GEOLOGY OF THE GROSSVILLE SCHOOL AREA,

MASON COUNTY, TEXAS

A Thesis

By

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The farm and ranch owners of the thesis area are due a special note of appreciation for the generosity shown by them in allowing free access to their land, and for their assistance in locating significant geologic features which otherwise might have gone unnoticed in almost inaccessible areas. Gracious hospitality was also shown by the residents of Mason, and their friendship was deeply appreciated.

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GEOLOGY OF THE GROSSVILLE SCHOOL AREA, MASON COUNTY, TEXAS

A B S T R A C T

The Grossville School area is located in south-central Mason County, Texas, on the southwestern flank of the Llano Uplift, a large topographic basin. The area is approximately 2.5 miles south of the town of Mason. Drainage in the area is accomplished by tributaries of the Llano River.

Rock units of Precambrian and Late Cambrian age are exposed in the thesis area. The Precambrian rocks are divided into metamorphic and igneous rocks: the metamorphic rocks have two units, the gneiss and the schist; and the igneous rocks have two units, the medium-grained granite and the fine-grained granite, which are the result of textural gradation within an igneous mass.

The Upper Cambrian rocks are divided into the Riley and Wilberns formations. The Riley formation is divided into three members: the Hickory sandstone, the Cap Mountain limestone, and the Lion Mountain sandstone. The Hickory sandstone is chiefly reddish-brown, non-glauconitic, and coarse-grained. The dark red sandstones in the upper part of the member grade upward into the brown, calcareous sands and arenaceous limestones of the lower portion of the Cap Mountain member. The upper part of the Cap Mountain member consists of grayish-brown, slightly glauconitic and fossiliferous limestone beds. These beds are in turn overlain by the highly glauconitic Lion Mountain sandstone member, which contains characteristic "trilobite hash" lenses and has hematite nodules dotting the landscape of its upper reaches.

The Wilberns formation consists of the following members: the Welge sandstone, the Morgan Creek limestone, the Point Peak shale, and the San Saba limestone. The yellowish-brown, essentially non-glauconitic beds of the Welge sandstone overlie the upper beds of the Lion Mountain member. The Welge sandstone beds are composed principally of quartz grains which glitter in the sunlight. These beds grade upward into the purple, arenaceous beds of the lower part of the Morgan Creek limestone, which in turn grade upward into greenish-gray, coarse-grained, very glauconitic and fossiliferous limestone beds of the upper part of the member. A thin zone of small, purple to gray bioherms is encountered in the upper portion of the Morgan Creek member. The Morgan Creek limestone beds are overlain by interbedded green to gray, calcareous shales, limestones, and conglomerates of the Point Peak shale member. This member contains a zone of large stromatolitic bioherms in its upper portion. Fine-grained, thin-bedded, glauconitic limestone beds of the San Saba member also occur in the bioherm zone. This zone is overlain by grayish-brown, arenaceous limestone beds of the San Saba member.

The strikes observed on the foliation planes of the Precambrian metamorphic rocks were generally in a west-northwest direction. Small isoclinal folds are evident in the schist unit in several places. Possible larger-scale Precambrian folding was indicated by the variations in dip of the Precambrian metamorphic rocks. The Paleozoic strata generally have a northeast-southwest strike with a moderate southeastward dip. They have been intensely faulted by a northeast-southwest - trending major fault system, along with various other smaller faults. The two major faults bound a graben in the southern part of the thesis area, in which a probable synclinal fold in the hilly south-central portion is located. Smaller folds due to fault drag and differential compaction around bioherms are also found in various parts of the area.

The geologic history of the general area indicates a transgression of Paleozoic seas over an eroded Precambrian surface of high relief, and the deposition of strata of Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, and Cretaceous age, most of which have been removed by erosion. The Paleozoic deformation observed in the thesis area probably took place during post-Bend and pre-Canyon (Middle Pennsylvanian) time.

The most important natural resource of the area is ground water, and the Hickory sandstone is the most important aquifer. Farming and ranching are the main sources of revenue. Rocks in the area have been used locally for building stone and road metal. There is very little possibility of future oil and gas production in the area.

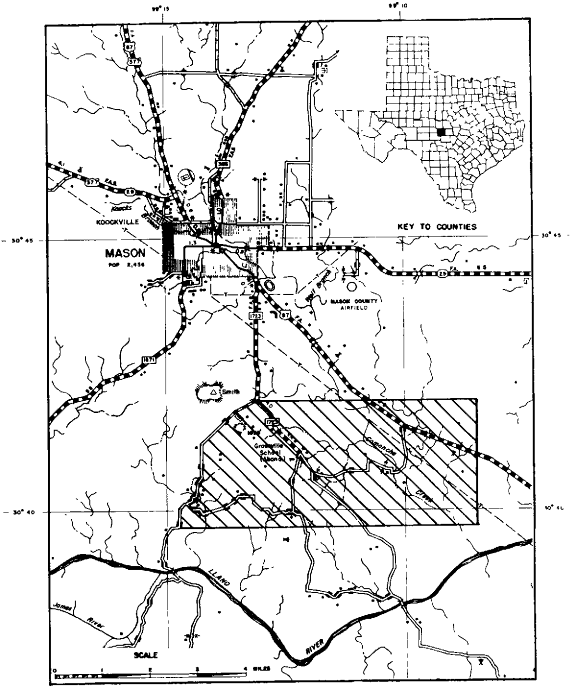
INTRODUCTION

LOCATION AND ACCESSIBILITY

The Grossville School area lies southeast of the city of Mason, in the south-central part of Mason County, Texas. It is on the western flank of the Llano Uplift. It includes about 17 square miles and approximates the shape of a rectangle, with the northwest corner at the intersection of Farm Road 1723 and the James River road, the southwest corner at the right angle bend in the James River road approximately one mile north of the Llano River, the northeast corner at the intersection of a line drawn east from the northwest corner and a line drawn north from the junction of Comanche Creek with the Llano River, and the southeast corner at the intersection of a line drawn east from the southwest corner and a line drawn south from the northeast corner. The western boundary follows the James River road, while the other boundaries are arbitrary lines connecting the above mentioned corners. The abandoned Grossville School, from which the area is named, is located in the west-central portion. The northwest corner of the area is approximately 2.5 miles south of the Mason City Limit.

Accessibility of the thesis area is fairly good. U. S. Highway 87 cuts across the northeast portion, and Farm Road 1723 extends from the northwest corner diagonally across the area toward the southeast. The James River road marks the western boundary. Cross-roads between these main roads provide easy access to all parts of the area except the southeast corner. Private ranch roads, rough but passable, provide access to this corner, thus making all parts of the area fairly easily reached.

Figure 1



Reproduced from Highway Map of Mason County, Texas, prepared by Texas State Highway Department, 1956

LOCATION MAP OF GROSSVILLE SCHOOL AREA
MASON COUNTY, TEXAS

PROCEDURE OF FIELD AND OFFICE WORK

The field work on this thesis project was carried out at various times between June 6 and September 7, 1956. The original mapping in the field was done on acetate covering individual U. S. Department of Agriculture aerial photographs dated November 2, 1948. Their approximate scale is one inch equals 1667 feet. The essential photographs used in coverage of the area were 95, 96, and 97 of series DFZ-2E; 20, 21, 22, 51, 52, 53, 91, 92, and 93 of series DFZ-3E; and 182 of series DFZ-5E. The ground shown on photographs DFZ-3E-21 and DFZ-3E-52 lay entirely within the thesis area, while that shown on the others lay only partly within it. The original mapping was then transferred to an acetate base map covering the whole area and later to the finished map.

A pocket stereoscope was used in conjunction with the aerial photographs to aid in the initial location of many geologic features, which were later confirmed by actual observation and study in the field. Most of the faults and formation contacts were walked out in the field before being placed on the map. A few faults and contacts were plotted mainly on the basis of stereoscopic examination of the aerial photographs. Most of the strikes and dips plotted on the geologic map represent an average of several readings made with a Brunton compass in the immediate vicinity of each point.

The examination of thin-sections prepared from Precambrian rock samples obtained in the field was carried out between February 11 and March 28, 1957.

The measured and described section in the Appendix represents an exposure of unfaulted sedimentary rocks in the hilly south-central portion of the thesis area.

The horizontal distances used for the structural cross sections were scaled from the aerial photographs, and the relative elevations were determined from a stereoscopic examination of the photographs, supplemented by observations made in the field.

REVIEW OF THE LITERATURE

Ferdinand Roemer (1846) was the first to study the intricate geology of the Llano region and to publish his observations. In the years 1845, 1846, and 1847, Roemer traveled with a group of German colonial explorers north from Fredericksburg to the Mason, Menard, and Walnut Springs areas. The trip afforded Roemer an opportunity to study the formations of the area and their fossil content. He later published his account of the trip, together with descriptions of the rocks and fossils. Roemer was the first to recognize and cite the older Paleozoic, Carboniferous, and Cretaceous rocks in the Llano region.

In 1855 and 1856, an expedition of Army engineers traveled through the Llano region while exploring in central and western Texas and in New Mexico. Dr. G. G. Shumard (1886), accompanying the expedition, studied the geology of parts of the San Saba River Valley and the vicinity of Fort Mason, and later published a brief description of his findings.

On the basis of their fossil content, B. F. Shumard (1861) correlated the rocks of the Llano region with those of the Potsdam group (Upper Cambrian) of the New York sequence. The rocks studied were in Burnet, San Saba, Llano, McCulloch, Mason, and Lampasas counties.

An Azoic classification was given to the granites of the Llano region by S. B. Buckley (1874), then State Geologist, in his brief resumé of the geology and mineral resources of the area.

Walcott (1884) confirmed the Late Cambrian age of Shumard's previously described Potsdam group in the Llano area, and also studied the metamorphic rocks and granite masses. He gave the name Llano group to the metamorphic rocks, assigned an Early Cambrian age to them, and gave a pre-Potsdam age to the granite masses.

The Llano region was mentioned briefly by Hill (1887) in his review of the geology of Texas. Later, Hill (1889) assigned a Carboniferous age to rocks exposed at Marble Falls. Erosion processes affecting these and other Carboniferous rocks exposed in the Llano region were also discussed by Hill (1890) in his publication on the major geographic features of Texas.

A report discussing the geology and mineral resources of the region was made by T. B. Comstock (1890) in connection with the first detailed and systematic geologic investigation of the Llano Uplift by the newly formed (1889) Texas Geological Survey. In his report, Comstock introduced the terms Hickory series, Riley series, and San Saba series for the sedimentary rocks, and the terms Valley Spring series and Packsaddle series for the metamorphic rocks exposed in the region. His sedimentary series have since been revised. He reported the occurrence of the Hickory and Riley series in Mason County between the city of Mason and the Llano River. The economic geology of the region was also discussed in detail.

The drainage pattern of the Llano region, and its origin in particular, was discussed by Tarr (1890) in his paper concerning central Texas drainage features.

The Second Annual Report of the Texas Geological Survey, concerned primarily with the state's mineral resources and their exploitation, included a report by E. T. Dumble (1891) in which he gave the name Bend to Pennsylvanian rocks exposed on the Colorado River. Isolated exposures of Devonian rocks in the Llano region also were indicated by Comstock (1891) in this report.

In 1911 and 1912, the rocks in the central part of the Llano region were studied extensively by Sidney Paige (1911), who named and described the Wilberns, Cap Mountain, Ellenburger, and Smithwick formations. A discussion of the mineral resources and Precambrian geology of the region was included in a later report (1912), as was a detailed geologic map of the Llano-Burnet area. In the description and map, Comstock's term "Hickory series" was dropped in favor of Hickory sandstone.

The first comprehensive geologic map of Texas was prepared by Udden, et al. (1916), and published by the Bureau of Economic Geology and Technology. In the map the Paleozoic rocks of the Llano region were divided into the Pennsylvanian, Paleozoic (undivided), and Cambrian-Ordovician. The Precambrian rocks were undifferentiated.

The Wilberns reefs were mentioned and discussed by Deen (1931) in his paper on the Cambrian algal reefs of Texas.

C. L. Dake and Josiah Bridge (1932), who, together with E. O. Ulrich, had studied the older Paleozoic rocks of the Llano region in 1930, correlated units of the Ellenburger limestone there with similar Ordovician strata of other states, particularly the Missouri section. This correlation was based on faunal content. No boundaries for the Ellenburger sequence were suggested.

The earlier work of Paige on the Precambrian rock structure and succession was revised and enlarged by Stenzel (1932).

The stratigraphy of the rocks of the Llano region was briefly reviewed by Sellards, Adkins, and Plummer (1932) in their report on the stratigraphy of Texas.

In a later report on the structural and economic geology of Texas, Sellards and Baker (1934) described the deformation of the Llano region during Paleozoic times. Precambrian structural features in the region were discussed by Stenzel in this report.

A report on Precambrian unconformities in the Llano region was presented by Stenzel (1935). An intrusive sequence was also outlined in this report.

In 1933, N. H. Darton studied the geology of the Llano region, checked his findings with those of previous workers in the area, and incorporated all of the information obtained into a new state geologic map, which he prepared with the aid of other geologists (Darton, et al., 1937). Outcrops of some of the formations mentioned previously were plotted on this map for the first time.

Bridge (1937) studied the lower Paleozoic rocks of the western side of the Llano Uplift and their faunal content. He collected many fossils, redescribed Roemer's earlier type localities, and named and described the Lion Mountain sandstone member of the Cap Mountain formation. Later in the year, Roemer's Paleozoic fossils were redescribed by Bridge and Girty (1937), whose report included excellent comments on the general geology of the area.

Barnes and Parkinson (1940) described the occurrence of dreikanters in the basal Hickory sandstone and mapped dreikanter localities in Mason, Llano, and Blanco counties.

D. Keppel (1940) studied the coarse-grained granite masses of central Texas, giving particular attention to their structure and texture. He reported the occurrence of concentric textural patterns in each massif.

Cheney (1940) included a reclassification of the Pennsylvanian beds in his article concerning the stratigraphy and structure of the Paleozoic rocks of the north-central Texas region. His suggestions were based largely on subsurface data acquired from a study of well logs outside the Llano area.

The Wilberns formation was divided into its five present members by Bridge and Barnes (1941). Correlation was also attempted between several stratigraphic units within the Llano Uplift region.

A study of the granitic rocks of central Texas was made by Goldich (1941). From the data obtained, he offered a theory of evolution of these granites which explained their chemical and textural characteristics.

Barnes, Dawson, and Parkinson (1942) presented a report on the building stones of central Texas which contained excellent descriptions of these rocks at certain localities. A granite mass which extends into the northwestern portion of the thesis area was described in this report.

A quartz sand horizon in the middle Wilberns formation of northwestern Mason County was described in detail by Plummer (1943a).

Gypsum in the Edwards limestone of central Texas was discussed in a report by Barnes (1943a). In addition to this Cretaceous limestone, the Paleozoic and Precambrian rocks in that region were also described. The names of the Upper Cambrian units of the Llano Uplift were published, and the members of the Wilberns formation were given their present terminology. These members had been described but not named in an earlier unpublished manuscript by Bridge and Barnes in 1941. In the later report, the Lion Mountain sandstone was still placed as a member within the Cap Mountain formation, as defined by Bridge.

The Big Branch gneiss in Llano County was named and described by Barnes (1943b) in his report on soapstone and serpentine in the Central Mineral region of Texas. This report included a review of Precambrian stratigraphy.

Ground water occurrences in the Hickory sandstone and the Ellenburger limestone were discussed by Plummer (1943b) in his report on Texas water resources.

Devonian rocks in the Llano region were first described by Barnes, Cloud, and Warren (1945). The Pillar Bluff and Stribling formations were named and assigned to the Lower and Middle Devonian.

In a progress report on the stratigraphy of the Ellenburger group, Bridge, Barnes, and Cloud (1945) redefined units of the Lower Paleozoic rocks in central Texas. The Riley beds were reduced to formation status. The pre-Wilberns strata of Late Cambrian age -- the Hickory sandstone, Cap Mountain limestone, and the Lion Mountain sandstone, were redefined as members of this formation. The top of the Cambrian was placed at the upper limit of the Wilberns formation. The Ellenburger limestone was designated as Early Ordovician in age, and it was redefined as the Ellenburger group. New members of the Ellenburger group were defined and called the Tanyard, Gorman, and Honeycut formations.

The Upper Cambrian was again revised and redefined by Bridge, Barnes, and Cloud (1947). The two formations and eight members were described thoroughly, thus providing a standard reference to the Upper Cambrian strata of the Llano region.

A summary of the classification of Lower Pennsylvanian strata in central Texas was presented by Plummer (1947).

The Devonian stratigraphy in the region was again described by Barnes, Cloud, and Warren (1947), and two younger formations, the Bear Spring and Zesch formations, were added to the older Devonian Lillar Bluff and Stribling formations.

The Ellenburger of the region was thoroughly described by Cloud and Barnes (1948), and defined as a group consisting of the Tanyard, Gorman, and Honeycut formations, respectively, from the base to the top. Brief descriptions of pre-Ellenburger strata at various localities were also given.

Gravity observations were correlated with the geology of the Coal Creek serpentine mass in Blanco and Gillespie counties by Romberg and Barnes (1949). The Red Mountain gneiss was named by Barnes in this report.

Plummer (1950) presented a report and large-scale map pertaining to the stratigraphy and paleontology of the Carboniferous rocks of central Texas. Pre-Carboniferous stratigraphy was also mentioned and described briefly.

Barnes, Shock, and Cunningham (1950), in their report on the utilization of serpentine of the Llano region, included an excellent review of the geologic history of the region, particularly the Precambrian history.

Exfoliation and certain other weathering features found on some Precambrian granite masses in the Central Mineral region were described by Blank (1951a and b).

The geology of an area a few miles south of Mason, Texas, was described and mapped in detail by Alexander (1952). This area extends slightly into the northwest portion of the Grossville School area.

Cheney and Goss (1952) described the origin and development of the structures in the Llano region in their article on the tectonics of central Texas.

Barnes, Cloud, and Duncan (1953) were the first to report Upper Ordovician rocks in central Texas. These rocks were named the Burnam limestone and were correlated with similar beds found in the Mississippi Valley.

Parke (1953) described and mapped in detail the geology of an area slightly southwest of the city of Mason, Texas.

The Enchanted Rock pluton was extensively studied and reported on by Hutchinson (1953). Its relationship with the surrounding rocks was also described.

Duvall (1953) described and mapped in detail the geology of an area to the south of Mason, Texas. This area extends slightly into the western portion of the Grossville School area.

The Precambrian to Pennsylvanian rocks in the western part of the Llano region were described by Barnes and Bell (1954) in a guide book prepared for a field trip to that region.

The faunas of the Riley formation in central Texas were described in detail and illustrated in a report by Palmer (1954). The stratigraphy of the region was also briefly reviewed.

The geology of an area located a few miles southwest of Mason, Texas, was described and mapped in detail by Fritz (1954).

A resumé of the geology of the eastern part of the Llano Uplift, including a detailed discussion of the stratigraphy, was contained in a guide book prepared by Barnes, Pavlovic, and Hazzard (1956).

Flawn (1956) presented a detailed report on the geology of the Precambrian basement rocks of Texas and southeast New Mexico. In this report, the Llano Uplift region was included in the discussion of the Texas craton. Data derived from subsurface study were integrated with published data on exposed basement rocks. A discussion of petrographic and structural nomenclature and concepts was included in the report.

Barnes (1956) reported on the lead deposits found in the Upper Cambrian rocks of central Texas. Detailed stratigraphic sections of the Cambrian rocks were included in this report, and igneous rocks of Carboniferous or younger age were recognized in the region for the first time.

GEOGRAPHY

CLIMATE

The Grossville School area is located in a semi-arid to sub-humid region of Texas. The Texas Almanac (1956-57, p. 677) states that the average annual rainfall in Mason County is 22.50 inches. The annual rainfall varies considerably from year to year, and in turn is irregularly distributed throughout the year, heavy rains alternating with long dry periods. A large part of the annual rainfall may occur within a single week. The heaviest rains usually occur in the spring and winter months, while the summer months are generally hot and dry.

The mean annual temperature in the area is about 64 degrees F. The temperature ranges from about -5 degrees F. in winter to about 110 degrees F. in summer. The average daytime temperature during the summer is about 90 degrees F. A 30 degree variance in temperature in a single day may occur in either summer or winter.

VEGETATION

The vegetation found in the Grossville School area is that typical of regions with a rocky terrain, unevenly distributed precipitation, and severe temperature range.

The nature of the soils derived from the different rock types greatly affects the types and abundance of plant life found in different parts of the area. The sandy soils which usually develop from the Pre-cambrian rocks generally support mesquite, scrub oak, black jack oak, shrubs, and a variety of cacti and grasses. Paleozoic limestone soils usually support the growth of scattered oak, cedar, agarita, catsclaw, prickly pear, Spanish dagger, and Mexican persimmon. This type of vegetation is especially characteristic of the limestone hills in the south-central part of the thesis area. The soils derived from Paleozoic shale commonly support mesquite, bee-brush, catsclaw, and various grasses, with the vegetational growth generally being sparse. Rather dense growths of mesquite, scrub oak, Spanish dagger, cacti, and various grasses are characteristic of the uncultivated sandstone outcrops. Pecan and willow trees are present along Comanche Creek and a few of its tributaries. The grasses present in the area are curly mesquite, needle, buffalo, and crow-foot.

INDUSTRY

Regionally speaking, the Llano area is primarily a ranch country, with secondary importance given to cultivated crops. According to Plummer, (1947, p. 11), about 60 percent of the land is used for grazing cattle, sheep, and goats; 8 percent is used strictly for crops; and 32 percent for stock farms on which both small crops and small herds of cattle and sheep are raised.

In the thesis area, most of the farms are of the stock farm type, in which farming and small-scale ranching are combined. Most of the income is derived from the production of beef cattle, sheep and wool production being secondary. Hereford cattle predominate in the area, but Brahma and Jersey cattle also are raised. Jimmie Zesch has introduced Santa Gertrudis and Angus cattle. The hilly portions of the area are utilized mainly for goat and sheep grazing. Hog and poultry raising is also carried on to a limited extent.

Most of the cultivated fields are centered in the central and northern portions of the thesis area, where rolling or relatively flat land predominates. Corn, wheat, oats, hay, barley, grain sorghum, and peanuts constitute the principal crops, and watermelons, fruits, and vegetables also are grown. Due to the lack of rainfall in the past few years, farming has been on the decline, a decline that may ultimately be counteracted, however, by the steadily increasing use of ground water for irrigation.

Hunting and fishing in the general Mason region interest visitors as well as the area residents. Many sportsmen are especially attracted to the vicinity during the deer-hunting season. Wild turkey, quail, and dove are also found in abundance. The fishing is excellent along the Llano River and in several of the larger stock tanks in the area. Some small-scale trapping is also carried on occasionally.

PHYSIOGRAPHY

GEOMORPHOLOGY

The Grossville School area lies on the southwestern flank of the Llano Uplift, which, although structurally a dome, is topographically a broad basin. The basin is floored by Precambrian igneous and metamorphic rocks and Paleozoic sandstones and limestones, the Paleozoic rocks generally occurring as downdropped fault blocks. Within the basin the Paleozoic limestones generally form flat-topped hills, the Precambrian granites round-topped knobs, and the gneisses sharp ridges, whereas the schists and sandstones form most of the lowlands. An escarpment of relatively flat-lying Cretaceous limestone encloses most of the region. The total relief in the Llano region is about 1,600 feet. In Mason County the elevation ranges from 1,300 feet to 2,200 feet above sea level.

Both Precambrian and Paleozoic rocks outcrop in the thesis area. The maximum elevation in the area is probably about 1,700 feet above sea level, and the total relief is about 300 feet. The highest elevations are found on Tod Hill in the northwestern part and in the limestone hills in the south-central part of the thesis area. The lowest elevations are found along Comanche Creek. The Precambrian rocks and the Hickory sandstone member outcrop in the northwest, north-central, northeast, and southeast portions of the area, and in these places a flat or gently rolling topography predominates, with very little relief. Some hills composed of Hickory sandstone are found, however, especially in the northwestern part, and several granite and gneiss knobs or low hills also rise above the gently undulating surface in some parts of the area. Much of the Hickory sandstone member and parts of the highly weathered Precambrian surface are under cultivation. Gently-dipping limestones of the Cap Mountain member form low hills in the southwestern part of the area. In the graben portion in the south-central part, the Paleozoic rocks (predominantly limestones) rise rather sharply to form a very hilly section of high relief, dissected by small creeks. Sharp, rather easily traceable ledges are found in this hilly section.

EROSION

Running water is the most effective erosional agent at work in the thesis area, particularly in the sparsely vegetated portions. Rains, when they occur, are generally concentrated, and the rainwater removes much of the limited surface soil. High winds have some erosional effect on loose sand in areas of very sparse vegetation.

Some of the topographic features evident in the thesis area are the result of faulting. Movement along many of the faults has brought less resistant Precambrian rocks up against more resistant Paleozoic rocks, with the result that the structurally high block has been reduced by erosion to a topographically low area. The more resistant Paleozoic rocks are generally high topographically. Erosion also works more easily in fractured areas associated with some faults.

DRAINAGE

The Llano Uplift region is drained by the Colorado River system: the San Saba River on the north, the Colorado River on the east, the Llano River in the central part, and the Pedernales River on the south. The major stream drainage pattern was probably initiated on an eastward-tilted Cretaceous plain in Tertiary time. The rivers and all but their smaller tributaries were later superimposed on the domed Precambrian and Paleozoic rocks with only slight departure from their original courses. The rivers now generally rest upon harder Precambrian and Paleozoic rocks, the softer strata having been eroded. The Llano River, which flows eastward to meet the Colorado River in Llano County, is located from .5 to 3 miles south of the southern border of the thesis area.

The principal stream of the thesis area, Comanche Creek, flows over Precambrian and Paleozoic rocks in a southeasterly direction, disregarding the structure, and enters the Llano River at a point .5 miles south of the southeast corner. All but the southwest and south-central portions of the area are drained by Comanche Creek and its tributaries. These portions are drained by smaller southward-trending tributaries of the Llano River.

Faults and fault scarps are changing the general dendritic drainage pattern of some of the minor streams to a more angular pattern.

The streams in the thesis area are all intermittent, and only during periods of heavy rainfall is water flowage in these streams initiated. Ranch tanks have been built across several of the smaller creeks in the area, and flowing wells in the southwestern part maintain limited pools in several small creeks.

Comanche Creek and many of its larger tributaries have their beds covered by thick layers of angular gravel derived from the easily eroded basement rocks.

STRATIGRAPHY

GENERAL STATEMENT

Rocks of Precambrian and early Paleozoic age are exposed in the Grossville School area. The age of the Precambrian rocks is not known but has been postulated by Paige (1912, p. 25) and Sellards (1932, p. 31) to be Algonkian. Flawn (1956, facing p. 68) has postulated a late Middle Precambrian age for these rocks. Until conclusive evidence is presented, however, this dating must remain uncertain. The Paleozoic rocks exposed in the area are Late Cambrian in age, and are separated from the underlying Precambrian rocks by an angular unconformity. Lower and Middle Cambrian rocks are absent in the entire Llano region and throughout Texas. The geologic column for the thesis area follows:

- Paleozoic systems
  - 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
- Precambrian rocks
  - Igneous rocks
    - Medium-grained and fine-grained granites
  - Metamorphic rocks
    - Gneiss and schist units

PRECAMBRIAN ROCKS

Precambrian igneous and metamorphic rocks are exposed in a large portion of the thesis area, mainly in the eastern and central parts. Granite and gneiss predominate, but schist and pegmatite veins are also found in varying amounts.

Metamorphic Rocks

General Statement

The term Llano group was applied to the series of sedimentary rocks exposed in the Llano region by Walcott (1884, p. 431), who assigned an Early Cambrian age to the group. Comstock (1890, p. 558) was the first to divide the metasedimentary rock group into two units, the Valley Spring gneiss and the Packsaddle schist. The type localities for these two units are both in Llano County, at Valley Spring and Packsaddle Mountain, respectively. No definite thicknesses are given for the units at either type locality.

Paige (1911, p. 25, and 1912, p. 18) summarized the geology of the Llano region and reviewed the work which had been done in the area previously. He redefined the above units and applied the names to the metamorphic rocks which he had mapped in the Llano-Burnet area. Paige gave an Algonkian (Proterozoic) age to these rocks. He said that the Valley Spring gneiss was the older of the two, and that essentially both were originally sedimentary rocks which had been subsequently metamorphosed. He did say that possibly some of the metamorphic material in the Valley Spring gneiss may have been igneous originally. Many of the rocks have been altered by metamorphism to such an extent that it is very difficult to determine whether they were originally igneous or sedimentary.

Sellards (1932, p. 32) agreed with Paige on the relative ages of the two formations, saying that the Valley Spring gneiss was the older. Stenzel (1932, p. 143), however, after a study of the Valley Spring gneiss, stated that it was igneous in origin and younger than the Packsaddle schist. He described the gneiss as an orthogneiss, intrusive, with conformable contacts, into the schist. The Packsaddle schist was thus the only Precambrian sedimentary formation under this interpretation.

Sellards (1932, p. 32) defined the Valley Spring gneiss as a gneiss, mostly light colored, consisting essentially of feldspathic and quartzitic materials. He based the separation of the Valley Spring gneiss from the overlying Packsaddle schist partly on the more massive character of the gneiss and partly upon its greater content of felsic materials. He also stated that the gneiss not only contains schist, but also grades into the schist in such a way as to make definite separation in many localities very difficult, if not impossible. This is especially true in the thesis area, where in many places the gneiss grades into the schist almost imperceptably, making separation almost impossible. This same condition is true throughout most of the western flank of the Llano uplift.

Sellards (1932, p. 33) defined the Packsaddle schist as a thick unit of metamorphosed sediments, originally consisting mostly of shales with some sandstones and limestones, into which acidic and some basic igneous rocks were intruded. The original sediments, being metamorphosed, became schists - mica, hornblende, amphibole, and graphite - depending on the character of the rock from which they were derived. The sandstones were altered to gneiss or schist, and the limestones to marble.

A third metamorphic unit, the Big Branch gneiss, a dark, fine- to medium-grained, quartz-diorite gneiss, was described by Barnes (1943,

p. 55-56) from exposures along the Big Branch of Cacl Creek in Gillespie and Blanco counties. He stated that this gneiss intruded both the Packsaddle schist and the Valley Spring gneiss, and that it was in turn intruded by the granites, pegmatites, and aplites of the area.

Paige (1912, p. 33) recognized one other gneiss in the Llano region, at Red Mountain, a granite ridge in the southeast corner of the Llano quadrangle. He said that this gneiss was formed almost certainly by the metamorphism of intrusive granites. The granite of the ridge becomes more gneissoid northeastward until it can hardly be distinguished from beds that are believed to represent sedimentary strata. Barnes (Romberg and Barnes, 1949, Fig. 1) designated these rocks as the Red Mountain gneiss, but did not describe them in detail.

In the thesis area, two main groups of metamorphic rocks, a gneiss unit and a schist unit, have been recognized. As mentioned before, the gneiss grades almost imperceptably into the schist in most places, and, for this reason, these two units were not mapped separately. The gneiss unit predominates and was mapped as the main metamorphic unit. Definite schist localities were also marked on the accompanying geologic map.

Gneiss Unit

Occurrence and relationships

The gneiss unit is exposed in several parts of the thesis area. The best exposures are found along both banks and in the bed of Comance Creek in the southeast part of the area, and at various localities in the north-central and northwestern parts. In the central, east, and southeast portions of the area the gneiss is overlain unconformably by basal Hickory sandstone deposits, while in the northwest portion it is adjacent to the granites. In the northeast portion of the area scattered remnants of basal Hickory sandstone are found on the surface of the gneiss unit. In several places the gneiss is faulted against the Hickory member, and a few minor faults which cut the gneiss only were located from aerial photographs.

Along Comanche Creek the gneiss is found in very large masses or knobs which protrude as much as 50 feet above the surrounding topography (Plate III, Figure 1). This type of exposure does not predominate, however, and in most other places the gneiss is exposed only in low mounds or as boulders, or else has been completely broken down, leaving a gently rolling topography, with a few pegmatite remnants being the only rocks visible (Plate III, Figure 2).

The color and mineralogic composition of the gneiss unit are very similar to those of the Valley Spring gneiss. This identification, if correct, would make the gneiss unit older than the granites in the area, which are being related to the Town Mountain type. No actual contact of the gneiss with the granites was seen in the area, but the proximity of the two units in several places with no apparent gradation suggests that the granite is intrusive into the gneiss. Wilson (1957), however, in the nearby Big Bend of the Llano River area, has observed and described a transition zone between what appears to be the same granite and gneiss units. This, together with the fact that the mineralogic composition of the gneiss is very similar to that of the granites exposed in the thesis area, suggests a possible igneous origin for the gneiss as postulated by Stenzel, although resulting from a later intrusion than the one he suggested.

Plate III

Surface Expression of Precambrian Gneiss

Figure 1.--Large Precambrian gneiss mass, located on west bank of Comanche Creek one-half mile south of F. Hoerster ranch house

Figure 2.--Typical gently undulating topography of Precambrian gneiss, looking northwest from a point seven-eighths mile northeast of H. Kettner ranch house

Megascopic description

The gneiss is generally fine-grained, and has a light reddish-pink color in fresh exposures. It weathers fairly rapidly to light-brown to reddish-brown colors. The minerals easily distinguished in hand specimens are pink feldspar, colorless to cloudy quartz, and black biotite. The feldspar grains are most abundant, probably comprising from 25 to 40 percent of the rock, and they give the gneiss its characteristic pink color. The remainder of the rock is made up of quartz and biotite, together with smaller amounts of other minerals. The grain size is fairly uniform, usually being less than 1 mm., except that the biotite grains are very small, and are generally seen only as specks.

The gneiss is deeply weathered in many places, and the weathered gneiss greatly resembles the weathered fine-grained granite found in the area. Biotite seems to be absent on the weathered surfaces of the gneiss.

The foliation planes are very distinct in the gneiss unit in several parts of the area, and strike and dip measurements were obtained.

Microscopic description

As the gneiss unit is extensively weathered in many places, great care was taken to obtain a hand sample from the center of a relatively fresh boulder, which was found several hundred yards to the east of Comanche Creek in the extreme southeastern part of the thesis area. A thin section cut perpendicular to the foliation planes was prepared from this hand sample and studied.

The minerals found in the thin section were quartz, microcline, plagioclase (andesine), biotite, orthoclase, apatite, ilmenite, zircon, and allanite (?) (Plate IV). Chlorite and leucoxene were found as alteration products.

Plate IV

Photomicrographs of Gneiss

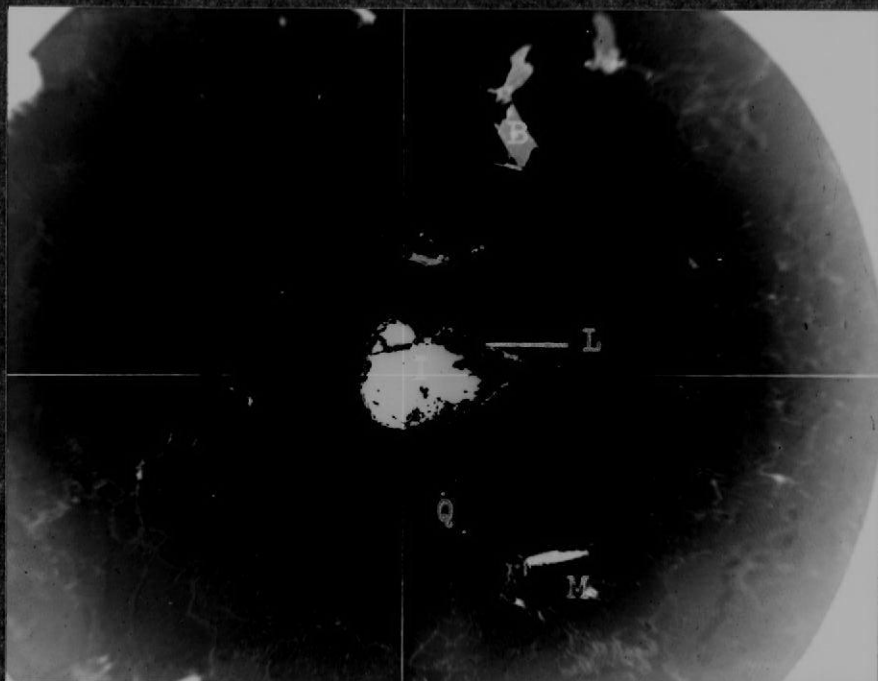


Figure 1.—Photomicrograph of gneiss, showing some constituent minerals (B - biotite, M - microcline, Q - quartz, I - ilmenite, L - leucoxene) (x20)

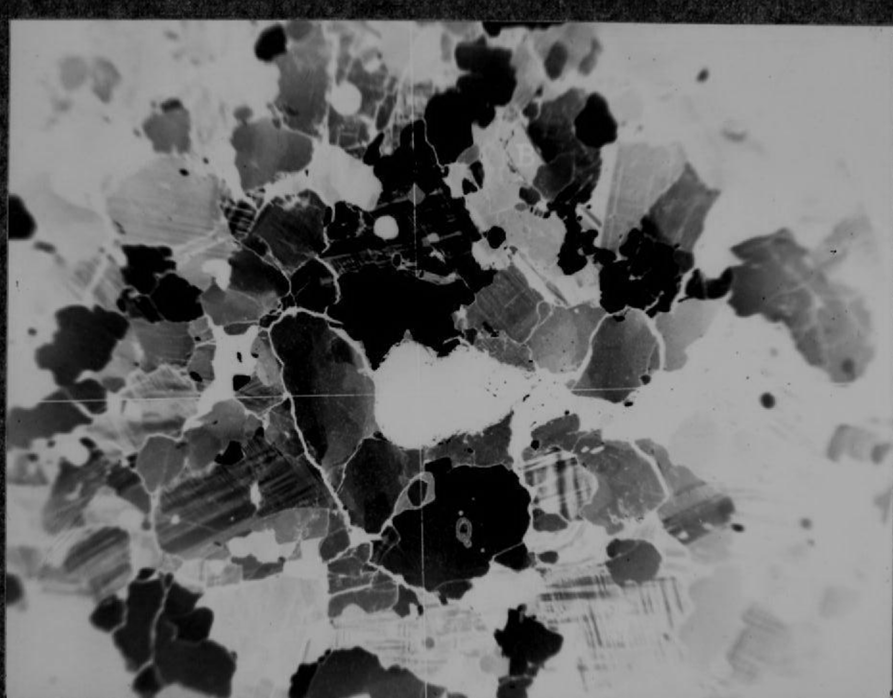


Figure 2.—Same as Figure 1, but with crossed nicols

The most abundant minerals present in the thin section were quartz and microcline. The quartz was present in anhedral grains ranging from .10 mm. to 1.3 mm. in diameter, the average being about .50 mm. The extinction was generally undulatory and a characteristic first order white to gray interference color was evident in a majority of the grains.

Microcline was also very abundant, and, together with the quartz, seemed to comprise at least 70 percent of the rock as seen in the thin section. The microcline grains ranged from .20 to 1.50 mm. in diameter, the average being about .75 mm. These grains were easily identified by their characteristic "gridiron" or "quadrille" structure.

Plagioclase was present in anhedral grains ranging from .25 mm. to 1.10 mm. in diameter, the average being about .60 mm. Albite twinning and the index of refraction were the distinguishing factors used to classify the plagioclase as andesine, the maximum extinction angle measured on an albite twin being about 16 degrees, and the index of refraction being greater than balsam.

Scattered anhedral to subhedral grains of pale green to brownish-green biotite were also relatively abundant. These grains showed good cleavage in one direction, the extinction being parallel to the cleavage traces. The absorption of these grains was stronger when the cleavage traces were parallel to the vibration plane of the lower nicol. The grains were longer in the direction of cleavage, with a few grains reaching a length of about .80 mm. The average length was .45 mm.

Orthoclase was present in anhedral to subhedral, generally colorless grains, averaging about .60 mm. in diameter. The diameters ranged from .20 to 1.5 mm. The index of refraction of the grains was lower than balsam, and the interference colors seemed to be a little lower than those of the quartz grains. Carlsbad twinning was very evident on several of the grains, and was one of the characteristics used in identification.

Several fairly large, irregular grains of ilmenite were prominent. The grains were black and opaque, had a metallic luster, and an average diameter of 1.00 mm. The chief characteristic used to identify the ilmenite was the presence of an opaque, grayish-white alteration product, leucoxene, which completely or partially surrounded several of the grains.

Small, subhedral apatite grains were also present, some as inclusions in several of the microcline and plagioclase grains. These apatite grains had a very weak birefringence, and an average diameter of about .16 mm. Small quartz inclusions, generally slightly larger than the apatite inclusions, were also present in many of the microcline and plagioclase grains.

Several small grains of zircon were present, generally as inclusions in larger grains of other minerals, usually biotite and quartz. They were surrounded by strong pleochroic halos, generally in the biotite.

A few reddish-brown grains which appeared to be darker toward the edges were also present. These grains were generally less than .10 mm. in diameter. They were surrounded by strong pleochroic halos in the biotite. Possible radioactivity was also exhibited by this mineral, especially in one case where a grain was adjacent to a biotite grain and appeared to have broken down the surrounding area of the biotite and changed its characteristics. This mineral was tentatively identified as allanite (?), which has been changed to a metamict mineraloid.

Chlorite occured as an alteration product, and was generally closely associated with the biotite. The chlorite had a characteristic pale- to medium-green color.

Topography and vegetation

The gneiss unit is extremely susceptible to weathering and very easily eroded. Therefore, in areas where the gneiss is exposed, a gently rolling topography is dominant. This unit generally forms lowlands, with a few low hills composed of more resistant outcrops. Weathered exposures greatly resemble the weathered fine-grained granite in many places. The pegmatites which are found in the gneiss unit are generally more resistant than the gneiss, and quartz and microcline fragments are found scattered on the surfaces of the low hills, as well as on the lowlands (Plate V, Figures 1 and 2).

The land in most cases has been cleared of brush and appears as low, rolling, grassy country, with a few trees dotting the landscape. The vegetation is generally sparse and forms irregular patches, with mesquite and catsclaw predominating. Minor amounts of agarita, prickly pear, shin oak, cedar brush, tasajillo, and various grasses are also found.

Schist Unit

Occurrence and relationships

Good exposures of the schist unit are found in only a few parts of the thesis area. The best exposures are found along both banks and in the bed of Comanche Creek in the north-central and central parts. In most cases these schist exposures grade into the gneiss unit along the strike, and are of limited areal extent.

Plate V

Gneiss and Quartz Fragments on Precambrian Gneiss Terrain

Figure 1.—Small gneiss and quartz fragments on gently undulating Precambrian gneiss terrain, located one-half mile northeast of F. Kettner ranch house

Figure 2.—Large milky quartz fragments on Precambrian gneiss terrain, located three-fourths mile northeast of H. Kettner ranch house

A few fairly good exposures of the schist are found along several of the larger tributaries of Comanche Creek. Excellent exposures occur along this creek immediately to the north of the thesis area and near the U. S. Highway 87 bridge.

The schist exposures seem to grade into the gneiss unit in such a way as to make definite separation very difficult in many cases. The schist areas marked on the accompanying geologic map are those places in which the schist unit is fairly well defined. In other places only isolated patches or remnants of the schist are present and grade into the gneiss. In many places pegmatite veins and veinlets, composed chiefly of quartz, have intruded the schist (Plate VI, Figure 1), and in others the schist appears to be intercalated with highly metamorphosed gneiss (Plate VI, Figure 2).

In view of the previously described correlation of the gneiss unit with the Valley Spring gneiss, the schist unit may be tentatively correlated with the Packsaddle schist. The gradational relationship of the gneiss and schist mentioned above has been said by Sellards (1932, p. 32) to occur between the Valley Spring gneiss and the Packsaddle schist in many parts of the Llano area.

Megascopic description

The schist is greenish-black in color on fresh surfaces, with thin white to gray parallel layers traversing the greenish-black material. No definite determination of the minerals could be accomplished by a megascopic study of the rock, but the greenish-black mineral which gives the schist its general color appears to be hornblende. This mineral comprises approximately 50 to 70 percent of the rock. Abundant biotite is

Plate VI

Occurrence and Relationships of the Schist Unit

Figure 1.—Pegmatite veins and veinlets intruding schist unit, located in bed of Comanche Creek one-half mile northwest of F. Grote ranch house

Figure 2.—Schist intercalated with the gneiss unit, located in bed of Comanche Creek one-half mile northwest of F. Grote ranch house

also present in some exposures of the schist unit, but those exposures are very badly weathered, thus precluding the possibility of obtaining good thin section samples from them. Therefore the thin section samples were obtained from the hornblende schist, as it is harder and less weathered. Compared to the gneiss, the schist contains relatively small amounts of feldspar and quartz and other lighter colored minerals.

The schist is crystalline and has a highly developed schistosity. In some places it is highly consolidated, while in others it splits very easily into smooth-surfaced layers along the direction of schistosity, and may even crumble under slight pressure.

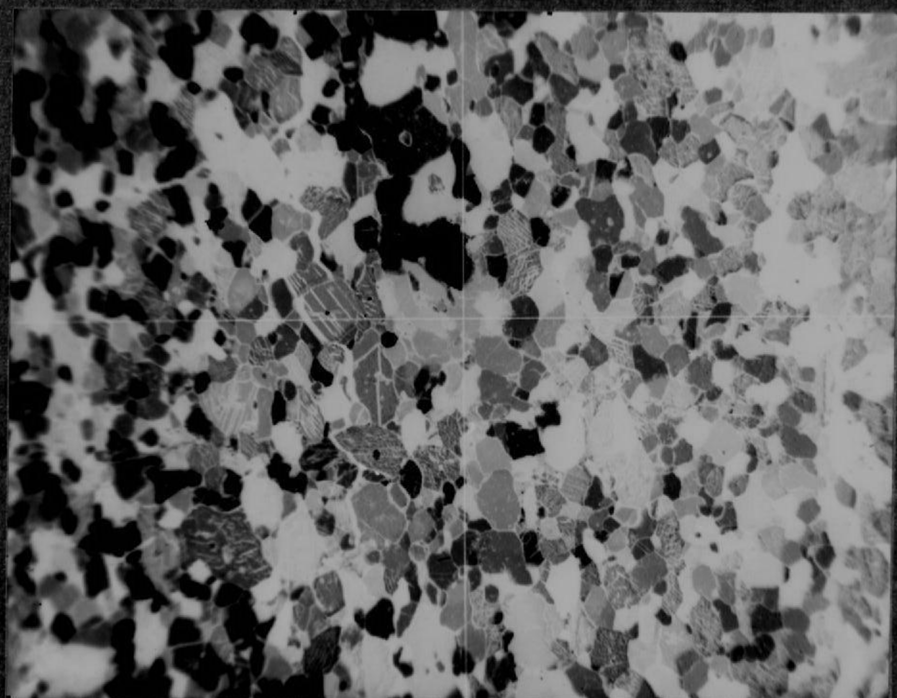
Weathered surfaces of the schist have a medium-brown to purplish-black color, and iron oxide stains are quite common. The schist is highly weathered in many places, and has produced a deep, dark black soil.

Microscopic description

Two samples of relatively fresh hornblende schist were obtained from separate exposures several hundred feet apart along Comanche Creek at the northern limit of the area. Thin sections cut at right angles to the foliation were prepared from these samples and studied.

The minerals seen in both thin sections were the same, but the sections did differ in grain size and fabric. One thin section had a mosaic fabric in which the grains were nearly equidimensional (Plate VII). Sharp, straight contacts were evident between the adjacent grains, which had an average diameter of .15 mm. The grains seemed to be more elongated and aligned in the direction of elongation in the other thin section. They were also inequigranular, with the average grain size being about .30 mm., although the biotite grains elongated parallel to the cleavage traces were generally longer.

Plate VII



Photomicrograph of schist, showing mosaic fabric (crossed nicols, x30)

The minerals found in the thin sections were hornblende, quartz, orthoclase, magnetite, plagioclase (andesine), apatite, zircon, sphene, and albite (?) (Plate VI.I).

Hornblende was the most abundant mineral present and seemed to comprise at least 50 percent of the schist, as seen in the thin sections. The schist was thus classified as hornblende schist. The hornblende grains were pleochroic from light pale green to dark brownish-green, and occurred both in basal sections and as grains elongated parallel to the cleavage traces. On the elongated grains, the extinction angles measured varied from about 10 to 16 degrees. Twinning was evident in many of these grains. The extinction was symmetrical to the cleavage traces in the basal sections. The diameter of the basal sections ranged from .15 mm. to .60 mm., the average being about .35 mm. The elongated grains ranged from .30 to 1.5 mm. in length, the average being about .65 mm. Inclusions of small, colorless, subhedral to euhedral grains were common in the hornblende and in several of the other minerals. These inclusions seemed to have a biaxial negative (?) interference figure, and their index of refraction was very close to that of balsam. The mineral was either orthoclase or a plagioclase, probably albite (?).

Quartz and orthoclase were both relatively abundant in the schist. The quartz occurred in small, anhedral, generally colorless grains which usually had undulatory extinction and a first order white to gray interference color. These grains ranged from .15 to 1.6 mm. in diameter, and averaged about .30 mm.

Orthoclase was present in colorless to cloudy, anhedral to subhedral grains. The relief was lower than balsam, and several grains

Plate VIII

Photomicrographs of Schist

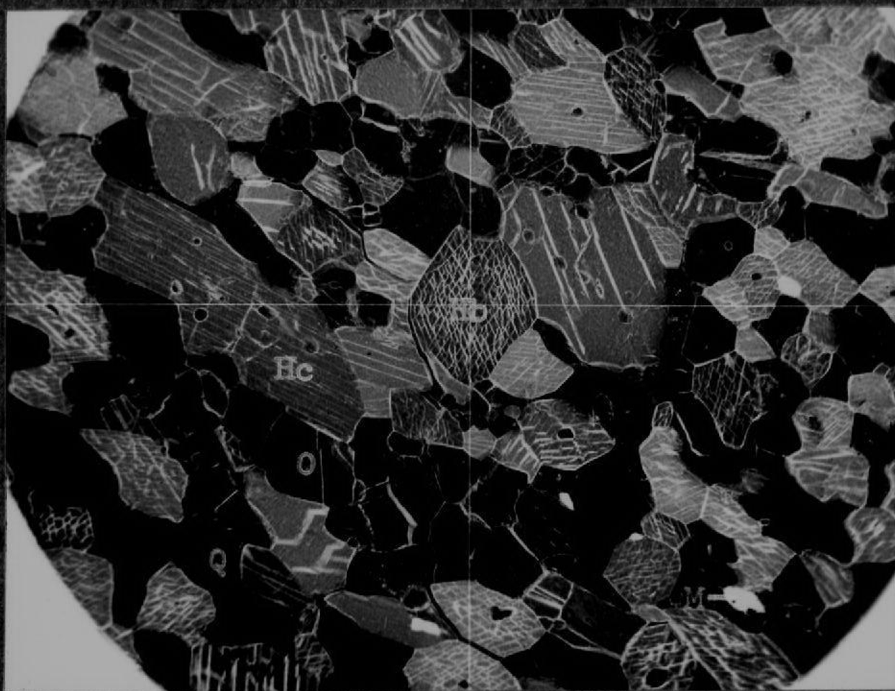


Figure 1.—Photomicrograph of schist, showing some constituent minerals (Hb – hornblende, basal section; Hc – hornblende, cleavage grain; O – orthoclase; M – magnetite; Q – quartz) (x70)

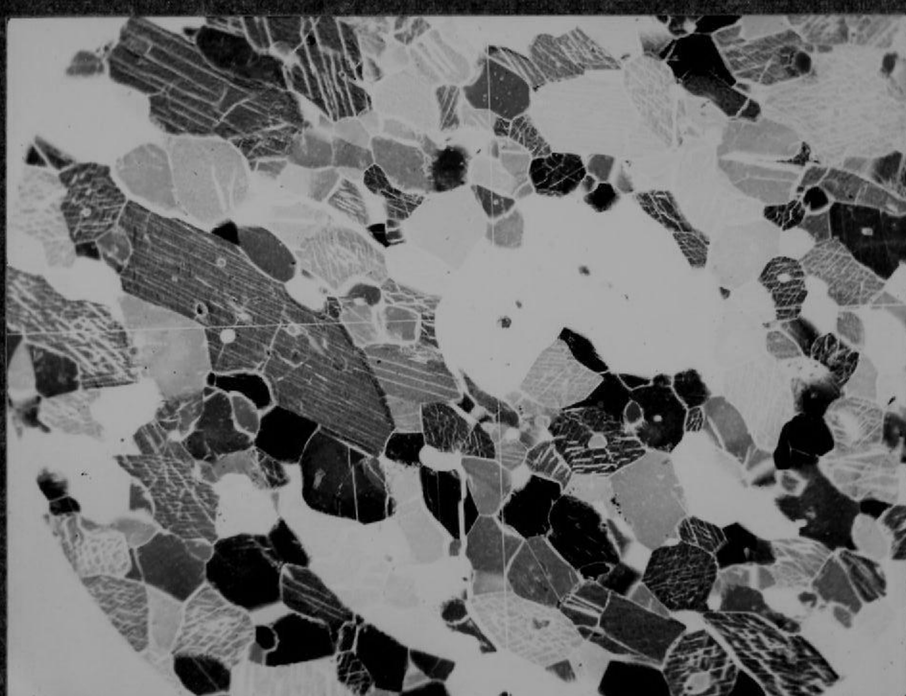


Figure 2.—Same as Figure 1, but with crossed nicols

showed cleavage traces. Carlsbad twinning was evident on some of the grains, and was used as a distinguishing characteristic. A biaxial negative interference figure was obtained from several of the grains. The grains ranged from .10 to .50 mm. in diameter, the average being about .30 mm. Possible occurrences of this mineral as inclusions have already been mentioned.

Many small grains of magnetite were detected in the schist. The grains were euhedral to anhedral, several distinct crystals being evident. The grains were black and opaque, with a metallic luster, and their average diameter was about .10 mm., although it ranged from .04 mm. to .20 mm. In most cases the magnetite grains were adjacent to the hornblende, but this was probably accidental, as the magnetite was primary and not an alteration product of the hornblende.

Many anhedral to subhedral grains of plagioclase, averaging about .30 mm. in diameter, also occurred in the schist. Albite twinning and the index of refraction were the distinguishing characteristics used to identify the plagioclase as andesine. The index of refraction was greater than that of balsam, and the maximum extinction angle measured on an albite twin was 19 degrees. A few small grains of hornblende were found as inclusions in the plagioclase.

Small, subhedral to euhedral apatite grains occurred both as isolated grains and as inclusions in other minerals. These grains had moderate relief, weak birefringence, and an average diameter of about .16 mm. A good interference figure was unobtainable.

A few small zircon grains were also present, generally as anhedral inclusions in larger grains of other minerals, mostly biotite. Strong pleochroic halos surrounded most of the zircon grains, which averaged about .07 mm. in diameter.

Many small irregular grains and euhedral crystals of sphene were present (Plate IX), many occurring as inclusions in the hornblende. These grains showed very high relief, had a pale grayish-white color in ordinary light, and were different shades of blue and yellow, with an anomalous blue color predominating, under crossed nicols. The irregular grains averaged about .08 mm. in diameter, while the crystals averaged about .12 mm. in length, and .04 mm. in width.

Topography and vegetation

Since the schist is very easily eroded and therefore not well exposed, no characteristic topography can be presented for this unit. The hornblende schist produces a rich, black soil, which is very pronounced in limited parts of the area.

Because of its limited exposures, no definite vegetational characteristics can be presented for the schist unit. In general, however, the same type of vegetation found on the soils of the gneiss unit may also be found on the soils that have been derived from the schist unit.

Igneous Rocks

General Statement

Extensive granitic intrusions have invaded the Precambrian sedimentary formations of the Llano Uplift. Smaller intrusions of more basic rocks, such as diorite and gabbro, are also found. According to Sellards (1932, p. 33), the larger masses of the basic intrusives are in the southeastern portion of the region.

Paige (1912, p. 25) classified the granites into three types, mainly on the basis of their textural differences. More recent studies by

Plate IX

Photomicrographs of Schist

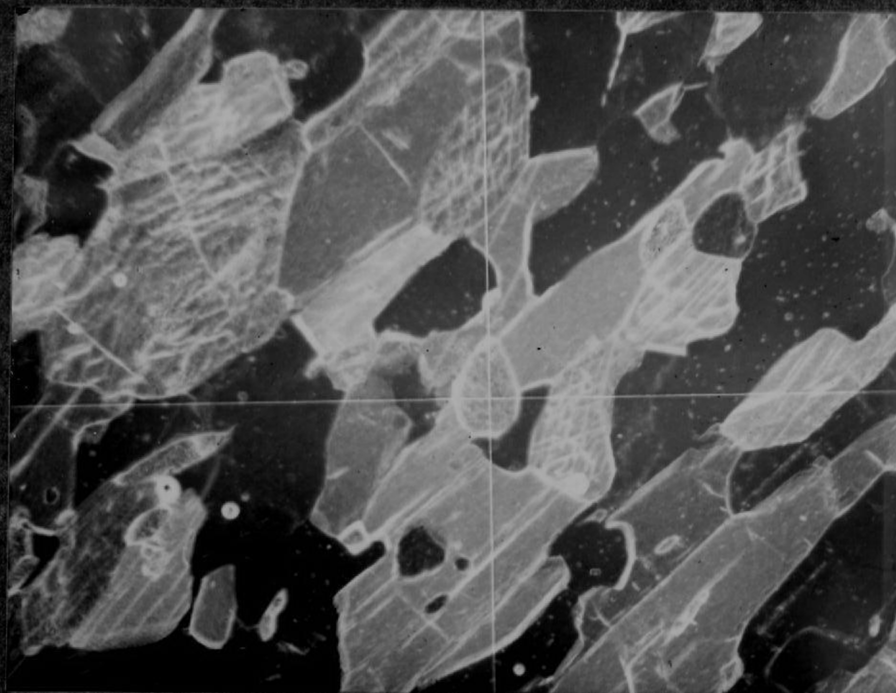


Figure 1.—Photomicrograph of schist, showing grain of sphene under cross hairs (x110)

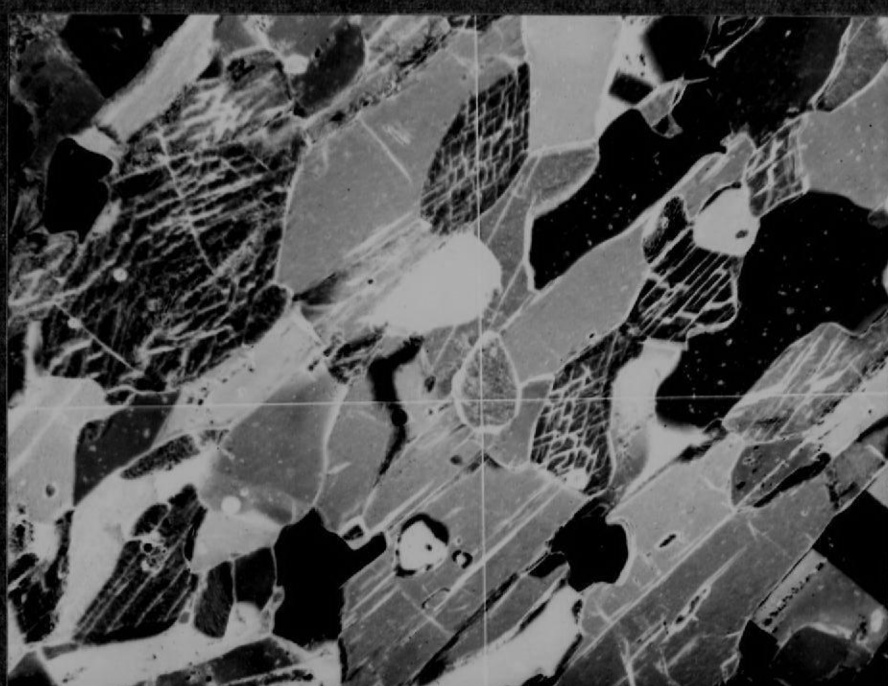


Figure 2.—Same as Figure 1, but with crossed nicols

Keppel (1940) and Goldich (1941) have led to a criticism of this type of classification. It has been recognized that textural gradations and concentric textural patterns within single granite masses are common, and thus a differentiation of types based chiefly on textural differences is extremely hazardous. This textural gradation is evident in the thesis area.

Stenzel (1932, p. 143 and 144, and in Sellards and Baker, 1934, p. 74-75) divided the Precambrian of the Llano uplift into three series from the point of view of structure, the oldest being the "folded-frame" metamorphic rocks, and the younger two being igneous rocks. These igneous rocks are the batholithic intrusions, which comprise the various granites and their aplite and pegmatite dikes; and the later or younger dike intrusions, which comprise the opaline quartz-porphyry rocks and felsites. Stenzel in turn divided the granites of the batholithic intrusions into (from oldest to youngest) the Town Mountain granites, consisting of coarse-grained to porphyritic granites, commonly with abundant feldspars; the Oatman Creek granites, consisting of medium-grained, gray to pink, cataclastic granites; and the Sixmile granites, consisting of finer-grained, gray, biotite granites. All three names are from localities in central Llano County.

Two different textural types of intrusive granites, a medium-grained granite and a fine-grained granite, are exposed in the thesis area. These types do not represent two separate granitic intrusions, but rather a probable textural gradation within a single granite mass. In the thesis area, as elsewhere in the Llano region, the granite mass is accompanied by pegmatite dikes and veins which are also exceedingly common in the metamorphic rocks.

Medium-Grained Granite

Occurrence and relationships

A medium-grained granite is exposed in the extreme northwest portion of the thesis area. This granite is probably part of a larger granite mass located four miles south of Mason which was described by Barnes, Dawson, and Parkinson (1947, p. 85). According to them, the freshest granite is exposed along a creek, with the granite exposure being about 400 feet across, and with the outcrop extending south of the creek for about 700 feet before being overlapped by the Cambrian sandstone. Only that portion of the granite exposed in the thesis area was mapped by the present author. Alexander (1952, Plate I) showed the granite mass extending several hundred feet to the west of the thesis area before being cut off by the Simon fault. The northern limit has not been determined.

In the thesis area, this granite is overlapped on the south and southwest by the Hickory sandstone member. There is evidence that the granite grades into a finer-grained type toward the edges of the exposure. This is especially true to the southeast of the main medium-grained mass. Here the fine-grained granite is adjacent to the medium-grained granite, and no abrupt change is evident.

No actual contacts, either concordant or discordant, between the granite and the gneiss, are evident in the area. The proximity of the two units in several places, however, seems to indicate that the granite is intrusive into the gneiss. If intrusive, the medium-grained granite is definitely younger than the gneiss and other metamorphic rocks and probably of the same age as the fine-grained granite, the textural difference being the result of gradation within one mass.

Barnes, Dawson, and Parkinson (1947), although describing the medium-grained granite mass, did not attempt to correlate it directly with one of the three granite divisions of Stenzel (1932, and in Sellards and Baker, 1934). They have, however, described it as a smaller unnamed mass under the general heading of red and pink granites. This would seem to relate the granite with the other pink, medium- to coarse-grained granites in the Llano region, which have been called the Town Mountain by Stenzel. Also the mineralogic composition of the granite in the thesis area is very similar to that of a typical Town Mountain granite, the Enchanted Rock body, which contains microcline, plagioclase, quartz, biotite, hornblende, magnetite, titanite, apatite, zircon, sericite, and chlorite (Barnes, Dawson, and Parkinson, 1947, p. 45). It is also very similar to that of other known Town Mountain masses. According to Stenzel, the Town Mountain granite is the oldest in the Llano region. Flawn (1956, p. 27) dated the age of the batholithic intrusions in the Llano region at 1,000 million years, which would give them a later Middle Precambrian age according to his chart (1956, facing p. 6?).

Megascopic description

This granite is medium- to coarse-grained and has a pink to red general appearance with black spots. The minerals easily seen in a hand specimen are clear to cloudy quartz, brown to black biotite, medium to large pink to red feldspar grains, and black hornblende. The minerals seem to be fairly well distributed, with the feldspar grains being most prominent, comprising about 35 to 45 percent of the rock, and giving it the pink to red general color. Equal parts of quartz and biotite make up all but about 5 to 10 percent of the remainder of the rock, with this part being composed of hornblende and other accessory and related minerals.

The average grain size ranges from 5 to 7 mm. Some of the feldspar grains are slightly above this average, several being as large as 20 mm. in diameter. The quartz, biotite, and other grains compensate for this by generally being slightly under the average. Several pegmatites were observed in this granite.

The rock becomes light pink to gray on weathering, and becomes somewhat friable. The granite is deeply weathered in most places, and the weathering is especially evident at the granite quarry at the junction of Farm Road 1723 and the James River road (Plate X, Figure 1). The biotite is almost entirely absent on the weathered surfaces and its susceptibility to alteration is probably the chief cause of the intense weathering evident in the granite. Before the granite could be used as building stone, one foot or more of the surface material would have to be discarded.

According to Barnes, Dawson, and Parkinson (1947, p. 85), the main joints in the granite mass trend N. 22° W. and N. 72° E., and other rather prominent joint directions are also present. This author observed several different joint directions in the granite, the main joint directions mentioned above being prominent. Barnes, Dawson, and Parkinson (1947, p. 85) also reported that the granite takes a good polish.

Microscopic description

Great care was taken to obtain the freshest possible sample of the granite from which a thin section could be prepared. The sample described in the following paragraphs was obtained from the center of a nearly fresh boulder near the granite quarry.

Plate X

Surface Expression of Medium-Grained Granite

Figure 1.--Quarry in medium-grained granite, located slightly east of Farm Road 1723, in extreme northwest corner of thesis area

Figure 2.--Medium-grained granite boulder, located in same area as given for Figure 1

The minerals found in this thin section were microcline, plagioclase (oligoclase), quartz, biotite, hornblende, zircon, and magnetite (Plate XI). Chlorite formed by alteration was found, and microperthite was also common. Barnes, Dawson, and Parkinson (1947, p. 85), in addition to the above essential minerals, reported the presence of apatite, fluorite, and a few crystals of altered allanite. They also reported sericite and calcite as minerals formed by alteration, and the presence of micropegmatite. Although these minerals were not observed in the particular thin section studied by this writer, they would probably be found if several thin sections of the granite had been prepared and studied.

The most abundant mineral present in the thin section was microcline. It was colorless and generally present in anhedral grains. This mineral was easily distinguished by its characteristic "gridiron" or "quadrille" polysynthetic twinning. The average diameter of the grains was 1.0 mm., but ranged from .25 to 2.15 mm. Small quartz inclusions were present in several of the microcline grains. In many cases albite was intergrown with the microcline to form "microperthite."

Albite twinning was the distinguishing characteristic used to classify the plagioclase as oligoclase, the largest extinction angle measured on an albite twin being 11 degrees. Carlsbad twinning was also found in a few grains. The grain diameters ranged from .20 mm. to 1.75 mm., the average being about .50 mm.

The quartz generally occurred in anhedral grains with an average diameter of .75 mm. Large single grains reached 2.25 mm. in diameter, and small grains found in groups were sometimes only .30 mm. in diameter. A few basal sections of the quartz were found which gave fairly good inter-

Plate XI

Photomicrograph of medium-grained granite, showing some of the primary minerals (Crossed nicols, x 30)

(O - oligoclase; B - biotite; Q - quartz) ference figures. A characteristic first order white to gray interference color was evident, and the extinction was irregular or undulatory. No cleavage or twinning was found.

The biotite occurred in subhedral to anhedral grains, pleochroic from light greenish-brown to dark yellow-brown. Good cleavage was shown in one direction (001). A distinctive characteristic of the grains was that the absorption was stronger when the cleavage traces were parallel to the vibration plane of the lower nicol. The grains were naturally longer in the direction of cleavage, with a few grains reaching a maximum length of 4 mm. The average length was 1.5 mm. Much of the biotite was altered in some degree to chlorite. This chlorite had a dull green color, showed weak birefringence, and usually partially or totally surrounded the biotite grains. Zircon inclusions surrounded by strong pleochroic halos were found in some of the biotite and quartz grains.

A few anhedral to subhedral, greenish-brown hornblende grains were found, and identified by their characteristic cleavage in two directions at angles of 56 and 124 degrees. This cleavage and other characteristics were rather hard to distinguish, however, and in most cases the hornblende appeared to be somewhat altered. Considering its relative abundance in hand samples, the small amount found in the thin section probably does not represent accurately the amount of hornblende present in the granite, and other sections probably would show a greater abundance.

A few small, irregular magnetite grains in the thin section were identified by their characteristic black color and their opaqueness even in thin section. They averaged about .30 mm. in diameter.

Topography and vegetation

A distinctive characteristic of the medium-grained granite in the thesis area is its susceptibility to weathering. As mentioned before, this characteristic is shown especially well in the granite quarry south of Mason at the junction of Farm Road 1723 and the James River road. Here the granite is deeply weathered, and rubbing it will cause the surface material to easily fall away. As a result of this weathering, layers of granite wash or "grus" from a few inches to several feet thick may overlie the bedrock (Plate X, Figure 2). In other parts of the area, the granite is exposed in small knobs, sometimes as large as small ridges, with a resultant slightly to moderately rolling or undulating topography. Irregular boulders generally make up these knobs and ridges.

Sparse to moderate vegetation is found on the medium-grained granite areas. The vegetation consists primarily of shin oak and post oak and mesquite, together with smaller amounts of Spanish dagger, prickly pear, tasajillo, and various grasses.

Fine-Grained Granite

Occurrence and relationships

The fine-grained granite is exposed in the north-central to northwest portion of the thesis area, where it is found in small knobs composed of irregular boulders. The granite is overlain on the south and west by lower Hickory sandstone. On the east and north it is generally adjacent to the gneiss, but no actual contact with the gneiss was found. To the north and northwest the granite appears to grade into the medium-grained granite. Several faults bring the fine-grained granite into fault contact with lower to middle Hickory sandstone in some parts of the area.

The assumption has previously been made that the medium-grained granite and the fine-grained granite are components of the same granite mass. Thus the correlation of the medium-grained granite with the Town Mountain granite would also hold true for the fine-grained granite, giving it a late Middle Precambrian age.

Megascopic description

This granite is fine- to medium-grained and has a pinkish-red general appearance with black spots. Both the minerals and their proportions seen in a hand specimen are the same as those of the medium-grained granite described previously, with quartz, biotite, feldspar, and hornblende predominating.

The grain size is fairly uniform in this granite, the grains having an average diameter of 3.5 mm. The feldspar grains are generally slightly longer than the others, averaging about 4.5 mm. in length. Pegmatites were observed in this granite in several places.

The rock becomes friable and light grayish-pink on weathering. The weathering characteristics described for the medium-grained granite hold true for this granite, and deeply weathered fine-grained granite boulders lying in a deep granite grus are found on the Milton Zesch property just south of Farm Road 1723.

Joints, although more obscure in this granite, in general approximately followed the trends described for the medium-grained granite.

Microscopic description

A thin section of the fine-grained granite was obtained from a sample acquired from the center of a nearly fresh boulder located about 50 feet to the east of Farm Road 1723 approximately one-half mile south of the medium-grained granite quarry.

The fine-grained granite has essentially the same mineralogic composition as the medium-grained granite. Only a few exceptions to this similarity were noted.

Microcline, plagioclase (oligoclase), quartz, and biotite were the primary minerals found in the fine-grained granite (Plate XII). The diameter of the microcline grains ranged from .20 to 1.75 mm., the average being .60 mm. The quartz grains were generally smaller, averaging about .50 mm. in diameter.

Many extinction angles were measured on the albite twins of the plagioclase, the largest being 10 degrees. This classified the plagioclase as oligoclase. The grain diameters ranged from .15 mm. to 1.25 mm., averaging about .50 mm.

The biotite grains, although elongated, were generally small in size, the average length being .35 mm. The range in lengths was from .10 mm. to .90 mm.

Only a few traces of hornblende were evident in this thin section. The hornblende was more abundant in hand samples, however, and additional thin sections would probably show it in larger amounts.

Small quartz crystals were found as inclusions, generally in the microcline grains. Small, isolated zircon grains, with characteristic pleochroic halos, were present in a few quartz grains. Chlorite was found as an alteration product, generally associated closely with the biotite. Microperthite was also evident, apparently in more abundance than in the medium-grained granite. No magnetite grains were evident in this thin

Plate XII

Photomicrograph of fine-grained granite, showing some of the primary minerals (crossed nicols, x20)

(M - microcline and microperthite, B - biotite, Q - quartz) section, but probably would be found if additional thin sections had been prepared and studied.

Topography and vegetation

The fine-grained granite is generally more resistant than the medium-grained granite, and it is usually found in knobs or boulders, mostly smaller than those of the medium-grained granite. The weathered fine-grained granite is very similar to the weathered gneiss found in the area. A flat to moderately rolling topography is usually evident where this granite is found.

The vegetation is essentially the same as that found on medium-grained granite areas. It consists primarily of mesquite and various types of oak, with smaller amounts of Spanish dagger, tasajillo, prickly pear, Mexican persimmon, and various grasses.

Pegmatite Dikes and Veins

Many pegmatite dikes, veins, and veinlets composed of quartz and feldspar occur in the granites, gneiss, and schist. These pegmatites, especially the quartz pegmatites, are much more resistant than the gneiss and schist, and occur as remnants scattered over the characteristic low undulating topography, as seen on the Francis Kettner property just south of U. S. Highway 87. In several instances the strike of the quartz veins was measurable, and was found to approximate a general N. 70° W. direction.

The quartz of the pegmatites has been intensely fractured, and is generally massive, and white, although in some areas it is stained by abundant iron oxides. Pink and red microcline grains comprise the feldspar, many of the grains reaching diameters of two or more inches.

CAMBRIAN SYSTEM

Riley Formation

Definition and Thickness

In the Llano region, rocks of Late Cambrian age rest unconformably on the Precambrian basement. These rocks belong to the Riley formation, which contains the lowest Paleozoic strata in the Llano region. Cloud, Barnes, and Bridge (1945, p. 154) proposed the name Riley formation to include all the Cambrian strata in central Texas that lie below the Wilberns formation. They designated three units in the Riley formation, namely, from base to top, the Hickory sandstone member, the Cap Mountain limestone member, and the Lion Mountain sandstone member. The above-defined Riley formation should not be confused with the "Riley series," involving some of the same rocks, used by Comstock and Dumble (Comstock, 1890, p. 564). This term has since been rejected for use in the classification of the United States Geological Survey.

The Riley formation is named for, and has its type locality in, the Riley Mountains of southeastern Llano County, where the members are very well exposed. The total thickness of the formation in the Moore Hollow area of the Riley Mountains, as measured by Cloud (Cloud, Barnes, and Bridge, 1945, p. 154), is 180 feet. Due to the very irregular topography of the Precambrian erosional surface, the thickness of the Riley formation in other measured sections is highly variable, and generally ranges from about 600 feet to almost 800 feet, but it may be less than 200 feet. This latter thickness is encountered in southwestern San Saba County, where the Cap Mountain limestone member rests directly on Precambrian rocks. The average thickness of the formation, according to Barnes and Bell (1954, p. 36), is about 695 feet. The formation is thickest in southeastern Llano County and is thinnest in the northwestern corner of the Llano region. In the Grossville School area, the thickness of the Riley formation is estimated to be about 715 feet.

Hickory Sandstone Member

Definition and thickness

The name Hickory was first used by Comstock and Dumble (Comstock, 1890, p. 564) as a series, named for Hickory Creek, in Llano County. Paige (1912, p. 42) revised it to the Hickory sandstone. The unit was finally brought to its present member status by Cloud, Barnes, and Bridge (1945, p. 154), who lowered the upper boundary of Paige's unit.

Bridge, Barnes, and Cloud (1947, p. 112) gave the Hickory sandstone member an average thickness of about 360 feet, with a range of from about 415 feet to a feather edge. As stated by them, this variance in thickness is due to the variation in Precambrian topography, depositional irregularities, and lateral gradation of the upper beds to limestone. The measurement of the complete member in the Grossville School area could not be accomplished due to the nature of the exposures, but the total thickness is estimated to be about 400 feet.

Lithology

The Hickory sandstone member is exposed in a large part of the thesis area. Most of the member is exposed, although a complete section is not found in any one part of the area.

The Hickory member is essentially a marine, yellow-brown to red, medium-grained sandstone that is very rich in iron oxides (limonite and hematite). It is generally noncalcareous and nonglauconitic.

The Hickory sandstone was deposited on an eroded Precambrian surface of very high relief. Bridge, Barnes, and Cloud (1947, p. 113) estimated as much as 800 feet of relief in some portions of the Llano region at the time of deposition of the Hickory member. Thus, it is readily understood that its thickness varies greatly from place to place.

The basal Hickory sandstone is a light gray to yellowish-brown, thick- to massively bedded, coarse-grained sandstone. Cross bedding (Plate XIII, Figure 1) is sometimes evident in these lower beds, and continues on up into the middle portion of the member. Large quartz grains or pebbles are found in these basal beds and were probably reworked from the underlying Precambrian rocks. These large grains range from subangular to rounded, and are found in irregular bands. The size of the grains decreases above the base. The rock is very hard, almost quartzitic, in some places, but is soft to friable in others, depending on the abundance of cementing material. Several large pebbles, 3.5 inches or more in diameter, are found in the thesis area, and even larger ones have been reported elsewhere. The pebbles are often wind-faceted and stained by the abundant iron oxides. Several pebbles have as many as six faces, although most of them have only two or three. Some original crystal faces are recognizable on a few of the pebbles, indicating the possibility that the faces on many of the other pebbles are also original crystal faces that have been frosted by wind action. These ventifacts are usually found near the Hickory sandstone - Precambrian rock contact in the thesis area, and are especially well exposed at the contact near the Francis Kettner farm house.

Plate XIII

Sedimentary Features in Hickory Sandstone

Figure 1.—Cross bedding in Hickory sandstone, located on west bank of Comanche Creek one-eighth mile south of F. Kettner ranch house

Figure 2.—Ripple marks in Hickory sandstone, located one-sixth mile south of M. Simon ranch house

Thin beds of fine siltstone and shale are interbedded with the sandstone (Plate XIV) in the lower-middle and middle portions of the member, and intraformational conglomerates are also sometimes present. The beds are soft to medium-hard, and the grain size ranges from fine to medium, with a few larger subrounded quartz grains still occurring. Fucoids (possibly seaweed) show as ridges on the surfaces of some beds, and ripple marks (Plate XIII, Figure 2) are also evident in this part of the section. Phosphatic brachiopods, mostly Lingula, are abundant in this part of the member.

The upper part of the middle Hickory sandstone is a thin- to medium-bedded, dark, brownish-purple, well-cemented sandstone containing hard, rounded, medium, poorly sorted sand grains. Abundant hematite gives a characteristic purple color to the beds. A few phosphatic brachiopods are scattered in these beds, but they become decidedly sparse in the upper portions of the member.

The upper Hickory sandstone consists of dark brown to dull red, massive sandstone, with rounded sand grains cemented with ferruginous cement. This portion is generally less resistant, easily weathered, and often cultivated. It is much richer in iron oxides, and many of the quartz grains are colored by hematite. Very small spherical balls or bean shaped bodies of hematite present in this part of the member may represent oxidized glauconite. Very thin shale partings lie between the sandstone layers and may be coated with caliche. The member becomes slightly calcareous towards the top. A deep red soil, the result of abundant iron oxides, is characteristic of this part of the member.

Plate XIV

Figure 1

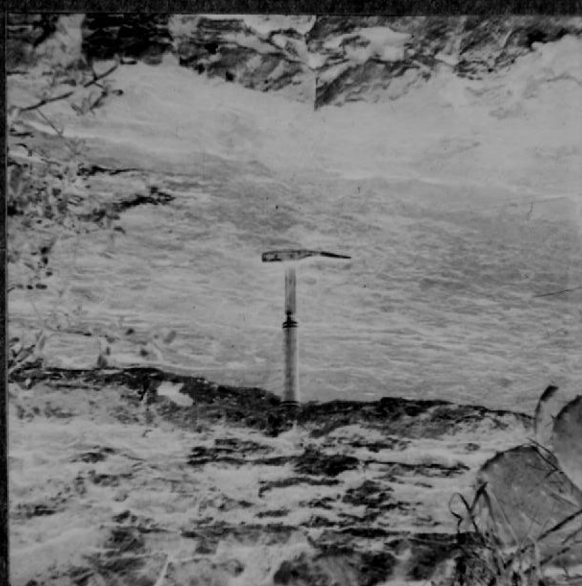


Figure 2

Silty beds in Hickory sandstone, located on west bank of Comanche Creek one-fourth mile south of F. Kettner ranch house

Topography and vegetation

The Hickory sandstone member is generally characterized by low topographic relief, due to the rapid disintegration of the sandstone. Both the lower and extreme upper portions of the member weather to form level sandy soils which are utilized for farming. The Hickory member also contains well-cemented sandstones, however, which do not weather easily. These sandstones have rather bold topographic relief, and usually form gentle cuestas and isolated hills, as seen in the western part of the thesis area.

Vegetation is necessarily sparse on those parts of the Hickory sandstone member which have been cleared, with only clumps of grasses and mesquite trees being present generally. Dense vegetation, consisting mainly of several types of oak, along with mesquite, Spanish persimmon, prickly pear, tasajillo, and various grasses, makes passage difficult where the land has not been cleared.

Cap Mountain Limestone Member

Definition and thickness

The Cap Mountain limestone member, as now recognized, is a redefinition by Cloud, Barnes, and Bridge (1945, p. 154) of the original Cap Mountain formation, as defined by Paige (1911, p. 45). Paige's formation included the present Lion Mountain sandstone member at the top, with the lower boundary somewhere above the present top of the Hickory sandstone. Thus, the member, as presently defined, includes fewer strata at the top and more at the base than Paige's original definition.

The type locality is at Cap Mountain in eastern Llano County. According to Bridge, Barnes, and Cloud (1947, p. 113), the thickness of the member ranges from 135 to 455 feet, with an average thickness of about 280 feet. The variation in thickness is due mainly to the gradation of the lower beds laterally into the underlying Hickory sandstone member. The Cap Mountain limestone member is well exposed in the thesis area, and its thickness is estimated to be about 250 feet. Duvall (1953, p. 26) estimated this thickness for the member in the South Mason-Llano River area, just to the west.

Lithology

The dark red to brown, noncalcareous sandstones of the Hickory member grade gradually into the lighter brown, arenaceous limestones of the overlying Cap Mountain member, and the contact is very difficult to distinguish in the thesis area. The essential factor in differentiation is the calcium carbonate content; the ferruginous cement of the Hickory sandstone decreases steadily while the calcareous cement increases. Thus, the sandstone becomes increasingly harder as it grades upward into sandy limestone. The contact is generally picked at the base of the first predominantly calcareous bed. Small calcite grains, possibly cavity fillings, are evident, and their first appearance can be used to supplement the basis mentioned above for determination of the contact. The sharp topographic and vegetational break at the contact mentioned by Bridge, Barnes, and Cloud (1947, p. 113) is not too evident in the thesis area.

The Cap Mountain member is essentially a fine-grained, medium- to massively bedded, sandy limestone. It is light tan to yellow-brown on the fresh surface, and weathers to a brownish-gray or pink color. Limonite stains may be present. The lower part of the member is made up of alternating layers of medium-grained, brownish-red, arenaceous limestone and calcareous sandstone. Scattered calcite and glauconite grains are present. Higher in the member, the limestone layers become fossiliferous and contain a few phosphatic brachiopods, and the sandstone layers become thinner, finer-grained, lighter in color, and almost absent in the upper reaches, although some fine-grained sand stringers do persist throughout it. The limestone becomes granular and massively bedded. A characteristic property of this part of the member is the presence of brown spots, probably limonite, scattered in the tan to grayish-brown, bedded limestone. This gives a mottled appearance to the beds which is similar to parts of the San Saba limestone member.

The bedding of this member is generally better exposed than that of the underlying Hickory member because of the higher calcium carbonate content. Thus, prominent limestone ledges, many of which exhibit honeycombed surfaces, are distinctive characteristics, and constitute most of the member. They cap many of the low rolling hills in the southwestern part of the thesis area. The ledges show the effect of jointing in places and may break off in blocks, generally in the lower, more arenaceous portions of the member.

The decrease of limonite in the upper parts of the member makes the color lighter. The limestone is generally brownish to pinkish-gray, fine- to medium-grained, glauconitic, slightly fossiliferous, and much less sandy than the lower portions. Also, there are some thin shale layers near the top of the member.

The contact of the Cap Mountain limestone member with the overlying Lion Mountain sandstone member is transitional and has been picked on topographic and vegetational changes, as well as changes in the appearance and content of the beds.

Topography and vegetation

The Cap Mountain limestone member is generally resistant and usually forms hills or cuestas where it crops out, as is seen in the southwestern part of the thesis area. The basal beds weather to produce level sandy soils which may be found in some areas, with the overlying beds forming the cuestas.

The vegetation is rather sparse on the lower level areas, with grasses and scattered mesquite predominating, but is relatively thick on the cuesta scarp slopes. Vegetation on these slopes generally consists of mesquite, scrub oak, Mexican persimmon, Spanish dagger, tasajillo, prickly pear, and catsclaw.

Lion Mountain Sandstone Member

Definition and thickness

The Lion Mountain sandstone was named as the uppermost member of the Cap Mountain "formation" by Bridge (1937, p. 234). It was named from Lion Mountain in the northwestern part of the Burnet quadrangle. Cloud, Barnes, and Bridge (1945, p. 154) retained the unit and type locality, but made it the top member of the Riley formation, since Cap Mountain as a formation name had been dropped.

The thickness of the Lion Mountain sandstone member is only about 20 feet at the type locality. It extends throughout the Llano region, however, and attains a thickness of 50 or more feet in other parts of the region. It is well exposed in the thesis area, where a thickness of 64 feet was measured. An unusual thickness of 106 feet of Lion Mountain sandstone about four miles northwest of the thesis area, as measured by Alexander (1952, p. 35), may be due to repetition by faulting or uncertain determination of boundaries.

Lithology

The contact of the Lion Mountain sandstone member with the underlying Cap Mountain limestone member is gradational and therefore not very distinct. The contact is picked on the basis of both topographic and vegetational changes, and is generally mapped at the lower limit of a characteristic sparsely vegetated bench. The Lion Mountain sandstone beds weather more easily than the Cap Mountain limestone beds, and the contact is usually marked by a change from the scarp slope of the Cap Mountain member to the relatively flat weathered surface of the Lion Mountain member. Changes in the appearance of the limestone are sometimes characteristic, and a purple color is a good indicator of the Lion Mountain member. The Lion Mountain member is composed of thinner beds than the upper part of the Cap Mountain member, and is also coarser and much more sandy.

The Lion Mountain member is essentially a coarse-grained, glauconitic, calcareous sandstone. The abundant glauconite is an important characteristic, as no other members exposed in the area contain as much. The lower part of the member contains tangential lenses of limestone composed essentially of abundant trilobite fragments and some brachiopod fragments ("trilobite hash"). The lenses are light gray to dark green in color, well-cemented, very glauconitic, and often cross-bedded. Some thin beds of siltstone and fine-grained sandstone occur above these lenses. These beds are generally soft and weather easily.

The upper portions of the member consist of thin- to medium-bedded sandstone which contains a few phosphatic brachiopod fragments. This sandstone is highly glauconitic and weathers to a dull green or dark grayish-brown, while the fresh surface shows a lighter color, with glauconite very evident.

The Lion Mountain sandstone ground surface is easily recognisable due to the abundant occurrence of "ironstone pebbles" dotting the landscape (Plate XV). These numerous, rounded, dull to shiny black pebbles are composed essentially of hematite and sand, and are believed to be weathering products of the glauconite.

A disconformity marks the upper limit of the Lion Mountain sandstone member, a disconformity which also marks the upper boundary of the Riley formation and the lower boundary of the Wilberns formation.

Topography and vegetation

The Lion Mountain sandstone member topographically forms a bench of variable width above the Cap Mountain limestone member. Due to this bench and its characteristic vegetation, the member has a distinctive appearance on aerial photographs, appearing as a light band of variable width, generally narrow. It can be confused only with the bench occurring at the top of the Hickory member.

The typical bench formed by the Lion Mountain member has clumps of scattered vegetation, making it distinct from the uniform vegetation of the overlying and underlying members. For the most part, the vegetation present consists of grasses, Mexican persimmon, scrub oak, prickly pear, tasajillo, and scattered mesquite.

Plate XV

Figure 1

Figure 2

Typical sparsely vegetated Lion Mountain sandstone bench, with trilobite hash fragments and hematite nodules, located one-third mile north of A. Schmidt ranch house

Wilberns Formation

Definition and Thickness

Cambrian rocks of the Wilberns formation lie above the Cambrian Riley formation and immediately below the Ordovician Ellenburger group. Paige (1912, p. 46) originally named and described the Wilberns formation from exposures at Wilberns Glen in Llano County. This original unit did not include the San Saba member of the present Wilberns formation. Instead, the San Saba member, although recognized by Paige as being of Cambrian age, was placed in the Ellenburger group because of lithologic similarities and the difficulty involved in determining the Ellenburger-San Saba contact. Paige's (1912, p. 46) lower boundary has persisted, but the upper boundary was redefined by Cloud, Barnes, and Bridge (1945, p. 150) and placed at the top of the Cambrian. The present five gradational members of the formation were described in detail by Bridge, Barnes, and Cloud (1947, p. 114-123). The fifth member, the Pedernales dolomite member, is not present in the western part of the Llano region.

According to Bridge, Barnes, and Cloud (1947, p. 114), the thickness of the Wilberns formation in the Llano Uplift region generally ranges from 540 to 610 feet. In the southeastern corner of the region, however, it is only about 360 feet thick, due to truncation and disconformity at the upper part. Discounting this area, the average thickness is about 580 feet. The thickness of the formation in the Grossville School area is estimated to be about 313 feet, but this is not a full section, as a few feet of the basal San Saba member constitute the highest part of the Wilberns formation in the area. Most of the San Saba member has been eroded. Alexander (1952, p. 37) measured 625 feet of Wilberns formation in the South Mason area, and Duvall (1953, p. 32) measured 596 feet in the South Mason-Llano River area.

Welge Sandstone Member

Definition and thickness

The Welge sandstone member, the basal member of the Wilberns formation, was named by Barnes (1944, p. 34) from strata exposed in the Welge land surveys between Threadgill and Squaw Creeks in Gillespie County. The member was first described fully by Bridge, Barnes, and Cloud (1947, p. 114).

According to these authors, the thickness of the member at its type locality along Squaw Creek, half a mile north of the Gillespie County line, is 27 feet. The thickness ranges from 9 to 35 feet throughout the Llano region, averaging 18 feet. The northern and western ends of the region contain the thicker sections. A thickness of 19 feet was measured in the Grossville School area. Alexander (1952, p. 37) measured thicknesses of 26 and 29 feet in the South Mason area, and Duvall (1953, p. 32) measured 17 feet in the South Mason-Llano River area.

Lithology

Excellent exposures of the complete Welge sandstone section are present in the hilly south-central portion of the thesis area. The contact of the Welge member with the underlying Lion Mountain member is very distinct and easily traced in most parts of the area. In certain places, however, weathering of the lower beds of the Welge sandstone has masked the contact (Plate XVI, Figure 1), and the contact in these places is usually picked on the basis of a vegetational change, the vegetation of the Welge member being much denser.

Plate XVI

Surface Expression of Welge Sandstone Member

Figure 1.—Masked Lion Mountain sandstone - Welge sandstone contact, located one-third mile north of A. Schmidt ranch house

Figure 2.—Weathered Welge sandstone ledges, located west of Farm Road 1723, seven-eighths mile northeast of A. Schmidt ranch house

The Welge member is a rather uniform fine- to medium-grained, well-cemented sandstone. A characteristic of the quartz grains is their degree of roundness, which is usually greater than that of quartz grains of the Hickory sandstone. The sand grains also have a higher degree of sorting than those of the Hickory sandstone. The fresh surface of the beds is light gray or brown, weathering to red or yellowish-brown. Many of the quartz grains glitter or sparkle in the sunlight due to the reflection from their recomposed or recrystallized faces. Very little glauconite is found in this member, although scattered grains are contained in some beds.

Most of the Welge member is thick- to massively bedded. The lower sandstone beds occasionally show cross bedding. The presence of easily weathered silty shale layers in the upper part of the Lion Mountain member probably accounts for the fact that many ledges of Welge sandstone are slumped in the area (Plate XVI, Figure 2).

This member is transitional into the Morgan Creek limestone, and the upper Welge sandstone beds become calcareous as the contact is approached. The upper limit of the Welge member is placed at the base of the first characteristic purple limestone bed of the Morgan Creek member.

Topography and vegetation

In the thesis area, the Welge sandstone member generally forms an abrupt scarp at the upper edge of the bench formed by the Lion Mountain sandstone member. This feature is very evident where the Welge sandstone ledges are distinct. In other places, however, weathering and slumping of the lower Welge sandstone ledges have masked the contact.

This member is very heavily vegetated, and is characterized by a dark, narrow line of vegetation that is pronounced on aerial photographs. Mesquite, whitebrush, tasajillo, scrub oak, and Mexican persimmon are the predominant types of vegetation.

Morgan Creek Limestone Member

Definition and thickness

The Morgan Creek limestone member was first named by Josiah Bridge from outcrops on the north and south forks of Morgan Creek in Burnet County. The type section is located at a point just north of the junction of these two forks. This member was included by Paige (1912, p. 46-47) in the lower part of his original Wilberns formation, and was first fully described by Bridge, Barnes, and Cloud (1947, p. 114-115).

According to Bridge, Barnes, and Cloud (1947, p. 114), this member is about 110 feet thick at its type section. In other areas the thickness ranges from 70 to 160 feet, averaging about 120 feet. The thickness in the thesis area is estimated to be about 140 feet. Alexander (1952, p. 39) reasure 179.2 feet of Morgan Creek limestone in the South Mason area, and Duvall (1953, p. 34) measured 154 feet in the South Mason-Llano River area.

Lithology

The contact between the Morgan Creek limestone member and the underlying Welge sandstone member is transitional, and is usually mapped at the base of the lowest purplish-red, somewhat arenaceous limestone bed, a distinctive basal Morgan Creek member marker. These beds grade into buff and greenish-gray, medium- to coarse-grained, slightly fossiliferous, less sandy limestones (Plate XVII, Figure 1), which make up most of the member. The entire member contains an abundance of glauconite.

Plate XVII

Surface Expression of Morgan Creek Limestone Member

Figure 1.—Morgan Creek limestone beds, located in gully bed one-half mile northeast of A. Schmidt ranch house

Figure 2.—Morgan Creek limestone slope, located on south side of hill one-fourth mile northeast of A. Schmidt ranch house

The limestone ledges of the entire member are generally very hard and resistant to weathering, and many are easily traced for long distances. The average thickness of an individual bed is one foot. Thinner, soft, calcareous claystones are interbedded with the limestones in places, however, and weather easily, causing some of the more resistant ledges to be broken down also (Plate XVII, Figure 2).

Well-rounded quartz and glauconite grains are especially evident in the lower part, and beds appearing to contain equal parts of calcite, glauconite, and quartz are a lower Morgan Creek member characteristic.

A zone containing Eorthis texana is generally present about 60 feet above the base of the member. The material of this zone has often been called a "brachiopod hash" because of the abundance of brachiopods. These brachiopods, along with trilobites, are also found scattered from this zone on up to the top of the member in thin- to medium-bedded, gray, slightly argillaceous limestones. Thin, silty, calcareous shale beds alternate with the limestone toward the top of the member.

A zone of small, gray to light purple stromatolitic bioherms is found just below the top of the member (Plate XVIII). The zone is very irregular and has a variable stratigraphic position, but it generally ranges from two to nine feet below the top of the member. The individual bioherms are spheroidal to ellipsoidal in shape, and vary from three or four inches to one foot or more in diameter. The material ranges from impure sub-lithographic limestone which is impregnated with brown and green stains, probably from the influence of hematite and glauconite, to very pure, sub-lithographic limestone. The small size of the bioherms distinguishes them from those found in the Point Peak shale.

Plate XVIII

Figure 1

Figure 2

"Baby" bioherms near top of Morgan Creek limestone, located near top of small hill one-fourth mile northeast of A. Schmidt ranch house

The Morgan Creek member is transitional into the overlying Point Peak member and the contact is usually based on the first appearance of good thin siltstone layers. Gentler slopes and vegetational changes also generally appear at the contact.

Topography and vegetation

The Morgan Creek limestone member generally forms a prominent steep slope above the Welge sandstone scarp and below the rather gently sloping Point Peak shale member. The Morgan Creek limestone is usually a distinctly bedded member, and many individual beds are traceable for long distances on aerial photographs.

Vegetation on this member is plentiful and rather uniform, but not as dense as that of the underlying Welge member. Spanish dagger, scrub oak, agarita, prickly pear, and tasajillo predominate.

Point Peak Shale Member

Definition and thickness

The Point Peak shale member was named by Josiah Bridge from exposures on Point Peak, an isolated hill about four miles northeast of Lone Grove, Llano County. The type section is located on the south slope of Point Peak. The member was first described fully by Bridge, Barnes, and Cloud (1947, p. 115-116).

According to Bridge, Barnes, and Cloud (1947, p. 115), the thickness of this member at its type section is about 270 feet. The average thickness is about 160 feet, the member being thicker in the southeastern portion of the Llano area, and thinner in the northeast portion. The member may be as thin as 25 feet, due to facies changes and variations in sedimentation in certain areas. On the basis of its thickness in nearby areas, the thickness of the member, including the bioherm zone, in the thesis area is estimated to be about 150 feet. Duvall (1953, p. 36) estimated a thickness of about 165 feet of Point Peak shale in the South Mason-Llano River area.

Lithology

The underlying Morgan Creek member is transitional into the Point Peak member, the base of the Point Peak member generally being placed at the lowest thin siltstone or shale bed. In the thesis area, this contact is very hard to establish, and the above criterion was supplemented by vegetational characteristics. The beginning of the more abundant growth of mesquite can be used to mark the basal Point Peak shale. In other areas, sharp topographic and vegetational changes occur at the contact.

A stromatolitic bioherm zone has been recognized in the upper Point Peak shale and was distinguished and mapped as a distinct zone of the Point Peak member.

The lower part of the Point Peak member is composed mainly of fine clastic material, and consists of interbedded calcareous, gray siltstones or shales, and fine- to medium-grained, thin, crystalline, buff to gray, glauconitic limestones. The limestones are very similar to those of the Morgan Creek member. These alternating well-bedded layers, along with intraformational conglomerates, make up the major portion of the member. Ripple marks, mud cracks, fucoids, and rain prints are evident in some beds. Brachiopods are also found in some parts of the member.

As mentioned above, intraformational conglomerates are frequently encountered in this member. These beds vary from one inch to two feet in thickness, averaging about six inches, and consist of flat Point Peak siltstone and limestone pebbles in a matrix of brown, medium-grained limestone and silt. Many different sizes and colors of pebbles are evident, with red, green, yellow, and brown being the predominant colors. This conglomerate has often been called edgewise conglomerate, but the pebbles are generally oriented with their flattened surfaces parallel to a horizontal plane. Glauconite is also present in the conglomerate.

Beds of the Point Peak member are not resistant and are very susceptible to erosion. They weather easily to form gentle to moderate slopes covered with slabs of conglomerate and limestone, and pieces of caliche. The slopes in the thesis area are usually rather steep, however, due to the protective influence of the overlying hard bioherm zone.

The stromatolitic bioherm zone at the top of the Point Peak member is distinct and rather easily recognized and traced, and was thus mapped separately. Thin, green to gray glauconitic limestones and calcareous shales are interbedded with the bioherms and dip around them (Plate XIX, Figure 1). In places the bioherms coalesce. The bioherms are gray in color, consist essentially of microgranular to sub-lithographic limestone, and are often marked by characteristic brown stains, with "cabbage-head" structure being evident in the entire zone (Plate XIX, Figure 2). The thickness of the zone is highly variable, and ranges from 15 to at least 40 feet in the thesis area.

The Point Peak shale member is transitional into the overlying San Saba limestone member. The contact is generally placed at the top of the bioherm zone. Some limestone layers, resembling basal San Saba limestone member beds, are interstratified with the top few feet of the

Plate XIX

Characteristics of Bioherms of the Upper Point Peak Member

Figure 1.--Dip of strata around Point Peak bioherms, located on crest of hill one mile east of A. Schmidt ranch house

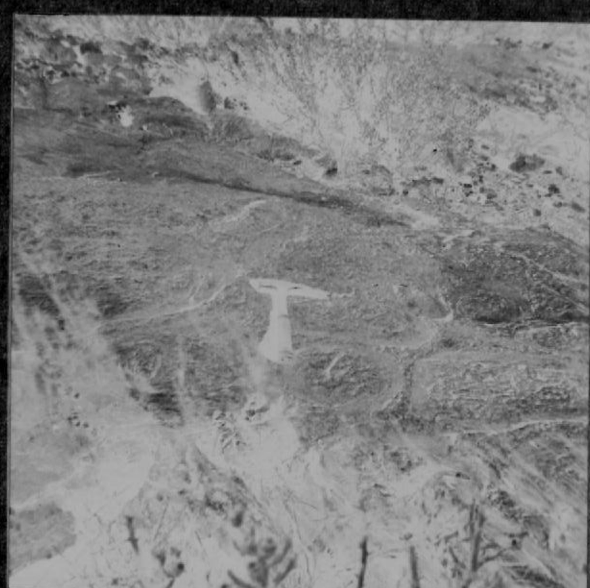


Figure 2.--Point Peak bioherm, showing "cabbage-head" structure, located on crest of hill one mile east of A. Schmidt ranch house

bioherm zone, and were included in the Point Peak member in the thesis area.

Topography and vegetation

The lower portion of the Point Peak shale member, immediately above the Morgan Creek member, is generally characterized by a low, gentle topographic shelf or slope of weathered siltstone. The upper portion of the member is better protected by the bioherm zone capping the top of the slope, and forms a steeper slope rising from the lower shelf. The bioherm zone caps most of the hilly portions in the south-central part of the thesis area.

The bioherm zone tends to be more heavily vegetated than the lower moderate to rather steep slopes of the Point Peak member. The first appearance of mesquite trees in the Wilberns formation is especially characteristic of the lower Point Peak member, along with other sparse vegetation consisting of live oak, prickly pear, agarita, and Spanish dagger. The bioherm portion supports dense vegetational growth consisting of Mexican persimmon, prickly pear, catsclaw, Spanish dagger, and agarita. No mesquite is present in this portion.

San Saba Limestone Member

Definition and thickness

Comstock (1890, p. 566) first used the name San Saba as a series term applied to exposures of limestone along the San Saba River near Camp San Saba in McCulloch County. Dake and Bridge (1932, p. 729) gave these beds a younger age than suggested by Paige (1912, p. 46) in his original Wilberns definition, and advocated the revival of Comstock's San Saba terminology for them. The term San Saba was revised to its present member status by Josiah Bridge, and Bridge, Barnes, and Cloud (1947, p. 117) fully defined and described it as including the glauconitic limestones overlying the Point Peak shale member and underlying the Tanyard formation of the Ellenburger group. The type section is located along both sides of the Mason-Brady highway near the San Saba River bridge.

The San Saba limestone and the Pedernales dolomite members are essentially equivalent facies, the San Saba limestone predominating in the western and the Pedernales dolomite predominating in the eastern parts of the Llano region.

According to Bridge, Barnes, and Cloud (1947, p. 117), the type section of the member is 280 feet thick. A complete section is not exposed in the thesis area. Duvall (1953, p. 38) reported a thickness of 261 feet of San Saba limestone measured just southwest of the South Mason-Llano River area at a section exposed in the bed of the Llano River.

Lithology

The basal contact of the San Saba member is placed at the upper boundary of the stromatolitic bioherm zone of the Point Peak member. Bedded limestone of the basal San Saba member generally lies directly over these bioherms, but in some places is interbedded with or draped over them, as the bioherms may occur irregularly at different elevations in the section. In the latter case, the contact is difficult to determine and map with accuracy. In this situation in the thesis area, the interbedded limestones were included in the upper Point Peak member and the upper limit of the bioherms was chosen as the contact.

Only the basal few feet of the San Saba limestone member are exposed in the thesis area. These beds are exposed on the tops of a few ridges in the hilly south-central portion. The thickness of these beds reaches a maximum of about four feet.

The San Saba limestone exposed in the area consists of well-bedded, granular, arenaceous limestone. The color of these beds is grayish- to tannish-brown, with scattered green specks of glauconite. Differential weathering causes these lower beds to appear as thin slabs with a brown and orange, characteristically rough surface.

The following short description of the remainder of the San Saba member is taken from descriptions of exposures in other areas. Generally, arenaceous, medium-bedded, medium- to coarse-grained limestone makes up most of the San Saba member. Pure limestone with some sub-lithographic beds makes up the upper part of the member. A sandy section is found in some areas about 50 feet above the base of the member. Varying amounts of glauconite are present throughout the member, generally being more abundant in the lower portions. Thin, calcareous silts and fine-grained sands are often interbedded in the limestone. Tan to brown, fine-grained dolomite zones are also reported as occurring in the member. Most of the sequence is fossiliferous, containing brachiopods and trilobites, sometimes forming a "hash." The gastropod Lytospira gyrocera is also present in the upper part of the member.

The upper part of the member is made up of thin-bedded, slightly glauconitic, sub-lithographic limestone, which grades upward into the similar but purer, non-glauconitic limestone of the Ellenburger group. This lithologic difference, along with differences in fossil content, is generally used to select the contact.

Topography and vegetation

Although not evident in the thesis area, the San Saba limestone member is generally characterized by an irregular, rolling topography. Individual beds and ledges are usually resistant and do not weather readily, the outcrop surface being very rocky. The bedding lines are usually seen on aerial photographs.

Vegetation on this member is generally moderate and scattered. The member is so sparse in the thesis area that its characteristic vegetation is hard to distinguish, but usually mesquite, scrub oak, Mexican persimmon, prickly pear, turkey pear, and cedar are most abundant.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Llano region is structurally a dome, but topographically a basin in which the metamorphosed and intensely folded and deformed Precambrian basement rocks have been exposed in many places. The overlying Paleozoic beds in the area probably originally dipped gently away from the center of the dome, which is elliptically shaped and has a general west-northwest - trending axis. Younger beds, essentially flat-lying, have been removed by erosion in most parts of the area, thus leaving the Precambrian and Paleozoic rocks exposed.

The Precambrian and Paleozoic rocks have been distrubed and broken into blocks dipping at various angles by severe faulting, which, according to Cloud and Barnes (1948, p. 118), occurred near the close of Strawn and before Canyon time. According to them, these normal tensional faults have dips ranging from 60 to 90 degrees, are downthrown to the northwest, and trend in a general northeast-southwest direction. These faults were designated by Sellards and Baker (1934, p. 85) as the Llano system of faults. According to these authors, they often form extensive grabens, and have displacements ranging up to 3,000 feet. The beds in the thesis area, except for those immediately adjacent to the faults, generally are found to have a strike of about N. 70° E. and a dip of approximately 5 degrees to the southeast.

There is some evidence of Paleozoic folding in the Llano region, generally in the form of broad structural warps, tight folding being absent for the most part. Small local folds due to slumping, drag along faults, and compaction around bioherms are also found.

PRECAMBRIAN STRUCTURAL CONDITIONS

General Statement

Stenzel (1934, p. 73) stated that the Precambrian rocks of the Llano region are somewhat altered and usually intensely deformed, and that the kind of Precambrian deformation found in the region is widespread and found in the Precambrian of other parts of the state. The Precambrian regional structure of the region generally consists of wide, open folds which have a northwest-southeast trend, and an average pitch of 16 degrees to the southeast. The metamorphic rocks within these broad folds are in turn compressed into smaller intricate isoclinal and zigzag folds. Stenzel (1934, p. 74) also stated that the bedding and schistosity are parallel, and that the grain in the schists and gneisses is parallel to the pitching axes of the open folds.

Local Precambrian Structural Conditions

The structures observed in the Precambrian rocks of the Grosseville School area generally seem to agree with the Precambrian deformation of the entire Llano region.

The strike and dip of the foliation planes of the gneiss and schist were observed and measured in many parts of the thesis area. In other parts of the area, however, the rocks are too fractured, weathered, or metamorphosed to give good measurements. It was found that the strike of the foliation planes ranges from N. 80° W. to N. 50° E., the average strike being N. 70° W. The dips range from 20 degrees to almost vertical, and are generally in a northeast direction. The strike of several pegmatite and quartz veins was measureable, and was also found to be generally N. 70° W.

In almost all parts of the thesis area where the gneiss and schist are exposed, the strike of the foliation planes departs only slightly from the N. 70° W. average mentioned above. In one part of the southeastern corner, however, the strikes measured gave the extreme northeast-southwest trend mentioned earlier. These measurements were taken not more than five feet from a fault in that part of the thesis area, and the effect of the faulting was probably the cause of the variation in strike of the foliation planes.

The measurements of strike and dip of the foliation in the metamorphic rocks were not in sufficient number to particularly indicate the presence of wide, open folding as described by Stenzel for the Llano region. The dip of the foliation planes does vary, however, as mentioned above, and possible folding is indicated, although no definite pattern could be ascertained.

A characteristic feature is very evident in the few schist outcrops found in the bed and along both banks of Comanche Creek in the north-central portion of the thesis area. In these outcrops, very tight folding is prominent. These folds are very small, plunge at a high angle, and are not traceable for any distance. In general, the axes of these small folds are aligned in a northwest-southeast direction. Evidence of this type of folding is also seen in several of the gneiss outcrops.

Many small faults and fractures were also observed in the gneiss and schist, particularly along Comanche Creek, where these units are best exposed. The majority of these small faults have throws of only several feet at the most, and generally the displacement can be measured in inches.

The trends of Precambrian deformation just discussed are not reflected in the Paleozoic rocks exposed in the thesis area.

FAULTING

A complex system of normal faults is evident in the Grossville School area. Two major faults and numerous other faults are present, the majority trending in a general northeast-southwest direction. Most of the faults are located in the southern portion of the area.

Major Faults

The two major faults trend in a general northeast-southwest direction diagonally across the thesis area. They are approximately one and three-fourths miles apart at the widest point. The fault to the southeast, named the Schep Creek fault by Sliger (1957), is downthrown to the northwest. The fault to the northwest, named the Peters Creek fault by Wilson (1957), is downthrown to the southeast in the central and southwest portions of the area, thus forming a graben in the center. A probable synclinal fold is located in the hilly south-central portion of the area - in the downdropped block of the graben. The Schep Creek fault generally has a persistent northeast-southwest trend, and the Peters Creek fault has a northeast-southwest trend in the southwest part of the area, which probably continues through the northeast part, although it could not definitely be traced through the intervening Precambrian gneiss outcrop.

The Schep Creek fault appears to terminate the hilly section of high relief in the south-central portion of the area. The throw of this fault ranges from 100 to 400 feet, the lower Hickory sandstone being in fault contact with the Cap Mountain limestone in some places, and the Cap

Mountain limestone being in fault contact with beds of Lion Mountain, Morgan Creek, and Point Peak age in others. The fault also brings the Precambrian gneiss unit into contact with the Hickory sandstone in the area near Comanche Creek, and the throw here could not be determined accurately. The amount of throw on this fault decreases to the northeast. A gentle to moderate scarp is found on the downthrown side of the fault.

The effect of this fault on the strike and dip of the beds immediately adjacent to it can be seen in several places, particularly on the upthrown side, where the Cap Mountain limestone beds have been deformed so as to dip down toward the fault plane at varying angles.

Fault breccia is evident at several places along the trace of the fault and was very helpful in accurately tracing it. This breccia is very well developed where the fault cuts through the hilly south-central portion of the thesis area.

The Peters Creek fault was estimated to have a maximum throw of about 300 feet. There is a distinct possibility that this fault continues northeast across the Precambrian gneiss outcrop to join the fault present in the extreme northeast corner of the area, which is downthrown to the northwest. If this is the case, the throw of the fault must be zero at some point within the gneiss outcrop, thus making the fault much harder to detect in that portion. No evidence of this reversal of throw is evident along the Schep Creek fault in the thesis area, however.

To the southwest the Peters Creek fault is located entirely within the Cap Mountain limestone, while to the northeast it brings Hickory sandstone against Cap Mountain limestone, lower Hickory sandstone against upper Hickory sandstone, and Precambrian granite against Hickory sandstone.

Still further to the northeast, the fault is entirely within the Precambrian gneiss, and if extended to join the fault in the northeast corner, brings Hickory sandstone into contact with the Precambrian gneiss.

The effect of this fault on the strike and dip of the beds is not as noticeable as that of the other major fault, but indications of dip into the fault are seen in several places, particularly in the Cap Mountain beds near the fault in the southwestern part of the area.

A scarp as such is not evident on either side of this fault, although the relief is generally much greater in the area to the southeast of the fault.

Fault breccia is evident along the fault in a few places, mostly in the west-central part of the thesis area.

Two major faults, the Schmidt fault and the Simons fault (Alexander, 1952, p. 48), are located immediately to the northwest of the thesis area. According to Parke (1953, p. 47-49), these faults both trend in a northeast-southwest direction, are downthrown to the northwest, and have throws ranging from 350 to 800 feet. The Simons fault brings Ellenburger group beds against Hickory sandstone strata northwest of the James River road.

Other Faults

The other faults in the thesis area can be classified into two types: (1) slivers along the major faults, and (2) isolated faults.

The slivers or splinters from both the major faults usually strike in a direction varying from slightly east of north to northeast. These faults are very abundant and are probably the result of splitting of the major faults along their length into smaller compensating or adjusting faults. Their characteristics and displacements are generally controlled by their relation to the prominent faults from which they are offshoots. This is particularly true as far as the upthrown and downthrown sides are concerned. The displacement along these faults is generally small, usually less than 100 feet. Detection of these sliver faults was much more difficult than the detection of the major faults, except in the case of the large sliver fault trending east from the Peters Creek fault in the central portion of the area. This sliver fault curves to trend northeast in the east-central part, where several smaller sliver faults branch off from it. This fault, being controlled by the Peters Creek fault, is downthrown to the east and southeast, and it in turn controls the direction of displacement of the smaller sliver faults. The large sliver fault is well exposed in the immediate vicinity of Comanche Creek, where it was easily traced. It has a maximum displacement of about 100 feet.

The small sliver faults, in conjunction with several of the isolated faults, form smaller grabens and horsts, many being within the larger graben block bounded by the two major faults.

Isolated faults are those faults which appear to have no definite connection with any other major or sliver faults in the area. Several are present in the hilly south-central portion, where they trend in a general northeast-southwest direction, are downthrown to the southeast, and have small throws ranging from 10 to 40 feet. Most of the others are located in the area to the northwest of the graben zone. They are generally located entirely within the Hickory sandstone, but several have brought beds of the Hickory member into contact with Precambrian rocks. The displacement along these faults is generally very small. One of them, located in the Hickory sandstone in the northwest part of the area, has a strike of N. 40° W., nearly perpendicular to the strike of most of the other faults in the area.

Several of the isolated faults are located in the Precambrian rocks. These faults were, in the main, detected from aerial photographs, and it was usually impossible to determine the upthrown and downthrown sides.

Many still smaller faults, with throws ranging from only a few inches to several feet, are located in the area, usually between the faults actually mapped. In general, their trends coincide with those of the larger faults. Most of them are located within the Hickory sandstone member (Plate XX).

The recognition of the other faults, in general, was more difficult than the recognition of the major faults. Omission of strata, termination of key beds, or the presence of fault breccia were often the only indications of the presence of other faults in a certain area. Many of these faults were easily spotted, however, and typically appeared on aerial photographs as lines of denser vegetation. This is the result of the fractured zones providing more rooting space and moisture for the trees and smaller plants.

The regional strike and dip have been altered along some of the faults discussed, especially the faults bounding the graben, and several of the other faults. Drag dips next to some faults have values ranging from 7 degrees to about 85 degrees. These latter large values were measured on upturned Hickory beds that are exposed right at the fault plane of an isolated fault in the northwest-central part of the thesis area (Plate XXI).

Plate XX

Small fault in middle Hickory sandstone, located in cut on James River road 400 yards northwest of M. Simon ranch house

Plate XXI

Figure 1

Figure 2

Upturned Hickory sandstone in contact with Precambrian along fault, located one-third mile northwest of M. Zesch ranch house

This deformation is generally limited to the areas immediately adjacent to the faults, and does not extend very far from the fault planes. In other places along the faults, however, there is little disturbance of the strike and dip of the beds, the faults apparently having broken the beds cleanly. No evidence of "reversed" drag is seen in the thesis area.

Origin of Faulting

Several theories have been advanced concerning the origin of faulting in the Llano region.

Paige (1912, p. 74) stated that the faults were the direct result of compressive forces. He based his opinion on the fact that most of the faults in the region are vertical or nearly so, saying that these faults, combined with folds, indicate an expression of relief from compression by vertical movement.

Cloud and Barnes (1948, p. 118) stated that faulting in the Llano region probably accompanied the late Paleozoic folding involving the sediments of the Llanoria geosyncline, with movement in the geosynclinal area placing the Llano region under torque and causing it to fracture. Rocks of the Llano area were thought to have comprised a relatively resistant mass around the western and northern sides of the Llanoria geosyncline. They did not explain the precise mechanism which caused the faulting, but did attribute it to tensional rather than compressional forces.

The theory that the origin of the faulting was due to tension rather than compression is substantiated in the thesis area by the presence of the previously described large graben, together with the smaller associated grabens in its downdropped block. The downdropping of the blocks probably resulted as potential void spaces were developed by the tensional forces which caused the faulting.

Detection of Faulting

Most of the faults in the Grossville School area were located by an intensive examination of aerial photographs. Variations in vegetational characteristics, such as alignments and offsets in the vegetational pattern, which occur along the major faults and many of the smaller ones were usually easily spotted on the photographs. These observations were then verified by field work; the faults located from the photographs were found and traced in the field. This field tracing enabled many of the faults to be carried farther than they appeared on aerial photographs and allowed several previously isolated faults to be connected.

Several criteria were used to locate and trace these faults, as well as other smaller faults which exhibit no sharp vegetational change, in the field. The most important were the deviation in the observed normal strike and dip of the beds, repetition and omission of strata, abrupt termination of key beds, occurrence of fault breccia, and detection of upturned beds right at the fault break.

Faulting in the Precambrian rocks of the thesis area was very difficult to detect in the field, and this also held true generally for faulting within the Hickory sandstone member. Faulting involving beds of the other Upper Cambrian members was generally much easier to find.

FOLDING

Alexander (1952, p. 53) stated: "Preliminary observations between the South Mason area and the Llano River by Dr. H. R. Blank and the writer indicate that the southeastward-dipping beds of the Hickory sandstone in the southeastern corner of the area may be part of the northwest flank of a gentle fold whose axis trends northeast-southwest. The dip of the beds becomes more gentle toward the Llano River; south of the river the Paleozoic strata begin to dip gently to the northwest."

The southeastward-dipping beds of Hickory sandstone mentioned by Alexander are located in the northwestern part of this author's thesis area. These beds are terminated by a fault just to the southeast of the area mentioned by Alexander, and do not appear again in the thesis area. Therefore, the preliminary observations postulating a possible fold could not be checked by this author in his thesis area.

A probable gentle warp of synclinal nature, located in the hilly south-central portion of the thesis area, was indicated by strike and dip measurements taken in that immediate vicinity. These measurements, taken on beds of the Lion Mountain and Cap Mountain members, showed the strikes to form the pattern of a general northeast-southwest trend on the western side of the hilly area, varying to an approximate east-west trend on the north side, and on to a general northwest-southeast trend on the eastern side. The dips are generally toward the hilly portion and vary from one to ten degrees. This strike and dip pattern, along with the outcrop pattern in the area, indicates a general north-south or north-northwest - south-southeast axis almost perpendicular to the strike of the faults bounding the graben in which the probable synclinal fold is located.

In addition to the probable large-scale folding mentioned above, evidence of small-scale folding is also seen is several parts of the thesis area. These small folds are due to fault drag and differential compaction around bioherms (Plate XIX, Figure 1). Evidence of fault drag folding is found in various localities, whereas the compaction folding is limited to a few occurrences in the hilly south-central portion of the area.

AGE OF DEFORMATION

The folding and faulting described previously affect even the youngest beds exposed in the Grossville School area, and evidently the deformation took place after the deposition of the now-present sediments. Therefore, accurate dating of the structural movements from evidence available in the thesis area is impossible, but as local structural conditions coicide closely with the trends of major Paleozoic deformation in other parts of the Llano region, it is logical to assume that the local deformation occurred simultaneously with the regional deformation.

Cloud and Barnes (1948, p. 121) have assigned a post-Bend and pre-Canyon age to the major late Paleozoic faulting. They based their opinion on several lines of evidence. Unfaulted Canyon-age beds overlie faulted rocks of Ellenburger age in the western part of the Llano region. Also, faults have been found in the region involving the Smithwick shale and certain rocks of the Strawn group. The authors, however, stated that they knew of no evidence to indicate whether the faulting was in progress during Strawn time or was a post-Strawn and pre-Canyon event.

GEOLOGIC HISTORY

The following geologic history portraying the sequence of events which occurred in the Llano Uplift region is generally supported by evidence available within the thesis area. Some of the history, however, must be inferred from evidence derived from other portions of the Llano region.

The Precambrian metamorphic rocks in the thesis area are probably derived from original thick sedimentary deposits which consisted of sandstones, shales, and some limestones. As these great thicknesses of sediments were deposited, they became deeply buried, and were folded, faulted, and metamorphosed by intense heat and pressure. Later, very high temperatures deep below the surface of the earth caused the formation of magma. This magma intruded the sedimentary deposits and solidified, forming granitic batholiths. The coarse-grained texture of most of the intruded igneous rocks indicates that these masses cooled slowly and crystallized at great depths. In the thesis area, the medium- and fine-grained granites may represent the outer portions of a large granite mass (Town Mountain type). Precambrian schists, gneisses, and granites are all exposed in the thesis area due to uplift and extensive erosion. The region was extensively eroded during late Precambrian time, and this period of erosion lasted into Paleozoic time.

The area remained above base level and continued to be eroded until Late Cambrian time, when the sea transgressed over an irregular Precambrian rock surface of considerable relief. The basal coarse-grained portion of the Hickory sandstone was formed as the invading Paleozoic sea reworked eolian deposits of the Precambrian surface, as is shown by the presence of numerous ventifacts, some being present as much as several feet above the base of the Hickory sandstone, as reported by Barnes and Parkinson (1939, p. 668).

The nature of the sediments indicates that shallow water conditions probably prevailed throughout the time of deposition of the Hickory member. Many of the lower and middle Hickory sandstone strata are cross-bedded, and symmetrical ripple marks are found in places. A few intraformational conglomerates are found in the middle Hickory member, and phosphatic brachiopods are found in the middle and sparingly in the upper portions. Much of the sand, especially in the upper Hickory member and higher, was probably derived from the north, northwest, or west, because the Precambrian surface generally sloped upward in these directions during the time of Cambrian sedimentation (Barnes, 1956, p. 8). Relatively quiet seas prevailed, seas which became somewhat deeper later, as is shown by the absence of cross bedding in the upper parts of the Hickory member, and the gradation of its marine sandstone into the Cap Mountain limestone. No definite interruption in sedimentation is evident.

A shallow sea depositional environment, probably somewhat warmer, prevailed during the time of deposition of the Cap Mountain limestone member, as is shown by the presence of some phosphatic brachiopod and trilobite fossils throughout the member. The limestone of this member is highly arenaceous, which would seem to indicate that the source area from which the sediments were being derived was being reduced in elevation to a large degree and stripped of quartzose detritus.

Renewed small-scale uplift and subsequent erosion probably provided the quartzose material which went to make up the Lion Mountain and

Welge members. Both members are fossiliferous, thus showing the presence of marine conditions, probably shallow water. The disconformity between the highly glauconitic regressive sandstone of the Lion Mountain member of the upper Riley formation and the slightly glauconitic transgressive sandstone of the Welge member of the lower Wilberns formation is probably just the result of slight uplift in the area, followed by subsidence. The source of sand at this time was probably to the northwest, as both the Lion Mountain and Welge members thin to the southeast.

The deposition of sandy material decreased gradually toward the end of Welge and into Morgan Creek time, and limestone deposition by a probably deeper sea became prevalent, as is shown by the basal arenaceous limestone of the Morgan Creek member. The presence of abundant glauconite in the middle and upper portions, and fossils throughout the member, indicate a shallow, warm, relatively quiet sea at this time. The small stromatolitic bioherms in the upper Morgan Creek member indicate shoaling and warming of the sea water.

The Point Peak shale member was probably formed in a quiet marine environment, as is evidenced by the fine-grained argillaceous material, marine fossils, and lack of cross bedding. Cloud and Barnes (1948, p. 112) stated that quantities of argillaceous material were derived from a westerly direction. The sea must have been very shallow, as there are numerous intraformational conglomerates in the member. Shallow, relatively warm, quiet sea conditions are also indicated by the presence of large bioherm deposits in the upper Point Peak member. Mud cracks seen in some areas are indicative of tidal flat deposits.

Subsidence increased in the area during the deposition of the San Saba member, which was deposited immediately above the bioherms. The presence of several arenaceous zones in the San Saba limestone suggests that a spasmodic land mass was providing arenaceous material at various times during its deposition. Ripple marks and cross bedding are present in some of these zones. Cloud and Barnes (1948, p. 112) suggested that this intermittent land mass may have been located to the west.

The above depositional conditions continued during the deposition of the Ellenburger group of Ordovician times. Stable, warm, slightly deeper seas with minor fluctuations in depth, temperature, and conditions of the bottom prevailed during this time, as is shown by the sub-lithographic to cherty nature of theEllenburger limestone deposits. little or no clastic material was being derived from the source area, which had probably been buried by this time. Sellards (1947, p. 82) noted the thinning of the Ellenburger group toward the west, and attributed this to overlap. Some of the older beds found in the eastern part of the region are not present in the western part. Barnes (1956, p. 9) attributed the difference in total thickness in the Ellenburger group to erosion, which has removed all of the Honeycut formation and part of the Gorman formation in the northwestern area.

The sediments of Middle and Late Ordovician and Silurian times, if any were deposited, were eroded before Devonian time, for none are present in the area, except for some possible Upper Ordovician in collapsed areas recently reported by Barnes, Cloud, and Duncan (1953). A period of emergence and tilting to the east before Devonian time is suggested by the character of the Devonian deposits, the oldest being found in the eastern and the youngest in the western parts of the region. This is probably the result of a sea transgressing over the area from east to west. Due to a period of erosion preceding Mississippian deposition, only isolated remnants of Devonian rocks are found in the region, mostly in collapsed areas of the Ellenburger group.

The first evidence of domal uplift in the Llano region is seen in the behavior of the Mississippian beds, which thin over the area, and generally rest on highly eroded Ellenburger beds. Mississippian beds are absent in areas in the eastern part of the uplift. Warm sea conditions probably prevailed during the deposition of the Mississippian beds and continued into Pennsylvanian time, as is seen by the abundant marine fossil content of these beds.

The Pennsylvanian Marble Falls formation was deposited on the eroded surface of Mississippian and older beds. The presence of marine black shales of the Smithwick formation would seem to indicate stagnant sea conditions. A great period of erosion occurred in post-Pennsylvanian time; thus, our knowledge of conditions during the Pennsylvanian is limited. It is deduced, however, that the disturbance which caused the extensive faulting evident in the Llano region was probably related to the Ouachita orogeny and occurred in post-Bend and pre-Canyon time.

No record of Permian, Triassic, or Jurassic sedimentation is evident, and the Llano region was undoubtedly undergoing extensive domal uplift and erosion during these periods. It was probably during this time of pronounced erosion that the Precambrian metamorphics and granites, as well as the older Paleozoic sediments, were originally exposed.

The region was again submerged during Cretaceous time and Cretaceous sediments, mostly limestones, were deposited over the erosional surface of older rocks. Subsequent erosion has removed the Cretaceous sediments in many parts of the region, again exposing the older Paleozoic and Precambrian rocks. Barnes, Shock, and Cunningham (1950, p. 8) stated that Cretaceous rocks are in contact now with the Precambrian rocks only along the south side of the region. What Cretaceous sediments are left around the region are still essentially undisturbed.

There have been no post-Cretaceous invasions by the sea, and Cenozoic rocks occur only in some stream and river deposits.

ECONOMIC GEOLOGY

The most important natural resource of the Grossville School area is ground water. Many surface earthwork reservoirs of varying sizes have been constructed by the ranchers in order to conserve and supply water for livestock and other needs, but due to the periods of extended drought common in the area, farming and ranching, the principle industries, are forced to rely to a large degree on wells obtaining water from the ground-water aquifers in the area. Many farmers are already irrigating their crops from well water, and the number doing so is steadily increasing.

The principal aquifer in the thesis area, as it is for Mason and the general surrounding vicinity, is the Hickory sandstone member. Some wells produce from cracks and joints in the Precambrian granite, and a few small springs are located in Precambrian terrain, mostly along fault planes. There are several flowing wells located in the extreme western portion of the thesis area, and just outside it toward the west. These wells also probably produce from the Hickory sandstone member.

The soils used for farming in the thesis area are those derived from the Hickory sandstone, especially the middle and upper parts of the member. The upper Hickory sandstone soils have a characteristic deep red color, and are extensively cultivated in the central portion of the area. A few cultivated fields in the Cap Mountain limestone and Lion Mountain sandstone members were also noted, and there are even a few instances of Precambrian soils being tilled. All but the Hickory sandstone soils are generally rocky and shallow, and are of limited areal extent.

Another natural resource of possible importance in the thesis area is building stone. This resource has not been fully exploited for several reasons, mainly the lack of adequate and suitable transportation facilities, and also the poor quality and extent of outcrops and poor accessibility in most areas.

Barnes, Dawson, and Parkinson (1947, pp. 85-86) reported on the economic possibilities as building stone of a granite mass four miles south of Mason. A portion of this granite mass is located in the northwestern part of the thesis area. They reported that, although the granite is beautiful, the presence of calcite as an alteration product is detrimental, the surface of the granite mass is highly weathered, and the nearest railroad is 33 miles away. They concluded that, in general, it is not favorable for quarrying. Weathered granite from this mass was quarried, however, at a location near the junction of the James River road and Farm Road 1723, and used for road metal in the vicinity. Various schists, gneisses, and granites in the area have also been used as road bed material in their immediate vicinities.

Hard sandstones and limestones have formerly been used in the area as building stones, mainly for fences and stock pens, although there are a few old houses in the area that were constructed with these native stones. Resistant ledges from the Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone members furnished material for most of this construction, although fences were built from any material at hand. This use of the stone as building material in the area has generally been abandoned, although many of the old structures remain.

Although not found by this writer, the occurrence of topaz in streams and creek beds in and near the granite outcrops has been reported. This topaz was probably formed in pegmatite veins in the granites, and occurs as placer deposits due to differential weathering.

No petroleum is found in the area, and, according to Cloud and Barnes (1948, p. 33), future petroleum production is very improbable due to the complex faulting and present exposures of the potential source beds.

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APPENDIX

Section of the lower Morgan Creek limestone, Welge sandstone, Lion Mountain sandstone, and upper Cap Mountain limestone exposed along both sides of road beginning at a point near the windmill on the northwest side of a small fault 1300 feet east-northeast of A. Schmidt ranch house and extending westerly 3000 feet to a point about 1800 feet northwest of A. Schmidt ranch house, Mason County, Texas

	Thickness in feet
Wilberns formation:	
Morgan Creek limestone member:	
9. Limestone; grayish-rust-red, weathering to a dark grayish-brick-red; medium-hard; rather distinct thin bedding, beds ranging from .25 to 1 foot thick, a few very thin shale beds interspersed with the limestone; medium-grained; arenaceous, containing poorly sorted sand grains, but not as much as in next lower unit; glauconitic; caliche evidence; slightly fossiliferous; ferruginous brown stains; beds appear as rounded ledges on slopes of hills.	12.1
8. Limestone; greenish-red, weathering to brownish-purple; medium to hard; distinct thin bedding, beds from .25 to 1 foot thick; medium-grained; very arenaceous, poorly sorted sand grains in calcareous cement;	

	Thickness in feet
somewhat glauconitic; some ferruginous stains. . .	7.2
Total measured thickness of Morgan Creek limestone member	25.3

Welge sandstone member:

7. Sandstone; yellowish-brown, weathering to rust reddish-brown; distinct bedding, alternating hard and soft layers, harder layers containing more ferruginous cement, hard layers range from .5 to 2 feet thick, soft layers from .5 to 2 inches thick; fine- to medium-grained; rather well sorted; sub-rounded to rounded frosted quartz grains with ferruginous cement; marked by a sharp line of scrub oak; lower beds broken down because of soft underlying beds.	18.2
Total measured thickness of Welge sandstone member	18.2

Riley Formation:

Lion Mountain sandstone member:

6. Siltstone; light grayish-green, weathering to dark greenish-brown; soft; medium-bedded; fine-grained silt with calcareous cement; distinct purple shale layer 4 feet from top, about .75 foot thick and of same material as beds above and below, distinct because of color; contains purple

Thickness in feet

hematite nodules, .25 to .5 inches in diameter; glauconitic; this unit and others below form a gentle slope below overlying Welge member. . . . . 5.

5. Arenaceous limestone; greenish-purple, weathering to deep purple; medium-hard; irregular, hard to distinguish bedding, beds which are distinguishible are about .5 feet thick; very sandy; glauconitic; hematite pebbles; fossiliferous, containing brachiopods, actually a "hash," but not as many fossils as in lower beds; breaks off in chunks. 4.8

4. Calcareous sandstone; whitish-purple, weathering to dark purple-brown; hard; irregular bedding, thin and indistinct, sandstone beds generally highly weathered; medium- to coarse-grained; very glauconitic, some in thin layers; very fossiliferous, containing brachiopod hash; some hematite stains, large hematite nodules, from marble size to 1 foot or more in diameter on slope, dark grayish-red on inside to a darker purple on outside; beds break off in chunks on slope 18.2

3. Calcareous sandstone; greenish-purple, weathering to dark greenish-brown; medium-hard; medium-bedding, .75 to 2 feet thick, sandstone beds generally

Thickness in feet

highly weathered; medium- to coarse-grained; not as fossiliferous as above unit but still contains hash; limonite stains; small hematite grains and pebbles; abundant hard calcite; much more glauconitic and finer-grained than unit below. . . 23.0

2. Calcareous sandstone; brownish-green, weathering to bluish-brown; medium to hard; distinct thin bedding, beds average from .25 to .75 feet thick; medium-grained; some hematite nodules; very glauconitic; some brachiopod hash; hematite stains and grains; forms gentle slope 13.0

Total measured thickness of Lion Mountain sandstone member 64.2

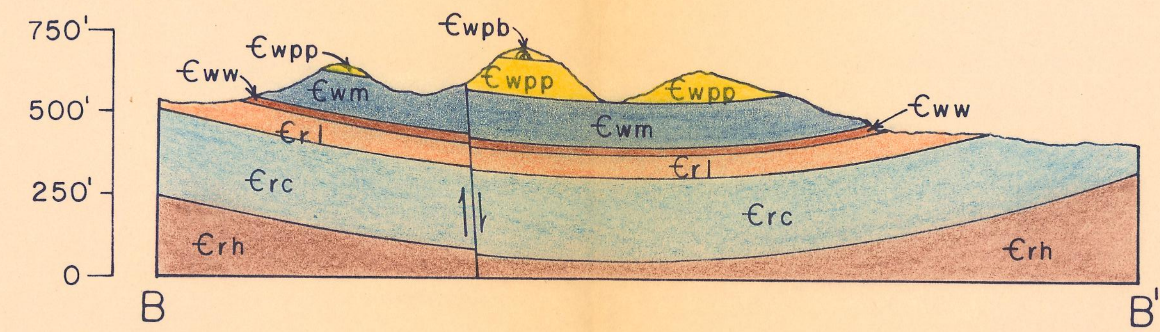
Cap Mountain limestone member:

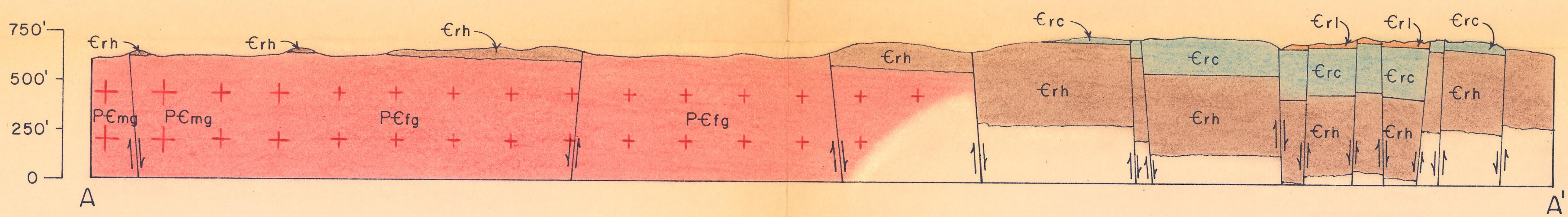
1. Limestone; greenish-gray, weathering to dirty bluish-gray; hard; distinctly bedded, beds about 2 feet thick; fine- to medium-grained; poorly sorted; glauconitic; slightly fossiliferous, containing trilobites; limonite stains; hematite grains and pebbles; ledges usually easily traced; caps hills 28.3

Total measured thickness of Cap Mountain limestone member 28.3

Total measured thickness of section. 136.0

STRUCTURE SECTIONS





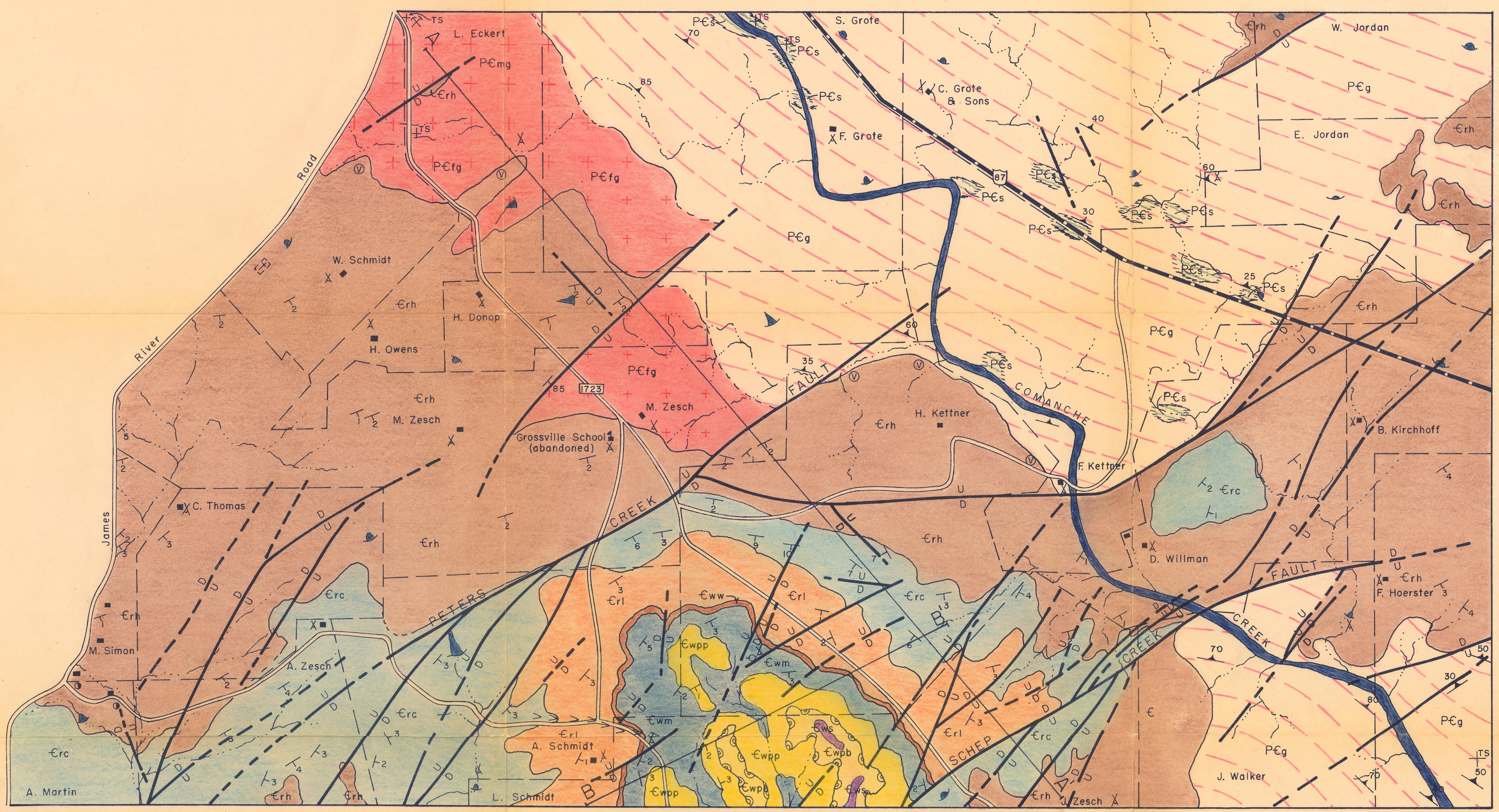
Horizontal scale

0 850 1700 3400 5100 6800 8600 10200 FEET

Legend on plate I

Vertical Scale { 3 X horizontal scale
0 = arbitrary datum

Geology by R. L. Fuller



Base from U.S. Department of Agriculture, Soil Conservation Service, aerial photographs, 1948

Geology by R. L. Fuller, 1956

GEOLOGIC MAP OF THE GROSSVILLE SCHOOL AREA, MASON COUNTY, TEXAS

EXPLANATION

CAMBRIAN

Upper Cambrian

Wilberns Formation

- €ws — San Saba limestone member
- €wpb / €wpp — Point Peak shale member (Bioherms at top)
- €wm — Morgan Creek limestone member
- €ww — Welge sandstone member

Riley Formation

- €rl — Lion Mountain sandstone member
- €rc — Cap Mountain limestone member
- €rh — Hickory sandstone member

UNCONFORMITY

PRECAMBRIAN

- P€mg, P€fg — Medium-grained and Fine-grained granites
- P€g, P€s — Gneiss and Schist

Normal fault — U, upthrown side; D, downthrown side

Inferred normal fault

Observed and inferred contacts

Strike and dip of strata and foliation

Property line fence

Intermittent stream

Flowing stream

A — A' Structure section line

Spring

Flowing well

Windmill

Road metal quarry

Stock tank

Cemetery

Ranch buildings

Highways

Improved and Graded earth roads

TS Thin-section locality

V Ventifact locality

> > > > > Measured section

10°

N

SCALE 1:20000

0 — 1/2 — 2 MILES

0 850 1700 3400 5100 6800 8500 10200 FEET