasional stringers of fine-grained, brownish-yellow sand. These massive ledges constitute the greater part of the member. Above them is a thin section of light gray to brown, medium-grained, glauconitic, fossiliferous limestones which weather easily. The upper contact is a transition from brown, massive limestone to greenish-gray limestone and also marks the beginning of a gentler slope and less dense vegetation.

Topography and vegetation

The Cap Mountain is relatively resistant and forms a conspicuous cuesta wherever it outcrops. Some of the basal beds are farmed, but the majority of the outcrop is too rocky to be cultivated.

The vegetation is relatively thick, especially on the scarp slopes of the cuestas near the Hickory contact. The difference in vegetation between the Hickory and Cap Mountain members is easily seen on the aerial photographs, and the contact is usually marked by the lower side of the dark band on the cuesta scarp slopes. Shin oak is the predominant plant, and Spanish dagger, prickly pear, cedar brush, and catsclaw constitute most of the remaining vegetation.

Lion Mountain Sandstone Member

Definition and thickness

Bridge (1937) named the Lion Mountain sandstone as the top member of the Cap Mountain formation. Cloud, Barnes, and Bridge (1945) retained the unit and made it the uppermost member in the Riley formation.

The thickness at the type locality at Lion Mountain in the northwest part of the Burnet quadrangle is 20 feet, but it reaches a maximum thickness of 50 feet elsewhere in the Llano region. It is doubtful if the Lion Mountain is present in the thesis area. No good outcrops were found, so the measurement and descriptions are from previous work done in the South and West Mason areas. Alexander (1952) measured a thickness of 52 feet in the South Mason area.

The only indication of the Lion Mountain in the thesis area is a narrow, short, barren bench on which are scattered hematite pebbles. A sandstone bed is associated with the bench, but its correlation with other Lion Mountain beds is uncertain.

Lithology

The Lion Mountain sandstone is usually mapped with the aid of topographic and vegetational changes. The lower contact with the Cap Mountain is chosen at the lower edge

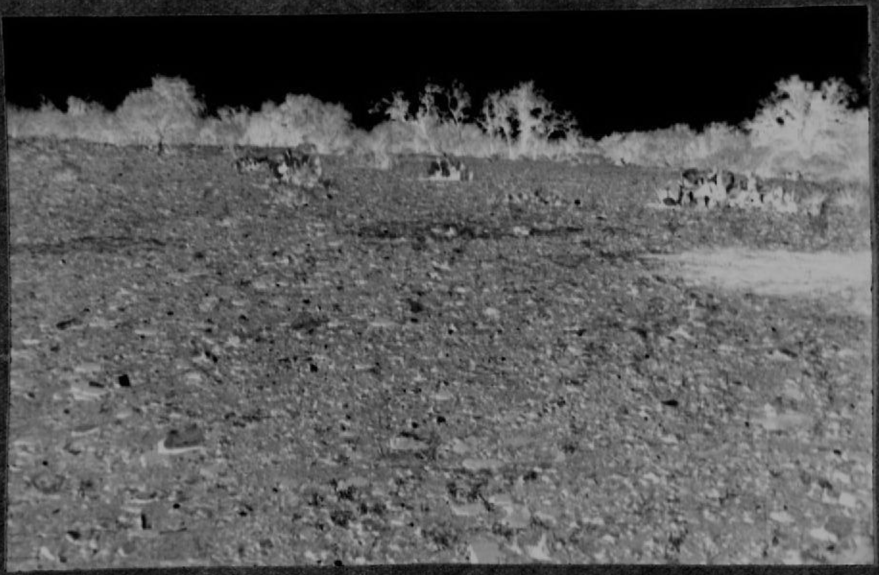


Fig. 15--Barren Lion Mountain bench with h hematite pebbles.

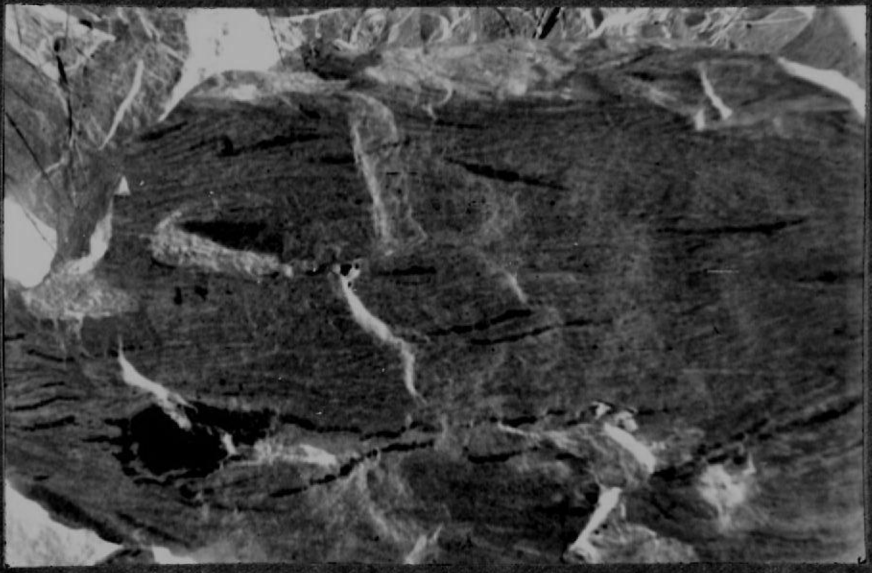


Fig. 16--Lenses of "trilobite hash" in Lion Mountain.

(These photographs were taken from US 377 west of Streeter.)

of the characteristic bench. This lower boundary is gradational and is marked by a change from massive, brown, Cap Mountain limestone to thin-bedded, greenish-gray limestone.

Most of the member consists of coarse-grained, highly glauconitic sandstone. The lower portion contains the above-mentioned glauconitic limestones which are composed almost entirely of tangential lenses of a well-cemented trilobite and brachiopod coquina, conveniently called "trilobite hash" (Fig. 16). The upper part of the member includes some highly glauconitic beds containing phosphatic brachiopods. Shiny black pebbles of hematite which are abundant on the outcrop (Fig. 15) are believed to be weathering products of the glauconite. The upper limit of the member is a disconformity, which is also the top boundary of the Riley formation.

Topography and vegetation

The Lion Mountain is marked topographically by a sparsely vegetated bench of variable width which appears as a light, narrow band on the aerial photographs. Mexican persimmon, prickly pear, shin oak, and tasajillo are found thinly scattered over the outcrop.

Wilberns Formation

The Wilberns formation consists of the Cambrian rocks below the Ordovician Ellenburger group and above the Cambrian Riley formation. From exposures at Wilberns Glen in Llano County, Paige (1912) named and described a Wilberns formation which does not contain the San Saba member of the present Wilberns formation. Paige (1912) recognized the Cambrian age of the San Saba, but placed it in the Ellenburger group because of lithologic similarities and an inability to properly determine the San Saba-Ellenburger contact. Cloud, Barnes, and Bridge (1945) redefined the upper boundary of the Wilberns formation and placed it at the top of the Cambrian San Saba member. Paige's (1912) original lower boundary is still used. Bridge, Barnes, and Cloud (1947) described the five gradational members which are, from oldest to youngest: 1) Welge sandstone, 2) Morgan Creek limestone, 3) Point Peak shale, 4) San Saba limestone--Pedrenales dolomite. The Pedrenales is a facies change of the San Saba not found in the thesis area.

The Wilberns formation has a thickness generally ranging from 540 feet to 610 feet, except in the southeast corner of the Llano region where it is only 300 feet thick. The general average thickness is 580 feet. The formation is at least this thick in the thesis area, and its maximum thickness is not known because most of the Welge member has been removed by faulting. 590 feet of the Wilberns were measured in the West Mason area by Polk (1952), and 635 feet in the South Mason area by Alexander (1952).

Welge Sandstone Member

Definition and thickness

The Welge sandstone member was named by Barnes (1944) from the exposures in the Welge land surveys in Gillespie County.

At the type locality along Squaw Creek near the Mason-Gillespie County line it is 27 feet thick. The thickness range throughout the Llano region is 9 to 35 feet, and the average is 18 feet. The base of the Welge is not exposed in the thesis area. The thickness could not be measured in the thesis area because the base of the member is not exposed. Polk (1952) measured a section about 25 feet thick in the West Mason area.

Lithology

The lower contact of the Welge with the Lion Mountain was not found in the thesis area. According to all other descriptions this boundary is a disconformity.

The Welge is a yellowish-brown to brown, somewhat friable, medium- to coarse-grained sandstone. The grains usually have a higher degree of sphericity and roundness than those of the Hickory. Many of these quartz grains have secondary recomposed faces which cause the rock to sparkle in the sunlight.

The lower portion contains cross-bedding in some argillaceous sandstone beds, while the remainder of the strata are generally thick-bedded to massive. The upper limit of the Welge is gradational with the Morgan Creek and is mapped at the bottom of the lowest purple limestone bed of the Morgan Creek.

Topography and vegetation

The Welge usually forms a gentle scarp at the upper edge of the Lion Mountain bench, but this feature does not occur in the thesis area.

The Welge vegetation resembles the Hickory growth in density, but not in variety. The outcrop on the aerial photograph is shown by a narrow, dark band. The predominant types, mesquite, tasajillo, and whitebrush, are found with lesser amounts of shin oak, Mexican persimmon, and prickly pear.

Morgan Creek Limestone Member

Definition and thickness

The Morgan Creek limestone member was named by Bridge (1937) for the type locality at the junction of the north and south forks of Morgan Creek in Burnet County. Paige (1912) included this member in the lower portion of his now obsolete Wilberns formation.

The member at the type locality is 110 feet thick according to Bridge, Barnes, and Cloud (1947). The thickness in the thesis area is about 150 feet.

Lithology

The lower contact of the Morgan Creek is gradational and is mapped at the lowest reddish-purple limestone bed. The entire member consists of arenaceous, glauconitic, hard, limestone ledges alternating with thinner glauconitic, soft, nodular, calcareous claystones. The latter weather easily and are seen only in fresh exposures. The lower limestone beds are highly arenaceous and weather to a characteristic reddish-purple color. These grade upward into gray and greenish-gray, less sandy limestone. All of the limestones contain well-rounded quartz and glauconite grains which are enclosed in cleavable white calcite.

Although not seen in the thesis area, the brachiopod, Eoorthis texana, is generally found in a zone about 60 feet above the base of the member. Small stromatolitic bioherms (Figs. 17,18) form a biostrome four feet thick six feet below the top of the member. At the top, thin shale beds alternate with the limestone ledges. The Morgan Creek-Point Peak contact is transitional and is mapped at the change to gentler slopes and sparser vegetation.

Topography and vegetation

The topographic expression of the Morgan Creek is generally a steep slope between the Welge sandstone and the Point Peak shale members.

The Morgan Creek vegetation is not as abundant as the Welge, but it is still plentiful and evenly distributed. Shin oak and Spanish dagger are most abundant and are accompanied by tasajillo, prickly pear, and agarita. The abundant Spanish dagger is conspicuous because of its relative absence in the underlying and overlying members.

Point Peak Shale Member

Definition and thickness

The Point Peak shale member was named by Bridge (1937) for exposures on Point Peak, an isolated hill about four miles northeast of Lone Grove, Llano County.

The thickness at the type locality is 270 feet. Due to variations in sedimentation and to facies changes, the Point Peak may be as thin as 25 feet. The member in the thesis area has a thickness of about 145 feet, 108 feet of which is shale.

Lithology

The Point Peak member was mapped as two separate zones, a lower zone consisting primarily of fine clastics, and an

Fig. 17

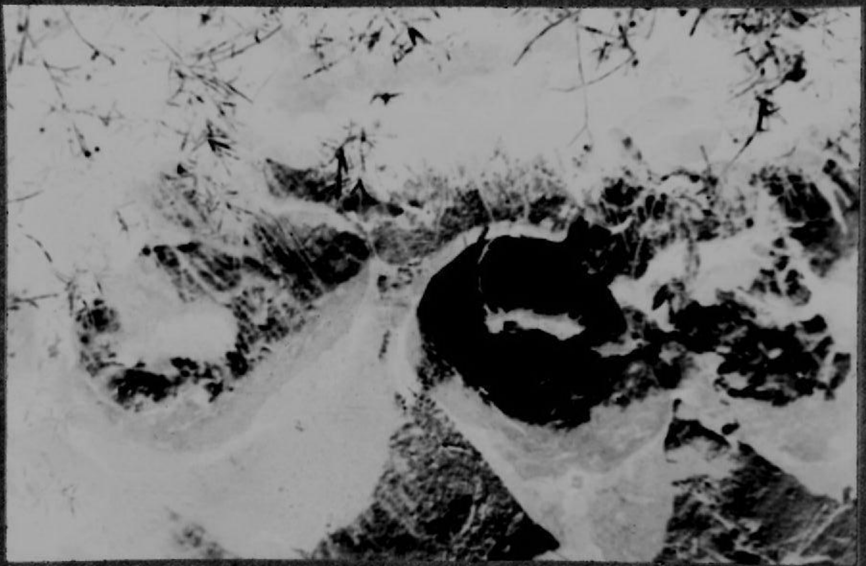


Fig. 18

Morgan Creek bioherms in Honey Creek.

upper biostrome zone. The lower contact of the Point Peak is transitional, but it is easily recognized because the lithologic change from Morgan Creek limestone to Point Peak shale is sharp and causes topographic and vegetational breaks. The boundary between the two zones is the base of the lowest bioherms. This contact varies vertically as much as three feet because of the irregular compaction of the uppermost fine clastic beds by the overlying bioherms. This contact is also very uneven because the bioherms do not all coalesce smoothly, thereby forming a very irregular lower surface. In other areas in the Llano region, the bioherms are not so well developed as in the thesis area, and the upper contact with the San Saba is chosen at the highest significant shale.

The lower zone is 108 feet thick and is composed of grayish-green to yellowish-green, thin-bedded, soft to moderately indurated, calcareous shales (Fig. 19). Occasionally interbedded with the shales are thin, discontinuous layers of brownish-gray, fine- to medium-grained, fossiliferous limestone, and thin to one foot beds of intraformational conglomerate which consist of many flat, fine-grained, yellowish-green limestone pebbles embedded in a matrix of brown to green, medium-grained limestone. The lower limestone beds seem to be a diminishing continuation of Morgan Creek type beds into the Point Peak.

The clastic beds in the Point Peak have almost always been called shale with the concession that much silt is present. Although no mechanical analyses were made, the writer is certain that most or all of the Point Peak clastics in the thesis area are composed of silt. The test used in the field for distinguishing between shale and silt particles was to lightly chew the grains. Shale particles feel smooth between the teeth, while the silt particles are gritty. This criteria was used at about one foot intervals in the 108 feet of beds, and in no place was an abundance of shaley material found. There was also no good fissility seen, but its absence may be due to deep weathering. The abundance of silt grains and the apparent lack of fissility would seem to classify this lower zone of the member as a siltstone rather than a shale. However, the definition of a shale is flexible enough to allow this lower zone to be called a shale. According to Twenhofel (1950), "If....siltstones have cleavage parallel to the bedding, the term shale should be applied". Pettijohn (1948) says that "Shale is a laminated or fissile claystone or siltstone".

The upper zone is represented by at least 25 feet of very well developed bioherms which are interbedded with a few limestone and siltstone layers. Because this zone consists primarily of coalescing bioherms which have a definite

Fig. 19--Lower Point Peak shale. This exposure is the lower part of the measured section in the southwest corner of the area.

Fig. 20--Point Peak biostrome along Honey Creek.

stratigraphic position in the thesis area, it will be referred to as a biostrome (Fig. 20). The stromatolitic limestone of the bioherms is microgranular to sublithographic and light brownish-green, olive-gray, or gray. The structure of the bioherms has a subcircular pattern which has been called "cabbage head" structure (Figs. 21,22). The interbioherm beds consist of granular, brownish- to greenish-gray, glauconitic limestones, and a few green, calcareous siltstones (Fig. 23). All of these beds are very irregular and discontinuous due to uneven deposition, compaction, and draping over the bioherms. The limestones strongly resemble the basal San Saba beds, and probably represent a gradation of the two members. Also closely associated with the bioherms are intermittent, massive beds of a bright brown, very hard, medium-grained, arenaceous limestone. The thickness varies from one foot to five feet, with three feet being the average. The discontinuity of these beds was first atrributed to numerous small faults, but additional investigation proved that they are not regular strata. At one location the brown limestones may be seen under, around, and above the bioherms. This irregularity prevents using these prominent beds as mapping horizons.

Topography and vegetation

The lower siltstone zone weathers very easily and is generally represented by a low topographic bench immediately above

Fig. 21--Point Peak bioherms along Honey Creek.

Fig. 22--"Cabbage head" structure of Point Peak bioherm.

Fig. 23--Point Peak bioherms with interbedded limestone beds along Honey Creek. Note rapid facies change from bioherms to limestone beds.

Fig. 24--Point Peak biostrome-San Saba contact along Honey Creek.

the Morgan Creek. The upper zone is very resistant and in the thesis area forms the edge of the major fault-line scarp. The dip slope of the biostrome is almost completely devoid of soil. The lower Point Peak vegetation consists of characteristic mesquite trees accompanied by a considerable growth of live oak, eedar, prickly pear, red oak, Spanish dagger, and agarita. The biostrome supports abundant prickly pear and sparsely scattered shin oak, catsclaw, Spanish dagger, agarita, and Mexican persimmon.

San Saba Limestone Member

Definition and thickness

The name Sam Saba was first used by Comstock (1890) as a series term for some of the limestone exposures along the San Saba River near Camp San Saba in McCollough County. Dake and Bridge (1932) said that these beds were younger than Paige's (1912) original Wilberns and suggested the use of Comstock's name, San Saba. Bridge (1937) revised the term, San Saba, to member status and further separated it from the Ellenburger group. Bridge, Barnes, and Cloud (1947) applied the name to the series of glauconitic limestones overlying the Point Peak member and underlying the Tanyard formation of the Ellenburger group.

At the type locality on the Mason-Brady highway near the San Saba River bridge, the member is 280 feet thick.

The member is about 270 feet thick in the thesis area. Polk (1952) measured 151 feet and acknowledged the large fault in the exposure on Honey Creek. Careful observation shows many minor northeast trending faults traversing the section. These breaks are too numerous and too small to be mapped, but they almost certainly cause an error in any measurements.

Lithology

The lower contact of the San Saba was mapped at the top of the uppermost biostrome in the Point Peak (Fig. 24). This contact may be very uneven due to the draping of basal San Saba limestone beds over the irregular biostrome surface.

The limestones are thin- to thick-bedded and fine- to coarse-grained, with some becoming sublithographic in the upper beds. Some of the lower limestones appear thin-bedded because of differential weathering. The predominant colors are gray to greenish-gray, and yellowish-brown to brown. Glauconite and silt are present in varying amounts. Most of the beds are fossiliferous and contain gastropods, trilobites, and brachiopods.

In the thesis area the San Saba contains an abnormally large amount of sand and silt. The silt usually contaminates the limestones while the sand is found in calcareous sandstones and arenaceous limestones which, according to

Cloud and Barnes (1948), occur in four zones in the Bear Spring area immediately south of the thesis area. In the Bear Spring area the upper seven foot sand zone is persistent and maintains a position 28 to 35 feet below the Cambrian-Ordovician boundary. Cloud and Banres (1948) say that this zone has been noted and used as an aid in determining the upper limit of the Cambrian, but not mapped.

The upper part of the San Saba is composed of very distinctive, small, thin-bedded, brownish-yellow limestones with veins of crystalline calcite. They are sublithographic, sparingly fossiliferous and contain small amounts of glauconite. The upper contact is chosen with the help of faunal evidence and the presence of glauconite which is absent in the Ellenburger. An indefinable vegetational and topographic difference may be seen between the San Saba and the Ellenburger outcrop areas on the aerial photographs. The "seven foot sand zone" mentioned above was not prominent enough in the thesis area to be used as a mapping aid.

Barnes and Bell (1954) have recently discovered some fossil evidence which indicates that Cambrian-Ordovician boundary may be higher in the section than the contact mapped for this thesis.

Topography and vegetation

The San Saba limestone member causes rolling hills which are similar to the Ellenburger topography. The outcrop surface is very rocky.

The vegetation is generally scattered, becoming more plentiful toward the base of the member. Shin oak and Mexican persimmon predominate, and agarita, prickly pear, tasajillo, and cedar are minor. On the aerial photographs, the San Saba vegetation appears very similar to the Ellenburger growth.

ORDOVICIAN SYSTEM

Ellenburger Group

General Statement

Paige (1912) named the Ellenburger limestone from the Ellenburger Hills in southeastern San Saba County. Cloud, Barnes, and Bridge (1945) revised the term by removing the Cambrian San Saba and restricting the term to beds of lower and middle Ordovician age. They also divided the group into three formations, from oldest to youngest: 1) Tanyard, 2) Gorman, 3) Honeycut.

Where the group is complete, the thickness ranges from about 1500 feet to 1800 feet. According to Cloud and Barnes (1948), the Ellenburger is only 973 feet thick in the Bear Spring area because the Honeycut formation has been removed by erosion.

No attempt was made to recognize or separate the formations for this thesis and only a brief description of the beds is offered.

Lithology

The Cambrian-Ordovician contact was the most difficult boundary to map in the thesis area. The contact was chosen between the highest glauconite in the San Saba and the first appearance of the uncoiled gastropod Lytospira gyrocera in the Ellenburger.

The various limestones of the Ellenburger in the thesis area may be best described as white to gray, thin- to thick-bedded, sublithographic, and very hard. The weathered surfaces are rough and solution pitted. Also found was a microgranular, purplish-gray, dolomitic limestone that had sphenoidal weathering. Some of the limestones weathered to large blocks that covered the surface, while other limestones decomposed completely, leaving only scattered chert pebbles.

Topography and vegetation

A rolling, hilly terrain is characteristic of the Ellenburger in the thesis and other areas. The surface is very rocky and the only farmed land on the outcrop is in alluvium.

The Ellenburger has a characteristic irregular sparse vegetation pattern which consists mostly of shin oak with smaller amounts of Spanish dagger, tasajillo, prickly pear, agarita, Mexican persimmon, live oak, catsclaw, and cedar brush. There is a noticeable lack of mesquite.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Llano region is an eroded structural dome which exposes the pre-Cambrian basement complex. The uplift area is elliptically shaped with a westnorthwest-trending axis and is approximately 40 miles wide and 70 miles long. Total structural doming is about 6,000 feet. The uplifting has caused the Paleozoic beds to dip away gently from the center. The Mesozoic beds (Cretaceous) are flat-lying and originally completely covered the area, but they have since been removed by erosion, leaving an erosional inlier which exposes the pre-Mesozoic rocks.

The Paleozoic faulting happened near the close of Strawn and before Canyon time (Cloud and Barnes, 1948), and generally has a northeast trend with one major exception in the east central part of the Llano region. Most of the faults dip from 60 to 90 degrees and have displacements ranging from a few feet to 3,000 feet.

Tight folding of Paleozoic rocks is almost nonexistent, and the only large folds are several probable broad warps scattered throughout the region. Local folds are due to drag along faults, slumping into limestone sinks, and compaction around hard units such as bioherms. The only Paleozoic folds in the thesis area are some very minor folds due to drag along faults and to differential compaction above and below the bioherms (Fig. 25).

PRE-CAMBRIAN DEFORMATION

General Statement

According to Stenzel (1934) and King, et al. (1944), the regional structure of the pre-Cambrian rocks in the Llano uplift consists of several large broad open folds which have a northwest-southeast trend and a pitch of 16 degrees southeast. These metamorphic rocks within the broad folds are locally intricately compressed into smaller isoclinal and zigzag folds. Stenzel (1934) says that the "grain" of the schist and gneiss is strictly parallel to the axes of the regional folds.

Local Structure

The local structure in the thesis area consists of a series of tight folds involving the marble and other metamorphic rocks (Plate II). Throughout most of the area the strike of the beds remains fairly constant, ranging from N 75 E to N 75 W with the average strike being about N 85 W. The dip ranges from vertical to 50 degrees south. However, at the eastern ends of the two marble "tongues", and locally within the main marble mass, the strike turns through 180 degrees, indicating the presence of plunging folds. The consistent strike and dip in most of the area shows that the folds are isoclinal or nearly so (Fig. 26) and slightly overturned toward the north.

No attempt has been made to trace all of the individual folds in the large marble mass. There is not enough lithologic variation in the types of marble to outline them by using stratigraphic successions and repetitions. Probably the only way to map the structure would be to trace the individual folded beds. The best structural expressions are seen north of the large marble mass where the two "tongues" of marble alternate with the gneiss unit due to an interfolding of the two units.

The axes of these "tongues" probably give the best measurement of the trend of the metamorphic rocks in the thesis area. Except at the noses of the "tongues", the strikes of the individual beds closely follow the trend of "tongues", and the dips are vertical or steeply to the south. The problem is whether these "tongues" are remnants of the bottoms of marble synclines, or the tops of marble anticlines lying below the gneiss unit. An answer may come from the plunge of the eastern noses of the "tongues". At the northernmost nose the beds dip 85 degrees southeast, and in the northeastern corner of the large marble mass they dip 70 degrees southeast, indicating folds plunging in this di-

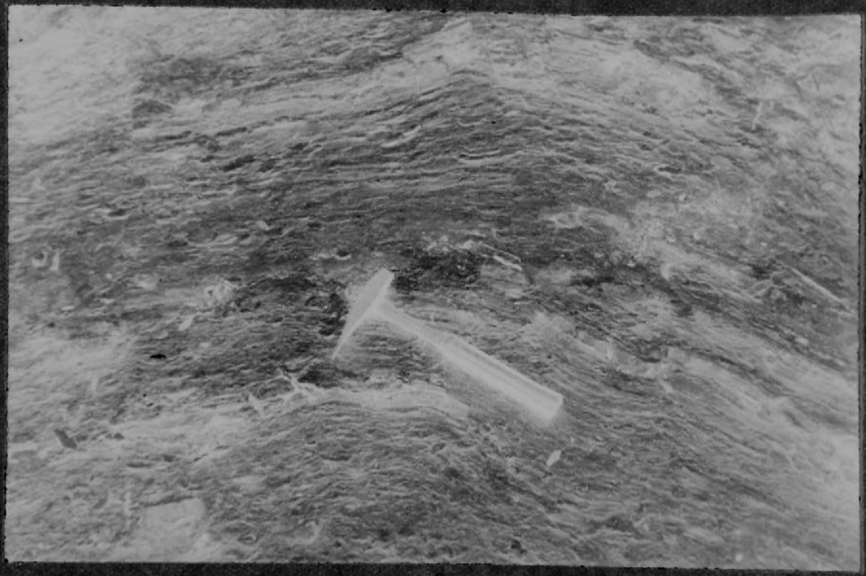


Fig. 25--Folding in lower Point Peak shale due to irregular overlying bioherms.

Fig. 26--Isoclinal folding in pre-Cambrian marble by G. Loeffler's ranch house.

rection. Also in this same northeast corner are prominent drag folds (Figs. 27,28) whose orientation indicates that the northeastern edge of the main marble mass is the northern flank of an anticline which plunges 76 degrees east. A similar plunge of 70 degrees southeast is shown by the "grain" (crenulations) of the phyllite on the Old Junction Road between the ends of the two marble "tongues". The axial plunges of 85, 76, and 70 degrees are exceptionally steep, but the dips are outward toward the east, which proves that the marble "tongues" are now lying in the form of anticlines. Some slight additional evidence for calling them anticlines is found where a fault cuts the northern "tongue". The downdropped side, exposes a narrower area of marble than the upthrown side as would be expected after erosion if the marble is presently in an anticline.

Although the "tongues" are now in the forms of anticlines, they may have originally been folded as synclines. All of the above evidence will also apply to synclines which originally plunged to the west and later were inverted so much that their axes now plunge eastward. The folds have been abnormally tilted to a plunge of about 80 degrees (if they are anticlines), and the forces which caused this tilting could easily have acted in the opposite direction for approximately 110 degrees to cause inverted synclines. The "tongues" will be called anticlines, making the marble the

Fig. 27

Fig. 28

Drag folds at northeast edge of main marble mass.

oldest metasedimentary formation, but it must be remembered that the folds may originally have been synclines, and therefore the stratigraphic succession could be the reverse of that described.

Possible Regional Relations

The metamorphic rocks in the thesis area are generally not recognized on regional maps, so it is difficult to see how they fit into the regional structure.

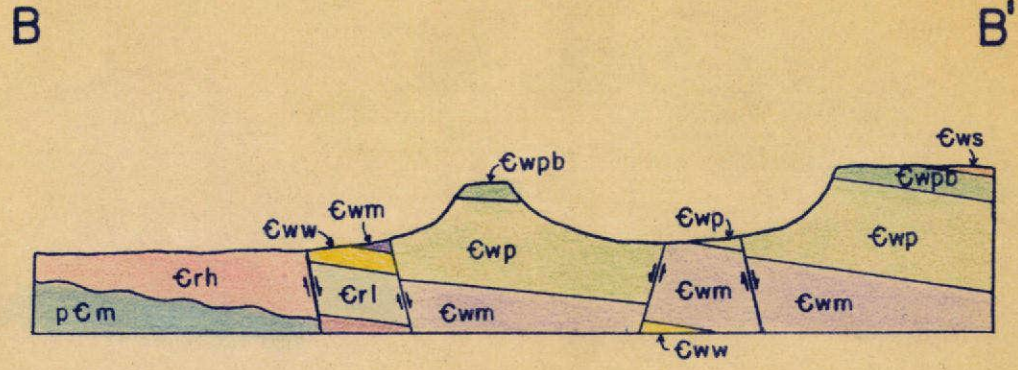
That the thesis metamorphic rocks may have counterparts elsewhere in the exposed Llano series is suggested by lithoaligically similar outcrops near Llano, 33 miles east of Mason. Marble beds and a graphitic slate or schist at that locality (Paige, 1912) might be correlated with the dark phyllite and marble in the thesis area. Paige (1912) says that at Llano the graphitic schist is interbedded with marble, which is not the case in the thesis area. The rocks at Llano have not been studied by the writer.

It is equally possible that the metamorphic rocks in the thesis area are exposed nowhere else in the Llano region, and that they are much lower in the pre-Cambrian sequence than the rocks at Llano. According to Paige (1912) and King (1944), the metamorphic rocks between Llano and the thesis area lie in two broad synclines plunging east of south. The western flank of the westernmost syncline appears on King's (1944) map as broader, and therefore presumably thicker, than any other continuous pre-Cambrian sequence in the Llano region. The rocks of the thesis area, which lie at the extreme western edge of this flank, may therefore be the oldest of the pre-Cambrian rocks in the region. It is not known to what extent these hypothetical relations may be affected by the faults and igneous intrusions occurring east of the thesis area.

FAULTING

The faulting in the thesis area consists of a very complex system of normal faults (Plate III). The major fault zone, which is generally marked by a prominent fault-line scarp, trends about N 70 E and is downthrown to the northwest. The major displacement occurs along an irregular series of major faults that are accompanied by a series of smaller breaks which are found predominantly in the limestones on the downthrown block. However, similar fractures could be just as abundant in the upthrown Hickory and metamorphic rocks, only harder to find. The minimum displacement observed along these major faults is about 550 feet, being between the basal Cap Mountain and the lower Point Peak. The maximum displacement is at least 1200 feet.

To add to the complexity of the fracturing two or more



GENERALIZED CROSS SECTION ALONG B-B'

This section shows typical major and minor faults, the graben referred to, and general topography.

PLATE III

smaller fault systems have been developed at various angles to the major faults. For simplicity these minor systems have been divided into northeast and northwest trending groups. These groups appear to be secondary because 1) their faults seldom have major displacements, 2) they do not extend over great distances, and 3) the trend of many of the faults is relatively inconsistent.

Where the major zone crosses Honey Creek, a minor northeast group is represented by a peculiar cluster of faults which are conspicuous in their curving parallelism, amount of displacement, and an off-trend of N 10°E. Many of the faults in the thesis area are curved somewhat, but all of the faults in this cluster have a well developed curvature which is concave to the northwest. This concavity may provide some clues about the mechanics of tectonism. The displacements in the cluster are minor, ranging from a few feet to less than 50 feet. Just west of this group, the faults along which the major displacements occur are offset sharply to the northeast by a fault which may be affected by the small cluster along Honey Creek.

Some of the faults in the northwest trending groups strike about N 50 W, and the remainder have random trends. The displacements of these groups are comparable to those of the minor faults of the northeast trending group, ranging

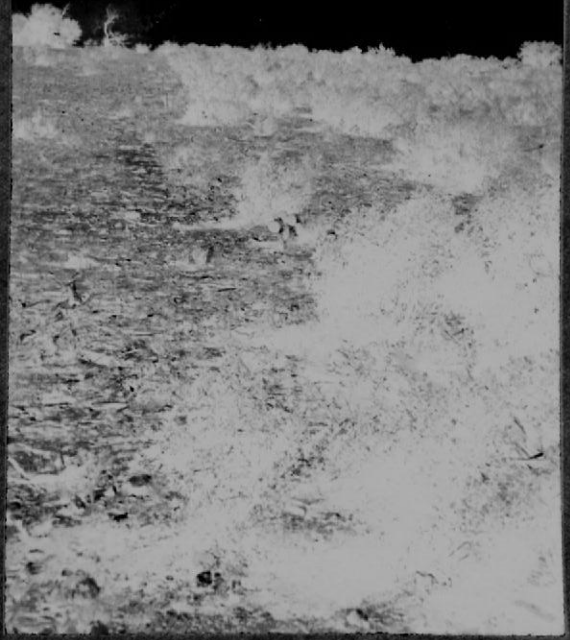


Fig. 29--Vegetation break along San Saba (barren)-Point Peak fault in southwest corner of area.

Fig. 30--Small fault within the upper Point Peak bioherms along Honey Creek.

from about 50 feet to joints which have no displacement.

An attempt was made to prove different relative ages for the northeast and northwest trending zones, but the random displacement of faults by each other strongly suggests simultaneous movement in both zones during most of the time of faulting. The evidence seems to indicate that the northwest trending faults are primarily "cross-faults" which affect the blocks caused by the major and some minor northeast faults and may or may not cut the northeast faults.

Because no stratigraphic study was made of the Ellenburger, it was practically impossible to determine the amount of throw on the faults in these beds. All breaks in the Ellenburger are mapped as probable because some are joints. The large joints in the limestone resemble faults on the aerial photographs because of solution enlargements and consequent soil and vegetation differences. These joints appear unique on the aerial photographs because two apparent faults seem to cross without displacement of either.

No definite age can be assigned to the faults solely from observation in the thesis area. However, in other parts of the Llano region, associated faults affect Strawn, but not Canyon beds. The faults in the thesis area almost certainly occurred at this time.

Fig. 31--Major fault between coarse-grained granite and Ellenburger (rocky).

Fig. 32--Fault breccia developed elsewhere along above fault.

CAUSE AND MECHANICS OF FAULTING

According to Cloud and Barnes (1948), the faulting in the Llano region accompanied the late Paleozoic folding of the sediments in the Ouachita geosyncline to the south and east. These compressional forces are supposed to have placed the region under torque and fractured it. They say that the theoretical breaks compare very well with the faults presently found in the Llano region.

According to Paige (1912) the faults in the Llano region were caused by compressional forces. Cloud and Barnes (1948) later showed that tension rather than compression caused the normal faulting. Cheney and Goss (1952) presented a debatable theory when they concluded that the grabens in the Llano region were formed at a different time than the horsts. In the thesis area, tensional forces are proven by the graben in the southwestern corner of the area (Plate III). This graben block was downdropped into a potential void set up by the tensional forces which caused the faulting.

The complex normal faulting in the thesis area suggests that some additional forces were complicating the fracturing in and around the thesis area. Assuming that Cloud and Barnes' (1948) "torque" theory is correct and that torque was the primary cause for the faulting, there still must have been some additional secondary forces which caused the intense faulting in and west of the thesis area.

The most likely source of additional forces is a probable local uplift which is manifested in the following ways: 1) the off-trend of a regional fault as it passes through the thesis area; 2) the anomalous dips found in and around the thesis area; and 3) the above-mentioned complex faulting. The relation of each of these manifestations to additional forces is discussed in the following paragraphs.

An inspection of the map in Plummer's (1943) report shows a regional fault which normally trends about N 20 E, but swings sharply to a trend of about N 70 E as it approaches and passes through the thesis area. This sudden eastward swerve of the major fault could have been caused by an offsetting action related to the minor faults caused by the local uplift. The major fault may have been offset or diverted by these minor faults when it tried to cut across them.

The thesis area is located on the west side of the Llano region. Therefore the beds which were tilted by the Paleozoic uplifting should dip toward the west, or perhaps, southwest. However, the predominant dip in the thesis area is to the southeast and south. A local uplifting to the north or northwest of these anomalous dips is strongly suggested. The exact locus of this local movement has not been determined, but its presence is further confirmed by the attitude of the beds to the north, northwest, and west of the thesis area. Most of these beds seem to dip away from the northwest corner of the thesis area.

An outstanding feature of the fault systems in the thesis area is the peculiar cluster of minor faults along Honey Creek. The consistent westward concavity of these faults suggests that they may be peripheral faults related to a small uplift to the west of the cluster. Some of the northwest-trending faults could be radial faults related to this same uplift. Grote (1954) has studied fault patterns in this vicinity and discovered a broad, northeast-trending anticline which is located just to the west of the thesis area. The forces which caused this large fold may also have caused or at least affected the faulting in the thesis area.

GEOLOGIC HISTORY

The metasedimentary rocks in the thesis area are derived from a great series of sediments which once covered the Llano region. At least the marble, and probably most of the other metamorphic rocks in the thesis area, were deposited by a warm sea. The different lithologic types above the marble (gneiss, phyllite, and quartzite) indicate a time of irregular clastic deposition following a long stable interval during which no clastics were deposited. That the "contact" between these two intervals of deposition may represent a time of non-deposition is suggested by the abrupt change in lithology at the marble-gneiss contact.

With continued deposition, the sedimentary rocks were deeply buried, complexly faulted and folded, and metamorphosed by heat and pressure. The granitic intrusions followed the metamorphism. The intrusive bodies were the Town Mountain batholith and the younger Oatman Creek stock.

During the interval which began after the last intruion and ended before the deposition of the upper Cambrian sandstone the area was above base level and being eroded to an irregular surface. The first Paleozoic sea then entered this area of high relief and reworked eolian sediments in its basal, coarse-grained, cross-bedded deposits.

Barnes and Parkinson (1939) have found ventifacts as high as four feet above the base of the Hickory and conclude that this indicates a continuation of ventifact formation after the deposition of the Hickory was well under way. However, the sea could have fluctuated and in doing so disturbed and rewashed its first thin layer of sediments and redeposited them at another locality on top of a primary layer of sediments containing ventifacts. Or the ventifacts could have been transported in from some positive area which had not yet been cleared of loose material. It seems much easier for the ventifacts to be formed during the very long hiatus rather than during the relatively short interval required to deposit four feet of sediments.

That the original sea was never very deep or distant from a sediment-contributing source area is shown by the subrounded grains and crossbedding in the Hickory. Relatively quiescent and perhaps deeper neritic waters gradually appeared as is shown by the gradation of the marine sandstones into the limestones of the Cap Mountain. The lateral gradation of the Hickory sandstone into Cap Mountain limestone proves that the top of the Hickory does not represent a definite time line. The impurity of the Cap Mountain shows that the depositional environment was never entirely devoid of clastics. A warm climate is indicated by the existance of phosphatic brachiopods and numerous trilobites. The sands for the Lion Mountain and Welge members were provided by the erosion of a new small uplift. That these two members are marine is proven by the glauconite and fossils. The small disconformity between these members is further proof for minor regional movement.

The end of Welge time is marked by a decrease in the supply of sediments and a gradual transgression of the limestone-depositing sea so that the alternating beds of Welge and Morgan Creek were formed. Abundant glauconite and marine fossils such as the stromatolitic bioherm and brachiopods again indicate warm, shallow, marine waters during Morgan Creek time.

The silt in the Point Peak was probably deposited by a quiet sea because of the fine grains and a lack of cross-bedding. The occasional limestone ledges and marine fossils also indicate marine deposition. However, the seas must have been shallow because most of these thinly interbedded limestones contain a considerable amount of intraformational conglomerates. Paige (1912) says that these "flat-pebble" conglomerates are suncracked fragments which were formed on widespread tidal flats that were alternately flooded and dried by the sun. There must have been extensive shoaling in warm shallow waters in the thesis area because of the very well developed biostromal deposits in the top of the Point Peak.

The San Saba limestone beds which lie directly on the bioherms show that the sea became deeper in San Saba time. The presence of an occasionally rising source area is strongly suggested by the beds of marine sandstones several feet thick found in the San Saba. The uppermost of these sandstones is found only a few feet below the upper contact with the Ellenburger. According to Cloud and Barnes (1948), both this sand and the Point Peak silt show the continued or intermittent presence of a land mass to the west.

The same shallow sea which deposited the San Saba continued its deposition into the Ordovician. The Cambrian and Ordovician rocks are unique in their continuity. The general absence of clastics in the Ellenburger suggests that the positive area at this time was not contributing sediments and that there was a minimum of tectonic movement.

According to Cloud and Barnes (1948), the truncation of the Ellenburger by erosion was at a maximum in the western part of the Llano region. They also say that the oldest Devonian beds are found in the eastern part and the youngest beds are found in the western part of the uplift. This sequence of erosion and uneven deposition suggests that the region was tilted to the east and truncated largely before Devonian time. Then came a slow east to west Devonian marine invasion with a continuing erosion of the western emergent areas.

The first uplifting of the pre-Cambrian core is seen in the Mississippian beds which thin over the Llano region. The fossiliferous, marine Mississippian and Pennsylvanian indicate the presence of a warm sea which contained an abundant fauna. Paige (1912) says that the Pennsylvanian black shale suggests a return to low, swamp-like conditions. Although no Permian, Triassic, and Jurassic beds are available for study, the uplifting of the pre-Cambrian core is believed to have ceased completely by the end of Pennsylvanian time. The Permian period is represented in the Llano region by a hiatus.

The Triassic and Jurassic periods comprise the remainder of the long erosional period which began in the Permian. This erosion bared all previous rocks in the Llano region, including a large expanse of pre-Cambrian. The erosional surface had as much as 800 feet of relief in the Llano region. The Cretaceous seas then transgressed and deposited a series of limestones and clays with basal sands on the uneven surface. Since this deposition there has been erosion of the Cretaceous which again exposed the Paleozoic and pre-Cambrian rocks.

The only occurrence of Cenozoic rocks in the Llano region is as stream and river deposits.

ECONOMIC GEOLOGY

Perhaps the most important natural resource in the thesis area is ground water. The most prolific aquifer is the Hickory sandstone. The artesian well in the southwest corner of the thesis area and other artesian wells farther south also produce from this member. Most of the other water wells in the thesis area produce from the marble and the coarse-grained granite.

Building stones could be the second most important natural resource of the thesis area, but they have not been fully exploited because of the long distance to the nearest railroad. Barnes, Dawson, and Parkinson (1942) presented excellent descriptions of the fine-grained granite and marble and made recommendations for their use as building stones. They said that the granite is a sound stone composed of interlocking grains and is undoubtedly very strong and durable. Their recommendations for the marble were that the marble was of a somber color, but good quality and could be used as a building stone.

The schist, phyllite, and granite wash have been mined and used as road metal in and around the thesis area.

Plummer (1943) reported the occurrence of a middle Wilberns glass sand in northwestern Mason County, but the horizon was not found in the thesis area.

Topaz is found in stream beds in and leading from the fine-grained granite stock. The gem is probably formed in pegmatite veins in the granite and then occurs as placer deposits because of its specific gravity and resistance to weathering.

Comstock (1889, 1890) reports a possible ore locality at "Caylor's Diggings" on the divide between Honey and Little Bluff Creeks and south of the Junction City Road. The minerals mentioned are "segregated limonite and hematite in limestone", dolomitic marbles, calcite, quartz, traces of silver and some possible galena. Several excavations have been dug, mostly along intrusive contacts, but since no suitable ore has ever been found, extensive mining operations have never been developed.

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APPENDIX

Section of lower Point Peak on G. Loeffler ranch (5 miles west of Mason, Texas) where Bluff Creek turns westward at major fault-line scarp.

Thickness in feet

Wilberns formation

Lower Point Peak shale member

12. Bioherm, olive gray, weathers to dark gray, massive, but weathering along horizontal lines causes appearance of 1 foot beds, very hard, microgranular to sublithographic, "cabbage head" structure on top surface. This unit is usually not included in the lower Point Peak 9.5

11. Covered slope. This unit is probably very similar to unit 9. A few scattered exposures show thinly bedded calcareous siltstone with an occasional thin (½ inch) lens or stringer of silty limestone. A 5 inch bed of greenish-gray to brown, glauconitic, fossiliferous, hard limestone. The bioherms cause compaction of the upper beds so that the top of this unit varies vertically as much as 3 feet 29.5

10. Intraformational conglomerate, grayish-purple and grayish-green with brown limonite stains, weathers tan and dark gray, ½ inch to 8 inch beds, contains many small (1 inch) beds of calcareous silt, glauconitic, pebbles are nodular and flat and range from ½ inch to 2 inches in diameter, pebbles are darker green and slightly more resistant than matrix, causing some to stand out on the weathered surface and giving the beds a very irregular appearance. Beds do not weather everywhere alike; what appears to be 1 foot of massive beds at one place will grade into a series of smaller resistant and soft layers. This unit forms a ledge or steeper slope between the soft unit below and the covered slope above 13.3

9. Siltstone, grayish-green, brownish-purple, and tan, beds ½ inch to 3 inches thick, unindurated on weathered surface, contains occasional small, fossiliferous, limestone lenses, all beds calcareous. Two 4 inch beds of intraformational conglomerate are 9.5 feet and 35.3 feet above the base of the

unit. About the upper 15 feet of the unit becomes highly calcareous and slightly better indurated. The upper 8 feet contains 1 and 2 inch beds of very glauconitic siltstone 36.5

8. Siltstone, yellowish-tan, weathers tan and dark gray, bedding varies from ¼ inch to 4 inches, 2 inch and thicker beds are well indurated and form ledges, occasional lenses of purplish-gray limestone and intraformational conglomerate, lower 1 foot has purplish tint, glauconite not prominent, calcareous 10.2

7. Limestone, purplish-gray and tan, weathers to dark brownish-gray, silty, contains many ½ inch greenish-gray siltstone lenses, 10 inch calcareous siltstone parting near middle of unit, hard, except for parting unit appears to be massive, finely glauconitic . . 4.9

6. Siltstone, same as unit 2, limonite stains and glauconite not prominent, beds ¼ inch to 2 inches thick. Beds are wavy because of compaction over the small limestone lenses. . 3.1

5. Limestone, purplish-gray with brown limonite stains, composed mostly of 1 inch and 2 inch beds of nodular intraformational conglomerate

which weathers to a very uneven surface, hard, very glauconitic 1.5

4. Same as unit 2, limestone found in small lenses 1.7

3. Limestone, purplish-gray to greenish-gray beds of nodular intraformational conglomerate and silty, fossiliferous limestone, limestone beds are 1 inch thick, intraformational conglomerate beds are 2 inches thick, glauconitic, pebbles are irregular, vari-colored nodules with 3/4 inch diameter, contains lenses of calcareous siltstone, some beds of intraformational conglomerate weather more readily than others 2.3

2. Siltstone and limestone, alternating thin beds of purplish-gray, silty, hard, fine-grained, limestone and calcareous greenish-gray siltstone, limonite stained, limestone layers weather to a pink buff color, beds about 3/4 inch thick, finely glauconitic, weathers easily. This unit contains the lowest siltstone exposed and is probably the base of the Point Peak member 1.7

1. Limestone, grayish-purple with brown limonite stains, undulating beds ¼ inch to 2 inches thick, medium-grained, fossiliferous, very glauconitic, contains small lenses of calcareous siltstone and intraformational conglamerate with 1 inch pebbles	0.8
Total thickness measured	117.0