GEOLOGY OF THE CAMP AIR-WEST AREA,

MASON AND MC CULLOCH COUNTIES, TEXAS

A Thesis

By

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GEOLOGY OF THE CAMP AIR-WEST AREA, MASON AND MC CULLOCH COUNTIES, TEXAS

ABSTRACT

The Camp Air West area is located on the northwestern flank of the Llano uplift of Central Texas, 9.4 miles north of the city of Mason, Texas. Rocks cropping out in the area include a coarse-grained granite of Precambrian age, the Riley and Wilberns formations of Late Cambrian age, the basal part of the Ellenburger group of Early Ordovician age, and limestone and sandstone of Early Cretaceous age.

The granite outcrop is the southwestern edge of the Katemcy mass, thought to be part of the Town Mountain granite.

The Riley formation, estimated to be about 700 feet thick in the area, is comprised of three members: the Hickory member, a yellowish-brown to very dark red, coarse-grained sandstone; the Cap Mountain member, a gray to brownish-gray, arenaceous limestone; and the Lion Mountain member, a coarse-grained, highly glauconitic, sandstone containing beds and lenses of limestone composed essentially of trilobite fragments.

The Wilberns formation, estimated to be about 450 feet thick in the area, is composed of the Welge member, a yellowish-brown, non-glauconitic sandstone; the Morgan Creek member, a purplish-red to gray, brown, and green speckled, arenaceous, glauconitic limestone; the Point Peak member, essentially comprised of gray and greenish-gray, thin-bedded siltstone with interbedded greenish-gray limestone and vari-colored intra-formational conglomerate; and the San Saba member consisting of stromato-litic bioherms at the base grading upward into yellow, gray, and brown granular limestone and gray sublithographic limestone.

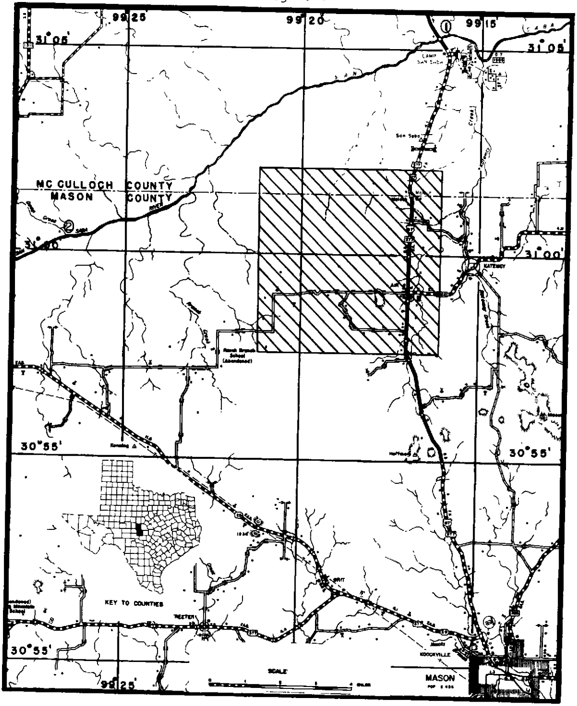
The basal beds of the Ellenburger group are in gradational contact with the underlying San Saba member of the Wilberns formation. They consist of gray, thin-bedded to massive, sublithographic limestone and are estimated to be about 60 feet thick in the area.

Lower Cretaceous rocks exposed in the area are gray, fine-grained limestones with basal conglomeratic sandstone beds. Essentially flat-lying, these strata rest with pronounced unconformity on the truncated edges of the Paleozoic rocks. The equal truncation of Paleozoic rocks of varying resistance underlying the Cretaceous strata suggests that a condition of peneplanation existed in the area prior to Cretaceous deposition.

Paleozoic rocks cropping out in the area strike N. 35° to 45° E. and dip 3° to 5° NW., so that successively younger rocks are exposed from southeast to northwest. The essentially homoclinal structure is interrupted by a series of northeastward striking, steeply dipping, normal faults of relatively small displacement.

Ground-water and arable soil are the most important natural resources in the area; and the Hickory sandstone, furnishing as it does the major part of these resources, is the most important geologic unit within the area.

Figure I



INDEX MAP OF THE CAMP AIR WEST AREA, MASON AND MC CULLOCH COUNTIES, TEXAS

Reproduced from highway maps of Mason and Mc Culloch Counties, Texas, Prepared by Texas State Highway Department, revised to Jan, 1956

① Camp San Saba Section
② Calf Creek Section

GEOLOGY OF THE CAMP AIR-WEST AREA, MASON AND MC CULLOCH COUNTIES, TEXAS

INTRODUCTION

STATEMENT OF THE PROBLEM

The purpose of this thesis is to present the results of a geologic study of a small area within the Central Mineral region of Texas, with the hope of contributing thereby to the geologic knowledge of the region. Primary consideration is given to descriptions of the stratigraphy and structure of the area and to presentation of stratigraphic and structural relationships on an aerial geologic map. Secondary considerations include the physiography, geologic history, and economic geology of the area.

LOCATION

The Camp Air-West area, a rectangular area of approximately twenty-seven square miles, is located on the northwestern flank of the Llano uplift of Central Texas. The major part of the area lies in the northwestern part of Mason County, but the northern edge extends about 0.7 mile into the south-central part of McCulloch County (see fig. I). The area is bounded by latitudes 30° 57.5' and 31° 02' North and by longitudes 99° 16' and 99° 21' West.

ACCESSIBILITY

The Mason-Brady Highway (U. S. Highways 377 and 87) runs north-south through the area 0.8 mile from the eastern border and gives access to the area from the towns of Mason, Texas, lying 9.4 miles to the south, and Brady, Texas, lying 12.2 miles to the north. From the small settlement of Camp Air, located on the Mason-Brady highway 1.6 miles within the southern border, an unimproved farm road runs east-west across the area. From this east-west road, another unimproved road banches southward 1.6 miles west of Camp Air and circles back eastward to intersect the Mason-Brady highway 1.1 miles south of Camp Air. Private ranch and farm roads connect with the main roads to give excellent access to the eastern part of the area but only limited access to the western part.

METHODS OF INVESTIGATION

The field investigation upon which this report is based was conducted between July 3, and August 29, 1956. U. S. Department of Agriculture aerial photographs CJC - 23 - 141 through 145 and CJC - 4 - 133 through 137 give coverage of the area and were used as base maps for plotting geologic information. To facilitate the field investigation of faults and lithologic boundaries, the aerial photographs were also used to detect vegetative patterns and soil changes indicative of such features.

A Brunton compass was used to measure the dips and strikes of outcropping bedded rocks, and the same instrument was used with a Jacob's staff to measure the thickness of dipping strata. A hand level and a Jacob's staff were used to measure the horizontal Cretaceous beds.

In the preparation of cross sections, topographic relief was estimated from the aerial photographs by use of a stereoscope, and horizontal distances were scaled directly from the photographs.

PREVIOUS INVESTIGATIONS

The earliest reference to the Llano region appearing in geologic literature was made by Ferdinand Roemer (1846). This early account of the geology of Texas was concerned primarily with Cretaceous rocks and fossils from bordering areas, but brief mention was made of specimens of granite from outcrops north of Fredericksburg. Roemer considered that the plutonic rocks of the Central Mineral Region were part of the crystalline mass of the Rocky Mountains, and that the Cretaceous rocks, which were knownto overlap the granite near Fredericksburg, were the only stratified rocks existing in central Texas. Roemer (1848), in a second paper on the geology of Texas, gave an account of his travels with an exploring party of German colonists to the San Saba River. In this paper he noted the occurrence of granite, "Lower Silurian", and Carboniferous rocks in the region. Later he published a more comprehensive report of his travels in Texas, including an account of the Paleozoic rocks and fossils of the Central Mineral region and a geologic map of the state (Roemer, 1849). Roemer (1852) gave a detailed account of the Cretaceous rocks and fossils of Texas. In an appendix to this paper he included descriptions of Paleozoic strata and fossils of the Llano region.

In 1855 and 1856, Dr. G. G. Shumard, while accompanying an expedition of Army engineers passing through the Llano region, made notes on his observations of the geology. These notes were incorporated in a paper published thirty years later (G. C. Shumard, 1886).

B. F. Shumard (1861) published descriptions of the Upper Cambrian rocks and fossils of the region and correlated them with the Potsdam group. His work in the region confirmed much of the earlier work of Roemer.

Descriptions of the Cambrian rocks were published by Walcott (1884) after he visited the region in 1883.

R. T. Hill (1887) briefly discussed the geology of the Llano region in a review of Texas geology, and two years later (Hill, 1889) named and established the age of the Carboniferous rocks cropping out in the vicinity of Marble Falls.

T. B. Comstock (1890) published a description of the geology of the region with particular emphasis on the minerals and ores. He introduced the names Valley Springs and Packsaddle to apply to the Precambrian gneisses and schists and the terms Hickory series, Riley series, and Katemcy series to apply to the Cambrian rocks exposed in the uplift.

R. S. Tarr (1890 a and b) reported on the topography and drainage patterns of the region. He concluded that the major streams of the region were developed originally on the relatively flat-lying Cretaceous strata and that they had been superposed upon the underlying Paleozoic structure.

Paige (1911) named and described the Cap Mountain, Wilberns, Ellenburger, and Smithwick formations and redefined the Valley Springs gneiss and the Packsaddle schist. His Cap Mountain formation included most of the Cap Mountain member and all of the Lion Mountain member of the present Riley formation, while his Wilberns formation included the same beds as the present Wilberns formation with the exception of the San Saba limestone. He included the San Saba limestone in the Ellenburger formation. Paige adopted the name Hickory sandstone in lieu of Hickory series as used by Comstock and placed the upper boundary of the unit within the lower beds of the present Cap Mountain limestone. Paige (1912) published a detailed geologic map of the Llano and Burnet quadrangles with an accompanying description of the geology.

In 1916, the Bureau of Economic Geology and Technology published the first comprehensive geologic map of Texas (Udden et al, 1916). On this map the rocks cropping out in the Llano region were grouped into five divisions: Cretaceous, Pennsylvanian, undivided Paleozoic, Cambrian-Ordovician, and Precambrian.

Plummer and Moore (1922) published a map of the outcropping Carboniferous rocks of the region and introduced the name Barnett to apply to the shale beds below the Marble Falls limestone.

Girty and Moore (1919) discussed the age of the Bend series, and Girty, in the same paper, correlated the Barnett shale with the Moorefield shale of Arkansas and the lower Caney shale of Oklahoma. He concluded that the correct age of the Barnett shale was Mississippian. Girty (Roundy, Girty, and Goldman, 1926, pp. 3 - 4) established an Early Mississippian age for the crinoidal limestone beds beneath the Barnett shale. This new formation, which was first discovered by P. V. Roundy and K. C. Heald of the U. S. Geological Survey, was given the name Chappel by Sellards (1933, p. 91).

Dean (1931) studied the algal reefs in the Wilberns formation and discussed them in a paper read before the Paleontological Society of America.

The first attempt to establish faunal zones within the older Paleozoic rocks of the Llano area and to correlate them with Paleozoic rocks outside the state was made by Dake and Bridge (1932).

Sellards (1933) reviewed the Precambrian and Paleozoic stratigraphy of the Llano region.

Stenzel (1932) redefined the Valley Springs gneiss and postulated that it was of igneous origin.

Sellards (1934) discussed the Paleozoic deformation of the Llano region and proposed a Middle Mississippian age for the initial doming. Precambrian structural conditions of the region were discussed by Stenzel in the same report (pp. 74-78).

The U. S. Geological Survey (Darton et al, 1937) issued a new geologic map of the state showing the Paleozoic rocks of the Llano area divided, in ascending order, into the Hickory sandstone, the Wilberns and Cap Mountain limestones, the Ellenburger limestone, the Marble falls limestone, the Smithwick shale, the Strawn group, and the Canyon group.

Bridge (1937) named the Lion Mountain sandstone member of the Cap Mountain formation and relocated most of the fossil localities established by Roemer. Bridge and Girty (1937) redescribed Paleozoic fossils that had been described earlier by Roemer and published notes on the geology of the region.

The first descriptions of ventifacts from the Hickory sandstone were made by Barnes and Parkinson (1939). In this paper, which included a map showing localities where ventifacts had been found, they expressed the belief that the Hickory sandstone contains some aeolian deposits.

Keppel (1940) published the results of a study of the coarse-grained granites of the Llano-Burnet area.

Cheney (1940) suggested a new classification for the Pennsylvanian strata of north-central Texas, but his members and most of his formations are absent or difficult to recognize in the Llano area. In the same paper, he noted that the Ellenburger limestone and later sediments thin toward the Concho Arch, indicating an Early Ordovician age for the initial uplift of the arch.

Barnes (1941), in a paper read before the Geological Society of America, described the overlap of Lower Cretaceous sediments on the Llano Uplift.

Cloud, Barnes, and Bridge (1945) subdivided the Ellenburger group, in ascending order, into the Tanyard, Gorman, and Honeycut formations. In the same paper, they proposed the name Riley formation to include the Hickory sandstone, the Cap Mountain limestone, and the Lion Mountain sandstone members. Barnes, Cloud, and Warren (1945) published the first descriptions of rocks of Devonian age in the Llano region, and two years later (Barnes, Cloud, and Warren, 1947) they described two more Devonian formations.

Plummer (1946), in a report on the water resources of Texas, discussed the importance of the Hickory sandstone and the Ellenburger limestone as water bearing formations. Plummer (1947) published a summary of the classification of Lower Pennsylvanian strata in Central Texas. A posthumous publication on the Carboniferous stratigraphy of the Llano region by Plummer (1950) included resumes of the other Paleozoic systems and of the Cretaceous system of the region.

Bridge, Barnes, and Cloud (1947) reviewed the Upper Cambrian stratigraphy of Central Texas and gave brief descriptions of each formation and member. Cloud and Bridge (1947) published a comprehensive paper on the Ellenburger group of Central Texas, and included brief descriptions of other Paleozoic strata cropping out at various localities in the region.

Blank (1951 a and b) discussed the exfoliation of granite domes in the Llano region and the peculiar, doughnut shaped weathering features found on the granite.

Polk (1952), Alexander (1952), Duval (1953), Parke (1953), Grote (19 4), and Fritz (1954) prepared detailed maps and described the stratigraphy and structure of small areas in the vicinity of Mason, Texas. Rogers (1954) reported on an arkosic conglomerate of probable Early Cretaceous age found as scattered deposits in Mason, Menard, and Kimble Counties, Texas.

Barnes and Bell (1954) reviewed the stratigraphy of the Llano region and published measured sections of the Upper Cambrian formations. Barnes (1956), in a report on lead deposits in the Upper Cambrian rocks of Central Texas, briefly reviewed the structure and Upper Cambrian stratigraphy of the region.

G E O G R A P H Y

CLIMATE

The climate of the Llano region is semi-arid. The annual rainfall in Mason County averages about 20 inches, most of which falls in periodic heavy showers occurring during the winter and early spring months. The tendency toward widely spaced heavy rains separated by long dry spells causes a large amount of the rainfall to be lost as surface runoff.

During the past six years the region has been subjected to a severe drought, and the mean yearly precipitation has dropped considerably below the normal.

Temperatures vary between the summer and winter extremes of 110° and -5°, and daily variations may be as much as 30°. Mean temperatures are about 45° for winter months and 90° for summer months. The average annual temperature is about 70°.

VEGETATION

The vegetation of the area is limited to those types which are hardy enough to subsist under conditions of thin topsoil and little water. On areas underlain by granite, post oak and blackjack oak are the dominant types. Weathered sandstone outcrops commonly support growths of mesquite and needle grass, but in areas where the sandstone bedrock has not decomposed, dense growths of oak occur. On the limestones, post oak, Mexican persimmon, and many varities of cacti flourish. Cedar, which once grew in abundance on the limestone hills, has been killed off by the ranchers as a ground-water conservation measure.

Vegetation is particularly dense on the uncultivated parts of the Hickory sandstone, on the Cap Mountain and Morgan Creek limestones, and on the calcitic reefs; but it is somewhat thinner on the San Saba and lower Ellenburger limestones and is sparse on the weathered sandstone outcrops, on the Point Peak shale, and on the dolomitized reefs. Cretaceous upland areas support dense growths of oak, Mexican persimmon, and prickly pear.

INDUSTRY

Economic development of the Camp Air-West area is limited to ranching and farming. The ranching industry was originally devoted principally to beef cattle, but overgrazing and years of drought have curtailed the raising of cattle in large numbers. In recent years the ranchers have turned to goat raising as their chief source of income.

The small farms, located on the sandstone outcrop belts, were devoted primarily to the raising of peanuts, melons, corn, and hay; but the prolonged drought has made dry farming extremely hazardous. A few of the farmers have installed irrigation wells, but the majority have either moved away or turned to grazing small flocks of sheep.

P H Y S I O G R A P H Y

TOPOGRAPHY

The Camp Air-West area lies on the northwestern flank of the Llano Uplift, a structural dome of Paleozoic and Precambrian strata exposed in a topographic basin eroded through relatively flat-lying Cretaceous rocks. Within the basin, maximum relief is about 1,600 feet. Maximum relief in the Camp Air-West area is approximately 250 feet from the bed of West Prong Creek in the east to the top of the Cretaceous outcrop in the south-central part of the area.

In the semi-arid climate of the region, limestone is more resistant to erosion than is sandstone. As a result, ridges and upland areas are developed on the limestone outcrops while benches and lowland areas are developed on the sandstone outcrops. The resistance of the coarse-grained granite to erosion is about equal to that of the sandstone, and it too normally underlies lowland areas.

The granite outcrop in the southeastern corner of the thesis area occupies a broad, rugged lowland in which the bedrock has been dissected into a series of irregular knobs. The Hickory sandstone outcrop to the west of the granite also has been reduced to a broad lowland, but in contrast to the rugged granite outcrop, the Hickory sandstone outcrop is gently undulating with only scattered exposures of bedrock protruding through the soil cover. An exception to the gentle character of the surface underlain by Hickory sandstone is a large conspicuous hill rising about 150 feet above the surrounding terrain, 0.7 mile west of Camp Air. West of the Hickory sandstone outcrop, the Cap Mountain limestone, Lion Mountain sandstone, Welge sandstone, and Morgan Creek limestone form a series of elongated northeast-southwest trending ridges and benches which pass beneath the relatively flat Cretaceous tableland in the southern portion of the area.

In the central part of the area, between the dip slope of the westernmost ridge composed of Morgan Creek limestone and the eastern edge of the reef outcrop, a broad alluvium filled valley has been developed by erosion of the Point Peak shale. From the western rim of the valley a gently northwestward dipping, rugged, rubble-strewn surface, developed on calcite and dolomite reefs, extends to the moderate slopes of the San Saba limestone outcrop. In the northwestern corner of the area, gently rolling hills and valleys have been developed on the Ellenburger limestone.

Faulting has affected topography by repeating the valley and bench forming sandstones and the ridge forming limestones in the eastern part of the area, but faults within the San Saba and Ellenburger limestones indiscriminately cross hills and valleys with no apparent effect on topography.

DRAINAGE

The Camp Air-West area lies just north of the drainage divide between the Llano River to the south and the San Saba River to the north. Within the area, a local drainage divide is formed by the Cretaceous outcrop in the south and the Morgan Creek ridge running diagonally across the center of the area. To the east, the small streams and gullies drain into West Prong Creek, a tributary to Katemcy Creek. Katemcy Creek, east of the area, drains northward into the San Saba River. Streams and gullies west of the divide drain into several small, unnamed tributaries to the San Saba River. All streams in the thesis area are ephemeral.

Faults have had little effect on the drainage patterns in the area. The major drainage lines cut obliquely across several faults along their courses with no apparent tendency to exploit the fault zones. Some small tributary gullies have formed along fault zones, however, and it is probable that, were the climate more humid, faults would have a pronounced effect upon the minor drainage lines.

STRATIGRAPHY

GENERAL STRATIGRAPHY

The rocks exposed in the Camp Air-West area range from a Pre-cambrian granite in the southeast corner through Upper Cambrian sandstones, limestones, and shales in the central part and Ordovician limestones in the northwestern corner to Cretaceous limestones in the south-central part. Recent alluvium and caliche mask the bedrock in the valleys, on the dip slopes of cuestas, and around the edges of the Cretaceous outcrop. Bedrock is poorly exposed throughout the area except on the scarp slopes of cuestas. For this reason no extensive sections were measured and described. The Camp Air-West area lies approximately midway between the localities of the Camp San Saba and Calf (Camp) Creek sections, described by Barnes and Bell (1954, pp. 45-67) (see locations 1 and 2, Fig. 1 of this thesis), and the rocks exposed in the area are similar in thickness and lithology to those of both sections. In the case of the San Saba limestone and the bioherm zone, the stratigraphic relationship and lithology occurring in the Camp Air-West area are transitional between the Camp San Saba section and the Calf Creek section.

The stratigraphic column for the thesis area is as follows:

Cenozoic

Quaternary System

Recent alluvium

Mesozoic

Cretaceous System

Lower Cretaceous (Comanchean) Series

limestone and conglomeratic sandstone

Paleozoic

Ordovician System

Lower Ordovician Series

Ellenburger limestone

Cambrian System

Upper Cambrian Series

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

Granite

PRECAMBRIAN

The Precambrian basement complex exposed in the Llano Uplift includes schists, marbles, and gneisses of metasedimentary and possible metaigneous origin that are intruded by predominantly acidic rocks in the forms of batholiths and dikes.

In the Camp Air-West area, the only representative of the Precambrian complex is a coarse-grained granite exposed in the southeast corner of the area.

Granite

Name and definition: Stenzel (1932) subdivided the granite intrusives of Llano and Burnet Counties into three groups on the basis of lithology and structural relationships. His subdivisions, from oldest to youngest, are: the pink, coarse-grained, Town Mountain granite; the gray, medium-grained, Oatman granite: and the gray, fine-grained, Six-mile granite.

The granite cropping out in the southeast corner of the Camp Air-West area is part of the Katemcy mass, a large elliptical body which extends from the north-central part of Mason County into the southeastern edge of McCulloch County. Barnes and Bell (1954, p. 80) considered this mass to be part of the Town Mountain granite.

Lithology: Detailed megascopic and microscopic descriptions of granite from the Katemcy mass at a location 0.5 mile southeast of Katemcy and at Flatrock dome, 3 miles west of Fredonia, Texas, were given by Barnes (1947, pp. 81-82 and 86-87). Keppel (1940, p. 975) published the results of a Rosiwal analysis of a specimen from Flatrock dome.

The granite exposed on the thesis area is a pink, coarse-grained, biotite granite. Megascopically, it appears to be composed essentially of pink microcline, white feldspar (probably plagioclase), clear quartz, and biotite. The microcline occurs as phenocrysts averaging about 20 millimeters in length, but crystals as long as 35 millimeters are common. Quartz grains average about 6 millimeters in diameter, but juxtaposition of grains in some cases has formed irregular, elongated, vein-like areas 15 to 20 millimeters in length. The biotite occurs as scattered groups of platy flakes of 6 millimeters diameter in the matrix of white feldspar and quartz grains. Pegmatite and aplite dikes averaging a few inches in width are common in the exposure.

Weathering changes the color of the granite to a dull pinkish-gray and leaves a rough surface by differential removal of the matrix around the phenocrysts. The entire outcrop has weathered to a series of irregular knobs. Along the western edge, near the contact with the overlying Hickory sandstone, these knobs protrude through a thick layer of granite wash formed over the outcrop; but eastward they broaden, and the mass is devoid of sediments. Solution pits are common on the flatter parts of the outcrop, and two small "doughnut" weathering features similar to those described by Blank (1951) were found near the western edge of the exposure. The doughnuts measured about 1.5 feet across their outer rims.

At the one exposure of the Hickory contact found in the area (location 1, Plate I) the granite has been weathered in place to a grayish-white clay. In the process of kaolinization, the outlines of feldspar crystals have been retained; but they crumble when touched and appear to be completely altered to clay. Depth to solid granite bedrock beneath the contact could not be determined.

Stratigraphic relation: Elsewhere in the Llano uplift, granites of this type are intruded into Precambrian schists and gneisses. In the Camp Air-West area, however, no evidence of the metamorphic rocks remains. The granite-Hickory sandstone contact is covered over most of the area, but in the exposure on West Prong Creek the basal Hickory sandstone overlies the granite unconformably (Plate II). Apparently the metamorphic rocks were stripped from this part of the area during the long interval

Plate II

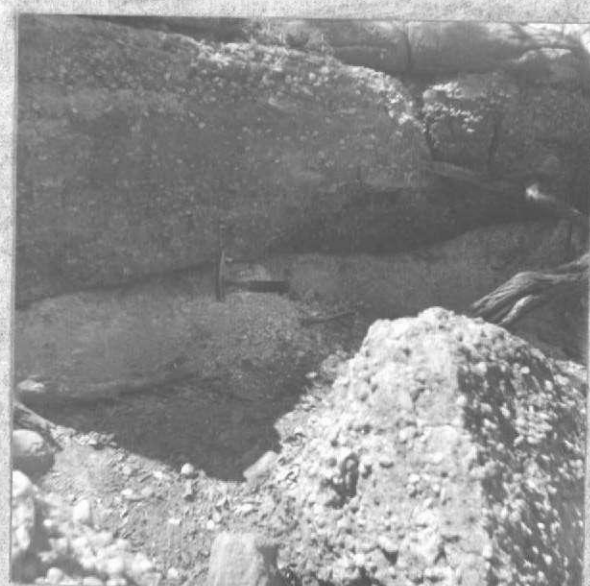


Figure 2.

Quartz pebble conglomerate of the basal Hickory sandstone in contact with weathered Precambrian granite in bed of West Prong Creek.

of erosion between Precambrian and Late Cambrian times, and the basal Hickory sandstone was deposited directly upon the granite.

Bridge, Barnes, and Cloud (1947) reported that relief on the Precambrian surface was approximately 800 feet prior to deposition of the Hickory sandstone. Evidence of considerable relief on the Precambrian surface occurs in the thesis area one mile northwest of Camp Air. There, two miles northwest of the main granite outcrop, a small granite mass is exposed on the upthrown side of a fault near the Hickory sandstone-Cap Mountain limestone contact. This exposure, about 0.2 mile in width, is not continuous along the fault, but dips beneath the Hickory sandstone in all directions. About 0.8 mile south of the exposure toward the main granite outcrop, an irrigation well was drilled to granite at a depth of 245 feet (location 2, Plate I). A fault that would account for some of the difference in elevation is known to trend toward the vicinity of the well, but it could not be proved to pass between the well and the small granite exposure. Since this exposure is not continuous along the regional strike, and because it is two miles removed and up-section from the main granite outcrop, it is probably the top of a buried hill. The contact between the Hickory sandstone and the granite hill is covered with alluvium, but judging by soil colors in its vicinity and by outcrops along the regional strike away from the hill, the top of the hill is estimated to lie slightly above the middle stratigraphic level of the Hickory sandstone.

CAMBRIAN SYSTEM

Although Lower and Middle Cambrian rocks have not been recognized in the Llano uplift, Upper Cambrian rocks form extensive outcrops throughout the region. Two formations are currently recognized - the Riley formation, comprised of three members; and the Wilberns formation, comprised of four members. All seven members of the two formations crop out in the Camp Air-West area.

Riley Formation

The name "Riley series" was proposed by Comstock (1890) to apply to strata which comprise parts of the Hickory sandstone and Cap Mountain limestone of the present classification. Comstock's classification had long been abandoned when Cloud, Barnes, and Bridge (1945, p. 154) introduced the name Riley formation "... to include all of the Cambrian strata in Central Texas beneath the Wilberns formation". As defined by these authors, the Riley formation is comprised, from bottom to top, of the Hickory sandstone, the Cap Mountain limestone, and the Lion Mountain sandstone members. The common contacts of the members intergrade both laterally and vertically.

At its type area in the Riley Mountains of southeastern Llano County, the formation is about 780 feet thick; however, its thickness varies considerably throughout the Llano region. The average thickness is about 695 feet, according to Barnes and Bell (1954, p. 36). The variation in thickness is attributed to topographic relief of the Precambrian surface upon which the formation was deposited.

In the Camp Air-West area, the thickness of the Riley formation is estimated to be about 700 feet.

Hickory Sandstone Member

Definition and thickness: Comstock (1890) used the name Hickory, taken from Hickory Creek in Llano County, to apply to the lowermost of the three Cambrian series he established in the region. Paige (1911) used the name Hickory sandstone in lieu of Comstock's Hickory series and placed the upper boundary of the unit within the lower calcareous sandstone beds of the present Cap Mountain limestone. Cloud, Barnes, and Bridge (1945, p. 154) classified the Hickory sandstone as the basal member of the Riley formation and lowered the Hickory sandstone-Cap Mountain limestone contact to the top of the non-calcareous sandstone beds below the limestone.

According to Bridge, Barnes, and Cloud (1947), the thickness of the Hickory sandstone varies from slightly over 400 feet to a feather edge and averages about 360 feet. The variable thickness is attributed to the topographic relief of the Precambrian surface upon which the member was deposited, to unequal deposition, and to more rapid gradation into limestone in some areas. Because the effect of faulting is masked by soil cover, the thickness of the Hickory sandstone within the Camp Air-West area cannot be estimated with reasonable accuracy. The great breadth of outcrop, however, indicates that the thickness must approach the maximum of 400 feet reported for the region.

Lithology: The Hickory sandstone is a light grayish-white to brown, dull orange, and deep red, fine- to coarse-grained, non-calcareous, essentially non-glauconitic, quartz sandstone. The grayish-white color occurs at the base where the member is a coarse-grained conglomeratic sandstone varying laterally to a quartz pebble conglomerate. Ventifacts occur in the basal beds of the member at several localities in the region, according to Barnes and Parkinson (1939). Above the basal beds the grain size decreases, and in the middle stratigraphic levels a brown to greenish-gray, thin-bedded, shaley siltstone with lenses of fine-grained sandstone occurs. In its upper part, the Hickory member is a brown to deep rust-red, medium- to coarse-grained sandstone. The deep red color is imparted by hematite encrusting well rounded quartz grains and acting as cement. The well rounded quartz grains encrusted with hematite give an oolitic texture to the rock, and it bears a marked physical resemblance to the well known oolitic iron ores from the Red Mountain formation of Silurian age in the Southern Appalachian Mountains.

Cross-bedding is pronounced in the lower beds but is by no means restricted to them. Highly cross-bedded strata occur locally throughout the entire stratigraphic extent of the member. Graded bedding is also common throughout, but it too is more pronounced in the lower beds. Ripple marks have been reported from the middle and upper stratigraphic levels of the Hickory sandstone in many localities, and small brachiopod shells, reported to be phosphatic, are common in these beds.

The Hickory sandstone crops out across the southeastern corner of the Camp Air-West area in a two mile wide belt trending northeast-southwest. Most of the outcrop belt is covered by soil, and bedrock is exposed only at scattered localities. The Hickory sandstone granite contact is exposed in West Prong Creek (location 1, PlateI). There, the basal Hickory sandstone is a grayish-white quartz pebble conglomerate, with quartz pebbles averaging about 1.5 inches in length imbedded in a matrix of coarse quartz sand (see Plate II). The quartz pebbles are very well rounded and show no evidence of wind faceting. The conglomerate, about 3 feet thick, overlies kaolinized granite; however, at some places along the exposure, the extreme basal part of the conglomerate is replaced laterally by up to 0.5 foot of coarse-grained sandstone. At the top of the 3 foot interval the conglomerate changes abruptly to coarse-grained sandstone. Cross-bedding is present in both the conglomerate and the sandstone.

Northward along the creek from location 1, the lower Hickory sandstone retains its high degree of cross-bedding but becomes finer grained and changes to a light buff color in scattered exposures that are successively higher stratigraphically (see Plate III).

Two miles southwest of Camp Air, apparent lower Hickory sandstone is exposed along the upthrown side of a fault (location 3, Plate I). At that location and southwestward along the northern side of the fault, the Hickory member is a light rust-red, coarse-grained sandstone containing scattered sub-angular pebbles of milky quartz that vary from 0.5 inch to 2 inches in length. A few brown chert pebbles and one quartzite ventifact measuring 2.5 inches in length were found at this locality. The ventifact is composed of light gray quartzite faintly tinted with purple - distinctly different in color and hardness from the sedimentary quartzites common to the Hickory sandstone. Quartzite of this type is known to occur in the region in the lower Cretaceous beds only; and chert, although common in some formations of the Ellenburger group, is also common in Lower Cretaceous beds of the region.

Although the chert pebbles and the quartzite ventifact are imbedded in the sandstone bedrock and there is no evidence of stream channeling, the most logical explanation for their presence is that they were deposited much later than Cambrian time and most probably just prior to or during Early Cretaceous time. They occur at an elevation approximately equal to the level of the basal Cretaceous strata exposed in the

Plate III

Cross-bedding in Hickory Sandstone

Figure 1. Cross-bedding in lower beds of the Hickory sandstone in the bed of West Prong Creek. The stratigraphic position of these beds is about 30 feet above the basal contact.

Figure 2. Cross-bedding in the Hickory sandstone about 50 feet above the basal contact. Exposure is in the bed of West Prong Creek.

thesis area and were possibly part of the pre-Cretaceous surface residuum that became cemented into the partially disintegrated bedrock. Although the sandstone containing the chert pebbles and quartzite ventifact, is lithologically characteristic of the lower part of the Hickory member, there is a possibility that it is of Cretaceous age.

At location 4, about 0.2 mile southeast of location 3 (see Plate I), light gray shales of the middle stratigraphic level of the Hickory sandstone are exposed in a road ditch. Two miles northeast of Camp Air (location 5, Plate I) and approximately along the strike from location 4, ten feet of middle Hickory shales and sandstones are exposed in the bank of a small creek. The entire section consists of light grayish-green and pink, thin-bedded, fissile shales alternating with 0.3 foot to 1.5 foot thick beds of pinkish-brown, very fine-grained sandstone. The lowermost bed, 1.3 feet thick, is comprised of chocolate brown and brownish-gray mottled sandstone.

About 0.8 mile north of Camp Air, a probable channel fill in the lower part of the upper Hickory sandstone is exposed in a road cut on the west side of the Mason-Brady highway (location 6, Plate I) (Plate IV). A dark brown to red, coarse-grained sandstone bed with a gently concave upper surface underlies orange, fine- to medium-grained, highly corss-bedded sandstone. The two sandstone units are separated by a 0.3 inch, nodular to botryoidal layer of ferruginous material. Both units contain small brachiopod shells, but the shells in the upper unit are much less numerous and are more fragmented than those of the lower unit. Although the ends of the exposure are obscured, and the lateral truncation of beds along the sides cannot be observed, the concavity of

Plate IV

Figure 1.

Figure 2.
Possible channel fill in the Hickory sandstone exposed in road-cut 0.8 mile north of Camp Air.

the contact surface in contrast to the normal bedding surfaces, the sharp lithologic change across the contact, and the high angle of cross-bedding in the upper unit strongly suggest a channel fill or a tidal inlet fill.

About 1.5 miles north of Camp Air, the uppermost beds of the Hickory sandstone are exposed in an abandoned iron-test pit (location 7, Plate I). At that location, 26 feet of deep red to buff, fine- to coarse-grained, thick-bedded, jointed sandstone was measured below the contact with the overlying Cap Mountain limestone. At the base of the section the sandstone is dark purplish-red, coarse-grained, and thick-bedded, with individual beds varying from 1 foot to 2.5 feet in thickness. The individual sand grains are well rounded and are coated with layers of iron oxide, imparting an oolitic appearance to the rock. Near the contact with the Cap Mountain limestone, the sandstone is dark brown to buff, fine- to medium-grained, and slightly cross-bedded, with beds varying from 0.5 foot to 2 feet in thickness.

The iron oxide of the Hickory sandstone, concentrated in its upper levels, was possibly deposited contemporaneously with the sand. Abundant glauconite in the overlying sediments, especially in the Lion Mountain member, and the abundance of iron oxide in the Hickory member attest to the high iron concentration in waters of the Late Cambrian seas. The fact that this iron was deposited as an oxide in the Hickory sandstone and in a reduced state - in the form of glauconite - in the Lion Mountain sandstone might possibly reflect the relative rate of deposition of the two members as well as the variations of bottom conditions between them. ZoBell (1946) has shown that, although the reducing potential of bottom deposits increases with depth below the depositional surface, the reducing capacity of those deposits decreases rapidly with depth, and that most chemical diagenesis occurs in the upper few inches of the newly deposited sediments. This decrease in the reducing capacity is related to a similar rapid decrease in the number of bacteria.

Iron derived from source rocks and transported by streams to the ocean would most likely be in the oxidized state. Where deposition was slow and reducing conditions existed on the bottom, the iron, though deposited as an oxide, would probably be reduced, and glauconite or other ferrous iron compounds would form. Cross-bedding in the Hickory sandstone suggests that it was probably deposited in agitated, oxygenated water; and, in this case, the iron would not be subjected to reducing conditions. However, with rapid deposition, the sediments would be buried below the zone of chemical diagenesis before reduction could take place even though reducing conditions, instead of oxydizing conditions, are assumed for the Hickory environment.

Locally, the Hickory sandstone, particularly in the upper stratigraphic levels, has been cemented to quartzite. The quartzite is common along fault zones (Plate V) but is not restricted to them in its occurrence. So-called quartzite dikes have formed along some joints and stand out in relief because of differential weathering. A particularly extensive occurrence of quartzite that appears to bear no relation to faulting is located atop the hill 0.7 mile west of Camp Air (location 8, Plate I). Practically all beds cropping out on the hill top are altered to some extent. In some cases the ferruginous material common to the sandstone has been compltely removed, leaving the quartzite almost white.

Plate V

Resistant quartzite along fault zone in Hickory sandstone on north side of road 1 mile west of Camp Air.

Although the quartzite is well indurated and breaks across the sand grains, the alteration does not extend to great depth in individual beds. Some of the beds studied had a layer of quartzite 1 to 2 inches thick on their upper surfaces but were relatively friable below the quartzite layer. A definite gradation between sandstone and quartzite occurs in these beds, but the transition zone is thin. Some beds studied were altered to depths in excess of 1 foot. Overall, the alteration seems to be controlled by bedding planes and vertical joints.

The alteration of the sandstone to quartzite was probably accomplished by silica-bearing ground-water, but the factors influencing its localized development are not evident. The Hickory member does not appear to be more highly jointed than normal at this location; and for that reason, the concentration of quartzite cannot be related to a localized fracture zone in the sandstone. The soluble silica necessary to form the quartzite was probably derived from the weathering of glauconite in the overlying Cap Mountain limestone and Lion Mountain sandstone, and it is possible that the localized nature of the quartzite was caused by fracture zones in overlying beds that controlled the downward movement of ground-water. The quartzite of the Hickory sandstone formed subsequent to faulting in the region and probably after uplift and erosion had elevated the sandstone to the level of ground-water circulation.

Stratigraphic relation: The Hickory sandstone is separated from the Precambrian basement rocks by a distinct unconformity. Its contact with the overlying Cap Mountain limestone, however, is not so sharply defined, being gradational both laterally and vertically. The boundary established by Cloud, Barnes, and Bridge (1945) is at the top of the non-calcareous sandstone beds, and the contact is picked there for detailed field studies. Because the transition from non-calcareous sandstones to limestone occurs over a relatively short interval, the established boundary is coincident, within the limits of mapping accuracy, with a topographic and vegetational break occurring between the sandstone and the limestone. The break is usually distinct on aerial photographs and, for mapping purposes, is the best criterion for picking the contact.

Cap Mountain Limestone Member

Definition and thickness: Paige (1911, p. 23) first used the name Cap Mountain formation, taken from Cap Mountain, Llano County, to apply to strata between the then recognized Hickory and Wilberns formations, He placed the upper boundary of the formation above the presently recongnized Lion Mountain sandstone and placed the lower boundary above the calcareous sandstone beds presently assigned to the Cap Mountain limestone. Cloud, Barnes, and Bridge (1945, p. 154) redefined the Cap Mountain as a member of the Riley formation. They relocated the boundaries to exclude the Lion Mountain sandstone and to include the calcareous sandstone beds assigned by Paige to the underlying Hickory sandstone.

According to Bridge, Barnes, and Cloud (1947), the thickness of the Cap Mountain limestone varies from 135 feet to 455 feet and averages 280 feet. They attribute the variable thickness to a northwestward lateral gradation of the lower beds into the Hickory sandstone.

In the Camp Air-West area, the Cap Mountain limestone is about 270 feet thick.

Lithology: The Cap Mountain limestone varies from dark reddish-brown and buff, fine- to medium-grained, calcareous sandstone and brown, arenaceous limestone at the base to gray, medium-grained, sandy, glauconitic limestone near the top. Immediately below its contact with the overlying Lion Mountain sandstone, the Cap Mountain limestone is highly glauconitic and contains a few thin shaley beds. The thickness of individual beds varies from less than 0.5 foot to about 3 feet, but beds from 0.5 foot to 1 foot are predominant on weathered slopes. The thicker beds are more common in the lower and upper levels of the member, particularly in the zones of transition between sandstone and limestone. Glauconite is particularly abundant in the upper beds, but at some localities it occurs below the middle stratigraphic level of the member in sufficient quantities to give the fresh rock a green speckled appearance.

Although it is highly jointed throughout its vertical extent, the Cap Mountain limestone is relatively resistant in the arid climate of the region and tends to form elongated ridges or cuestas between lowlands developed on the Hickory sandstone below and benches developed on the Lion Mountain sandstone above.

The Cap Mountain limestone crops out in a northeast-southwest trending ridge extending from the south-central part to the northeastern corner of the thesis area. Bedrock is poorly exposed along the ridge except at scattered localities along the scarp slope and in the beds of ephemeral streams. The best exposure of the basal beds is in the abandoned iron-test pit 1.5 miles north of Camp Air (location 7, Plate I). There, dark brown to yellowish-brown, calcareous siltstone and sandstone beds are exposed above the contact with non-calcareous sandstones of the

Hickory member. The basal beds are 1 foot to 2.5 feet thick and are highly jointed. Laminae of ferruginous material are present along many of the bedding surfaces. Upward, the beds thin and become more calcareous, grading into buff arenaceous limestone and finally into gray limestone.

The approximate middle stratigraphic level of the Cap Mountain limestone is exposed at location 9 (Plate I) in the bed of a small ephemeral stream. At that locality the limestone is fine- to medium-grained, silty, and gray, with specks and mottlings of brown. Individual beds vary from 0.5 foot to 1 foot in thickness, and leaching along the edges of some of the beds has produced a honeycomb texture on the surface.

Beds of the upper stratigraphic levels of the Cap Mountain limestone are poorly exposed along the dip slope of the ridge. Above the middle stratigraphic levels the member is a light gray, speckled with brown and green, fine- to medium-grained, glauconitic limestone in 0.5 to 1 foot thick beds. The amount of glauconite and the thickness of beds increase toward the top of the section. Near the contact with the overlying Lion Mountain sandstone, brown and gray, silty, glauconitic limestone beds alternate with beds of gray shales and brown, glauconitic, calcareous siltstones.

Stratigraphic relation: Both the upper and lower boundaries of the Cap Mountain limestone are gradational. The contact with the underlying Hickory member is picked at the first significant occurrence of calcium carbonate for detailed field studies and at the topographic and vegetational break between the limestone ridge and the sandstone lowland for mapping purposes. The contact with the overlying Lion Mountain sandstone is picked, for mapping purposes, at the lower edge of the sparsely vegetated bench normally developed on the sandstone outcrop. For detailed field studies, the upper boundary is picked at the first bed of trilobite "hash" or the first bed of abundantly glauconitic sandstone above the thick bedded limestone.

Lion Mountain Sandstone Member

Definition and thickness: Bridge (1937, p. 234) named the Lion Mountain sandstone as the top member of the then recognized Cap Mountain formation. Cloud, Barnes, and Bridge (1945, p. 154), in revising the Upper Cambrian stratigraphy of the Llano region, retained the unit with its original boundaries as the upper member of the Riley formation.

At its type locality on Lion Mountain in Burnet County, the member is 20 feet thick, but the thickness varies throughout the uplift to a maximum of 50 feet. The thickness of the Lion Mountain sandstone could not be measured in the thesis area because of faulting and soil cover, but it is estimated to be in excess of 30 feet and is probably close to 50 feet.

Lithology: The Lion Mountain member is a medium- to coarse-grained, highly glauconitic sandstone with beds and lenses of limestone in the lower part. The limestone consists, for the most part, of an indurated coquina of trilobite fragments, but some beds are non-fossiliferous and some contain brachiopod shells. Locally, thin shale beds occur between the limestone beds and between the limestone and sandstone lithologies. The limestone is well bedded near the base of the unit at some localities, but at higher stratigraphic levels it occurs as tangential lenses of trilobite coquina in the sandstone. In the northwestern part of the Llano uplift, the Lion Mountain sandstone and the overlying Welge sandstone typically underlie benches between resistant ridges of Cap Mountain limestone and Morgan Creek limestone. In the eastern part of the region and in the sourthern part near the Llano River, however, the Welge sandstone is more resistant to erosion than is the Lion Mountain sandstone, and outcrops of the two members are separated by a small scarp developed on the Welge sandstone.

An abundance of hematite nodules which form as weathering products of the highly glauconitic sandstone is characteristic of the weathered outcrop of the Lion Mountain sandstone.

The Lion Mountain sandstone crops out in two narrow, diagonal belts trending northeastward across the central part of the thesis area. No exposures of fresh bedrock were found along the southeastern outcrop belt, and the member was recognized there only from the occurrence of hematite nodules and from occasional slabs of trilobite "hash" protruding from the soil cover. In the northwesternmost of the two outcrop belts, one good exposure of the upper beds of the member occurs in a small gully 0.2 mile northeast of the Roy Schmidt ranch house (location 10, Plate I). At that locality, the member is an olive green, well-sorted, coarse-grained, glauconitic, quartz sandstone, with occasional layers of almost pure glauconite and a few small, 1 to 2 inch thick lenses of trilobite "hash". Well displayed in the exposure are intermediate stages of weathering of the glauconitic sandstone into deep red, ferruginous sandstone that ultimately forms the characteristic hematite nodules associated with weathered outcrops of the member. Silica and iron oxide cements derived from the chemical weathering of glauconite have formed deep red spots of induration on the surface of the bedded sandstone. The red tones deepen and the induration increases with the degree of breakdown of the glauconite. Differential weathering leaves the indurated parts of the bedrock as surface residuum and continuation of the weathering process ultimately results in the complete alteration of the sandstone fragments into highly ferruginous quartzite pebbles and cobbles aptly described as hematite nodules.

The basal beds of the Lion Mountain member are covered by soil on the thesis area but are exposed in several small gullies just off the southwestern corner of the area. In that vicinity, the lower 5 to 8 foot interval of the member consists of highly glauconitic, nonfossiliferous limestone and trilobite and brachiopod "hash" in beds averaging about 0.3 foot in thickness. Although the exposures are restricted and the individual beds cannot be traced more than a few feet laterally, the interval appears to be comprised of well developed beds and not of lenses. No evidence of this bedded limestone interval was found on the eastern part of the thesis area where small lenses of trilobite "hash" protrude through the soil cover within a few feet of the thick upper beds of Cap Mountain limestone. The exposures off the southwestern corner of the area are thought to represent a local development, possibly resulting from deposition in a local depression that remained below the level of wave action longer than the surrounding area.

All of the trilobite limestone observed in the Lion Mountain member is composed of fragments. This evidence of conditions of bottom agitation appears anomalous in view of the abundance of glauconite in the sandstone. The formation of glauconite requires reducing conditions, and oxygenation of bottom waters by agitation would prevent it formation. One explanation for the anomaly is that both the glauconite and the trilobite fragments were derived from pre-existing nearby sediments. It is doubtful, however, that the great quantity of glauconite occurring in the Lion Mountain sandstone could have been weathered from sediments exposed to sub-aerial conditions and transported to the site of deposition without extensive chemical alteration. Another possibility is that the glauconite and trilobite fragments were derived from pre-existing unconsolidated ocean bottom deposits brought up to the level of wave action by regression of the sea. This is more plausible, but in this case the occurrence of glauconite and trilobite fragments should be restricted to the lower beds of the member. It seems probable, therefore, that the Lion Mountain glauconite is authigenic, and another solution to its anomalous occurrence in the presence of evidence of agitation must be sought.

Cloud (1955) discussed the formation of glauconite in recent and ancient sediments, concluding that it requires marine waters, reducing conditions, and appropriate source material. They further concluded that its formation is favored by high organic content of bottom sediments and slow or intermittent deposition. As discussed earlier, ZoBell (1946) has shown that the reduction of material in ocean bottom sediments takes place almost entirely within a few inches of the depositional surface.

If the conclusions of these authors are accepted, the occurrence of abundant glauconite in the Lion Mountain sandstone might be explained by assuming long periods of quiescence and slow sedimentation in which reducing conditions existed on the sea bottom, followed by periods of wave agitation during which the unconsolidated sediments were reworked, the fine material was winnowed out, and the fragmented trilobite remains were redeposited in depressions on the sea floor. In support of this possibility, the following quotation from Lochman (1949, p. 56) is offered.

> "Both in recent sediments and in the geologic column, glauconite may be associated with evidences of agitated water - an apparent anomaly until it is realized that the phenomena ... indicate(s) a sporadic ... wave or current action alternating with periods of quiet water."

Stratigraphic relation: The Lion Mountain sandstone is the top member of the Riley formation and underlies the Welge sandstone of the Wilberns formation. The contact between the two sandstones has been described as "sharp" by Bridge, Barnes, and Cloud (1947, p. 114) and by many subsequent authors. The word "sharp" refers to the distinct and abrupt lithologic change from highly glauconitic sandstone to non-glauconitic sandstone across the boundary at most localities.

Only one exposure of the contact was found in the Camp Air-West area. This exposure, occurring in a small gully just west of the Mason-Brady highway 2.5 miles north of Camp Air (location 11, Plate I), is limited in lateral extent to about two feet and cannot be considered as diagnostic; however, the contact does not appear to be an unconformity. The "sharp" change in lithology may be the result of rapid environmental change and not of uplift and erosion. Certainly no profound unconformity exists between the Riley and Wilberns formations, since at no place is the Lion Mountain sandstone reported to be extensively eroded. One would have to imagine a remarkably level land area of great extent to propose an erosional unconformity at the top of the Lion Mountain member over the entire Llano region that did not result in its complete removal in the more landward localities.

The basal boundary of the Lion Mountain sandstone is one of gradation into the underlying Cap Mountain limestone. For mapping purposes, the basal boundary is picked at the topographic and vegetational break occurring between the relatively thickly vegetated dip slope of the ridge normally developed on the limestone member and the sparsely vegetated bench normally developed on the sandstone member.

Wilberns Formation

Paige (1911, p. 23) named the Wilberns formation from exposures at Wilberns Glen, Llano County. Cloud, Barnes, and Bridge (1945, p. 155) redefined the formation and raised the upper boundary to coincide with the Cambrian-Ordovician boundary in the eastern part of the uplift where an unconformity separates the two systems. According to Barnes and Bell (1954), however, later field work has shown that the Wilberns type lithology transgresses the systemic boundary toward the west where no unconformity occurs. According to Bridge, Barnes, and Cloud (1947) the Wilberns formation, in normal sections, varies in thickness from 540 to 610 feet and averages 580 feet. In the southeastern corner of the region, erosion of the upper beds has reduced the thickness of the formation to 360 feet. The aggregate thickness of members of the Wilberns formation cropping out in the Camp Air West area is about 490 feet. However, the accuracy of measurements of most of the members is doubtful because of the effect of faulting; and it is possible that the thickness of the formation in the area is greater.

As presently subdivided, the Wilberns formation consists of four members. In ascending order these are: the Welge sandstone, the Morgan Creek limestone, the Point Peak shale, and the San Saba limestone.

Welge Sandstone Member

Definition and thickness: Barnes (Bridge, Barnes, and Cloud, 1947, p. 114) named the Welge sandstone from the Welge land surveys in Gillespie County, and chose the type section on Squaw Creek, 0.5 mile north of the county line. In its type section, the Welge sandstone is 27 feet thick, and its average thickness throughout the Llano region is 20 feet. The thickness of the member in the thesis area could not be determined accurately, but it is estimated to be about 20 feet.

Lithology: The Welge member is a yellowish-brown, non-glauconitic to slightly glauconitic, non-calcareous, fine- to coarse-grained sandstone. It is relatively non-resistant in the arid climate of the region, and its normal topographic expression is a bench margin with a similar feature formed on the underlying Lion Mountain sandstone. In the sourthern and eastern parts of the uplift, however, the Welge sandstone is more resistant than the Lion Mountain sandstone, and in those areas it tends to form small scarps between the Lion Mountain benches and the more pronounced scarps developed on the Morgan Creek limestone.

In the Camp Air-West area, the Welge sandstone crops out along the northwestern margins of the Lion Mountain outcrop belts discussed previously. Bedrock exposures are limited to scattered localities, particularly along faults, where silicification has made the sandstone resistant to erosion. In these exposures, the member is a light yellowish-brown to dark brown, fine- to coarse-grained, indurated quartz sandstone varying to quartzite.

An excellent exposure of the member occurs in a creek bank about 0.3 mile off the southwestern corner of the thesis area. At that locality, 18 feet of grayish-white, massive, fine- to medium-grained sandstone crops out below the basal beds of the Morgan Creek limestone. The contact with the underlying Lion Mountain sandstone is not exposed, and the full thickness of the Welge member could not be determined. There is a marked contrast between the color of the sandstone at this locality and its color in exposures on the thesis area. The upper beds near the contact with the Morgan Creek limestone are light buff-colored, but the exposure is predominantly white. The normally reddish-purple beds of the Welge sandstone-Morgan Creek limestone transition zone and of the basal Morgan Creek limestone are also much lighter in color than normal, and they appear to have been extensively leached. It is probable that ground-water seeping into the adjacent stream leached the ferruginous material from both the sandstone and the overlying limestone, thus altering their characteristic colors.

Stratigraphic relation: At its upper boundary, the Welge sandstone grades into the Morgan Creek limestone. The zone of transition between non-calcareous sandstone and limestone is relatively thin, and for mapping purposes the boundary is placed at the topographic and vegetational break between the sparsely vegetated or cultivated sandstone bench and the more thickly vegetated limestone ridge. The lower boundary is marked by an abrupt change from highly glauconitic sandstone of the underlying Lion Mountain member of the Riley formation to the non-glauconitic sandstones of the Welge member of the Wilberns formation. In the thesis area there is no discernible change in topography or vegetation across the lower boundary.

Morgan Creek Limestone Member

Definition and thickness: The Morgan Creek limestone was first defined in the literature by Bridge, Barnes, and Cloud (1947, p. 114). At its type locality, near the junction of the north and south forks of Morgan Creek in Burnet County, the member is 110 feet thick; but its thickness varies from 70 to 160 feet and averages 120 feet throughout the Llano region. In the thesis area, the Morgan Creek limestone is 115 feet thick.

Lithology: The Morgan Creek limestone consists of medium- to coarse-grained, highly glauconitic, limestone in beds varying from 0.3 foot to 1.5 feet in thickness. Near its lower boundary, the member contains dull red to purplish-red, calcareous siltstone beds varying from 0.3 foot to 0.5 foot in thickness. These basal beds grade upward into medium-grained, sandy, glauconitic limestone. Upward in the section the beds thicken, the red color grades to greenish-gray, and the amount of sand decreases. In the middle stratigraphic levels, the member consists of gray, speckled with brown and green, abundantly glauconitic, nonfossiliferous to highly fossiliferous limestone in beds varying from 0.5 foot to 1 foot in thickness. Small bioherms of gray micro-granular limestone and thin beds of intraformational conglomerate are common in the upper levels of the member at many localities. Near the contact with the overlying Point Peak member, shale beds alternate with the limestone.

Locally, the Morgan Creek limestone is highly fossiliferous, containing a variety of brachiopod and trilobite remains. Two fossils occurring in laterally persistent but vertically restricted zones are of particular aid in recognizing the member where the characteristic basal beds are missing or covered. The brachiopod Eoorthis texana, occurring in a 5 to 10 foot zone approximately 40 feet above the base of the member furnishes a good criterion for recognizing the lower stratigraphic levels, whereas a less restricted zone of cystoid (?) columns and plates, normally occurring about 30 feet below the upper boundary, is diagnostic of the upper stratigraphic levels.

The Morgan Creek limestone crops out in two parallel ridges trending northeastward across the central part of the Camp Air-West area. The easternmost of these exposures is terminated by faulting in the east-central part of the area, but the westernmost exposure persists throughout the area except in the southern part where it is covered by Cretaceous strata. The basal red limestone beds of the member are well exposed along the scarp slopes of the ridges, but caliche and soil mask the bedrock on the dip slopes of the ridges except at scattered localities where limited exposures of the middle and upper beds of the member occur in small ephemeral streams and gullies. The basal beds of the member are best exposed on the eastern slope of a hill immediately behind the Roy Schmidt ranch house (location 12, Plate I). At that locality the Morgan Creek limestone is in fault contact with the Welge sandstone, but the fault is within one or two feet of the base of the limestone. Below a 15 foot covered interval extending downward from the Cretaceous strata atop the hill, a 25 foot interval of dull red, sandy, coarse-grained limestone in beds varying from 0.5 foot to 1 foot in thickness is exposed. On the north side of the same hill, gray to greenish-gray and brownish-gray, glauconitic limestone in beds averaging about 0.8 foot in thickness is exposed in a small gully. This exposure is at the approximate middle stratigraphic level of the member. Some beds at this locality are highly fossiliferous, containing brachiopod shells; but the zone of *Eoorthis texana* was not found. The zone probably occurs in a covered interval below these beds. On the western slope of the hill, bedrock is poorly exposed, but several small bioherms of gray, micro-granular limestone protrude through the soil cover. Some of these masses are coated with a thin layer of yellow to orange dolomite, and a few are comprised entirely of dolomite.

In a small ephemeral stream 0.7 mile west of the Roy Schmidt ranch house (location 13, Plate I), reddish-brown to gray and greenish-gray limestone beds of the upper part of the member are exposed in a 3 foot interval extending about 40 feet laterally along the stream bank. The more protected beds in this exposure average about 1 foot in thickness, but laterally along the outcrop, they have weathered to thinner beds averaging about 0.4 foot in thickness. The occurrence of cystoid (?) columns and plates in a reddish-brown limestone bed at the base of the interval was of considerable aid in locating the Morgan Creek limestone-Point Peak shale boundary in this part of the thesis area.

Stratigraphic relation: The Morgan Creek limestone overlies the Welge sandstone and underlies the Point Peak shale. Both boundaries are gradational. For mapping purposes, the lower boundary is most conveniently picked at the top of the sparsely vegetated or cultivated bench normally developed on the Welge sandstone. The upper boundary is marked by a topographic and vegetational break between the ridge normally developed on the Morgan Creek limestone and a gentle, sparsely vegetated, caliche-covered slope or bench normally developed on the Point Peak shale.

Point Peak Shale Member

Definition and thickness: The Point Peak shale member was named by Bridge (Bridge, Barnes, and Cloud, 1947, p. 115) from Point Peak near Lone Grove, Llano County. According to these authors, the thickness of the member varies from a maximum of 270 feet in its type section on the south slope of Point Peak to a minimum of 25 feet in the Scott Klett ranch section along the Pedernales River in Blanco County. The average thickness of the member in the Llano region is about 160 feet. Its thickness in the Camp Air-West area is estimated too be about 110 feet.

Lithology: The Point Peak shale member consists of gray to greenish-gray and brown, soft, calcareous siltstones and shales with interbeds of fine- to medium-grained glauconitic limestone and intraformational limestone conglomerate. Small sub-circular bioherms of gray micro-granular limestone and yellowish-brown, fine-grained dolomite occur locally throughout the stratigraphic extent of the member, but are most abundant in the lower beds.

The limestone of the Point Peak member is highly glauconitic, and many of the beds are mottled with brown. Some beds bear a marked resemblance to the upper beds of the Morgan Creek limestone and to some of the lower and middle beds of the overlying San Saba limestone. The intraformational conglomerate occurs in beds averaging about 0.3 foot in thickness and consists of gray, brown, and green, angular to well rounded and flattened limestone pebbles imbedded in a matrix of gray to brown, medium-grained limestone. Limestone beds are most abundant near the lower and upper boundaries of the member.

The normal topographic expression of the Point Peak shale is a gentle, sparsely vegetated, caliche-covered slope between more steeply rising slopes developed on the Morgan Creek and San Saba limestones. In the Camp Air-West area the normal topographic expression of the member has been destroyed by the formation of subsequent drainage lines along its outcrop which has been reduced to a broad alluvium-filled valley trending northeast-southwest across the central part of the area. In the outcrop belt, the only bedrock exposures are occasional beds and slabs of limestone and intraformational conglomerate and a few scattered masses of gray micro-granular limestone protruding through the soil cover. The siltstone and shale beds of the member are completely masked by soil. The exposures of limestone and intraformational conglomerate are closely spaced near the boundaries of the member but are widely scattered in the center of the outcrop belt. The small biohermal masses of micro-granular limestone occur only near the lower boundary in the main part of the area, but in the southwestern part of the area, west of the Cretaceous outcrop, they occur in abundance near the top of the member.

Stratigraphic relation: The Point Peak shale grades into the San Saba limestone at its upper boundary and into the Morgan Creek limestone at its lower boundary. Both boundaries vary considerably in the vertical direction because of facies changes from shale to limestone. Bridge, Barnes, and Cloud (1947) noted that the upper boundary dropped 80 feet stratigraphically in a horizontal distance of 3 miles near Sudduth in Burnet County. They noted a still greater drop in the stratigraphic position of the upper boundary along the Pedernales River in Blanco County. Similar vertical variations of the lower boundary were reported by the same authors.

The upper boundary of the member is picked at the highest significant shale bed where the bioherm zone does not intervene between the Point Peak member and the overlying San Saba member. Where the bioherm zone does occur, placement of the upper boundary requires that the exact relationship of the bioherms to the two members be determined. The lower boundary is picked in the zone of transition between limestone and shale at a point above which the limestone beds are thin and widely separated. For mapping purposes this boundary is most conveniently picked at a topographic and vegetational break between the ridge developed on the underlying Morgan Creek limestone and the bench or gentle slope developed on the Point Peak shale.

San Saba Limestone Member

Definition and thickness: Comstock (1890) first used the name San Saba to apply to the uppermost of two "Silurian" series he proposed for the Llano region. Bridge (Bridge, Barnes, and Cloud, 1947, p. 117) revived the name and applied it to the limestone beds intervening between the Point Peak shale and the Ellenburger limestone. At least part, if not all, of these beds were included in the San Saba series of Comstock. The member is about 299 feet thick in its type section which begins at the San Saba River bridge on the Mason-Brady highway in southern McCulloch County and extends northward for 0.7 mile.

In the Camp Air-West area, the San Saba limestone was mapped as two units - a basal unit containing stromatolitic bioherms and an upper unit comprised of bedded limestone. The thickness of the bioherm unit is estimated to be about 110 feet, and that of the bedded limestone about 140 feet.

Bioherm Unit

General statement: Throughout most of the Llano region, a zone of stromatolitic bioherms occurs near the boundary between the Point Peak shale and the San Saba limestone. The zone is not continuous over the region, but is replaced laterally by shale or bedded limestone.

The probable algal origin of these reef masses suggests that their development would be controlled by the zone of photosynthesis which, in turn, would be determined by depth and clarity of the sea. Their sensitivity to water clarity is questionable, however, in the light of their occurrence entirely within the Point Peak shale at some localities in the Llano region and entirely within the San Saba limestone at others. The zone has not been studied in sufficient detail to determine with certainty the direction of transgression of the lithologic boundary, but it appears that the masses have their maximum development in shale in the southern and eastern parts of the uplift and in limestone in the western and northern parts. The apparent adaptability of the reef forming algae to varying environmental conditions suggests that the zone might approach a time plane. The dependency of the life process of these organisms on light is inescapable. However, their development under conditions of both fine-clastic and limestone deposition suggests that they existed under varying conditions of light, and their growth must have been affected appreciably by water depth as controlled by position of the strand line. It is doubtful, then, that the zone could be considered as a time marker over a large area. In a localized area such as the Llano region, however, its deviation from a time plane would probably be small and its transgression of the lithologic boundary between shale and limestone might be considered as evidence of non-parallelism of time and lithologic boundaries.

The occurrence of the bioherms in both the San Saba limestone and the Point Peak shale makes it difficult to place the boundary between the two members. Proper placement of the boundary may be determined by the occurrence of shale above the bioherms or by the occurrence of granular, bedded limestone below them. Where neither of these conditions is evident, and where tracing of the zone fails to indicate whether the bioherms are replaced laterally by shale or by limestone, the boundary should be placed above the bioherms to be consistent with previous work in the region.

In the Camp Air-West area, the zone consists of scattered bioherms separated by bedded limestone and intraformational conglomerate and replaced laterally by girvanella limestone. In the south-central part of the area, near the Cretaceous outcrop, yellow and brownish-gray, granular, well-bedded limestone crops out beneath the zone of bioherms and above the Point Peak shale. The lateral facies change to Girvanella beds, and the occurrence of bedded limestone between and beneath the biohermal masses were the criteria used for placing the zone in the San Saba limestone.

Lithology: The lithology of the bioherm zone is highly varied. The large "cabbage head" masses normally consist of gray, bluish-gray, and brownish-gray, sub-lithographic limestone, but in some areas on the northwestern flank of the uplift, they are comprised of gray and pink dolomite. Locally, the masses are in juxtaposition and form a continuous, hummocky surface. More commonly, however, they are scattered;

and granular limestone, micro-granular limestone, intraformational conglomerate or shale beds intervene between the "cabbage heads". Possibly the "cabbage heads" are individual algal colonies.

The bioherm zone underlies a gently dipping, rubble-strewn slope trending northeastward across the west-central part of the thesis area. Within the outcrop belt, three merging but very dissimilar facies occur - a normal calcite reef facies, a Girvanella limestone facies, and a dolomite reef facies.

At the northern end of the belt, large sub-circular masses - the typical stromatolitic bioherms - are well developed. They occur as scattered masses of blue-gray sublithographic limestone separated by beds of gray and greenish-gray, glauconitic limestone; yellowish-brown, fine-grained dolomite; and gray, green, and brown mottled intraformational conglomerate.

In the central part of the northern one half of the outcrop, the "cabbage head" masses are almost completely replaced by limestone. The limestone of this facies is of three types: gray, massive, micro-granular limestone commonly having networks of dolomite ridges on the upper surface; pearl gray, bedded, micro-granular limestone with streaks and mottlings of brown; and brownish-gray, massive, silty, micro-granular limestone that weathers to rounded, honeycombed masses. Locally, all of these limestones contain varying quantities of light gray to ivory, subspherical, pea-sized to marble-sized bodies of algal origin which appear as light "eyes" on the weathered surfaces. These bodies, called girvanellas (Girvanella) by Bridge, Barnes, and Cloud (1947), are most abundant throughout the interval in the pearl gray and brown mottled limestone, but their greatest single concentration is in masses of brownish-gray, silty, micro-granular limestone near the western limit of the exposure.

Bridge, Barnes, and Cloud (1947) discussed the occurrence of _Girvanella_ beds in the San Saba limestone at various localities in the Llano region. These occurrences vary from a 5 foot interval in the type section near Camp San Saba to the entire stratigraphic extent of the member in a section north of Fall Creek near the juncture of San Saba, Llano, and Burnet Counties. In the thesis area, the _Girvanella_ interval is estimated to be about 70 feet thick.

At the eastern edge of the exposure of the _Girvanella_ facies in the thesis area (see Plate I), the bodies are widely scattered in beds of pearl gray, mottled with brown, micro-granular limestone. These beds are massive in fresh exposures but weather into thin slabs varying from 0.2 foot to 0.8 foot in thickness. Westward, the specimens of _Girvanella_ are more abundant and occur in gray, massive, micro-granular limestone and in brownish-gray, massive, silty, micro-granular limestone as well as in the pearl gray, mottled limestone. Near the western edge of the reef outcrop, the _Girvanella_ bodies are extremely abundant, occurring in very silty micro-granular limestone that weathers into rounded honeycombed masses (Plate VI). In the vicinity of these masses, the ground is littered with individual specimens of _Girvanella_ that have weathered from the limestone.

Southward, in the approximate center of the outcrop belt, the _Girvanella_ facies merges with dolomitized bioherms. In the zone of transition, the _Girvanella_ occur in small residual blocks and slabs of gray and pink mottled dolomite (Plate VII, Fig. 1). The entire southern half of the reef outcrop belt consists of dolomitized reefs. The dolomite is more susceptible to weathering than calcite, and as a consequence, the majority of the reef masses have been reduced to a residuum of rounded

Plate VI

Girvanella Specimens

Figure 1. Honeycombed masses of silty micro-granular limestone containing girvanellas. Western edge of bioherm zone, Girvanella "facies", 0.3 mile from northern border of area.

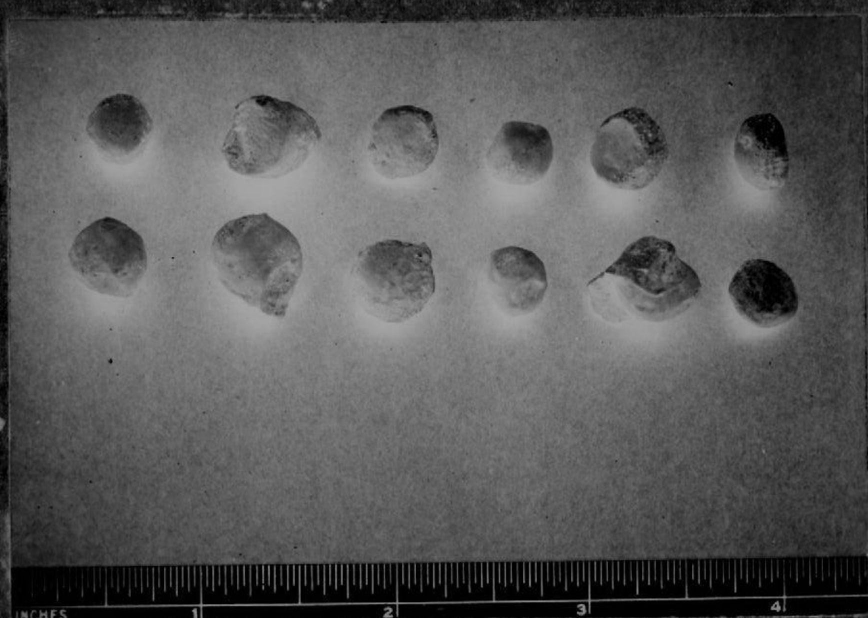


Figure 2. Specimens of Girvanella picked from surface residuum in vicinity of honeycombed masses pictured in figure 1.

Plate VII

Dolomite of the Bioherm Unit

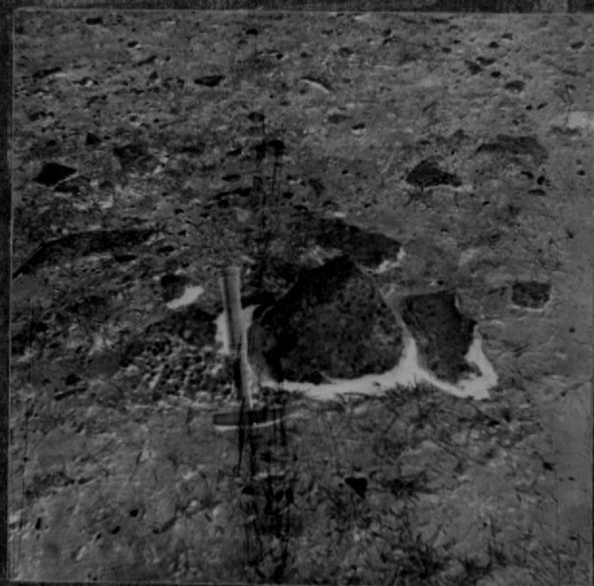


Figure 1. Dolomite containing girvanellas. At southern extremity of girvanella "facies" of bioherm zone.

Figure 2. Dolomitized bioherm exposed in dry gully near private road to Kelly Schmidt ranch house, four miles west of Camp Air.

boulders. However, some of the larger masses have partially retained the typical "cabbage head" structure (Fig. 2, Plate VII). The dolomite of the reef masses varies from brownish-gray, coarse-grained, and vuggy, to pink and gray mottled, fine-grained, and compact. It weathers to a dull brownish-gray and develops a spongy texture on the out surface. Near the southern extremity of the exposure, beds of yellowish-orange, fine-grained, compact dolomite and greenish-gray and brown mottled, dolomitic limestone crop out between the bioherms.

The bioherm section of the Camp Air-West area appears to be transitional between the calcite reefs of the Camp San Saba section and the dolomite reefs of the Calf Creek section described by Barnes and Bell (1954, p. 45 - 67).

Stratigraphic relation: At its lower boundary, the bioherm zone grades into the Point Peak shale, and at its upper boundary it grades into the bedded limestones of the San Saba member. As discussed earlier, facies changes from limestone to shale cause the zone, as it is presently mapped, to vary in position between the San Saba and Point Peak members. Proper placement of the zone at any locality depends upon the determination of its exact relationship to the two members.

Bedded Limestone Unit

Lithology: The bedded limestone unit, which constitutes the entire San Saba member in areas where the bioherm zone is absent or within the Point Peak shale, is the most variable Upper Cambrian stratigraphic unit in the Llano region. It is characterized by marked facies changes which, at some localities, involve the entire unit. Most commonly it consists of vari-colored, gray, green, brown, and yellow, granular limestones in its lower and middle levels and of gray micro-granular limestone in its upper levels. Locally, however, sublithographic limestone occurs throughout the entire stratigraphic extent of the unit and may overlie or be interbedded with the bioherms.

In the eastern part of the Llano region the unit is comprised of dolomite which grades westward into the normal limestone facies, and in the extreme western part of the region intervals of bedded sandstone occur with the limestone.

Bedded limestone of the San Saba member crops out in two narrow irregular belts of low hills and moderate slopes trending diagonally across the northwestern corner of the thesis area. The breadths of the two outcrop belts are controlled by faulting and topography.

Granular limestones of the lower part of the unit are exposed in a small ephemeral stream 0.7 mile south of the northern border of the area (location 14, Plate I). At that location, Girvanella beds of the reef zone are exposed by "reversed" drag along the upthrown side of a fault. Above the girvanella beds, light gray, medium-grained, glauconitic limestone with green and brown flecks and mottlings alternates with yellowish-brown, fine-grained limestone and with gray and brown mottled, coarse-grained limestone containing trilobite and brachiopod remains. The beds vary in thickness from 0.2 foot to 0.5 foot and the entire interval is 20 feet thick. About 100 yards east of location 14, a 50 foot interval of gray, brown, and green mottled, medium-grained limestone; gray and brown mottled, coarse-grained limestone; and vari-colored gray, green, and pink mottled intraformational conglomerate containing rounded and flattened pebbles of highly glauconitic limestone is exposed.

Near the southern end of the eastern outcrop belt, the lower beds of the unit cap a small hill just west of the Kelly Schmidt ranch house (location 15, Plate I). The sides of the hill are mostly covered with soil and limestone talus, but occasional beds of limestone are exposed. The limestone at this locality is yellowish-brown, medium-grained, and non-glauconitic near the base of the hill and gray, speckled with green and brown, medium-grained, and highly glauconitic near the top.

The lower part of the bedded limestone unit shows considerable variation between its scattered exposures in the thesis area. Most of the outcrop belt is soil-covered and beds could not be traced laterally more than a few feet, but outcrops aligned along the apparent strike of the unit were found to be very dissimilar lithologically. This apparent rapid facies change was probably caused by the effect of the underlying biohermal masses on deposition.

The upper beds of the San Saba limestone are exposed along a small creek at the northern border of the area (location 16, Plate I). Immediately below the Ellenburger contact, picked at the first occurrence of the uncoiled form of Lytospira gyroceras, the beds consist of light gray, micro-granular limestone that weathers into thin, nodular, shaly-appearing beds. Some beds are mottled with light brown and orange dolomite. About 30 feet below the upper boundary, light yellowish-brown, fine- to medium-grained, limestone beds averaging about 0.3 foot in thickness are interbedded with micro-granular limestones, and at 50 feet below the boundary, interbeds of vari-colored gray, pink, and green intraformational conglomerate and greenish-gray, medium- to coarse-grained limestone occur. Some of the coarse-grained limestone beds contain trilobite and brachiopod remains.

The light gray micro-granular limestone beds of the upper part of the member are continuous across the San Saba-Ellenburger boundary at most localities in the area.

Stratigraphic relation: Bedded limestones of the San Saba member grade into the underlying bioherm zone, or in its absence, into the Point Peak shale. At its upper boundary, the member, in the eastern part of the Llano uplift, is separated from the overlying Ellenburger limestone by an unconformity. Over most of the region, however, the member is in gradational contact with the Ellenburger group, and on the northwestern flank of the uplift, the San Saba limestone transgresses the Cambrian-Ordovician boundary.

ORDOVICIAN SYSTEM

Ellenburger Group

Definition and thickness: Paige (1912, p. 52) named the Ellenburger limestone formation from the Ellenburger Hills in southeastern San Saba County. As defined by Paige, the formation included some beds presently assigned to the San Saba member of the Wilberns formation. Cloud, Barnes, and Bridge (1945, p. 133) raised the formation to group status and subdivided it, from bottom to top, into the Tanyard, Gorman, and Honeycut formations. They adjusted the lower boundary of the group to coincide with an erosional and faunal break representing the Cambrian-Ordovician boundary in the eastern part of the uplift, but subsequent work in the region, according to Barnes and Bell (1954), has shown that the base of the Ellenburger group lies well above the systemic boundary in the western part of the uplift where no unconformity occurs between the two systems.

According to Cloud and Barnes (1945), the thickness of the Ellenburger group, in complete sections, ranges from 1500 to 1800 feet. In the Camp Air-West area, the Ellenburger limestone is estimated to be about 80 feet thick. Erosion has removed all but the basal limestone beds of the group - probably the lower part of the Tanyard formation of Cloud, Barnes, and Bridge (1945).

Lithology: Throughout the Llano region the Ellenburger group is comprised essentially of relatively pure, light colored, thin-bedded to massive, sublithographic limestones and light to dark colored, micro-granular to coarse-grained dolomites. Intraformational conglomerates occur locally in the lower part of the group.

As exposed in the Camp Air-West area, the lower beds of the Ellenburger group are comprised of pearl gray, thin- to medium-bedded, sublithographic limestone, with local developments of medium gray, weathering to blue-gray, massive, sublithographic limestone. The pearl gray sublithographic limestone appears to be thick-bedded in fresh exposures, but it weathers to thin-bedded in creek banks and to smooth surfaced slabs on slopes. Many of the beds are mottled with light brown to orange dolomite "trails". These beds are continuous across the San Saba limestone-Ellenburger group boundary over most of the area, but locally they are replaced at the contact by gray, massive, sublithographic or micro-granular limestone that weathers into large rectangular blocks 1 foot or more in thickness. The outer surface of these blocks weathers to a dark bluish-gray, and they closely resemble some of the massive reef limestone blocks of the bioherm zone. It is probable that they are localized algal reef developments.

Intraformational conglomerates occur locally near the lower boundary of the group.

Stratigraphic relation: At its lower boundary in the Llano uplift, the Ellenburger limestone is in gradational contact with the San Saba member of the Wilberns formation except in the eastern part of the region where it overlies that unit disconformably. At its upper boundary, the group is overlain unconformably by strata of Devonian, Carboniferous, and Cretaceous age.

CRETACEOUS SYSTEM

Comanchean Series

General statement: Relatively flat-lying strata of Early Cretaceous age, resting with pronounced unconformity on older rocks, border the Llano region on all but the northern side. Equivalent strata deposited over the uplift have been removed by erosion with the exceptions of occasional spurs jutting from the basin rim and scattered remnants capping isolated hills. Plummer (1950) discussed the overlap of basal Cretaceous beds in the Llano region, and noted that these beds become progressively younger from southeast to northwest. Barnes (1941) postulated that the Edwards limestone was the first Lower Cretaceous stratigraphic unit to completely cover the region.

The Lower Cretaceous beds cropping out in the southern part of the Camp Air-West area are part of a large spur extending into northwestern Mason County from the basin rim in eastern Menard County. The relation of these strata to those of the standard section could not be determined, and they were mapped only as limestones and sandstones of Early Cretaceous age.

Lithology: Cretaceous strata underlie a broad, relatively flat tableland in the southern part of the thesis area. The rocks exposed consist of buff, fine-grained sandstone; grayish-buff to grayish-white, calcareous, conglomeratic sandstone; grayish-white, nodular, shaley marl; and light gray, very fine-grained limestone.

The conglomeratic sandstone, comprised of angular to well rounded pebbles of gray chert, milky quartz, and white to purplish-gray quartzite imbedded in a matrix of fine- to coarse-grained, calcareous sandstone, crops out around the border of the Cretaceous exposure and forms an abrupt escarpment on the eastern side. To the north and west, the escarpment is not well developed, and the conglomeratic sandstone is separated in outcrop from exposures of Paleozoic rocks by a gentle, detritus-covered slope. Measurements made along the northeastern border of the outcrop indicate that the conglomeratic layer occurs 5 to 15 feet above the Cretaceous-Paleozoic contact and is about 10 feet thick. In that vicinity, a 3 foot thick bed of light buff, fine-grained quartz sandstone is exposed below the conglomeratic sandstone, but other beds present are covered by float.

Differential weathering has produced a series of low benches, underlain by resistant limestone beds, that rise in broad stair-step arrangement toward the south-central part of the outcrop. On air photographs these benches appear as closed irregular lines surrounding the higher parts of the exposure. Around the southeastern part of the outcrop the benches extend to the edge of the escarpment, and the conglomeratic sandstone, if present, is covered by talus.

An 88 foot section of Cretaceous limestones above the conglomeratic sandstone was measured and described at the escarpment two miles southwest of Camp Air (location 17, Plate I) (see appendix).

Stratigraphic relation: The Lower Cretaceous strata exposed in the thesis area unconformably overlie truncated Paleozoic rocks varying from the Hickory sandstone to the Point Peak shale. Elsewhere in the Llano region rocks of Early Cretaceous age are in contact with older strata varying in age from Precambrian to Pennsylvanian.

Rogers (1955) estimated that the pre-Cretaceous erosional surface in the Mason, Kimble, and Menard Counties area had an average gradient of eight feet per mile toward the southwest. The existence of this slope could not be verified in the thesis area because no instruments for determining exact elevations were available. However, the condition of equal truncation evident on Paleozoic strata of varying resistance from which the Cretaceous cover has been recently removed attests to the probability that the base level of erosion must have been closely approached in the area prior to Cretaceous deposition and that a condition of peneplanation must have existed. The hill of Hickory sandstone 0.7 mile west of Camp Air (location 8, Plate I) appears to be slightly higher in elevation than the base of the Cretaceous outcrop, and it possibly stood as a monadnock on the pre-Cretaceous surface.

QUATERNARY SYSTEM

Recent alluvium comprised of detrital material derived from Cretaceous bedrock has accumulated around the edges of the Cretaceous outcrop in the southern part of the thesis area. These deposits were mapped at localities where the identity of underlying bedrock was doubtful.

STRUCTURAL GEOLOGY

REGIONAL STRUCTURE

Primary

The Llano uplift is a structural dome of Precambrian and Paleozoic rocks exposed in a topographic basin rimmed by relatively flat-lying Cretaceous rocks. Precambrian basement rocks exposed in the center of the uplift are 7,000 to 10,000 feet higher, structurally, than basement rocks in bordering areas.

According to Cheney and Goss (1952), evidence indicating the earliest Paleozoic uplift of the Llano region with respect to surrounding areas is a slight thinning of Mississippian sediments toward and over the region. Structural development of the dome was essentially completed by Late Pennsylvanian (Late Lampasas or Early Strawn) time when, according to Cheney and Goss (1952), the Precambrian basement surface had reached its present elevation above basement rocks in the flanking Fort Worth and Kerr basins.

Faults

Nature of faulting: Precambrian and Paleozoic rocks exposed in the Llano region have been extensively cut by a series of steeply dipping, predominantly northeastward striking, normal faults, most of which are down thrown toward the northwest. According to Cloud and Barnes (1948) dips of the faults range from 60° to 90° with the steeper dips predominating. No evidence that movement other than dip-slip occurred along any of the faults has been presented.

Time of faulting: Cheney and Goss (1952, p. 2249) dated the faulting in the Llano region as Late Lampasas to Early Strawn (Des Moines), basing this conclusion on subsurface information from wells in Mills County just off the northeastern flank of the uplift where

> "...typical Strawn sands and shales reveal....only minor structural movement although the underlying section shows a difference of 1,000 feet in thickness in two wells 5 miles apart..."

Evidence from outcrops within the Llano region, presented by Cloud and Barnes (1948), dates the faulting as pre-Canyon (pre-Missouri) and post-Strawn (post-Des Moines)in age. These authors reported finding rocks of the Strawn formation in fault contact with the Marble Falls limestone and noted that unfaulted beds of Canyon age rest upon faulted Ellenburger limestone near Calf Creek in western McCulloch County. No evidence has been reported from surface outcrops to indicate whether faulting was contemporaneous with Strawn deposition or was entirely post-Strawn.

Cause of faulting: Although the geology of the Llano region has been studied for a number of years, no theory which explains adequately the origin of faulting in the region has yet been presented in the literature. Several theories relating the normal faulting in the region to compressional stresses existing in the Ouachita geosyncline have been offered, but none of these have shown the mechanics whereby the stress distribution producing the geosynclinal folds was translated into that resulting in relative tension in the Llano uplift.

Cloud and Barnes (1948) proposed that "theoretical tensional couples developed from east and south" (from the Ouachita geosyncline) produced the faulting in the Llano region. The authors explained neither the meaning of these "tensional couples" nor the stress distribution obtained with them, but concluded that they would result in "fractures aligned dominantly in the northeast-southwest direction". Another proposed hypothesis attributes the faulting to tensional stresses developed over the crests of northeast-southwest trending folds. This requires a maximum principal stress in a northwest direction to form the folds, but this stress direction is not in agreement with that needed to explain the faulting.

In considering the ultimate cause of faulting in the Llano region, certain facts and assumptions are pertinent. These are:

1. No evidence of movement other than dip-slip movement has been found on faults in the Llano region, and they are, therefore, assumed to be normal faults with negligible strike-slip components.

2. The predominant strike direction of major faults in the region is northeast, although some deviation from this direction occurs. Cloud and Barnes (1948) reported that a few of the major faults in the region strike in the north-northeast to north-northwest directions.

3. The age of the normal faulting in the Llano region is coincident, or nearly so, with orogenic activity, possibly involving thrust faults, in the Ouachita trough.

4. During Morrow and Lampasas time, the Ouachita trough attained its most pronounced development, undergoing rapid subsidence while the Llano region, comparatively, subsided relatively little.

5. During Lampasas time the Fort Worth basin to the northeast and the Kerr basin to the southwest underwent great subsidence relative to the Llano region, as evidenced by the accumulation, reported by Cheney and

Goss (1952), of 5,000 to 6,000 feet of clastic sediments of Lampassas age in these basins, while at the same time the Llano region received only a few hundred feet of dark limestone and shale.

6. Areas of thrust faulting and other intense deformation in many foldbelts of the world, including the Southern Appalachian Mountains, the Canadian Rockies, and the Swiss Alps, are bordered by relatively flat-lying undisturbed sediments showing no evidence of the compressive stresses that must have accompanied deformation of the foldbelts.

Consideration of the above data in the light of theories of the mechanics of faulting presented by Anderson (1951), Hubbert (1951), and Hafner (1951), leads to the following conclusions:

1. If the assumption of normal faulting is valid and the stress distribution theories of Anderson, Hubbert and Hafner are assumed to apply, the direction of the maximum principal stress acting in the Llano region was nearly vertical, and the magnitude of that stress was essentially equal to overburden pressure.

2. The predominance of northeastward strikes of the faults establishes the direction of intermediate principal stress as northeast-southwest, toward the Fort Worth and Kerr basins.

3. The direction of minimum principal stress, then, must have been northwest-southeast - in apparent opposition to possible compressional forces existing in the Ouachita trough.

4. According to the theories advanced by Anderson, Hubbert, and Hafner, thrust faults and normal faults cannot be formed by the same regional stress distribution. This suggests that normal faulting in the Llano region bears no direct relation to deformation of the Ouachita

geosyncline, even though contemporaniety of deformation in the two areas is assumed.

5. The faulting in the Llano region was possibly caused not by compressional stresses from the Ouachita geosyncline but by a condition of unbalanced stress distribution engendered by maximum subsidence in the Ouachita trough to the southeast, which established the minimum principal stress direction, and intermediate subsidence in the Fort Worth and Kerr basins to the northeast and southwest, which established the intermediate principal stress direction.

Obviously, the complex faulting of the Llano region cannot be treated so simply, and the above discussion is not proposed as a complete explanation of the cause of that faulting.

Folds

With few exceptions, folding in the Paleozoic rocks of the Llano uplift is gentle and is of minor significance compared to the deformation caused by faulting. Cloud and Barnes (1948) reported folding associated with, and incidental to, faulting and structural sinks in the Ellenburger limestone and associated with faulting in many other lithologic units cropping out in the uplift. Cheney (1940) described four relatively minor arches, the Richland Springs, Pontotoc, San Saba, and Lampassas axes, trending northeast-southwest across the region. He considered these structures to be "tilted segments of the Concho arch occurring between narrower blocks which have moved downward". Twelve years later, Cheney (1952, p. 2251), he referred to these axes as "pronounced northeast trending folds". Minor folds are common in the Point Peak shale and in the San Saba limestone in the vicinity of the bioherm zone.

Folds in the Paleozoic rocks of the Llano region have not been studied in sufficient detail to determine their cause.

LOCAL STRUCTURE

Primary

The Paleozoic rocks exposed in the Camp Air-West area strike N. 35° - 45° E. and dip 3° - 5° NW., forming a gently dipping homocline that is cut by a series of northeast-southwest trending, steeply dipping, normal faults of varying throw. The northwestward dip of the bedded rocks is normal for the location of the area with respect to the central crystalline core of the uplift, and the northeast-southwest trend of the faults is consistent with the regional fault trends.

Cretaceous rocks exposed in the southern part of the area are essentially flat-lying and are unaffected by faulting.

Faults

In comparison with faulting in other areas of the Llano region, the faulting in the Camp Air-West area is of minor nature. No fault in the area has a stratigraphic throw in excess of 200 feet.

The throws of faults occurring within the Hickory sandstone cannot be estimated with reasonable accuracy because of difficulties in recognizing stratigraphic levels within the member and because of the irregular surface of the Precambrian basement. Apparent lower Hickory sandstone crops out on the northwestern side of one such fault traced northeastward from the Cretaceous outcrop for approximately 0.7 mile (location 2, Plate I), and beds approximately 50 feet above the middle stratigraphic level of the member are exposed on the southeastern side.

Northeastward along the projected strike of the fault, no evidence of the lower Hickory sandstone occurrs; instead, the bedrock within a few hundred feet of the last trace of the fault appears to be characteristic of the lower beds of the upper part of the member. If the estimated thickness of 400 feet for the Hickory sandstone in the area is assumed to be correct, a stratigraphic throw in excess of 200 feet is indicated for the fault. It is questionable whether a fault of this magnitude could die out within a few hundred feet. An alternative explanation is that the fault is one of small throw essentially within the upper part of the Hickory member, and that a basement hill similar to the one exposed one mile northwest of Camp Air underlies that part of the fault where lithology similar to that of the lower Hickory sandstone is exposed.

The most pronounced fault within the Hickory sandstone occurs very near the contact between the Cap Mountain limestone and the Hickory sandstone and persists almost the entire length of the thesis area. Its zone is easily traced in the sourthern part of the outcrop where it is exposed at several localities along a small ephemeral stream and where a hill developed on upper Hickory sandstone on the up-thrown side of the fault is topographically higher than the Cap Mountain limestone on the down-thrown side. The stratigraphic throw of this fault is estimated to be about 150 feet. Northward along its strike, the trace is marked by occasional masses of quartzite protruding through the soil (Plate V) and by changes in soil color. One mile northwest of Camp Air, a granite hill extending above the middle stratigraphic level of the Hickory sandstone is exposed on the up-thrown side of the fault. North of the granite hill, the trace of the fault is lost in alluvium, but its continuance is indicated by offsets in the outcrop pattern and by shortening of the section. About 1.3 miles north of Camp Air, on the Mason-Brady highway, a small graben (or large slice) of Cap Mountain limestone and upper Hickory sandstone is formed between this fault and one of smaller throw. The trace of the plane of the smaller fault is exposed in the road cut on the western side of the highway (location 15, Plate I).

Other faults in the eastern and central part of the area include one with approximately 70 feet of stratigraphic throw affecting the outcrop pattern of the Cap Mountain, Lion Mountain, Welge, and Morgan Creek members; one very small but persistent fault paralleling the principal Morgan Creek limestone-Welge sandstone contact throughout most of the area; and one of variable throw affecting the outcrop pattern of the Morgan Creek and Point Peak members in the center of the area.

The first of these faults is persistent throughout most of the area, beginning in the extreme southwestern corner, passing beneath the Cretaceous outcrop and continuing to the northeastern corner where its trace is lost in the Hickory sandstone. In the southwestern and south-central part of the area, it is essentially a strike fault with Lion Mountain sandstone exposed on the up-thrown side and Morgan Creek limestone exposed on the down-thrown side. In the vicinity of the Roy Schmidt ranch house, however, it veers slightly to the east and trends obliquely across the regional strike until, in the north-central part of its trace, it terminates the southeasternmost outcrop belts of the Morgan Creek, Welge, and Lion Mountain members. In that vicinity, it is intersected by a fault of opposite displacement, and northward from the point of intersection the throw apparently decreases.

The intersecting fault has an estimated stratigraphic throw of about 50 feet and follows the upper boundary of the Cap Mountain limestone throughout most of its trace from the Cretaceous outcrop in the south to the point of intersection.

The small fault trending parallel to the Morgan Creek-Welge contact in the central part of the area is little more than a fracture, having a displacement of 10 to 15 feet, yet it is remarkably persistent and can be traced from the vicinity of the Cretaceous outcrop in the south to the northern part of the area, where its trace is lost in soil. Throughout most of its extent, the trace is marked by blocks of quartzite which at several localities protrude through the soil in such close proximity that they resemble a small dike.

The remaining fault in the central part of the area has an estimated stratigraphic throw of approximately 80 feet near the vicinity of the Roy Schmidt ranch house where the Point Peak member crops out on the down-thrown side and the Morgan Creek limestone crops out on the up-thrown side. The trace of this fault could not be found to the south because of soil cover. To the north it apparently decreases in throw and intersects the small fault striking parallel to the Morgan Creek outcrop.

Faulting in the northwestern corner of the area has formed a graben of Ellenburger limestone bordered by San Saba limestone. The stratigraphic throw of the easternmost of the bordering faults, estimated to be about 80 feet in the line of section A-A' (Plate I) increases in throw toward the south. An odd feature of this fault is "reversed drag" occurring on the up-thrown block near the northern border of the thesis area (location 14 and northward, Plate I). Reversed drag is relatively common on the down-thrown sides of normal faults in poorly consolidated sediments, but its occurrence on the up-thrown side of faults in consolidated rock is difficult to understand. Cloud and Barnes (1948) noted the occurrence of "reversed" drag along other faults in the Llano region and postulated that it resulted either from "non-compensatory" movement in a direction opposite to the original movement or from "slumping or pitching of the strata toward openings along the zone of displacement". The first of these conjectures might well have caused the "reversed" drag observed in the thesis area, but the second is more applicable to the down-thrown side of normal faults where backward rotation of slump blocks might produce "reversed" drag. Openings along fault zones which might cause slumpage or pitching on either side of a steep fault are not likely to occur at depths greater than a few tens of feet.

The fault bordering the northwestern side of the graben is estimated to have a stratigraphic throw of about 150 feet in the southern part of its trace, but it diminishes in throw toward the north. At about the mid-point of its trace across the area, it splits into two faults, the easternmost of which intersects the eastern border fault of the graben about 0.2 mile south of the northern border of the area. The northwestern branch continues northward off the area but appears to diminish in throw to the north.

The true nature of faulting within the area could not be determined, because no fault planes were exposed sufficiently to permit detailed studies of their surfaces. The most clearly exposed fault crosses the Mason-Brady highway 1.3 miles north of Camp Air (location 18, Plate I) and the trace of its plane is exposed in the west bank of the road cut. The plane dips approximately 75° to the southeast and movement along the fault was probably entirely dip-slip, although no evidence could be found to exclude the possibility of diagonal slip. It is probable that faults in the area are normal faults with high angles of dip and that movement along the faults was predominantly, if not entirely, dip-slip.

Folds

Folding in the Camp Air-West area is restricted to the vicinity of the bioherm zone where limestone beds of the San Saba member are locally folded by compaction between the reef masses. The extent of this compaction is exemplified by a small domal structure partially exposed in a small creek in the northwestern part of the area 0.3 mile from the northern border (location 19, Plate I) (Plate VIII).

Plate VIII

Figure 1.

Figure 2.
Small domal structure formed in San Saba limestone by compaction around bioherms. Exposed in valley of small ephemeral stream 0.3 mile from northern border of area (location 19, Plate I).

SUMMARY OF REGIONAL GEOLOGIC HISTORY

PRECAMBRIAN HISTORY

The most ancient rocks exposed in the Llano region are schists and gneisses of metasedimentary and possible metaigneous origin. The occurrence of marble and graphite in the schists strongly suggests that the sediments from which these rocks originated were deposited in marine waters supporting some form of primative life. Following deposition of the early sediments, and possible early emplacement of igneous intrusives, the region was subjected to severe orogenic activity. Existing rocks were tightly folded, metamorphosed, and intruded by granite. The general coarse-grained nature of the granite intrusives, taken as a criterion of deep seated emplacement, attests to a great thickness of Precambrian sediments in the region. Subsequent to the intrusion and deformation, which probably occurred in three or more phases, the region was uplifted and subjected to prolonged erosion, resulting in removal of the metamorphic rocks to the extent that the granitic masses were locally exposed at the surface.

PALEOZOIC HISTORY

The interval of erosion which probably began near the end of Precambrian time continued, so far as the geologic record shows, until Late Cambrian time, and dissection of the uplifted area developed a topographic relief of approximately 800 feet on the erosional surface. When the sea again overlapped the region in Late Cambrian time, the Hickory sandstone was deposited over the truncated folds of metamorphic rocks and over the exposed granite, incorporating in its lower beds ventifacts, wind faceted sand, and other residuum of the erosion surface. The shallow sea remained over the region throughout Late Cambrian time; but, subsequent to deposition of the Hickory sandstone, the supply of detritus diminished and the Cap Mountain limestone was deposited under conditions of decreasing sedimentation and a relatively quiet, reducing, bottom environment. A slight regression of the sea but possibly no great influx of sediments is suggested by the clastic and glauconitic nature of the Lion Mountain sandstone.

Renewed transgression of the sea and an increase in the rate of sedimentation and/or continual oxygenation of bottom waters is suggested by the non-glauconitic Welge sandstone. The abrupt change from the abundantly glauconitic Lion Mountain sandstone to the non-glauconitic Welge sandstone possibly indicates a rapid change from non-deposition or slow deposition under reducing conditions to rapid deposition under oxydizing conditions.

Deposition of the highly glauconitic Morgan Creek limestone probably took place in waters deeper than those of Welge sandstone deposition; but, again, the abundance of glauconite suggests reducing bottom conditions and slow sedimentation that would allow the sediments to remain in the zone of chemical diagenesis over the time interval required for the formation of glauconite.

Shallowing of the sea and an influx of fine clastic material, possibly reflecting the reduced elevation of the source area, is suggested by the Point Peak shale. The formation of small algal bioherms and intermittent beds of limestone possibly resulted from periodic fluctuations in the rate of sedimentation which deepened the zone of photosynthesis by allowing the seas to clear. Intraformational conglomerates occurring in the Point Peak member are indicative of intermittent shallowing of the seas possibly to the extent that the sediments were locally exposed on tidal flats.

The occurrence of the massive bioherms near the San Saba limestone-Point Peak shale contact, the occurrence of Girvanella beds in the San Saba limestone, and the occurrence of other limestones of algal origin in the San Saba member and the lower part of the Ellenburger group suggest that relatively quiet, clear-water conditions persisted throughout the remainder of Cambrian and into Early Ordovician time. That the sea remained shallow is attested to by the intraformational conglomerates occurring in the San Saba limestone and lower Ellenburger limestone, and by the occurrence of contraction polygons indicative of sub-aerial exposure, reported by Cloud and Barnes (1948), in beds of the Ellenburger limestone.

General emergent conditions subjecting the Ellenburger limestone to erosion probably existed in the region from the later part of Early Ordovician time through Silurian time, since no rocks belonging to this time interval have been found in the Llano region. During this interval, erosion and truncation of the Ellenburger group was greatest in the western part of the uplift where, according to Cloud and Barnes (1948), the entire Honeycut formation was removed. The possibility that seas may have reached the region in Middle Ordovician time is suggested by the presence, noted by Barnes, Cloud, and Warren (1945), of Middle Ordovician conodonts incorporated in Mississippian limestone in Blanco County.

Return of the sea in Devonian time resulted in progressive east-west overlap of the region by Devonian sediments, according to Cloud and Barnes (1948) who noted that the oldest known Devonian strata occur in the eastern part of the uplift whereas the youngest known strata of that system occur in the western part.

Following Devonian deposition, the region was again subjected to erosion; so that, with the reinvasion of the region by Mississippian seas, sediments were deposited on bared Ellenburger strata as well as upon Devonian strata. Mississippian rocks are relatively wide spread over the Llano region; and, according to Cloud and Barnes (1948), are more persistent laterally than are beds of Devonian age. Thinning of Mississippian strata toward and over the uplift is the earliest known Paleozoic evidence of the region being uplifted relative to immediately adjacent parts of the continental mass.

Withdrawal of the Mississippian seas from the region was followed by sub-aerial erosion that locally cut through the Mississippian sediments and exposed the Ellenburger limestone. Pennsylvanian strata exposed in the region today ordinarily overlie Mississippian rocks unconformably, but at some localities they are in contact with the Ellenburger limestone. During Late Lampasas and Early Strawn (Early Des Moines) time, and possibly coincident with the Wichita orogeny to the northeast and with orogenic activity in the Ouachita trough to the south and east, tectonic activity in the Llano region resulted in extensive faulting. The faulting reached its culmination before Canyon (Missouri) time, as evidenced by Canyon strata being unaffected by faults which cut all rocks of pre-Canyon age.

Subsequent to Canyon deposition, the Llano region was uplifted relative to bordering areas and was subjected to extensive sub-aerial erosion that bared the Precambrian basement in the central part of the uplift. There is no evidence in the geologic record that the seas returned to the region during the remainder of Paleozoic time, although Paleozoic rocks younger than Canyon occur in the Fort Worth and Kerr basins to the northeast and southwest of the uplift.

MESOZOIC HISTORY

Emergent conditions which began in Late Pennsylvanian time continued until Early Cretaceous time, and the region was reduced to a broad surface with little relief. Rocks ranging in age from Late Pennsylvanian to Precambrian were exposed at the surface, and sediments of the Early Cretaceous sea progressively overlapping the region from south to north were deposited on the truncated edges of the Paleozoic rocks and over the exposed Precambrian basement.

CENOZOIC HISTORY

There is no evidence that the sea ever returned to the Llano region after its withdrawal at the close of Cretaceous time. Since that time, erosion of the Cretaceous rocks has resulted in the formation of a topographic basin in which the Paleozoic and Precambrian rocks are exposed.

ECONOMIC GEOLOGY

The resources of the Camp Air-West area are limited to grazing lands, arable soils, and an excellent, though not unlimited, water supply. The Hickory sandstone is the most important stratigraphic unit cropping out in the area, providing the majority of the soil suitable for farming and yielding the major part of the water. Some water production is obtained from the Welge sandstone, the Ellenburger limestone, and the Cretaceous sandstone, but yields from wells in these units have steadily decreased during the prolonged drought that has affected the region for about six years. Continuation of the drought will cause increasing dependency on the Hickory sandstone as a source for water, not only for the small farms located on its outcrop but also for the ranches located on the limestone outcrops. Under present conditions the water levels in wells drilled near the up-dip limit of the Hickory sandstone outcrop are being lowered steadily, and increasing down-dip demand on the aquifer will cause an even faster depletion of the water available for up-dip users unless a cooperative development plan is followed.

Neither the limestones nor the coarse-grained granite are suitable for building stones, and their only potential use is for road metal.

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A P P E N D I X

Section of Lower Cretaceous limestone at escarpment 2 miles southwest of Camp Air (location 17, Plate I). The section begins at the base of the escarpment on the eroded surface of the Hickory sandstone and continues westward to a point 200 feet beyond the rim.

	Thickness of interval Feet
Lower Cretaceous	
15. Limestone; light gray, hard, fine-grained, silty limestone with small vugs. Weathers to mottled gray and brown with nodular upper surface	4.6
14. Soil covered, very gentle slope.	2.0
13. Limestone; grayish-white, hard, fine-grained limestone in beds varying from 0.2 foot to 0.7 foot in thickness.	5.0
12. Limestone; dirty-white, thin-bedded fine-grained, silty limestone.	2.0
11. Limestone; brown and white mottled very hard, fine-grained, silty limestone with abundant small vugs.	2.5
10. Limestone; white, weathering to dirty-buff, thin-bedded, nodular, fine-grained limestone.	1.5
9. Limestone; very light buff, fine-grained, silty limestone with fine streaks of brown .	2.0

8. Limestone; light brownish-white, shaley to nodular, very fine-grained, silty limestone. 5.6

7. Limestone; light pinkish-white fine-grained limestone. 0.5

6. Limestone; light brownish-white, shaley to nodular, very fine-grained silty limestone becoming very hard and very fossiliferous toward the top. Fossils are poorly preserved gastropods and pelecypods . 4.3

5. Limestone; Light brown and white mottled, hard, vuggy, fine-grained, silty limestone. 2.0

4. Limestone; light brownish-white, mottled, shaley to nodular, silty, limestone. 4.4

3. Limestone; light buff-white, weathering to dull gray, fine-grained, very silty, limestone with dark brown streaks of iron oxide on weathered surface 5.5

2. Limestone; light buff-white, fine-grained, fossiliferous, very silty limestone with festers of hematite on weathered surface. Fossils are poorly preserved gastropods and pelecypods. Unit contains 2 beds - one 4.5 feet thick and one 2.5 feet thick. . . . 7.0

1. Talus and caliche covered slope to base of section on eroded surface of Hickory

sandstone. Interval probably includes conglomeratic sandstone beds exposed to the north. May contain beds of Hickory sandstone in lower part. 39.6

Total measured thickness 87.7

8830